1 NON-TECHNICAL SUMMARY

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1.1 Introduction

What you are holding in your hands is the *Strategic Environmental Assessment Report for the Polish Nuclear Programme.* This study was meant as an objective and impartial analysis of all known and foreseeable environmental impacts that may arise from the development of nuclear power in Poland.

Without exaggeration, we can say that Poland is facing a great challenge – modification and development of its energy sector. Commencement of the national nuclear energy programme should be part of this development – in terms of both technology and organisation. At present, nearly all industrialised countries in the world make use of nuclear energy. Countries such as Italy, Sweden, and the United Kingdom have included the development of nuclear power in their plans. In addition, 50 developing countries have applied to the International Atomic Energy Agency for IAEA's assistance in the development of their nuclear energy programmes. As we can see, Poland is no exception to the general trend – focus on the development of the country's nuclear sector.

We must note that there are important reasons to support modernisation of the energy sector in Poland, including the development of nuclear power. So far, the country's power sector has been based almost entirely on coal, which is clearly contrary to the international focus on environmental protection. In the coming years, Poland will be forced to pay high charges for carbon dioxide emissions, and after 20 years we will see an unavoidable increase in electricity costs and the Polish industry will ultimately become uncompetitive.

In line with the principle of diversification of energy sources, it is necessary to explore renewable energy sources (RES) despite the considerable costs associated with their use. With the technologies currently available, RES will not satisfy the ever-increasing demand for electricity. One of the reasons is that renewable energy sources, such as wind and solar energy, are intermittent. Therefore, we need a reliable and cheap source of energy produced in baseload power plants – producing energy at a constant rate that meets the continuous energy demand of all users. Nuclear power plants may serve as a cheap and clean energy source – provided that they have no negative impact on ecosystems or people's health and well-being.

This Report is the first-ever attempt at a comprehensive study of the impact of nuclear energy on the natural environment in Poland, including all its components, as well as on the living environment and health of humans. The Report was developed by a team of authors with in-depth knowledge of environmental protection, enhanced with the input of recognised experts in the field of nuclear energy who have studied its environmental impacts for a number of years, and presents all aspects of the expected impact of the Polish nuclear programme on the country's natural environment. The current state of the environment in Poland, as well as all requirements relating to the protection of various species of plants and animals, are described in detail. The findings are presented on maps, depicting both the protected areas and the suggested siting of nuclear power plants. The existing environmental constraints are described and estimated for all short-listed locations of nuclear power plants.

The Report also discusses the possible consequences of the 'zero-option', i.e. withdrawal from the programme and from the plan to build nuclear power plants (no action alternative). The complete end-to-end process of electricity production in nuclear power plants is discussed in detail. The Report focuses on radiological safety and accident prevention methods that are applied to effectively eliminate the possibility of any breakdown similar to the Chernobyl disaster. In accordance with the international requirements, the Environmental Impact Assessment includes not only the operational phase of a nuclear power plant, but also its construction and decommissioning. The Report also contains a detailed description of the impact of individual phases of the project (construction, operation, and nuclear decommissioning phase) on biodiversity, human health, plants and animals, water, air, the Earth's surface, landscape, climate, natural resources, historical buildings, and material goods.

Although the Report cannot be used as a decisive factor that will determine the location of the first nuclear power plant in Poland, it will serve as a source of valuable information on the possible local impacts of any project that can be used by the investor, the society, and administrative bodies and authorities. At the same time, it will put the environmental aspects in the spotlight, next to the social, political, or economic considerations. It is of key importance for the country's sustainable development.

This summary is an integral part of the Report and should not be treated as a separate document. The summary recaptures the key information presented in the main body of the Report in a synthetic and condensed manner, avoiding the technical and specialist language (whenever possible). In many cases (for example, the location analysis), more inquisitive readers may feel more inclined to read the main report. By all means they are encouraged to do so.

1.2 About the Report

The Strategic Environmental Assessment Report for the Polish Nuclear Programme (hereinafter referred to as the "Report" or "SEA Report") was prepared in accordance with the agreement signed by and between the Minister of Economy and the company Fundeko Łukasz Szkudlarek. The Report was based on draft Polish Nuclear Programme dated 16 August 2010 and the position of the General Director of GDOS (General Directorate for Environmental Protection) and Chief Sanitary Inspectorate regarding the scope of the Strategic Environmental Assessment Report for this document.

The Polish Nuclear Programme – background

The decision to develop the Polish Nuclear Programme was adopted by resolution of the Polish Council of Ministers No. 4/2009 of 13 January 2009 on actions taken to develop the Polish nuclear power sector. On 10 November 2009, the Council of Ministers adopted the Polish Energy Policy until 2030. One of the key priorities of the Policy is Diversification of the electricity generation structure based on the introduction of nuclear energy.

Adoption of the Policy was based on the Strategic Environmental Assessment of its environmental impacts, including also social consultations. Therefore, we must note that the present Strategic Environmental Assessment Report for the Polish Nuclear Programme is not a document that was meant to justify the introduction of nuclear energy in Poland (the rationale for the Polish Nuclear Programme has already been presented in the Strategic Environmental Assessment for Polish Energy Policy until 2030).

Contents of this SEA Report

The scope of the Polish Nuclear Programme covers mainly legal, organisational, and formal measures, and as such has no negative impacts on the natural environment. However, the outcomes of these activities will include the launch of the first two nuclear power plants in Poland. This Report focuses on the environmental impacts of these outcomes. The scope of this Report is in accordance with Art. 51 of the Act of 3 October 2008 on Access to Information on the Environment and its

Protection, Public Participation in Environmental Protection and on Environmental Impact Assessments (Journal of Laws No. 199 item 1227).

Methods applied in the Strategic Environmental Assessment

There are two basic methods applied to conduct a strategic environmental assessment:

- **Method 1** is applied to assess the environmental impacts of specific projects. The procedure consists in a number of separate assessments for every project with a precisely defined implementation framework. As a result, environmental impacts of a project are defined as precisely as possible and proven in a scientific manner. The review of alternatives is based mainly on location or technology alternatives within the adopted or evaluated option.

- **Method 2** is used to evaluate policies and strategic documents. The main goal is to define the objectives of the document itself and to evaluate their implementation – not the direct environmental impact of individual projects. This procedure is much less formal and more condensed than the first model. It focuses more on the relationship between the assessment and the decision-making process that includes the assessment as its integral part.

The Report basically applies the first method to analyse the possible environmental impacts resulting from the construction of the first nuclear power plants in Poland as foresightedly as possible, based on the available information regarding both the environmental impact of nuclear plants and their potential locations. Analyses included the scope of environmental impacts that may result from the planned installation of different types of nuclear reactors in Poland. The Report also focuses on the analyses of potential locations of nuclear power plants recommended by the Ministry of Economy, as well as their possible environmental impacts. For each of those locations, their potential environmental impacts were evaluated to the extent possible with the information available as at the date of the Report.

The assumptions and analytical methods adopted in the Report include:

- reference objects method - applying the impacts of a specific implemented project to the location of the planned investment. Monitoring data and the relevant EIA reports are used for this purpose.

- analysis and evaluation of emissions from nuclear power plants – analysis of radiological exposure that is the main source of concerns,

- analysis of impact on Natura 2000 areas based on available literature data,

- location analysis – GIS techniques are used in the analysis of project locations and cartographic visualisation,

- analysis of the Programme’s relations with other documents,

- analysis of potential social conflicts,

- economic aspects – the SEA Report does not include any economic analyses prepared by its authors – it was not the basic purpose of the Report. However, economic analyses presented in the existing publications were quoted and used in the Report to discuss certain aspects relating to environmental changes both for the no-action alternative and for all other alternatives.

We must strongly point out that the adopted methodology that focuses mainly on negative environmental impacts may be misleading both for the reader and for authorities that will evaluate the Report. Therefore, the Report also evaluates and presents certain positive environmental impacts of the Programme.

During the development of this Report, we encountered a number of problems that required an individual approach to problem solving. Some of these problems are presented in the following table.

PROBLEM	SOLUTION
• A large number of issues to study.	• A team of 14 recognised experts in various fields of study (connected with scientific circles) was appointed. • Analyses conducted as part of other studies and expert reports were used. • The reference objects method was used.
• Lack of hydrological data necessary to evaluate the sufficiency of cooling water resources for some locations (Bełchatów, Pątnów, Krzywiec, Lisowo, and Wiechowo). • Lack of detailed alternative location analyses (for all locations).	• The available hydrographical data as well as brochures and reports furnished by the suppliers of nuclear energy technologies were used. • Authors used the knowledge of experts and publications on the cooling systems as well as water and effluent management systems in nuclear power plants.
• No access to data on the implemented nuclear power projects including Generation III EPR, AP1000 and ESBWR reactors that will be potentially used in Poland.	• Information and knowledge offered by the IAEA expert was used – based on the analysis of reactors similar to those proposed for Poland. • To prepare the model of environmental impacts of Generation III nuclear power plants, we used monitoring data recorded for Generation II nuclear power plants that was extrapolated to Generation III projects, as well as data from safety analyses.
• Lack of detailed meteorological studies for individual typical locations (inland, coastal, in the vicinity of lakes and hills, etc.).	• Uniform weather conditions (plus a safety margin) were provisionally assumed for a typical location in Central Europe.
• No binding acts of law. The Atomic Energy Act and Resolutions of the Council of Ministers on nuclear energy have not been finally approved.	• The proposed regulations were assumed as the applicable guidance and were used to evaluate the impact of the future Polish nuclear power plant on the ecosystem and human health and well-being.
• Lack of precise data on the fauna and flora in specific locations.	• The evaluation of natural resources is as complete as possible, based on a very detailed analysis of the available scientific data.
• Authors were not able to verify economic calculations quoted in the Report.	• All sources of information presented in the Report were thoroughly analysed for their reliability, based on the quality of publications (references to source data and detailed description of methodologies applied) and the composition of the team of authors (consisting of experts in the field).
• The Polish Nuclear Programme does not present any concrete and consistent information on the target planned volume of electricity to be produced in nuclear power plants.	• Consistency of the adopted data with other documents (such as the Polish Energy Policy) was verified on a case-by-case basis. Sources of data were specified for all references to the specific amounts/quantities; the most realistic and probable data was selected.

1.3 References to other strategic documents

About 50 documents relating to energy in general and nuclear energy in particular were analysed in terms of the protection of the natural and human environment. We have reviewed documents prepared at the Community, national, and regional level, as well as documents constituting the international body of law for the nuclear power sector. This review indicates that the structure of the energy sector in Poland must be modified, mainly to ensure compliance with the global trend of reducing air pollution and CO2 emissions. The majority of strategic documents in Poland provide that the share of conventional energy sources should be reduced in favour of the RES technologies (wind, geothermal power, water, biomass burning). This reduction seems by all means justified, especially considering the very alarming information regarding the condition of the natural environment near brown coal mines. However, alternative ‘clean’ methods are subject to certain limitations and often have a very strong impact on certain components of the environment, including the reduction in the number of some species of animals (this problem applies mainly to wind power plants and hydroelectric power plants). The high cost and the relatively low profitability of many RES projects are also highlighted.

With only few exceptions, the analysed national strategic documents say nothing about the development of the nuclear power sector in Poland. It does not come as a surprise, because they had been prepared before works on the Polish Nuclear Programme were closed. It means that at that time, nuclear energy was not given a green light in Poland. Also, the criteria for the selection of individual locations for nuclear power plants and the type of reactors to be used were not clear. Therefore, the scale and the type of impact of these projects on individual components of the natural environment could not be determined.

The first mention of the possible introduction of nuclear power technologies can be found in *Polish Energy Policy until 2030 with Annexes and the Strategic Environmental Assessment Report for the Polish Energy Policy until 2030 (final report).* They indicate the potential positive role of nuclear energy in the reduction of harmful emissions to the atmosphere in accordance with Poland’s obligations assumed at the time of the country’s accession to the European Union. At the same time, the said Report highlights the controversies surrounding the construction of nuclear power plants and management of nuclear waste, consisting mainly in the failure to organise the national debate and gain the social approval for the Programme.

Our review of international documents, starting from American documents generally considered to be examples of best practice, through the requirements and guidance of the IAEA, up to the nuclear power conventions signed by Poland, indicates that their authors consider nuclear power to be a model sector of the industry – ensuring clean air, water and soil, and generating cheap and reliable electric energy. Nuclear power plants proposed for Poland must meet the most stringent requirements for radiological protection and safety. At the moment of introduction of nuclear energy to the Polish economy, there is an extensive body of international law that can be used to our benefit.

1.4 Current state of the natural environment in Poland

When determining the current condition of the natural environment in Poland, all its basic components were evaluated separately, specifically taking into account the aspects relating to the potential development of the nuclear energy sector in Poland.

Natural topography (relief) and land use structure

Natural topography or land relief is one of the main elements of the environment that determines both its internal structure and the rate of energy and matter cycle. In Poland, land relief is diversified and poses a complex problem from the perspective of variability of terrain forms and their origin.

Generally speaking, today's land relief structure in Poland can be divided into a series of alternating belts of lowlands and uplands arranged into east-west-trending zones, which resulted from long-term natural internal and external processes.

Surface of the land is changing – also as a result of human activity. In recent years, i.e. from 2000 to 200', the share of woodland areas in Poland's total surface area has increased at the expense of arable land, meadows and pastures (grassland). This trend is confirmed by the studies of the Central Statistical Office. The share of orchards has also increased slightly. At the same time, the share of built-up and urbanised areas has increased considerably, particularly in the vicinity of large cities where the suburban areas, including large housing estates, have developed.

Seismic activity in the Earth's crust – earthquakes

Poland is generally considered a safe region in terms of the country's seismicity. The last large earthquakes occurred in this area about 150-200 million years ago. However, both historical data and present-day records indicate that seismic activity in Poland is a permanent phenomenon. It may be caused by natural factors and by human activity in mining areas.

The majority of earthquakes recorded in the past originated in the Czech Republic, Hungary, or somewhere else in Europe. They were quite common in the Karkonosze Mountains, the Kłodzko Valley, the Carpathian Mountains, and the Carpathian Foothills (Subcarpathian Region). Only a small number of these earthquakes caused building disasters, usually damaging the structure of churches and houses. Silesia was the region that recorded the highest seismic activity. However, almost all earthquakes in this region were caused by mining activities. Earthquakes recorded in Bełchatów (for instance in 1980 or in 2001) and in the LGOM (Legnicko-Głogowski Copper Mining Area) had a similar origin. In 1992–1993, a series of earthquakes was recorded in the Beskids (Beskid Sądecki and Beskid Niski Mountains). Similar series of quakes were recorded in September 1995 in the Podhale Region. In more recent years, earthquakes that originated in the area of Baltiysk in Sambian Peninsula (Kaliningrad Oblast) on 21 September 2004 made the headlines. They were probably the strongest earthquakes in this region in the past 1000 years.

However, we must emphasise that the magnitude of these earthquakes does not compare to high-seismicity areas, and they are caused mainly by the mining activity. In the European scale, let alone the global scale, the seismic activity is Poland is low. Detailed analyses of data recorded by special seismometer stations indicate that no strong, large, or major earthquakes have been recorded in Poland since 1964. Therefore, earthquakes recorded in the analysed period carried no risk of major infrastructural damage. Still, 21 earthquakes of medium magnitude have been recorded. These earthquakes could potentially cause damage of medium severity. The strongest earthquake in this period was recorded on 1 April 2000 near the town of Żerków, SE of Poznań. Other larger quakes occurred mainly in the southern part of the country, and also up north – in the Kaliningrad Oblast and the Bay of Gdańsk. Medium–magnitude quakes originate mainly in the SW part of Poland – the regions of Lower Silesia, Lubuskie, and Wielkopolska (Greater Poland). Single earthquakes of this magnitude were also recorded in the regions of Upper Silesia and Małopolska (Lesser Poland).

The problem of earthquakes is important from the perspective of structural safety of power generating facilities, and as such was discussed by the International Atomic Energy Agency (IAEA). A standard nuclear power plant must be designed to withstand the so-called *Design Basis Earthquake* (DBE). Designers of nuclear power plants must prove that the plant will meet all safety parameters (for given ground conditions). For all structures, systems, and elements that are considered essential for nuclear safety, a location-specific Seismic Margin Assessment (SMA) will be introduced.

Surface and ground waters, and the risk of floods in Poland

The amount of water per capita in Poland is among the lowest in Europe – only about 1700 cubic meters per annum (the average for Europe is about 4500 cubic meters per year per capita). Therefore, higher-quality ground waters are used for drinking, while surface waters are used for other purposes (mainly economic activity). The total area of surface waters in the territory of Poland is 640.5 thousand hectares (in 2008), which represents a major decrease compared to 2000 (about 830 thousand hectares). These values indicate that the resources of surface water in Poland have been shrinking. However, water supply quality problems are still more serious than quantity-related problems. The quality of waters in Polish rivers has been improving steadily, but still the majority of watercourses are considered “unclassified”, i.e. not meeting the standards mainly due to their sanitary condition.

Major Ground Water Reservoirs (MGWR) were selected in the territory of Poland. They include natural water bodies located in underground deposits that collect groundwater and meet the specific quality and quantity criteria. 163 MGWRs were selected, of which 53 were classified as top-quality reservoirs.

High water levels in rivers are a major problem in Poland. They represent the most common environmental risks in the country. Increasing water levels in river beds are natural phenomena than cannot be avoided. Floods in Poland have different origins, severity, and dynamics, but they always involve an outflow of water from river beds into floodplains. Floods are associated with areas occupied or used by humans, not river valleys in their natural state.

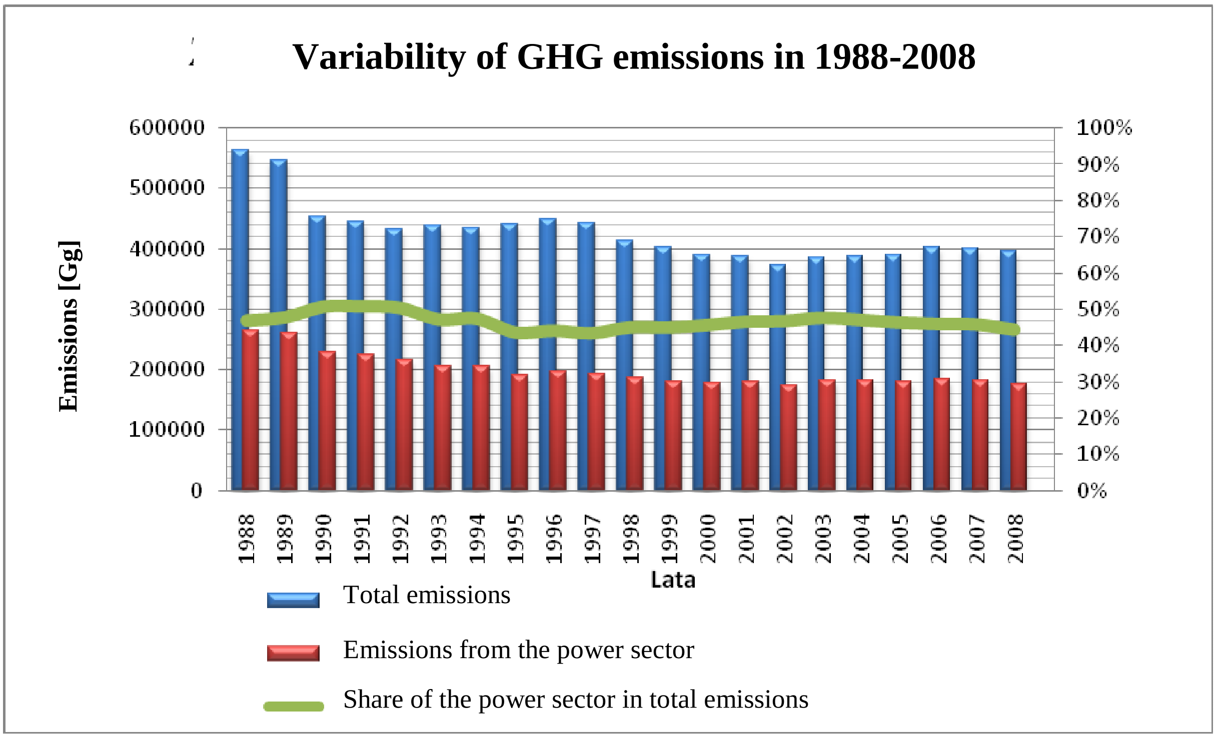
The most recent floods that occurred in 2010 have yet again exposed the gaps in the Polish system of flood protection. Rivers would break flood defences and flood the bottoms of river valleys. To make matters worse, the public was not properly informed about the flood threats and risks.

Condition of atmospheric air in Poland and emissions of air pollutants

Given that pollutants can move freely through air, air pollution poses the most serious environmental threat – it cannot be contained within a specific area. Air pollution is recorded if air is composed of any gases, liquids or solids that do not constitute the natural components of atmospheric air, or if their concentration exceeds the natural composition of the Earth’s atmosphere.

The 2008 annual air quality assessment commissioned by the Chief Inspectorate for Environmental Protection indicates that the overall condition of air in Poland is good. In most cases under analysis, the levels of gaseous pollutants were within the adopted standards. Dust is a more serious problem. The limits of dusts in atmospheric air are exceeded mainly due to emissions from individual building heating systems or due to unfavourable weather conditions during tests and traffic-related emissions.

The Polish power sector is also the key pollutant responsible for large emissions into the air. The largest portion of these emissions comes from coal-fired power plants (using both lignite and bituminous coal). According to the international agreements, Poland is under the obligation to reduce its emissions of greenhouse gases. Considering that over 40% of the GHG emissions come from power plants, their reduction depends to a large extent on the modification of the country’s energy sector.



Variability of GHG emissions in 1988-2008; changes in land use and the forestry sector are not considered

Noise

The impact of noise on the environment, including on human beings, depends on the time and type of exposure. In Poland, road traffic is the main source of noise. In the power sector, individual components of power plants may be the key sources of noise – including starting valves and boiler safety valves, compressors, and ventilation fans. Minor sources of noise include transformer stations, fan cooling towers, and steam discharged from starting valves and safety valves. Fans, pumps, and turbines are usually enclosed in sound-absorbing housings.

Waste

The volume of waste produced in Poland has been decreasing steadily (from 138 million Mg in 2000 to 130 million Mg in 2008) which results mainly from the reduction of industrial waste (from 125 million Mg to 115 million Mg, respectively). On the other hand, an upward trend has been recorded in the production of municipal waste. However, municipal waste (about 12 million Mg per annum) represents a minor problem compared to industrial waste – only about 10% of total volume of waste generated in Poland.

Industrial waste includes mainly waste materials produced during the extraction and processing of mineral resources, as well as waste from power plants (ashes and slags). About 75% of industrial waste produced in Poland is recycled, compared to only 7% of municipal waste. The remaining portion is deposited.

Hazardous waste accounts for approx. 1% of the total volume of waste produced in Poland (about 1.5 million Mg per annum). 36% of hazardous waste is recycled, and the remaining portion is neutralised (61%, of which 19% by deposition) and stored (3%).

In Poland there are currently about 35 hazardous waste landfills – either separate landfills or designated sections of general landfill areas for waste other than hazardous or inert substances. Hazardous waste produced in Poland includes a small portion of radioactive waste generated when using radioactive substances in medicine, the industry, or scientific research. The total volume of radioactive waste processed per year is 40-100 cubic meters. In addition, research reactors in Świerk produce spent nuclear fuel of various degrees of enrichment. Radioactive waste is processed by the Radioactive Waste Neutralisation Plant (Zakład Unieszkodliwiania Odpadów Promieniotwórczych) that ensures partial recovery of chemical elements, reduction of the volume of waste, and waste solidification. Processed radioactive waste is deposited in the National Radioactive Waste Depository in the municipality of Różan, 99 kilometers from Warsaw, in the area of a former military fort. The Depository in Różan is the only radioactive waste depository in Poland. It is used mainly to deposit short-lived, low- and medium-active radioactive waste. However, there is no depository for high-active and long-lived waste. Spent nuclear fuel from Polish research reactors is temporarily stored in water pools at the facility in Świerk. This waste will be transported back to the country where the nuclear fuel came from, in this case to Russia, in accordance with the Global Threat Reduction Programme financed by the US Government.

Cultural resources

Cultural resources include movable (collections, ceramics, etc.) and immovable cultural assets (such as buildings and their parts), archaeological resources, and UNESCO World Heritage Sites. In Poland, the register of historical monuments and sites includes: 64,673 immovable objects (as at 4 October 2010), 352,822 movable objects (as at 31 December 2007), 7,523 archaeological sites (as at 30 June 2009), and 13 UNESCO World Heritage Sites. The province of Podkarpackie has the largest number of historical monuments and sites, followed by Dolnośląskie, Mazowieckie, Małopolskie and Wielkopolskie provinces. Therefore, the southern and central parts of Poland are places to look for historical monuments. They are relatively less numerous in the northern part of the country.

Biotic elements of the natural environment and protected sites

Plants

Poland's vegetal cover includes plant species (flora) and plant communities (vegetation). Its natural diversification is lower than at the corresponding latitude in North America or Asia. It results mainly from its geological history (for instance, the impact of the continental glacier in the Pleistocene) and the many centuries of human activity. Compared to the rest of Europe, the diversity of natural plant cover in Poland is medium, which results primarily from the country's location in the moderate climate zone. Poland's plant diversity is higher than in the Nordic countries but lower than in the southern and western Europe.

Animals

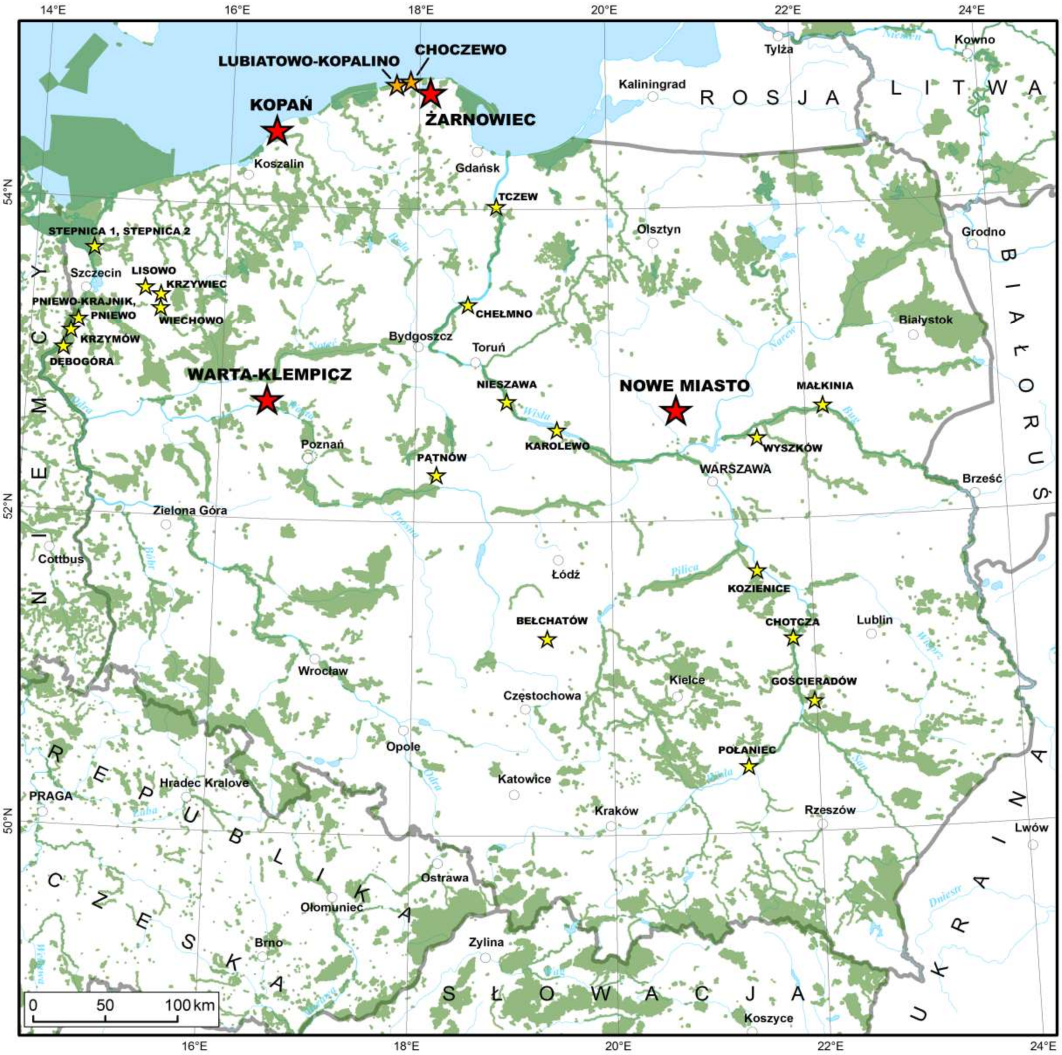
Polish fauna includes all present-day local species of wild animals (within their natural range) or foreign species that can be found in the territory of Poland. So far, about 36,000 species of animals have been recorded in Poland. The exact number is impossible to determine – on the one hand, new species are discovered all the time (both in Poland and in general), on the other – some species become extinct or change their natural range. Invertebrates account for the vast majority of Poland's fauna. However, vertebrates are the most researched group of animals, even though they represent only 2% of the country's fauna. They are found at the highest levels of the alimentary chains, and therefore are highly sensitive to any changes in their natural environment. Birds are a good indicator of the state of the environment – they are relatively easy to observe and react quickly to any changes in the environment.

Forms of nature protection in Poland

Within the meaning of the Act, protection of nature in Poland consists in the preservation, sustainable use, and renewal of the resources of the following components of nature: wild species of plants, animals and fungi (both protected and unprotected), natural habitats (both common and rare), elements of animate and inanimate nature, fossil plants and animals, as well as the landscape, green areas in cities and villages, and tree plantings/woodlots. In short, nature protection includes all its elements, as well as the landscape and greenery in human settlements. Effective protection of nature requires very specific provisions of law. In Poland, these provisions are found mainly, but not exclusively, in the Nature Protection Act of 16 April 2004 (Journal of Laws of 2004 No. 92 item 880).

Forms of nature protection in Poland include national parks, nature reserves, national scenic areas (the so-called landscape parks), protected landscape areas, ecological sites, inanimate nature documentation sites, nature and landscape complexes, monuments of nature, and ecological corridors. In accordance with the Community requirements, the European Ecological Network Natura 2000 was created. The purpose of Natura 2000 is to preserve endangered habitats as well as plant and animal species at a European level, as well as the typical and common habitats. Natura 2000 network includes two types of sites: Special Areas for Conservation (SACs) of Habitats and Special Protection Areas (SPAs) for Birds. Scientific criteria are the only factors taken into account when designating Natura 2000 sites.

POTENTIAL LOCATIONS OF NUCLEAR POWER PLANTS VS. NATURA 2000 SITES (SPECIAL AREAS FOR CONSERVATION OF HABITATS)



Proposed locations

★ recommended locations

★ backup locations

☆ other proposed locations

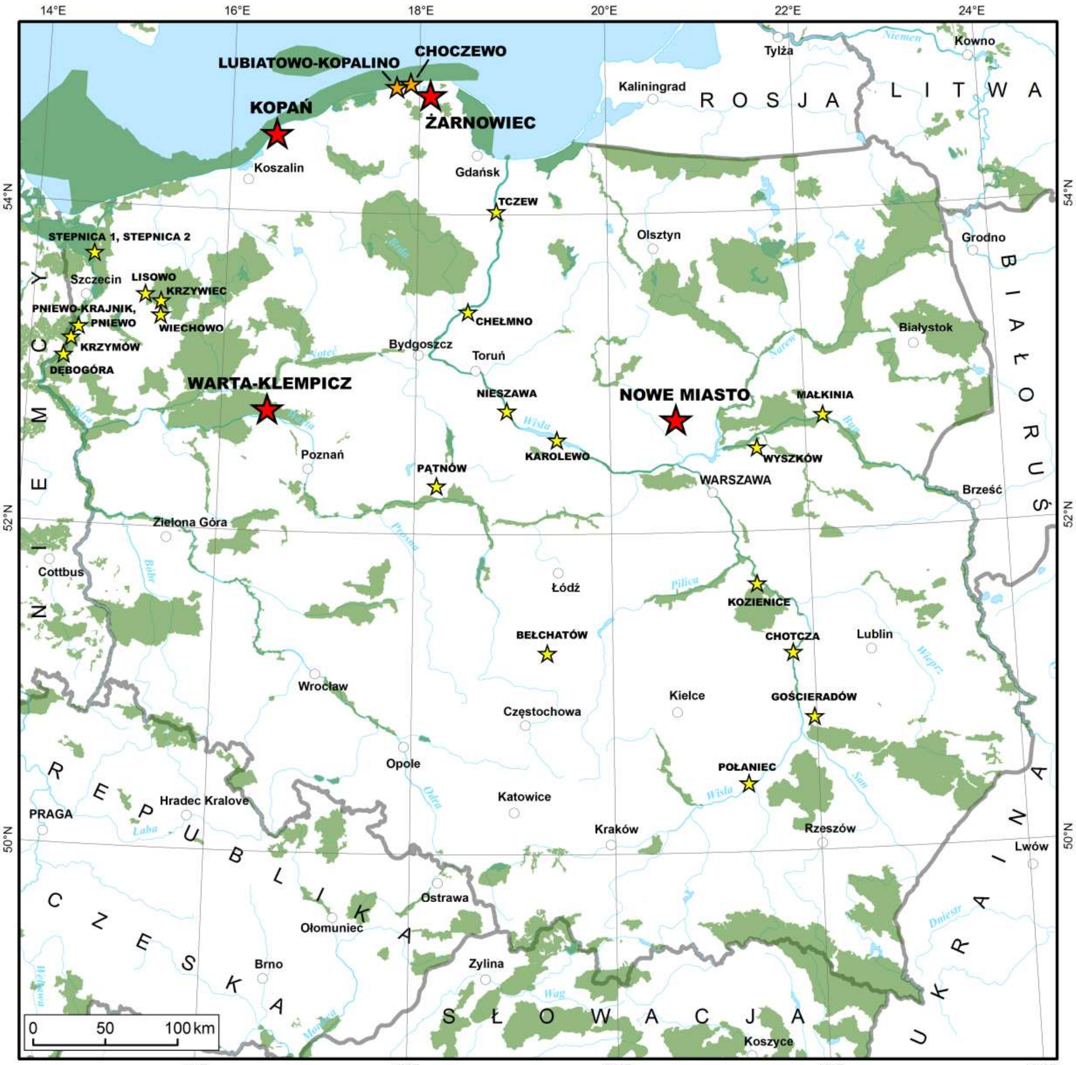
NATURA 2000 sites (SACs for Habitats)

Prepared by: mgr Kacper Jancewicz

Sources:
"*Ekspertyza na temat kryteriów lokalizacji elektrowni jądrowych oraz wstępna ocena uzgodnionych lokalizacji*" [Expert opinion concerning the siting criteria for nuclear power plants and preliminary evaluation of the agreed locations];
www.eea.europa.eu;
VMAP Level 0 (www.gis-lab.info)

Potential locations of nuclear power plants vs. location of Special Areas for Conservation of Habitats.

POTENTIAL LOCATIONS OF NUCLEAR POWER PLANTS VS. NATURA 2000 SITES (SPECIAL PROTECTION AREAS FOR BIRDS)



Proposed locations

- recommended locations
- back-up locations
- other proposed locations
- NATURA 2000 sites (SPAs for birds)

Prepared by: mgr Kacper Jancewicz

Sources:
"*Ekspertyza na temat kryteriów lokalizacji elektrowni jądrowych oraz wstępna ocena uzgodnionych lokalizacji*" [Expert opinion concerning the siting criteria for nuclear power plants and preliminary evaluation of the agreed locations];
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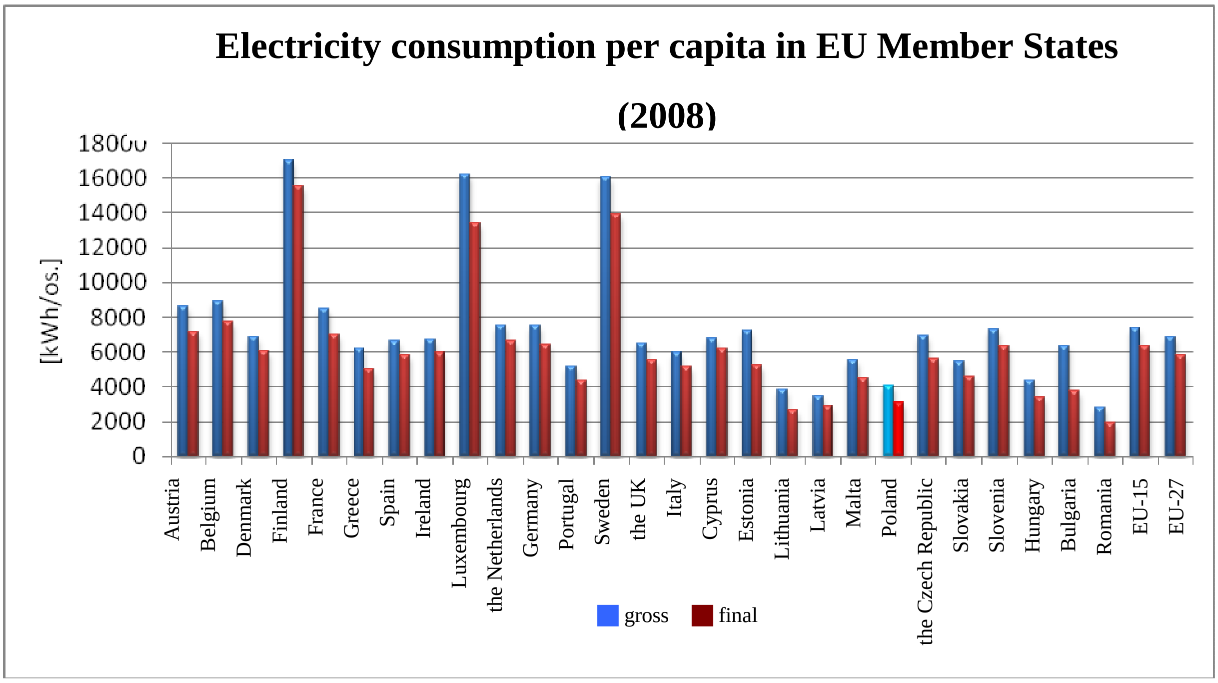
Potential locations of nuclear power plants vs. location of Special Protection Areas for Birds.

1.5 No-action alternative – impact on the natural environment in Poland

The current condition of the Polish power sector is highly unsatisfactory, especially given the predominant share of energy produced from coal and high emissions of pollutants. In the coming years, the sector will be forced to meet the ever-increasing requirements in order to achieve emission reduction levels adopted in the international agreements on the one hand, and to satisfy the ever-growing demand for electricity that ensures steady economic growth on the other. It is highly probable that these objectives are impossible to achieve at present. Therefore, new energy strategies need to be defined for Poland, with the Polish Nuclear Programme as one of their key elements. Adoption of the do-nothing option will mean that the consistent strategy of electricity generation in Poland will not be implemented. As a result, an energy crisis in Poland may become a fact, leading to an economic downturn and deterioration of the living standards for Polish citizens. Actions resulting in the postponement or withdrawal of the Programme could be justified if we expected a reduction in electricity consumption or the decision to continue (or even increase) the production of electricity from traditional sources (mainly black coal), whose resources are both limited and valuable for other purposes (potential application in the pharmaceutical sector, hi-tech sector, and chemical sector). The zero-option would also mean that emissions of air pollutants would remain at today's levels. As a result, Poland would be forced to pay high emission charges, and the Polish society would have to pay the high price of environmental pollution. Most of all, the no-action alternative would mean that Poland is left without any energy security strategy and that the country does not take any action to become independent based on diversified energy sources.

Electricity is a key element that ensures the proper functioning and development of any country. Today, the consumption of electricity in Poland per capita is 2.1 times lower on average than electricity consumption in the most developed Member States of the European Union.



Consumption of electricity per capita in EU Member States.
[prepared by: W. Kiełbasa based on Eurostat data (2010) and the Central Statistical Office data (2010)]

All forecasts of Poland's economic development provide that electricity consumption will continue to increase, despite the simultaneous improvement in the efficiency of electricity production and consumption.

To ensure a reliable comparison between the impact of the current electricity production system in Poland (based mainly on coal-fired power plants) and the new system planned in the Programme (assuming the steady growth of the nuclear power sector), we must consider not only the costs of electricity generation and purchase, but also costs of health effects caused by the resulting emissions, their impact on ecosystems, results of climate changes, etc. – that is, the total cost borne by the society. Analyses conducted in the Report according to the adopted calculation methods (ExternE and the cost curve) have demonstrated that the introduction of nuclear power in Poland is the most effective way to achieve the adopted goals (i.e. reduction of social costs and reduction of GHG emissions). At the same time, it is the most cost-effective method.

1.6 Nuclear energy – background information

Operation of reactors and nuclear power plants

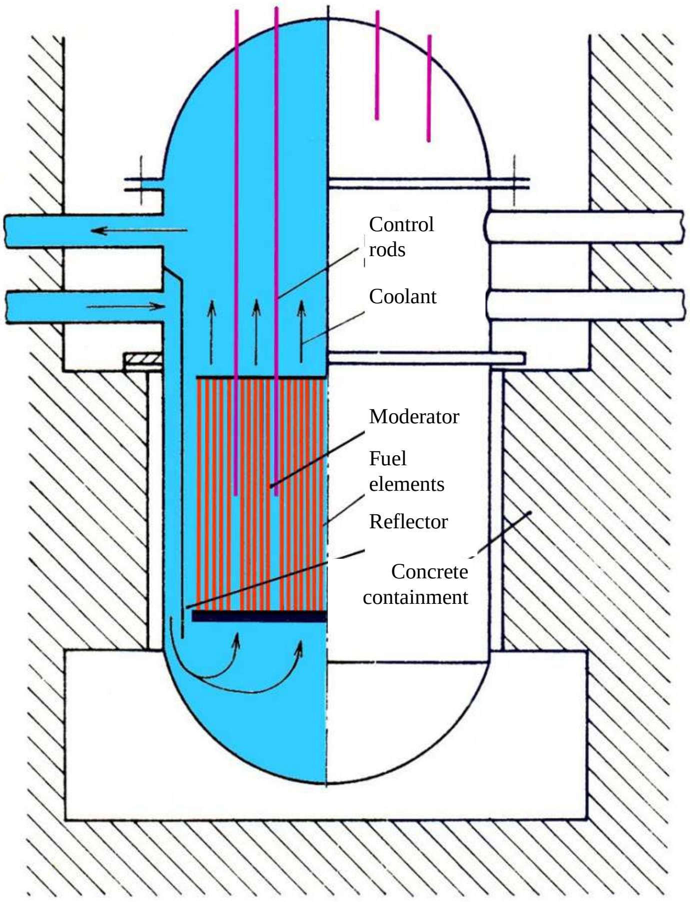
In a nuclear power plant, energy is generated as a result of a **controlled nuclear fission chain reaction** involving heavy nuclei of certain isotopes, especially the so-called 'fissile isotopes' of uranium (U-235, U-233) and plutonium (Pu-23', Pu-24'), occurring in a reactor as a result of the absorption of neutrons by the nucleus. This self-sustaining reaction is possible as the fission reaction produces 2 or 3 new neutrons that may induce new fissions. In a nuclear reactor, the chain reaction is controlled – that is, we are able to control the instantaneous balance of neutrons, and at the same time the amount of energy generated during this time (reactor power). Energy produced by nuclear fission of a single U-235 uranium nucleus is over 50 million times higher than energy produced by oxidation (burning) of coal to CO_2. As a result, a **very high concentration of energy** in achieved in nuclear power reactors, and nuclear power plants need much less fuel (in terms of its mass and volume) than traditional thermal power plants fired with fossil fuels. The vast majority of energy produced by nuclear fission is **collected in the form of heat** generated in the **nuclear fuel** material.

In a typical nuclear reactor, nuclear fuel takes the form of rods – the fuel material is enclosed in an airtight tube (the 'jacket') plugged at both ends. As a result, the **fuel element** resembles a rod:

The fuel element of a water reactor

About 200–300 such fuel elements are typically combined into **fuel assemblies or bundles**. In this form, nuclear fuel is used in nuclear reactors, where it is loaded and fixed on the so-called **reactor core**, i.e. the place where the controlled nuclear fission chain reaction takes place. Almost all power reactors use uranium enriched in U-235 (2-5%) or in plutonium (about 7%).

In the vast majority of nuclear power reactors (especially in light water reactors that will most likely be built in Poland), the core is enclosed in a pressure vessel (see the figure below). In addition to nuclear fuel, the reactor core contains the so-called ***moderator*** (a material that reduces the speed of neutrons to low energy values, where nuclear fission is more probable) and the ***coolant*** that flows in the bottom-up direction to the top section of the core, washing over and cooling down fuel rods by absorbing their heat generated by nuclear reactions.



Thermal reactor with moderator and water coolant

In a nuclear reactor, the fission chain reaction is controlled – i.e. only a pre-defined number of fissions per a unit of time are allowed. The fission reaction, and thus the reactor's power output, is controlled by using materials that have high absorption capacity for neutrons (boron, cadmium, indium, silver). Introduction or removal of absorbing materials to or from the reactor core regulates the number of neutrons in the core. All types of reactors have control rods that contain neutron-absorbing materials, and pressurised water reactors additionally contain coolant absorbents.

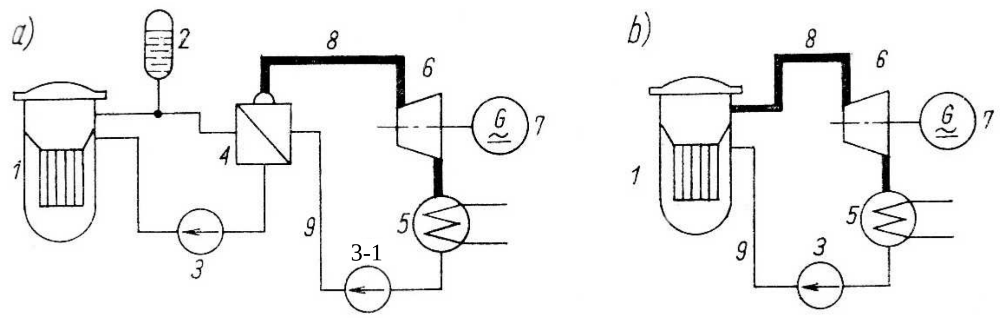
At the design stage, the proportion of the moderator vs. nuclear fuel is defined very precisely in order to achieve the most optimum performance parameters. When the moderator is heated as a result of an increase in power, its density is lower. It reduces the neutron slowing effect, which in turn leads to the decrease in the number of fissions. In addition, absorption of neutrons in fuel (by the non-fissile U-238 isotope) is increased. As a result, neutrons are lost – they cannot take part in the fission reaction. It creates a self-regulating effect, which is especially powerful in reactors with a water moderator.

It must be noted that the design of Generation III or III+ power reactors that are planned in Poland is completely different than the Chernobyl-type reactors (RBMK reactors) and a breakdown similar to the Chernobyl disaster (the so-called reactivity disaster – an uncontrolled sudden increase of power) is physically impossible in new-generation reactors.

There are many types of nuclear power reactors. The most common type of reactors used around the world is the Light Water Reactors (LWR) – they account for 82% of all nuclear power reactors in operation today. In LWRs, neutrons are slowed down (moderated) by ordinary water ('light' water, H_2O – as opposed to 'heavy' water, D_2O, where D stands for deuterium – a hydrogen isotope). Light water is also used as a coolant. There are two basic types of Light Water Reactors: Pressurized Water

Reactors (PWRs) and Boiling Water Reactors (BWRs). Nuclear power units offered currently to Poland include these two types of reactors.

PWR is the most common type of a nuclear power reactor (currently accounting for 61% of all reactors in operation around the world). The core is enclosed in a steel pressure vessel filled with *water* under high pressure (15÷17`MPa), which serves both as a *moderator* and a *coolant*. This pressure is high enough to prevent the boiling of water even at very high water temperatures (about 300°C) inside the reactor. Electromagnetic drives of control rods and safety rods are attached to the lid of the reactor vessel. Rods are moved up or down by the drives – inside or out of the reactor core. These movements of control rods regulate the nuclear fission reaction intensity and ultimately the reactor's output. The majority of neutron-absorbing rods are kept outside of the core. They are the so-called *safety rods*. If need be, all these rods may be dropped into the core, which will break the fission reaction immediately and shut the reactor down. Heat energy generated during the controlled nuclear fission chain reaction in the reactor core, and more specifically in nuclear fuel, increases the temperature of fuel elements. The reactor is connected to a cooling system, composed usually of 2 to 4 loops, where cooling water circulates in a closed–circuit system (primary loop). The primary loop is fitted with a pressuriser used to compensate water volume changes related to the changes in temperature and to maintain constant pressure in the system (see below).



Light Water Reactors: a) PWR, b) BWR

1 - reactor core, 2 –.pressuriser assembly, 3 – main circulation pump, 3-1 – supply pump, 4 – steam generator, 5 – turbine condenser, 6 – steam turbine, 7 – generator, 8 – steam, 9 – water.

Water from the primary loop flows to heat exchangers (steam generators) where its heat is absorbed by water circulating in the second closed-circuit loop (secondary loop), and after cooling down it is returned to the reactor. Pressure in the secondary loop (and in steam generators) is much lower than in the primary loop (6÷7 MPa). As a result, water in steam generators boils and evaporates. Water vapour so generated is supplied to a steam turbine, where it is depressurised going through subsequent levels in the turbine and transfers its energy to rotor blades, which starts the rotating movement of the rotor in a turbine. The rotor drives the synchronous generator where mechanical energy is converted to electric energy. After the turbine, water vapour is depressurised down to 0.0035 ÷ 0.0055 MPa and cools down, moving to the turbine condenser where it undergoes condensation. Condensate is supplied by supply pumps back to steam generators. In this way, the steam and water secondary system is closed. The turbine condenser is cooled by cooling water that circulates in an open loop or closed loop (fitted with a cooling tower).

Boiling Water Reactors (BWRs) are much less commonly used in the nuclear power sector than PWRs (they account for 21% of all power reactors in operation today). The design of BWRs is basically similar to the design of PWRs: the core is enclosed in a pressure vessel, and fuel assemblies are built in a similar way. However, operating parameters of the reactor are much lower (pressure: 7 MPa, steam temperature at outlet: up to 290°C), and they are typical for the parameters of the secondary loop in PWRs. As a result, unlike in the PWRs, water boils and evaporates inside the reactor (see the figures presented above). Steam is generated in the reactor, and not in heat exchangers (steam generators) – as in the case of PWRs. In addition, there is no pressuriser in the BWR cooling system. But the electricity generation process itself is essentially the same as in any nuclear power plant using PWR units.

PGE S.A., the company that will invest in the first nuclear power plants in Poland, has received offers for two types of Generation III+ nuclear power units fitted with PWRs (EPR and AP 1000), and one offer for a BWR unit (ESBWR). All these units will ensure a high level of nuclear safety.

- EPR (European Pressurized Reactor), designed by a French company AREVA NP in co-operation with the German company Siemens KWU, represents the so-called "evolutionary line" in the development of nuclear power reactors.

  EPRs offer a number of solutions that ensure safety not only in normal operating conditions and during design–basis accidents, but also contain the effects of serious breakdowns – including those that involve the complete meltdown of the nuclear core (in particular a solid two-layer concrete containment fitted with a 'core catcher' to prevent damage of the containment structure by the molten core). In addition, the design took account of any potential external threats, both natural and man-caused, including plane crashes (also of large passenger planes) or external explosions.

- The AP 1000 *(Advanced Passive)* reactor, designed by the US company Westinghouse Electric LLC (part of Toshiba Corporation), represents the so-called 'innovation line' in the development of nuclear power reactors.

  The AP 1000 is an upgraded reactor with built-in safety features that offers a wide range of passive safety solutions that use natural forces and phenomena (natural convection, gravity, spring force, and compressed gas pressure). The passive safety systems of the AP 1000 absorb heat from the reactor core and cool down the safety containment for as long as 3 days without any AC power supply or operator's involvement.

- The ESBWR *(Economic and Simplified Boiling Water Reactor)*, offered by GE Hitachi Nuclear Power Americas, is an innovative, economical, and simplified Generation III+ Boiling Water Reactor with natural convection in the core and passive nuclear safety features.

  Passive systems ensure cooling of the reactor and its containment. This ensures high level of nuclear safety. No action from the operator and no A/C power supply are needed for 3 days after a breakdown.

Principles of nuclear safety

From the very beginnings of nuclear power plants, people were aware of the potential threats and actions were taken to protect the personnel and the society from the effects of a possible breakdown. The basic assumption is that nuclear risks should be smaller than risks associated with any other electricity production methods.

Defence in depth

The objective of defence in depth is to compensate for potential human errors and component failures. A system of defence in depth is based on the assumption that we cannot rely completely on any single element resulting from the design, maintenance, or operation of a nuclear power plant.

Defence in depth ensures that units with 'active' safety systems are redundant to ensure that safety functions are maintained even if one component is damaged. However, this strategy is not limited to the construction of additional redundant units. Defence in depth is structured in five levels of safety:

I. ***Level one –*** prevention of abnormal operation and system failures in a nuclear power plant. It is based on reliable and conservative design (high safety margins and careful selection of materials), as well as redundancy, independence, and diversification of systems and equipment critical for nuclear safety, and the high quality of construction, maintenance and operation of a nuclear power plant, in particular the culture of safety – adoption of a rule that safety always comes first.

II. ***Level two –*** control of abnormal operation and detection of failures to prevent incidents turning into breakdowns. This level involves the use of systems defined in safety analyses (i.e. normal systems in a nuclear power plant, such as power reduction system and normal reactor shutdown) and the optimum operational procedures to prevent or reduce damage caused by operational incidents.

III. ***Level three –*** control of accidents within the design basis in an unlikely case when certain operational incidents are not controlled at level two and evolve into a more serious accident. This level is based on the inherent safety features of a nuclear power plant and the designed (engineered) safety systems whose objective is to restore the controlled state first and then move on to a safe shutdown, and to ensure that at least one barrier that confines radioactive materials remains intact.

IV. ***Level four –*** mitigation of consequences of severe accidents (beyond design basis conditions) to confine the external releases of radioactive materials at the lowest level possible. The key objective at this level is to maintain the highest efficiency of the safety containment to confine the release of radioactive substances to the environment.

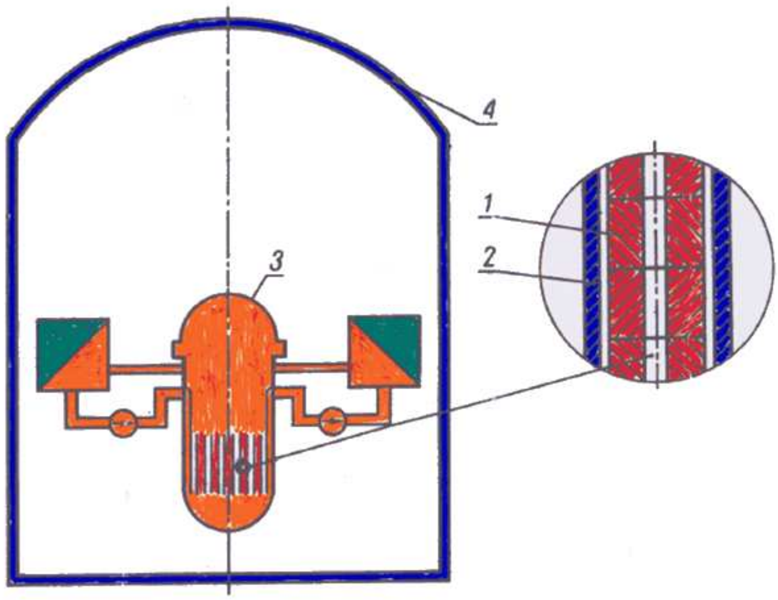
V. ***Level five –*** mitigation of the radiological consequences of significant external releases of radioactive substances that may result from an accident. It requires in particular a well-equipped emergency management centre and implementation of the effective on-site and off-site emergency response plans. At this level, off-site emergency response activities are necessary to reduce the exposure of people to radioactive materials, including administration of stable iodine pills, an order to stay at home or keep cattle indoors if pastures are contaminated, or temporary evacuation from the nearest vicinity of the nuclear power plant.

Natural safety features and safety systems of a nuclear power plant that are designed to contain the accident are upgraded continually, and reactors have become safer over decades. The key focus is now on the appropriate design of nuclear reactors, with built-in safety features based on natural phenomena such as gravity or natural convection.

Safe design of nuclear power plants

A system of barriers that contain the spread of radioactive substances in the event of an accident

The defence in depth principle is implemented in particular by using a series of physical barriers that confine radioactive substances in designated locations on site and prevent their uncontrolled release to the environment. These barriers are shown in the figure below.



Safety barriers: 1 - nuclear fuel material, 2 – fuel rod jacket, 3 – pressure limits of the reactor cooling system, 4 – safety containment.

The vast majority of radioactive isotopes (~99%) are trapped in nuclear fuel pellets inside fuel rods. Volatile products of the fission reaction (radioactive noble gases and aerosols) go through the gas gap between the fuel pellets and the fuel rod jacket and are stopped by the jacket (only a very small quantity goes through to the coolant that circulates in the primary loop).

Activity of cooling water in the primary loop is determined partially by volatile radioactive products from nuclear fuel going through micro-gaps in fuel rod jacket, and partially by activation of the coolant itself and any impurities contained therein or chemicals added to the coolant (radiation of neutrons in the reactor). The coolant undergoes continuous treatment. Any radioactive substances are also removed from the coolant.

The reactor and its entire primary loop are enclosed in a leak–proof safety containment designed for overpressure that may be created by rupture in the primary loop, which will cause a release of considerable amounts of radioactive substances (mainly from fuel released from damaged jackets), but also designed for external loads (seismic events, extreme weather conditions such as hurricanes, explosions, or plane crashes).

Considerable amounts of radioactive substances may be released from nuclear fuel as a result of a mechanical damage (direct effect of mechanical forces) or overheating (insufficient cooling may cause damage to all fuel rod jackets, defragmentation, and even melting of the fuel material).

To prevent or minimise damage to nuclear fuel caused by operational incidents or breakdowns, the following actions are needed:

- reliable and immediate shutdown of the reactor,
- reliable and effective release of after-heat generated in nuclear fuel after the shutdown.

In emergency situations, the safety of people and the environment – i.e. reduction of the uncontrolled releases of radioactive substances from the nuclear plant into the environment –

depends to a large extent on the integrity and tightness of the safety containment as well as its efficiency in the removal of radionuclides released from nuclear fuel and the cooling system.

Efficiency of the system of safety barriers was confirmed in practice when a breakdown occurred in nuclear unit no. 2 of a Pressurised Water Reactor (PWR) in the Three Mile Island nuclear power station, involving a meltdown of the nuclear core (1979, TMI-2, USA). Barriers 1 and 2 were lost, but the reactor vessel (barrier 3) and the safety containment (barrier 4) remained tight. It was the largest accident in a water reactor ever, but despite the damage to the reactor itself, its radiological effects were rather limited – nobody lost their life or health due to this accident (average off-site radiation doses reached 1% of the annual natural background radiation doses). We should note that the Three Mile Island reactor was a Generation II reactor with single safety containment, much weaker than the double containment design of the Generation III+ reactors offered to Poland.

Natural safety features and passive safety systems

A nuclear power plant design includes a number of features and systems based on the laws of nature, such as gravity, that ensure natural control and protection without any external energy source. The key feature is the internal stability of reactors cooled and moderated with water (including PWRs and BWRs that are the most common types of nuclear reactors used around the world today). This stability is based on the fact that after nuclear fission neutrons move very fast (fast neutrons), while the fission of uranium requires slow-moving neutrons (thermal neutrons). Water is used to slow neutrons down; in reactor technology, water is a 'moderator'. Fast neutrons collide with hydrogen nuclei and lose their kinetic energy. After repeated collisions they finally become thermal neutrons. The more water is used, the slower the neutrons will move and they become more capable of causing fission of uranium nuclei. On the other hand, a small portion of neutrons that collide with hydrogen is absorbed. Therefore, we cannot use too much water. The amounts of water and fuel are precisely calculated and adjusted to ensure that the neutron-slowing effect and the capacity of nuclear fission reaction are the highest at normal operating temperature. When water is heated and its density is reduced or – worse still – when water evaporates and its volume in the core is reduced, the neuron-slowing effect is lower, and instead of colliding with uranium nuclei neutrons will rather escape from the core and will be absorbed by the surrounding structural materials. As a result, the number of fission reactions in the core will drop and the nuclear fission chain reaction will stop. It is a critical feature that ensures stability of PWRs. It is the exact feature that was missing in Chernobyl.

Reactor safety system is another system that uses natural forces. It involves the use of neutron-absorbing rods. During normal operation of a PWR, neutron-absorbing rods are suspended over the core and kept in place by electromagnets. In the event of an electrical power failure or a breakdown signal from the safety system, voltage in electromagnets will drop and rods will fall automatically into the core under gravity to stop the reactor.

Emergency flushing of the core with cooling water if the primary loop is broken

If the primary loop is broken, cooling water escapes and the core is uncovered. If fuel rods are not cooled down, fuel temperature will increase and fuel would eventually melt down. Therefore, after the reactor is shut down, the first action is to inject cooling water into the reactor to make sure that the core remains immersed in water. Today's Generation II reactors and the so-called 'evolutionary' Generation III reactors are fitted with active and passive emergency core cooling systems. Active systems consist of three or four parallel sub-units with coolant tanks, pumps and valves, designed to ensure that any single unit is sufficient to immerse the core in water and cool it down effectively. On the other hand, passive systems perform their functions without any external source of electricity.

Absorption of excess heat in emergency situations based on natural convection

After–heat is generated in the reactor core after the shutdown of a nuclear reactor (as the name suggests) as a result of decay of radioactive radionuclides contained in nuclear fuel. After-heat in PWRs is absorbed in steam generators in the secondary loop where cooler water circulates. If primary loop pumps are switched off due to an accident, water in the reactor core will evaporate. If the flow of coolant is interrupted, steam will collect in the reactor vessel above the core and gradually push water out of the core. As a result, the core could be exposed and nuclear fuel damaged. To prevent this situation, designers of nuclear reactors locate the individual elements of the primary system in such a way as to make sure that the core is located well below steam generators, which ensures the flow of coolant from the core to steam generators in a natural convection system – which is sufficient to absorb after-heat.

Passive systems that ensure safety when the power supply is interrupted

If power supply from the power grid is interrupted, nuclear power plants may use their own back-up power generators powered by high-reliability Diesel engines. However, if these back-up units happen to fail too and power supply is interrupted for a number of days, active heat absorption systems cannot perform their functions without the supply of electricity. This situation is extremely unlikely, especially that in many cases nuclear power plants have a direct connection with an adjacent hydroelectric power plant that is able to supply electricity within a short time. However, this scenario is still taken into account when analysing possible emergency conditions.

If the power supply from all sources is interrupted, it may result in a core meltdown, melting of the reactor vessel, and release of molten fuel materials and structural materials outside of the vessel into the safety containment. Therefore, today's nuclear power plants are fitted with systems that will contain the effects of even such an unlikely serious accident. The general trend in the latest state-of-the-art reactors is to introduce the **highest possible number of passive safety systems** that require no signals to be triggered, no external power supply, and no operator involvement.

Principles of safety system design

- Resistance to a single damage

If certain safety functions cannot be guaranteed by using passive systems, high-reliability active safety systems are used. These systems are designed to perform their functions also when any one of their component parts is damaged due to some unforeseen events. Therefore, these components are usually redundant; in most nuclear power plants there are three or (in the most modern plants) even four parallel subsystems, each sufficient to perform all safety functions.

- Diversification of safeguards

Existence of two or more elements that ensure redundancy will prevent a single breakdown of one of these elements, but will not prevent a failure of the entire system due to a common cause that was not known at the time when the reactor was designed or that was considered improbable at that time. To protect the reactor from a loss of safety functions due to a common cause, redundant subcomponents of the safety systems are made of different elements, whenever possible, so that one event that caused a single breakdown cannot cause the simultaneous loss of all safety subsystems.

- Spatial separation

Safety systems are separated physically to make sure that an event such as fire will not cause a loss of two or more subsystems at the same time. In state-of-the-art nuclear power plants, each of the four safety subsystems is located in a different section of the reactor building, separated physically from other sections. In this way, even a plane crash will not cause a loss of more than one safety subsystem. Control cables and power cables of safety systems are laid separately from any cables connected to non-safety systems. In addition, control cables are laid in troughs that are separated from troughs that contain power cables.

- Resistance to fire, flooding, seismic shock, and ambient conditions

Neither redundancy nor diversification of safety-critical elements will be sufficient to ensure safety unless these elements are resistant to seismic shock and the expected temperature, pressure and humidity conditions. In particular, fires are hazardous as they may cause a loss of a number of safety elements within their reach. Therefore, when designing safety-critical systems in a nuclear power plant, a fire risk analysis is performed for any locations where these systems are installed, and safeguards are introduced to eliminate or reduce the risk of fire – for instance, replacement of oil with water as a lubricant for pump bearings. If the risk of fire is not eliminated, its potential reach and duration is analysed and certain measures are introduced to prevent the spread of fire, including fire detection and fire fighting systems. A systematic fire risk analysis must be conducted for all premises in the nuclear power plant, and all necessary safeguards must be introduced, including modification of building plans and specifications.

The same applies to the risk of flooding. If there is a possibility that safety-critical equipment may be flooded, a waterproof version should be always used. Any systems located inside the safety containment, where water is sprinkled to reduce the pressure of vapour after a rupture in the primary loop, must be resistant to steam and water under pressure equal to the maximum pressure level in emergency conditions.

All safety-critical systems must be resistant to maximum seismic shock levels expected for a given nuclear power plant.

Safety culture

In nuclear power plants, the culture of safety governs all activities and co-operation between all persons and organisations working in the nuclear power industry. The overriding principle is that **nuclear safety and radiological protection are superior** to any other aspect of operation of a nuclear power plant – especially its production goals.

Responsibility for nuclear safety must be clearly defined. Both the management and personnel of a nuclear power plant must be sufficiently trained to make sure they are aware of the importance of nuclear safety. Employees are encouraged to learn from their mistakes and treat errors made by others as lessons learned.

1.7 Analysis and evaluation of the impact of radioactive emissions from nuclear power plants

General information

Chapter 7 discusses the feature of nuclear power plants that is most critical from the perspective of the environmental impact of the nuclear power sector – namely, emissions of radioactive substances and radiation doses generated by nuclear power plants during normal operations, any possible breakdowns, and nuclear decommissioning of the facility. This chapter is structured in a way that reflects the logical progression of a possible chain of events. First, we present historical data on the emissions of radionuclides from nuclear power plants that have been in operation for the past half-decade and are similar to nuclear power plants offered to Poland. Based on the knowledge of modifications introduced to the latest cutting-edge reactors (Generation III or III+), the possible release of radioactive substances from nuclear power plants in Poland was evaluated. To this end, we defined the amount of radioactive products of nuclear fission reactions in the reactor and their potential release, i.e. emissions outside of the safety containment – for normal operations, design-basis accidents, and the most serious possible accidents that can happen once in millions of years. As doses of radioactive materials that humans and the environment are exposed to depend not only on the level of emissions, but also on the conditions determining the spread of isotopes in the atmosphere, the next part of this Chapter discusses the methods of assessment of weather conditions for the long-term operation of nuclear power plants (both average representative conditions during the year and emergency conditions). Based on the emissions and conditions determining their spread in the atmosphere, we evaluated the expected doses of radioactive substances from nuclear power plants during normal operation and in a state of emergency.

As the specific reactor type that will be used in nuclear power plants in Poland has not been selected yet, the study includes an analysis of the environmental impacts of three reactors of the latest generation, representing the solutions expected to satisfy the nuclear safety and radiological protection requirements defined in the most recent draft Atomic Energy Act and the related regulations of the Polish Council of Ministers.

On the basis of the safety features of these representative reactors, we defined the restricted-use area outside of which early evacuation or permanent resettlement of humans is not required (even after a serious accident), and the possible intervention will be easy to introduce and will not interfere with the living conditions of the local population in the long term (for instance, administration of stable iodine pills). We also defined the range of the zone outside of which no intervention is planned. These evaluations assumed the typical weather conditions determining the spread of radioactive substances in the atmosphere. As these conditions are different in each location, the reference weather conditions must be defined and precise calculations must be performed for the selected location. However, the general findings of these assessments indicate that the radius of a restricted–use area will reach about 800 meters, and radius of the emergency planning zone – about 3 km around the reactor. These figures were applied to the suggested locations and used to prove that the most preferred locations will need no arrangements with the local communities and authorities of the neighbouring countries as to the planned interventions.

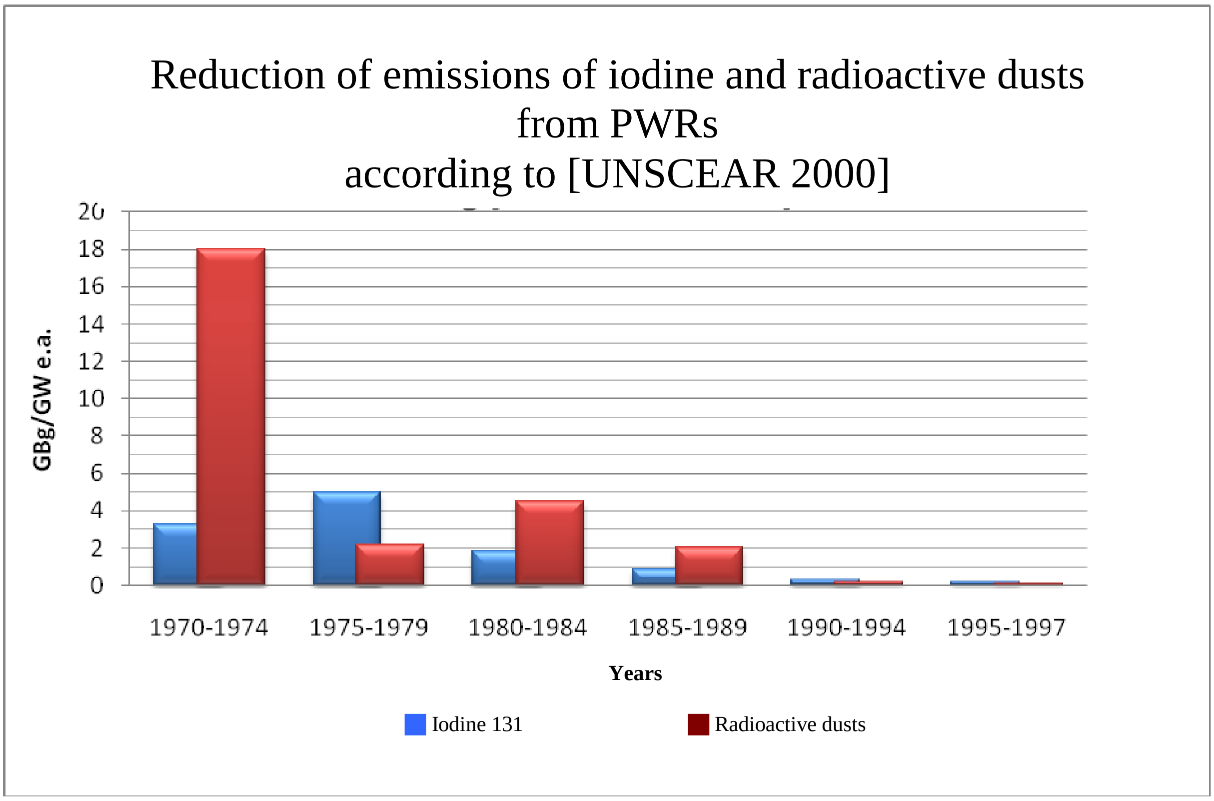
The subsequent part of this Chapter discusses the environmental impacts of nuclear decommissioning operations, as well as the potential health effects of radiation (assuming radiation doses defined for the entire life cycle of the nuclear power plant).

The general conclusion is as follows: radiation from a nuclear power plant does not pose any threat during its normal operation or design-basis accidents. Even in the case of more serious accidents that can occur once in millions of years, the risk is limited to the restricted-use area. Outside of this area, no interventions are needed after design-basis breakdowns, and after serious accidents they will be limited to actions that will not interfere with the living conditions of the local population in the long term, such as administration of stable iodine pills, within a small distance around the nuclear power plant (estimated at about 3 kilometers, depending on the local weather conditions and type of reactor).

Analysis of radioactive emission levels

Emissions of fission products during normal operation of nuclear power plants have been decreasing steadily as plant introduce state-of-the-art technologies and methods of work that keep the exposure to radioactive substances as low as reasonably possible. This trend is presented in Fig. 7.1 showing the drop in emissions of iodine and radioactive dusts from PWRs. Of the reactors proposed for Poland, two are Pressurised Water Reactors that use the experience gained during the last half-decade of their operation. They represent the EPR range (Evolutionary Pressurized Reactor) and

AP1000 – (Advanced Passive Reactor). Assessments based on the analysis of design modifications in the EPR (representing Generation III reactors) indicate that emissions from this reactor during normal operation are negligibly low.



Reduction of iodine and radioactive dusts emissions from PWRs – data from the UNSCEAR report

Emissions from PWRs are lower than emissions from BWRs, because the entire primary loop with the coolant (that contains radioactive substances and is activated when flowing through the core) is located inside a solid and tight safety containment. Outside the containment there is a turbine driven by a steam loop (secondary system) that collects heat from the primary system through walls of heat exchange tubes in steam generators and that does not contain any radioactive substances and poses no threat of radiation. In BWRs, steam generated directly in the core goes into the turbine. This steam contains radioactive substances and its releases (for instance if safety valves are opened) involve the release of radioactive substances. If the steam pipe is broken outside of the containment, iodine and other fission products may be released to the environment.

Given these differences, emissions generated during normal operation and in emergency conditions should be conducted separately for PWRs and BWRs. It turned out that during normal operation all emissions are low. Advanced technical measures used in Generation III reactors, including:

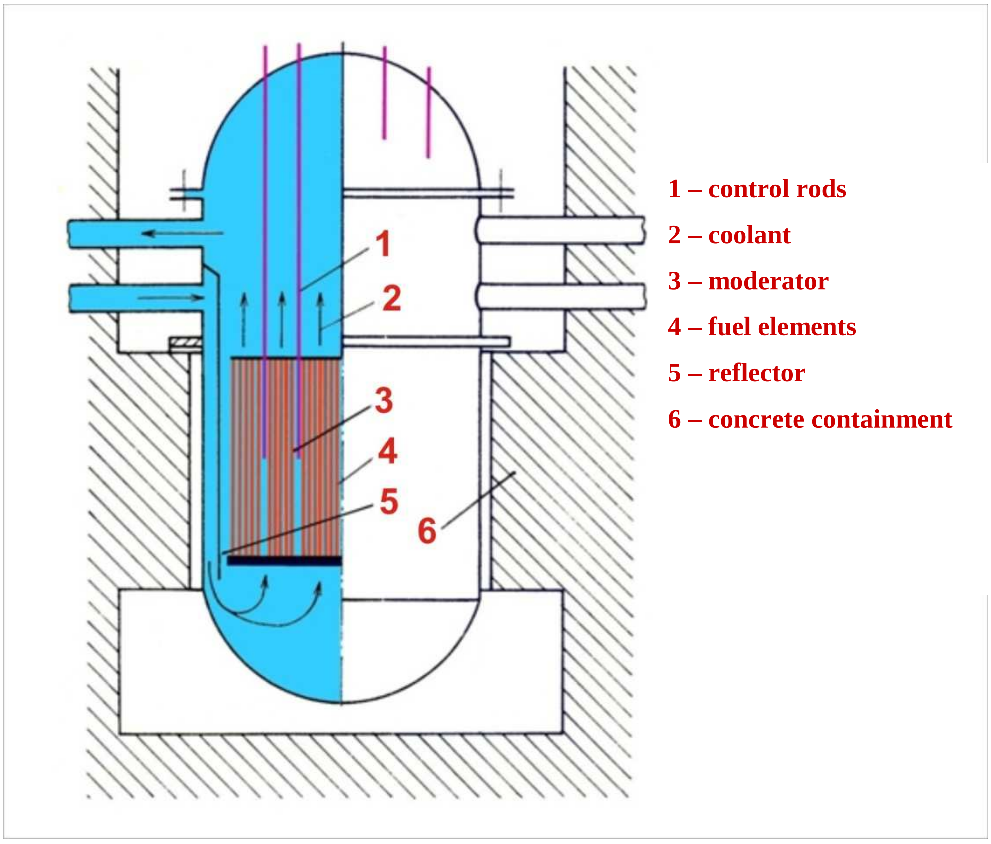
– consistent introduction of redundant safety systems,

– designing safety systems that are mutually independent, diversified, spatially and physically separated, and resistant to any potential emergency conditions in their environment,

combined with the consistent upgrading of the methods of operation in emergency situations ensure the high resistance to breakdowns and effective reduction of emissions if a breakdown occurs nevertheless. The weak link of BWRs is the possible rupture in the steam loop, which leads to significant releases of radioactive materials. On the other hand, both EPR and AP1000 are characterised by very low emissions after design-basis accidents.

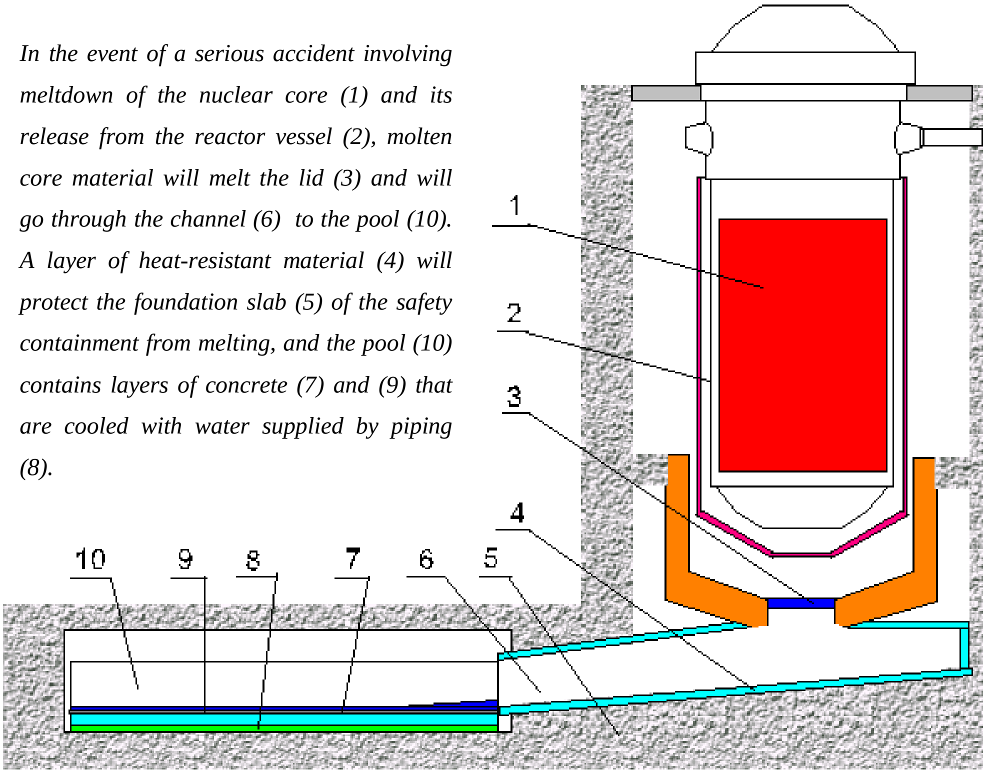
The probability of serious accidents and the related radioactive emissions is also low both for EPR / AP1000 and the ESBWR boiling water reactor (although threats are reduced by different means). All reactors have a solid safety containment; in EPRs, it will resist even the impact of the largest passenger airplane crashing down. In addition, EPR plants have four safety systems located in four separate buildings as an additional safeguard against an external attack. The fundamental feature of Generation III reactors is that their safety systems assume a core meltdown as the starting point, regardless of the very low probability of any accident that causes a core meltdown, and that reactor features and technical measures will protect people from this hypothetical threat.

All reactor designs include safeguards against early and sudden damage of the safety containment, for instance due to an explosion of hydrogen generated at high temperatures caused by the chemical reaction between water vapour and zirconium. A number of other systems ensure the reliable absorption of heat from the reactor and its safety containment. In the AP1000, the shaft where the reactor is located may be flooded with water (in the event of a serious accident) to ensure that the reactor vessel is cooled down from the outside and to prevent any puncture in the vessel caused by the hot core. In the EPRs and ESBWRs, this type of cooling would be insufficient as their capacity is higher. Therefore, a molten core catcher was introduced – a pool installed under the reactor vessel where the molten core will leak in the event of a breakdown and spread over a large surface of liquid (ensuring effective cooling of the molten layer of core materials).



Absorption of heat in the case of a serious accident in the AP1000 reactor – from the molten core through reactor vessel to water inside the reactor shaft.

In the event of a serious accident involving meltdown of the nuclear core (1) and its release from the reactor vessel (2), molten core material will melt the lid (3) and will go through the channel (6) to the pool (10). A layer of heat-resistant material (4) will protect the foundation slab (5) of the safety containment from melting, and the pool (10) contains layers of concrete (7) and (9) that are cooled with water supplied by piping (8).



Core catcher in the EPR

These methods were tested and approved by the nuclear regulatory authorities in the leading countries such as the USA, France, the UK, Finland, Japan, Korea, China, and Russia. Their effectiveness is beyond any doubt. With these systems we may expect that after a serious accident (involving damage of the nuclear core), inhabitants of the zone outside of the restricted-use area will not be affected.

Assessment of the direct and indirect routes of radiological exposure in emergency conditions

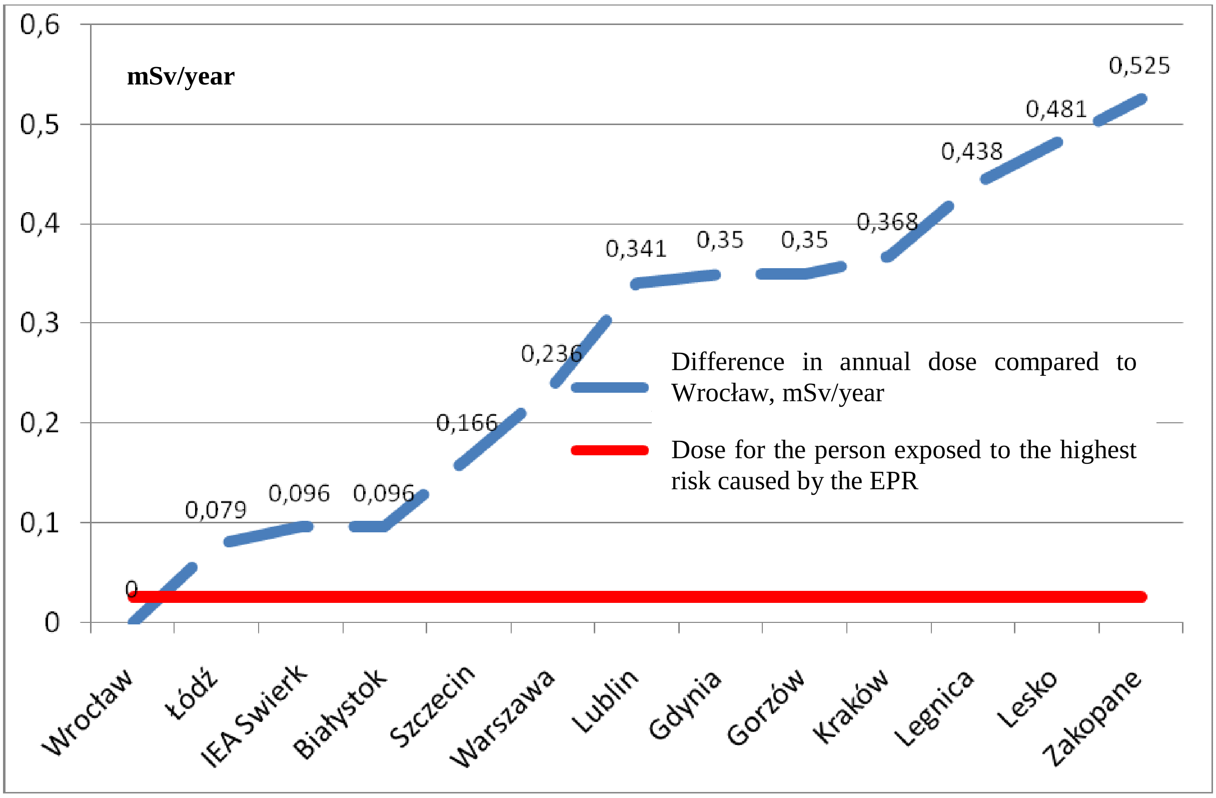
If radioactive substances are released from the nuclear power plant to the atmosphere, radioactive exposure will depend on the atmospheric dispersion factor. This factor depends of the atmospheric stability class, wind velocity, and distance from the emission source. The most adverse weather conditions are connected with low dispersion, i.e. high stability of the atmosphere and low wind velocity. As weather characteristics are different for each location, the report uses calculations for a single representative type of atmospheric dispersion selected in accordance with the guidance from the US Nuclear Regulatory Commission (US NRC). These dispersion conditions are better than assumed in safety analyses conducted by manufacturers of reactors. It is rather obvious, since manufacturers try to prove that their reactors can be installed even in the most disadvantageous locations and will still meet the applicable safety criteria. It is very likely that after the specific location is selected, it will probably turn out that radiation doses defined by the manufacturers can be reduced.

Summary of the impact of radioactive emissions from nuclear power plants during normal operation

Calculation of doses of radioactive substances emitted during normal operation of the EPR indicates that these doses are very small. If we consider the input from atmospheric emissions, deposits on fields and the contaminated food produced on land, as well as fish exposed to radiation coming from nuclear power plants, inhabitants of highest-risk areas within 500 m around the reactor will be exposed to radioactive doses amounting to about 26 microsieverts, i.e. much LESS than the difference in annual doses between average towns and cities in Poland. For instance, the average dose of external radiation in Kraków is higher by 390 microsieverts than in Wrocław. It means that an inhabitant of Wrocław who decides to move to Kraków will be exposed to an additional dose of radiation 10 times higher than they would be exposed to in Wrocław if a nuclear power plant was built in front of their house with the fence of the nuclear facility right in front of their window.

The comparison of maximum doses of radiation from the EPR and differences in doses between towns and cities in Poland is presented below.

Still, nobody in their right mind would shy away from going to Kraków for fear of higher radiation. By the same token, we are not afraid of going to Zakopane, where radiation levels are even higher. We may therefore conclude with certainty that the low additional radiation in the immediate vicinity of a nuclear power plant during its normal operation is not a problem for the ecosystem and for human health.



Comparison of external radiation doses in various cities and towns in Poland and the additional dose of radiation that a person could be exposed to through all routes of exposure in highest-risk areas in the vicinity of the EPR.

Summary of impacts in transient and emergency conditions

In the event of design-basis accidents that are rare or very rare (down to failures that occur every 100,000 years), doses of radiation from the EPR that a person in the highest-risk area may be exposed to are very low. For breakdowns inside the safety containment, these doses will reach about 1 mSv per person, and for accidents during the unloading of nuclear fuel and involving the release of radioactive materials outside the safety containment this dose will reach 5.5 mSv (assuming the unfavourable atmospheric dispersion factor). For atmospheric dispersion factors expected in the suggested locations in Poland, doses of radiation caused by all design-basis accidents in the EPR will not exceed 5 mSv even at the distance of 800 m from the reactor.

The situation is worse for ESBWRs. If the steam piping is broken outside of the safety containment (which is classified as a design–basis condition) and if we assume a worst-case scenario for the atmospheric dispersion factor, the dose of radiation at the limits of the restricted-use area will reach 126 mSv. This dose will be lower in better weather conditions, but the restricted-use area needs to be much larger than 800 m to make sure that the dose outside of this area is within the limits assumed in the current draft of the Act.

Summary of impacts caused by serious accidents

In the event of a serious breakdown, emissions from Generation III reactors are limited thanks to the technical solutions and natural safety features, so that a long-term or severe exposure of the local population is not possible even for the core meltdown scenario assumed in the analysis. Special safety requirements adopted by the European power utilities (known as EUR, European Utility Requirements) assume that reactors must be safe not only during normal operation and design–basis failures, but also during serious accidents involving the nuclear core meltdown. The same requirements were introduced to the proposed provisions of the Polish Atomic Energy Act and the related regulations of the Polish Council of Ministers. Reactors offered to Poland must conform to these requirements.

Thorough verification of all safety features is only possible after completion of an analysis of the reactor’s documentation by the nuclear regulatory authorities. However, for the purposes of this study it was assumed that the results of analyses of three reactor designs by the EUR Committee and the nuclear regulatory authorities in the USA, Finland, France, China and the UK will be sufficient. AP1000 and ESBWR reactors offer considerable reduction of the frequency of serious accidents and have special solutions to prevent early and significant releases of radioactive materials after the reactor core melts. They meet the requirements concerning reduction of the likelihood of accidents and reduction of the hazard in the event that a serious accident does occur despite all of the preventive measures.

In general, we can expect that reactors built in Poland will meet the requirements of the Polish standards proving that in the event of a serious accident that involves the nuclear core meltdown, there is no need to take early and long-term intervention (such as evacuation or permanent resettlement) outside of the restricted-use area whose radius is currently defined at about 800 m (depending on the actual local weather conditions and the type of reactor). Mitigation measures with limited and medium-term scope, including administration of stable iodine pills, may be required after a serious accident within the LPZ (low population zone) – about 3 km around the reactor according to the EUR requirements (also depending on the local weather conditions and the reactor type).

The following table presents a summary of the parameters of radiological impact on humans and the environment for the nuclear power plant proposed for Poland, with an envelope including the results for Generation III reactors, taking into account the standards proposed for Poland.

Parameters of radiological impact on humans and the environment for the nuclear power plant proposed for Poland defined for the limits of a restricted-use area.

PARAMETER	RESULT IN ANALYSES PREFORMED FOR:			FOR THE NUCLEAR PLANT IN POLAND
	EPR	AP1000	ESBWR	
Atmospheric dispersion factor χ/Q for the distance of 800 m from the nuclear power plant and for the time of 2 h, s/m^3	$1*10^{-3}$	$5.1*10^{-4}$	$2*10^{-3}$	$2.5*10^{-4}$
Radius of the restricted-use area, m	800	800	800	800
Annual dose during normal operation, mSv	0.025 mSv,	0.121 mSv,	0.012 mSv,	0.30 mSv, 800

		500 m from the plant	800 m from the plant	800 m from the plant	m from the plant
Dose after an accident without core meltdown, 800 m from the plant, mSv	at χ/Q assumed in reports presented by suppliers of reactors	5	22	126	10
	at χ/Q assumed for the nuclear plant in Poland	1.4	10.8	15.8	
Dose after a serious accident with core meltdown, for 2 hours, for the assumed χ/Q, mSv	at χ/Q assumed in reports presented by suppliers of reactors	122	246	130	100
	at χ/Q assumed for the nuclear plant in Poland	30.5	120.6	16.3	
χ/Q for the boundary of a low population zone LPZ (2,400 m) s/m^3					
0-2 h		1.75*10^{-4}	2.2*10^{-4}	1.9*10^{-4}	Data must be defined for the specific location, based on the annual cycle of meteorological measurements
2-8 h		1.35*10^{-4}	2.2*10^{-4}	1.9*10^{-4}	
8-24 h		1.00*10^{-4}	1.6*10^{-4}	1.4*10^{-4}	
24-96 h		0.54*10^{-4}	1.0*10^{-4}	0.75*10^{-4}	
96-720 h		0.22*10^{-4}	0.8*10^{-4}	0.3*10^{-4}	
χ/Q for the boundary of a low population zone LPZ s/m^3, arithmetic average for 30 days		2.63*10^{-5}	8.53*10^{-5}	3.87 *10^{-5}	
Dose after a serious accident with core meltdown, for 30 days, for χ/Q for the boundary of a low population zone LPZ, mSv		111	234	353	
Frequency of serious accidents involving high releases outside of the safety containment		Less than 10^{-6} /reactor-year	6*10^{-8} /reactor-year	Less than 10^{-8} /reactor-year	Less than 10^{-6} /reactor-year

Nuclear decommissioning of the EPR – impact on the ecosystem

Chapter 7 also analyses the possible course of action and effects of the nuclear decommissioning procedure for a Generation III reactor such as the EPR. Experience in decommissioning of nuclear power plants and other nuclear installations to date indicates that the nuclear sector has the necessary skills and technical measures to implement this process effectively. Decommissioning of a nuclear power plant with full-capacity reactors (900 MWe) in a number of different countries (the USA, Japan, Germany) has shown that the costs and time frames of this process are within the design, and radiological risks for the personnel and the surrounding area are small, comparable to the risks associated with normal operation of the nuclear power plant.

In the case of Generation III nuclear power plants, their designs included the nuclear decommissioning requirements from the very start. It was manifested in:

– optimum design of the geometry of all systems – to ensure easy dismantling,

– selection of materials – to reduce the activation of materials and eliminate the collection of radioactive substances,

– introduction of local protective shields - to reduce the personnel's exposure during decommissioning works.

Detailed analysis of the expected decommissioning operations for the EPR shows that this reactor was well designed and ensures the highest possible reduction of the radiation exposure for humans and the ecosystem.

Flamanville nuclear power plant - case study summary

The case study of the impact of the new EPR unit no. 3 in the Flamanville nuclear power plant in France on human health and the ecosystem has shown that:

- very small emissions of non-radioactive gases will have no detectable impact on the quality of air in the area of Flamanville,
- operation of the EPR will have no significant impact on the current radioecological conditions around the nuclear power plant,
- nuclear waste will be reprocessed and stored in the power plant building to make sure that containers will not leave the controlled area without prior control and approval,
- radioactive waste will be transported by rail or by road only in final containers that will meet the requirements defined by the nuclear regulatory authorities,
- methods of transport of containers with radioactive waste will meet all the applicable requirements for transport by rail or in trucks.

Summary of the impact of small doses of radiation on living organisms

Long–term studies conducted in many parts of the world and among different populations have proven beyond any doubt that small doses of radiation – comparable to natural background radiation – have no negative impact on human health, including adults, children, and the offspring of persons exposed to radiation.

Still, up until recently, comparative analyses would assume that every dose of radiation carries a risk that is proportional to the dose. All analyses performed by 2005, the results of which are quoted in this study, were based on this assumption.

The leading specialists in health protection call for additional studies and development of models that would explain the impact of small doses of radiation on human health. Studies are underway, but in the meantime everyone agrees that small doses of radiation either have no negative impact at all or these impacts are undetectable even when studying the largest populations. On the other hand, many renowned scientists and highly reputed institutions claim that the majority of results even suggest a positive effect of small doses of radiation.

1.8 Analysis and evaluation of other expected significant impacts related to the operation of nuclear power plants

Impacts at the Programme implementation stage

Planned activities related to the implementation of the Polish Nuclear Programme will have an insignificant impact compared to the construction and operation phases, but their effects will be long-term (until 2022) and multi-dimensional. At the first stage of the Programme, the appropriate bodies will be set up and the legal framework will be established for the development the nuclear power sector in Poland. These actions will have long-term positive effects, as they will pave the way for the development of a new energy sector in Poland. Then, actions will be taken to train the Polish specialists in nuclear power generation, and to educate the Polish society based on information and education campaigns. The impact of these actions on people will be positive: the environmental awareness and knowledge of the Polish citizens will improve, and the knowledge of specialists and experts in the field will help improve the technologies currently used in Poland. In the long term, these actions may prove very useful in the development of innovative technologies in the country.

Impacts at the construction stage

Impacts at the stage of construction of nuclear power plants are significant, as construction works usually last for about 6–7 years.

Impact on water

In the construction phase, waters are mainly exposed to impacts caused by earthworks conducted on site, especially in areas where ground waters are not separated from the surface by an impermeable layer. However, the very basic safeguards during normal construction works will eliminate the risk of groundwater contamination with substances from the surface of the construction site.

During the first commissioning and tests of the nuclear reactor, the possible emissions of chemicals to water are analysed. The actual amounts of these chemicals depend on the type of cooling systems installed and the local conditions for the intake and discharge of water, and they should be specified in detail for a given location of the project.

Impact on the air

In the construction phase, dusts may be emitted to the atmosphere as a result of earthworks, transport of soil and building materials, production of concrete, or storage of loose materials. However, there are effective methods to prevent the excessive production of dust, for instance by sprinkling water on roads and worksites (where cutting or crushing of building materials takes place). The quantity of dusts emitted to air may be evaluated only during the environmental impact assessment for the construction of a nuclear power plant in a specific location. The same applies to emissions of exhaust gases from machinery and vehicles. Their impact will be evaluated only after the specific location of the project and transport routes leading to the construction site have been defined.

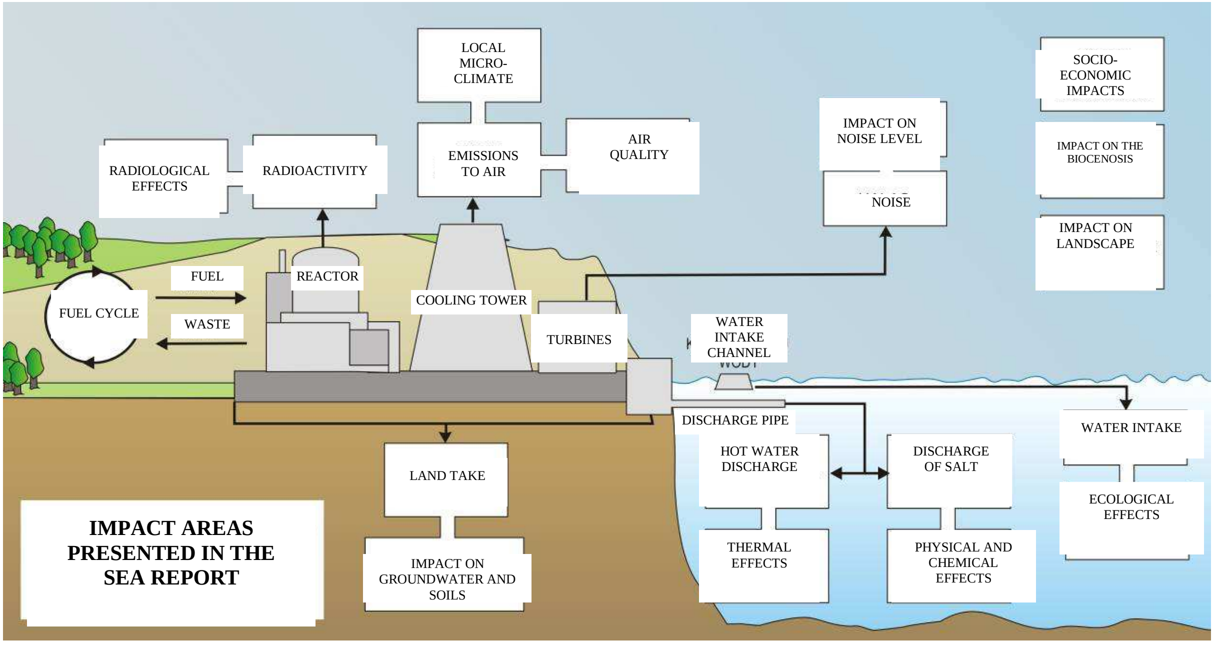
In the testing phase during the pre-commissioning of the entire installation, it will be heated up to high temperatures for the first time. As a result, chemical substances may be released to the atmosphere. Even if we assume the worst-case scenario, the impact of these emissions on the air will be insignificant, and precise models are not necessary.

Impact on the Earth's surface

The impact of the construction of power generation facilities and the related transmission infrastructure will consist mainly in the stripping of topsoil and modification of the ground structure in the immediate vicinity of the planned investment. Impacts of this type may also be observed in the location of the temporary storage of building materials and structural elements. The potential impacts also include the pollution of soil with petroleum products that mat be released into the ground due to leakage or breakdowns of mechanical vehicles. However, impacts of this type will occur only in the direct vicinity of the project and, given their limited scale, do not require any recultivation works as a rule.

Impacts at the stage of normal operation of the nuclear power plant

The following Figure presents the impacts of a nuclear power plant on individual elements of the environment in the operational phase. This Chapter discusses these impacts one by one, with the exception of radiological impacts – they have been discussed earlier. The summary presents key elements of the entire scope of impacts. Certain less significant aspects are only recaptured in the Table below to avoid repetitions.



Impacts related to the fuel cycle

The fuel cycle includes the supply of raw materials to the nuclear power plant (extraction, processing, and enrichment of uranium, production of fuel elements, and transport), use of fuel to produce electricity, and management of spent fuel (reprocessing, including recycling, transport, neutralisation, and deposition).

The analysis conducted as part of the SEA Report indicates that resources of uranium currently available in Poland are scarce, and many years of exploration and prospecting works will be required to find new uranium deposits (if any). Therefore, the best option is to import fuel from abroad. The indentified worldwide resources of uranium extracted at a price lower than $130/kg amount to 5.5 million tonnes. Known resources of uranium ore extracted at about $130-260/kgU amount to 0.9 million tonnes. The resulting 6.4 million tonnes of uranium ore will satisfy the demand (at the current level of production of 61 thousand tonnes of uranium per year) for more than 100 years. With the introduction of breeder reactors and fuel recycling technologies that considerably increase the energy efficiency of nuclear fuel, the same resources will suffice for several thousand years (at the current level of electricity production). Given the availability of global uranium deposits (including deposits that have not been documented yet), it would be unreasonable to search for uranium ore in Poland. However, we should highlight the fact that hundreds of thousands tonnes of phosphorites are processed in Poland. Uranium contained in phosphorites forms an unwanted component of phosphates. It seems worthwhile to use this source of uranium – it will offer about 50 tonnes of uranium per year and will have a positive environmental impact.

Mining activities involving the extraction and processing of uranium ore have significant impacts on the environment. These impacts depend on the type of uranium deposit, parameters of the surrounding area, and the adopted mining technology. As the processing of uranium ore involves a chemical separation of this element, it may lead to migration of radioactive isotopes deposited in uranium ore during millions of years as a result of uranium decay. Migration of these isotopes may be reduced by using the optimum extraction and processing technologies. The processing of uranium ore produces waste that may contain radioactive isotopes deposited in uranium ore during millions of years as a result of uranium decay. We must note that these activities will not lead to any increase in the amount of radioactive elements in the lithosphere, and the only risk is related to their relocation or easier migration to water and air. A properly designed radioactive waste depository (using mining pits whenever possible) will ensure permanent neutralisation of natural radioactive isotopes in a manner that is not much different from their original state. Migration of radium, radon, and other products of uranium decay is a natural process, and radium and radon waters are commonly found in the lithosphere and sometimes used for medical purposes. Uranium mining and pre-processing takes place in areas where the quantities of radioactive elements are naturally higher, and their negative impact on the environment should not be exaggerated. In addition, these impacts will occur outside of Poland.

A nuclear reactor in a power generating unit with the capacity of about 1000 MW will use less than 20 tonnes of nuclear fuel per year - equal to one freight wagon per year (as a comparison, about 3 million tonnes of coal per year must be burned in a coal-fired power plant with the same capacity – which equals about 160 carriages). The fuel cycle in a nuclear reactor, i.e. the period of fuel burn-up followed by its replacement, lasts for 12 to 24 months, and fuel assemblies will remain in the core for about 3 fuel cycles (i.e. 3 to 5 years). The reactor is filled with new fuel only partially in carefully planned configurations (the reactor core contains several hundreds of fuel assemblies of various degree of enrichment and burn-up) to ensure the most efficient use of nuclear fuel. Fuel cycles must be planned in advance, based on the analysis of long–term electricity production plans. These plans are a source of data necessary to place orders for nuclear fuel. Under the Polish Nuclear Programme, nuclear fuel will not be produced in Poland. Ready-for-use fuel assemblies will be purchased from global producers of nuclear fuel. Suppliers of the specific types of reactors are the most obvious and likely suppliers of nuclear fuel, but it may be ordered from another supplier, too. If need be, fresh fuel can be kept in store in a nuclear power plant for many years (given the low demand for nuclear fuel in terms of its quantity). Fresh fuel is transported (by sea, rail, or road) in special containers that protect fuel from damage, also in the case of accidents. Ionising radiation emitted by fresh uranium fuel is insignificantly small, so no radiation shields are necessary.

Spent fuel removed from the reactor is placed in a water pool, where it stays for at least 3 years (usually 7-10 years). During this time, it is cooled down and de-activated by tens of per cent. If spent fuel is not reprocessed, it is moved to the interim storage facility (usually located on site) where it can be stored for additional 40-50 years. Next, spent nuclear fuel is deposited in geological formations. Spent fuel removed from the reactor is highly radioactive and emits heat generated as a result of radioactive decay. After about 4 years, the activity of fission products contained in spent nuclear fuel declines by 4 times. After about 300 years, the activity of fission products declines by 1000 times and spent nuclear fuel becomes practically harmless. Spent nuclear fuel removed every year from a typical large reactor with the capacity of 1000 MWe (in the amount of about 30 tonnes) contains about 300 kg of fissile isotopes that can be recovered by reprocessing and reused in reactors. If fuel is used only once in a thermal reactor, the energy-generating potential of fuel materials is utilised to a very limited extent. If fuel is reprocessed and recycled, its energy-generating potential is increased – we can achieve approx. 30% savings of uranium and reduce the waste volume (by about 5 times) and waste radiotoxicity (by about 10 times). Spent nuclear fuel is transported in special containers that ensure protection from radiation and absorption of heat, meeting the strict safety requirements.

Studies of radioactive waste management in Poland are currently underway. Works are co-ordinated by the Team responsible for the development of the National Plan for Radioactive Waste and Spent

Nuclear Fuel Management Analyses conducted by the Team will be used as a basis to formulate recommendations as to the methods of management of spent nuclear fuel (whether it will be reprocessed and deposited in the country or partially removed abroad). A deep underground depository for highly radioactive waste and spent nuclear fuel will be needed about 30-40 years after the first nuclear power plant is put into operation in Poland – i.e. not earlier than in about 2050. Until then, spent nuclear fuel (unless it is reprocessed earlier) will be kept in water pools next to the reactor (for 10 years) and then moved to an interim storage facility on site (for up to 50 years). The radioactive waste management plan will be developed as a separate document and should be adopted by the Council of Ministers in 2011, following the adoption of the Polish Nuclear Programme.

Direct radiation from radioactive waste does not pose a threat – several meters of soil are enough to confine this radiation underground, and radioactive waste is usually stored several hundred meters below the surface. Therefore, the only risk is that radioactive waste could be washed up to the surface by water. Radioactive substances could be dissolved in water, reach the surface, and be consumed by people, which will cause a radiological threat. To reduce this threat, a number of successive physical barriers are used to contain the possible spread of radioactive substances and absorb radiation. The effectiveness of these barriers depends on their multi-stage design that prevents radioactive substances contained in nuclear waste from getting released, dispersed, sprayed, or washed away with water. Therefore, the degree of exposure of the environment to the negative effects of ionising radiation emitted by nuclear waste is very small, even if we assume a worst-case scenario.

Impact of cooling systems

Two different cooling systems can be used in a nuclear power plant. open-circuit system (without a cooling tower – heat is absorbed by surface waters) and closed-circuit system (with a cooling tower – heat is released directly to the atmosphere). At this stage, designs of cooling systems for nuclear power plants in Poland have not been developed yet. They will be developed for specific locations selected by the investor. An open-circuit cooling system in a nuclear power plant may be used in locations with an access to large reservoirs of cooling water. In practice, this option is possible only for coastal locations and locations in the lower course of large rivers. Seawater is an attractive option given its unlimited resources and lower temperature of water, but the intake and discharge of seawater is a technical problem. On the other hand, water from rivers can be used for cooling purposes in a nuclear power plant, but there are certain limitations to water intake amounts and water heating (after mixing, water temperature must not exceed 26°C). Closed-circuit cooling systems may be fitted with wet cooling towers (with natural draft) and hybrid cooling towers (mechanical draft supported by fans). Different technologies are characterised by different consumption of cooling water (lower for hybrid cooling towers), ranging from about 1 to 2.5 m^3/s (for nuclear power plants with 2 generating units), i.e. from about 25 to 71 million m3/year. Nuclear power plants should be located in areas with sufficient water resources to cover this demand. So far, sufficiency of cooling water resources has not been analysed in detail for the proposed locations. This Report attempts at a preliminary estimate of the sufficiency of water resources. This problem does not apply to coastal locations where seawater will be used for cooling. In the case of river sites in the lower course of the Vistula and the Oder River (including Szczecin Lagoon), open-circuit cooling systems are planned (although the final decision has not been taken yet). In the case of locations at lakes, open–circuit cooling systems cannot be used (due to the existing limitations). Therefore, closed-circuit system (most probably with hybrid cooling towers) must be assumed. For other riverside and inland locations, closed-circuit systems are assumed (usually with natural-draft cooling towers, optionally with hybrid cooling towers). However, in certain cases the available resources of cooling water may not be sufficient to compensate for non-recoverable losses. Demand for raw water of a nuclear power unit with the capacity of 1000 MWe is relatively low (about 530 m^3/d on average).

Operation of cooling systems in a nuclear power plant also involves the emission of heat to water or air, and release of chemicals into water in connection with the water treatment processes. These impacts are summarised in the following table as impacts on surface waters and impacts on the air.

Impacts related to the emissions of pollutants to the air

One of the outcomes of the Programme will include the partial replacement of electricity generation in coal-fired power plants with electricity production in nuclear power plants. As the emissions of pollutants to the air are much lower for nuclear power plants, the Programme will reduce the emissions of pollutants in the atmosphere resulting from electricity generation. This Chapter attempts to estimate the possible reduction of these emissions. Based on data presented in the literature and our estimates, we arrived at a conclusion that implementation of the Programme may potentially reduce emissions of CO2 to the atmosphere by about 18% vs. today's emission levels, emissions of dusts - by about 16%, and emissions of other pollutants from the power sector (SO2 and NO_x) by about 15-17%.

Impact of noise

The level of noise during operation of a nuclear power plant, with no consideration given to background noise and natural topography of the area, will not exceed the acceptable standards within 350 m from noise sources. Therefore, operation of the nuclear power plant will not increase the level of noise in the environment to a considerable extent. Emissions of noise come mainly from operation of cooling towers (fans, pumps, air intake and exhaust vents, and water dripping in wet cooling towers).

Impacts related to the land take

A nuclear power plant is a project that occupies a large area. Therefore, its construction and operation requires that an extensive area of land is excluded – either agricultural land or a meadow ecosystem, depending on the specific location. Deforestation may be also necessary – trees in the area of the planned project must be removed. The actual built–up area depends on the adopted technology – the type of reactor (from 6 to 9 hectares) and installation of cooling towers (4 hectares). The entire nuclear power plant (with 2 power blocks) with the associated infrastructure will occupy about 40 hectares of land. As no detailed location analyses have been performed yet including the determination of land use, these are only estimates based on previous projects involving the construction of similar installations.

As a result of hardening and sealing of the surface area, the amount of water going through to ground waters will be reduced, which may cause lowering of the groundwater level and increased run-off of water from the area to surface waters.

Land take may potentially restrict the access to resources of minerals. The analysis of the available maps of mineral deposits indicates that there are no useful deposits of minerals in the area of the planned projects.

Impact of the infrastructure development

Analyses indicate that the majority of the existing network infrastructure (power transmission lines, transformer stations) may be used for the next 10-20 years. This expected useful life is safe in the case of network facilities such as transformer stations, switches, and 400 kV line components. However, it is too short for 220 kV lines. Implementation of power network investments, including (but not limited to) the connection of nuclear power plants, needs several years to complete the preparation and implementation phase. According to regulations currently in force, this period is about 7 years. Power offtake from a nuclear power plant requires one transformer station and two HV lines. Positive impacts of these investments include the creation of favourable conditions for electricity transmission. Negative impacts in the implementation phase will include an increase in the level of noise, exhaust gases and dusts generated by construction machinery and equipment, as well as the removal of trees and shrubs along the route of the power line and in sections of construction sites. In the operation phase, 400 kV and 110 kV equipment may generate the following environmental impacts: permanent land take for poles and power stations; creation of restricted-use areas; permanent emissions of electromagnetic field; interferences with radio and TV signals; generation of acoustic noise; permanent and significant landscape changes; and permanent risk for birds and bats.

Construction of any power plant, not only a nuclear facility, will require the sufficient amount of cooling water (about 50.2 m^3/s for the nuclear power unit). Therefore, the appropriate infrastructure must be provided for the intake and discharge of heated water. In addition, it will require an extension or modernisation of the local road network and elements of the railway network, as well as building of piers/wharfs for the loading and unloading of large or overloaded cargo including construction equipment and components (in the case of power plants located at large rivers or the sea). Development of the infrastructure will require the use of certain environmental resources (especially water and energy), just as for any other large industrial plant. Passenger and technical transport vehicles will generate additional emissions of exhaust gases to the environment. However, these amounts will not be considerable. We should note that passenger traffic will be more intensive than traffic of technical vehicles, given the low demand for raw materials but high demand for workforce (high number of employees on site). Operation of the infrastructure will also produce waste.

Impacts on the landscape

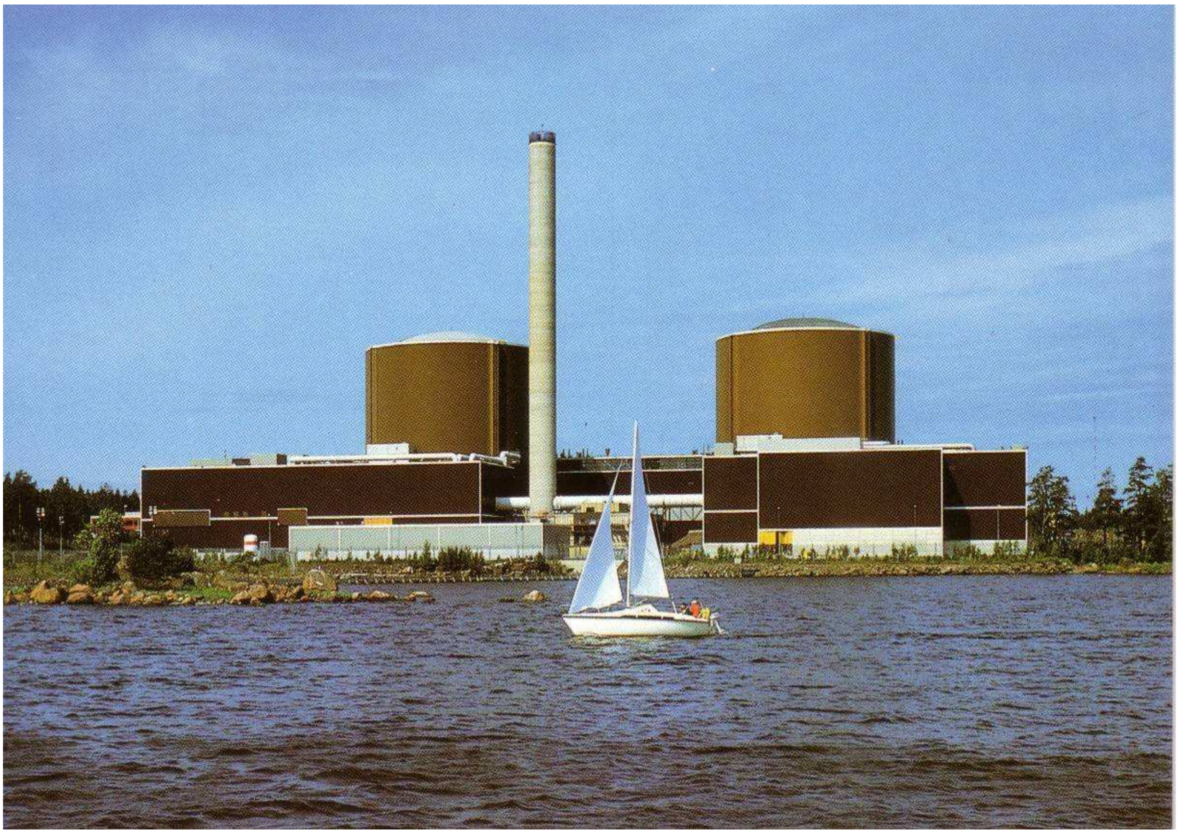
Impact of the nuclear power plant on landscape is closely related to the location of the project and type of land use in the neighbouring areas. Therefore, it depends on the scale of the investment, cubage of buildings and facilities, and the associated infrastructure, as well as the urban layout and components of the natural environment in the area. Therefore, the expected impacts cannot be precisely defined at this stage. Still, we may analyse impacts recorded for the adopted reference projects.

It seems beyond any doubt that all large investments in the power sector change the existing spatial arrangement. These changes include single point, surface, and linear objects (such as roads or transmission lines). Their vertical range (and thus visibility from a distance) is also diversified. Given that a qualitative evaluation of this interference is difficult, we could use quantitative data for a project with a comparable or generally high electricity production capacity (e.g. in terms of the area occupied by the project or the area where raw materials are extracted). The following examples illustrate different methods of presentation of various projects and how it influences the way we perceive these projects. Supporters and opponents of various types of investments often use quite different images – photographs of landscapes.

Landscapes in the area of various types of power plants – examples of one-sided presentation

To some extent, operation of a nuclear power plant depends on good communication – including transport by road or rail and power lines. The first two problems seem marginal, given that fuel deliveries and removal of spent fuel are not too frequent, and the number of people who come to work at the power plant is not too high. However, high-capacity transmission lines and the associated infrastructure will definitely change the original spatial arrangement. Still, this effect is observed for all large electricity–generating facilities, irrespective of the technology, and in all places where transmission lines are installed – even if there is no power plant in the area. The following photographs illustrate examples of the siting of large facilities (nuclear power plants) in the surrounding landscape, in accordance with the principle of keeping the negative impacts on the landscape at a minimum.

Nuclear power plant in Neckarwestheim (Germany)



Nuclear power plant in Loviisa (Finland)

Social and economic impacts

The impact of a nuclear power plant must be also analysed in terms of its operation as a very important production facility. As such, the project will be of high importance for the economy of the specific municipality and of the neighbouring municipalities. This impact will include:

- higher value of land in the area
- increased income of the municipality
- improved infrastructure

- lower unemployment rate
- economic revival in the region
- higher energy safety in the region

Natural threats to the operation of a nuclear power plant

Natural threats are understood as the impact of nature's forces that poses a threat to human life and health or to human-made infrastructure. As a rule, these are extreme or abnormal phenomena. They include extreme weather conditions (storms, tornados, droughts, etc.), hydrological phenomena (storms, floods, low water, etc.), seismic events (earthquakes, rock bursts), mass movements (avalanches, landslides, mud and debris flows), as well as events in the biotic world (such as locust swarms etc.). They are rather unpredictable, occur suddenly, and have serious consequences for the economy.

The Report analyses all threats defined in the regulation of the Council of Ministers on the requirements for nuclear power projects. These threats apply both to nature's forces and to engineering solutions adopted for the potential investments. At the stage of development of the SEA Report and with no concrete data on the adopted engineering solutions and the selected location, we are not able to refer directly to all these requirements. Still, the key factors connected with natural threats to nuclear power faculties and the associated infrastructure are described.

As far as earthquakes are concerned, no strong, large or extreme earthquakes have been recorded in Poland for the past 1000 years – only moderate earthquakes that can affect only buildings in a bad technical condition, and only to a limited extent. Maintaining the construction standards prescribed by the International Atomic Energy Agency (IAEA), selection of proper building materials, and technical control and proper maintenance of nuclear power facilities under operation should guarantee absolute safety of nuclear power plants in Poland as regards their resistance to seismic shock.

Geotechnical and hydrogeological threats should be eliminated by the proper analysis of ground conditions during preparatory works for the project and by using top-quality building materials and techniques Therefore, detailed analyses of the geology of sub-surface layers and the system of groundwaters are of key importance. Accurate determination of the existing hydrogeological and geological conditions and application of the proper building technologies will guarantee stability of the nuclear power plant when its operation starts.

Weather conditions that may pose a threat to safety in a nuclear power plant include mainly snowfalls and rainfalls (and also hail) – their intensity, frequency, and time; wind – its speed and gustiness; atmospheric discharges; extreme temperatures; and other phenomena, such as tornados. Adverse weather conditions will affect mainly the safety of the associated infrastructure of a nuclear power plant, including electricity transmission lines. They can be expected especially in winter months. In the winter of 2009–2010, HV power lines would break down under the weight of ice. However, the problem concerned mainly old lines that had not been properly maintained. It may be expected that a properly designed, constructed, and managed nuclear power plant will be resistant to extreme weather conditions. The same applies to the related associated services, including proper organisation of transport of fuel and spent fuel.

Hydrological risks are of key importance for all potential locations of nuclear power plants at the bottom of river valleys. The specificity of the technological process that requires water for cooling eliminates the possibility to move a nuclear power plant at a large distance from water intake points.

High water is one of hydrological risks that require special attention. The increase in water level due to oversupply of water or a blockage along the river course is generally considered the highest risk in Central Europe. In Poland, floods – defined as high water that affects people's lives – occur in various rivers each year and practically during all seasons. The most serious floods affecting a large part of major river basins occur in the warmer seasons of the year. Floods are also a problem in the melting season – in spring and mid-winter. There is one another category – floods that are caused by the build-up of ice or slush-ice, affecting mainly rivers in lowlands (such as the annual ice build-up in the Włocławek part of the Vistula). With the currently available building technologies and engineering solutions, it would be possible to protect a nuclear power facility against the negative effects of even the highest water levels. A well-designed nuclear power plant and the associated infrastructure should not be affected by floods. On the other hand, low water (i.e. lowering of the surface and ground water levels) may also become a problem. A nuclear power plant must have access to sufficient water resources. If this water comes from surface water courses, its level must not drop below the minimum flow limit that is required by organisms living in that water course.

Non-radiological impacts at the nuclear decommissioning stage

Demolition works will produce higher emissions of dusts into the atmosphere and higher noise levels. These emissions may be considered a nuisance by inhabitants of the surrounding area. However, they will be only temporary and should not be particularly problematic, given that nuclear power plants are located away from residential areas. Decommissioning of a nuclear power plant will produce large amounts of waste that should be reused or recovered to the highest degree possible or neutralised.

All buildings should be completely demolished, and the area must be cleaned and recultivated. If these works are successfully completed, the impact of the decommissioning stage is considered positive – it removes 'foreign' elements from the landscape. Removal of the large hardened surface will also have a positive impact on soils and waters in the area, leading to the restoration of biologically active surfaces and the natural circulation of water by allowing its infiltration into the ground.

Impact on biodiversity, including biological resources protected under the Natura 2000 network

Construction of a nuclear power plant involves certain environmental impacts. They may include the impact of such a large project on the flora and fauna, or more broadly speaking – on the entire biodiversity and Natura 2000 sites. At the current stage of works, as the location for the project has not been selected yet, it is difficult to predict the specific impacts in this area. All potential locations have different sensitivity and there are only few common impacts that can be assumed for all proposed location to a similar extent. Each location is different in terms of the protection of plants, animals, biodiversity, or Natura 2000 sites.

In addition, every stage of the project has different negative impacts – in terms of their type or severity. Land take has a different importance on the (broadly defined) protection of nature at the construction stage, when modification of the existing environment is the most severe in comparison with the operation stage, when the environment has already been modified and is subject to permanent and repeatable impacts caused by the operating facility. Impact of the nuclear decommissioning stage is again different, as it involves the use of heavy construction machinery.

Therefore, each location has a different degree of sensitivity to various impacts in all phases of the project, given its geography and natural resources. With the large number of these potential impacts, combined with the gaps in knowledge due to the lack of specific studies dedicated to individual locations, we can only list a number of potential impacts but we cannot assign them to any specific location.

We should also note that different actions taken in the course of the project may result in similar environmental impacts; for instance, increased death rate among animals may be caused both by overhead power lines and by vehicle traffic.

In conclusion, if the Programme is given a green light, we can assume that any of the identified negative impacts can be observed in any location. The specific impacts assigned to the selected locations will be analysed at the EIA stage.

1.9 Identification and description of the expected environmental impacts of the Programme

Summary of the identified significant impacts

Significant impacts on biotic elements of the natural environment identified and described in the SEA Report resulting from the implementation of the Polish Nuclear Programme are summarised in the following table. The authors believe that this form of presentation of data will be easier for the reader. Description of the expected impacts on the individual components of the natural environment is broken down into construction, operation, and decommissioning phases for a potential nuclear power plant.

PHASE	DESCRIPTION OF EXPECTED IMPACTS
	Impact on humans
CONSTRUCTION	**Noise will not reach significant levels**, because nuclear power plants will not be located in the vicinity of any residential areas. The transport route leading to the construction site should minimise any nuisance factors for the local population. **Increased dust level** is always associated with the construction of large projects, but it can be effectively reduced by introducing preventive measures. **New jobs** will be created.
OPERATION	**Emissions of radiation** during normal operation of a nuclear plant are within the adopted standards. Radiation doses are much lower than the current average annual radiation dose caused by natural radiation (for instance from rocks), medical sources, or emissions from other industrial sources. Additional radiation dose from a nuclear power plant is also much lower than the difference between doses in individual Polish towns and cities, which means that an inhabitant of Wrocław who decides to move to a city like Kraków will be exposed to a much higher dose of radiation than they would be exposed to in Wrocław if a nuclear power plant was built right in front of their house. In the particular example discussed in the Report, emissions of radiation had no negative effects on humans within 20 years of the plant's operation.
	Effects of small doses of radiation that may be emitted during normal operation of a nuclear power plant were the subject of long-term studies involving the population and selected groups of employees or patients. It was found that small doses of radiation have no negative impact on people's health. Quite on the contrary, most studies indicate that the impact of small doses of radiation is even positive for living organisms, including humans, as they have an anti-cancer effect.

PHASE		DESCRIPTION OF EXPECTED IMPACTS
		Noise is emitted by plant and machinery operated on site. The nuisance level depends mainly on the actual location of a nuclear power plant. Noise levels may be higher for plants with cooling towers. Noise should not be a major nuisance factor for humans, as nobody will live in the restricted-use area (about 800 m around the nuclear power plant).
		Supply of electricity and improvement of the natural environment Introduction of nuclear power in Poland will improve the country's energy security and ensure reliable supplies of electricity to end users at relatively low cost. Generation of electricity in nuclear power plants will produce less air pollution. Therefore, condition of the natural environment will be improved by reducing the current level of emissions from the power sector.
	Accidents	In the event of a nuclear reactor breakdown, the key threat is connected with radioactive substances released to the environment through air (mainly) or water. These substances may be either inhaled or ingested by humans. Therefore, all reactors have an entire system of safeguards and protections – including devices and solutions that prevent the potential release of significant quantities of radioactive substances to the environment. Still, we must note that a potential serious accident that would result in significant releases of radioactive substances to the environment, primarily to air and (in smaller amounts and with lower likelihood) to water, could pose a serious threat to people's health. However, considering the adopted safeguards and state-of-the-art technologies to be used in the first nuclear power units in Poland, the risk of such a serious breakdown is virtually eliminated. Radiological protection procedures have been defined and will be followed in any emergency situation. These intervention measures will minimise any potential negative health effects. The design of new-generation reactors meets the safety requirements defined in draft Polish legislation and in generally accepted European standards. Design-basis accidents will require no intervention outside of the restricted-use area (about 800 m around the plant). Serious accidents may require measures such as administration of stable iodine, but will not affects people's lives in any other way, and their probability is less than once in a million years of the reactor's operation.
DECOMMISSIONING		**Emissions of radiation** during and after nuclear decommissioning will pose no threat to humans. Employees working on nuclear decommissioning will be exposed to doses of radiation that are comparable to normal radiation doses emitted during normal operation and maintenance of a nuclear power plant, and these doses will not cause any harm to their health – as confirmed in a study involving 500,000 people working in the nuclear power sector. **Noise** will be an insignificant nuisance factor, as the nuclear power plant will not be adjacent to any residential area. Transport will be also a source of noise. However, the selected transport route should minimise any nuisance factors for the local population. **New jobs** will be created.
Impact on surface waters		
CONSTRUCTION		There will be no significant negative impact on surface waters in the construction phase. We may only expect local changes in water circulation caused by the fact that ground waters will be pumped out of excavations and trenches and released to surface waters.

PHASE		DESCRIPTION OF EXPECTED IMPACTS
OPERATION		**Emissions of heat** to surface waters will increase their temperature. The increase in temperature of surface waters is limited by law. The temperature of heated water released to surface water bodies must not exceed 35°C for rivers and seas, and 26°C for lakes and their tributaries. Excessive increase in the temperature of surface waters may facilitate the growth of aquatic organisms and excessive fertilisation (eutrophication) of surface waters. The temperature of water has a direct impact on all living organisms and their physiological processes, and an indirect impact on the amount of oxygen dissolved in water. If water is heated up, it affects the solubility of oxygen and facilitates decomposition of organic matter, which leads to faster consumption of oxygen. The actual increase in the temperature of a water body that will accept the heat released by the nuclear power plant can only be calculated for the specific location. A detailed analysis will be conducted after the project location has been determined, and the increase in temperature will be precisely defined in °C on this basis. The water reservoir used for cooling purposes will be analysed in detail during the operation phase to determine the scope and type of impacts caused by the release of heat.
		Chemical pollutants are released to water from products used to prevent depositions on the surface of elements of the cooling water system, disinfectants, and products of corrosion in heat exchangers and piping. In *nuclear power plants on river sites*, additional water used in the cooling system or cooling water itself must be treated. Various water treatment methods will produce deposits that contain some heavy metals. Deposits are collected in special sedimentation tanks, condensed, dried, and removed to landfill dumps. Deposition of this type of waste has no negative impacts on the environment. As calcium and magnesium are removed in the form of deposits, the content of dissolved substances is lower in water released to surface water bodies compared to water that is taken in. In nuclear power plants on coastal sites chlorine must be used to maintain the required purity of water used in water circulation systems. Chlorine reacts with organic compounds and can form harmful chemicals. If concentrations of various chemicals in water released to surface water bodies do not exceed the adopted standards by 1%, their impact may be considered negligible. Oxidising compounds are the only substances that exceed the adopted standards. However, they are very short-lived and they decompose quickly, so the standards will be exceeded only in the closest vicinity of the water discharge area.
	Accidents	A potential release of radioactive substances to surface waters may occur only as a result of a very serious accident. New-generation reactors include additional systems and structures that protect the integrity of the safety containment and the foundation slab. As a result, the risk of an accidental release of radioactive substances is reduced practically to zero. However, in the event of an accidental release of radioactive substances to the atmosphere, radioactive particles will slowly deposit on the surface of the ground, or will be washed away quickly by rain or snow and will finally get to surface water bodies. Depending on the existing weather conditions, potential pollution of surface waters is therefore possible.
DECOMMISSIONING		No significant negative impact on surface waters is expected in the nuclear decommissioning phase.
Impact on ground waters		

PHASE		DESCRIPTION OF EXPECTED IMPACTS
CONSTRUCTION		**Pollution of groundwater** in the construction phase is possible in areas where ground waters are not isolated from the surface and are therefore sensitive and highly sensitive to pollution. Areas where ground waters are separated from the surface with an impermeable layer of clay offer the best protection of groundwater from potential pollution. **Changes in hydrographical conditions** may be caused by earthworks, especially where ground waters are located close to the surface. Deep excavations need intensive drainage works, which may drain the adjacent areas. However, excavations required to build nuclear power plants are not too deep – the maximum depth will not exceed 14.00 m. A large hardened area, including the nuclear power plant and the associated infrastructure, may change the level of shallow groundwater and cause the local drainage of the surface.
OPERATION		**Potential pollution of groundwater** is rather unlikely. All structural elements, systems, and equipment in a nuclear power plant will meet very stringent quality control standards, environmental protection norms, supervision standards, and Best Available Technology requirements, which will minimise the risk of potential accidental release of harmful substances to the ground. Storage containers, storage areas for chemical substances, fuel unloading areas and areas of other works that could cause environmental pollution will be located on hardened surfaces or confined with leak proof barriers that will contain any possible releases of harmful substances. Therefore, operation of the nuclear power plant will have no impact on the quality of the ground and groundwater – unless a serious accident occurs. To control the quality of groundwater in the area of the nuclear power plant, groundwater will be sampled to detect any potential pollution.
		Changes in groundwater levels may be caused by the hardening of a large area that will reduce the infiltration of water into the ground. The level of groundwater will be controlled, and the impact of the project on the local changes of groundwater flows in the area of buildings will be determined.
	Accidents	**Release of radioactive substances** to groundwater may occur only as a result of a very serious accident. New-generation reactors include additional systems and structures that protect the integrity of the safety containment and the foundation slab. Polish regulations provide that reactors cannot be built without these systems that ensure proper protection of the safety containment. As a result, the risk of an accidental release of radioactive substances is reduced practically to zero. **Release of other substances** may be caused by uncontrolled leakages. Therefore, provision of emergency water collection tanks and development of emergency procedures is a key element in the design and construction phase. In the event of any accidental release of pollutants, an emergency procedure will be launched to detect and neutralise source of the leakage and the contaminated area in order to prevent the pollution of groundwater.
DECOMMISSIONING		Complete removal of buildings and the associated infrastructure, including all hardened surfaces, will have a positive impact on water resources by increasing the infiltration area.
Impact on the air		

PHASE		DESCRIPTION OF EXPECTED IMPACTS
CONSTRUCTION		**Emissions of pollutants during the production of materials** required to build the nuclear power plant are relatively low, given that the demand for materials is relatively limited (per one unit of electricity production). Therefore, emissions of gases and dusts into the air during the construction of the nuclear power plant and production of the associated equipment are much lower than in the case of other electricity production facilities. Long-term works under the EU's EXTERNE programme have confirmed that nuclear power plants are the most environmentally-friendly and human-friendly of all sources of energy. **The level of dust** will increase due to construction works. However, this level may be reduced, for instance by sprinkling. The amount of materials required to build the nuclear power plant is relatively small (per one unit of electricity production), and therefore the level of dust generated in the construction phase is also low. **Emissions of exhaust gases from vehicles and machines** are related to the increased traffic of heavy machinery. This impact will depend on the location of the construction site and the selected access route.
OPERATION		**Potential reduction of air pollution** resulting from the introduction of nuclear power in Poland was evaluated based on the analysis of emission volumes from various energy sources for the entire electricity production cycle (from the extraction of raw materials up to the deposition of waste). This analysis indicates that emissions of gases and dusts in a nuclear power plant are the lowest in comparison with coal-fired power plants. It was determined by calculation that the potential reduction of air pollution is considerable – from 15% to 17% for different types of pollutants.
		Emissions from cooling towers are related to the release of water contaminated with water treatment products or microorganisms (if the water treatment system is ineffective) to the atmosphere. These problems should be eliminated by an effective water treatment system, and their impact will be only marginal.
		Emissions of exhaust gases are generated from transport vehicles and emergency power generating units. Their impact will be only temporary and will depend on the specific location and the transport infrastructure on site. Emissions related to the transport of fuel and waste (in small amounts) will be limited compared to the transport of employees.
	Accidents	In the event of a serious accident, a potential release of radioactive substances to the atmosphere will be the most likely source of radioactive pollution. Impact of the radioactive cloud and its spread in the air will depend on the weather.
DECOMMISSIONING		The nuclear decommissioning phase will involve an increase in heavy machinery traffic and the related increase in the emissions of exhaust gases to the air. This impact will depend on the location of the construction site and the selected access route.
Impact on the climate		

PHASE	DESCRIPTION OF EXPECTED IMPACTS
CONSTRUCTION	Emissions of greenhouse gases (mainly CO2) are related to the operation of construction equipment and transport of building materials and the workforce to the construction site. These emissions will not create any major nuisance for the local environment. They do not represent significant values in the global balance, because they will be limited to the construction and decommissioning phases (short-term impact).
OPERATION	**Potential reduction of GHG emissions** results from the fact that production of electricity in nuclear power plants generates no CO2 emissions, and the introduction of nuclear power plants to the electricity production sector will reduce CO2 emissions, which may have a positive impact on the climate. Very low emissions of CO2 will be generated in the construction and decommissioning phase, as well as during the fuel cycle.
	Emissions of heat to the atmosphere results from the generation of heat as a side-product of electricity production. Heat may be transferred through a water environment, and it is released to the atmosphere gradually (evaporation, radiation from water surface, and absorption in air). Given the large temperature differences, these processes may produce fog in the area where heated water is discharged. The area covered by fog will be limited. Heat may be also released to the air directly from cooling towers. Cooling towers will release humid and heated air. This air cools down and produces a cloud of vapour. The cooler and more humid the surrounding air, the longer the cloud will remain in the air. This process, as well as the process of deposition of the cloud on the surface of the ground, will depend on the weather and design of the cooling tower. Fogging may also be more intensive in the surrounding areas.
	Accidents: No major impacts.
DECOMMISSIONING	Emissions of greenhouse gases (mainly CO2) are related to the operation of construction equipment and transport of building materials and the workforce to/from the site. These emissions will not create any major nuisance for the local environment. They do not represent significant values in the global balance, because they will be limited to the construction and decommissioning phases (short-term impact).
Impact on the Earth's surface	
CONSTRUCTION	Impact on the Earth's surface will depend on the scale and phase of the project. The key impacts will include exclusion of the biologically active surface and changes in the ground structure (compaction, removal of a humus layer, etc.). The potential impacts also include the pollution of soil with petroleum products that mat be released into the ground due to leakage or breakdowns of mechanical vehicles.

PHASE	DESCRIPTION OF EXPECTED IMPACTS
OPERATION	**Land take** The area occupied by the nuclear power plant and the associated infrastructure depends on the adopted technologies and may reach 40 hectares. Hardening of this surface will reduce the biologically active area and the infiltration of water.
	Production of solid waste: - radioactive waste – 30 tonnes/year - chemical and inert waste – 294 tonnes/year - hazardous (non-radioactive) waste – 63 tonnes/year
	Accidents: In the event of an accidental release of radioactive substances to the atmosphere, radioactive particles will slowly deposit on the surface of the ground as the radioactive cloud spreads out, or will be washed away quickly by rain or snow, depending on the weather. As a result, contamination of soil is possible.
DECOMMISSIONING	Complete removal of all facilities and infrastructure of the nuclear power plant and proper recultivation of the area that restores the former condition of land will have a positive impact on the Earth's surface.
Impact on the landscape	
CONSTRUCTION	Impacts on the landscape will depend on the specific location and the type of land use in the neighbouring areas. In the construction phase, it is also of key importance to select the most optimum route for the transport of building materials. Impacts on the landscape will result not only from the construction of the nuclear power plant, but also the associated infrastructure, including access roads, overground power lines, and water intake and discharge piping. The construction phase will probably have more impacts on the landscape than the operation phase (high cranes).
OPERATION	**Nuclear power plant buildings** will have an impact on the landscape that will depend on the specific location and the type of land use in the neighbouring areas. Cooling towers will change the landscape even more. The impact of a nuclear power plant without cooling towers in much lower.
	Associated infrastructure Power lines connected to the nuclear power plant will be a key element of the associated infrastructure. They will cross both natural systems and man-made systems. The scale and type of impacts caused by power lines will depend mainly on their linear layout and technical parameters (i.e. height of utility poles, type of structures - tubular poles or lattice towers) that will clearly change the landscape.

PHASE		DESCRIPTION OF EXPECTED IMPACTS
	Accidents	A potential accident will have no impact on the landscape. However, protection of the area after a breakdown may affect the environment.
DECOMMISSIONING		It is expected that nuclear decommissioning, involving the complete dismantling of all facilities and structures and restoration of the area to the condition as close to the original state as possible, will have a positive impact on the landscape.
Impact on natural resources		
CONSTRUCTION		Construction of a nuclear power plant will involve the consumption of large amounts of water and mineral resources used to build power generating units and the associated infrastructure. At the same time, it will generate large amounts of waste. (including inert, construction, and municipal solid waste and sewage). There are no useful deposits of minerals in the area of the planned investment, so access to mineral deposits will not be restricted during the construction phase.
OPERATION		**Securing the supply of nuclear fuel for the project** – in the short-term perspective (about 20 years) nuclear fuel will be purchased from foreign suppliers of technologies or other producers (if this option proves more economically viable). Production of nuclear fuel in Poland is not a feasible alternative given the relatively limited scale of the nuclear power projects and current prices of uranium ore. In addition, the analysis of deposits available in Poland indicates that they are rather limited and economically non-viable, and the demand will rather be covered from external sources. However, as the nuclear power sector develops and market prices of uranium increase, extraction of the country's uranium ore deposits may become viable in the future, and the nuclear fuel processing infrastructure may develop in Poland.
		Reduced consumption of raw materials We can expect that the development of nuclear power will result in a significant reduction in the demand for fossil fuels – from 20% to 25% depending on the adopted option.
	Accidents	No major impacts.
DECOMMISSIONING		No direct impacts of the nuclear decommissioning phase on natural resources were identified.

PHASE	DESCRIPTION OF EXPECTED IMPACTS	
Impact on historical buildings/cultural resources		
CONSTRUCTION	A nuclear power project will have the same impact on the country's historical heritage as any other large building covering a similar area. The most serious problem is related to the destruction of archaeological sites, but it is rather unlikely – any works performed in areas that include documented archaeological sites will be supervised and approved by the Regional Building Conservation Officer. In addition, construction works covering such a large area may actually lead to the discovery of new undocumented sites of cultural significance and their subsequent exploration.	
OPERATION	At this stage, the impact on historical monuments is difficult to predict, and the actual location for the project has not been selected yet. However, given the specific type of the project, it is rather unlikely that it will have any impact whatsoever on the movable cultural assets, and the potential locations do not overlap with the UNESCO World Heritage Sites. We should therefore focus on the potential impact on immovable cultural assets and archaeological sites. This impact will be determined only in the EIA Report prepared for the specific location where the nuclear power plant will be built.	
	No negative impact on historical buildings and other cultural resources is expected in the operation phase. On the contrary, we may venture to say that the project will reduce the pollution that may have a negative impact on the structure of historical buildings and other cultural assets. As the nuclear power plant will provide a source of electricity, new coal-fired or gas-fired plants will not be built in the area and their current number may even be reduced, which will also reduce emissions of harmful substances to the air. When combined with water, substances emitted by coal-fired power plants cause acid rains that dissolve and change the surface of stone buildings and structures. This risk applies in particular to structures made of limestone and marble – they are composed mainly of calcite that is dissolved in acids relatively quickly.	
	Accidents	No major impacts.
DECOMMISSIONING	No significant negative impacts on cultural assets are expected in nuclear decommissioning phase. Impacts will be comparable to those caused by the dismantling of any other facilities covering a similar area. In the areas adjacent to places of historical and cultural significance, the site may be brought to the state that corresponds to the land use in the surrounding areas.	
Impact on material assets		
CONSTRUCTION	Construction of a nuclear power plants will require significant investments. Therefore, in a short-term perspective it will consume material assets. Only after the construction phase is completed can we expect a positive impact in the context of the economic balance.	

PHASE		DESCRIPTION OF EXPECTED IMPACTS
OPERATION		The analysis of examples of nuclear power projects indicates that operation of a nuclear power plant may have a positive impact on material assets: - increased value of land in the area of the investment (the initial drop is only possible at the beginning of the construction/operation phase) - increased income of the municipality - improved infrastructure - lower unemployment rate - economic revival in the region
	Accidents	Any potential accident will cause significant material losses suffered by the investor and the adjacent areas – which must be partially compensated in accordance with the current provisions regarding the liability for nuclear accidents.
DECOMMISSIONING		Nuclear decommissioning will be financed with funds deposited in a special bank account during the operation of the nuclear power plant, in accordance with draft amendment to the Atomic Energy Act. The impact on material assets will depend on how the area of the former nuclear power plant will be managed.
Impact on biodiversity, including biological resources protected under Natura 2000 network		
CONSTRUCTION		Like any other large investment, construction of a nuclear power plant will have an impact on the natural environment. Selection of an optimum location is the key. If the selected location is not recommended for reasons related to environmental protection, the integrity and objectives of Natura 2000 sites may be affected, functions of ecological corridors undermined, habitats fragmented, and valuable species endangered (both at the country's and international level). If a less sensitive location is chosen, significant negative impacts are not expected.
OPERATION		In the operation phase, the extended overhead traction network will have a significant impact. In some locations, it may cause the increased death rate among large flocks of migrating birds. Other significant impacts will include discharges of heated water to rivers or other water bodies, which may lead to changes in ecosystems and affect biodiversity (a two-way impact involving both negative and positive aspects).
	Accidents	As the risk of a radioactive leakage in nuclear power plants that are allowed in Poland is negligibly small, the release of a radioactive cloud is the key threat. Depending on the weather conditions, it may lead to contamination that will affect living organisms to a greater or lesser extent.
DECOMMISSIONING		The complete decommissioning of a nuclear power facility and restoration of the environment to the state as close to natural as possible will ultimately have a positive impact on the natural environment. However, demolition work itself may have a negative impact on Natura 2000 sites (in sensitive locations), as it will generate vibrations, noise, possible contamination of surface and ground waters, and may also temporarily affect functions of the ecological corridor.

Description of impacts

The identified impacts were presented based on their source and origin (direct and indirect, secondary), duration (short-, medium, and long-term), and frequency (permanent and temporary), as well as the probability of their occurrence. Impacts were also classified in terms of their direction (negative and positive) and scale (moderate and significant).

In the construction phase, many negative impacts were identified (affecting all elements of the natural environment except the climate), the majority of which are temporary and short-term. Positive impacts on humans were also listed (creation of new jobs).

In the operation phase, the identified significant negative impacts (on humans, water, and air) will occur only in emergency situations, but their likelihood is very low (the impact is nearly impossible and assumed only in a worst-case scenario). Other negative impacts will be moderate. We can also expect significant positive impacts on humans (related to the reliability of electricity supplies and the overall improvement of the natural environment), on the air (reduced emissions of gases and dusts to the atmosphere), on the climate (reduced emissions of carbon dioxide), on natural resources (reduced consumption of fossil fuels), and on material goods (improved energy security in the country).

In the decommissioning phase, the identified negative impacts (on humans, water, Earth's surface, natural resources, and material goods) are less frequent than in the construction phase, and are mostly temporary and short-term. At the same time, positive impacts on humans, the air, the Earth's surface, the landscape, and natural resources were identified.

Possible environmental impacts of the Programme in the neighbouring countries

At this stage of a strategic document (the Polish Nuclear Programme), the assessment of environmental impacts in neighbouring countries can be only preliminary. To evaluate these impacts, an analysis was conducted to decide which countries could be affected by the potential impact in the operational phase of the planned nuclear plant in Poland.

Considering the small likelihood that the first nuclear power plants in Poland will be built in one of the locations defined as "other" in the Programme, we can conclude than none of the neighbouring countries will be exposed to any impacts (direct or indirect). However, if we assume that any "other" location is selected, Germany will be exposed to direct impacts from the Polish nuclear power plant. Germany, Belarus and Russia are the countries whose societies may be potentially interested in the participation in social consultations (given the distance from the potential sites).

In the context of the analysis of transboundary impacts it should be also pointed out that Poland is not a pioneer in the nuclear power sector. Apart from Lithuania and Belarus, all other neighbouring countries operate nuclear power plants in their territory.

Analysis of potential social conflicts

The draft Polish Nuclear Programme (p. 95) provides that "social support for nuclear power is one of the most important pre-conditions for the Polish Nuclear Programme" and that "steady and conscious support (or at least acceptance) of the majority of the society is a condition precedent to the introduction of nuclear power that will prevent the Programme being used as a subject of political debates". The draft gives a figure for the support declared by the Polish society for the introduction of nuclear power at 40-50%. At the same time, it was emphasised that this support is unstable and to a large extent it is not based on the society's knowledge of nuclear power, which is an outcome of 20 years of no education whatsoever in this area, among other.

When actions towards the development of nuclear power in Poland were resumed, social conflicts became a fact and the public opinion was clearly divided from day one. It is all happening despite the fact that for quite some time articles in the press have been forecasting an ever-increasing demand for electricity and potential problems with electricity production in the future[1].. Some environmental organisations criticise the potential locations and the very purpose and safety of nuclear power projects. At the same time, the fierce protests of environmentalists reported in the media, combined with actions taken to disrupt the implementation of major infrastructural projects important for the country or local communities (even those that are reasonable and based on sound argumentation), trigger protests from other groups in the society. In the worst-case scenario, the significance of environmental initiatives may be undermined by the excessive and stubborn focus on single elements of the natural environment of relatively minor importance for the entire ecosystem.

Social conflicts are an inherent part of any large project. In holds true in particular in the case of investments in the energy sector. Not a long time ago, environmentalists voiced their protests against projects such as construction of the Niedzica dam on the Dunajec River, the man–made Czorsztyn Lake, or the Niedzica – Sromowce Wyżne Hydroelectric Power Plants. In more recent years, wind power projects are the source of serious conflicts. Wind farms projects with wind turbines were rejected by the inhabitants and local authorities in many regions of Poland. Villages in the Kłodzko Valley or the Kaczawskie Foothills are just one example. In addition to the significant impact on the landscape and risks for birds and bats, opponents of wind power projects claim that wind turbines may have an impact on people's health and well-being. Projects of new open-pit mines and brown-coal mining projects for the purposes of electricity generation are as controversial. The plans of relocation of villages north of Legnica encountered a backlash from the protesting local communities. An initiative called 'STOP the PIT' was set up. Inhabitants of these areas reject the proposed compensatory payments and refuse to relocate.

Public opinion on nuclear power in Poland and other electricity production methods and technologies is summarised in the report of CBOS (Public Opinion Reserach Centre) published in September 2009 titled "Public Opinion on Nuclear Power. Quantitative Research Report" ("Opinie o energetyce jądrowej. Raport z badań ilościowych"). The respondents were requested to evaluate the efficiency of the following sources of energy: bituminous coal, lignite coal, crude oil, natural gas, nuclear energy, biofuels, hydropower, solar energy, wind power, and geothermal energy.

Findings presented in the CBOS Report are as follows:

- public support for the nuclear power plant project in Poland is increasing, but its supporters include usually well-educated people;
- lack of knowledge of nuclear power gives rise to fear and concerns that are expressed in the form of protests against the construction of a nuclear power plant or location of a radioactive waste depository;
- arguments of opponents always focus on irrational fears and general concerns;
- information and argumentation must be targeted mainly at social groups with a lower education level and inhabitants of rural areas, as well as young people (aged 15–17 lat) whose knowledge of nuclear power is simply a disaster;
- a radioactive waste dopository raises more concerns than a nuclear power plant;

- any location for a radioactive waste depository will be accepted only on condition that it is properly protected with safety measures, but at the same time we may expect that the effectiveness of these safety measures will be questioned;

- there is a wide social support for compensatory payments for inhabitants of areas close to a nuclear power plant – they should include a number of elements, with special focus on health care and reduced electricity charges;

- the self–assessment of the respondents' knowledge of nuclear power is very low – Poles are well aware of the fact that their knowledge is poor; at the same time, data clearly indicates that the level of knowledge corresponds to the level of acceptance. The knowledge of nuclear power comes mainly from the media: the press, TV, and radio. Less than 1 in 5 respondents declares that he or she gained this information from school, university, or work.

Findings presented in the CBOS Report are very interesting. Special attention should be given to the society's low level of knowledge of nuclear power, as well as the sources of this information – the public media rather than school curricula or specialist publications. Still, public approval for nuclear power in the period 2008–2009 increased by nearly 70%, and nuclear energy ranked second (after renewable sources) among all suggested options for the development of the energy sector.

Information on the feedback to nuclear power in other countries, especially in countries where nuclear power plants are in operation, is presented in the Study no. OT-575 "Reaction of the local European communities to the proposed location of a nuclear power plant in their close vicinity" prepared by the Analyses and Documentation Office, Analyses and Topical Papers Unit of the Chancellery of the Polish Senate in November 2009. This study is an attempt to answer the question whether it is possible and acceptable to locate nuclear power plants in a region attractive for tourists and what the consequences for the local community are. Regions that are attractive for tourists often overlap with regions of high natural or scenic value, and therefore this study has a deeper meaning. The study concludes that no examples were found that location of a nuclear power plant will affect tourism in a given village/town. It also underlines the positive impact of nuclear power projects on the development of municipalities in the area. It was found that persons who live in an area where a nuclear power plant actually operates are in support of nuclear power. The remaining respondents, who do not benefit from nuclear power projects in their region, are usually against a nuclear power plant in the area where they live. Respondents (e.g. from the UK) agree that new nuclear power plants could be built in the same location as old nuclear facilities that are dismantled, and respondents who work for the nuclear sector, either directly or indirectly, actually expect that a new nuclear power plant will be built after the old one is decommissioned. The same applies to radioactive waste depositories. On the other hand, the study also indicates that there are signs of clear opposition against the development of nuclear power in Germany.

Organisations opposing the development of nuclear power in Poland and their initiatives

The draft Polish Nuclear Power Programme and its assumptions are clearly in opposition to the assumptions and objectives of a number of environmental organisations that do not accept the development of nuclear power in Poland or anywhere in the world. The one organisation that stands out in particular is a group called Anti-Nuclear Initiative (Inicjatywa Antynuklearna) – it identifies very strongly with anti-nuclear protests in Germany where the police regularly fight with the opponents of nuclear power on the streets or with groups of protesters who block transport routes leading to nuclear power plants. A group of scientists also voice their protests against nuclear power, including a number of scientists who are published in the press.

Arguments against the development of nuclear power in Poland are focused on a number of key areas. The vast majority of these arguments are based on the economic viability of nuclear power projects. Other arguments result from concerns about a possible terrorist attack, a breakdown or a serious accident in a nuclear power plant and the potential environmental pollution that could pose a threat for humans. The example of Chernobyl is showcased regularly, but often based on wrong interpretation of data or even on information that is simply not true. These arguments completely disregard the technological advancement and development of nuclear safety standards. Other arguments include the examples of other countries that do not use any nuclear power or do not build any nuclear power plants.

What is interesting is the fact that many anti-nuclear initiatives that are active on the Internet often remain anonymous (the website of Inicjatywa Antynuklearna is the best example), unlike the supporters of the development of nuclear power (Energetyka Jądrowa website). This makes a serious and constructive discussion difficult.

We should note that the activities of Inicjatywa Antynuklearna and other environmental organisations are often propaganda-like. It applies in particular to the practice of presenting unverified or even false information.

However, some environmental organisations that promote cleaner environment and protection of nature also promote nuclear power. Environmentalists for Nuclear Energy (EFN) are one of them. it was established back in 1996 and now has about 9 thousand members around the world. In Poland, Stowarzyszenie Ekologów na Rzecz Energii Nuklearnej (SEREN) is the leading organisation of this type. Its objectives are to create an association for the supporters of nuclear power for peaceful purposes, and to present to the society the complete and objective information on the power sector and its environmental impacts.

Opinions expressed by Patrick Moore, co-founder of Greenpeace are also very suggestive. Moore changed his mind about nuclear power and now opposes the official position of his organisation. In an article published in 2006 in Washington Post, he states that nuclear power must complement the power generation sector based on renewable energy sources. Of the same opinion are other experienced environmentalists, including Stewart Brand (author of the Whole Earth Catalogue), James Lovelock (originator of the Gaia Theory, member of EFN), or the late British bishop Hugh Montefiore (founder and one of directors of Friends of the Earth). Last year, they were joined by Stephen Tindale who had acted as the Executive Director of Greenpeace in the United Kingdom for many years (from 2000 to 2005). In 2009, he took a U-turn on nuclear power and with a group of other respected British environmentalists expressed his support for the development of nuclear power.

<u>Main barriers to the development of nuclear power – arguments for and against</u>

The development of nuclear power in Poland will encounter a number of barriers: incompatibility of the Polish law, lack of clear vision of the future – how to meet the energy security requirements with the ever-increasing need to protect the natural environment and to meet the society’s expectations, and different views expressed by various groups. The relatively low level of public knowledge of nuclear power and opinions based on inaccurate information will be also a major source of barriers.

Presented below is our review of the main problems related to the development of nuclear power in Poland that are discussed by the public and the media. These problems are discussed from the perspective of both the supporters and opponents of nuclear power - for each item, arguments and views for and against are presented. In this way we are trying to ensure an impartial approach to every problem.

Arguments for and against the introduction of nuclear power relating to the feasibility of a nuclear power project in Poland.

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"With the current consumption levels, global resources of uranium will suffice until 2061. However, development of the nuclear power and the ever-increasing consumption of energy may lead to the depletion of uranium resources already in 2030." "The expected bottlenecks in uranium ore supplies may become a more serious problem than we would expect – given the disproportion between countries that extract uranium ore and countries that use it. Of all countries in the world that operate nuclear power plants, only Canada and Republic South Africa are not dependent on uranium imports. The largest 'atomic' countries either do not extract their own uranium ore (France, Japan, Germany, South Korea, Sweden, Spain) or have uranium ore resources that will not be sufficient for their reactors in a longer term (the USA, Russia). If we consider the problem of fuel supply for nuclear reactors, nuclear power cannot be the main source of domestic electricity production almost anywhere in the world. Russia in particular will soon face the first uranium supply crisis. This in turn may affect operators of nuclear power plants in the European Union that purchase about one-third of their nuclear fuel from Russia. China and India may also be forced to cope with a similar crisis if they continue to increase the number of their nuclear reactors, as they have declared."	**Sufficiency of raw materials**	"The available resources of uranium depend strongly on its market price. Until 2001, the price of uranium ore was exceptionally low – about $20/kgU. It was caused mainly by overproduction of uranium by 1990 and lack of social acceptance for nuclear power, resulting in overstocked inventories of uranium ore accumulated by power utilities. Nuclear disarmament reduced the prices even further by introducing cheap uranium from dismantled nuclear heads to the market. The inventory of uranium that came from disarmament has been almost used up by now, and the threat of a climate disaster put nuclear power back in the picture. As a result, the price of uranium has increased significantly. In 2005-2007, a 'uranium bubble' occurred – a sudden, exponential increase in the price of uranium, up to $300/kgU. The current price (2009) is settled around $100/kgU. This trend made it possible to explore uranium deposits that had been considered economically unviable before. With the increased outlays on the prospecting of new uranium ore deposits in 2001-2007, the known resources of cheap uranium increased by 40%. In 2007, the assured uranium resources that could be mined at less than $80/kgU were estimated at 5,469,000 tonnes. IAEA estimates that these resources will suffice for at least 100 years of operation of nuclear reactors currently used, and the expected discovery of new deposits should extend this time frame up to 300 years. Civil nuclear power sector has been developing for 52 years only.(…). In the next 20-30 years, the introduction of Fast Breeder Reactors (that are currently developed as part of the Generation IV nuclear power programme) will make it possible to use both spent nuclear fuel produced by reactors currently under operation and the resources of depleted uranium left after the enrichment process. As a result, current resources of uranium will suffice for thousands of years." "The security of supply of nuclear fuel for Polish nuclear power plants should not raise any concerns if we adopt the solutions developed in the European Union. Still, when paving the way for the first nuclear power plants in Poland, we

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		must actively follow the situation in the uranium market and fuel cycle services market. When doing so, we should use documentation prepared by the EURATOM Supply Agency and other global organisations (IAEA, OECD/NEA) and participate in the relevant long-term EU projects (especially SNE-TP). The focus on the uranium and fuel cycle services market in the coming years may give us valuable information well in advance as to the resistance of the future Polish nuclear power sector to potential disruptions in the fuel market in its first 'formative' years."
"The question whether radioactive waste can be isolated from the biosphere for hundreds of thousands of even millions of years is a philosophical question. It just goes beyond our imagination. Only 5 thousand years have passed since the pyramids were built, and we must now think about how to safely deposit waste produced by German nuclear power plants in 2010 until 10010 or even 100010. But we have no choice: because nuclear waste does exist and we cannot be 100% certain about the answer to this question, we must develop the most optimum technical solution to the best of our today's knowledge." "In 2000, the amount of spent nuclear fuel deposited in the world totalled 220,000 tonnes. This amount increases at a rate of about 10,000 tonnes every year. Still, although many methods of deposition of spent nuclear fuel have been analysed for the past decades, including its deposition in space, the nuclear power industry has not found a solution to this problem yet. Most proposals for the management of highly radioactive waste involve its deposition in deep geological formations. However, there is no way of saying if the containers, the depository itself, or the surrounding rocks will ensure a sufficient barrier against radiation. The Yucca Mountain repository in Nevada, the USA, is one example of a failed nuclear waste deposition project. After twenty years of analyses and billions of dollars spent on the project, not even one gram of spent nuclear fuel was deposited in Yucca Mountain. The very fundamental questions regarding the geological feasibility of this	**Deposition of radioactive waste**	"...highly radioactive waste is deposited deep under ground, e.g. at the depth of 500 meters, and radiation is no problem as long as its stays there – only several meters of the ground are enough to reduce radiation to undetectable levels. The only risk is the potential corrosion of containers caused by water, which may wash radioactive waste out of glass in which it was vitrified and move it up towards the surface and sources of potable water. Radioactive waste may become a threat only when ingested by humans. But, as an example, salt deposits would dissolve in water long time ago if water was able to penetrate through to them. And salt is dissolved in water much faster than glass! If we deposit containers with nuclear waste in salt layers, we can be sure that water cannot get through to them. But for how long? For much longer than the period during which nuclear waste remains hazardous. Our life is short compared to half-life of some radioisotopes, but geological changes take much longer time. The rate of removal of vitrified nuclear waste from glass will be slow, because methods of containment of waste used by the nuclear power industry are very effective. As a result, waste will be separated from the biosphere for a very long time, and even if it is removed from glass, the infiltration rate will be very slow. Moreover, the storage of nuclear fuel in tight containers will separate it from the environment for thousands of years! It is technically feasible and not difficult – the nuclear power industry is ready to build this type of depositories for radioactive waste in a number of countries.

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area were never answered. On top of that, it was discovered that scientific data had been manipulated, which triggered an investigation. Problems with radioactive waste deposition are not limited to highly active waste (i.e. the most radioactive waste generated in a reactor, which can cause death on exposure). There are many examples of depositories for low-active nuclear waste that are a source of harmful radiation. Drigg in the UK and La Hague in France are just two of them. Nuclear waste emits radiation for tens, or even hundreds of thousands of years. No human language has survived for more than several thousand years, and no one can tell whether pictograms or other symbols will be interpreted correctly in the future. Therefore, there is no way of ensuring that the future generations are warned about radioactive waste repositories.		How much land is needed to deposit highly radioactive waste? According to the EU studies, if nuclear power plants with the capacity of 30,000 operate for 60 years without breaks and at full capacity, they will produce 5400 cubic meters of high-active nuclear waste (after reprocessing of spent nuclear fuel). After this waste is vitrified and closed in cylinders (22 cm in diameter and 110 cm high), it may be deposited in 600 openings drilled in the area of just 0.4 square kilometers.
Nuclear power plants are an attractive target for terrorist and military attacks, given their importance in the power sector, threats resulting from the release of radioactive substances, and their symbolic meaning. An attack targeted against a nuclear power plant may result in a disaster several times more serious than in Chernobyl. Nuclear facilities may be attacked during wars if they are allegedly used for military purposes. They may be attacked in a variety of ways – from the sea, land, or air. There is evidence that more and more terrorist groups are considering potential attacks on nuclear facilities. In this context, the decision of the nuclear power industry and governments of some countries to increase the number of nuclear reactors worldwide is a sign of their stupidity and recklessness. "We may also assume with 100% certainty that none of the 436 reactors used at the beginning of 2010 around the world would withstand a targeted attack of a filled-up wide-body jet aircraft. In Western industrialised countries the risk of accidental crashes of small passenger or military aircraft was taken into account when building many nuclear reactors. However, accidental crashes of filled-up large passenger aircraft were considered so unlikely that this scenario was not assumed by any country in the world and no	**Terrorist attack**	"It may seem that nuclear facilities (including power plants) are an easy target for terrorists – it is enough to plant a bomb, throw a hand grenade, or crash an aeroplane. But in reality, nuclear facilities ensure ***the best possible protection against potential terrorist attacks*** – much better than for example chemical plants, water intake points, or coal-fired power plants(…). The system of protection of nuclear materials and facilities is a combination of administrative measures and a number of different types of physical barriers. This system consists of many interrelated elements: procedures for the personnel, methods of operation of equipment, plans of location of physical barriers in the expected sensitive areas in the facility, etc. (...).Terrorist attacks in New York proved that an external attack is easy. Therefore, certain measures are now more commonly introduced to prevent terrorist attacks such as destruction of physical barriers with armoured fighting vehicles filled with explosive materials, or a similar attack from the air or (potentially) the sea (as in Japan) in cases where nuclear facilities are located on coastal sites. In these cases, special coastal patrols are organised. Although a number of factors that may potentially lead to a nuclear accident have been considered since the early years of nuclear power,

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effective procedures were developed. A planned attack using a passenger aircraft as a targeted missile was beyond the limits of imagination of nuclear reactor designers.”		analyses indicate that older nuclear facilities that had been built in countries that used Soviet technologies, as well as the first nuclear reactors built in Western countries whose structural elements were affected by natural degradation, are not 100% resistant to this type of attacks. There are in urgent need of upgrades, just as certain facilities located near airports. In the United States, the mandatory safety zone of 10 miles around the reactor was introduced. If the damage caused by a terrorist attack is limited to one function or a single component of a nuclear reactor (e.g. a breakdown of the primary loop cooling system or external power failure), small corrective action will minimise this damage to a large extent. However, the situation is more serious if a number of elements are damaged. Structural design of a reactor building plays a major role in minimising the impact of a potential terrorist attack targeted at a nuclear facility with a reactor (power plants, research centres) – both external attack and internal sabotage. New buildings that house a reactor core have double walls (nearly 1 meter wide) made of reinforced concrete (with a free space of about 2 m between the walls that is monitored on an on-going basis) and additionally reinforced with a steel wall (several centimetres wide). The structure of this wall is similar to a ship’s hull. Inside the building, a reactor core is placed in a safety containment made of steel and reinforced concrete (several meters wide). Simulations have proved that **this structure can be damaged from the outside only by a major nuclear explosion.** This structure will withstand strong earthquakes and hurricanes (the Three Mile Island facility in the USA survived a 6.7 earthquake (the Richter Scale) and hurricanes with wind speed of 200 miles/h).”
“It was calculated that a nuclear power plant emits 1/3 of CO2 (a greenhouse gas) compared to a modern gas-fired power plant with the same capacity. However, this ratio will be multiplied if we add emissions of greenhouse gases from deposited nuclear waste and from nuclear decommissioning after the nuclear power plant is closed. Highly radioactive waste	**Nuclear power vs. climate**	“Nuclear power plants have a lower negative impact on the natural environment than other commonly used sources of energy. They do not generate greenhouse gases, do not release pollutants to the atmosphere, and they produce waste that is deposited in safe locations and subject to close monitoring. We often see huge clouds of smoke

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must be cooled down 24 hours a day, for thousands of years! One of the methods of management of low- and medium-active nuclear waste is to build underground repositories in rocks for concrete or steel containers with nuclear waste. All these energy-intensive processes are a source of greenhouse gases. Therefore, the relative benefits that may be expected only assuming a failure-free operation of nuclear power plants (which cannot be guaranteed), are neutralised by the damage caused by GHG emissions." "Nuclear energy is the most expensive and most dangerous of all types of energy. The risk of proliferation of nuclear weapons, the problem of radioactive waste, the possibility of breakdowns and threat of terrorist attacks – these factors make it an unviable alternative. It is high time we stopped wasting public money on 'dirty' technologies and focus on renewable energy sources that are the only way to stop climate changes".		released from smokestacks in nuclear power plants – but it's not pollution, just water vapour free of any pollutants and completely neutral to the natural environment. In addition, nuclear power plants do not deplete valuable resources that can be used for other purposes. Moreover, they are able to generate high capacity using a relatively small area. The nuclear power sector helps protect the environment by eliminating about 2.4 Gt (2,400,000,000,000 kg) of CO2/year. Obviously, nuclear power will not eliminate CO2 emissions altogether, but it sets the direction – how not to increase GHG emissions, at the very least. Just as an example: a coal-fired power plant with the capacity of 1000 MWe uses from 2 to 6 million tonnes of fuel per year (depending on the type of coal), and at the same time produces and releases 6.5 million tonnes of CO_2 (960 t CO_2/GWh) to the atmosphere. A similar gas-fired power plant uses 2 to 3 billion cubic meters of gas and produces 480 t of CO_2/GWh. An oil-fired power plant will use 1.5 million tonnes of fuel oil and produce 730 t of CO_2/GWh. A biomass plant with the same capacity will need an area of 6000 square kilometers as a source of biomass, a wind farm will cover an area of 100 square kilometers, and a solar power plant - 50 square kilometers. Unlike these facilities, an emission-free nuclear power plant with the capacity of 1000 MWe will use only 35 tonnes of fuel per year and will cover only several square kilometers. In the European Union alone, nuclear power plants reduce CO2 emissions by about 700 million tonnes per year, which equals the total CO2 emissions produced by all cars owned by citizens of all Member States."
"The CapEx of a nuclear power plant construction project assumed in the Programme (3.0-3.3 billion euro/1000MW) is not up-to-date. Data presented by power utilities and rating agencies put the figure at 4.5 up to 5.4 billion euro/1000 MW. This data is confirmed by EDF. In its published results for Q2 FY 2010, EDF informed about the increase in the cost of construction of a nuclear power plant in Flamanville, France - from 3.3 to 5 billion euro. It suggests that the CapEx for nuclear power plant projects assumed in the Programme is	**Costs of nuclear power**	"The cost of electricity generated in a nuclear plant is 35 euro/MWh, in a coal-fired plant – 64.4 euro/MWh, in a gas-fired plant – 59.2 euro/MWh, in a peat-fired plant – 65.5 euro/MWh, and in a wood-fired plant – 73.6 €/MWh (wood is not subject to the CO_2 tax). Wind farms can supply electricity at the price of 52.9 euro/MWH assuming that they work at full capacity for 2,200 h a year and bear no costs due to discontinued operation. In a nuclear power plant, investment outlays are the key element of costs, and the cost

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underestimated by as much as 60% and does not reflect the real costs of their construction. CapEx translated into electricity depends to a large extent on the interest rate on borrowings and the period of repayment of the construction loan. As nuclear power plants are commercial projects, cost analysis is based on data assumed for a typical commercial loan for the construction of a power plant. If we assume the interest rate on a loan at 7% and return on equity at 10.5% (1.5 x borrowing costs), and 70% of funds coming from borrowings, the average cost of capital will reach 8.05%. The cost of capital per 1 MWh of electricity produced in a nuclear power plant depends on the loan repayment period. Typically, loans are granted for 20 years, of which 5 years for construction and 15 years for operation of the project. In order to take out loan for a period longer than 20 years, especially for the construction of a nuclear power plant, state guarantees will be required. Still, even if a state guarantee is secured for the nuclear project and the period of loan repayment is extended, which is not possible under regulations currently in effect, this project will be economically unviable compared to other technologies. For a 20-year period of loan repayment, CaPex will reach 100 – 80 PLN/MWh for coal-fired power plants, 65.64 PLN/MWh for gas-fired power plants, and 282.61 PLN/MWh for nuclear power plants. For a 50-year period of repayment, these costs will reach, respectively: 66.90, 43.48 and 195.45 MWh – that is, three times higher when compared to coal-fired power plants and five times higher compared to gas-fired power plants. The Programme says virtually nothing about the operating costs in nuclear power plants. The complex technology and stringent safety requirements increase the OpEx in nuclear power plants. According to data from US nuclear power plants where production is managed at a very high level, these costs amount to 138 PLN/MWh. However, we must take into account total costs. Calculations were based on the following assumptions: 1 euro = 4 PLN, CO_2 = 30 euro/Mg, fuel cost: black coal - 11.5 PLN/GJ; brown coal – 6.7 PLN/GJ; gas – 320 USD/1,000 mJ, nuclear fuel – 12.5		of nuclear fuel is low. For other power plants, costs of fuel are the main cost component. Wind farms are an exception to this rule. In wind power plants, CapEx per one unit of peaking capacity is two times lower than in nuclear power plants, but much higher per one unit of average capacity during the year. "Total cost of coal and CO2 emissions will reach **413 million euro/year**. This figure is much higher than in a nuclear power plant, but CapEx in a nuclear power plant is much higher compared to coal-fired power plants. In the Flamanville nuclear power plant, CapEx amounts to 2450 euro/kW, i.e. **3266 USD/kW**. We should note that the Flamanville 3 project is implemented without delays and in accordance with the adopted budget. The CAPEX of the first nuclear power plant in Poland may be higher than in nuclear power projects currently implemented in France, but to compare a number of plants we should assume average the CAPEX typically assumed around the world. The latest estimates of OECD assume 2.75 billion euro per 1000 MWe. For the second and every subsequent nuclear power plant in Poland, we may assume the positive effect of the learning curve in the nuclear power industry and lower investment costs. However, we will assume the worst-case scenario – CaPex will be higher than the latest OECD estimate and will be equal to CaPex of the second unit in the Florida nuclear power station in the USA – ***3220 €/kWe.*** These investment costs are higher than in Flamanville 3, because CAPEX in the USA is always higher than in Europe (by about 20-30%) – not only for nuclear power projects, but also for coal-fired power plants. Therefore, CAPEX assumed at 3220 €/kWe gives us a large safety margin. For coal-fired power plants in Poland, prices in 2008 reached from 1800 €/kWe to 2000 €/kWe. We will assume the cost of 1875 €/kWe, just as for the new power plant in the former Czeczot coal mine. The resulting difference in CapEx for the second and every subsequent nuclear power plant in Poland amounts to 1345 €/kWe. This is an amount equal to the difference in fuel costs and CO2 emission charges

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USD/MWh. These figures indicate that nuclear energy is the most expensive type of energy and its cost reaches nearly 100 euro/MWh with a very long period of loan repayment. It is over two times higher than assumed in the Programme. Publication of underestimated costs of electricity production in nuclear power plants may be interpreted as an attempt to mislead the public opinion."		that must be incurred when burning imported coal instead of nuclear fuel during a 4-year period. Obviously, these findings should not be interpreted as a complete economic calculation, only as an illustration presenting the key elements that determine the final cost of electricity produced in nuclear and coal-fired power plants. As we can see, thanks to very low cost of nuclear fuel, **nuclear power is an economically viable alternative despite the high capital expenditure.**"
"We don't need a nuclear accident to release radioactive substances to the air, water and soil. Day-to-day operation of a nuclear plant is enough – and these emissions are allowed pursuant to the Government's regulations. Radioactivity is measured in the curie (Ci). 1000 medical laboratories that use radioactive isotopes will contain the equivalent of 2 Ci. In comparison, an average reactor core will contain about 16 billion Ci, which is equal to long-term radiation from at least 1000 atomic bombs dropped on Hiroshima. Piping, valves, and tanks in a reactor may have leakages. Leakages can be also caused by mechanical breakdowns or human errors. Ageing affects the entire reactor and its individual components, and leakages are more frequent with time. A portion of contaminated water is discharged on purpose from the reactor pool to reduce the amount of radioactive substances and corrosive compounds that would otherwise destroy valves and pipes. This water is filtered and returned to the cooling system or released to the environment. A typical 1000 MW nuclear power plant with a PWR and a cooling tower needs 80 thousand litres of water from a river, lake or the sea per minute for cooling. This water is transported through 80 km of pipes. 20 thousand litres per minute are discharged back to the source, and the rest is released to the atmosphere as water vapour. A 1000 MW reactor without a cooling tower needs even more water - up to several million litres per minute. After circulation in the plant's loops, water is released to the environment. It is	**Radiation in the area of nuclear power plant**	"In the Flammanville nuclear power plant in France with two PWRs with the capacity of 900 MWe, the typical dose of radiation from all emissions from this power plant is 0.0003 mSv/year. The Souleau Commitee appointed by the French government determined that the maximum doses of radiation corresponding to the allowed limits would amount to 0.3 mSv/year, and the actual dose of radiation measured outside of the power plant reached 0.01 mSv on average, i.e. 30 times lower than the adopted limits and 200 lower than the dose coming from natural background radiation. Also in the USA, the average radioactive emissions from all nuclear power plants are much lower than the acceptable maximum levels. Negative health effects caused by these low emissions have never been determined, and it is expected that they will never occur. Despite the claims presented in publications by anti-nuclear activists, a study by the US National Cancer Institute conducted on a wide scale (500,000 persons) confirmed that there are no signs of the increased cancer rate in the vicinity of nuclear power plants in the USA. Poles should not think that results recorded by the Swiss, Germans or Americans are beyond our reach due to some differences at the level of technical culture or social conditions. In the neighbouring country of Slovakia, a nuclear power plant was built in late 1980s with two WWER-440 reactors (similar to those planned in the Żarnowiec power plant in Poland). The political changes in Slovakia put the Mochovce project on hold for a couple of years, but the project was never abandoned and finally both reactors were put into

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contaminated with radioactive elements – their concentration is not known and it is difficult to measure, but it does affect our lives. Some radioactive gases removed from cooling water are contained in waste gas decay tanks before they are released to the atmosphere through fans fitted with filters. Some gases are released inside the nuclear power plant buildings and are removed from time to time during what is known as 'airing'. These free gases will contaminate not only the air, but also water and soil. Radioactive leaks from a nuclear reactor that occur during normal operation are often not fully detected and not reported. Emissions caused by nuclear accidents may not be verified or documented in full. For certain key side-products of a nuclear reactor (radioactive hydrogen – tritium, noble gases such as krypton and xenon), there are still no effective and economically feasible techniques of filtering and monitoring. Some liquids and gases are kept in containers to allow for the decay of less permanent radioactive materials before they are released to the environment. Regulations currently in force approve the release of radioactive water that contains 'acceptable' concentrations of pollutants. But 'acceptable' does not necessarily mean 'safe'. Detectors installed at reactors are set up to allow the release of unfiltered water that contains more pollutants that 'acceptable'. Detection of leakages and predicting the spread of radioactive pollution by US Nuclear Regulatory Commission is based on reports and computer models provided by operators of nuclear power plants. A large part of the environmental monitoring data comes from extrapolation instead of actual observation. We just do not have the accurate data for the entire amount of nuclear waste released to the air, water and soil during all phases of the nuclear power production process. This cycle includes: extraction and processing of uranium ore, chemical processing, enrichment, production of fuel, nuclear reactors, as well as pools, trenches, and barrels where nuclear waste is kept. The ever-increasing economic pressure on cost cutting triggered by the deregulated electricity production industry may further		operation – after the introduction of certain modifications. These reactors now produce electricity that is 50% cheaper than electricity produced in conventional power plants, and at the same time they meet all safety requirements adopted in the EU. Radiological analyses indicated that doses of radiation in the area are so small that they cannot be even measured. When measurements were finally taken, it turned out that in the period of 6 years since the opening of the Mochovce nuclear power plant, additional annual doses of radiation from this facility never exceeded one MILLIONTH of a Sievert (ranging from 0.1 to 0.7 micro Sv)."

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undermine the effectiveness of monitoring and leakage reporting systems (that is already questioned). Delayed upgrades may increase the emissions of radioactive substances and the resulting risks. Many side-products of nuclear reactors are able to emit radioactive particles and rays for a very long time – defined based on their 'half-life'. Radioactive materials will emit harmful radiation for at least 10 half-lives. The half-life of one of iodine isotopes (iodine-129) is 16 million years; the half-life of technetium-99 is 211 thousand years, and of plutonium-239 – 24 thousand years. Xenon-135 (noble gas) will decay to caesium-135 – a long-lived isotope with the half-life of 2.3 million years.` It is a scientifically proven fact that low-level radiation damages our tissue, cells, DNA, and other vital molecules, and causes the gradual cell death (apoptosis), genetic mutations, cancer, leukaemia, birth defects, as well as disorders of our reproductive, immune, and secretive systems."		
"Polish nuclear power plants will pose a threat of another Chernobyl disaster. The system selected by the Polish government is so hazardous that the British decided to ban the construction of this type of reactors. Polish experts are inexperienced and take producers at their word - said a renowned expert in nuclear energy as a word of caution. "The British Nuclear Installations Inspectorate refused to approve the EPR project (European Pressurised Reactor with the capacity of 1600MW) based on safety concerns", explained prof. dr hab. inż. Władysław Mielczarski, professor ordinarius at the Technical University of Łódź, member of the European Energy Institute, in his publication in Wirtualny Nowy Przemysł. And British experts are among the most experienced nuclear energy experts in the world. They claim that reactors that Poland intends to purchase have major safety issues. including the maintenance of the optimum temperature and pressure. And when these problems arise, a nuclear power plant cannot be stopped immediately. According to prof. Mielczarski, the problem of safety of nuclear reactors is not	**Safety**	"Since the very beginning of nuclear power, nuclear power plants in Western countries have been designed in such a way as to ensure that the effects of any potential (even very unlikely) accident do not exceed the acceptable level. A number of different and reliable safeguards were used, mainly based on natural mechanisms such as the force of gravity, safety systems with three or four redundant subsystems, large safety margins assumed in the design, and many other design and organisational measures described in the article titled "Protection against hazards after breakdowns in nuclear power plants" published in the September issue of PSE Bulletin. For design-basis accidents, it was assumed as a rule that safety systems in a nuclear power plants must be sufficient to control the accident in any given element of the plant, even if the accident occurs in the most difficult location from the operator's perspective and in the most adverse conditions, and will be accompanied by a single additional failure in any given system in the nuclear power plant, also in a system that is supposed to control and contain this very accident. Based on these assumptions, designers of nuclear power plants had to make plans for the worst-case scenario and the most

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discussed in Poland at all, and the government presents them as a super-safe solution. "Some time ago, people were convinced that they had built a super-reliable machine. It was a ship – and her name was the Titanic. Since that time, nothing has been called super-safe or reliable. When I hear lobbyists singing praises about the safety of nuclear reactors, it is worthwhile to stop and think - maybe they are trying to sell us a ticket for the new Titanic?", said prof. Mielczarski. He suggests that Polish experts have no experience in this area whatsoever. They have completed one-week courses and information from producers is all they have to rely on. And this information is not always true. That is why the decision regarding the selection of a particular type of a nuclear reactor for Poland in 2010 must be well prepared. Otherwise, the new Polish nuclear power plants may destroy Poland."		adverse conditions – for instance, loss of power supply from an external network (irrespective of the additional single failure in any system in the nuclear power plant), and prove that the existing safety systems are sufficient to shut the power plant down, cool it down, and prevent the release of radioactive substances. We did witness one accident in a nuclear power plant that included a PWR core meltdown. It happened during a nuclear accident in the Three Mile Island (TMI) nuclear power station, where the power supply was not interrupted, but wrong decisions taken by operators caused the failure of the emergency core cooling systems and melting of the nuclear fuel. However, although the core and the entire nuclear reactor had been damaged to such an extent that the subsequent repair of the nuclear power station was not possible, the reactor pressure vessel maintained its integrity, and the safety containment prevented the release of fission products – as a result, the doses of radiation outside the nuclear power plant were negligibly small. Nobody lost their life or health as a result of the TMI accident. The TMI case proves that even 'old' reactors have safety margins that will ensure the containment of the effects of beyond-design basis accidents involving the nuclear core meltdown. At the same time, the TMI accident serves as a warning – human error is possible and fast and effective interpretation of the emergency processes may be difficult and may lead to very wrong decisions. Therefore, analyses were launched to determine whether effective rules of procedure can be developed to prevent human error on the part of operators. At the same time, additional safeguards were introduced to the planned and existing reactors to contain the release of radioactive substances in the worst-case scenario of the most serious hypothetical accidents. There works took many years, and the resistance of nuclear power plants to beyond-design basis accidents have improved over time. At the end of the 20th century, the EU Member States adopted the practice that safety features and systems in a nuclear power plant should be able to contain not only design-

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		basis accidents, but also beyond-design basis conditions in order to prevent the release of large amount of radioactive substances outside of the safety containment. Now, after 25 years since the TMI accident, both the EU and the USA have developed state-of-the-art reactor designs (Generation III reactors) that will guarantee safety for inhabitants of the local area even in the event of serious nuclear breakdowns with nuclear core meltdown.”

1.10 Review of alternatives to the solutions presented in the Programme

Alternative solutions for energy security

In Poland, electricity is generated mostly in coal–fired power plants (as much as 92%) – using both black and brown coal. In the EU, electricity is produced in nuclear power plants (28%), coal-fired power plants (27%) and gas-fired power plants (23%), as well as from renewable energy sources (18%). Poland clearly needs to diversify its energy sources in order to reduce environmental pollution and consumption of coal, and to ensure reliable supply of electricity.

Energy conservation (improvement of energy efficiency) is one alternative to the increase in electricity production volumes. Saving of energy is necessary and brings benefits, but it is possible only to a limited extent, because increased consumption of electricity is a pre-condition for the dynamic growth of any country.

Another alternative is to use renewable energy sources (RES) that must be developed under the obligations assumed by Poland. However, these technologies are expensive, and their energy-generating capacity in Poland is very limited. Hydroelectric power plants are the most commonly used source of renewable energy nowadays. Despite minor negative environmental impacts (related to the modification of the natural river system), hydroelectric power is the most environmentally-friendly source of energy, but their development potential is also rather limited. It is expected that by 2030 it will be used in 100%. Biomass and biogas burning is a method that uses local materials, including waste materials, to produce electricity. Development of this type of RES facilities has a positive impact on the local community (new jobs, market for local products, economic revival of the region). However, also in this case the electricity production potential is limited by the limited volume of biogas and biomass that can be produced (without the excessive reduction of the production of foodstuffs). The Polish Energy Policy until 2030 assumes the highest possible utilisation also for these sources of renewable energy. Wind farms have the widest scope of negative impacts. They are related mainly to the intermittent operation of wind turbines depending on the wind, and the fact that it is impossible to store electricity produced in wind farms (when the wind is gone or when stronger winds start, it is simply not possible to switch the wind farm on or off – they must operate continuously to secure the supply of electricity). Wind farm projects are also very expensive and material-intensive, and require a large area. Electricity produced in wind farms is therefore more expensive and the price is paid by consumers. In general, costs related to the introduction of renewable energy sources are much higher than costs of nuclear power. It is a common misconception that RES offer ‘free’ energy in a way, because its comes from ‘free’ sources such as solar energy or wind power. However, to produce this energy it is necessary to built projects with relatively limited efficiency, and their manufacture, transport, operation, and decommissioning also deplete natural resources and release certain amounts of emissions to the environment. The most fundamental problem concerning the large-scale use of RES is the fact that there are no technologies for the effective and efficient storage of energy, and renewable energy sources (especially wind power) produce electricity in an intermittent manner. Introduction of excessive amounts of electricity to the power grid will destabilise the system of electricity generation and transmission. However, some of these technologies may be unrivalled at a local level where electricity is consumed 'on the spot' and long-distance transmission is not necessary. If this is the case, transmission losses are reduced, as is the demand of individual consumers for electricity from the power grid, thus reducing the overall demand for electricity and the growth in electricity production volumes in the country.

Another alternative is to modernise the conventional energy production sector in order to increase its efficiency and reduce emissions to the environment. Implementation of technologies that reduce the emissions of pollutants to the atmosphere is expensive, and new technologies are implemented very slowly. But their further development is necessary, considering that even if the Polish Energy Policy until 2030 is implemented in its entirety, still 47% of total volume of electricity in Poland will be produced in coal-fired power plants in 2030 (according to the Programme). Therefore, the development of methods that will minimise their negative impacts on the environment is more than justified. .

We can conclude that the necessary modernisation of the Polish energy sector should not be limited to the introduction of nuclear power, as assumed in the Programme, but should also involve the development of RES (in an appropriate scale), investments aimed at the reduction of electricity consumption (energy efficiency projects), and modernisation of conventional energy sources (state-of-the-art electricity generation technologies and the so-called 'clean' coal technologies). Considering the requirements related to the reduced emissions of greenhouse gases and the ever-growing demand for electricity, it is necessary to adopt a policy that promotes all these alternatives, as soon as possible. However, introduction of the Polish Nuclear Programme is still the key element of this policy, in the context of the necessary reduction of GHG emissions, diversification of energy sources, and reduction of electricity production costs. This solution is justified by the fact that of all energy sources, nuclear power has the largest potential to reduce negative environmental impacts at the lowest implementation costs. Therefore, if the overriding objective of the current energy strategy is to reduce emissions and ensure sustainable energy security combined with the reduction in social costs of electricity production at the lowest implementation costs possible, the development of nuclear power is the direction we should take.

Technological alternatives

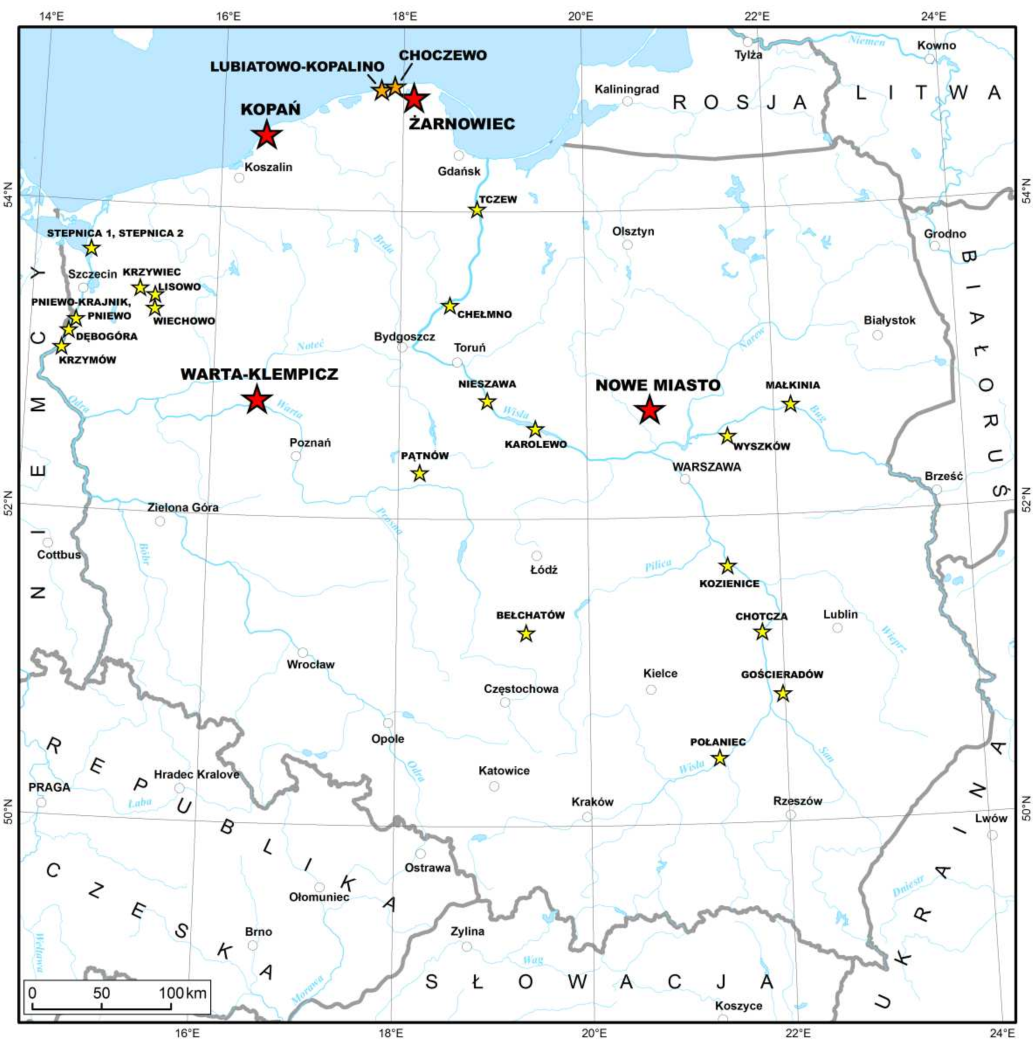
This Report analyses different environmental impacts resulting from the potential use of different types of new-generation nuclear reactors. These reactor types differ in terms of the volume of radioactive emissions (but all of them generate emissions much lower than the adopted standards during normal operation), energy generation parameters, consumption of cooling water, and land take. A number of alternatives for the cooling technologies were also discussed – with or without cooling towers. These systems have different environmental impacts in terms of the demand for cooling water, release of waste heat to the air or water, emissions of chemical substances to the air or water, emissions of noise, and impact on the landscape. An alternative solution involving the utilisation of heat produced in a nuclear power plant was also considered. This solution would reduce a number of negative environmental impacts related mainly to the release of heat to the atmosphere and water. Combined energy sources (producing electricity and heat at the same time) offer higher efficiency in the use of primary energy, which has a positive impact on natural resources. Therefore, it is a highly recommended alternative from the perspective of environmental protection.

At this stage of the SEA Report, we are not able to specify the most viable technological alternative as this decision will depend to a large extent on the actual location for the project. Combined generation of electricity and heat in the planned nuclear power plant should be the recommended alternative, but its viability will depend on the sufficient number of potential customers for heat. As regards the choice of different types of reactors and different types of cooling systems, the final decision should be taken at the public procurement stage on the basis of the Best Available Technology principle, considering the many aspects of their environmental impacts, dependency on the actual location, and the continuous advancement in reactor design technologies.

Location alternatives

Potential locations of nuclear power plants in Poland were selected by the Ministry of Economy based on a list of possible locations considered before 1990 and subsequently updated in consultation with local and regional authorities. The list includes 28 potential sites for the location of nuclear power plants, classified as recommended, backup, and other locations. They are presented in the following map:

POTENTIAL LOCATIONS FOR NUCLEAR POWER PLANTS



recommended locations — backup locations — other locations

To make the choice of the most optimum location easier, a multi-factor analysis was performed for environmental impacts and technological options for recommended, backup, and other locations. The analysis of potential environmental impacts of the planned investment was based on: number of towns and villages in the restricted-use area; energy efficiency of wind; close vicinity of protected landscape areas; risk of land take and potential restriction of access to natural resources; potential impact on the cultural heritage; and impact on plants and animals. In addition, the analysis included technical factors related to the access to water resources during the technological process, and possibility of connection to the transmission network.

The analysis of recommended locations and backup locations as regards the expected restricted-use area indicated that resettlement of people will be necessary only if the nuclear power plant is built in Nowe Miasto. The analysis conducted for the remaining sites showed that in two other cases (Połaniec, Chełmno) resettlement of people is possible in two towns/villages, and resettlement of one town/village is possible in Karolewo, Kozienice, Małkinia, Wyszków, Pątnów, Krzywiec, Pniewo-Krajnik, Nieszawa, and Chotcza. In other locations, resettlement will not be necessary.

Analyses of wind power zones indicated that wind conditions are good and very good in all recommended and backup locations, which will ensure that potential emissions of pollutants from nuclear power plants will not accumulate in one area.

Analyses also considered the close vicinity of protected landscape areas and the potential negative impact of nuclear projects on these areas. National scenic areas (Landscape Parks) are situated in recommended locations near Żarnowiec and Choczewo, but at a sufficient distance to reduce the potential risk of deterioration of their scenic value. As regards backup locations, only the town of Chełmno is situated in the central part of a Landscape Park. Chotcza, Karolewo, Kozienice, Małkinia, Wyszków, Lisowo, Wiechowo, Pniewo, Pniewo-Krajnik, Dębogóra, and Krzymów are located at a short distance. Other locations are situated away from protected landscape areas.

As regards the local natural resources base, no limitation of access to mineral deposits and their exploration was determined during analyses. Natural resources were found in the vicinity of several towns and villages: brown coal (Bełchatów, Nieszawa), rock materials (Gościeradów, Karolewo, Pątnów), and chemical materials (Stepnica 1 and 2, Połaniec). However, given the considerable distance from the planned sites, access to these resources should not be limited.

Geological and hydrological conditions are an important factor, including in particular the parameters describing the rate of water infiltration. They are of key importance when water and ground is contaminated and pollutants may go through to rock formations. The location analysis indicated very diversified geological and hydrogeological conditions in different locations. The planned locations are characterised by low or very low sensitivity to groundwater pollution. Only the Żarnowiec site is very sensitive to the potential contamination of groundwater. In backup locations, the most unfavourable hydrogeological conditions were found in Kozienice, Wyszków, Pniewo, Pniewo-Krajnik, and Dębogóra. These sites are very sensitive to potential contamination of groundwater. The best hydrological conditions were found in Tczew, Nieszawa, Bełchatów, Karolewo, and Małkinia.

Close vicinity of cultural assets and archaeological sites is another factor analysed in this Report. As regards the recommended locations, works should be conducted under archaeological supervision only in one location (Lubiatowo – Kopalino), given the vicinity of archaeological sites. In other locations, archaeological sites are located at a safe distance from the construction site or have not been documented in the area. Archaeological sites are found in the close vicinity of certain backup locations (Chełmno, Gościeradów, Karolewo, Połaniec, Pątnów, Krzywiec, Lisowo, Wiechowo, Dębogóra), and the planned project may have a negative impact on these sites. In other locations, we do not expect any risk to cultural assets and any conflict between cultural heritage and the planned project in the construction stage, or any delays if the project is suspended for the period of archaeological works.

Our analysis of the potential utilisation of cooling systems in a nuclear power plant in recommended locations shows that sufficient water resources are found in all cases. In addition, an open–circuit cooling system is recommended for Kopań, Choczewo, Lubiatowo – Kopalino, and a closed-loop system is recommended for Warta – Klempicz and Nowe Miasto. Żarnowiec will use either an open-circuit or a closed-circuit system, depending on the technical solutions adopted. The analysis of backup locations indicated that with the exception of Krzywiec, Bełchatów, Lisowo, and Wiechowo, the existing water resources are sufficient for the planned processes. In Bełchatów, the existing resources are either insufficient or the planned cooling system concept has not been defined. Based on the analysis of the proposed cooling system alternatives, an open-circuit water cooling system was proposed for the following locations: Chełmno, Nieszawa, Karolewo, Tczew, Stepnica 1 and 2. A closed-circuit water cooling system was proposed for: Gościeradów, Chotcza, Kozienice, Małkinia, Wyszków, Połaniec, Pniewo, Pniewo-Krajnik, Dębogóra, and Krzymów.

Analysis of the potential connection to the existing transmission network indicates that four out of six planned locations are worth considering, and further detailed analyses are needed. Warta – Klempicz is the top recommendation here. On the other hand, the location of Nowe Miasto is especially unfavourable – mainly due to the lack of network infrastructure in this region of the country, with no plans for its development in the nearest future. As for backup locations, the following are recommended: Chełmno, Karolewo, Kozienice, Tczew, and Połaniec. The remaining locations are not recommended.

One additional aspect considered in the analysis are the potential threats to the planned location of the nuclear power station. The identified threats included a possible building disaster in the Włocławek dam whose technical condition has deteriorated (Nieszawa, Karolewo) and a possible explosion in the planned high-pressure pipeline (Gościeradów).

Among backup locations, Bełchatów seems to have the least negative impacts on the fauna and the areas of nature protection. The diversity of animal species in this particular location is rather low and it is not close to any protected areas that could be affected. On the flip side, this location will interfere with the network of ecological corridors. The proposed location in Połaniec is difficult to evaluate – it could be classified in a similar way as Bełchatów, but it is located in the Vistula valley. There is no published data on the biodiversity of animal species in this location, but it may as well result from the fact that its natural value is slightly less attractive compared to other section of the Vistula valley. The problem is that even the relatively less diverse ecosystems of river valleys are still usually much more diverse than the common ecosystems in agricultural and woodland areas. Therefore, this location should be approached with caution and further detailed analyses are needed. Other locations are situated within Natura 2000 sites or in their close vicinity, and some are situated near bird migration routes and interfere with the network of ecological corridors.

Based on the adopted method of evaluation of the diversity of plant cover on the basis of the number of plant species recorded in published sources and types of habitats in individual locations, their representative comparative analysis was possible. Significant differences between individual locations were highlighted. The plant cover diversity is the lowest in the location of Nowe Miasto (central lowlands). This location stands out, both in terms of the plant cover and habitats, and as regards the lack of any forms of nature protection – which means that there is nothing to protect in this location. especially in comparison with other recommended and backup locations, four of which are situated in the coastal area where a large number of rare and protected taxa are found (both plant species and habitats). Coastal sites are also surrounded with many forms of surface protection areas. The location in Nowe Miasto is therefore the most optimum location if we want to minimise the potential threats to the existing plant cover. Of all backup locations, Bełchatów has the lowest diversity of plant species. It is situated far away from any protected areas. In addition, the surrounding landscape has already been modified, and the potential new threats are much lower than in other locations.

1.11 Findings and recommendations

Method of Programme implementation

The basic positive environmental impact of the implementation of the Programme is to be the reduction of the negative impacts connected with the current operation of the energy sector, especially by lowering the social costs of energy generation and reducing the emission of greenhouse gases (chapter 5). However, to achieve these objectives, we must start the planned activities immediately and implement these projects in accordance with the adopted schedule. Otherwise, the costs of Programme implementation will not bring the expected effects.

Selection of an optimum location for the future nuclear power plants is the key aspect of the Programme – many environmental impacts of the planned project will depend on the specific location. Technologies adopted for this project should use the latest and best available technological options at the implementation stage. When selecting the location, we should consider and analyse the available technologies and economic feasibility of the combined heat and power generation in a nuclear facility.

Implementation of the Polish Nuclear Programme should not be an isolated effort. It should rather function as an important element within the larger framework of Poland’s strategy for the modernisation of the country’s energy sector. At the same time, under the Polish Energy Policy until 2030, the country must modernise its conventional power plants, improve its energy efficiency (also through the improvement of the existing transmission infrastructure), and develop new RES systems in accordance with their actual power generating potential, etc. However, As the analysis of energy security alternatives indicates, there are two sides to every story. Objectives set for the Polish energy sector cannot be fully achieved without the implementation of the Polish Nuclear Programme, but also implementation of the Polish Nuclear Programme alone will not bring the expected results.

Actions reducing the scale of potential social conflicts

Social approval and acceptance is required for the development of new electricity generation methods in Poland in general, and for the development of nuclear power in particular. The nuclear power sector should develop in such a way as to prevent the escalation of potential social conflicts and to ensure full transparency of all actions and an effective dialogue with all stakeholders. It is important to use the best available technologies and practices that ensure safety in a nuclear power plant, but at the same time the adopted goals should be achieved – the supply of cheaper and ‘cleaner’ electricity, protection of the natural environment, and improvement of the living conditions for Polish citizens. Ultimately, nuclear power plants must become an element that will diversify energy sources, satisfy the demand for electricity, and guarantee the country’s energy security. At the same time, each and every citizen shall have the inalienable right to information on the operation of nuclear power plants and their impact on the environment (save for any information that could compromise nuclear safety). To achieve this objective, an information and education programme should be implemented. However, this programme cannot be used as a propaganda tool for nuclear power; instead, it should provide the source of reliable information to the society and highlight the benefits of nuclear power and its proper place among different energy production methods.

In order to implement these objectives (specified in more detail in previous Chapters of this Report), the authors suggest the following action plan (again, described in more detail in the main Report):

- A genuine debate with the society on the development of nuclear power in Poland using mass communication channels – the press, radio, TV, Internet, and other media.
- Face-to-face meetings with inhabitants of the regions where nuclear power projects are planned, with the involvement of nuclear power and environmental protection experts, and – at a later stage – authorised representatives of potential investors.
- Collecting feedback on the expectations and concerns of Polish citizens regarding the planned development of nuclear power and considering this feedback when designing potential nuclear power plants.
- Using the experience of other countries in the construction and operation of nuclear power stations to ensure the highest safety and the lowest negative environmental impact. It includes both the implementation of state-of-the-art technologies and development of the necessary implementing legal provisions and methods of management of nuclear facilities.
- Education of the society, including at all levels of school education, as regards the modern methods of electricity production – including a broad presentation of nuclear power as one of the methods of effective diversification of energy sources in Poland.
- Support for the local initiatives such as the project planned in the Municipality of Gniewino - organisation of a training centre for teachers of natural sciences, not only from the Pomorskie province but for the entire country.. We recommend that the intensive training programme should be supported, and its results and lessons learned communicated to other regions of Poland.
- Support for the projects that focus on the creation of civic society in Poland – a society of people who protect their living environment, use the best available environmental protection solutions, and save energy and natural resources to preserve them for future generations.
- An honest debate with opponents of nuclear power in order to eradicate false, unconfirmed, and harmful data and information that can mislead the society – on both sides.

As regards the follow-up measures, regular and reliable public opinion polls should be organised by professional research companies using the appropriate methodologies and tools of statistical analysis.

Actions at the Environmental Impact Assessment stage

At the Environmental Impact Assessment stage, the proposed course of action will include:

- a comprehensive analysis of the necessary infrastructure that will be required in the location of the planned nuclear power plant, and obtaining a single environmental decision (decision on environmental constraints) for the entire project.
- a application for the decision on environmental constraints for three alternative locations. This will make it possible to conduct a detailed analysis of alternatives for at least three alternative locations of nuclear power plants. The final location will be selected upon completion of the report and the social consultation procedure. This approach will guarantee that environmental protection will be given the same priority as social and economic aspects of the project.

Protection of surface and ground waters

Negative impacts of the nuclear power plant on surface waters may be kept at a minimum or eliminated altogether by using the proper technologies and selecting the optimum technological parameters that are described in detail in this Report. The planned nuclear power plant will increase the demand for cooling water. Therefore, selection of the optimum technology and cooling system is of key importance in the decision-making process as regards the location of the project.

To keep the negative impacts on surface waters at a minimum, special attention should be paid to the following aspects:

- rational management of water and effluents, as well as the cooling water system (including application of best available solutions in the design of cooling water systems and other components - to minimise the non-recoverable losses of water and emissions of harmful substances to the environment).
- installation of systems for the collection, treatment/pre-treatment, and discharge of effluents and sewage;
- adoption of strict limits for the concentration of substances used in processes in the nuclear power plant;
- monitoring of effluents for the concentration of certain substances;
- monitoring of the condition of water bodies to which treated effluents and sewage are discharged;
- regular maintenance of all plant and machinery and transmission networks.

According to the analysis of the existing geological and hydrogeological conditions in areas considered as the potential locations of nuclear power plants, the degree of sensitivity of the ground and rocks to the potential infiltration and penetration of pollutants to ground waters is very diversified, depending on the location. Therefore, this important factor must be taken into account when selecting the most optimum location. During normal operation of the nuclear power plant, the negative impacts on the condition and quality of groundwater resources will not increase.. However, the scenario may be quite different in the event of a breakdown or an uncontrolled leakage.

In the implementation phase, the negative impacts on the condition of groundwater may be reduced i.e. based on:

- proper location and organisation of construction site facilities,
- good technical condition of construction equipment,
- reduction of the area of land occupied by the construction site to a minimum,
- introduction of any possible safeguards to prevent the release of petroleum products to the ground and water environment, for instance by designating special parking areas (with protected surface) for construction machinery and equipment.

In the operation phase, the level and quality of groundwater must be monitored.

Special attention should be paid to effective protection of groundwater intake points, usable groundwater bodies (especially major ground water reservoirs) and their protected areas, as well as local water bodies of lower importance, in particular when they are not naturally isolated from the surface and if they are used as a source of water supply.

Protection against radiation

It must be ensured that the Parliament passes the relevant laws that will guarantee radiological protection and safety of people. The relevant information should be disseminated by the press and other media.

The necessary weather data and other information required to assess the environmental impacts of the nuclear power plant should be collected for at least two leading locations, and preferably for 3 or 4 typical locations, with due consideration given to the existing local conditions, even if it involves additional costs. Then, the necessary safety data sheets should be collected from the suppliers of nuclear reactors and used as a basis for an independent assessment of their environmental impacts during normal operation and in emergency conditions.

The investor and nuclear regulatory authorities should conduct a preliminary verification of nuclear safety of the proposed projects and nuclear regulatory authorities should approve the areas designated as restricted-use areas and areas of potential mitigation measures for each type of proposed nuclear power plants. The society should be then informed of the limits of these areas. It must also be ensured that the investor considers the level of safety for a given reactor type when analysing bids in the procedure of public procurement for the supply of reactors for Polish nuclear power plants.

Before the commencement of any construction works, the complete measurements of the existing level of radiation in the ecosphere in the area of the planned project should be taken. Results of these measurements will serve as a point of reference to determine the environmental impact of the nuclear power plant and to define the target radiation level to be achieved after nuclear decommissioning. It is of key importance, because radiation levels generated by a nuclear power plant in normal operating conditions are very low, and it is difficult to distinguish it from natural background radiation. These analyses should include natural and artificial radioactivity of the environment (i.e. both natural and man-made radioactive isotopes) as well as radioactive pollution affecting the inhabitants of the area in the vicinity of the nuclear power plant. A well-prepared programme of comprehensive radiometric measurements adjusted to the specific locations should cover the area of 15-25 km around the nuclear power station. More details on the required measurements are presented in the main body of the Report. Before the commencement of any construction works, assessment of the health condition of the local population should be conducted, to serve as a point of reference when determining the radiological impact of the nuclear power plant in the future. It is the only way to define a baseline for any future analyses. Additional measurements and analyses should also be performed to compare this data with other regions of Poland and other countries.

Monitoring solutions and proposals to prevent, reduce, or compensate the negative environmental impacts on the objectives of Natura 2000 network and the protected Natura 2000 sites and their integrity

To reduce the negative environmental impacts of a nuclear power plant at the construction and operation phase, the following actions should be taken:

- construction plans and specifications should be consulted with experts in the field of botany and zoology, so that any threats to terrestrial or aquatic animals and plants are identified and minimised as they occur;

- construction works should be performed at an appropriate time that does not interfere with the nesting period of birds;
- buildings and construction machinery should be provided with sufficient lighting in the construction and operation phase to prevent the increased death rate of birds caused by collisions;

If any serious and irreversible impact on any Natura 2000 site has occurred, the appropriate compensation measures must be introduced.

Organisational activities

It is recommended that a single-person unit be established at the Nuclear Energy Department of the Ministry of Economy, responsible for the monitoring of environmental impacts and implementation of the necessary mitigation and compensation measures. This unit would function within the framework of the Ministry of Economy but report the results of its works to the Minister of the Environment. Based on this approach, environmental aspects will be given the same priority as any social and economic aspects.

2 CHARACTERISTICS OF THE REPORT

AUTHORS: *Łukasz Szkudlarek*

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2.1 Formal and legal grounds for the Report

The Strategic Environmental Assessment Report for the Polish Nuclear Programme (hereinafter referred to as the "Report" or "SEA Report") was prepared in accordance with the agreement signed by and between the Minister of Economy and the company Fundeko Łukasz Szkudlarek.

The Report was based on draft Polish Nuclear Programme dated 16 August 2010 and the position of the General Director of GDOS (General Directorate for Environmental Protection) and Chief Sanitary Inspectorate regarding the scope of the Strategic Environmental Assessment Report for this document.

The decision to develop the Polish Nuclear Programme was adopted by resolution of the Polish Council of Ministers No. 4/2009 of **13 January 2009** on actions taken to develop the Polish nuclear power sector, which provided that:

"To ensure the national energy security, and taking into account the economic development, a Polish nuclear power program shall be developed and implemented. The draft of such program shall be developed and submitted to the Council of Ministers by the government's plenipotentiary; this program shall determine the nuclear power plants' number, size and possible sites. Moreover, the government obligates the National Treasury Minister to ensure that PGE Polish Energy Group SA shall cooperate on the program's development and implementation. "

On 10 November 2009, the Council of Ministers adopted Poland's Energy Policy until 2030. The document provides that one of the main directions of development of Poland's energy policy is *"diversification of the generation structure by introducing nuclear energy."* The adoption of the policy took place after the strategic environmental assessment for the effects of implementation of the Polish energy policy until 2030 was prepared, which included public consultations. Therefore, it must be emphasized that the present Strategic Environmental Assessment Report for the Polish Nuclear Programme is not a document that was meant to introduce nuclear energy in Poland or to justify such actions (the rationale for the Polish Nuclear Programme has already been presented in the Strategic Environmental Assessment for the Polish Energy Policy until 2030).

The Polish Nuclear Programme only provides the framework and the schedule of actions needed to introduce nuclear energy and, thus, to achieve the objectives of the Polish Energy Policy until 2030. It presents the scope and the organizational structure of the actions that must be taken to implement nuclear energy and to assure safe and effective operation of nuclear energy facilities. A result of such implementation will be the commissioning of the first two nuclear power plants in Poland, which will have some environmental impacts. Therefore, this Report focuses on analyzing and assessing such impacts.

The report does not avoid the issue of impacts resulting from the expansion of the necessary power distribution infrastructure, the fuel cycle including the generation, transport, and storage of radioactive waste. However, this is not included in the subject matter of the Report. It must be emphasized that a detailed discussion of the aforementioned issues related to the environmental impact of expansion of the necessary power distribution infrastructure and the selection of the fuel type and the best, in the Polish conditions, method of storage of radioactive waste will be included in the strategic environmental assessment reports for the updated Development Plan for Satisfying the Present and Future Demand for Electric Energy and the National Radioactive Waste and Spent Nuclear Fuel Handling Plan.

This approach is in compliance with **art. 5.2 of Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment:**

"The environmental report prepared pursuant to paragraph 1 shall include the information that may reasonably be required taking into account [...] the contents and level of detail in the plan or programme, its stage in the decision-making process and the extent to which certain matters are more appropriately assessed at different levels in that process ***in order to avoid duplication of the assessment.****"*

Given the above, the following Report was elaborated.

2.1.1 The basic sources of community law regulating the Environmental Assessment procedure:

- Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (SEA directive);
- Council Directive 85/337/EEC of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment (EIA directive);
- Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitat directive);
- Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds (Bird directive).

2.1.2 The basic sources of Polish law regulating the Environmental Assessment procedure:

- Act of 27 April 2001, Environmental Protection Law (AEPL);
- Act of 16 April 2004 on the protection of the environment (APE)
- Regulation of the Council of Ministers of 9 November 2010 concerning undertaking with potential high environmental impact (EA Regulation);
- Act of 3 October 2008 on Access to Information on the Environment and Its Protection, Public Participation in Environmental Protection and on Environmental Impact Assessments (the EA Act);
- Act of 27 March 2003 on spatial planning and management;
- Act of 7 July 1994 – Building Code;
- Act of 18 July 2001 – Water Code;
- Act of 14 June 1960 – Code of administrative procedure (CAP).

2.1.3 The basic sources of international law that regulate the environmental impact of nuclear energy facilities

European Union law:

- The EURATOM treaty;
- Council Directive 2009/71/Euratom of 25 June 2009 establishing a Community framework for the nuclear safety of nuclear installations;
- Council Directive 96/29/Euratom: basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation;
- Council Decision 87/600/Euratom of 14 December 1987 on Community arrangements for the early exchange of information in the event of a radiological emergency (6) which established the

framework for notification and transfer of information to be used by member states to protect the population in the case of a radiological emergency;

- Council Directive 89/618/Euratom of 27 November 1989 on informing the general public about health protection measures to be applied and steps to be taken in the event of a radiological emergency (7) which imposes on member states the duty to inform the public about radiological emergencies;
- Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants (so-called NEC directive);
- Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control and Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control (the “IPPC” directive);
- Directive 2001/80/EC on the limitation of emissions of certain pollutants into the air from large combustion plants (the LCP directive);
- Directive of the European Parliament and of the Council of 7 July 2010 on industrial emissions.

International conventions signed and ratified by Poland

- United Nations Framework Convention on Climate Change made in New York on 9 May 1992;
- Kyoto Protocol to the United Nations Framework Convention on Climate Change, made in Kyoto on 11 December 1997;
- Convention on Nuclear Safety (1996);
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (2001);
- Convention on Early Notification of a Nuclear Accident (1986);
- Convention on Assistance in the Case of Nuclear Accident or Radiological Emergency (1987);
- Convention on the Physical Protection of Nuclear Material (1987);
- Nuclear Non-Proliferation Treaty (NPT).

2.1.4 International requirements, guidelines, recommendations, and standards

- *European Utility Requirements for LWR Nuclear Power Plants, “EUR” 2001;*
- IAEA standards[2];
- WENRA recommendations[3].

2.1.5 Selective secondary legislation to the Atomic Law (currently in force):

1. Act of 29 November 2000 – Atomic Law;
2. REGULATION OF THE COUNCIL OF MINISTERS of 21 April 2004 amending the regulation on the documents required upon the submission of a licensing request for operations which involve exposure to ionising radiation or upon reporting such operations;
3. Regulation of the Council of Ministers of 21 October 2008 concerning the permit and approval for importation into the territory of the Republic of Poland, exportation from the territory of the

Republic of Poland, and transit through this territory of radioactive waste and spent nuclear fuel – in force since 25 December 2008;

4. Regulation of the Council Of Ministers of 4 November 2008 on the physical protection of nuclear materials and nuclear facilities – in force since 25 December 2008;
5. Regulation of the Council of Ministers of 18 January 2005 on ionizing radiation dose limits;
6. Regulation of the Council of Ministers of 6 August 2002 on nuclear regulatory inspectors;
7. Regulation of the Council of Ministers of 20 February 2007 on the basic requirements for controlled and supervised areas;
8. Regulation of the Council of Ministers of 12 July 2006 on detailed safety requirements for work involving ionising radiation sources;
9. Regulation of the Council of Ministers of 23 March 2007 on the requirements for the individual dose registration;
10. Regulation of the Council of Ministers of 3 December 2002 on radioactive waste and spent nuclear fuel;
11. Regulation of the Council of Ministers of 23 December 2002 on the requirements for dosimetric equipment;
12. Regulation of the Minister of Environment of 30 December 2002 on detailed rules for the creation of a restricted-use area surrounding nuclear facility, indicating relevant restrictions concerning its uses;
13. Regulation of the Council of Ministers of 18 January 2005 on emergency plans for radiological emergencies;
14. Regulation of the Council of Ministers of 20 February 2007 amending the regulation on emergency plans for radiological emergencies;
15. Regulation of the Council of Ministers of 27 April 2004 on intervention levels for various intervention measures and criteria for cancelling intervention measures;
16. Regulation of the Council of Ministers of 27 April 2004 on prior information to the general public in the event of a radiation emergency;
17. Regulation of the Council of Ministers of 27 April 2004 on the protection against ionising radiation of outside workers exposed during their activities in controlled areas;
18. Regulation of the Council of Ministers of 27 April 2004 on the determination of entities competent to inspect maximum permitted levels of radioactive contamination of foodstuffs and feeding stuffs following a radiation event;
19. Regulation of the Council of Ministers 20 February 2007 on the terms for import into the territory of the Republic of Poland, export from the territory of the Republic of Poland and transit through this territory of nuclear materials, radioactive sources and equipment containing such sources.

2.1.6 Polish regulations in the course of elaboration (with agreed essential contents)

- Draft amendment to the Atomic Law of 2010:

- o Assumptions of the draft act on amendment of the Atomic Law and on amendment of some other statutes, constituting a transposition of the Council Directive 2009/71/Euratom of 25 June 2009 (EU Official Journal L 172 of 2 July 2009, p. 18, and EU Official Journal L 260 of 3 October 2009, p. 40), version dated 31 May 2010 - adopted by the Council of Ministers on 22 June 2010;
- o Draft act on amendment of the Atomic Law and on amendment of some other statutes – version dated 26 October 2010 (elaborated by the Government Legislation Centre).

- Draft Regulation of the Council of Ministers of ... on the factors considered when performing an evaluation of the site intended for location of a nuclear facility and on the requirements for the siting report for a nuclear facility;
- Draft Regulation of the Council of Ministers of ... on the basic nuclear safety and radiological protection requirements that must be taken into account in designs of nuclear facilities;
- Draft Regulation of the Council of Ministers of ... on the nuclear safety and radiological protection requirements at the commissioning and operation stages of nuclear facilities;
- Draft Regulation of the Council of Ministers of ... on the nuclear safety and radiological protection requirements at the decommissioning of nuclear facilities and on the content of report from the decommissioning of nuclear facilities;
- Draft Regulation of the Council of Ministers of ... concerning requirements for safety analyses conducted prior to applying for a permit to build a nuclear facility and for the content of safety report for a nuclear facility.

2.2 Content and main objectives of the program

2.2.1 Content of the Program draft

Chapter I presents an introduction to the nuclear energy programme in Poland and the main reasons for its implementation.

Chapter II presents the schedule and the detailed lists of preparatory tasks necessary to implement nuclear energy programme in Poland, divided into the individual states and with the dates of their implementation.

Chapter III refers to the European Energy Policy and the Polish Energy Policy until 2030 and presents important decisions that have been made concerning the development of the nuclear energy programme in Poland.

Chapter IV presents an analysis of the costs and the economic justification for development of the nuclear energy sector. The analysis assumes the individual costs of electricity generation based on the forecasts of global research centres, with a very conservative approach to state-of-the-art technologies (mostly nuclear power plants). The results of the analysis, in line with the facts presented in the program, confirm the significant advantage of nuclear power plants compared to conventional power plants and RES. Moreover, the analysis confirms the need to implement the nuclear energy programme due to the need to assure the operation of the Polish energy system after 2020 with Poland fulfilling its obligations.

Chapter V describes the organization of the works related to the Programme’s implementation.

Chapter VI covers the matter of establishing the conditions for safe implementation of the nuclear energy sector.

Chapter VII discusses the cost of performance and sources of financing of the Programme.

Chapter VIII discusses the issue of selection of the locations for the future nuclear plants in Poland. The chapter presents a review of the siting studies for nuclear power plants in Poland performed before 1990 and information on the current status of the works related to the updates of the previous studies and the new research. The results of the studies was the ranking list prepared by the Ministry of Economy, which included 28 locations. The results of the analysis were submitted to the future investor, the Polska Grupa Energetyczna S.A. (PGE) which selected 4 main locations and 2 backup locations for further detailed studies.

Chapter IX discusses the matter of preparation and the required changes in the national power grid system. It mentions the need to expand the national grid system, in particular the 400 kV lines. Upgrade of the system was included in the development plan, to the extent necessary to satisfy the current and future demand for electricity in the years 2010-2025, prepared by the PSE-Operator S.A. The Polish Nuclear Programme underscores the fact that the solutions proposed in the development plan are inadequate and that it is necessary to determine the basic criteria that the connection of the nuclear power plant to the National Power Grid must meet. The Programme indicates that this task should be performed in close cooperation between the PSE-Operator S.A, the Investor, and the Energy Regulatory Office and with the support of independent consultants and experts. The chapter also points at important problems that must be resolved on the occasion of expansion of the National Power Grid, which are connected mostly to the long and excessive administrative procedures.

Chapter X focuses on environmental protection. It discusses mostly questions related to CO2 emissions and, eventually, it will be replaced with this Report.

Chapter XI emphasizes the need to assure an appropriate number of qualified staff at the project preparation stage, construction phase, and operation phase. It was clearly stated that failure to complete the basic intent described in the chapter will constitute a serious risk to timely completion of the Programme.

Chapter XII describes the formation of the National Centre for Nuclear Research as the technical and scientific-research support for the Polish nuclear energy programme. The Centre will support the government and the nuclear regulatory office in the area of safe operation of nuclear facilities.

Chapter XIII pertains to the very important matter of assuring safe supply of nuclear fuel. It provides the basic information on the capacity and availability of uranium deposits in the world and, potentially, in Poland.

Chapter XIV pertains to the management of radioactive materials at various stages of the fuel cycle. The chapter describes the basic methods of handling spent nuclear fuels used in the world. The chapter also describes Poland's experience with radioactive waste that has been collected in the course of operation of the radioactive waste repository in Różan. It also includes a brief presentation of the actions planned with regards to management of radioactive waste in Poland related to the nuclear energy programme.

Chapter XV discusses the potential benefits to the domestic industry as a result of implementation of the Polish Nuclear programme. The chapter discusses the Investor's efforts to involve the Polish industry as well as the future benefits to the Polish economy.

Chapter XVI focuses on the issue of public participation and support for the Polish Nuclear programme. The chapter presents a list of actions needed to win public support for the location of the first nuclear power plant in Poland.

2.2.2 The main objectives and directions of actions assumed in the Program draft

The preparatory activities related to the implementation of the Polish Nuclear Energy Program are to be performed in compliance with Poland's domestic laws and with full respect to international laws and EU regulations, as well as the recommendations of the International Atomic Energy Agency (IAEA).

The schedule of the activities results from the provisions of Poland's Energy Policy until 2030, the Strategic Plan of the Ministry of Economy, and the Framework Schedule of Actions for Nuclear Energy. It is also one of the necessary tools to assure the economic growth by increasing the potential of the Polish energy sector which was described in the report titled "Poland 2030. Development challenges." The schedule of the Polish Nuclear programme is shown in the table below.

Table 2.2.1 Schedule of the Polish Nuclear Programme

PHASE	DATES	TASKS
Stage I	by 30 June 2011	elaboration and adoption by the Council of Ministers of the Polish Nuclear Programme by 31 December 2010 adoption and entry into force of the laws required for the development and functioning of the nuclear energy sector by 30 June 2011
Stage II	1.07.2011 - 31.12.2013	determination of the location and conclusion of the contract for the construction of the first nuclear plant
Stage III	1.01.2014 - 31.12.2015	elaboration of the technical design and obtaining of all the legally required approvals
Stage IV	1.01.2016 - 31.12.2022	building permit and construction of the first power unit of the first nuclear plant; commencement of construction of further power units/nuclear plants
Stage V	1.01.2023 - 31.12.2030	construction of additional power units/nuclear power plants

Of key importance to timely completion of the individual stages is timely completion of the most important actions comprised in Stage I, in particular entry into force of the laws required for the development and functioning of the nuclear power sector in Poland. Any delays in this area will result in postponement of the dates of completion of the successive stages. At the time of writing of this Report, it is known that the Polish Nuclear programme will not be elaborated and adopted by the Council of Ministers by 31 December 2010 due to the need to perform the strategic environmental impact assessment. Consequently, the adoption of the programme will most likely be delayed by approximately six months, i.e. until 30 June 2011. Thus, the successive stages will be pushed back by the same periods of time.

Table 2.2.1 Description of the actions enumerated in the Polish Nuclear programme

ACTION NUMBER	ACTION NAME	ACTION OBJECTIVE
Action 1	Legal framework for the construction and functioning of the nuclear energy sector in Poland	The objective is to elaborate, adopt, and implement laws that are necessary to allow building of the nuclear energy sector and the associated infrastructure, as well as its functioning. The application of such laws will be systematically monitored and evaluated. The necessary changes will be introduced in an ongoing fashion.
Action 2	Elaboration and implementation of the Polish Nuclear programme	The objective is to elaborate and implement the PNE Programme as the necessary comprehensive basis for all the efforts related

ACTION NUMBER	ACTION NAME	ACTION OBJECTIVE
		to introduction of the nuclear energy sector into Poland in the fastest and most effective way
Action 3	Nuclear power plants siting analyses	The objective is to select potential locations for nuclear power plants
Action 4	The final phase of the fuel cycle – management of radioactive waste and spent fuel – Analysis and studies concerning the location for low- and moderate-activity radioactive waste repository, preparation of the design of the repository, and construction of the repository.	The objective is to determine the location for a new low- and moderate-activity radioactive waste repository due to the fact that the currently used repository is nearly completely full. Preparation of the design of the new repository and construction of the repository.
Action 5	The final phase of the fuel cycle – management of radioactive waste and spent nuclear fuel – National radioactive waste and spent nuclear fuel handling plan	The objective is to prepare and to implement a technically and economically reasonable and socially acceptable management of radioactive waste and spent nuclear fuel, which is one of the key elements related to the functioning of the nuclear energy sector
Action 6	Education and training of staff for institutions and businesses involved with the nuclear energy sector	The objective is to prepare the staff for the Polish nuclear energy sector, both for the preparation and development of the infrastructure, and for the operation of nuclear power plants
Action 7	Information and educational campaign	The objective is to present to the public a credible and reliable information on nuclear energy and to improve the public's knowledge of this matter by education activities
Action 8	Scientific and research institutions	The objective is to form strong scientific and research institutions working for the nuclear energy sector, which is necessary for Poland to take full advantage of the advantages and opportunities related to its introduction
Action 9	Participation of Poland's industry in the nuclear energy programme	The objective is to assure the broadest possible participation of the Polish industry in the supply of equipment for the nuclear energy sector and of Polish companies in the construction of nuclear power plants in Poland and in other countries
Action 10	Initial phase of the fuel cycle – assuring the supply of uranium from foreign and domestic sources	The objective is to obtain data about the deposits of uranium present in the territory of Poland and about the possibilities of its use, as well as to obtain information on the most advantageous potential supply of uranium for the Polish nuclear power plants
Action 11	Functioning of the nuclear and radiological regulatory institution	The objective is to assure the functioning of an independent, modern, and professional nuclear and radiological regulatory institution which, as a public-trust institution, will be able to meet the challenges related to the development of the nuclear energy sector in Poland

ACTION NUMBER	ACTION NAME	ACTION OBJECTIVE

The presented actions constituting the basis of the Polish Nuclear Programme cover mainly legal, organisational, and formal actions, and as such have no negative impacts on the natural environment. The result of these activities will be the launch of the first nuclear power plants in Poland. This Report focuses on the environmental impacts of this outcome.

2.3 Assumptions made in the Report

2.3.1 The objective and the scope of the Report

The purpose of this document is to analyze the potential environmental impact of the results of the implementation of the Polish Nuclear Programme. The Strategic Environmental Assessment Report contains:

- information on the contents, the main characteristics of the proposed document, and its relations with other documents;
- information on the methods used when preparing the Report;
- proposals regarding the anticipated methods of analyzing the outcomes of implementation of the provisions of the proposed document and the frequency of the analysis;
- information on possible trans-border environmental impact of the programme;
- a non-technical summary.

This Strategic Environmental Assessment Report also defines, analyzes, and evaluates:

- the present condition of the environment and the potential changes to the conditions in the event that the proposed document is not implemented;
- the condition of the environment in the areas where significant impact is anticipated;
- existing problems with environmental protections that are important from the point of view of implementation of the proposed document, in particular those pertaining to the areas that are protected under the Act of 16 April 2004 on environmental protection;
- the environmental protection objectives set forth on the international, community, and national level that are important from the point of view of the proposed document and the ways that these objectives and other environmental problems have been considered during the preparation of the document;
- the anticipated significant impacts, to include direct, indirect, secondary, cumulative, short-term, mid-term, and long-term, permanent and temporary, as well as positive and negative impacts on the objectives and object of protection of Natura 2000 areas and the integrity of such areas, as well as on the environment, in particular on biodiversity, people, animals, plants, water, air, Earth surface, landscape, climate, natural resources, historical monuments, and material goods, taking into account the relations between these elements of the environment and between the impacts on these elements.

To the extent that is appropriate in the case of this analysis, the following were also taken into account:

- solutions intended for prevention, limitation, or environmental compensation of negative environmental impacts that may result from the implementation of the proposed document, in particular the impacts on the objectives and objects of protection of Natura 2000 areas and their integrity;
- the objectives and the geographic range of the document and the objectives and the object of protection of Natura 2000 areas and their integrity – solutions that are alternative to those presented in the proposed document, with justification for their selection and a description of the methods of evaluation resulting in the selection, or explanation of the reasons for the lack of alternative solutions, to include information on encountered difficulties resulting from shortcomings of the technology or inadequate knowledge.

The table below shows how the content of this Report will be made to conform to Art. 51 of the Act of 3 October 2008 on Access to Information on the Environment and its Protection, Public Participation in Environmental Protection and on Environmental Impact Assessments (Journal of Laws No. 199 item 1227).

Table 2.3.1 Description of the actions enumerated in the Polish Nuclear Programme

REPORT CONTENTS REQUIRED BY THE STATUTE		**CHAPTER**
information on the contents, the main characteristics of the proposed document, and its relations with other documents		2, **3**, **6.3**, **6.6**
information on the methods used when preparing the Report		**2.3**, 7, 8, 10
proposals regarding the anticipated methods of analyzing the outcomes of implementation of the provisions of the proposed document and the frequency of the analysis		7,8, 10.4, **11**
information on possible trans-border environmental impact of the programme		**9.5**, 10.3
a non-technical summary		**1**
ANALYSES AND EVALUATIONS		**CHAPTER**
the present condition of the environment and the potential changes to the conditions in the event that the proposed document is not implemented		**4**, **5**, 8.3.2, 10.3
the condition of the environment in the areas where significant impact is anticipated		**4**, **10.3**
existing problems with environmental protections that are important from the point of view of implementation of the proposed document, in particular those pertaining to the areas that are protected under the Act of 16 April 2004 on environmental protection		**4**, 5, 7, 8, **10.3**
the environmental protection objectives set forth on the international, community, and national level that are important from the point of view of the proposed document and the ways that these objectives and other environmental problems have been considered during the preparation of the document		**3**, **6.3**, **6.6**
the anticipated significant impacts, to include direct, indirect, secondary, cumulative, short-term, mid-term, and long-term, permanent and temporary, as well as positive and negative impacts on the objectives and object of protection of Natura 2000 areas and the integrity of such areas, as well as on	biodiversity	4.9, **4.10**, **8.5**, **9.3**, **10.3**
	people	5, 7, 8, **9.1.1**, **9.6**, **10.3**
	animals	4.9, **4.10**, **8.3.2**, 8.3.5, 8.3.7, **8.5**, **9.3**, **10.3**
	plants	4.9, **4.10**, **8.3.2**, 8.3.5, 8.3.7, **8.5**, **9.3**, **10.3**
	water	4.3, 4.4, **7.6**, **8.2.1**, **8.3.2**,

the environment, in particular on:		**8.3.3**, 8.4, **9.1.2**, **9.1.3**, 10.3
	air	4.5, **5**, **7.2**, **8.2.2**, **8.3.2**, **8.3.4**, **9.1.4**, **10**
	Earth surface	4.1, **8.3.6**, **9.1.6**, **10.3**
	landscape	4.1, **4.9**, **8.3.8**, **9.1.7**, **10.3**
	climate	**5**, **8.2.2**, **9.1.5**, **10**
	natural resources	**8.3.1**, **9.1.8**, 10.3
	historical monuments	4.8, **9.1.9**, 10.3
	material goods	4.8, **9.1.10**, 10.3
taking into account the relations between these elements of the environment and between the impacts on these elements		4, 5, 6, 7, 8, 9.1, 9.2, 9.3, 10, 11

THE WAY THAT THE FOLLOWING ELEMENTS WERE CONSIDERED	CHAPTER
solutions intended for prevention, limitation, or environmental compensation of negative environmental impacts that may result from the implementation of the proposed document, in particular the impacts on the objectives and objects of protection of Natura 2000 areas and their integrity	6.3, 6.6, 10, **11**
the objectives and the geographic range of the document and the objectives and the object of protection of Natura 2000 areas and their integrity – solutions that are alternative to those presented in the proposed document, with justification for their selection and a description of the methods of evaluation resulting in the selection, or explanation of the reasons for the lack of alternative solutions, to include information on encountered difficulties resulting from shortcomings of the technology or inadequate knowledge	**4.9**, 4.10, 6.4, 8.5, 10, **10.3**, 11

2.3.2 Methods applied in the Strategic Environmental Assessment

There are two basic methods applied to conduct a strategic environmental assessment[4]:

- **The first method** is based on the procedure of environmental impact assessment that is used for specific projects in the course of an administrative process resulting in the issue of a permit for the performance of the project. It is based on a formal procedure, which is often separate from the procedure of the strategic document itself which is the object of the report, and which separately lists each project whose framework is defined in the proposed document. As a result, environmental impacts of a project are defined as precisely as possible and proven in a scientific manner. The review of alternatives is based mainly on location or technology alternatives within the adopted or evaluated option. The model works well in the case of documents that define the framework of performance of specific projects with a similar form and scope at the evaluation stage.

- **The second method** is based on the British experiences with policy appraisal. The main element of this method is to define the objectives of the document itself and to evaluate their implementation – as opposed to evaluating the direct environmental impact of individual projects. This procedure is much less formal and more condensed than the first model. It focuses more on the relationship between the assessment and the decision-making process that includes the assessment as its integral part. This model works well in appraisal of policies, development strategies, and statutes – documents that do not define the framework for implementation of the different documents but rather the frameworks and directions of development of various processes in the social, economic, legal, and environmental arena.

In principle, the Report applies the first method to analyse the possible environmental impacts resulting from the construction of the first nuclear power plants in Poland as thoroughly as possible, based on the available information regarding both the environmental impact of nuclear plants and their potential locations.

For this purposes, a matrix of environmental impacts that may result from the planned installation of different types of nuclear reactors in Poland was elaborated. The Report also focuses on the analyses of potential locations of nuclear power plants recommended by the Ministry of Economy, as well as their possible environmental impacts. For each of those locations, their anticipated significant environmental impacts were evaluated to the extent that was possible with the information available as of the date of the Report. The following elements were also considered:

- the nature of the impacts (direct, indirect, secondary, and cumulative);
- the duration of the impacts (short-, mid-, and long-term);
- the frequency of the impacts (continuous and momentary).

Also, the likelihood of occurrence of the anticipated significant impact on the environment and on Natura 2000 areas was analyzed. In determining the anticipated impact on Natura 2000 areas, the impact on the object of their protection, their cohesion, and their integrity was taken into account.

However, it must be emphasized that the adopted methodology that focuses mainly on **the negative environmental impacts** may be misleading both for the reader and for authorities that will evaluate the Report. Therefore, the Report also evaluates and presents certain positive environmental impacts of the Programme.

2.3.3 The structure of the Report

The distribution of the contents of this document, in general terms, is based on a typical environmental impact assessment (EIA) prepared in accordance with Art. 51 of the Act of 3 October 2008 on Access to Information on the Environment and its Protection, Public Participation in Environmental Protection and on Environmental Impact Assessments (Journal of Laws No. 199 item 1227). However, the complexity of the task at hand and the diverse nature of the environmental impacts that need to be studied have required some modification of the typical distribution of the contents used in strategic environmental assessment reports. This is mostly due to the fact that the analyzed Nuclear Energy Development Program covers a number of actions aimed to determine the location for the first nuclear power plants in Poland. The actions include not only performance of a specific project by way of building (two) nuclear plants but also a number of formal-legal and organizational actions and performance of associated projects that are necessary to assure the functioning of the nuclear energy sector in Poland (e.g. acquiring the raw materials, development of the power grid, location of a nuclear waste repository, etc.).. A description and an analysis of the different environmental impacts related to the full spectrum of the actions that are to be undertaken have turned out to be difficult and incomprehensible when using the structure of the Report as defined in the EIA Act without any changes. At the same time, the requirements for the Report given by the General Director for Environmental Protection have imposed on the authors a duty to analyze in detail numerous aspects contained in the Programme while maintaining the structure.

The complexity of the problem at hand required individual approach to the study. Thus, an broadened model of description of environmental impacts was developed. It was based on a multi-level analysis of impacts related to the operation of nuclear power plants. Then a conclusion chapter was prepared where the radiological and non-radiological impacts that had been identified were collected and assigned to appropriate statutory elements.

Below you can find a discussion of how the adopted method influenced the structure of the Report.

The first part of the Report describes a study of the relations between the Polish Nuclear Program and other strategic documents (**chapter 3**). Next, in accordance with the strategic environmental assessment procedure, the current condition of the environment is described (**chapter 4**). Because the Program in question concerns, in a way, the whole territory of Poland and the final locations of the individual projects have not been identified, the chapter refers to the condition of the environment in Poland, with the level of detail appropriate for further analyzes conducted in the Report. Then, in accordance with the strategic environmental assessment procedure, the zero-option, i.e. the consequences of withdrawal from implementation of the program, was analyzed (**chapter 5**).

In the next part of the Report, in accordance with the method selected, the reader is familiarized in detail with the technical aspects of the nuclear energy sector, to include the issue of nuclear safety and possible breakdowns (**chapter 6**). This approach facilitates understanding of the complex analyses presented in the following chapters.

The next chapters consider in detail the individual environmental impacts of nuclear power plants. First, an analysis and evaluation of the impact of radioactive emissions from nuclear power plants were performed. Because the impact is unique to nuclear power plants and raises the greatest controversies in the public, a separate chapter was devoted to it (**chapter 7**). All the data in this chapter is numerical and accurate and presented as objective values, without interpretation concerning the consequences of the different consumption and emission values in the form of environmental impact.

Chapter 8 discusses all the remaining impacts related to the operation of nuclear plants. A separate subchapter (8.5) discusses, in accordance with the recommendation of the General Director for Environmental Protection, the impact on biotic elements of the environment, to include Natura 2000 areas.

In order to meet the statutory requirements of environmental impact assessments, **chapter 9** identifies and characterizes the impacts (described in detail in the preceding chapters)with respect to their effects to the different elements of the environment. The results of such analyzes were presented in tables, for the sake of transparency. Sub-chapter 9.1 presents all the impacts identified in **chapters 7 and 8**, divided into impacts on the different elements of the environment (biodiversity, people, animals, plants, water, air, Earth’s surface, landscape, climate, natural resources, historical monuments, and material goods). Sub-chapter (9.2) presents the characteristics of such impacts with regard to their scale, nature, duration, continuity, and likelihood of occurrence. Sub-chapter (9.3), on the other hand, presents a total balance of impacts, both positive and negative.

In the successive sub-chapter (9.4), the reader is made familiar with the possibility of cumulative impacts, while sub-chapter (9.5) presents, in accordance with the statutory requirement, an analysis of the possibility of transborder impacts. The last sub-chapter (9.5) comprises an analysis of the likelihood of public conflicts.

Chapter 10 presents analyses of possible alternative scenarios. Because of the unique assessment of the strategic document, in addition to the analyses of possible technical and location scenarios, an additional analysis was performed of the possible scenarios of the strategy to acquire energy for Poland and to assure the country’s energy safety. The analysis of the location scenarios focused most of all on the six most likely locations, as the impact matrixes prepared in the previous chapters were superimposed on them. Also, less detailed references to the remaining locations were made (the expert opinion on the location, prepared by Energoprojekt Warszawa S.A. defines them as not suitable as a site of a nuclear power plant.

The document ends with a concluding chapter which presents the conclusions and recommendations, as well as the anticipated methods of analysis of the consequences of the program's implementation (**chapter 11**).

2.3.4 Description of the assumptions made and the methods of the individual analyses

The reference objects method

The reference objects method was selected to determine the anticipated significant impacts related to the performance of the Polish Nuclear Program. The method consists in applying the impacts of a specific implemented project to the location of the proposed investment. For this purpose, the monitoring data and the relevant EIA reports are used for this purpose.

No data on the implemented nuclear power projects including Generation III EPR, AP1000 and ESBWR reactors that will be potentially used in Poland was available during the preparation of this Report. The author of the Report has, however, obtained access to safety analyses of such nuclear power plants, which define the radiation impact of the plant on the environment and on people during regular operation and during emergencies.

Also, monitoring data for Generation II nuclear power plants that has been built in other countries was used. Because Generation III nuclear power plants will have all the good characteristics of the operating Generation II plants, the monitoring data from the existing plants can be used to determine the likely impacts of Generation III plants.

Thus, to determine the consequences of the implementation of the Programme, a mixed method was used, which consisted in extrapolating the monitoring data for Generation II plants to Generation III plants and in using the data from the safety analyses. Based on this, a model of Generation III nuclear power plant's impact on the environment was elaborated; this model will be applied to the proposed locations.

Analysis and evaluation of the impact of emissions from nuclear power plants

A separate chapter (**chapter 7**) is dedicated to the matter of radiological impact, which is the single impact causing the greatest concern.

The information presented in that chapter is based on the data that has been published and verified by nuclear regulatory offices. In reference to Generation II reactors – i.e. reactors being in operation currently – historical data, concerning both regular operation and emergencies, was used. The data covers a total of over 12,000 years of operation of the reactors, i.e. it is based on very extensive statistics, collected over a period of 50 years. Because, over the course of all these years, no radiological emergency has taken place in civilian power generation reactors (Generation II and III), which led to the loss of life or health of any staff member or anyone in the local population, the historical data does not allow for presenting any statistics regarding the loss of human lives per year of reactor operation - there has been no such loss at all. Nevertheless, both for existing reactors and for Generation III reactors being built there are probability assessments that can be used to determine the conditions for safe operation of nuclear power plants to be built in the future.

The probability data and the results of the safety analyses for the three types of reactors recommended for Poland, i.e. the EPR reactor by AREVA, the AP1000 reactor by Westinghouse Toshiba, and the ESBWR reactor by General Electric-Hitachi, has been used to determine the characteristics of the impact of these reactors on the ecosystems during regular operation and in emergencies. Because no tender has been announced in Poland and the documentation for these reactors has not been submitted, the information on their parameters and behaviour has been taken from the extensive – albeit not complete – documentation presented for evaluation to the nuclear regulatory offices in the United Kingdom and the United States. The data in the documentation is true, because it is checked by the nuclear regulatory offices of two very competent countries; however, it is not complete in the sense that the reactor suppliers can still be requested to answer any and all the questions that the Polish party will definitely have in the process of licensing of one of these reactors in Poland. Consequently, the analyses are not based on a complete sate of data, for example while full data concerning emissions in emergencies is not available, the doses that may be received by the local population are stipulated. Because the doses are of key importance to Poland's population, as they determine the health consequences of any failures or make reactor failures harmless, the document provides more extensive information about the doses and the emission data is limited to that which has been taken from available literature.

Also, preliminary evaluations of the atmospheric dispersion in Poland have been prepared using the method adopted by the American nuclear regulatory office, NRC; they were compared with the values presented by the reactor suppliers. This has made it possible to find a common denominator in the assessment of the various reactor manufacturers and to determine whether construction of a nuclear power plant in Poland will involve a radiation exposure outside of a very limited zone with radius estimated to be approx. 800 m from the reactor.

Chapter 7 also includes information on possible decommissioning of the nuclear power plant, defines the costs of such an operation and the potential radiation doses.

At the end of the chapter there is information of the impact on health of small radiation doses and on whether radiation from nuclear power plants may cause damage in ecosystems and people involved in the operation of nuclear power plants.

The remaining impacts are analyzed in chapter 8. As far as cooling water is concerned, the demand for water has been analyzed on the basis of information on the quantity of heat to be transferred in water (based on the heat balance of the different types of power units) and the irreversible losses. The data was compared with hydrological data in order to perform a preliminary assessment of sufficiency of the cooling water supply, for all the possible (and reasonable) types of cooling systems and locations.

The analysis of the consequences of discharge of heat into the water and the air and of chemical substances into the water was performed on the BAT document issued by the European Commission[5] and on relevant environmental impact reports for the UK EPR and UK AP1000 reactors. The analysis of non-radiological emissions was performed based on the UK EPR report. The demand for raw water has been estimated based on the environmental assessment report for the UK EPR report by comparing it with the demand for nuclear power plant formerly planned to be built in Żarnowiec. The emission of substances was calculated per 1,000 MWE generated by a nuclear power plant unit with a pressurized water reactor.

Analysis of impacts on Natura 2000 areas

Due to the lack of accurate data on the fauna and flora for the specific locations, the fullest possible assessment of the natural assets was performed based on the available scientific data. The basis was an analysis of various forms of environmental protection present in the vicinity of the identified sites. Most of all, data contained in the standard forms for the specific Natura 2000 (habitats and bird-protection areas) and characteristics of natural preserves was used.

In the part concerning the plant cover, data from the document titled "Plant reserves in Poland" was used, together with other available basic data concerning the distribution of plant species and plant communities in Poland.

The characteristics of the plants were determined based on the description of the site contained in the previous expert opinion, the map of potential natural vegetation of Poland, the listed documents concerning protected areas and plant reserves, and the "Habitat and specie protection manuals - methods", vol. 1-5. Based on the data, a list of protected natural habitats present in the vicinity of the individual sites was prepared.

The presence of rare species of vascular plants in the vicinity of the recommended locations has been determined on the basis of the Atlas of Distribution of Vascular Plants in Poland. The Atlas shows the presence of all the species in the form of frequency values in the atlas fields sized 10 x 10 km. Consequently, when evaluating the locations, we initially determined in which atlas fields the individual sites are located. Then, we checked whether and what species are present in the direct vicinity. Two species from Appendix 2 to the Natura 2000 Habitat Directive, species protected by a national Regulation, and species enumerated in the Red List Index of extinct and endangered species were selected for the analysis. Also, data contained in the following specialized literature was used: the Polish Red Book of Plants, the Habitat and Species Protection Handbook – the Methods Handbook, vo. 9 Plant species, and information published in other scientific literature. Based on the above-mentioned sources, it was possible to fairly accurately determine the rare and protected flora species in the different locations and their vicinity.

The data pertaining to the plant cover was presented in the form of a synthetic analysis for all the locations collectively, and a detailed analysis for each individual location.

The landscape conditions in the individual locations were also evaluated based on their location in relation to the existing Landscape Parks and Protected Landscape Areas.

Location analysis

In order to perform the location analysis and the cartographic visualization, the GIS techniques and the Geoxa Editor 2.0 software were used. Selection of the GIS software instead of a standard graphic application has made it possible to precisely present the source data as well as to use the existing data bases (to include those accessible through WMS servers) and the quantitative analyses of selected occurrences. This was possible thanks to the increase of the final essential value of the study with timely completion of the Report.

A number of maps in the 1:100,000 scale were prepared for the 28 potential locations of nuclear power plants included in the Report; the maps show the areas within a 10 km radius of the nuclear plant sites and the environmental protection measures present there. For this purpose, topographic data coming from generally accessible WMS servers and vector data concerning the range of environmental protection measures from the EEA and the General Directorate of Environmental Protection were used. The precise data concerning the location of the individual sites was taken from the document titled "Expert opinion concerning the siting criteria for nuclear power plants and the evaluation of the agreed locations." Also, in order to forecast potential transboundary impacts the distances between the sites and Poland's national borders were calculated.

The GIS techniques were also used to prepare maps in the 1:4,000,000 scale, showing the location of the recommended sites in the territory of Poland; this was done both for the purpose of their general presentation and for the purpose of comparison with the location of environmental protection measures and the location of areas affected by seismic events (point data from the IRIS database was used). The topography backgrounds for the aforementioned maps were prepared based on the generally accessible WMAP Level 0 database.

Analysis of the Programme's relations with other documents

The examination of the relations between the Polish Nuclear Programme and other strategic documents was performed based on an analysis of community, national, and local documents (on the province level); for this purpose, regions with the highest likelihood of location of nuclear power plants were selected (the Mazowieckie, Wielkopolskie, Pomorskie, and Zachodniopomorskie provinces). This was supplemented by the required analysis of documents constituting the basic legislative achievements of the global nuclear energy sector, for example the International Atomic Energy Agency (IAEA), US federal regulations, or the Convention on Nuclear Safety. The first step of the analysis was to become familiar with the contents of the documents. Then, the main provisions concerning the problems of the nuclear energy sector and the environmental protection were identified, especially in areas where these problems overlap. To achieve the objective of defining the relations between these documents and the document in question, also the background of the proposed transformations in the energy sector in Poland, to include provisions concerning the development of renewable energy sources technologies, were analyzed. The work was concluded by preparing an evaluation of the provisions of the analyzed documents and the Programme with regards to the environmental protection aspects.

Analysis of potential social conflicts

The analysis of potential social conflicts focused on the history of such conflicts in other countries and in Poland – in the past during construction of the Żarnowiec nuclear power plant and currently in connection with information on resumption of the works aimed to build a nuclear power plant. The program, objectives, and actions of the best known organizations and persons who opposed the development of the nuclear energy sector were studied. The arguments against construction of a nuclear power plant were collected and compared with the opinions of professionals involved in promoting this source of energy. The key problems related to construction of nuclear power plants were identified.

The analysis was based on the source materials that have been collected, which included books, official documents, programmes and petitions published on the Internet, contents of official web sites of environmental organizations, and articles published in the press. The broad spectrum of materials was needed to present the point of view of the parties in potential social conflicts. The analysis also used the results of completed studies, among others the data collected in the course of the social studies performed by Public Opinion Research Centre (Centrum Badania Opinii Społecznej – CBOS) in the period of 26 August – 2 September 2009 which involved a national representative sample PESEL (15+) of 1,181 persons, or conclusions from the Subject Study OT-575 of October 2009 titled “Attitudes of local communities in European countries to location of nuclear plant in their neighbourhoods” conducted by the Office of Analyses and Subject Studies of the Senate Chancellery.

Economic aspects

The Report does not include any economic analyses prepared by its authors – it was not the basic purpose of the Report. However, economic analyses presented in the existing publications were quoted and used in the Report to discuss certain aspects relating to environmental changes both for the no-action alternative and for all other alternatives. Due to the high extent of interdisciplinarity of the matters discussed in the Report, the anticipated economic effects, inherently connected with the impact on people and on the natural environment (in particular with regard to use of natural resources) are a valuable indicator that makes it possible to perform a measurable assessment of the impacts in question and to compare the scenarios being considered. However, the authors were not able to verify the economic calculations quoted in the Report. All the sources of information presented in the Report were analysed for their reliability, based on the quality of the publications (references to source data and detailed description of the methodologies applied) and the composition of the team of authors (consisting of experts in the field).

2.3.5 The difficulties encountered due to the technology shortcomings or insufficient scientific knowledge

What makes nuclear power plants different from other power plants is the fission reactions generating heat and constituting a potential hazard of radiation by the fission products. The analysis of the environmental impact of nuclear power plants consists in evaluating this hazard and assessing all the technical measures and natural phenomena that are used to limit the exposure of people and the whole ecosystem to radiation. The general safety principles as well as the structures, equipment, and elements used in nuclear power plants to eliminate or at least reduce this hazard are known.

Nuclear power plants are very complex and expensive facilities. Reactor suppliers focus on presenting the aspects of their products that emphasize the strengths of the adopted solution and avoid presenting any information that could limit their chances to win the contract. The reactor suppliers must provide full information on all the solutions adopted only at the stage of safety analyses conducted by the nuclear regulatory authorities. At the stage of preliminary analyses of the nuclear energy program the reactor suppliers are not required to answer questions asked by independent experts who may not even have any connections to the future investors (as the persons hired to prepare this Report). Thus, some information concerning the reactors that may be selected was hard to access.

This was an important difficulty in the process of evaluating the offered reactors. Nevertheless, the problem was overcome thanks to the fact that one of the experts involved in the project is an expert of the International Atomic Energy Agency who participated in the detailed safety analysis of the EPR, AP1000, and ESBWR reactors performed by the IAEA upon request of the nuclear regulatory authorities of the United Kingdom. The reactor suppliers who applied for licenses of the British nuclear regulatory authorities were required to submit to them – and, consequently, to the IAEA – a complete set of documents and to answer the questions they were asked. The persons who participated in these analyses had access to extensive documentation for these three types of reactors. Further information on the licensing process for the EPR and AP1000 reactors in the United Kingdom and the USA was received in an ongoing manner from the nuclear regulatory authorities of these two countries. Altogether, the information made it possible to conduct a thorough evaluation of the radiological effects of normal operation, incidents, and breakdowns in EPR reactors as well as in AP1000 and ESBWR reactors. Some data was not available, but the key results, i.e. the information on the radiation doses related to all the phases of operation of the aforementioned reactors, were available and used in the project.

Another difficulty was the sheer volume of the material to be studies in the relatively short time. Moreover, coordination of the work of many persons, who are experts in different fields and are located in various parts of Poland, and reaching common conclusions on difficult and sometimes controversial issues, was quite difficult. Also, it was not possible to clarify all the questions that the team working on the Report had concerning the documentation submitted by the reactor manufacturers. This has led to differences in the level of detail of the different analyses – they are more detailed for the EPR reactor, in which case the team of experts had three sets of safety documentation which were prepared for the UK and the USA, and less detailed for the other two reactors.

An important factor affecting the evaluation of the impact of potential failures on the hazard to people is the weather conditions, which determine the atmospheric dispersion factor and, consequently, the concentration of radioactive substances at the boundary of the exclusion zone. The studies of atmospheric dispersion of radioactive substances are usually performed for selected sites for periods of many months so as to obtain full information on the weather conditions that may occur during an accident. No such studies have been conducted in Poland and, considering the short time, it was impossible to obtain data for typical sites inland, in coastal areas, in the vicinity of lakes, hills, etc. Therefore, uniform weather conditions (plus a safety margin) were provisionally assumed for a typical location in Central Europe. These conditions are not representative of all the sites and this shortcomings will need to be compensated at the next stage of works. One must keep in mind that this is a very serious and time-consuming task.

Another significant problem was the fact that the Atomic Energy Act and the Resolutions of the Council of Ministers on nuclear energy have not been finally approved. If more time was available, we could have determined the items that required a decision by the nuclear regulatory authorities, submitted those items to them, and most likely obtained valid answers. However, given the short time we had to complete our work, such additional consultations were impossible. Consequently, the proposed regulations were assumed as the applicable guidance and were used to evaluate the impact of the future Polish nuclear power plant on the ecosystem and human health.

Other important issues were presented in the table below.

Table.2.3.2 Description of encountered problems and their solutions

PROBLEM	SOLUTION
• A very extensive scope of issues to include in the Report	• A team of 14 recognised experts in various fields of study (connected with scientific circles) was appointed. • Analyses conducted as part of other studies and expert reports were used. • The reference objects method was used.
• Lack of hydrological data necessary to evaluate the sufficiency of cooling water resources for some locations (Bełchatów, Pątnów, Krzywiec, Lisowo, and Wiechowo). • Lack of detailed alternative location analyses (for all locations). • The dimensions and location of the nuclear power plant lot and the positions of the main facilities with reactors of different types (preliminary general layout). • Solutions adopted for the cooling system, with the concept of cooling and raw water supply. • Lack of sufficiently detailed information concerning experience with operation of large hybrid wet-dry tooling towers.	• The available data from various sources (to include the Internet) were used, as well as hydrographical data, brochures, and reports of suppliers of nuclear plant technology. • The authors used the knowledge of experts and publications on the cooling systems as well as water and effluent management systems in nuclear power plants.
• No data on the implemented nuclear power projects including Generation III EPR, AP1000 and ESBWR reactors that will be potentially used in Poland was available during the preparation of this Report.	• Information and knowledge offered by the IAEA expert was used – based on the analysis of reactors similar to those proposed for Poland. The author of the Report has gained access to safety analyses of Generation III nuclear power plants, which define the radiation impact of the plant on the environment and on people during regular operation and during emergencies. Monitoring data for Generation II nuclear power plants that has been built in other countries was used and by using the mixed method consisting in extrapolation of the monitoring data from Generation II plants to

PROBLEM	SOLUTION
	Generation III plants and the data from safety analyses, a model of environmental impact of Generation III plants was prepared.
• An important factor affecting the evaluation of the impact of potential failures on the hazard to people is the weather conditions, which determine the atmospheric dispersion factor and, consequently, the concentration of radioactive substances at the boundary of the exclusion zone. The studies of atmospheric dispersion of radioactive substances are usually performed for selected sites for periods of many months so as to obtain full information on the weather conditions that may occur during an accident. No such studies have been conducted in Poland and, considering the short time, it was impossible to obtain data for typical sites inland, in coastal areas, in the vicinity of lakes, hills, etc.	• Uniform weather conditions (plus a safety margin) were provisionally assumed for a typical location in Central Europe. These conditions are not representative of all the sites and this shortcomings will need to be compensated at the next stage of works. One must keep in mind that this is a very serious and time-consuming task.
• No binding acts of law. The Atomic Energy Act and Resolutions of the Council of Ministers on nuclear energy have not been finally approved.	• The proposed regulations were assumed as the applicable guidance and were used to evaluate the impact of the future Polish nuclear power plant on the ecosystem and on human health.
• The authors had no uniform fauna and flora data for the specific locations that would make it possible to compare and evaluate them directly and reliably.	• The evaluation of natural resources is as complete as possible, based on a very detailed analysis of the available data presented in the relevant publications. Moreover, data from inventories performed as a part of other studies for similar locations was used.
• Authors were not able to verify economic calculations quoted in the Report.	• All sources of information presented in the Report were thoroughly analysed for their reliability, based on the quality of publications (references to source data and detailed description of methodologies applied) and the composition of the team of authors (consisting of experts in the field).

No data on the implemented nuclear power projects including Generation III EPR, AP1000 and ESBWR reactors that will be potentially used in Poland was available during the preparation of this Report. The author of the Report has, however, obtained access to safety analyses of such nuclear power plants, which define the radiation impact of the plant on the environment and on people during regular operation and during emergencies.

Also, monitoring data for Generation II nuclear power plants that has been built in other countries was used. Because Generation III nuclear power plants will have all the good characteristics of the operating Generation II plants, the monitoring data from the existing plants can be used to determine the likely impacts of Generation III plants.

2.4 The team who prepared the Report

Prof. dr inż. Andrzej Strupczewski – Vice-President of the Environmentalists for Nuclear Energy (Stowarzyszenie Ekologów na Rzecz Energii Nuklearnej) association, president of the Nuclear Safety Committee in the POLATOM Atomic Energy Institute, expert in nuclear safety of the European Commission and the International Atomic Energy Agency, and expert of Austria's Ministry of Environment for nuclear reactor safety.

For 50 years worked in the Atomic Energy Institute, to include 6 years in the IAEA in Vienna. He designed the MARIA research reactor and managed its process start-up, conducted the pioneer heat transfer tests in the core of the EWA reactor. As a deputy head of the Atomic Energy Institute, until 1992 he managed an international research programme on reactor safety and, for a period of 20 years after the construction of the Żarnowiec nuclear power plant was cancelled, he conducted continuous safety analyses of nuclear power reactors in various countries.

He studied the safety of nuclear power plants in Armenia, Bulgaria, and Slovakia, lead IAEA missions charged with assessing the safety of the Paks nuclear power plant in Hungary and the Dukovany and Temelin plants in Czech Republic, and performed analyses for the Temelin and Mochovice nuclear power plants in Czech Republic for the government of Austria. Also, he conducted an assessment of the impact on European Union's assistance on the safety of nuclear power plants in Russia and Ukraine and, lately, an assessment of the latest Generation III nuclear reactors offered to be built in the United Kingdom. His competences and impartiality are confirmed by the fact that he continues to conduct analyses for both the IAEA and the government of Austria which is against nuclear power plants. Currently, Professor Strupczewski is involved in the siting project for the largest contracted nuclear power plant in the United Arab Emirates.

He is the author of 4 books and 250 papers on nuclear power plants and the holder of 6 patents. He was the member of the Committee for Power Generation Problems and the Committee of Radiation Sciences of the Polish Academy of Sciences and Poland's representative in the Nuclear Energy Committee of the UNIPEDE and in the ISO Nuclear Energy Committee. Professor Strupczewski has been awarded the Knight's Cross of the Polonia Restituta order for his merits.

Prof. dr hab. Andrzej Solecki – a geologist, graduate of the University of Wrocław. In 2009 he completed the "Short Course in Economic Geology: Metallogeny and Exploration of Uranium Deposits" organized by the TU Bergakademie Freiberg. In the years 1999-2000 he completed the course titled "European Standards of Environmental Impact Assessment of Mineral Projects" and the course titled "European Standards for the Evaluation of Raw Materials Projects and Investments," both organized by the Centre for Continuing Education, Imperial College London.

Since 2004, he has been the head of the Institute of Mineral Materials Department of the Institute of Geological Sciences of the University of Wrocław. In the years 2009-2010 he was the head of a team of experts hired by Atkins-Polska Sp. z o.o. to conduct a study of uranium deposits in Poland for the Ministry of Environment. Since 2007, he was a member of the Fossil Resources Committee (Ministry of Environment) and a member of the Committee for Sustainable Management of Mineral Resources (Polish Academy of Sciences, Kraków). In the years 1996-1997, he was an expert of the consortium of Consulting&Engineering, Uranerz, and Iwaco companies which prepared a database on the Central European uranium mining. In 1996, he represented Poland in the IAEA project titled "Technologies for cleanup and remediation of radioactively contaminated sites." In 1995, he represented Poland in the IAEA project titled "Environmental Restoration in Central and Eastern Europe (uranium mines)."

He is the author of several dozens of publications, to include monographs on radiometric anomalies in the central part of the Sudeten Foreland, a popular book on radioactivity of the geological environment, and one of the co-authors of the IAEA technical document concerning reclamation of radioactive contaminated land. He is the author or co-author of numerous geological documents and expert opinions concerning management of mineral resources performed for domestic and foreign companies, to include Longview Capital Partners, Puma Resources Limited, Micon International Ltd, and Knauf Engineering.

Dr Wojciech Drzewicki – educated in the field of geology (search for and exploitation of fossil deposits, geochemistry) and environmental protection (geoecology and protection of fossil deposits). He completed graduate studies in law in environmental protection at the University of Wrocław. He is an assistant professor at the Applied Geology and Geochemistry Department of the Institute of Geological Sciences of the University of Wrocław. In 2008 he received a scholarship from the Wrocław's local government, as a part of the project titled "GRANT – support of doctoral students' research," financed by the European Social Fund. Distinguished expert in the field of impact of investment projects on water and soil environments.

Dr Dominika Lewicka-Szczebak – educated in the field of environmental protection (licentiate degree in environmental protection at the University of Wrocław) and geology (master's degree in geology at the University of Wrocław, specialty: geochemistry of environmental and waste management). Holder of a Doctorate in Earth Science, specialized in geology. Currently, she is an assistant professor at the Applied Geology and Geochemistry Department of the Institute of Geological Sciences of the University of Wrocław. Winner of the Scholarship of the Minister of National Education (2005), the award for the best geology graduate in 2006, Scholarship of the Local Government of Wrocław (2008) as a part of the project titled "GRANT – support of doctoral students' research," financed by the European Social Fund. In her scientific work, she focuses on the use of stable isotope analyses in environmental research. She is the co-author of scientific publications in global periodicals, to include six articles published in periodicals included in the so-called "Philadelphia list" (*Applied Geochemistry, Environmental Chemistry Letters, Isotopes in Health and Environmental Studies, Atmospheric Environment, Environmental Pollution, Polish Journal of Environmental Studies*). She is also the co-author of reports from environmental analyses performed as a part of industry-science cooperation (2005, 2008, 2009) and Environmental Impact Reports for Investment Projects (2009, 2010).

Dr Marek Kasprzak – graduate of the Institute of Geography and Regional Development (IGRD) of the Wrocław University, specialized in physical geography. In September 2009, he completed his doctoral studies in the Geomorphology Department of the IGRD. His doctoral thesis pertained to the geomorphologic effects of floods. He actively participated in many scientific conferences, to include the most important European symposia in the field of Earth Sciences – the European Geosciences Union in Vienna (2006 and 2007).. He completed numerous training courses in the field of environmental hazards, to include the *FORM-OSE Post-Graduate Training School on Multi-Risks: Concepts to approach multiple hazards and risk*s organized by the Rheinische-Friedrich-Wilhelms-Universität in Bonn, Germany (2006); the *Environmental Analysis and Geomorphologic Mapping for a Sustainable Development* in Ethiopia (2008) and the 1st Mid-European Summer School on Geomorphology: "Complex Response of Earth Surface Processes to Environmental Change" in Heimbuchenthal, Germany (2010). He is the author of several articles which have been reviewed and published in academic periodicals and monographs as well as dozens of other publications focusing mostly on geomorphology, geology, hydrology, and environmental hazards. Besides academic and didactic work at the University of Wrocław, he gained experience working for one and a half years as an assistant in a company that prepares environmental impact reports and assessments for projects, ecophysiography, environmental reviews, and other documents pertaining to environmental protection and management. He continues this track in his career by cooperating, for over a year, with the Fundeko company.

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Dr nauk prawnych Anna Haładyj (Ph.D. at law) – an adjunct at the Chair of Environmental Management Law, Faculty of Law, Canon Law, and Administration of the John Paul II Catholic University of Lublin. Her areas of scientific interest include the participation of the public in environmental protection and assessments of impact on the environment and on Natura 2000 areas.

Mgr inż. Władysław Kiełbasa – an expert in nuclear energy, graduate of the Faculty of Mechanics, Power Generation and Airspace Engineering of the Warsaw University of Technology, specialized in power generation systems and equipment (completed his studies under an individual programme focusing on nuclear power plants).

He has worked for 31 years in the power generation sector; for 15 years he has been involved in the Żarnowiec nuclear power plant project (from the project preparation, through construction and preparation for operation, until liquidation of the construction site).

His positions included manager of the Nuclear Safety Department and later the acting head engineer in charge of preparation for the operation and nuclear safety in the operation preparation department at the Żarnowiec nuclear power plant. In particular, he was responsible for the licensing process of the Żarnowiec nuclear power plant with respect to nuclear safety and for preparation for the operation with respect to supervision of the operation of the reactors and of the nuclear fuel management system. He also coordinated the cooperation with the five foreign expert missions evaluating various aspects of the Żarnowiec project (technical, safety, and economic aspects): 3 IAEA missions (Pre-OSART – Pre-Operational Safety Analysis and Review Team, Żarnowiec Site Safety Review Mission, Safety Review of the Containment of the Żarnowiec Nuclear Power Plant), as well as missions of Belgatom/Tractebel and Siemens.

He was also a member of the Nuclear Generation Study Committee (10.NUCLE) UNIPEDE and the International Research Team for VVER Reactor Physics.

He also won a scholarship from the International Atomic Energy Agency (IAEA). He has competed relevant training and obtained a license for the operating engineer on duty of a thermal power station (ZEC "Wybrzeże") and then the operating engineer on duty of a nuclear power plant (Education and Training Centre for the Nuclear Power Sector and the Nuclear Power Plant in Novovoronezh, Russia). Moreover, he has completed a course in radiological protection and failure-prevention measures in Argonne National Laboratory (University of Chicago, USA), as well as a training course in nuclear safety and reactor physics at the Bohunice nuclear power plant in Slovakia). He has taught post-graduate courses in nuclear power generation co-organized by the IAEA and courses at the Gdańsk University of Technology, as well as courses during the 2nd and 3rd Nuclear Power Generation School (Warsaw, Gdańsk).

For the last 15 years he has been professionally involved in the hydroelectric sector and for 4 years he was the head consultant at Energoprojekt-Consulting S.A. Since 2005 he has been the author or co-author (in most cases with doc. dr inż. Andrzej Strupczewski) of a number of significant publications supporting the introduction of the Polish nuclear programme (including those ordered by the Ministry of Economy, the PSE S.A., and the PGE S.A.), to include those concerning siting studies and analyses.

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Mgr inż. Andrzej Zając - graduate of the Wrocław University of Technology, Faculty of Mechanical and Power Engineering, Institute of Thermal Technology and Liquid Mechanics, specializing in boilers and turbines. He has many years of experience with operation and optimization of systems for co-firing of biomass at the EDF Polska group.

Mgr inż. Tomasz Chrapek – graduate of the Faculty of Geology, Geophysics, and Environmental Protection at the AGH University of Science and Technology in Krakow, specializing in environmental protection, hydrogeology, and engineering geology. Winner of the competition for best graduates of Polish universities in the field of environmental protection, organized by the Maciej Nowicki Foundation. Many years of professional experience in financing of environmental protection projects. He is an expert of the Infrastructure and Environment Operational Programme (1st and 2nd priority axis) and the Regional Operating Programme of the Silesia Province (protection of the Earth surface and waste management). Author of energy certificates and environmental impact reports for investment projects. He specializes in issues related to waste management.

Wojciech Błędowski – an ornithologist with over ten years of experience. He has worked for three years in the ornithologist team led by Professor Tomasz Wesołowski in the Białowieski National Park. He cooperates with the Ornithology Station of the Museum and Institute of Zoology of the Polish

Academy of Sciences. He holds a bird ringing license for all bird species. His professional focus is environmental monitoring and environmental impact assessments.

Mgr Danuta Mruk – graduate of the Department of Natural Sciences and Environmental Management, Geography major (specialty: physical geography) and the Philology Department, Journalism and Public Communication major (specialty: public relations) of the University of Wrocław. In 2010 she defended a master’s thesis titled “Phytoremediation and washout of heavy metals from the soil under the influence of an electric field.” She participated in the work on the *Strategic Environmental Assessment Report for the Polish Nuclear Programme* – she edited and verified Analysis no. 2 and verified the questions and answers given in the public consultations.

3 ANALYSIS AND EVALUATION OF THE IMPACT OF RADIOACTIVE EMISSIONS FROM NUCLEAR POWER PLANTS

AUTHORS: *Andrzej Strupczewski, Władysław Kiełbasa*

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3.1.1.1 Emissions from PWR and Generation II BWR reactors - current experiences

According to the principles adopted by the US Atomic Energy Commission in the middle of the 20th century, which was the very beginning of the development of the nuclear energy sector, a person may not be exposed to significant additional hazards as a result of operation of a nuclear power plant, and the risk to the public resulting from the operation of a nuclear power plant must be comparable with the risk resulting from other methods of power generation and may not significantly increase of the total risk to the public. To achieve this objective, it was agreed that the doses around a nuclear power plant must be limited so that the average risk of cancer in the population living within the radius of 16 km caused by the doses does not exceed 0.1% of all the cancer cases due to all other causes.[6.] At that time, 2 out of one thousand persons in the USA died out of cancer, so the permissible hazard ratio caused by nuclear power plants for the critical population group[7] was on average equal to 2 x 10^{-6} per person per year. Since then, the emissions of fission products from nuclear reactors into nuclear power plant surroundings have continuously decreased. Fig. 7.1.1 shows the reduction in the emissions of inert gases and Fig. 7.1.2 shows the reduction in the emissions of iodine and radioactive dusts into the atmosphere from nuclear power plants with PWR reactors (data from the UNSCEAR report[8]).

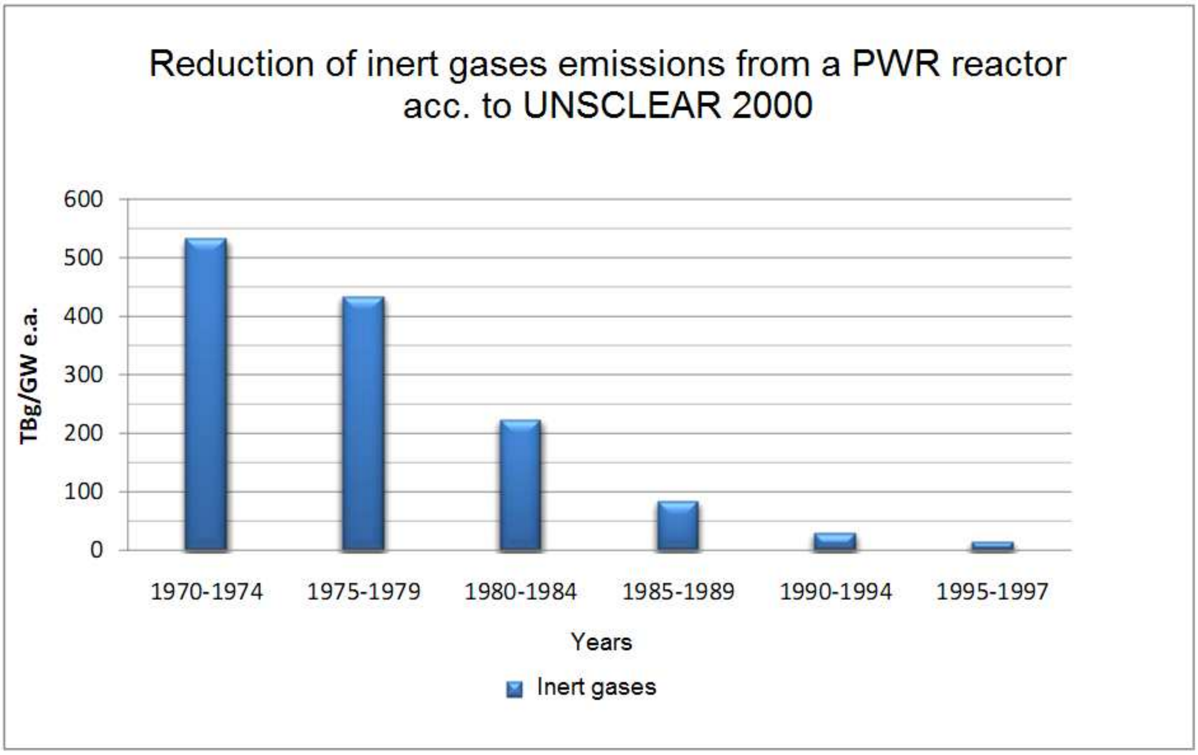

Fig. 3.11. **Reduction of inert gas emissions from PWR reactors; numerical data from the UNSCEAR report[8]**

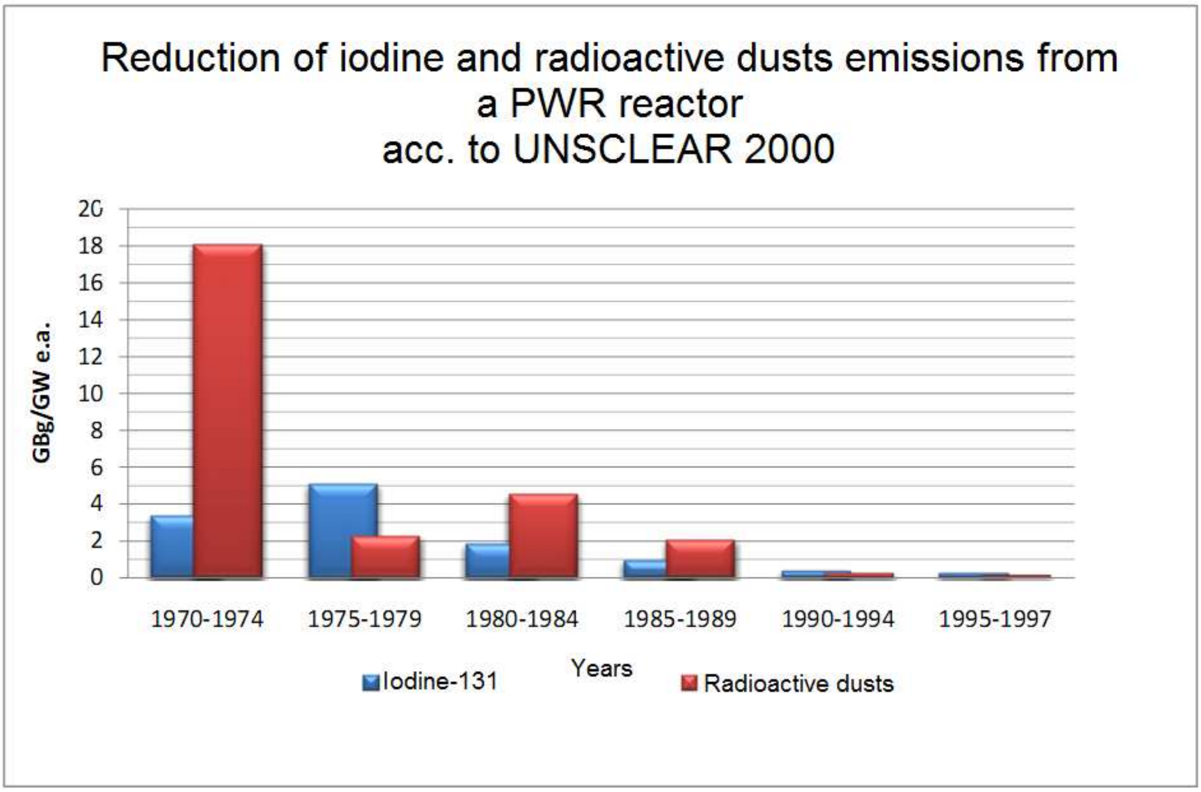

Fig. 3.1.2. Reduction of iodine and radioactive dust emissions from PWR reactors; numerical data from the UNSCEAR report[8]

It should be mentioned that not all fission products are equally hazardous. The most hazardous are radioactive dusts (which contain such elements as caesium or strontium), which get into the human body and (due to the long decay period) remain there for a long time. Iodine is less hazardous; even though it accumulates in the thyroid, it decays fairly quickly (the half-life of the J-131 isotope is 8 days and that of other isotopes – even shorter). Examinations of many persons who were irradiated with iodine for diagnostic or treatment purposes did not demonstrate any increase in cancer incidence[9]. Nevertheless, iodine, as a fairly air-borne element, is a typical hazard which is countered in an effort to lower the doses emitted at nuclear power plants.

The least hazardous are releases of inert gases, which do emit gamma and beta radiation but are released into the environment and do not accumulated in the human body. Figure 7.1.3 (data from the NEA report[10]) shows a comparison of the risk of cancer caused by releases of the same amount of radioactivity (measured as the number of radioactive decay instances per second, i.e. Bq) in inert gases (krypton Kr, xenon Xe), iodine (J), and caesium (Cs). The risk associated to caesium is the highest, because its half-life is 30 years and it remains in the environment long after iodine and inert gases are completely eliminated.

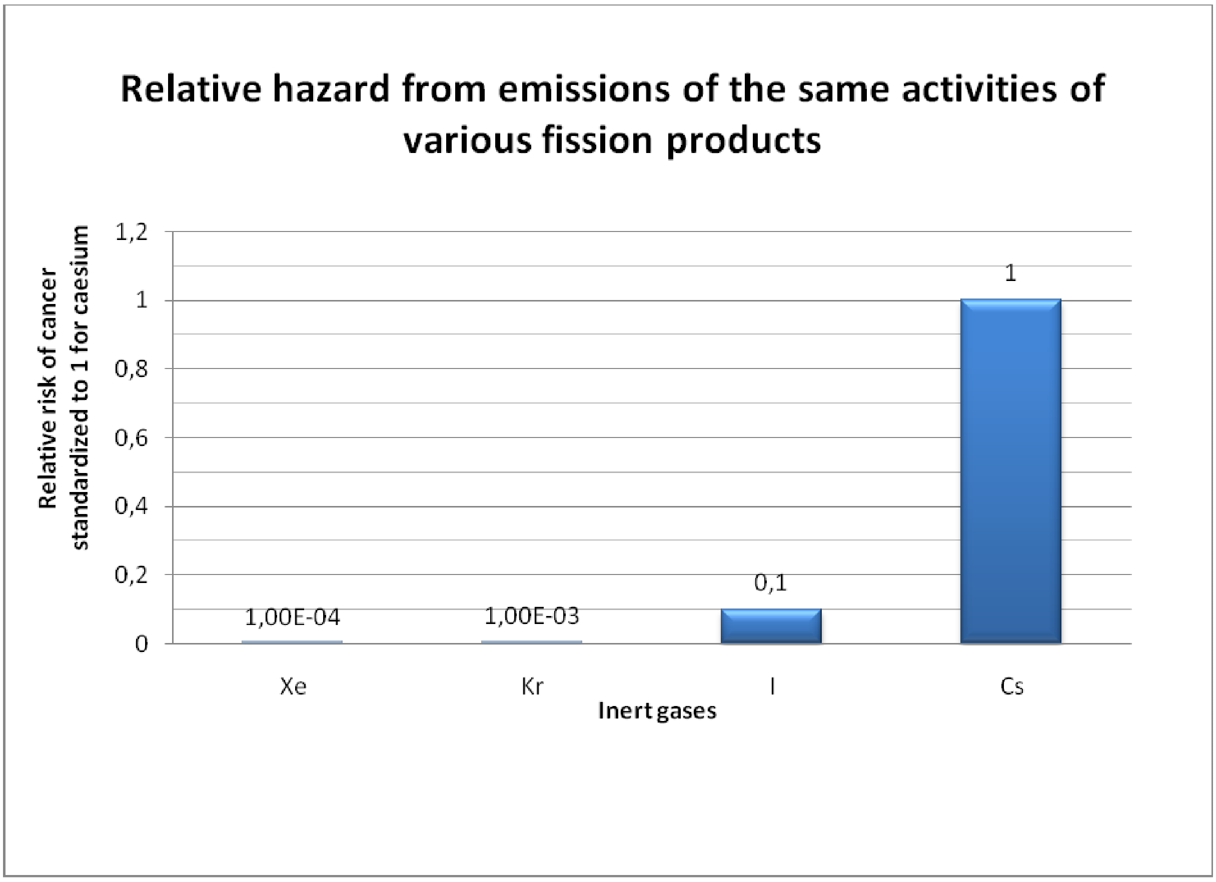

Fig. 7.1.3. Relative risk of cancer caused by release of a certain amount of radioactivity in fission products, normalized to one for caesium. As can be seen, iodine is less hazardous and the hazard on the part of inert gases is negligible. The data for the diagram was taken from the NEA report[10].

Considering the above, Figures 7.1.1 and 7.1.2 must be analyzed again. According to the report for the Convention on Nuclear Safety[11], the average release from PWR nuclear power plants in EU countries in 2003 per unit of generated electric energy, was equal to 4.9 GBq/GWh for inert gases, 0.000025 GBq/GWh for iodine, and 0.000042 GBq/GWh for aerosols. Evidently, the two latter values are over one hundred thousand times less than the former one. Release of the most hazardous isotopes is prevented the most effectively.

The nuclear power plants which are the most representative example of the development of the nuclear energy sector in Europe are the French nuclear power plants. Their total capacity is 62.8 GWe, which is approximately two times more than the capacity of all Poland's power plants. The average release of iodine and aerosols from the French nuclear power plants in 2000 was approximately 0.4% of the permissible yearly release value.[12] Release of liquid radioactive waste was equal to approx. 0.5% of the permissible value. The newer the reactors, the lower the release levels. For example, the nuclear power plants in Chooz and Civaus, which have the latest generation reactors, with the total capacity of 4 x 1450 MWe, release in total less than 4 TBq of inert gases and tritium and less than 0.4 GBq of iodine and radioactive dusts.

Fig**. 3.11.** Reduction of inert gas emissions from PWR reactors; numerical data from the UNSCEAR report[8]

Fig. 7.1.1 shows that as early as the end of the 20th century, the average global release of inert gases was approx. 13 TBq/GWe/year. The French nuclear power plants achieved a ratio of less than 1

TBq/GWe/year in total for inert gases and tritium, and less than 0.1 GBq/GWe/year in total for iodine and radioactive dusts! These values cannot be shown on Fig. 7.1.1 because they are on the horizontal axis.
Taking into account the improved technology of nuclear power plants, for the most recently built nuclear power plants with 1450 MWe reactors, the French nuclear regulatory body imposed limits that are 10 times lower than those for the previous 1300 MWe power units. While the previous limits for nuclear plants with 1300 MWe reactors were 110 GBq in total for iodine and aerosols and 3,300 TBq in total for inert gases, tritium and C-14, the limits for the new plants in Chooz and Civaux are 11 GBq and 330 TBq, respectively. Moreover, considering that the EJ released only small parts of the limiting values, France reduced the permissible emission values in general. Power units which renewed their licenses after 1995 must observe limits that are lower than those in force previously. Examples of the permissible values for 2 x 1300 MWe nuclear plants according to the old regulations and the present regulations are shown in Table 7.1.1.

Table 7.1.1. Permissible and actual emissions at French nuclear power plants operating under original permits (old limits) and current permits, renewed in accordance with new regulations (new limits)[12].

NUCLEAR POWER PLANT	Golfech, 2X1300 MWE (old limits)		Flamanville, 2X1300 MWE (new limits)	
	Limit	Actual emission	Limit	Actual emission
Inert gases, TBq/year	1,650	2.74	45	0.90
Tritium, TBq/year	1)	1)	5	2.03
Carbon C-14, TBq/year	1)	1)	1.4	0.416
Iodine, GBq/year	55	0.083	0.8	0.108
Aerosols, GBq/year	2)	2)	0.8	0.0049

1) The values were included in the "Inert gases" item
2) The values were included in the "Iodine and aerosols" item

As the table shows, the new limits are 30 times lower than the previous ones. The old limits were quite adequate from the point of view of human health, but the French government highlights the fact that thanks to the technological developments the old limits no longer make sense because the actual emissions were significantly lower. This is why new limits, 2 to 40 times lower (depending on the isotope and the plant) were introduced.

Other countries also systematically reduce the permissible emission levels.

3.1.1.2 Emissions during normal operation of an EPR nuclear power plant

3.1.1.2.1 Principles of optimization adopted as a basis for the design of an EPR reactor

The Franco-German design of an EPR reactor (Evolutionary Pressurized Reactor) was intended to meet stringent requirements regarding the emissions of radioactive substances imposed by the nuclear regulatory bodies of both countries. The requirements were formulated in the Technical Guidelines of October 2000 and included, among others:

- reduction of the exposure of the public to radioactive emissions into the atmosphere and water;
- reduction of activity and volume of materials removed as radioactive waste;
- required evaluation of measures aimed to reduce emissions with regards to the quantity of waste resulting from such measures.

The objectives were achieved through optimization and use of experiences, in particular those pertaining to selection of materials, primary loop chemistry, corrosion deposit reduction, processing of radioactive wastewater and gases, and neutralization of solid radioactive waste.

These requirements as well as other recommendations of the French nuclear regulatory body were adopted by the Electricité de France (EDF) group and became a basis for the solutions adopted by the EPR reactor designers in 1999 and 2000, namely:

- a 30% reduction of liquid radioactive waste compared to the average values for 13 MWe reactor power units, with the exception of C-14 carbon and H-3 tritium;
- reduction of cobalt content and improvement of the chemical composition in the primary loop in order to reduce leaks and the amount of waste.

3.1.1.2.2 Principles of evaluation of expected emissions from an EPR reactor

The expected level of emissions from an EPR reactor can be calculated in comparison with reference values based on experiences related to the operation of the existing French and German reactors and on an evaluation of the design improvements that were implemented.

The evaluation process consists of three stages:

- determination of a reference value based on the experiences;
- evaluation of improvements to the design of the EPR reactor;
- determination of expected emission values for the proposed operating parameters of the EPR reactor and the maximum possible emission values.

The experiences are used as a reference point, as it provides more realistic values than any theoretical considerations which, because of the complexity of the process of production, processing, and emission of radioactive substances, produce significantly higher values. The optimization of emission of radionuclides, which has been implemented for many years in nuclear power plants, demonstrates that it is possible to reduce emissions of radioactive isotopes by using appropriate operation strategies.

The reactors used as starting points for comparisons were the 1300 MWe EDF reactors which are the most fully tested and stable. Eight nuclear power plants, in operation over a period of 3 years, from 2001 to 2003, were considered.

In order to take into account the improvements to the design of the EPR reactor, it was compared with the existing 1300 MWe reactors in the following areas:

- primary emissions of fission products;
- main emission routes and their quantitative evaluation;
- design solutions that influence emissions in the EPR reactor and in the existing 1300 MWe power units.

3.1.1.2.3 Parameters of the EPR reactor used in the calculations

The capacity of the EPR reactor was assumed as follows:

- 4,500 MW thermal;

- 1,735 MWe gross;
- 1,630 MWe net.

The amount of energy generated was determined assuming a certain value of the Kd load factor. The value of this factor for 1,300 MWe reactors was **85%,** while for the EPR reactor it is expected to be **91%.**

The yearly energy production for the EPR reactor is 1,630 MW*8,760 h*0.91 ≈ 13,000 GWh.

3.1.1.2.4 Emissions of liquid radioactive waste[13]

3.1.1.2.4.1 Expected emissions of tritium

In the French reactors, 99% of tritium is in liquid state. In PWR reactors (the EPR reactor in question is one of them) the tritium production rate is a nearly linear function of the quantity of generated energy. Tritium is emitted as a result of two factors:

- electron capture in boron B-10 in the in the PWR reactors power adjustment system;
- neutron capture in lithium Li-6 (intended for maintaining proper pH in the coolant of the primary loop), whose quantity is proportional to the quantity of boron in the coolant.

Moreover, in the case of PWR reactors, there is no tritium filtration process implemented on an industrial scale, and the half-life of this isotope (over 12 years), as well as the significant volume of the liquid, makes it impossible to keep it in storage reservoirs until it decays.

Considering the high capacity of the EPR reactor and the deep burnup of nuclear fuel, the primary loop contains a large quantity of boron B-10 which is necessary for slow compensation of changes in reactivity resulting from the fuel burnup. Production control of liquid tritium is intended to maintain its speed on the same level as in 1,300 MWe units. It is achieved by implementing the following design solutions:

- strong poisoning of nuclear fuel with gadolinium (which allows for a reduction of boron B-10 concentration and, consequently, a reduction in tritium production);
- use boron enriched to 30-40% with boron B-10 (this leads to a reduction in the number of boron nuclei without reducing the number of B-10 atoms; because the quantity of lithium is proportional to the total quantity of boron and not to the quantity of the boron B-10 isotope, reduction of the total number of boron atoms leads to a reduction of the number of lithium atoms in the coolant and, eventually, to a reduction in tritium production).

Poisoning of the fuel with gadolinium reduces the concentration of boron B-10 which is the main source of tritium. On the other hand, it reduces the operation time between fuel changes, which has negative economic effects. An in improvement was implemented in the EPR reactor, which has resulted in the length of a fuel cycle equal to 18 months, with a reduction of concentration of the boric acid by 180 ppm, which corresponds to a reduction of activity of tritium by 6 TBq at a loss of 3 days of full-capacity operation.

The analysis of the expected operation tritium emissions considers two options:

- the average value, assuming uniform distribution from the beginning of the cycle during the year and a realistic load factor Kp = 91%;
- the maximum value, assuming that the reactor works continuously for 12 months at the load factor Kp = 100%.

Moreover, two possible lithium concentrations were considered, namely 3.5 ppm and 6 ppm.

The average yearly production of tritium for the operation strategies in question is within the range of 51 TBq/year – 54 TBq/year. The maximum yearly production of tritium is 75 TBq/year.

3.1.1.2.4.2 Releases of liquid carbon C-14

Production of carbon C-14 is a result of neutron irradiation of oxygen O-17 contained in water and, to a lesser extent, of nitrogen contained in the primary loop coolant. The quantity of produced carbon C-14 depends on the volume of irradiated water, the capacity of the reactor, and the content of nitrogen in the primary loop coolant. In PWR reactors, carbon C-14 filtration is not used on an industrial scale.

The experiences related to operation of power units with 1,300 MWe reactors in the years 2001-2003 in France demonstrate that the average yearly release of C-14 is in the range of 15.5-16.2 GBq, which - given the amount of energy generated in those units equal to 9,800 GWh a year - translates into 1.76 Bq/kWh.

More carbon C-14 is produced in an EPR reactor due to its larger capacity and size. Moreover, in EPR reactor reservoirs a gas cylinder is used, containing nitrogen as opposed to hydrogen, together with the pressurizer. This reduces the risk related to presence of hydrogen in the system. Production of C-14 is evaluated for a number of different possible nitrogen concentrations in the primary loop coolant, assuming in particular that it is equal to the concentration in the pressurizer, i.e. max. 27 ppm (or in the ECCS reservoirs, i.e. max. 12 ppm), at the load factor equal to 91%.

Table 7.12. Yearly production of carbon depending on the concentration of nitrogen in the primary loop of an EPR reactor

Concentration of nitrogen (ppm)	EPR (KP = 91%) Yearly production of carbon C-14 (GBq)
1	405
10	444 (34 Bq/kWh)
12	453
27	518

Reduction of nitrogen content in the coolant can be achieved by limiting the flow through the pressurizer and, if necessary, by using a vent installed on the relief line. Consequently, the evaluations of the EPR reactor assume that concentration of nitrogen in the primary loop will be equal to 10 ppm. It is assumed that all the carbon C-14 that will be generated will be released from the reactor. This translates to the average expected yearly release of C-14 to sewage equal to **23 GBq** (1.76 Bq/kWh x 13 TWh).

The maximum values of release from an EPR reactor is assumed, based on experiences with operation of 1,300 MWe units, to be equal to **95 GBq/year**.

3.1.1.2.4.3 Release of other radionuclides into wastewater[13]

Experiences related to operation of 1,300 MWe units demonstrate that releases of iodine isotopes were in the range of 4-18 MBq, with the average value of 0.7 mBq/kWh. The values are very low and cannot be detected with measurement devices. Therefore, instead of measurement data, the evaluation of EPR reactors uses threshold values. Releases of other fission products (FP) and activation products (AP) were in the range of 0.4-1.2 GBq, with the average value of 61 mBq/kWh.

An evaluation of the design improvements to EPR reactors demonstrated that they assure reduction of radioactivity released to wastewater (with the exception of carbon C-14 and tritium) by at least 10% compared with the best 1,300 MWe units.

In the case of liquid iodine isotopes it makes no sense to extrapolate the measurement results from the existing units since the values are so low that threshold values are used instead. Thus, the expected releases are 7 MBq/year which constitutes a 20% improvement in relation to the energy generated.

In the case of other fission products and activation products, it was assumed that the design improvements will lead to a 10% reduction of release values. The release values do not need to be correlated with the amount of generated energy. Consequently, two approaches are used to evaluate the release values:

First, release values per unit of generated energy: 61 mBq/kWh*13 TWh*0.9 = 0.71 GBq.

Second, gross yearly releases equal to 0.54 GBq.

Given this dual approach and the unreliability of measurements due to the low values of the measured parameters, in the design of EPR reactors it was assumed that the expected operation release of fission products and activation products will be equal to **0.6 GBq/year**.

The total value of releases of iodine isotopes and other fission products and activation products is much lower than 1 GBq which was defined by EDF as the design objective for the EPR reactor.

The maximum values of releases of liquid iodine isotopes are equal as those for 1,300 MWe units, i.e. **50 MBq/year**. **This constitutes a reduction of release by unit of generated energy by 24%.**

The maximum values of release of other liquid fission products and activation products reflect the design improvements to the EPR reactors which have resulted in a 10% reduction compared to 1,300 MWe units; based on the current experiences with the operation this leads to expected emissions equal to **10 GBq/year**.

3.1.1.2.5 Releases of radioactive gases[13]

Like in the case of release of liquids, in spite of the great progress achieved in reducing releases of radioactive gases from the existing French reactors, the EPR project involved efforts to reduce them even further, so that their impact on the environment is much smaller than the natural background radiation and the permissible limit values.

3.1.1.2.5.1 Releases of gaseous tritium

Experiences with the existing 1,300 MWe units demonstrate that releases of gaseous tritium are in the range of 0.77-1.86 TBq, with the average value of 91 Bq/kWh.

Unlike in the 1,300 MWe reactors, in EPR reactors there is no intermediate system for washing the tanks of the Emergency Core Cooling System (ECCS). Consequently, production of gaseous tritium in EPR reactors is due mostly to evaporation of water in the fuel storage pool, similarly to the 900 MWe series reactors and the N type reactors (1,450 MWe).

Assuming that the maximum concentration of tritium in the fuel pool is the same as that in the existing power units and taking into account the actual surface area of the pool, the value of release of tritium was calculated to be equal to 0.35 TBq/year. Moreover, taking into account the speed of evaporation and the quantity of steam which condensates on cooler coils in the reactor building ventilation system and the value of releases related to the in-containment refuelling water storage tank (IRWST), which is used as a boric acid tank in emergency situations, the value of tritium release was calculated to be in the range of 0-0.5 TBq/year.

The expected average releases of gaseous tritium was assumed to be 0.5 TBq/year, which constitutes a 60% improvement in the value per unit of generated energy compared with 1,300 MWe units.

The maximum yearly release of gaseous tritium was assumed based on the experiences with 900 MWe units and the N4 series units to be equal to **3 TBq/year** which constitutes a 45% in the value per unit of generated energy compared with 1,300 MWe units.

3.1.1.2.5.2 Release of gaseous carbon C-14

The experiences with the 1,300 MWe units operated in the years 2001-2003 have demonstrated that the average calculated values of gaseous carbon C-14 releases were in the range of 210-250 GBq or, on average, 24 Bq/kWh.

Extrapolation of these values for EPR reactors results in releases related to total energy generation equal to 24 Bq/kWh * 13 TWh = 312 GBq. The value must be added to the second value resulting from the use of a nitrogen blanket in the pressurizer, equal to 117 GBq for a scenario with average nitrogen content of 27 ppm , or 43 GBq for a more realistic scenario with average nitrogen content of 10 ppm.

The sum of these two values is in the range of 350-400 GBq. The EPR design assumes the value to be **350 GBq/year**. It is larger by about 10% than the values for 1,300 MWe units, which is due to the improvement safety of the power unit thanks to replacing hydrogen with nitrogen.

The maximum release of gaseous carbon C-14 for 1,300 MWe units is 700 GBq/unit/year. When the design requirements of the EPR reactor were taken into account, the assumed maximum release of gaseous carbon C-14 was equal to 900 GBq/year. The value in relation to the amount of generated energy is the same as for 1,300 MWe units.

3.1.1.2.5.3 Release of other gaseous radionuclides (iodine, inert gases, other fission products and activation products)

The experience with operation of 1,300 MWe units demonstrates that release of gaseous iodine isotopes is in the range of 16-110 MBq or, on average, 4.6 mBq/kWh.

The values for inert gases are between 0.26 and 7.75 MBq or, on average, 80 mBq/kWh.

Release of other gaseous fission products was between 2 and 11 MBq or, on average, 0.3 mBq/kWh. The release was related mostly to release of aerosols. These are very small values which are on the borderline for measuring abilities.

After analyzing the design improvements to EPR reactors compared with 1,300 MWe reactors, the average expected yearly release of iodine was assumed to be equal to 50 MBq/year, those of inert gases – 0.8 TBq/year, and those of other fission and activation products (mostly aerosols) – 4 MBq/year.

The maximum values for iodine isotopes are 400 MBq/year, for inert gases – 22 TBq/year, and for other fission products and activation products (mostly aerosols) – 340 MBq/year.

3.1.1.2.6 Maximum release values

As demonstrated above, the maximum release values have a certain margin compared to the expected operation values and comprise releases that may occur in the case of small leaks, drainage of the system for repair purposes, or change of chemism of water in order to meet the operation requirements. The efforts to set a realistic level for this margin were based on the experiences with operation of the currently active reactors.

The maximum values are – similar to the expected values of release during operation – based on the experiences with 1,300 MWe reactors, taking into account the design improvements.

Tables 7.1.3 and 7.1.4 show the expected average values of release during normal operation and the maximum values.

Table 3.1.1 Expected average value and maximum yearly value of release into water from EPR reactors

Expected yearly operation release into water	Average [GBq]	Maximum [GBq]
Tritium	52,000	75,000
Carbon C-14	23	95
Iodine isotopes	0.007	0.05
Other fission products and activation products	0.6	10

Table 3.1.2 Expected average value and maximum yearly value of release into the atmosphere from EPR reactors

Radionuclides	Expected yearly operation release into the atmosphere [GBq]	Maximum yearly release to the atmosphere [GBq]
Tritium	500	3,000
Carbon C-14	350	900
Iodine isotopes, total	0.05	0.400
Inert gases, total	800	22,500
FP/AP* – total	0.004	0.340

** FP/AP : other fission products or activation products which emit beta or gamma radiation*

The following spectrum is used in the case of radionuclides present in the group of major gaseous releases:

Table 7.1.5. 3.1.3. Spectrum of radionuclides released into the atmosphere

For maximum yearly release into the atmosphere	Spectrum of radionuclides
Tritium H-3	100%
Carbon C-14	100%
Iodine I-131	45.6%
I-133	54.4%
Inert gases	
Kr-85	13.9%
Xe-133	63.1%
Xe-135	19.8%
Ar-41	2.9%
Xe-131m	0.3%
FP/AP	
Co-58	25.5%
Co-60	30.1%
Cs-134	23.4%
Cs-137	21%

Table 3.1.4. Spectrum of maximum yearly release of radioactive substances from EPR reactors into water

X	Radionuclide	Spectrum
Tritium	H-3	100%
Carbon C-14	C-14	100%
Iodine	I-131	100%

FP/AP	Co-58	20.7%
	Co-60	30%
	Cs-134	5.6%
	Cs-137	9.45%
	Mn-54	2.7%
	Sb-124	4.9%
	Sb-125	8.15%
	Ni-63	9.6%
	Te-123m	2.6%
	Others	0.6%

The analysis cover the following chemical forms of radionuclides:

- In the case of gaseous emissions, it was assumed that tritium is present in the form of steam in the atmosphere.
- Carbon C-14 has the form of M-type particulate atmospheric carbon.
- Iodine isotopes have an inorganic form (I_2) because this is the most hazardous form for living organisms.
- In the case of releases of liquids, it was assumed that tritium has the form of a water solution.

3.1.1.3 Release during normal operation of a nuclear power plant with an AP reactor[14]

3.1.1.3.1 Radioactive waste management systems

Radioactive waste management systems of an AP1000 reactor assure proper handling of solid waste (solid radwaste system - WSS), liquid waste (liquid radwaste system – WLS), and gaseous waste (gaseous radwaste system – WGS).

The WLS system collects, processes, and controls liquid waste and consists of sedimentation tanks, circulation pumps, control equipment, etc. The main process in treating liquid waste is ion exchange.

The WGS collects, processes, and controls gaseous waste which may be radioactive or contain hydrogen, e.g. gases removed in the process of venting the reactor coolant and the reactor coolant drain tank (RCDT). The gaseous waste is kept in the system to assure decay of short-lived radionuclides and then it is forwarded to charcoal filters and discharged to the atmosphere through a ventilation stack.

Solid waste does not cause releases outside of the nuclear power plant.

3.1.1.3.2 Fission products

When defining the design release of fission products, it is assumed that a significant leak has occurred in the jacket of the fuel element, larger than that expected during normal operation. It is assumed that small jacket defects occur in fuel rods which generate 0.25% of the core (the term "0.25% fuel defect" is used). The parameters used to calculate the concentration of fission products in the reactor coolant are mentioned in **Błąd! Nie można odnaleźć źródła odwołania.**.

3.1.1.3.3 Corrosion products

Activity of corrosion products is defined on the basis of extrapolation data of reactors that are currently in operation and is independent of the level of defects of fuel elements. Concentrations of corrosion products and concentrations of fission products in reactor coolant are mentioned in **Błąd! Nie można odnaleźć źródła odwołania.**.

3.1.1.3.4 Tritium

The concentration of tritium in reactor coolant depends on a number of processes, namely:

- infiltration from the fuel (tritium is produced together with fission products) to the coolant through the jacket or defects in the jacket;
- reaction of neutrons with the boron dissolved in the coolant;
- absorption of neutron in the burned poison;
- reaction of neutrons with the lithium dissolved in the coolant;
- reaction of neutrons with deuterium in the reactor coolant.

The first two processes are the main sources of tritium in reactor coolant.

Tritium is present in reactor coolant in connection with hydrogen, i.e. a tritium atom replaces a hydrogen atom in a water particle, which makes it hard to separate from the coolant. The maximum concentration of tritium in the coolant is less than 3.5 μCi/g, due to losses connected with leaks and control discharge of tritium into the environment.

3.1.1.3.5 Nitrogen N-16

Activation of oxygen in the coolant results in creation of nitrogen N-16 which emits strong gamma radiation. Due to its short half-life, equal to 7.11 s, N-16 does not constitute a hazard to the surroundings of a nuclear power plant. After reactor shutdown, N-16 quickly decays and does not constitute a source of radiation inside the safety containment.

3.1.1.3.6 Activity of the second loop adopted as a design basis

Defects of pipes in the steam generator result in leaks of the coolant from the primary loop to the secondary loop. The resulting radioactivity in the steam loop depends on the rate of the leaks from the primary loop to the secondary loop, the decay coefficient of a given nuclide, and the rate of flow through the steam generator.

Błąd! Nie można odnaleźć źródła odwołania. shows a realistic evaluation of activity in the primary loop of an AP1000 reactor.

Table 3.1.5. Parameters used in design calculations of fission products activity in an AP1000 reactor

Parameter	Value
Core thermal power (MWt)	3,400
Liquid volume of reactor coolant (m3)	271
Average coolant temperature at full power (°C)	300.5
Flow rate in the cleaning loop (m3/h)	
Maximum	22.7
Normal	20.7
Effective flow through the cation bed demineralizer, yearly average (m3/h)	2.7
Nuclide release coefficients (product of the fraction of defective fuel rods and the coefficient of escape of fission products)	
Equivalent fraction of the core power generated in fuel rods with small jacket defects (fraction of defective fuel)	0.0025

Parameter	Value
Coefficient of escape of fission products during work at full capacity (s-1):	
Kr and Xe	6.5 x 10-8
Br, Rb, I, and Cs	1.3 x 10-8
Mo, Tc, and Ag	2.0 x 10-9
Te	1.0 x 10-9
Sr and Ba	1.0 x 10-11
Y, Zr, Nb, Ru, Rh, La, Ce, and Pr	1.6 x 10-12
Mixed-bed demineralizer in the volume and chemical composition adjustment system	
Resin volume (m3)	1.4
Coefficients of isotope decontamination in the demineralizer:	
Kr and Xe	1
Br and I	10
Sr and Ba	10
Other isotopes	1
Cation-bed demineralizer in the volume and chemical composition adjustment system	
Resin volume (mt3)	1.4
Coefficients of isotope decontamination in the demineralizer:	
Kr and Xe	1
Sr and Ba	1
Rb-86, Cs-134, and Cs-137	10
Rb-88, Rb-89, Cs-136, and Cs-138	1
Other isotopes	1
Initial concentration of boron (ppm)	1,400
Operation time (effective hours of operation at full capacity)	12,492

Table 3.1.6. Activity in reactor coolant adopted as a basis for the design of the AP1000 reactor

Nuclide	Activity (µCi/g)	Nuclide	Activity (µCi/g)
Kr-83m	1.8×10^{-1}	Rb-88	1.5
Kr-85m	8.4×10^{-1}	Rb-89	6.9×10^{-2}
Kr-85	3.0	Sr-89	1.1×10^{-3}
Kr-87	4.7×10^{-1}	Sr-90	4.9×10^{-5}
Kr-88	1.5	Sr-91	1.7×10^{-3}
Kr-89	3.5×10^{-2}	Sr-92	4.1×10^{-4}
Xe-131m	1.3	Y-90	1.3×10^{-5}
Xe-133m	1.7	Y-91m	9.2×10^{-4}
Xe-133	1.2×10^{2}	Y-91	1.4×10^{-4}
Xe-135m	1.7×10^{-1}	Y-92	3.4×10^{-4}
Xe-135	3.5	Y-93	1.1×10^{-4}
Xe-137	6.7×10^{-2}	Zr-95	1.6×10^{-4}
Xe-138	2.5×10^{-1}	Nb-95	1.6×10^{-4}
Br-83	3.2×10^{-2}	Mo-99	2.1×10^{-1}
Br-84	1.7×10^{-2}	Tc-99m	2.0×10^{-1}
Br-85	2.0×10^{-3}	Ru-103	1.4×10^{-4}
I-129	1.5×10^{-8}	Rh-103m	1.4×10^{-4}

Nuclide	Activity (µCi/g)	Nuclide	Activity (µCi/g)
I-130	1.1 x 10^{-2}	Rh-106	4.5 x 10^{-5}
I-131	7.1 x 10^{-1}	Ag-110m	4.0 x 10^{-4}
I-132	9.4 x 10^{-1}	Te-127m	7.6 x 10^{-4}
I-133	1.3	Te-129m	2.6 x 10^{-3}
I-134	2.2 x 10^{-1}	Te-129	3.8 x 10^{-3}
I-135	7.8 x 10^{-1}	Te-131m	6.7 x 10^{-3}
Cs-134	6.9 x 10^{-1}	Te-131	4.3 x 10^{-3}
Cs-136	1.0	Te-132	7.9 x 10^{-2}
Cs-137	5.0 x 10^{-1}	Te-134	1.1 x 10^{-2}
Cs-138	3.7 x 10^{-1}	Ba-137m	4.7 x 10^{-1}
Cr-51	1.3 x 10^{-3}	Ba-140	1.0 x 10^{-3}
Mn-54	6.7 x 10^{-4}	La-140	3.1 x 10^{-2}
Mn-56	1.7 x 10^{-1}	Ce-141	1.6 x 10^{-4}
Fe-55	5.0 x 10^{-4}	Ce-143	1.4 x 10^{-4}
Fe-59	1.3 x 10^{-4}	Pr-143	1.5 x 10^{-4}
Co-58	1.9 x 10^{-3}	Ce-144	1.2 x 10^{-2}
Co-60	2.2 x 10^{-4}	Pr-144	1.2 x 10^{-2}

The above values of activity are used to design the shields and the radioactive waste management system. In the event that 1% of fuel rods are defective (which corresponds to the maximum capacity of the liquid and gaseous radioactive waste management systems), the above-mentioned values must be multiplied by 4, with the exception of activity of corrosion products (Cr-51, Mn-54, Mn-56, Fe-55, Fe-59, Co-58, and Co-60).

Błąd! Nie można odnaleźć źródła odwołania. – Błąd! Nie można odnaleźć źródła odwołania. show the expected release values of iodine, inert gases, and other fission products from the AP1000 reactor into the atmosphere and into water, and a comparison with the release values from other PWR reactors.

Table 3.1.7. Expected yearly release of air-borne iodine isotopes into the atmosphere

Released activity, GBq/a						
		Building/ventilated area				
Nuclide	Gaseous waste management system	Safety containment building	Ancillary building	Engine building	Condenser venting system	Total release
I-131	7.4*10^{-3}	1.9 *10^{-2}	1.8*10^{-1}	2.4*10^{-3}	9.6*10^{-4}	2.1*10^{-1}
I-133	1.1 *10^{-2}	7.4*10^{-2}	2.6 *10^{-1}	7.4*10^{-4}	3.0*10^{-3}	3.5*10^{-1}

Total activity of volatile iodine isotopes: 6E-01 GBq/year.

Table 3.1.8. Release of gaseous fission products into the atmosphere from the AP1000 reactor (Ci/year)

Inert gases	Active gases system	Building/ventilated area			Condenser venting system	Total
		Safety containment	Ancillary building	Turbine building		
Kr-85m	0	3.0	4.0	0	2.0	3.6*10
Kr-85	1.65*10^{3}	2.4*10^{3}	2.9*10	0	1.4*10	4.1*10^{3}

Inert gases	Active gases system	Building/ventilated area			Condenser venting system	Total
		Safety containment	Ancillary building	Turbine building		
Kr-87	0	9.0	4.0	0	2.0	1.5*10
Kr-88	0	3.4*10	8.0	0	4.0	4.6*10
Xe-131m	$1.42*10^{2}$	$1.6*10^{3}$	2.3*10	0	1.1*10	$1.8*10^{3}$
Xe-133m	0	8.5*10	2.0	0	0	8.7*10
Xe-133	3.0*10	$4.5*10^{3}$	7.6*10	0	3.6*10	$4.6*10^{3}$
Xe-135m	0	2.0	3.0	0	2.0	7.0
Xe-135	0	$3.0*10^{2}$	2.3*10	0	1.1*10	$3.3*10^{2}$
Xe-138	0	1.0	3.0	0	2.0	6.0
					Total	$1.1*10^{4}$
Also:						
H-3 released with gases						350
H-14 released with gases						7.3
Ar-41 released as a result of ventilation of the safety containment						34

The release of tritium is 1.3 x 10^{13} Bq/year and the release of carbon C-14 – 27 x 10^{10} = 0.27 TBq/year.

Table 3.1.9. Comparison of release values of radioactive gases from an AP1000 reactor with release values from other nuclear power plants

	AP1000	South Texas 1	Braidwood 1	Cook 1	Vogtle 1	Sizewell B
Total release per 1,000 MWe per year, in GBq	10,311	7,692	561	12,571	2,184	70,115

Table 3.1.10. Release of aerosols into the atmosphere from the AP1000 reactor (Ci/year)

Inert gases	Active gases system	Building/ventilated area			Total
		Safety containment	Ancillary building	Turbine building	
Cr-51	$1.4*10^{-5}$	$9.2*10^{-5}$	$3.2*10^{-4}$	$1.8*10^{-4}$	$6.1*10^{-4}$
Mn-54	$2.1*10^{-6}$	$5.3*10^{-5}$	$7.8*10^{-5}$	$3.0*10^{-4}$	$4.3*10^{-4}$
Co-57	0	$8.2*10^{-6}$	0	0	$8.2*10^{-6}$
Co-58	$8.7*10^{-6}$	$2.5*10^{-4}$	$1.9*10^{-3}$	$2.1*10^{-2}$	$2.3*10^{-2}$
Co-60	$1.4*10^{-5}$	$2.6*10^{-5}$	$5.1*10^{-4}$	$8.2*10^{-3}$	$8.7*10^{-3}$
Fe-59	$1.8*10^{-6}$	$2.7*10^{-5}$	$5.0*10^{-5}$	0	$7.9*10^{-5}$
Sr-89	$4.4*10^{-5}$	$1.3*10^{-4}$	$7.5*10^{-4}$	$2.1*10^{-3}$	$3.0*10^{-3}$
Sr-90	$1.7*10^{-5}$	$5.2*10^{-5}$	$2.9*10^{-4}$	$8.0*10^{-4}$	$1.2*10^{-3}$
Zr-95	$4.8*10^{-6}$	0	$1.0*10^{-3}$	$3.6*10^{-6}$	$1.0*10^{-3}$
Nb-95	$3.7*10^{-6}$	$1.8*10^{-5}$	$3.0*10^{-5}$	$2.4*10^{-3}$	$2.5*10^{-3}$
Ru-103	$3.2*10^{-6}$	$1.6*10^{-5}$	$2.3*10^{-5}$	$3.8*10^{-5}$	$8.0*10^{-5}$
Ru-106	$2.7*10^{-6}$	0	$6.0*10^{-6}$	$6.9*10^{-5}$	$7.8*10^{-5}$
Sb-125	0	0	$3.9*10^{-6}$	$5.7*10^{-5}$	$6.1*10^{-5}$
Cs-134	$3.3*10^{-5}$	$2.5*10^{-5}$	$5.4*10^{-4}$	$1.7*10^{-3}$	$2.3*10^{-3}$
Cs-136	$5.3*10^{-6}$	$3.2*10^{-5}$	$4.8*10^{-5}$	0	$8.5*10^{-5}$
Cs-137	$7.7*10^{-5}$	$5.5*10^{-5}$	$7.2*10^{-4}$	$2.7*10^{-3}$	$3.6*10^{-3}$
Ba-140	$2.3*10^{-5}$	0	$4.0*10^{-4}$	0	$4.2*10^{-4}$
Ce-141	$2.2*10^{-6}$	$1.3*10^{-5}$	$2.6*10^{-5}$	$4.4*10^{-7}$	$4.2*10^{-5}$

The total activity of aerosols is 46.76 x 10-3 Ci/year, i.e. 0,173 x 10^{10} Bq = 1.7 GBq/year.

Table 3.1.11. Comparison of release values of liquid radioactive waste from the AP1000 reactor, with the exception of tritium, with release values from European nuclear power plants in the years 1995-1998

X	Unit	AP1000	Sizewell B	All PWR	Magnox and AGR Nuclear Power Plants	All BWR
No. of power units	0	1	73	30	10	
Minimum GBq/GWa	1.1	16	0	2	0	
Average GBq/GWa	2.4	21.8	4.9	12.2	65.5	
Maximum GBq/GWa	3.5	28	61	28	599	

Table 3.1.12. Comparison of release values of liquid radioactive waste from an AP1000 reactor with release values from other nuclear power plants

	AP1000	South Texas 1	Braidwood 1	Cook 1	Vogtle 1	Sizewell B
Total release per 1,000 MWe per year, in GBq	33,374	46,331	49,094	44,500 /	40,450	50,503

3.1.1.4 Emissions during normal operation of an ESBWR nuclear power plant

3.1.1.4.1 Sources of radioactivity

In an ESBWR (Economic Simplified Boiling Water Reactor), there is only one large radioactivity source inside of the primary containment, that is the reactor core. Another source of radioactivity is the control rod drives used for precise control of reactivity. An ESBWR has no circulation pumps outside or inside the reactor containment, a circular core sampling system, or heat exchangers, which may become contaminated in the course of normal operation.

The list of radioactivity sources in the primary containment of an ESBWR reactor presented in the report[15] submitted for consideration by the British nuclear regulatory authority do not include sources resulting from accidental contamination, such as corrosion deposits or fission products deposits on surfaces of valves and other elements of the primary loop.

3.1.1.4.1.1 Sources in the engine building (turbine building)

The main source of radiation in the turbine building is nitrogen N-16 generated after neutron capture and proton emission, which is contained in the steam rising above the reactor container. This isotope causes significant gamma radiation from elements through which the steam flows, with the dose of approx. 0.2-0.5 Sv/hour on the surface of pipelines and containers. The remaining sources of radiation in the turbine building are the venting system and the condenser and supply water system.

3.1.1.4.2 Releases from ESBWR reactors during normal operation

The radioactivity release values from boiling water reactors was determined based on many years of experience with operation of boiling water reactors according to the ANSI/ANS-18.1 standard. The observations made when switching from old design fuel to new design fuel were also taken into account. The radionuclides included in the design bases were divided into fission products and activation products.

3.1.1.4.2.1 Inert gases produced as fission products

The typical concentrations of 13 inert gases produced as fission products which are present in steam discharged from the reactor container are defined in the ANSI/ANS-18.1 Source Term Standard.[16] The concentration of such gases in the reactor water are negligibly low in normal operating conditions, because all gases emitted into the coolant are quickly eliminated with steam and moved to the main turbine condenser. Considering the quick elimination of such gases, the expected composition of the gaseous fission products in steam is independent of the reactor's design.

Table 3.1.13. Parameters assumed for determining releases of radioactivity in ESBWR reactors

Parameter	Value
Total release of 13 inert gases after 30 minutes (t30)	3,700 MBq/s
Normal operation rate of release of inert gases (t30)	740 MBq/s
Rate of release of radioactive iodine I-131 from the core assumed as the design basis	26 MBq/s
Expected rate of release of radioactive iodine I-131 from the core	3.7 MBq/s
Scale factor for concentration of I-131 in the coolant	5
Concentration of N-16 at the core outlet (the design basis must be the same as the normal operation value)	1.85 MBq/gm w/o HWC, 9.25 MBq/gm w/HWC
Rate of release of argon Ar-41 assumed as design basis	2.0 MBq/s
Normal operation rate of release of argon Ar-41	0.4 MBq/s

Błąd! Nie można odnaleźć źródła odwołania. shows the parameters adopted as the design basis for concentration of inert gases in steam.

Table 3.1.14. Parameters adopted as the design basis for concentration of inert gases in steam

Isotope	Decay coefficient	Concentration in steam		Release after T=30 minutes	
	Per hour	MBq/g	microCi/g	MBq/g	microCi/s
Kr-83m	3.73E-1	5.4E-05	1.5E-03	1.1E+02	2.9E+03
Kr-85m	1.55E-1	9.1E-05	2.5E-03	2.0E+02	5.5E+03
Kr-85	7.37E-6	3.6E-07	9.8E-06	8.9E-01	2.4E+01
Kr-87	5.47E-1	3.0E-04	8.1E-03	5.6E+02	1.5E+04
Kr-88	2.48E-1	3.0E-04	8.1E-03	6.5E+02	1.7E+04
Kr-89	1.32E+1	1.9E-03	5.2E-02	6.4E+00	1.7E+02
Xe-131m	2.41E-3	3.0E-07	8.1E-06	7.3E-01	2.0E+01
Xe-133m	1.30E-2	4.5E-06	1.2E-04	1.1E+01	2.9E+02
Xe-133	5.46E-3	1.3E-04	3.4E-03	3.1E+02	8.4E+03
Xe-135m	2.72E+0	4.0E-04	1.1E-02	2.5E+02	6.8E+03
Xe-135	7.56E-2	3.5E-04	9.4E-03	8.1E+02	2.2E+04
Xe-137	1.08E+1	2.4E-03	6.4E-02	2.6E+01	6.9+02
Xe-138	2.93E+0	1.4E-03	3.7E-02	7.7E+02	2.1E+04
Total		7.3E-03	2.0E-01	3.7E+03	1.0E+05

Concentrations of inert gases in steam after 30 minutes, when the decay of the fission products occurs, are used as a standard measure of leaks from fuel elements.

The typical rate of release of inert gases, which is equal to 3,700 MBq/s, after 30 minutes of decay, has been successfully used to design systems for processing the released gases in BWR reactors[17]. The rate was determined based on operational experiences, taking into account the effect of current design solutions.

3.1.1.4.2.2 Iodine isotopes produced as fission products

For many years, the design basis adopted for BWR reactors was the rate of iodine I-131 release from fuel in the core equal to 26 MBq/s[17]. However, based on the experiences, such a high rate of iodine release takes place only in the event that the core is operated with significant defects in the fuel elements. The rate of iodine isotopes release for the ESBWR reactor was determined based on the ANS standard[18].

Table 3.1.15. Concentrations of iodine isotopes in water and steam of an ESBWR reactor adopted as the design basis

Isotope	Decay coefficient	Concentration in water		Concentration in steam	
	Per hour	MBq/g	microCi/g	MBq/g	microCi/g
I-131	3.59E-3	3.9E-04	1.1E-02	7.9E-06	2.1E-04
I-132	3.03E-1	3.7E-03	9.9E-02	7.4E-05	2.0E-03
I-133	3.33E-2	2.7E-03	7.2E-02	5.3E-05	1.4E-03
I-134	7.91E-1	6.8E-03	1.8E-01	1.4E-04	3.7E-03
I-135	1.05E-1	3.8E-03	1.0E-01	7.6E-05	2.1E-03

The assumed ratio of concentration of iodine in steam to concentration of iodine in water (*carryover ratio*) is assumed to be equal to approx. 0.02.

3.1.1.4.2.3 Other fission products

This category includes products other than inert gases and iodine, among others transuranic nuclides. Some of the fission products are products of decay of inert gases produced in steam and condensate. One transuranic element which may be detected in significant quantities is Np-239. After introducing appropriate coefficients for concentrations that are typical for BWR reactors in the ANS standards [18], the concentrations for the ESBWR were obtained – See **Błąd! Nie można odnaleźć źródła odwołania.**. The ratio of concentration of these nuclides in steam to their concentration in water is less than 0.001. Thus, concentration in steam can be calculated by multiplying the concentration in water by the 0.001 factor.

Table 3.1.16. Concentrations of fission products in water in ESBWR reducers adopted in the design

Isotope	Decay coefficient	Concentration in water	
	(per hour)	(MBq/g)	µCi/g
Rb-89	2.74E+0	6.9E-04	1.9E-02
Sr-89	5.55E-4	1.7E-05	4.5E-04
Sr-90	2.81E-6	1.2E-06	3.1E-05
Y-90	2.81E-6	1.2E-06	3.1E-05
Sr-91	7.31E-2	6.4E-04	1.7E-02
Sr-92	2.56E-1	1.5E-03	4.1E-02
Y-91	4.93E-4	6.6E-06	1.8E-04
Y-92	1.96E-1	9.3E-04	2.5E-02
Y-93	6.80E-2	6.4E-04	1.7E-02
Zr-95/Nb-95	4.41E-4	1.3E-06	3.6E-05
Mo-99/Tc-99m	1.05E-2	3.3E-04	8.9E-03
Ru-103/Rh-103m	7.29E-4	3.3E-06	8.9E-05
Ru-106/Rh-106	7.83E-5	5.0E-07	1.3E-05
Te-129m	8.65E-4	6.6E-06	1.8E-04
Te-131m	2.31E-2	1.6E-05	4.4E-04
Te-132	8.89E-3	1.6E-06	4.5E-05
Cs-134	3.84E-5	4.5E-06	1.2E-04
Cs-136	2.22E-3	3.0E-06	8.0E-05
Cs-137/Ba-137m	2.63E-6	1.2E-05	3.2E-04

Isotope	Decay coefficient	Concentration in water	
	(per hour)	(MBq/g)	µCi/g
Cs-138	1.29E+0	1.4E-03	3.8E-02
Ba-140/La-140	2.26E-3	6.6E-05	1.8E-03
Ce-141	8.88E-4	5.0E-06	1.3E-04
Ce-144/Pr-144	1.02E-4	5.0E-07	1.3E-05
Np-239	1.24E-2	1.3E-03	3.6E-02

Table 3.1.17. Parameters adopted as a basis for calculation of release of radioactivity into the atmosphere from an ESBWR reactor

Parameter	Value (keep in mind that 1 Ci = 3.7 x 10^{10}Bq)
Sources of inert gases after t=30 min	740 MBq/s (20,000 µCi/sec)
Rate of release I-131	3.7 MBq/s (100 µCi/sec)
Power unit load coefficient	0,92
Release from turbine sealing system:	25 g /h
I-131	0.81 Ci/a per µCi/g I-131 in the coolant
I-133	0.22 Ci/a per µCi/g I-131 in the coolant

Table 3.1.18. Value of activity in the demineralizer of the RWCU system

Class	Isotope	MBq	Class	Isotope	MBq
Class 2	I-131	9.85E+06	Class 6	Sr-89	2.74E+06
	I-132	1.09E+06		Sr-91	8.10E+05
	I-133	6.97E+06		Sr-92	5.39E+05
	I-134	7.77E+06		Y-91	1.08E+06
	I-135	3.31E+06		Y-92	4.28E+05
				Y-93	8.64E+05
Class 3	Rb-89	2.30E+04		Zr-95	2.33E+05
	Cs-134	8.09E+05		Nb-95	1.51E+04
	Cs-136	6.41E+04		Mo-99	2.85E+06
	Cs-137	2.3E+06		Tc-99m	2.59E+05
	Cs-138	4.90E+04		Ru-103	3.94E+05
	Ba-137m	6.56E+01		Rh-103m	4.12E+02
				Rh-106	5.49E-01
Class 4	N-16	6.03E+02		Ag-110m	5.14E+04
				Te-129m	6.83E+05
Class 5	Na-24	6.36E+05		Te-131m	6.44E+04
	Cr-51	4.29E+07		Te-132	1.68E+04
	Mn-54	1.88E+06		Ba-140	2.66E+06
	Mn-56	1.28E+06		La-140	3.49E+05
	Fe-59	6.54E+05		Ce-141	4.95E+05
	Co-58	3.08E+06		Ce-144	1.58E+05
	Co-60	1.26E+07		Pr-144	1.88E+01
	Cu-64	8.11E+05		W-187	1.54E+05
	Zn-65	5.10E+07		Np-239	9.74E+06
				Total	1.64E+08

Błąd! Nie można odnaleźć źródła odwołania. shows the activity of radionuclides in the turbine condenser. The activity values are much higher in the filters.

Table 3.1.19. Values of radionuclides in the turbine condenser of an ESBWR reactor

Isotope	Activity MBq	Isotope	Activity MBq
Kr-85m	1.49E+04	P-32	1.09E+00

Isotope	Activity MBq	Isotope	Activity MBq
Kr-85	5.98E+01	Cr-51	8.16E+01
Kr-87	4.93E+04	Mn-54	9.52E-01
Kr-88	4.93E+04	Mn-56	6.24E+02
Kr-89	3.14E+05	Fe-55	2.73E+01
Xe-131m	4.93E+01	Fe-59	8.16E-01
Xe-133m	7.32E+02	Co-58	2.73E+00
Xe-133	2.09E+04	Co-60	5.44E+00
Xe-135m	6.58E+04	Ni-63	2.73E-02
Xe-135	5.68E+-4	Cu-64	7.95+01
Xe-137	3.89E+05	Zn-65	2.73E+01
Xe-138	2.25E+05	Sr-89	2.73E+00
Total	1.21E+06	Sr-90	1.90E-01
Class 2		Y-90	1.90E-01
I-131	1.29E+03	Sr-91	1.05E+02
I-132	1.21E+04	Sr-92	2.50E+02
I-133	8.72E+03	Y-91	1.09E+00
I-134	2.23E+04	Y-92	1.52E+02
I-135	1.26E+04	Y-93	1.05E+02
Total	5.70E+04	Zr-95	2.18E-01
Class 3		Nb-95	2.18E-01
Rb-89	1.14E+02	Mo-99	5.40E+01
Cs-134	7.34E-01	Tc-99m	5.40E+01
Cs-136	4.89E-01	Ru-103	5.44E-01
Cs-137	1.95E-01	Rh-103m	5.44E-01
Cs-138	2.28E+02	Ru-106	8.16E-02
Ba-137m	1.95E+00	Rh-106	8.16E-02
Total	3.47E+02	Ag-110m	2.73E-02
Class 4		Te-129m	1.09E+00
N-16	1.26E+08	Te-131m	2.69E+00
Class 5		Te-132	2.71E-01
H-3	6.08E+04	Ba-140	1.09E+01
		La-140	1.09E+01
		Ce-141	8.16E-01
		Ce-144	8.16E-02
		Pr-144	8.16E-02
		W-187	8.03E+00
		Np-239	2.17E+02
		Total	1.27E+08

Table 3.1.20. Value of radionuclides collected on filters of the ion exchanger of an ESBWR reactor

Isotope	Activity MBq
Class 2	
I-131	1.94E+06
I-132	2.15E+05
I-133	1.41E+06

Isotope	Activity MBq
I-134	1.52E+05
I-135	6.57E+05
Class 3	
Rb-89	2.28E+02
Cs-134	9.10E+03
Cs-136	1.18E+03
Cs-137	2.52E+04
Cs-138	9.55E+02
Ba-137m	6.48E-01
Class 6	
Sr-89	3.86E+03
Sr-90	4.93E+02
Y-90	3.17E-01
Sr-91	1.58E+03
Sr-92	1.05E+03
Y-91	1.66E+03
Y-92	8.39E+02
Y-93	1.66E+03
Zr-95	3.50E+02
Nb-95	2.47E+02
Mo-99	5.61E+03
Tc-99m	5.06E+02
Ru-103	6.68E+02
Rh-103m	7.93E-01
Ru-106	1.93E+02
Rh-106	1.06E-03
Te-129m	1.21E+03
Te-131m	1.26E+02
Te-132	3.30E+01
Ba-140	5.18E+03
La-140	6.82E+02
Ce-141	8.76E+02
Ce-144	1.88E+02
Pr-144	3.67E-02
Np-239	1.91E+04
Total	4.47E+06

Table 3.1.21. Releases into the atmosphere from the systems of an ESBWR reactor

Nuclide	Reactor building	Turbine building	Radioactive waste building	Vacuum pumps	Turbine sealing	Gas extraction system	Secondary containment
Kr-83m						1.4E-04	3.7E+01
Kr-85m	6.9E+04	5.7E+05				6.8E+03	1.5E+02
Kr-85						4.3E+06	3.3E+01
Kr-87	4.6E+04	1.4E+06				8.6E-10	1.4E+02
Kr-88	9.2E+04	2.1E+06				1.5E+01	3.0E+02
Kr-89	4.6E+04	1.3E+07	6.7E+05				3.7E+01

Kr-90							1.3E+01
Xe-131m						1.1E+05	1.8E+01
Xe-133m						8.1E-01	8.5E+01
Xe-133	2.5E+06	3.4E+06	5.1E+06	1.9E+07		8.3E+05	5.0E+03
Xe-135m	1.4E+06	9.2E+06	1.2E+07			4.3E-37	3.7E+01
Xe-135	2.9E+06	7.6E+06	6.4E+06	7.4E+06			1.2E+03
Xe-137	4.1E+06	2.3E+07	1.9E+06				5.5E+01
Xe-138	1.8E+05	2.3E+07	4.6E+04				1.2E+02
Xe-139							1.6E+01
I-131	9.4E+02	5.2E+03	3.4E+02	1.8E+03	4.7E+01		6.8E+03
I-132	8.5E+03	4.6E+04	3.0E+03				9.9E+02
I-133	6.2E+03	3.4E+04	2.2E+03		8.4E+01		6.5E+03
I-134	1.5E+04	8.4E+04	5.5E+03				6.9E+02
I-135	8.6E+03	4.7E+04	3.1E+03				2.9E+03
H-3	1.3E+06	1.3E+06					2.6E+05
C-14							
Na-24							5.4E-01
P-32							1.3E-01
Ar-41							
Cr-51	2.7E+01	2.2E+01	1.7E+01				1.1E+01
Mn-54	3.4E+01	1.5E+01	9.8E+01				1.7E-01
Mn-56							1.1E+00
Fe-55							4.7E+00
Fe-59	9.5E+00	2.4E+00	7.3E+00				1.2E-01
Co-58	7.3E+00	2.4E+01	4.9E+00				4.4E-01
Co-60	1.2E+02	2.4E+01	1.7E+02				9.4E-01
Ni-63							4.7E-03
Cu-64							6.9E-01
Zn-65	1.2E+02	1.5E+02	7.3E+00				4.6E+00
Rb-89							2.0E-02
Sr-89	1.2E+00	1.5E+02					4.3E-01
Sr-90	2.4E-01	4.9E-01					3.3E-02
Y-90							3.3E-02
Sr-91							6.7E-01
Sr-92							4.6E-01
Y-91							1.7E-01
Y-92							3.7E-01
Y-93							7.2E-01
Zr-95	2.4E+01	9.8E-01	2.0E+01				3.5E-02
Nb-95	2.4E+02	1.5E-01	9.8E-02				3.3E-02
Mo-99	1.6E+03	4.9E+01	7.3E-02				2.4E+00
Tc-99m							2.2E-01
Ru-103	1.0E+02	1.2E+00	2.4E-02				8.2E-02
Rh-103m							8.2E-02
Ru-106							1.4E-02
Rh-106							1.4E-02
Ag-110m	5.9E-02						1.3E-07
Sb-124	1.2E+00	2.4E+00	1.7E+00				
Te-129m							1.6E-01

Te-131m				5.5E-02
Te-132				1.4E-02
Cs-134	1.1E+02	4.9E+00	5.9E+01	1.3E-01
Cs-136	1.2E+01	2.4E+00		5.8E-02
Cs-137	1.5E+02	2.4E+01	9.8E+01	3.4E-01
Cs-138				8.5E-02
Ba-140	5.4E+02	2.4E+02	9.8E-02	1.3E+00
La-140				1.3E+00
Ce-141	2.2E+01	2.4E+02	1.7E-01	1.2E-01
Ce-144				1.3E-02
Pr-144				1.3E-02
W-187				1.3E-01
Np-239				8.3E+00

Table 3.1.22. Comparison of releases from an ESBWR reactor with the limit values according to USA regulations, 10CFR 20

X	Releases to the atmosphere from an ESBWR reactor	Concentration	Limit value acc. to 10CFR20
Nuclide	**MBq/yr**	**Bq/m³**	**Bq/m³**
Kr-83m	3.73E+01	2.36E-06	2.E+06
Kr-85m	6.50E+05	4.12E-02	4.E+03
Kr-85	4.29E+06	2.72E-01	3.E+04
Kr-87	1.45E+06	9.17E-02	7.E+02
Kr-88	2.18E+06	1.38E-01	3.E+02
Kr-89	1.40E+07	8.90E-01	4.E+01
Kr-90	1.25E+01	7.94E-07	4.E+01
Xe-131m	1.10E+05	6.97E-03	7.E+04
Xe-133m	8.59E+01	5.44E-06	2.E+04
Xe-133	3.11E+07	1.97E+00	2.E+04
Xe-135m	2.27E+07	1.44E+00	1.E+03
Xe-135	2.43E+07	1.54E+00	3.E+03
Xe-137	2.90E+07	1.84E+00	4.E+01
Xe-138	2.32E+07	1.47E+00	7.E+02
Xe-139	1.57E+01	9.93E-07	4.E+01
I-131	1.51E+04	9.57E-04	7.E+00
I-132	5.89E+04	3.74E-03	7.E+02
I-133	4.88E+04	3.09E-03	4.E+01
I-134	1.06E+05	6.72E-03	2.E+03
I-135	6.14E+04	3.89E-03	2.E+02
H-3	2.80E+06	1.78E-01	4.E+03
C-14	3.54E+05	2.24E-02	1.E+02
Na-24	5.42E-01	3.44E-08	3.E+02
P-32	1.34E-01	8.50E-09	2.E+01
Ar-41	2.85E+02	1.81E-05	4.E+02
Cr-51	7.73E+01	4.90E-06	1.E+03
Mn-54	1.47E+02	9.29E-06	4.E+01
Mn-56	1.07E+00	6.80E-08	7.E+02
Fe-55	4.72E+00	2.PPE-07	1.E+02

X	Releases to the atmosphere from an ESBWR reactor	Concentration	Limit value acc. to 10CFR20
Nuclide	MBq/yr	Bq/m^3	Bq/m^3
Fe-59	1.94E+01	1.23E-06	2.E+01
Co-58	3.70E+01	2.35E-06	4.E+01
Co-60	3.18E+02	2.02E-05	2.E+00
Ni-63	4.74E-03	3.01E-10	4.E+01
Cu-64	6.93E-01	4.39E-08	1.E+03
Zn-65	2.80E+02	1.78E-05	1.E+01
Rb-89	2.01E-02	1.27E-09	7.E+03
Sr-89	1.48E+02	9.38E-06	7.E+00
Sr-90	7.65E-01	4.85E-08	2.E-01
Y-90	3.27E-02	2.07E-09	3.E+01
Sr-91	6.72E-01	4.26E-08	2.E+02
Sr-92	4.63E-01	2.93E-08	3.E+02
Y-91	1.74E-01	1.10E-08	7.E+00
Y-92	3.68E-01	2.33E-08	4.E+02
Y-93	7.23E-01	4.58E-08	1.E+02
Zr-95	4.49E+01	2.85E-06	1.E+01
Nb-95	2.44E+02	1.55E-05	7.E+01
Mo-99	1.66E+03	1.05E-04	7.E+01
Tc-99m	2.23E-01	1.41E-08	7.E+03
Ru-103	1.04E+02	6.58E-06	3.E+01
Rh-103m	8.24E-02	5.22E-09	7.E+04
Ru-106	1.35E-02	8.56E-10	7.E-01
Rh-106	1.35E-02	8.56E-10	4.E+01
Ag-110m	5.86E-02	3.71E-09	4.E+00
Sb-124	5.37E+00	3.40E-07	1.E+01
Te-129m	1.63E-01	1.03E-08	1.E+01
Te-131m	5.50E-02	3.49E-09	4.E+01
Te-132	1.41E-02	8.91E-10	3.E+01
Cs-134	1.78E+02	1.13E-05	7.E+00
Cs-136	1.47E+01	9.31E-07	3.E+01
Cs-137	2.69E+02	1.70E-05	7.E+00
Cs-138	8.50E-02	5.39E-09	3.E+03
Ba-140	7.82E+02	4.96E-05	7.E+01
La-140	1.29E+00	8.19E-08	7.E+01
Ce-141	2.66E+02	1.69E-05	3.E+01
Ce-144	1.35E-02	8.53E-10	7.E-01
Pr-144	1.35E-02	8.53E-10	7.E+00
W-187	1.29E-01	8.21E-09	4.E+02
Np-239	8.28E+00	5.25E-07	1.E+02

3.1.1.5 Releases in the course of normal operation of a nuclear power plant in Poland according to the provisions of the Atomic Energy Act

3.1.1.5.1 Requirements set forth in Polish regulations

According to the draft regulations which are to be adopted in Poland, the general objective of atomic nuclear safety is to protect individuals, the society, and the environment by establishing and maintaining effective measures protecting them from radiologic threats. For a nuclear facility, the above-mentioned general objective translates into the basic objective of radiological protection, namely assuring that in the course of normal operation the exposure to ionizing radiation inside the building and to radiation doses resulting from release of radioactive substances are maintained on the lowest achievable level and below the maximum permissible values.

The same requirement - to maintain the doses resulting from release of radioactive substances on the lowest reasonably achievable level and below the maximum permissible values – in force in the United Kingdom for which the above-mentioned designs of EPR, AP1000, and ESBWR reactors were elaborated. The measures taken in the design of each of these reactors measures are sufficient to meet the requirement.

According to further texts of draft regulations of the Council of Ministers, in the case of nuclear power plants with light water reactors or with reactors with pressure channels, the typical safety functions performed by appropriate designs, systems, and equipment consist in "limiting the discharge or release of radioactive waste and radioactive substances that can be found in the air to values that are below the defined limits, in all operation states."

According to §193, a nuclear facility must be provided with appropriate systems for processing radioactive liquids and gases so as to maintain the quantities and concentrations of release of radioactive materials within certain limits in the course of normal operation and of anticipated operational occurrences. The principle of maintaining releases of radioactive materials on the lowest reasonably achievable level must also be observed. In particular, it is necessary to provide appropriate possibility to store gaseous and liquid discharges containing radioactive substances, especially if it is expected that disadvantageous environmental conditions in the vicinity of the site may cause extraordinary restrictions on their release into the environment.

The release limits for nuclear power plants are set by nuclear regulatory authorities. In Poland, the limits have not been defined. Therefore, one can only compare the release values for nuclear power plants with the limits in force in other countries of the European Union. The limits which are in force in France are very stringent and are the product of many years of work on improving the reactors and the operation procedures.

What follows is a verification if the reactors which have been analyzed in the earlier parts of the present document meet these limits.

3.1.1.5.2 Comparisons of three studied types of reactors

Błąd! Nie można odnaleźć źródła odwołania. shows the results of the comparison of the EPR, AP1000, and ESBWR reactor.

Table 3.1.23. Comparison of the limit values defined for new nuclear power plants in France with release values from the nuclear power plant in Flamanville 1, 2 (Generation II reactors) and for Generation III reactors with EPR, AP1000, and ESBWR reactors

NUCLEAR POWER PLANT	Flamanville, 2x1,300 MWe (new limits)		EPR, 1650 MWe	AP1000, per 1000 MWe	ESBWR[19] acc. to the table
Isotopes	Limit	Actual emission	Anticipated/Maximum	Anticipated	Anticipated

Inert gases, TBq/year	45	0.90	0.8 / 22.5	10.3	153
Tritium, TBq/year	5	2.03	0.5/3	13	2.8
Carbon C-14, TBq/year	1.4	0.416	0.35/0.9	0.27	0.35
Iodine, GBq/year	0.8	0.108	0.05/ 0.4	0.6	29
Aerosols, GBq/year	0.8	0.0049	0.004/0.34	1.7	4.6

The EPR reactor has the lowest anticipated release values of inert gases, tritium, iodine isotopes, and aerosols. The AP1000 reactor has the highest anticipated release values of inert gases, tritium, iodine isotopes, and aerosols. The release values of inert gases and iodine isotopes from the ESBWR reactor are two orders of magnitude larger, and of aerosols - three orders of magnitude larger than release values from the EPR reactor; the release values of tritium and carbon C-14 from these two types of reactors are approximately on the same level. The results of the comparison conform to the expectations, because reactors with only one water-steam look cannot prevent releases into the atmosphere as effectively as reactors with two loops separated with a partition consisting of heat exchange pipes in the vapour generator. Unlike in pressurized water reactors, where only a small part of the reactor coolant is vaporized (and discharged through the chemical and volume control system, CVSS, in order to continuously clean and control the boron in the primary loop), in boiling water reactors the whole reactor coolant is continuously evaporated in the turbine condenser. Nevertheless, emissions from ESBWR reactors do result in exceeding the permissible concentrations of radionuclides which are set forth in the 10CFR20 American federal regulations.

For each of the reactors, the radiation doses received by the inhabitants are defined in Chapter 7.3.

3.1.2 Emissions in transient and accident conditions

3.1.2.1 Emissions in transient and accident conditions from Generation II nuclear power plants

3.1.2.1.1 Characteristics of possible accidents in nuclear power plants with water reactors

According to their frequency, possible accidents in Generation II nuclear plants can be divided into three groups:

- moderately frequent accidents;
- rare accidents;
- borderline accidents which should never happen but are assumed in the analysis as borderline cases in order to determine the potential possibility of release of radioactive substances.

In the case of moderately frequent accidents, such as coolant pressure drop as a result of accidental opening of a relief valve, loss of flow in the main supply water circuit, loss of mains power supply, or a single operator error, the situation should be controlled by way of actions that do not lead to consequences larger than reactor shutdown. After the disturbance is eliminated, the nuclear power plant should be capable of resuming operation. Such events may not cause a breach of any of the three barriers which limit the spread of fission products or lead to category 2 and 3 accident conditions, in the absence of other simultaneous accidents.

In the event of rare accidents, such as significant leak of coolant in the primary loop, loss of forced coolant flow, erroneous movements of control rods, or erroneous loading of fuel, there may be small damage to a part of the fuel in the core, and the quantity of released fission products may be larger than in the course of normal operation. The released products may not, however, cause any hazards related to the use of pastures, farmland, etc. by people in areas located outside of the prohibited area. An accident of this type may not cause a category 3 accident condition or lead to the loss of tightness of the primary loop or the safety enclosure.

In the case of borderline accidents, such as rupture of the main primary loop pipeline or secondary loop pipeline, jamming of a pump rotor, or shooting of the control rod, the maximum quantity of fission products defined in regulations concerning the siting of nuclear plants may be released into the environment, but the safety systems that limit the consequences of accidents, shut the reactor down and cool it must remain in good working order.

3.1.2.1.2 Hazard after design condition accidents and hypothetical accidents in Generation II nuclear power plants

The safety principles adopted when designing, building, and operating nuclear power plants have proven to be so effective, that despite the experiences gathered in the course of over ten thousand of reactor-years of operations of nuclear power plants with water moderators and coolants, so far there have been no accidents where any member of the staff or the public would lose their life or health as a result of radiation exposure. The Chernobyl accident did involve loss of health and lives, but it occurred in a reactor which was fundamentally different than a light-water reactor, similar to military reactors which were designed to make plutonium. This accident cannot be included in the health balance of the purely civilian nuclear power sector.

As far as light-water reactors are concerned, the accident with the most serious consequences was the accident at the Three Mile Island (TMI) nuclear power plant, where the reactor core was completely destroyed to the extent that operation of the plant was no longer possible. Nevertheless, the health impact of this particular accident was negligible.

During another accident, that in the Browns Ferry nuclear power plant in 1975, which was caused by a technician who was checking the tightness of a cable duct, the fire destroyed most connections important from safety standpoint. As a result, the emergency core cooling system and all other core water injection systems were lost. The fire was eventually suppressed by injecting water to the cable duct, which involved the risk of short circuits in power cables and of further deterioration of the situation. Despite the very extensive damage in the reactor systems, the fire did not cause any loss of health or lives of any staff members or the public.

An analysis of the conclusions from the fire has resulted in a number of improvements in fire detection and suppression systems in all nuclear power plants, which in many cases required many months of outage. Once this process was completed, the fire safety level in existing nuclear power plants improved significantly. Also, new nuclear power plants were built taking into account the conclusions from the Browns Ferry accident.

Other accidents in nuclear power plants were of more limited scopes and did not lead to serious damage to fuel or release of fission product. Even then damage similar to that which initiated the accident at the Three Mile Island took place, the operators - aware of the errors made at the TMI – brought the nuclear power plant into a safe shutdown condition and prevented any damage to the core. .

According to the criteria adopted by the US Nuclear Regulatory Commission (NRC), the calculated frequency of accidents with core meltdown must be lower than 10^{-4}/reactor-year, and the calculated value of any release of fission products producing, at the distance of 0.8 km from the reactor, a dose absorbed by the whole body in excess of 0.25 Sv, must be less than 10^{-6}/reactor-year[20]. The requirements set forth by US power companies are even more stringent and set the target of reducing the frequency of accidents involving core meltdown to 10^{-5}/reactor-year. In European Union countries, power companies elaborated guidelines similar to the American guidelines, to be adopted as a basis for designing new nuclear power plants[21].

The requirements of the nuclear regulatory authorities are different in different countries, but new nuclear power plants meet the most stringent of them. For example, according to the 2008 decree of the government of Finland[22], the maximum dose for the critical group of people living in the surroundings of a nuclear power plant must not exceed 5 mSv after a class 2 design–basis accident which occurs less than one time per 1000 years of a reactor's operation and 20 mSv after a comprehensive combination of defects which a nuclear power plant must withstand without core meltdown. Releases of fission products in the case of a design-basis accident must not lead to restrictions in the use of the ground and food. The dose after a severe accident has not been defined, but the limits of release of fission products have been set forth. After an accident involving core meltdown, the limit value for release of radioactive substances is such a release that does not cause either severe damage to health among members of the public in the vicinity of the nuclear power plant or long-term restrictions of the use of large areas of soil and water[23].

After 50 years of experiences with the operation of nuclear power plants which are built and operated in accordance with the safety principles defined in Western countries and popularized by international agencies (IAEA), one can conclude that the nuclear power sector is one of the safest sectors of the industry. On the other hand, the example of the RBMK reactors in the former USSR and the Chernobyl accident demonstrate that any deviations from safety rules are not permissible.

Thus, even though the basic principles of safety and the nuclear safety are set above political motives, the defence-in-depth system guarantees that a nuclear power plant will remain safe even in the event of defective equipment and human error.

The organization and safety culture in European Union countries and in Poland appear to guarantee that in practice operation of a nuclear power plant does not lead to any risk to the natural environment or to the health or lives of the people living in its vicinity.

3.1.2.2 Types of accidents adopted in regulations recommended for Poland

The types of accidents which are adopted in the regulations currently recommended for Poland reflect the progress achieved in enhancing the safety of power reactors and sets appropriately high requirements for Generation III and Generation III+ reactors that may be built in Poland.

Art. 36 (f) (2) of the draft amendment of the Atomic Energy Act of 29 November 2000 (Journal of Laws of 2007, no. 42, item 276, as amended), has the following wording:

"The restricted-use area around a nuclear facility covers an area outside of which:

1) during operation of the nuclear facility, which includes regular operation and expected operation events, the yearly effective dose from all routes of exposure does not exceed 0.3 milisivert (mSv);

2) in the event of an accident without core meltdown, there will be no need to evacuate the public or to implement long-term restrictions in the use of soil and water around the power plant, or the "yearly effective dose caused by external radiation from the cloud and from deposits, and as a result of exposure through the respiratory tract, will not exceed 20 milisivert (mSv)"[24].

Art. 3 includes a definition of a severe accident:

"severe accident – accident conditions at a nuclear facility that are more severe than design-basis accidents and lead to significant degradation of the reactor core and, potentially, to significant releases of radioactive substances."

§2 (28) (b) of the draft Regulation of the Council of Ministers concerning requirements for safety analyses conducted prior to applying for a permit to build a nuclear facility and for the content of safety report for a nuclear facility divides accident conditions into the following groups:

- design-basis accidents, which can be further divided into:
  - category 1 design-basis accidents;
  - category 2 design-basis accidents;
- beyond design-basis accidents, which can be further divided into:
  - accidents without significant degradation of the core;
  - severe accidents.

Moreover, the draft Regulation of the Council of Ministers concerning the nuclear safety and radiological protection requirements that must be observed in nuclear facility designs defines design extension conditions as "a collection of sequences of beyond design-basis accidents, selected on the basis of deterministic and probabilistic analyses, for which the design principles and criteria are different than for design-basis accidents, which includes:

- complex sequences,
- selected severe accidents."

Item 6 of the aforementioned draft of the regulation provides that:

The design of a nuclear facility must assure limiting of release of radioactive substances outside of the safety containment of the reactor in accident conditions so that:

in the event of design-basis accidents, no interventions are required at a distance larger than 800 m from the reactor;

in the event of design extension conditions it is not necessary to:

a) take early intervention measures during release of radioactive substances from the safety containment at the distance of more than 800 m away from the reactor;

b) take mid-term intervention measures at any time at the distance of more than 3 km away from the reactor;

c) take long-term intervention measures at the distance of more than 800 m away from the reactor.

Thus, according to the regulations to be in force in Poland, design-basis accidents must be controlled by the reactor safety systems before the core is damaged. Accidents where the core becomes damaged, either partly (for example in the process of fuel melting occurring for a certain time, with the fuel remaining inside the reactor containment), or completely (for example where full core meltdown occurred with the fuel remaining inside the reactor containment (in an AP1000 reactor) or where the molten core is cooled down and kept in the core catcher inside the safety containment (in an EPR reactor)), are classified as severe accidents.

In the regulations in force in most countries of the European Union and adopted by the International Atomic Energy Agency, similarly to the Polish regulations draft, it is considered that nuclear power plant's safety systems are designed so as to limit the consequences of an accident to damage of the jackets of some fuel element and to stop the spread of the accident before core meltdown occurs. The values of emissions and doses during such accidents are demonstrated for the UK EPR reactor. They will be used as reference values for reactors that may be built in Poland.

In US regulations, on the other hand, it is assumed that, despite the presence of safety systems, accidents in a reactor may lead not only to damage to the fuel jacket, but also to partial fuel meltdown. The values of emissions and doses after such accidents are defined in reactor designs submitted to the US nuclear regulatory authorities for approval, e.g. the US EPR or the US AP1000. The values will be used as a measure of the hazard that may occur in Poland after accidents involving core meltdown, that is after events defined in the Polish regulations as severe accidents.

3.1.2.3 Values of releases in the event of design-basis accidents in nuclear power plants with EPR reactors

3.1.2.3.1 Main Design Objectives

Since 1992, Framatome and Siemens, in cooperation with the EDF and the major German power sector operators, have worked on developing the European Pressurized Reactor, also referred to as the Evolutionary Pressurized Reactor (EPR).

Two Design Objectives for the EPR reactor were defined.

Based on a thorough evaluation of the different solutions regarding passive safety systems, a decision was made to define the EPR reactor using an evolutionary approach, that is based on the experiences related to the operation of about 100 nuclear power plants built by Framatome and Siemens.

An objective which was equally important as the adoption of an evolutionary approach was to assure competitiveness of electric energy generation compared to other alternative energy sources. The EPR is to guarantee a significant reduction of the cost of generation of electricity compared to most modern nuclear power plants and large gas-steam power plants. In order to achieve this objective, a decision was made to design high-capacity units, in the order of 1,600 MWe.

The safety is assured by separable systems working in a direct mode. Four separate, redundant loops of all safety systems are installed in four separate buildings or safety building parts which are separated with resistant physical barriers and with assured strict separation (spatial and physical separation) so as to prevent their simultaneous failure caused, for example, by internal factors. Such a quadruple redundancy of the main loops of the safety systems assure flexibility with regards to making the design meet the requirements regarding maintenance and thus reducing the standard reactor downtime. In new generation nuclear power plants, new additional elements and functions are used to meet the safety criteria imposed by relevant nuclear safety authorities regarding improved protection during accidents and incidents, to include reactor core meltdown and its radiological effects, as well as resistance to external threats, in particular plane crashes and earthquakes.

Thus, the evolutionary approach selected by the designers of the EPR reactor constitutes an optimum mix of proven solutions from the most extensive available experiences and innovative solutions necessary to meet new requirements, especially as regards safety.

Class 1,600 MWe EPR reactors are characterized by high efficiency, reduced construction time, longer operation period, improved and more flexible use of fuel, and improved availability, which translates into their outstanding competitiveness with regards to costs per 1 kW of installed power and per 1 kWh of generated energy.

3.1.2.3.2 Recommendations of French and German nuclear safety authorities:

According to the principles set forth by French and German nuclear safety authorities for the next generation PWR reactors, an EPR reactor meets the following criteria:

"Evolutionary" design aimed at taking advantage of the accumulated experience in designing and operating PWR units which are currently in use in France and Germany and in countries where Framatome and Siemens have exported their technologies (Belgium, Brazil, China, Korea, South Africa, Spain, and Switzerland). The EPR is based mostly on the experiences related to the French technology used in N4 reactors and the German Konvoi technology.

Increased safety level. On the one hand, the likelihood of a reactor core meltdown was reduced by improving the availability of the safety systems; on the other hand, the design incorporates solutions aimed at reducing the radiological consequences in the event of a severe accident. In the event of an accident involving no core meltdown, the architecture of the peripheral buildings and the ventilation system eliminate the need to implement protective measures in relation to people living in the vicinity of a damaged nuclear power plant unit. In the event of the highly unlikely, but still considered, situation where the reactor core melts down in low-pressure conditions, the strengthened reactor building and the unique equipment mitigating the consequences of the accident will reduce the radioactive emissions. Only some very limited protective measures would be required. Moreover, the design of the reactor and the concept of the safety containment eliminate the possibility of situations which would cause large emissions at early stages of an accident.

In the case of an EPR reactor, the likelihood of an accident causing a reactor core meltdown – already very low in previous generation reactors – is reduced even further.

Taking potential operation problems into account at early stages of the design works. At the base stage of design works thorough analyses were performed to reduce as much as possible the collective radiological exposure of the nuclear power plant's staff. Maintenance of equipment has been made more effective by assuring easy access. Moreover, the design takes into account the human factor so as to minimize the chance for human errors in the operation of a power unit with an EPR reactor.

3.1.2.3.3 The requirements concerning protection of the environment from radiation adopted in the EPR design in accordance with the European Utility Requirements (EUR)

3.1.2.3.3.1 EUR requirements

The design of an EPR reactor has Design Conditions[25] that cover normal operation, incidents, and accidents, as well as design extension conditions. A separate category is a severe accident which will be described in Chapter 4.3.

In normal operation it is expected that the Design Objectives will assure observance of the applicable limit values of doses for the employees and the public defined by national or international regulatory authorities or licensing authorities. The criteria for incident conditions and accident conditions have values which are considered as appropriate to assure licensing in countries participating in the elaboration of the EUR requirements.

The Design Objectives for design extension conditions are determined so as to avoid the need to take significant protective measures outside of the nuclear power plant. The criteria for limiting the impact of such conditions which exceed the design assumptions would result in limited effects on the public.

In incident conditions, like during normal operation, the dose resulting from direct radiation from the reactor must not exceed 0.1 mSv/a. This value is the same irrespective of the reactor's capacity.

3.1.2.3.3.2 Objectives concerning emissions in accident conditions

Emissions in accident conditions, evaluated using the best evaluation method, must not exceed the targets set for each of the accident categories defined in Appendix B to the EUR document[26]. The relations between the accident categories and the frequency of their initiating events are shown in table 2 of the EUR document[26].

The targets are defined as a linear combination of releases in each of the isotope reference groups. The criteria and the methods of evaluating acceptability of such releases are shown in Annex B for all the accident conditions*.

The emission thresholds are also defined for design extension conditions.

Appendix B lists the acceptance criteria for all accidents within the category 3 and 4 Design Conditions. The criteria are selected so that the releases which do not exceed them constitute little hazard to people in the vicinity of the nuclear power plant and do not require intervention measures affecting the public at the distance of over 800 m away from the reactor. It is also expected that the economic consequences in such cases will be very limited (to the area of several square kilometers and one crop harvest).

Limited impact criteria for design extension conditions accidents.

The meeting of the criteria is verified in the following manner:

- The releases from the nuclear power plant into the atmosphere are divided into 9 isotope reference groups;
- The releases are added and compared with the criterion value in accordance with the following formula:

$$\sum_{i=1}^{9} R_{ig} \cdot C_{ig} + \sum_{i=1}^{9} R_{ie} \cdot C_{ie} < criterion$$

In the formula for the linear combination of releases, Rig and Rie are the total releases during the period of release from the safety containment (on the ground level and from the ventilation stack) for the 9 isotope reference groups.

For sequences where the safety containment remains intact, the period of release must be determined based on the pressure in the containment and the value of the releases. Rig and Rie have three different values, depending on the objective to be verified.

In the case of objective no. 1, R(1)ig and R(1)ie are releases during the first 24 hours; **in the case of objective no. 2**, R(2)ig and R(2)ie are releases during the first 4 days, and in the case of objective no. 3, R(3)Ig and R(3)ie are releases caused by a severe accident. Cig and Cie are coefficients listed in **Błąd! Nie można odnaleźć źródła odwołania.** and **Błąd! Nie można odnaleźć źródła odwołania.**, related to the effects of unit releases into the environment.

To verify if the economic consequences of possible accidents are within the permissible limits, only three isotopes are considered. The releases for each of them are compared to an independent criterion.

Table 3.1.24. Limited impact criteria assuring that no early intervention measures are required more than 800 m away from the reactor.

Isotope group	Release coefficient at the ground level, C_{ig}	Release coefficient at the ventilation stack, C_{ie}
Xe-133	$6.5*10^{-8}$	$1.1*10^{-8}$
I-131	$5.0*10^{-5}$	$3.1*10^{-6}$
Cs-137	$1.2*10^{-4}$	$5.4*10^{-6}$
Te-131m	$1.6*10^{-4}$	$7.6*10^{-6}$

Sr-90	$2.7*10^{-4}$	$1.2*10^{-5}$
Ru-103	$1.8*10^{-4}$	$8.1*10^{-6}$
La-140	$8.1*10^{-4}$	$3.7*10^{-5}$
Ce-141	$1.2*10^{-3}$	$5.6*10^{-5}$
Ba-140	$6.2*10^{-6}$	$3.1*10^{-7}$

$$\sum_{i=1}^{9} R_{ig} \cdot C_{ig} + \sum_{i=1}^{9} R_{ie} \cdot C_{ie} < 5 \cdot 10^{-2}$$

Rig and Rie (expressed in TBq): accumulated releases during the first 24 hours after a design extension conditions accident.

Table 3.1.25. Limited impact criteria assuring that no delayed intervention measures are required more than 3 m away from the reactor.

Isotope group	Release coefficient at the ground level, C_{ig}	Release coefficient at the ventilation stack, C_{ie}
Xe-133	0	0
I-131	$1.2*10^{-6}$	$3.5*10^{-7}$
Cs-137	$5.6*10^{-6}$	$8.9*10^{-7}$
Te-131m	$3.8*10^{-6}$	$7.0*10^{-7}$
Sr-90	$9.9*10^{-7}$	$3.2*10^{-7}$
Ru-103	$1.3*10^{-6}$	$2.2*10^{-7}$
La-140	$2.9*10^{-6}$	$4.8*10^{-7}$
Ce-141	$4.5*10^{-6}$	$8.1*10^{-7}$
Ba-140	$1.5*10^{-6}$	$2.5*10^{-7}$

$$\sum_{i=1}^{9} R_{ig} \cdot C_{ig} + \sum_{i=1}^{9} R_{ie} \cdot C_{ie} < 3 \cdot 10^{-2}$$

R_{ig} and R_{ie} (expressed in TBq): cumulative releases during the first 4 days after the accident.

Table 3.1.26. Limited impact criteria assuring that no long-term intervention measures are required more than 800 m away from the reactor.

Isotope group	Release coefficient at the ground level, C_{ig}	Release coefficient at the ventilation stack, C_{ie}
Xe-133	0	0
I-131	$1.2*10^{-5}$	$7.8*10^{-7}$
Cs-137	$6.5*10^{-5}$	$3.4*10^{-5}$
Te-131m	$2.6*10^{-5}$	$1.3*10^{-6}$
Sr-90	$1.4*10^{-5}$	$7.2*10^{-7}$
Ru-103	$2.3*10^{-5}$	$1.2*10^{-7}$
La-140	$7.9*10^{-5}$	$4.1*10^{-6}$
Ce-141	$7.6*10^{-5}$	$4.0*10^{-6}$
Ba-140	$1.1*10^{-5}$	$5.9*10^{-7}$

$$\sum_{i=1}^{9} R_{ig} \cdot C_{ig} + \sum_{i=1}^{9} R_{ie} \cdot C_{ie} < 1 \cdot 10^{-1}$$

For each reference isotope, the sum of releases on the level of the ground and of the ventilation stack over the whole time of accident should be comparable with reference values listed in the table below.

Table 3.1.27. Criteria of limited impact of an accident on economic effects

Isotope	Reference value (TBq)

I-131	4,000
Cs-137	30
Sr-90	400

3.1.2.3.4 The objectives limiting releases in the event of category 3 and 4 design basis accident.

In the case of accidents classified as category 3 and 4, the same general approach is used as in the case of Design Extension Conditions in order to demonstrate that the project will achieve the following objectives:

- no actions are required more than 800 m from the reactor;
- the economic impact of the accident is limited.

The methodology is similar to that used with regards to the previous three objectives. The difference is the possibility to consider fewer isotopes. It is recommended that releases from a nuclear plant be divided into three isotope groups, added, and compared with one criterion, in accordance with the following formula:

$$\sum_{i=1}^{3} R_{ig} \cdot C_{ig} + \sum_{i=1}^{3} R_{ie} \cdot C_{ie} < kryterium$$

where:

R_{ig} and R_{ie} are total release values at the ground level and at the level of the ventilation stack for the three reference isotopes during the whole period of release from the safety containment.

C_{ig} and C_{ie} are indicators defined in the tables below, related to the impact of unit releases on the environment. The indicators can be used for all design extension conditions accidents.

Table 3.1.28. Objectives related to releases during design-basis accidents aimed to exclude the need to take intervention measures at a distance of more than 800 m.

Isotope group	Release coefficient at the ground level, C_{ig}	Release coefficient at the ventilation stack, C_{ie}
Xe-133	$1.5*10^{-8}$	$3.0*10^{-9}$
I-131	$8.1*10^{-5}$	$5.5*10^{-6}$
Cs-137	$1.5*10^{-4}$	$8.1*10^{-5-}$

$$\sum_{i=1}^{3} R_{ig} \cdot C_{ig} + \sum_{i=1}^{3} R_{ie} \cdot C_{ie} < 1 \cdot 10^{-3}\ forclass\ 3\ DBC$$

The value of the criterion for class 4 accidents is five times larger because such accidents occur much less frequently.

$$\sum_{i=1}^{3} R_{ig} \cdot C_{ig} + \sum_{i=1}^{3} R_{ie} \cdot C_{ie} < 5 \cdot 10^{-3}\ forclass\ 4\ DBC$$

The release values are in TBq units.

The limitations listed in the table below affect the activity of crops and milk after an accident and are more stringent than the limitations of the impact of design extension conditions on the health of people. They pertain to only two isotopes - I-131 and Cs-137 – and have the following values:

Table 3.1.29. Objectives limiting releases considering the economic consequences.

Isotope	Objective for release on the ground level, TBq	Objective for releases at the level of the ventilation stack, TBq.
I-131	10	150
Cs-137	1.5	20

The same objectives apply to class 3 and 4 accidents.

3.1.2.3.5 Assumptions made when evaluating the values of releases from a reactor

Activity in the primary loop coolant can be determined based on the maximum values used in the technical specification for French nuclear power plants. In the case of an EPR reactor, the following values are used:

Activity of iodine in the primary loop in steady state equal to 20 GBq/Mg of iodine-131. Activity of iodine in the primary loop in transient state after change of capacity (iodine peak): 150 GBq/Mg equivalent activity of iodine-131 according to the formula:

I-131 eq = I-131 + I-132 / 30 + I-133 / 4 + I-134 / 50 + I-135 / 10.

Activity in the secondary loop can be calculated based on the following assumptions:

- Coolant activity in the primary loop is equal to the maximum values stipulated in the technical specification;
- Water leaks from the primary loop to the secondary loop at the rate of 20 l/h or 0.48 m^3/day.
- Blowdown of steam generators in accordance with the parameters for full-capacity operation
- The lift coefficients taken into account at the transfer of activity from water to the vapour phase in steam generators are as follows:
  - All inert gases contain in the water move to the vapour phase;
  - As far as other radionuclides are concerned, there are the following options:
    - In a steam generator with ruptured heat exchange pipe, the lift coefficient is 1%. In a steam generator with no ruptured pipes, the lift capacity coefficient is assumed to be equal to 0.25%.
    - The values of releases in the case of ruptured fuel element jacket assumed in the calculations are listed in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.1.30. Rate of release of activity in the case of a defective fuel jacket in an EPR reactor.

	Rate of release from UO2 fuel assumed in the calculations		Rate of release from MOX fuel assumed in the calculations	
Isotope	**Burnout ≤ 47 GWd/t**	**Burnout > 47 GWd/t**	**Burnout ≤ 33 GWd/t**	**Burnout > 33 GWd/t**
Kr-85	8 %	25 %	8 %	50 %
Other inert gases	2 %	8 %	2 %	15 %
Bromine, rubidium, iodine, caesium	2 %	8 %	2 %	15 %

Deposition of fission products: In the formulas describing the deposition of aerosols and molecular iodine in the safety containment, it is assumed that the deposition constants are equal to, respectively, 0.035/h and 0.014/h.

The rates of leaks through the safety containment is assumed, for the interior containment of an EPR reactor (with steel lining) to be equal to 0.3% of its volume per day at the design pressure (5.5 bar).

The efficiency of the filters is assumed to be as follows:

High-efficiency filters: inert gases – 0%; aerosols (to include iodine aerosols) – 99.9%; all other substances – 0%.

High-efficiency filters plus iodine trap: inert gases – 0%; organic iodine – 99%; molecular 99.9%; aerosols (to include iodine aerosols) – 99.9%.

3.1.2.3.6 Accidents involving steam loop rupture outside of the safety containment.

The analysis of the consequences of the steam pipeline rupture outside of the safety containment of an EPR reactor is based on the assumption that immediate rupture with two-side leak takes place in the valve room in one of the safety buildings, upstream of the main cut-off valve on the steam conduit. The pressure in the ruptured pipeline immediately drops to a value at which the defective pipeline is cut off.

Release into the atmosphere occurs through the overflow valves on the steam generators which were not damaged and continues for 8 hours, while release from the damaged steam generator continues for 9 hours (after that time the temperature on the secondary side of the steam generator drops to 100 ^{o}C).

In the event that a peak iodine release occurred before the accident or as a result of the accident, the following pessimistic assumptions are made:

- The control valve on the steam pipeline in loop no. 3 is damaged in the open position, which leads to the pipes in the steam generator being uncovered for 30 minutes and to a direct release of fission products into the atmosphere as a result of flashing in steam generator no. 3. The release ends when the main cut-off valve is closed on the steam conduit, when the pressure in the steam collector drops below 41 bar.
- Loss of one of the two mutually redundant iodine filtration systems in the control room.
- Loss of external power supply is not assumed because the option with available power supply is more hazardous from the standpoint of release of radioactivity into the environment. Moreover, it is assumed that the pipeline was ruptured upstream of the main cut-off valve so that the seizure of this valve in the open position cannot be considered as a single defect.

Of the various situations being considered, the most dangerous is the one with the iodine peak occurring earlier so that the concentration of iodine in the primary loop coolant has reached the maximum value equal[27] to iodine-131 dose equivalent (DE) of 60 µCi/g.

Another scenario under consideration is one where iodine peak occurs simultaneously with the accident involving pipeline rupture, when the rate of release of iodine into the primary loop increases 500-fold.

Moreover, a scenario considered in the case of a severe accident involves simultaneous burn-through of some fuel jackets and meltdown of a part of the fuel; however, such scenarios go beyond design-basis accidents and will not be discussed in this section.

To be on the safe side, it is also assumed that leaks from the primary loop into the ruptured steam generators are released directly into the atmosphere through the ceiling of the building, where the safety valves of the steam generators are located, without any reduction or restriction on the release. Such releases continue for 9 hours, until the loop cools down to 100 ^{o}C.

The potential radiological consequences of such an accident are limited to 2.7 mSv at the boundary of the restricted-use area.

3.1.2.4 Nuclear power plants with AP 1000 reactors

According to the safety documentation of the AP1000 reactor submitted in the United Kingdom[28], the greatest radiological impact results from an accident with rupture of the main pipeline of the primary cooling loop. Such an accident does not involve core meltdown but only to rupture of the fuel jackets. The radiological impact of other design-basis accidents is even less severe.

The fractions of fission products released from the gap between the jacket and the fuel pellets are defined in the US nuclear regulatory authorities 10CFR and in the Regulatory Guide 1.183. **Błąd! Nie można odnaleźć źródła odwołania.** lists such fractions, together with the fractions of releases that occur if the accident is not limited to rupture of fuel jackets but involves fuel meltdown.

In the case of design-basis accidents which do not involve fuel meltdown, the relative emission values (per unit of reactor's capacity) in AP1000 reactors do not exceed the relative emission values for EPR reactors. At the same time, one must keep in mind that the electric capacity of EPR reactors, which is equal to 1,650 MWe, is greater than that of AP1000 reactors, which is equal to approx. 1,100 MWe. Thus, one can assume, with accuracy that is sufficient for the purpose of this evaluation, that emissions calculated for an EPR reactor and for accidents not involving core meltdown are representative of other Generation III reactors.

The calculations included in the safety reports for the AP100 reactor are based on the assumption, which conforms to the requirements set forth by the US nuclear regulatory authority, that a radiological assessment assumes that first the activity contained in the primary loop coolant is released into the containment in 10 minutes, then the activity contained in the gap under the fuel jacket is released in 30 minutes, and then the core melts down in 1.3 hours while releasing the activity contained in the fuel. These assumptions are not appropriate for AP1000 reactors which are designed specifically to prevent core meltdown. Nevertheless, since such assumptions correspond to the traditional model of a severe accident which is defined in the NRC guidelines RG 1.183[29] and RG 1.145, they will be used to describe the consequences of severe accidents in Generation III reactors.

Table 3.1.31. Fractions of fission products released during a maximum design-basis accident assumed in the safety analyses of AP1000 reactors according to the RG 1.183.

Group of activity in a PWR reactor core	Fraction releases inside the safety containment		
	Early release from the gap under the jacket	Release during the core meltdown phase	Total release
Inert gases	0.05	0.95	1.0
Halogens	0.05	0.35	0.4
Alkali metals	0.05	0.25	0.3
Tellurium	0.00	0.05	0.05
Ba, Sr	0.00	0.02	0.02
Precious metals	0.00	0.0025	0.0025
Cerium	0.00	0.0005	0.0005
Lanthanides	0.00	0.0002	0.0002

The proportion of the different forms of iodine is assumed in accordance with the model defined in the NUREG-1465[30] document, namely:

- Aerosol 95%
- Molecular 4.85%
- Organic 0.15%

The quantity of fission products in the core is assumed for burnout corresponding to the end of a fuel campaign, with reactor power 2% higher than the nominal power[31]; the values are defined in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.1.32. Quantity of fission products in the core of an AP1000 reactor for thermal power of the core equal to 3,468 MWt (2% above the design power of 3.400 MWt)

Nuclides activity (Ci)			Nuclides activity (Ci)		
Iodine	I-130	$3.66*10^{6}$	Inert gases	Kr-85m	$2.63*10^{7}$
	I-131	$9.63*10^{7}$		Kr-85	$1.06*10^{6}$
	I-132	$1.40*10^{8}$		Kr-87	$5.07*10^{7}$
	I-133	$1.99*10^{8}$		Kr-88	$7.14*10^{7}$
	I-134	$2.18*10^{8}$		Xe-131m	$1.06*10^{6}$
	I-135	$1.86*10^{8}$		Xe-133m	$5.84*10^{6}$
Caesium	Cs-134	$1.94*10^{7}$		Xe-133	$1.90*10^{8}$
	Cs-136	$5.53*10^{6}$		Xe-135m	$3.87*10^{7}$
	Cs-137	$1.13*10^{7}$		Xe-135	$4.84*10^{7}$
	Cs-138	$1.82*10^{8}$		Xe-138	$1.65*10^{8}$
	Rb-86	$2.29*10^{5}$	Sr & Ba	Sr-89	$9.66*10^{7}$
Tellurium	Te-127m	$1.32*10^{6}$		Sr-90	$8.31*10^{6}$
	Te-127	$1.02*10^{7}$		Sr-91	$1.20*10^{8}$
	Te-129m	$4.50*10^{6}$		Sr-92	$1.29*10^{8}$
	Te-129	$3.04*10^{7}$		Ba-139	$1.78*10^{8}$
	Te-131m	$1.40*10^{7}$		Ba-140	$1.71*10^{8}$
	Te-132	$1.38*10^{8}$	Cerium	Ce-141	$1.63*10^{8}$
	Sb-127	$1.03*10^{7}$		Ce-143	$1.52*10^{8}$
	Sb-129	$3.10*10^{7}$		Ce-144	$1.23*10^{8}$
Ruthenium	Ru-103	$1.45*10^{8}$		Pu-238	$3.83*10^{5}$
	Ru-105	$9.83*10^{7}$		Pu-239	$3.7*10^{4}$
	Ru-106	$4.77*10^{7}$		Pu-240	$4.94*10^{4}$
	Rh-105	$9.00*10^{7}$		Pu-241	$1.11*10^{7}$
	Mo-99	$1.84*10^{8}$		Np-239	$1.93*10^{9}$
	Tc-99m	$1.61*10^{8}$			

Regardless of the formal NRC regulations which require including the release of fission products after partial fuel meltdown in the activity emitted from AP1000 reactors after design-basis accidents, one can expect releases from AP1000 reactors to be actually similar to those from EPR reactors. This will be the assumption in evaluation of releases in the case of severe accidents in the following parts of the present document.

In the case of accidents involving rupture of the steam loop outside of the safety enclosure, the radiological consequences can be assessed assuming that before the accident the reactor worked with the fraction of damaged fuel elements equal to 0.25% of the total fuel in the core and that due to the leaks in the heat exchange pipes in the steam generators the iodine activity gradually collected in the secondary loop. It is assumed that once the steam collector was ruptured, the flow of supply water to the damaged steam generator will be cut off and the generator will become dewatered. The iodine isotopes transported with the primary loop coolant into the secondary loop are emitted directly into the atmosphere. The reactor is cooled by evaporating the water from the steam generators that were not damaged.

If the iodine peak occurred before the accident, it is assumed that in the secondary loop coolant there is iodine I-131, in concentration equal to dose equivalent of 0.1 µCi/g, which constitutes 10% of the maximum concentration of iodine in the primary loop coolant in a balanced state. The concentration of alkali metals in the secondary loop water is also assumed to be equal to 10% of the concentration in the primary loop coolant in a balanced state. The rate of the leaks through each steam generator prior to the accident is assumed to be on the level of 150 gallons of coolant a day (or 0.567 m^3/day), which is an significantly exaggerated value.

The leaks take place through three paths:

- The secondary loop water is released into the environment as steam through the ruptures in the pipeline and it lifts the iodine and alkali metals isotopes it contains.
- Any leaks of the coolant from the primary loop to the secondary loop through the steam generator are released into the environment and (in principle) lift the iodine and alkali metals isotopes they contain (not taking into account the separation of iodine between the liquid phase and the gaseous phase or the iodine deposits on pipeline walls.
- The coolant which leaks from the primary loop into the steam generator that was not damaged is mixed with the secondary loop coolant and increases the concentration of activity in the secondary loop water. Even though when steam flows out of the steam generator that was not damaged iodine is separated into the liquid phase and the gaseous phase, the present analysis makes the cautious assumption that any activity transmitted into the secondary loop becomes released.

It is assumed that the time of increased releases of iodine into the primary loop (iodine peak) prior to the accident is 6 hours. This causes an increase of activity in the primary loop to 280 µCi/g dose equivalent Xe-133. The calculated dose values (see section 7.4.2.3) are larger than those from EPR reactors.

3.1.2.5 Nuclear power plants with ESBWR reactors

3.1.2.5.1 Types of accidents in ESBWR reactors

According to the American ANSI standard, design-basis accidents include events with frequency higher than 1 time per one million years.[32] Consequently, the design of the ESBWR reactor assumes that events that are less frequent are not included among design-basis accidents. This assumption conforms to the provisions of the draft regulation of the Polish Council of Ministers.

Anticipated operational occurrences (AOO) are events that, according to the 10CFR, take place one time during the useful life of a reactor. Because the useful life of an ESBWR reactor is 60 years, AOO cover all events whose frequency is 1 per 60 years; nevertheless, the design of an ESBWR reactor assumes a broader range, 1 time per 100 years (a more conservative assumption).

The provisions of the 10 CFR define accidents as any and all events which involve damage to one of the barriers preventing the release of fission products, which leads to radiological consequences outside of the nuclear power plant.

Because the regulations which set forth the actions taken by nuclear regulatory authorities when analyzing the safety of a nuclear power plant (Standard Review Plan) require the design basis to include all initiating occurrences involving a single defect or operator error, the ESBWR reactor design takes into consideration normal operation, to include anticipated operating occurrences, namely:

- infrequent incidents;
- accidents;
- external events;
- natural phenomena.

The most dangerous are the following accidents:

- loss of coolant (pipeline rupture) inside the safety containment;
- rupture of the main steam collector outside of the safety containment;
- accidents occurring during handling of spent fuel.

3.1.2.5.2 Accident involving damage to 1000 fuel rods in an ESBWR reactor

For a number of accidents, the number of fuel rods which fail due to transition boiling was assumed to be limited to 1,000. Such cases include the following accidents:

- defective pressure controller – closing of the control valves and valves on the turbine bypasses;
- generator load discharge connected with failure of a turbine bypass;
- shutdown of a turbine with complete loss of a turbine bypass.

The assumptions made for the purpose of evaluating the emissions are shown in the table below.

Table 3.1.33. The parameters assumed to calculate emissions in ESBWR reactors in the event of failure of 1,000 fuel rods.

Parameter	Value
A. Power, MWt	4590
B. Number of fuel assemblies in the core	1132
C. Activity of fission products released into the coolant	Acc. to RG 1.183
E. Number of failed fuel rods	1000
F. Radial coefficient of unequal distribution for defective fuel rods.	1,5
II. Data and assumptions to evaluate the released activity	
A. Fraction of iodine released from damaged fuel.	10%
Fraction of gaseous fission products released from damaged fuel rods	10%
Fraction of alkali metals released from damaged fuel rods	12%
B. Fraction of iodine released from reactor coolant	10%
Fraction of inert gases released from coolant	100%
Fraction of alkali metals released from coolant	1%
C. Fraction of iodine released from condenser	10%
Fraction of inert gases released from condenser	100%
Fraction of alkali metals released from condenser	1%
Quantity of fission products released into the environment	See the table below

Table 3.1.34. Activity of isotopes released into the atmosphere of the safety containment from the primary loop of an ESBWR reactor (MBq) after failure of 1,000 fuel rods.

Radioisotope	Activity
Kr-85	$8.47*10^{7}$
Kr-85m	$1.88*10^{9}$
Kr-87	$3.63*10^{9}$
Kr-88	$5.11*10^{9}$
Rb-86	$1.94*10^{7}$
I-131	$6.82*10^{9}$
I-132	$9.92*10^{9}$
I-133	$1.40*10^{10}$
I-134	$1.55*10^{10}$
I-135	$1.32*10^{10}$

Table 3.1.35. Cumulative releases of fission products into the environment after failure of 1,000 fuel rods in an ESBWR reactor (MBq)

Isotope	2 hours	8 hours	24 hours
Kr-85	$7.07*10^{4}$	$2.82*10^{5}$	$8.44*10^{5}$
Kr-85m	$1.34*10^{6}$	$3.56*10^{6}$	$4.77*10^{6}$
Kr-87	$1.79*10^{6}$	$2.65*10^{6}$	$2.69*10^{6}$
Rb-86	1.61	6.42	1.89*10
I-131	$5.67*10^{4}$	$2.24*10^{5}$	$6.49*10^{5}$
I-132	$6.12*10^{4}$	$1.23*10^{5}$	$1.34*10^{5}$
I-133	$1.13*10^{5}$	$4.09*10^{5}$	$9.42*10^{5}$
I-134	$6.24*10^{4}$	$7.84*10^{4}$	$7.86*10^{4}$
I-135	$9.85*10^{4}$	$2.95*10^{5}$	$4.63*10^{5}$
Xe-133	$1.16*10^{7}$	$4.54*10^{7}$	$1.30*10^{8}$
Xe-135	$3.57*10^{6}$	$1.15*10^{7}$	$2.05*10^{7}$
Cs-134	$1.36*10^{2}$	$5.44*10^{2}$	$1.63*10^{3}$
Cs-136	4.73*10	$1.88*10^{2}$	$5.50*10^{2}$
Cs-137	8.84*10	$3.53*10^{2}$	$1.06*10^{3}$

3.1.2.5.3 Accidents with failure in the radioactive waste systems of ESBWR reactors

Tab. 3.1.36 Parameters assumed for the purpose of evaluation of radiological effects in the radioactive waste system in ESBWR reactors

Parameter	Value
A. Quantity of fission products	Tables 12.2-13a to 12.2-13g
B. Fraction of released iodine	100%
C. Duration of release	Immediate
II. Control room parameters	
A. Control room volume, m^3	$2.2*10^{3}$
B. Unfiltered air intake, litres	200
C. Length of stay indicators	Acc. to RG 1.183
C. Released activity	See the table below

Table 3.1.37. Releases into the atmosphere after a failure in the radioactive waste system (MBq)

Isotope	Activity (MBq)
I-131	$9.7*10^{4}$
I-132	$9.4*10^{3}$

Isotope	Activity (MBq)
I-133	$7.8*10^{4}$
I-134	$6.2*10^{3}$
I-135	$3.1*10^{4}$
Total for iodine isotopes	$2.2*10^{5}$

3.1.2.5.4 Accidents occurring during handling of spent fuel in ESBWR reactors

Table 3.1.38. Releases into the environment in the case of an accident occurring during handling of spent fuel in an ESBWR reactor

Isotope	Activity (MBq)
I-131	$4.4*10^{6}$
I-132	$2.9*10^{3}$
I-133	$2.8*10^{6}$
I-134	$3.2*10^{-2}$
I-135	$4.6*10^{5}$
Kr-85m	$7.8*10^{6}$
Kr-85	$1.5*10^{7}$
Kr-87	$5.8*10^{2}$
Kr-88	$1.2*10^{6}$
Xe-133	$1.1*10^{9}$
Xe-135	$6.6*10^{7}$

3.1.2.5.5 Accidents involving rupture of the steam collector of an ESBWR reactor outside of the safety containment

Such accidents do not cause damage to fuel. The only activity is the radioactivity in the primary coolant and steam loop present before the accident.

Releases into the environment are not filtered and occur directly from the turbine building into the atmosphere. The calculations were made assuming that the complete activity contained in the steam is released into the atmosphere.

Table 3.1.39. Releases into the atmosphere after rupture of the steam collector outside of the safety containment of an ESBWR reactor[33]

Isotope	Activity in balanced state, MBq	Peak iodine activity, MBq	Isotope	Activity in balanced state, MBq	Peak iodine activity, MBq
Co-58	$1.4*10^{3}$	$1.4*10^{3}$	Te-131m	$1.3*10^{3}$	$1.3*10^{3}$
Co-60	$2.7*10^{3}$	$2.7*10^{3}$	Te-132	$1.4*10^{2}$	$1.4*10^{2}$
Kr-85	1.7	1.7	I-131	$2.4*10^{5}$	$4.9*10^{6}$
Kr-85m	$4.4*10^{2}$	$4.4*10^{2}$	I-132	$2.3*10^{6}$	$4.6*10^{7}$
Kr-87	$1.4*10^{3}$	$1.4*10^{3}$	I-133	$1.7*10^{6}$	$3.4*10^{7}$
Kr-88	$1.4*10^{3}$	$1.4*10^{3}$	I-134	$4.2*10^{6}$	$8.5*10^{7}$
Rb-86	0.0	0.0	I-135	$2.4*10^{6}$	$4.7*10^{7}$
Sr-89	$1.4*10^{3}$	$1.4*10^{3}$	Xe-133	$5.9*10^{2}$	$5.9*10^{2}$
Sr-90	9.4*10	9.4*10	Xe-135	$1.6*10^{3}$	$1.6*10^{3}$
Sr-91	$5.2*10^{4}$	$5.2*10^{4}$	Cs-134	$3.7*10^{2}$	$3.7*10^{2}$
Sr-92	$1.2*10^{5}$	$1.2*10^{5}$	Cs-136	$2.4*10^{2}$	$2.4*10^{2}$
Y-90	9.4*10	9.4*10	Cs-137	$9.7*10^{2}$	$9.7*10^{2}$
Y-91	$5.5*10^{2}$	$5.5*10^{2}$	Ba-139	0.0	0.0

Isotope	Activity in balanced state, MBq	Peak iodine activity, MBq	Isotope	Activity in balanced state, MBq	Peak iodine activity, MBq
Y-92	$7.6*10^4$	$7.6*10^4$	Ba-140	$5.5*10^3$	$5.5*10^3$
Y-93	$5.2*10^4$	$5.2*10^4$	La-140	$5.5*10^3$	$5.5*10^3$
Zr-95	$1.1*10^2$	$1.1*10^2$	La-141	0.0	0.0
Zr-97	0.0	0.0	La-142	0.0	0.0
Nb-95	$1.1*10^2$	$1.1*10^2$	Ce-141		$4.0*10^2$
Mo-99	$2.7*10^4$	$2.7*10^4$	Ce-143		0.0
Tc-99m	$2.7*10^4$	$2.7*10^4$	Ce-144	4.0*10	4.0*10
Ru-103	$2.7*10^2$	$2.7*10^2$	Pr-143	0.0	0.0
Ru-105	0.0	0.0	Nd-147	0.0	0.0
Ru-106	4.0*10	4.0*10	Np-239	$1.1*10^5$	$1.1*10^5$
Rh-105	0.0	0.0	Pu-238	0.0	0.0
Sb-127	0.0	0.0	Pu-239	0.0	0.0
Sb-129	0.0	0.0	Pu-240		0.0
Te-127	0.0	0.0	Pu-241	0.0	0.0
Te-127m	0.0	0.0	Am-241	0.0	0.0
Te-129	0.0	0.0	Cm-242	0.0	0.0
Te-129m	$5.5*10^2$	$5.5*10^2$	Cm-244	0.0	0.0

3.1.2.6 Reference nuclear power plant for conditions present in Poland according to the requirements set forth in the Atomic Energy Act

The values listed above indicate that emissions during design-basis accidents for the three analyzed types of reactors are significantly different. The largest difference can be seen when comparing the effects of rupture of the steam pipeline outside of the safety enclosure. While the emissions associated with such accidents in EPR and AP1000 reactors are not large, the emissions in ESBWR reactors are large (especially the release of iodine dissolved in the medium circulating in the primary loop). Even though, after an accident involving rupture of the steam pipe in an ESBWR reactor, the main cut off valves become closed (which prevents the loss of coolant in the core), the inert gases and the iodine isotopes which were in the loop outside of the containment at the moment when the accident started are released into the environment. If the content of iodine in the loop before the accident is in a balanced state, the release into the atmosphere is 2,4*105; if an iodine release peak occurred before the accident (for example due to the transient state during reactor start-up), the release into the atmosphere is estimated to be $4.9*10^6$ MBq. As will be described in the chapter on the radiological consequences of design-basis conditions, such high releases in ESBWR reactors result in high doses, which do fit within the limits permissible according to the US regulations, but much higher than the limit doses permissible in most countries of the European Union. In the case of an AP1000 reactor, the content of iodine in the steam loop is much lower, because the only sources of iodine are the leaks through the heat exchange pipes in the steam generator, which should remain tight.

In the case of an EPR reactor, the additional reductions of emissions result from the design characteristics of this reactor, which were described in section 7.4.1.4.

The regulations in force in Poland and their proposed modifications do not define permissible emissions during design-basis accidents and, instead, use the limit doses at the boundary of the restricted-use area. Consequently, the present document also focuses on the definition of dose limit values.

3.1.3 Emissions in the event of severe accidents

3.1.3.1 Nuclear power plants with EPR reactors

3.1.3.1.1 Frequency of severe accidents in EPR reactors

An analysis of the characteristics of EPR reactors demonstrates a very high conformance of the reactor with the EUR requirements.[34] In particular, the EPR reactor meets the requirements concerning low frequency of accidents involving core failure, as defined in section 2.1-2.6 of the EUR.

The probability objectives defined in the EUR are as follows:

- total frequency of core failure due to all causes must be less than 10^{-5} per reactor-year (RY);
- total frequency of exceeding the criteria for limited impact of radioactivity releases on the environment (Criteria for Limited Impact - CLI), defined in Annex B to the EUR, must be less than 10^{-6} per reactor-year;
- total frequency of sequences which may potentially lead to early rupture of the safety containment or to very large releases of radioactivity must be much less than the aforementioned value of the criteria for limited impact (10-6 per reactor-year).

The results of the evaluation of the UK EPR reactor are as follows: [34]

- the total core damage frequency CDF = $6.8*10^{-6}$/R-Y, to include due to internal failures in the plant $6.1*10^{-7}$, and due to external threats^{-7}.$2*10^{-7}$;
- the total frequency of exceeding the criteria for limited impact is less than 10^{-6}/R-Y;
- the frequency of delayed safety containment failures is $5.3*10^{-8}$/R-Y; the frequency of early safety containment failures is $3.9*10^{-8}$/R-Y. This is, respectively, 9% and 6% of the frequency of core damage frequency caused by internal accidents.

3.1.3.1.2 Value of emissions after a severe accident in an EPR reactor

According to US regulations, analyses of US EPR reactors assume the maximum design-basis accident to be one involving rupture of the primary loop where failure of fuel jackets is followed by fuel meltdown. The course of such an accident is defined in the RG 1.183 guidelines, which assume that the coolant leak out period (10 minutes) is followed by failure of the fuel jacket and release of the fission products from the gap between the jacket and the fuel (30 minutes), and then by fuel meltdown (90 minutes). Thus, an accident of this type is a severe accident with fuel meltdown.

Table 3.1.40. Phases of the accident after primary loop rupture according to US regulations (RG 1.183)

	PWR		BWR	
Phase	**Start**	**Duration**	**Start**	**Duration**
Release from under the jacket	30 s	30 minutes	2 minutes	30 minutes
Early fuel meltdown	30 minutes	90 minutes	30 minutes	90 minutes

The fractions of fission products released during the particular phases of the accident stipulated for LOCA type accidents in a PWR reactor in the RG 1.183 are shown in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.1.41. Fractions of fission products released into the safety containment during the particular phases of a LOCA type accident in a PWR reactor

Accident phase	Release from under the	Early release during core	Total release

	jacket	meltdown in the reactor containment	
Inert gases	0.05	0.95	1.0
Halogens	0.05	0.35	0.4
Alkali metals	0.05	0.25	0.30
Tellurium	0.00	0.05	0.05
Ba, Sr	0.00	0.02	0.02
Precious metals	0.00	0.0025	0.0025
Cerium	0.00	0.0005	0.0005
Lanthanum	0.00	0.0002	0.0002

The design of an EPR reactor includes a number of safety measures which are intended not only to reduce the frequency of severe accident but also to limit their impact. As a result, the values of releases from EPR reactors are limited, as stipulated in the EUR.

3.1.3.2 Nuclear power plants with AP 1000 reactors

Release values during accidents involving core meltdown in AP1000 reactors are (similarly to the EPR reactors), defined in the US nuclear regulatory authorities guidelines, RG 1.183. The quantity of activity in the core of an AP1000 reactor and the fractions of activity that, according to RG 1.183, are emitted from the core of an AP1000 reactor during an accident involving core meltdown are stipulated in the tables above.

The fractions of activity that are released from the safety containment into the environment of the nuclear power plant depend on the condition of the containment. The probability analysis for an AP1000[35] reactor considers the following containment condition categories:

3.1.3.2.1 IC (intact containment) release category.

It is assumed that leaks from the containment occur as provided for in the design, taking into account the external cooling of the molten core by the reactor containment, with control of the concentration of hydrogen in the containment and passive cooling of the containment. The most likely path for the leaks runs from the containment to the auxiliary building. To model the deposition of aerosols in the ancillary building, the release reduction coefficient equal to 1/3 was introduced. In the additional evaluation which does not include this coefficient (marked as Direct), the release values were calculated assuming that the releases occur directly into the reactor's surroundings.

3.1.3.2.2 BP (bypass) release category – safety containment bypass.

It is assumed that fission products flow from the core through the ruptured pipes in the steam generator into the secondary loop and then into the atmosphere through the safety valve which is stuck in the open position. This is a category of very large early releases outside of the safety containment (Large Early Release Frequency - LERF) for the AP1000 reactor.

3.1.3.2.3 CI release category

This category covers accidents where the safety containment is not insulated from the surroundings. As a result, the fission products released from the core to the inside of the safety containment also escape into the nuclear power plant's surroundings. CI releases contribute to the frequency of LERF releases.

3.1.3.2.4 CFE release category

This category covers releases of fission products caused by failure of the safety containment during a severe accident which may occur during core meltdown and relocation. Fission products are released into the containment and, before they settle on its internal surface, the containment is ruptured (e.g.

due to burning of hydrogen or a steam explosion) and the fission products escape into the environment. This category is also taken into consideration when calculating the frequency of LERF releases.

3.1.3.2.5 CFI release category

This category covers those releases of fission products that are due to rupture of the containment after core meltdown and relocation, within 24 hours after the core meltdown process starts, e.g. as a result of burning of hydrogen or long-time heating of the containment with the after-heat. The fission products are released into the interior of the safety containment. The atmosphere in the containment is well mixed and before containment failure the process of aerosols deposition begins.

This category contributes to large releases but it is not a process included in the LERF release category.

3.1.3.2.6 CFL release category

This category covers release of fission products into the environment after the safety containment is damaged after 24 hours as a result of increased pressure inside the containment due to the after-heat. The containment cracks due to the lack of cooling of the containment. Before the containment is damaged, the process of deposition of aerosols on surfaces inside the containment takes place. This is an example of a large, although not early, release of fission products.

3.1.3.2.7 CFV release category

This category covers releases release of fission products into the atmosphere due to ventilation of the containment after 24 hours. The operator removes some air from the containment in order to lower the pressure. This leads to large, although not early, release of radioactivity. The probability analyses assume that the frequency of such events in AP1000 reactors is equal to zero.

3.1.3.2.8 Direct release category

This category covers release of fission products directly into the environment, without deposition of aerosols in the auxiliary building.

Table 3.1.42. Fractions of fission products released from the inside of the safety containment into the environment within 24 hours after a severe accident of an AP1000 reactor for different categories of safety containment failure.

Cat.	Xe, Kr	CsI	TeO_2	SrO	MoO_2	CsOH	BaO	La_2O_3	CeO_2	Sb
IC	1.0E-3	1.2E-5	9.5E-6	1.1E-5	1.3E-5	1.1E-5	1.2E-5	1.3E-6	1.5E-6	1.3E-5
BP	1.0E-0	3.2E-1	2.5E-1	3.6E-3	4.5E-2	2.1E-1	8.9E-3	1.3E-4	8.0E-4	2.2E-1
CI	6.4E-1	4.6E-2	2.1E-2	2.0E-2	4.0E-2	1.8E-2	3.2E-2	2.4E-4	7.4E-4	2.7E-2
CFE	8.1E-1	5.7E-2	3.2E-2	3.5E-3	1.4E-2	5.5E-2	5.3E-3	6.5E-5	2.5E-4	2.3E-2
CFI	8.0E-1	3.3E-3	5.0E-3	2.2E-2	9.3E-3	3.3E-3	1.7E-2	8.3E-3	1.1E-2	7.2E-3
CFL	1.3E-3	1.2E-5	8.5E-6	1.7E-5	1.7E-5	1.1E-5	1.7E-5	8.5E-6	9.0E-6	1.7E-5
DIRECT	3.0E-3	3.6E-5	2.9E-5	3.3E-5	3.9E-5	3.3E-5	2.8E-5	3.9E-6	4.5E-6	3.9E-5

3.1.3.3 Nuclear power plants with ESBWR reactors

In the case of boiling water reactors - similarly to pressurized water reactors – a representative severe accident is considered to involve rupture of the primary loop with meltdown of a part of fuel (in accordance with the assumptions defined in the methods of evaluation of releases after reactor accidents set forth in the US RG 1.183 guidelines).

3.1.3.3.1 Rupture of primary loop inside the safety containment (LB LOCA)[36]

Table 3.1.43. Data and assumptions for analyses of accidents involving rupture of the primary loop of an ESBWR reactor inside the safety containment

I. Data and assumptions for evaluation of fission products releases	
A. Power, MWt	4,590
B. Fraction of activity in the core released during the accident	RG 1.183, Table 1
C. Chemical composition of iodine isotopes	
Iodine in molecular form, I2, %	4.85
Molecular (mostly CsI), %	95
Organic, %	0.15
D. Time until fuel meltdown starts, min.	20
E. Releases from the core	Table 15B-1
II. Data and assumptions for evaluation of radioactivity releases	
A. Primary safety containment	
Leak value, %/day	0,5
Fraction of the leak flowing into the reactor building (leak, %/day)	0.98 (0,49)
Fraction of the leak flowing into the ring around the containment (leak, %/day)	0.02 (0,01)
Volume, m^3	7,206
Rate of elimination of molecular iodine, h-1 (0-12 h)	0.92
Rate of elimination of aerosols, h-1	
0 – 0.333 h	0.0
0.333 – 0.833 h	5.0
0.833 – 2.333 h	3.0
2.333 – 3.0 h	1.0
3.0 – 4.0 h	0.8
4.0 – 5.0 h	1.0
5.0 – 6.0 h	0.6
6.0 – 7.0 h	0.4
7.0 – 9.5 h	0.2
9.5 – 12.0 h	0.1
>12.0 h	0.0
B. Reactor building	
Leak rate, %/day	50
Mixing indicator, %	40
Volume, m^3	60,500
C. Condenser data	
Free volume, m^3	6,230
Fraction of volume significant to the course of the accident, %	20
Coefficients of iodine elimination	
Molecular, %	99.5
Molecular, %	99.5
Organic, %	0
D. Data of the main cut-off valve on the steam collector, MSIV	
Leaks of the MSIV valve (total on all lines), m3/min.	0.0623
Deposition coefficients	0 (Not Credited)
III. Control room parameters	
A. Control room volume, m^3	2,460
B. Flow rate, m^3/min.	2.83
C. Unfiltered leak into the control room, m^3/min.	0.0113
D. Indicators of stay time in the control room	
0 – 1 day	1.0
1 – 4 days	0.6
4 – 30 days	0.4

3.1.3.4 Emissions during severe accidents from the types of reactors under consideration compared to the requirements in different countries

Different emission limits in the case of severe accidents have been defined in each country; in many cases instead of emission limits, limits of permissible doses to individuals or collective doses to the public were used. In order to make the requirements uniform, EU utilities companies introduced the EUR guidelines which define the limits of emissions after design basis conditions and after severe accidents (described in section 7.1.2.3.3.1).

For the purpose of comparison, data for several selected countries is provided below:

Canada

The Large Release Frequency (LRF) outside of the nuclear power plant caused by internal events (accidents) in a heavy water CANDU-9 reactor which require evacuation of inhabitants of the adjacent areas: 10^{-6}/R-Y[37].

Finland

The natural safety features of a nuclear power plant must guarantee that even in the case of core meltdown the fraction of solid fission products released into the atmosphere does not exceed 0.1% of their content in the core[38]. When applying for a permit to build a new nuclear power plant, the investor must prove that during a severe accident the release will not exceed 10 TBq of Cs-137 with the maximum permissible frequency of 10^{-6}/R-Y.

France

The likelihood that a nuclear power plant becomes a source of unacceptable radiological consequences must not exceed 10^{-6}/R-Y.

Germany

The total frequency of beyond-design condition failures must be within 10-4 to 10^{-5}/R-Y, and the frequency of accidents with large early release of radioactivity must be at least 10 times lower.

Japan

The area where, in the case of a hypothetic accident, the effective dose for an adult exceeds 250 mSv and the equivalent dose in the thyroid exceeds 1,500 mSv, is a restricted-use area.[39]. Usually, the radius of such an area, which corresponds to the restricted-use area in the Polish technology (basically with no permanent residents) is 400 m, and the radius of a low population density area is 1,000 m.

Russia

In new nuclear power plants, the likelihood of accidents with consequences exceeding the permissible limits (evacuation of a population centre of more than 100,000 inhabitants) must be less than 10-7/R-Y.[40] The release limit in severe accidents is considered to be 100 TBq of Cs-137 or 1000 TBq of I-131. In the case of smaller releases at the distance of over 25 km from a nuclear power plant, additional intervention measures are not required, with the exception of restrictions of consumption of local food products.[41]

The likelihood of death due to the presence of a nuclear plant which is less than 10-6/year is considered to be negligible.[42]

Sweden

The limit core damage frequency must be less than 10-5/R-Y and the safety containment must remain intact. Releases of radioactive substances during a severe accident, which cause contamination of the ground, such as caesium and iodine, must be less than 0.1% of their content in the core. This limit applies to nuclear power plants with thermal power equal to MWt; for larger capacity plants it must be appropriately adjusted.[43] Accident sequences of extremely low probability do not have to be considered.[44]

United Kingdom

According to the HSE definition, a severe accident is one which leads to a dose of 100 mSv at the distance of 3 km.[45] According to the paper by M. J. Lewis[46], release of 0.1% of caesium and iodine from the Sizewell B nuclear power plant (which was equal to 3,000 TBq of I-131 and 200 TBq of Cs-137) causes similar consequences. In moderate weather conditions, such a release does not lead to exceeding the 1st Emergency Reference Level (ERL) more than 3,500 m away from the nuclear plant; in bad weather conditions, the dose in the thyroid gland will exceed 1 ERL at the distance of up to 15 km.

USA

The frequency of large releases, which are defined as releases causing an effective dose in excess of 250 mSV at the distance of 800 m within 24 hours, must be less than 10-6/R-Y.[47] [48] This release corresponds approximately to the release of 0.1% of iodine and caesium content in the reactor core.

EUR

As early as during the initial formulation of assumptions to the EUR, it was assumed that the frequency of large early releases must be less than 10-6/R-Y and that sequences with very large releases, exceeding 000 TBq of I-131 and 100 TBq of Cs-137, must be even much more infrequent.[49]

The current limits set forth by the EUR assume that during a severe accident not only iodine and caesium but also other radionuclides will be released from the core. Therefore, the limits set forth in the EUR refer to a collection of radioisotopes and not only to iodine or caesium.

The probability criteria adopted in the EUR are as follows:

• cumulative frequency of core damage: less than 10^{-5}/R-Y;

• cumulative frequency of large release of radionuclides in excess of the limited impact limits: less than 10-^{6}/R-Y;

• much lower frequency of early or larger releases.

The EPR reactor meets the EUR requirements as well as the Finnish requirements which provide that release of caesium must not exceed 100 TBq. It can be concluded that reactors which will be built in Poland will need to meet similar requirements. However, the final decisions will be made taking into account both the type of reactor and the selected location, with its weather characteristics and the distance of the restricted-use boundary.

3.1.4 Emissions and radiation doses after decommissioning, during dismantling and after dismantling of a nuclear power plant

3.1.4.1 Principles of dismantling of nuclear plant

Until October 2010, 100 uranium ore mines, 80 nuclear power reactors, over 250 research reactors, and many fuel cycle installations have been decommissioned. Some of them, e.g. Maine Yankee, were completely dismantled to a “greenfield” condition[50]. As the experiences demonstrate, most components of a nuclear power plant are not radioactive or very contaminated. Most metal recovered during the dismantling may be recycled. There are tried and tested methods and equipment for safe disassembly. Their effectiveness has been verified on projects in various parts of the world. Dismantling works proceed effectively, according to the budget and the schedule.

The area occupied by a nuclear plant is much smaller than the areas needed for other power generation sources, especially those using renewably energy sources (RES). Consequently, there is no reason for hasty disassembly and dismantling of the reactor. Despite the current tendency to dismantle nuclear facilities just a few years of their final shutdown, delaying dismantlement by 20-50 years does not lead to any negative consequences, while significantly reducing the exposure of the staff to radiation and the cost of dismantling.

When a nuclear plant ends its useful life, it must be dismantled in observance of safety and radiological protection principles.[51] According to the US practice and regulations, the owner of a nuclear power plant can choose from among the following three options:

DECON (immediate dismantling) - soon after the nuclear power plant is shut down, its equipment, structure, and elements containing radioactive contaminants are removed or decontaminated so as to be able to hand over the area for further use without continued control by the nuclear regulatory authorities (NRC).

SAFSTOR (safe storage) – the nuclear facility is kept under control to allow time for decay of radioactive substances and then is dismantled.

ENTOMB (entombment) - protection of the nuclear power plant that allows for depositing the radioactive material present at the plant for ever (without supervision). This usually involves reducing the size of the area where radioactive materials are placed and closing the facility in the so-called sarcophagus, i.e. a durable structure (made, e.g. from concrete) which will last for a sufficiently long period to eliminate any problems with the residual radioactivity. The elements contaminated with radioactivity are permanently enclosed in the area of the former nuclear power plant, in durable structural materials, and monitored until their radioactivity diminishes to a level that allows for transferring the facility to be used without supervision of the nuclear regulatory authorities.

The license holder may decide to choose a combination of the first two methods and to dismantle and decontaminate some parts of the nuclear power plant, while leaving other parts under supervision in accordance with the SAFSTOR concept. The decision may depend on factors that are not directly related to radioactive decay (e.g. availability of facilities for disposal of low-activity radioactive waste).

According to US regulations, a nuclear plant must be dismantled no later than 60 years after its decommissioning.

3.1.4.2 Dismantlement of the Maine Yankee nuclear power plant

An example of successful dismantlement of a nuclear plant is the works conducted at the Maine Yankee plant with a 900 MWe PWR reactor which had safely generated 119 TWh of electricity between 1972 and 1996. The plant, built in Wiscasset, was the largest power plant in Maine. It was finally shut down in August 1997 when continued operation became no longer economically viable. Maine Yankee was one of the US's 69 PWR reactors (the remaining reactors are BWR reactors). Its dismantlement involved removal of 105 million kilograms of waste, to include 68 million kilograms of concrete. Over 50% of the waste (approx. 60 million kilograms) was radioactive. The safety containment was a typical large nuclear power plant containment, with the volume of approx. 70,000 m^3 (enough to fit a large school gymnasium inside). The thickness of the containment at the base was about 120 cm and decreased to approx. 60 cm at the top, with concentric layers of steel reinforcement bars. The weight of the containment was approx. 34 million kilograms.

To remove the major equipment from the containment, the workers had to use diamond blade saws. One of the easiest tasks was to remove the major nuclear equipment, such as the reactor pressure vessel and the three steam generators located in the core of the plant. The steam generators were removed as one piece. On the other hand, the reactor pressure vessel, which is a huge boiler made from carbon steel with a stainless steel lining and a metal frame holding the core and directing the water flowing around the fuel, was cut into pieces with water jets and cutting tools. The works were performed under water with remotely controlled tools. The technology to cut large metal equipment was provided by the French Framatome ANP company.

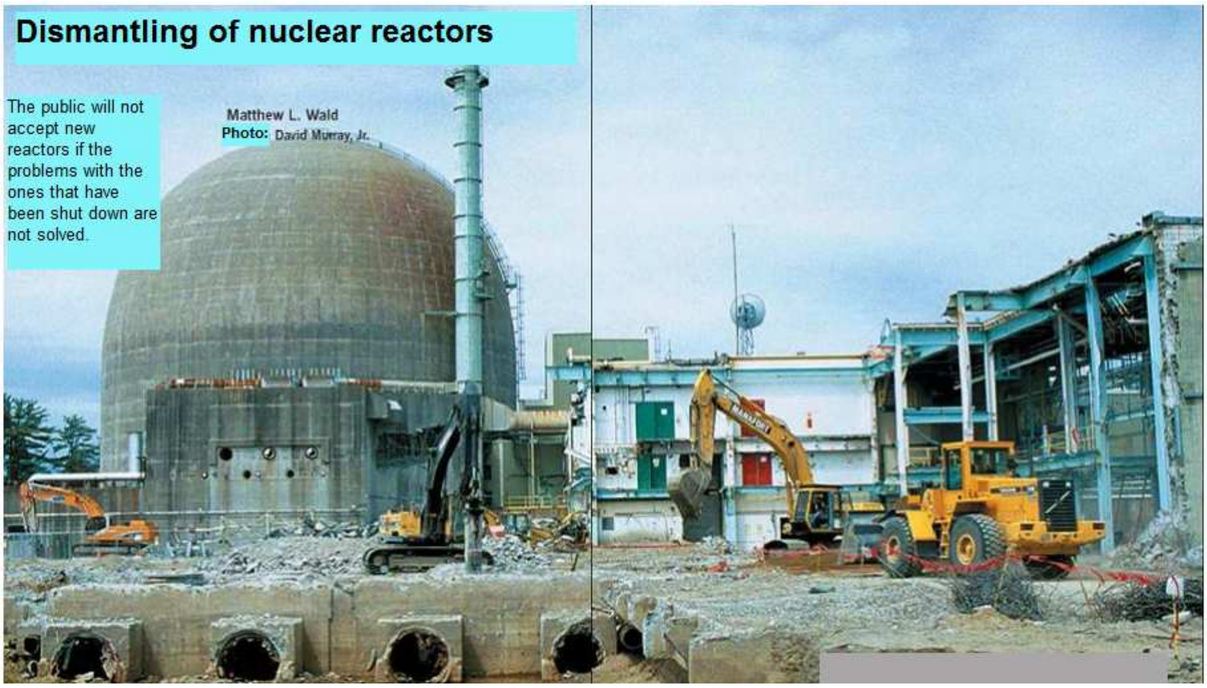

Figure 3.1.1. Demolition of the Maine Yankee nuclear power plant; figure from the work by M. Wald[52]

Figure 3.1.2. After dismantlement of the Maine Yankee nuclear power plant – a green field, additional radiation level below 0.1 mSV/year (the difference between Krakow and Wrocław is 0.37 mSv/year).

Afterwards, the reactor core was filled with cement, to reduce the possibility that the internal parts will lose stability in the coming centuries. The vessel was lifter and moved onto a barge which carried it to a low-activity radioactive waste storage site. Only containers filled with spent fuel remained at the former nuclear power plant. They were placed in a 6 acre lot. The containers form a new Independent Spent Fuel Storage Installation (ISFSI). This is one of numerous such installations in the USE. Their establishment at nuclear power plant sites is due to the delay in commissioning of a high-activity radioactive waste deposit site in Yucca Mountain.

Figure 3.1.3. Containers with spent fuel left at the former Maine Yankee site.

The residual radiation allowed by federal and state regulations is so low that the management of the nuclear power plant decided that it was necessary to measure the natural background radiation level. This will allow avoiding the need to eliminate radionuclides which were present at the site regardless of the presence of the plant.

According to the Maine Yankee dismantlement design, the maximum cumulative irradiation of workers is 11.15 person-Sv for all the works performed at the plant site. The value can be compared to the dose equal to 4.40 person-Sv a year when the last reactor fuel exchange was performed prior to the shutdown.[53]

The Maine Yankee reactor was the first large nuclear energy reactor which was fully dismantled to the so-called "green field" condition, i.e. to a condition where the site can be used for any purpose, to include food production. The works were performed according to schedule and within the budget. The site was completely decontaminated, to an activity level that is lower than that required by the NRC. A particularly important achievement during the dismantlement of the Maine Yankee plant was the outstanding cooperation of all the parties interested in reclaiming the site. The main achievements in their cooperation are:

- there were no accidents resulting in lost work time over the whole project performance period, i.e. more than 3 years;
- the dismantlement was completed with the cumulative dose received by the workers equal to 50% of the limit dose set forth by the NRC;
- the site was cleaned to the extent that the dose value is lower than the target value of 0.1 mSv/year;
- for the first time in history, explosives were used to demolish the reactor safety containment;
- the waste generated during the dismantlement of the plant was safely transported by train, truck, and on river barges;
- the project involved the largest ever campaign of transport of spent nuclear fuel from a wet store to a dry store;
- over 200 acres were handed over to be used for conservation and environmental education purposes;
- 400 acres owned by the plant were transferred to be used for business purposes.

Figure 3.1.4. Collection of soil samples from former Maine Yankee nuclear power plant site[54]

3.1.4.3 Status of dismantling of nuclear plants in the USA

Other nuclear power plants followed the example of Maine Yankee. In total, ten nuclear power plants have been dismantled in the USA, namely: Big Rock Point, Fort St. Vrain Nuclear Generating

Station, Haddam Neck - Connecticut Yankee, Shoreham Nuclear Power Station, CTVR (Pressurized Tube, Heavy Water), Pathfinder (Superheat BWR), Maine Yankee Atomic Power Station, Saxton, Trojan, and Yankee Rowe Nuclear Station. Additional nuclear power plants are in the immediate dismantling phase (DECON): Enrico Fermi, Humboldt Bay, San Onofre, and Three Mile Island 2. Moreover, 9 nuclear plants have been decommissioned and are being dismantled in accordance with the SAFESTOR concept. These are: Dresden Nuclear Power Station, Unit 1, GE VBWR (Vallecitos), Indian Point Unit 1, LaCrosse Boiling Water Reactor, Millstone Nuclear Power Station, Unit 1, N.S. Savannah, Peach Bottom Unit 1, Rancho Seco Nuclear Generating Station, Zion Nuclear Power Station, Units 1 and 2.

The overall characteristics of the status of dismantling of nuclear power plants in the USA is shown in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.1.44. The status of dismantlement of nuclear power plants in the USA as of 2008.

Type	Name	Location	Capacity [MWt]	Shutdown date	Status	Total dismantlement
BWR	Shoreham	Wanding River, NY	2,436	28 June 1989	immediate dismantlement	1994
	Dresden 1	Morris, IL	700	31 October 1978	safe storage	2036
	Millston 1	Waterford, CT	2,011	21 July 1998	safe storage	2056
HTG	Fort St. Vrain	Platteville, CO	842	18 August 1989	immediate dismantlement	1992
PWR	Yankee Rowe	Franklin Co, MA	600	1 October 1991	immediate dismantlement	2007
	Maine Yankee	Wiscasset, ME	2,700	6 December 1996	immediate dismantlement	2005
	Haddam Neck	Meriden, CT	1,825	5 December 1996	immediate dismantlement	2007
	Trojan	Ranier, OR	3,411	9 September 1992	immediate dismantlement	2005
	San Onfore 1	San Clemente, CA	1,347	30 November 1992	immediate dismantlement (ongoing)	2045
	Rancho Seco	Herald, CA	2,772	7 June 1989	immediate dismantlement (ongoing)	2009
	Indian Point 1	Buchanan, NY	615	31 October 1974	safe storage	2026
	Zion 1	Zion, IL	3,250	21 February 1997	safe storage	2026
	Zion 2	Zion, IL	3,250	19 September 1996	safe storage	2026
	Three Mile Island 2	Middletown, PA	2,770	28 March 1979	License in place only	2036

3.1.4.4 Experiences from dismantlement of nuclear power plants

In the last 40 years, significant experience has been gathered in dismantling of various types of nuclear installations.[55]

European reactors

When dismantling graphite-gas reactors in Chinon, Bugey, and St. Laurent, Electricite de France selected the option with partial disassembly and the final disassembly delayed by 50 years. Because other nuclear power plants are in operation on the same lots, monitoring the decommissioned reactors does not involve significant additional costs.

In the United Kingdom, the disassembly of 25 reactors has been started. The first reactors are two Magnox type reactors at the Berkeley nuclear power plant (2 x 138 MWe) which were shut down for economic reasons in 1989, after 27 years of operation. The removal of fuel from these reactors was completed in 1992. The reactor buildings are ready for the SAFESTORE phase. In the future, they will be dismantled and the land will be levelled and developed. Similar works are ongoing in other British nuclear power plants.

In Spain, the graphite-gas reactor at the 480 MWe Vandellos-1 plant was decommissioned in 1990 after 18 years of operation due to a fire in the engine house which made repair of the plant not cost-effective. In 2003 ENDRESA completed the 2nd phase of dismantling of the reactor, which makes it possible to hand over large parts of the site for other uses. After 30 years of safe storage (SAFESTOR), when the level of activity decreases by 95%, the remaining part of the plant will also be dismantled. The cost of the works, planned to be performed over a period of 63 months, is 93 million Euros.

In Japan, the Tokai-1 reactor, based on the design of the British Magnox type reactor, is undergoing dismantlement (after 30 years of operation which ended in 1998).. After storage for 5-10 years, the unit will be disassembled and the land will be handed over for other uses. The total cost is estimated to be 25 billion yen, or approx. 250 million USD.

Germany has opted for immediate dismantling of the shut down Greifswald nuclear power plant, where 5 reactors of the WWER-440 type were in operation. Similarly, the 100 MWe nuclear power plant in Niederaichbach in Bavaria was dismantled and the site was handed over for unrestricted farm use (“green field”) in mid-1995.

The 250 MWe Gundremmingen-A boiling water reactor was the first German commercial power reactor and was in operation in the years 1966-1977. Works on dismantling of this reactor started in 1983 and the more contaminated elements were dismantled in 1990, using the underwater cutting method. The works proved that dismantling can be safe, inexpensive, and fast, and that most materials can be reused.

Reactors in the USA

Of all reactors dismantled in the USA, 14 power reactors were dismantled using the SAFESTOR method and 10 - using the DECON method. The relevant procedures were defined by the Nuclear Regulatory Commission (NRC). The USA has significant experience with dismantling of nuclear power plants. In total, 31 reactors have been shut down and dismantled in the USA. The reclaimed sites were transferred for use, while maintaining pools for temporary storage of spent fuel there. Such pools can be eliminated only when the US Department of Energy collects the spent fuel (which is officially its property) and transports it to the Yucca Mountain repository.

The Rancho Seco nuclear power plant (a 913 MWe PWR reactor) was shut down in 1989, and in 1995 the NRC approved its dismantlement in accordance with the SAFESTOR method. However, at a later date the owner of the plant opted for gradual dismantlement and currently the works on dismantling the plant are advanced.

In the case of plants with several power units, the preferred strategy is to monitor the first shut down unit until the others end their useful lives. This allows for dismantling them at the same time and for optimum use of the staff and specialized equipment needed for cutting and remote disassembly (which leads to significant reduction of the cost).

Fourteen years after its complete cleaning, the second power unit of the Three Mile Island (TMI-2), which was destroyed because of the 1972 accident, it was dismantled according to the SAFESTOR method. The TIM-2 unit will be monitored until the operation license of power unit 1 expires in 2014 so that both power units can be dismantled at the same time. The SAFESTOR method was also implemented in power unit no. 1 in San Onofre which was shut down in 1992. It was to be dismantled when the licenses expire for units 2 and 3 in 2013, but after the changes implemented by the NRC, its dismantling started earlier and is not ongoing. The DECON method was used to dismantle the 60 MWe reactor in Shippingport which was in commercial operation between 1957 and 1982. This was an showcase of safe and inexpensive dismantling of a nuclear power reactor with fast transfer of the reclaimed land to other uses. Removal of the fuel was completed after 2 years and after 5 years the land was transferred for use without any restrictions. Due to the fairly small size, the reactor vessel was removed in its entirety. In larger plants, the vessel must be cut into parts prior to shipment.

The immediate dismantling using the DECON method was also used in the case of the 330 MWe high–temperature gas reactor at Fort St. Vrain which was shut down in 1989. The dismantling was performed under a 195 million USD contract, which means that the cost was below 0.01 USD per kWh, even though the plant was in operation for only 16 years. The project was completed according to schedule and the land was transferred for use in 1997. This was the first high-capacity power reactor dismantled in the USA.

At the 1,180 MWe PWR reactor Trojan nuclear power plant in Oregon, the dismantling was performed by the power company which owned the reactor. The plant was shut down in 1993. The removed steam generators (1995) and reactor vessels, including the internal elements (1999) were transported to Hanford. The lot was transferred for unrestricted use in 1005, with the exception of the spent fuel storage pool. The cooling towers were demolished in 2006.

At the Yankee Rowe nuclear power plant, the 167 MWe PWR reactor was shut down in 1991, after 30 years of operation. The dismantling was performed in accordance with the DECON method and completed in 2006. The lot was transferred for unrestricted public use in August 2007, with the exception of 2 hectares which were kept as a storage yard for spent fuel.

Another DECON type project was the dismantling of the Maine Yankee nuclear power plant, with an 860 MWe PWR reactor which was shut down in 1996 after 24 years of operation. The safety containment was demolished in 2004 and, with the exception of 5 hectares intended for a spent fuel dry store, the site was transferred for no-restriction public use. The works were performed in accordance with the budget and the schedule. The 590 MWe PWR reactor at the Connecticut Yankee nuclear power plant was shut down in 1996, after 28 years of operation. The demolition started in 1998 and was completed in 2006.

Disassembly of the remaining power units is ongoing.

3.1.4.5 Doses during disassembly of a nuclear plant and after its dismantling

The doses during disassembly of a nuclear power plant are small. For example, the cumulative dose expected for the dismantling of the Maine Yankee plant was 5.7 person-Sv, which is two times less than the limit dose set forth in the Environmental Impact Statement. In practice, the total cumulative dose during dismantling of the Maine Yankee plant was lower and equal to only 2.7 person-Sv.[56]

The work safety is also high. For instance, during the dismantling of the Maine Yankee plant, during the more than 2 million work hours there was not a single case of work lost as a result of an accident.

Moreover, the public with no professional connections with a nuclear power plant is not exposed to significant radiation doses. For the Maine Yankee plant it was assumed that the residual radioactivity after dismantling of the plant may not lead to a dose larger than 0.1 mSv/year through all exposure paths, to include 0.04 mSv/year through groundwater.[57] The difference in the natural radiation background value in Finland (7 mSv/year) and in Poland (2.5 mSv/year) is 4.5 mSv/year. What this means that living for one year at a former nuclear power plant site will result in the same additional dose as an 8-day trip from Poland to Finland!

In the case of nuclear reactors, approximately 99% of activity is related to the fuel, which is removed from the reactor after its final shutdown. Besides surface contamination, the remaining activity comes from activation products, such as the steel which is exposed to neutron radiation. Activation products contain such radioactive isotopes as Fe-55, Co-60, Ni-63, and C-14. The first two isotopes are highly radioactive and emit gamma radiation. However, their half life is short and after 50 years their activity is much lower. As a result their hazard to employees is reduced practically to zero.

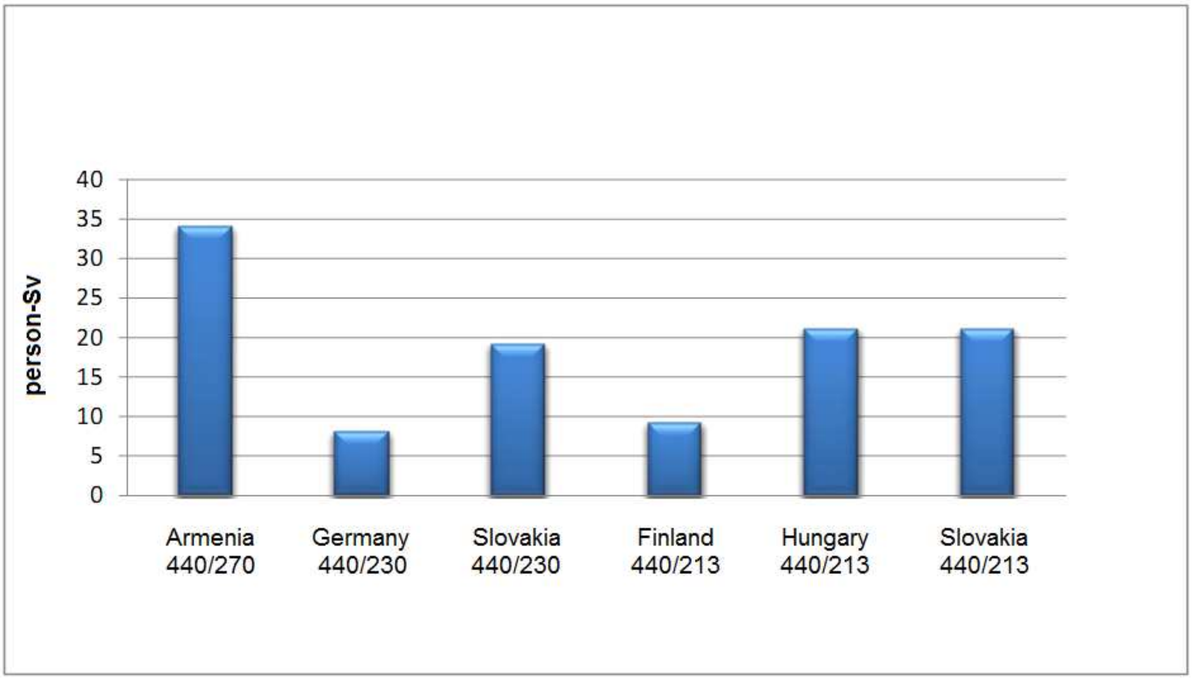

Figure 3.1.5. Expected equivalent collective doses of radioactivity in the case of immediate disassembly and dismantling of a nuclear plant with WWER reactors[58]

In the case of delayed disassembly, the doses are significantly smaller, which can be seen by comparing **Błąd! Nie można odnaleźć źródła odwołania.** and **Błąd! Nie można odnaleźć źródła odwołania.**. The lowest value has been defined by Finland; it is slightly higher than 2 person-Sv for a 20 years long period of cooling and removal of the reactor vessel, the internal elements, and the steam generators without cutting. The highest value, i.e. 21 person-Sv, was defined by Slovakia for a 50 years long period of cooling and cutting the primary loop on the disassembly site[58].

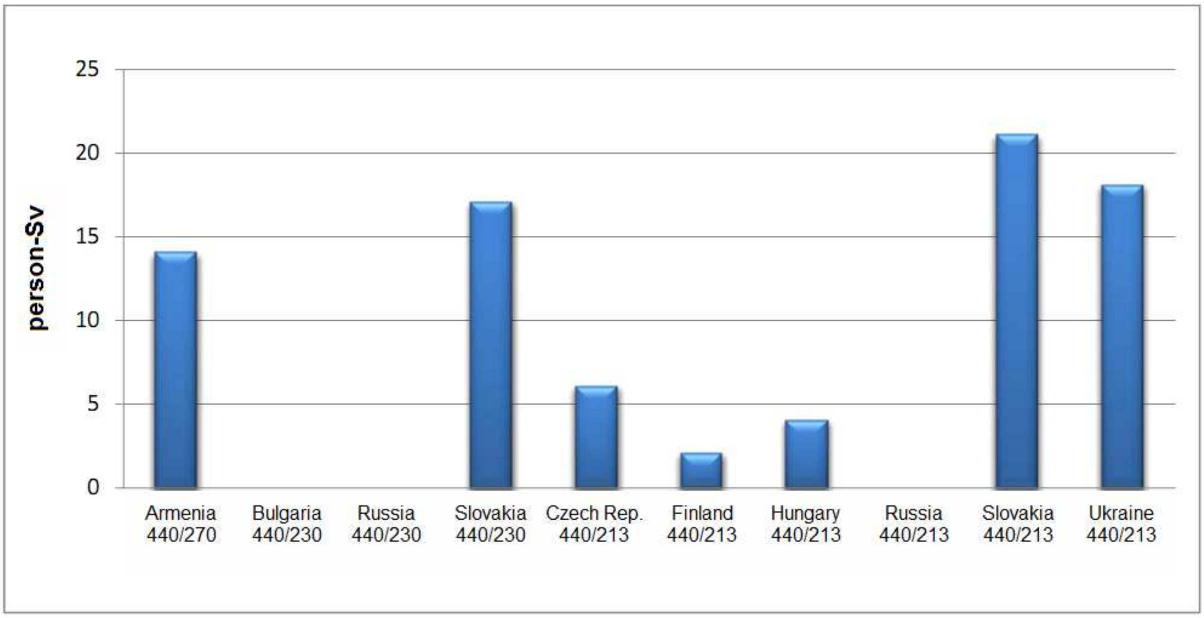

Figure 3.1.6. Expected equivalent collective doses of radioactivity in the case of delayed disassembly and dismantling of a nuclear plant with WWER reactors[5858].

In none of the dismantled nuclear power plants did emissions into the environment constitute a problem.

3.1.4.6 Emissions and contamination anticipated in the case of Generation III and III+ reactors

The radiological effects of dismantling of Generation III reactors will be evaluated using the example of an EPR reactor.[59]

3.1.4.6.1 Selection of materials

Reduction of activation of materials starts at the stage of design by taking actions to reduce the abrasion of materials and replacing materials with high content of cobalt (stellites) with materials without any of this element. Radioactive cobalt is the main cause of irradiation of workers during dismantling of a nuclear power plant. Thus, for example:

– in steam generator piper one can use alloy 690 (INCONEL) (with cobalt content below 0.018%) instead of INCONEL alloy 6000 (with cobalt content below 0.05%);

– in steel elements exposed to radiation, the content of cobalt is to be limited to 6 ppm;

– the content of silver in steel and alloys is also reduced and seals covered with silver are replaced with graphite seals (silver is a significant source of radiation for several years after plant shutdown);

– the use of antimony in seals is also reduced.

Increasing the tightness of fuel jackets significantly affects the classification of radioactive waste as it limits release of beta and alpha radiation emitters.

Hazardous materials

Reducing the use of hazardous materials is particularly important with regards to materials which may be activated, because removal of mixed waste is very difficult. This applies, in particular, to corrosive, toxic, and inflammable substances, heavy barium concrete, and combustible metals (e.g. Zircaloy) which require particular care in the process of cutting and packing, as well as to fibrous materials. The use of porous materials must be avoided due to the difficulties with their decontamination.

3.1.4.6.2 Design requirements

The purpose of design modifications implemented in Generation III reactors is to reduce the radiation doses received by workers during dismantling of a nuclear power plant, by reducing the time of stay in the vicinity of highly active elements and by increasing the speed of their removal from the installation.

Numerous pieces of equipment, such as measurement instruments in the core, steam generations, reactor circulation pumps, stabilizers, heat exchangers, etc., are designed for easy disassembly. In the case of most such equipment located in areas that are not available due to the level of radiation, the possibility of their removal in their entirety is studied, which requires proper designing of their connections and access doors. The design of the reactor well and the core catcher makes it possible to fill the reactor well with water, which allows for the reactor to be disassembled under water. Placing the in-containment refuelling water storage tank (IRWST) below the reactor vessel allows for collecting any water leaks occurring during disassembly of the internal elements of the reactor. The thermal insulation of the primary loop is modular and easy to disassemble.

A number of operations have been designed so as to facilitate the dismantling of the plant, e.g. drainage of the fuel pool and the steam generators, movement of fuel from the reactor building to the fuel building, solid, liquid, and gaseous waste systems, ventilation, fire protection measures, drainage of chambers and floors, power supply, compressed air system and water supply system, and the related systems and circuits. Division of the systems into four parallel circuits facilitates disassembling one circuit after the other, while maintaining the supply of the ancillary systems required in the fuel building and the auxiliary systems building. A number of improvements facilitate disassembly of large elements. An analysis of their disassembly options was performed as early as during the design phase. Improvements were also implemented to facilitate staff access, as well as shade and dismountable screens which limit the exposure of people during dismantling works. Other improvements limit the spread of contamination in the plant’s systems.

Overall, one can expect that dismantling of Generation III reactors will be easier and cheaper that the ongoing dismantling of Generation III reactors. As far as environmental impact is concerned, event the present methods of dismantling of nuclear plants produce very good results; the continued progress in limiting radioactive contamination and the quantity of activated material indicates that the impact will be reduced even further in the future. In conclusion, neither emissions nor large dosed during and after dismantling of nuclear power plants constitute a hazard to the environment and the public.

3.2 Evaluation of direct and indirect radiological hazard paths in emergency situations

3.2.1 Direct radiation

The main source of radiation during operation of a nuclear reactor is the reactor core, where the fission reactions take place. During every fission reaction, parts of the fission are emitted: two or three neutrons, as well as gamma and beta radiation. After radioactive decay of fission parts, further emission of gamma, beta, and alpha occurs. This is the so-called direct radiation. In order to protect the nuclear power plant’s staff, the reactor core is surrounded with huge screens which fully protect people inside the plant from such radiation.

Another source of radiation hazard is radioactive substances that leak in small quantities into the primary loop through microscopic openings in the fuel element jackets and are produced in the coolant as a result of activation of oxygen and pollutants (such as corrosion and erosion products) flowing with the coolant through the core. Therefore, the whole primary loop in a pressurized water reactor (PWR) is enclosed in a safety containment which constitutes another protection screen.

The safety containment also provides protection against direct radiation in the case of an accident (event the least likely accidents involving primary loop rupture and core failure). In the case of an accident in a PWR reactor, radioactive substances can escape from the core and the reactor's primary loop into the safety containment. This is why the thickness of the screening wall in the safety containment is selected so as to stop direct radiation from all fission products that can be released from the core. The design of the safety containment, to include the structural elements and the equipment located inside the containment, is calculated – with appropriate margins – for accident parameters (pressure and temperature) and for impacts and loads that may occur during an accident, as well as for loads from external occurrences and events (to include appropriate combinations of loads). Also, the containment must be appropriately leak-tight at maximum accident pressure (leaks from Generation III reactor containments may not exceed 0.25-0.30% of containment volume per day). In order to verify that these requirements are met, pressure tests and leak tests are performed (during the commissioning and then periodically during the operation). The hazard related to direct radiation outside of the containment is small and drops fast, in proportion to the distance from the containment.

The effectiveness of safety containments was confirmed by the analysis of the consequences of the Three Mile Island accident. This was the only accident during over 10,000 years of total operation of PWR and BWR reactors where core meltdown occurred and where fission products escaped into the containment. In spite of this, the proportion of direct radiation in the total exposure of the employees and the public was negligibly low.

The main source of hazard during an accident in a reactor is the radioactive substances that escape from the nuclear power plant and are carried in the air and in the water, and then are inhaled or swallowed with food by people.

3.2.2 **Hazard from leaks of radioactive substances from a nuclear power plant**

3.2.2.1 Release of radioactive isotopes into the atmosphere

A radioactive cloud affects people directly with beta and gamma radiation and exposes them to intake of isotopes, mostly through the lungs, but also through the skin. A radioactive cloud also causes formation of radioactive deposits on the soil and on plants. Radioactive isotopes are absorbed by plants and, once the plants are harvested, they are consumed by people with food. Releases during a nuclear power plant accident include:

- direct radiation from the cloud, inhalation, and contamination of skin caused by isotopes contained in the radioactive cloud;
- fallout of radioactive substances from the cloud onto open water reservoirs;
- fallout of radionuclides onto the ground and their seeping into the ground water, animal fodder, and edible plants.

Radioactive contamination of water is hazardous to people who are in water or on the bank and, most importantly, radioactive isotopes are absorbed by organisms living in water and are consumed by people in fish and other food from water plants and animals. Moreover, water used for irrigation of fields and for drinking contaminates crops and milk and, if drunk by people, leads to radionuclides depositing in their bodies.

3.2.2.2 Release of radioactive isotopes in liquid waste

In the case of a leak of radioactive liquid waste, the ground water becomes contaminated in a similar fashion as in the case of fallout from a radioactive cloud. The likelihood of a leak during normal operation is low, but it is considered in the case of a severe accident involving core meltdown which leads to the risk of melting through the base of the safety containment and of radioactive substances leaking into the ground layers beneath the containment. In order to prevent such an occurrence, Generation III reactors are provided with appropriate systems which protect the whole containment, to include its foundation slab.

Even though during an accident radioactive substances may be released into the water and the soil, the most likely risk is connected with releases into the atmosphere. After such a release, the public can be exposed to direct radiation from the radioactive cloud and by inhaling the radioactive dust from the cloud. As the cloud disperses, radioactive particles settle on the ground or are quickly washed by rain or snow. The public may then be exposed to radiation from radioactive deposits on the surface of the ground, to inhaling dusts which is lifted off the ground and suspended in the air, and to consuming contaminated food or water. The degree if such a hazard largely depends on the process of dispersion of radionuclides in the atmosphere.

3.2.3 Phenomena taken into account when calculating plume dispersion

The mechanism of dispersion of the radioactive plume in the air – which is considered by the NCR as one of the main safety features of a nuclear power plant location – was described very early, in the first regulatory guidelines, namely RG 1.3 and 1.4.[60] The process of atmospheric dispersion is dealt in these guidelines with a wide safety margin. However, in 1979, after obtaining new experimental data, the NCR issued the RG 1.145 guidelines which introduced significant changes which reduce the overly pessimistic assumptions made in the previous guidelines, i.e. RG 1.3 and RG 1.4. The RG 1.145 guidelines take into accounts meanders of the plume, relation between the dispersion and the direction of wind and the distribution of frequency of wind directions in a given location.[61]

The meteorology data needed to determine the atmospheric dilution factor χ/Q includes the speed and the direction of wind and the class of atmospheric stability. The data should be based on hourly averages collected over the period of a whole year. Wind direction is divided into 16 sections of the wind rose, 22.5 degree each. Atmospheric stability is determined based on the difference in temperatures in the vertical direction between the plume release height and the 10 m level. At small wind speed, the speed of mixing of atmosphere layers depends mostly on the ration of the vertical temperature gradient to the gradient corresponding to the adiabatic cooling of the air with its decompression as the height increases.

For dry air, the adiabatic temperature gradient is approx. -0.65^{o}C/100 m. When the actual gradient is higher (as shown on **Błąd! Nie można odnaleźć źródła odwołania.** a), the difference between the density of gases released into the atmosphere and the density of the air increases with increasing height, which in turns increases the uplift pressure of the gases. The mechanism is analogous in the other direction: when gases fall down, the adiabatic compression does not lead to the gasses heating up fast enough to reach the temperature of the surrounding air, which leads to an increase in the speed of their downward movement.

Thus, if the temperature gradient has a large negative value, all vertical movements of gases are accelerated, which leads to large turbulences in the plume (**Błąd! Nie można odnaleźć źródła odwołania.** a). When the value of the temperature gradient is reduced, the plume becomes more stable (**Błąd! Nie można odnaleźć źródła odwołania.** b). If the gradient has a positive value, the plume can travel over ten kilometers without any significant dilution (**Błąd! Nie można odnaleźć źródła odwołania.** c). A changing temperature gradient leads to the creation of either a rising plume (**Błąd! Nie można odnaleźć źródła odwołania.** d) - which is the most advantageous from the point of view of elimination of radioactive waste – or a fumigating plume (**Błąd! Nie można odnaleźć**

źródła odwołania. e) – which is the most dangerous because it causes contamination of the ground surface at large distances from the source (even though radioactive gases are emitted at large heights).

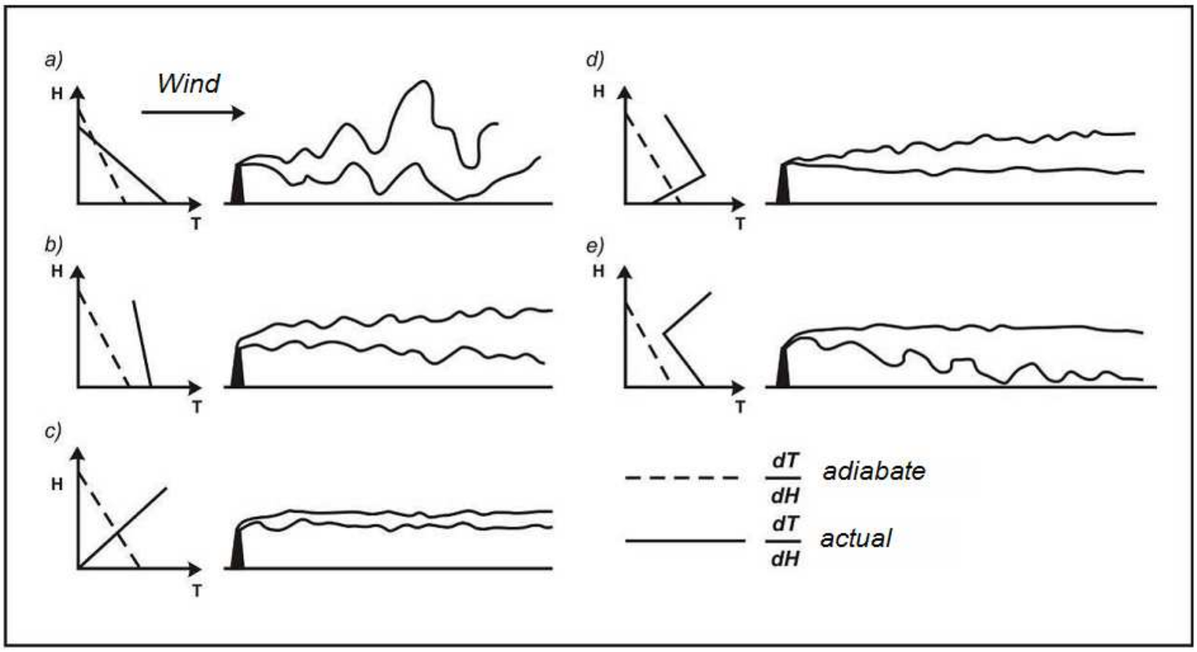

Figure 3.2.1. Impact of the vertical temperature gradient on the behaviour of a gas plume

The temperatures of atmosphere layers change in a daily cycle as the Earth absorbs the solar radiation heat during the day and warms up the lower layers of the atmosphere during the night. During the day, the plume is often unstable (looping), and during the night the surface of the Earth cools down faster than the atmosphere, which leads to plume inversion.

For the purpose of calculation, the atmosphere stability conditions are divided into categories, which are shown in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.2.1. Relation between stability of the atmosphere and the weather[62]

Wind speed, m/s	Insolation during the day			Night conditions, cloud cover	
	high	moderate	sparse	dense	sparse
2	A	A-B	B		
3	A-B	B	C	E	F
4	B	B-C	C	D	E
5	C	C-D	D	D	D
6	C	D	D	D	D
	A - high instability B - moderate instability C - low instability			D - neutral conditions E - low stability F - moderate stability	

For each of the categories, the parameters which describe the concentration of radioactive isotopes were defined, namely σy and σz, i.e. horizontal and vertical standard deviation of the distribution of the radioactive cloud density depending on the distance from the source of emission.

Assuming that gaseous fission products are released from a nuclear power plant in a uniform fashion over a longer period of time at the rate of Q (Bq/s), one can determine the concentration of radioactive substances in the cloud χ (Bq/m^3) using the Sagendorf formula[63].

$$\frac{\chi}{\dot{Q}} = 2{,}032\sum_{ij}\left\{\frac{n_{ij}}{Nxu_i\sum_{zj}(x)}\exp\left(\frac{-h_e^2}{2\sigma_{zj(x)}^2}\right)\right\}$$

where:

h_e - effective height of the emission point [m],

n_{ij} - time [h], during which a given wind direction, with speed i and atmosphere stability category j, was observed,

N – total observation time [h],

u - average wind speed at the height h_e [m/s],

x - distance from the emission point [m],

$\Sigma_{zj}(x)$ - elevation of the cloud with correction reflecting the impact of buildings, used only for ground level emissions [m]. In the case of emissions from a stack, $\Sigma_{zj}(x) = \sigma z,j$.

In the case of emission points situated higher than twice the height of the neighbouring buildings, the effective emission height he can be calculated using the following formula:

$h_e = h_{stack} + h_{elev} - h_{gr} - c$

where:

h_{elev} - elevation of the cloud above the emission point, depending on the outlet speed w_o, the temperature, and the stack diameter d [m],

h_{gr} - maximum elevation of the ground in relation to the base of the stack [m],

c - correction to take into account low outlet speed [m],

w_o -s vertical outlet speed of the plume [m/s][64].

In the case of accidents involving emission points situated less than 2.5 times the height of the neighboring buildings Dz, it is assumed that the source is situated on the ground level. Consequently, the effect of turbulences caused by buildings must be reflected.

3.2.4 Calculation of the atmospheric dilution factor

The RG 1.145 guideline requires calculating the atmospheric dilution coefficient **χ/Q** at the boundary between the restricted-use area around the nuclear power plant for 2 hours after the accident.

Releases through discontinuities in the containment include all releases taking place at heights lower than 2.5 times the height of the neighboring buildings. In the case of atmospheric conditions in the neutral D or stable E, F, and G class, when the wind speed is less than 6 m/s, one can consider horizontal meandering of the plume. The **χ/Q** value can be determined by selectively using a set of formulas describing the atmospheric dilution factor at the ground level on the centreline of the radioactive plume:

3.2.4.1 The case of fumigation

In the case of sites located 3,200 m or more away from large water reservoirs (a sea, an ocean), it must be assumed that at the time of the accident the fumigation conditions are present for a period of 0.5 h. If the χ/Q value with fumigation is higher than that without fumigation, then in the time between 0 h and 0.5 h the value with fumigation must be used. Then, in the period between 0.5 h and 2 h, the χ/Q value without fumigation must be used.

3.2.4.2 Determination of the χ/Q value for a given location

The values of χ/Q which are exceeded for no more than 5% of the total time around the excluded zone can be determined in the following manner:

One must determine the total cumulative distribution of probability of certain values of χ/Q. Then, one must make a graph of the function of the probability that a certain value of χ/Q will be exceeded. On the curve, one must select the value of χ/Q which is exceeded for 5% of the time.

The value of χ/Q used in the calculation is assumed to be the higher of the following values: the maximum value of χ/Q for the sector or 5% of the value of χ/Q for the location.

3.2.5 **Methods of calculating atmospheric dispersion of radioactive substances released during continuous operation of a nuclear power plant.**

Calculation of the hazard related to emissions into the atmosphere during normal operation of a nuclear power plant can be done in a similar fashion to calculation for accident conditions. However, it must take into account appropriate atmospheric dispersion factors, calculated for long periods and not for several or several dozen hours (as in the case of calculation of hazards after an accident). The value of atmospheric dilution factors for exposures over the course of a year is much lower due to changes in the wind direction. Moreover, releases of radioactivity occur at the stack level, which means that the exposure at the ground level in the vicinity of the plant is lower.

Various dispersion models are used in the calculations. In models with stable average wind direction, it is assumed that the stable wind lifts and disperses the radioactive plume in the whole area in question in accordance with the wind direction at the emission point. The most popular is the model with a straight-line trajectory, with Gauss distribution, where one assumes that the wind speed and the atmospheric stability category at the emission point are characteristic of the atmospheric conditions along the whole path of the radioactive plume.

3.2.5.1 Emission types

At short distances from the nuclear power plant, the yearly concentration of radioactive substances at the ground level are strongly dependent on the type of emission. The longer the distance from the emitter, the less the values are dependent on this factor.

In typical nuclear power plants, release of gaseous radioactive substances from high stacks cause the maximum concentration at the ground level at the distance of 1-3 km, whereas releases at the ground level usually cause concentrations of radioactivity which decrease monotonically as the distance from the plant increases. In some conditions, the radioactive plume may be pulled by a turbulence in the aerodynamic shade of a building and may fall to the ground at a short distance from the plant. In other conditions, the plume may be elevated above the emission point.

Methods have been developed to evaluate the effective emission height to calculate the concentration of radioactive substances for all distances along the path of the wind. Important parameters include the initial emission height, the location of the emission point in relation to the obstacles in the air flow, the dimensions and the shape of the emission site, the initial speed of the plume in the vertical direction, the heat content of the leaking gases, the ambient temperature, the wind speed, and the atmospheric stability class.

If the leak is pulled into the aerodynamic wake of a building, it is usually assumed that the leak is mixed in the air turbulence. The mixing zone can be a plume with the initial cross-section equal to a half or more of the cross-section of the building.

3.2.5.2 Process of removal of radioactive substances from the plume

As the leak moves from the emission point along the wind direction, a number of processes take place, which cause a reduction of the concentration of radioactive substances below the concentration corresponding to the very process of atmospheric diffusion. The processes include radioactive decay, dry deposition, and wet deposition.

Radioactive decay depends on the half-life and the time of movement of the radioactive substances. In the case of short-lived radionuclides, the time of the plume's flow from the emission point to the receptor has a large effect on reduction of the radiation hazard. In the case of long-lived substances, the time of movement is practically insignificant.

All substances settle through sorption on the surface of the ground, but the speed of dry transfer for inert gases, tritium, carbon-14, and organic iodine compounds is so low that their removal from the plume is negligible within the radius of 80 km from the emission point. Molecular iodine and substances which have the form of aerosols settle on the ground much faster. The process of transfer of radioactive substances to the dry surface of the ground can be described with the following formula:

concentration of radionuclides in the plume [Bq/m^3] x speed of transfer to the ground [m/s] = speed of settling [Bq/m^2s].

The speed of transfer is in direct proportion to the wind speed. Consequently, the settling speed is independent of the wind speed, since the concentration of radionuclides in the radioactive plume is inversely proportional to the wind speed.

Dry deposition is a continuous process. On the other hand, wet deposition occurs only during precipitation. Nevertheless, dry deposition is not as effective as wet deposition. In most locations, precipitation occurs only for few hours a year. Consequently, despite the higher efficiency of wet deposition, calculation of doses for long periods which take into account only dry deposition are not very different from calculations taking into account wet deposition. Still, wet deposition may be an important factor in calculation of doses caused by emissions from a stack in locations where the rainy season corresponds to the local cattle grazing season.[65]

The model with a constant wind direction does not describe the effects of time and space changes in the flow of air in the area in question. Unlike the model with variable wind trajectory, the model with constant wind direction can be based only on the meteorological data obtained from one meteorological station.

Usually, the analyzed area is located within 80 km from the plant. Therefore, when using the constant wind direction model, one must study the characteristics of the air flow and check if the measurements at the given location are representative for the conditions present between the plant and the nearest receptors (usually within 8 km) and for the conditions within 80 km from the plant.[66]

3.2.5.3 Dry deposition

Radioactive materials are divided into four groups according to their deposition speeds. These are:

- Inert gases (Kr, Xe) – do not undergo either dry or wet deposition;
- Molecular iodine (I_2 vapour in the air);
- Organic iodine, e.g. methyl iodide CH_3I;
- Aerosols (radionuclides in the form of aerosols or deposited on aerosols, e.g. aerosol iodine or metal oxides).[67]

Contamination of the surface beneath a radioactive cloud can be characterised using the deposition speed vd, defined as the ratio of the speed of deposition of contaminants on the surface dCd/dt to the concentration of radionuclides in the surrounding air χ. The speed of deposition on a standard surface of pastures, at the wind speed at the height of 10 m equal to U_{10}= 4 m/s is stipulated in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.2.2. Speed of deposition of radionuclides (m/s) on the surface of pastures at the wind speed of 4 m/s' data from the RODOC code.

Type of surface	Molecular iodine	Organic iodine	Aerosols
Pastures	$8*10^{-3}$	$0.1*10^{-3}$	$1.0*10^{-3}$

3.2.5.4 Wet deposition

Assuming that elimination of radioactive substances by rain or snow proceeds uniformly in the whole height of the radioactive cloud, the rate of elimination at any distance from the source of emission is proportional to the quantity of material reaching that distance.[68] Concentration in the air can be determined by using the modified size of the source in the following formula:

$$Q = Qo \exp(-\Lambda t)$$

where:

t - precipitation time [s];

Λ - sweeping coefficient [s^{-1}] in proportion to rain intensity I [mm/h]; Λ = α*I, whereas α depends on the characteristics of the material carried in the cloud, e.g. on the aerodynamic diameter of particles and solubility of the gas in water.

According to the methods provided for in the universally recognized RODOS standard,

$\Lambda (1/s) = \alpha (I/ 1 mm/h)^b$

whereas the values α and b for various radionuclides are listed in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.2.3. Parameters α and b used to determine wet deposition speed

Group of radionuclides	α	b
Inert gases	0	0
Aerosols	8 E-5	0.8
Molecular iodine	8 E-5	0.6
Organic iodine	8 E-7	0.6

In the event of rainfall, the quantity of material remaining in the cloud is

Q = Qo exp (-tΛ) = Qo exp (- Λ x/u)

where:

- x – distance from the emission point [m];
- u - wind speed [m/s].

It is assumed that sweeping occurs uniformly from the whole height of the cloud.

3.2.5.5 Impact of surface roughness

Table 3.2.4. Typical roughness values assumed in calculation codes

Surface type	Surface roughness, (M)
City buildings	1.0 - 3.0
Coniferous forest	1.3
Arable land (summer)	0.2
Arable land (winter)	0.1
Meadows (summer)	0.1
Meadows (winter)	0.001
Water	0.0001

3.2.6 Parameters of atmospheric dispersion for typical locations in Poland

Table 3.2.5. Frequency of atmosphere stability classes in the lowland parts of Poland

Stability class	Frequency	Most disadvantageous speed [m/s]
A convection	0.006	1
B	0.06	2
C	0.17	5
D neutral	0.6	5
E stable	0.07	3
F	0.08	2
G very stable	0.014	1

According to the aforementioned recommendations set forth in the NRC guidelines, for the purpose of calculating the dispersion in a given location, it is assumed that the weather conditions within the 95% envelope are present in the whole lot. Therefore, for the location as a whole, we will use the F class and wind speed equal to 2 m/s, which results in a 98.6% weather conditions envelope.

The following assumptions can be made in calculations for a typical location.

Source geometry:	point
Class of atmospheric stability	F
Wind speed at the height of 10 m	2 m/s
Type of terrain	flat
Terrain roughness	pastures

σy coefficients	acc. to the RG 1.145[69]
Emission elevation	ground level
Reactor building	50 m (wide) x 60 m (high)
Precipitation	none
Emission time	2 hours
Critical group	adults

The atmospheric dispersion coefficient for the distance of 1,000 m from the reactor, based on the calculation method recommended in the RG 1.145 guidelines for the above-mentioned parameters is:

$\chi/Q = 9,57*10^{-5}$ s/m3;

the coefficient for the distance of 500 m is:

$\chi/Q = 2,49*10^{-4}$ s/m^3.

If the value of the wind speed is assumed to be 1 m/s, the atmospheric dispersion coefficient values will be two times larger.

To demonstrate the effect of the distance, **Błąd! Nie można odnaleźć źródła odwołania.** shows the atmospheric dispersion coefficients for the distances of 500, 914, and 2,500 m for short releases lasting for one hour, for longer releases lasting 24 hours, and for long-term releases, measured for the Darlington nuclear power plant in the years 1997-2000. Apparently, the nature of the changes in the coefficient at different distances is similar to that shown above based on the formulas recommended by the NRC.

Table 3.2.6. Example atmospheric dispersion data for the Darlington nuclear power plant[70]

Time of release	χ/Q for 500 m (s/m^3)	χ/Q for 914 m (s/m^3)	χ/Q for 2500 m (s/m^3)
Short, 1 h	164×10^{-6}	83×10^{-6}	23×10^{-6}
Medium, 24 h	12.7×10^{-6}	6.09×10^{-6}	1.60×10^{-6}
Long	6.41×10^{-6}	2.48×10^{-6}	0.493×10^{-6}

3.3 Impact of radioactive emissions from a nuclear power plant during normal operation

3.3.1 Nuclear power plants with EPR reactors

3.3.1.1 Assumptions

The first stage of radiological assessments involves determination of the dose for the critical group, i.e. the group of people who are likely to receive the highest radiation exposure. For the various radionuclides, the dose per limit release (DPUR) coefficient [μSv*y^{-1}/Bq*y-1] is used, taking into account the location and the exposure chain through the air or water path. Four group of people are considered, i.e. embryo, baby, child, and adult. In order to calculate the coefficient – regardless of the location – designers of the EPR reactor use data from the Federal Guidance Report 12. To calculate exposure through inhaling and consuming food, the effective dose coefficient for absorption of radionuclides is taken from the EC BSS Council Directive 96/29/EURATOM. The dose coefficients used to evaluate the effective dose for an embryo, after absorption of radionuclides by the mother, were taken from the ICRP publ. 88.

For all release scenarios defined in this methodology, the DPUR is calculated for each radionuclide, each exposure path, and each age group, in accordance with the following formula:

DPUR p,r,a = CPURr x Hp,a x DFr,a

where:

- *DPUR p,r,a* is the dose per unit of release for a given exposure path, radionuclide, and age group [μSv*y^{-1}/Bq*y^{-1}];
- *CPURr* is the concentration of activity per unit of release in the given material (Bq*kg^{-1} (l^{-1} or m^{-3}) / Bq*y^{-1});
- *Hp,a* is the parameter describing the coefficients pertaining to the exposure route for a given age group, i.e. the rate of breathing [m^3/y] or the rate of food consumption [kg/y], or the time of stay in a given location [h/y];
- *DFr,a* is the dose per unit of consumption or absorption by inhalation [μSv/Bq], or the coefficient of exposure to external radiation [μSv*h^{-1} / Bq*kg^{-1}] for each radionuclide and each age group.

The total value of the DPUR for all exposure paths present in the given case is calculated for each age group. For each radionuclide, the DPUR value is compared for different age groups and the worst value is selected. Therefore, in the first approximation, the selected doses are doses for the most exposed group of embryos, babies, children, or adults.

3.3.1.2 The yearly dose of direct radiation of the most exposed person in the critical group

In this case, no measurement data is available and the direct radiation dose was calculated.

Because the outdoor limit of the dose received by the public is 1 mSv/year, one can calculate the dose value at the boundary of the restricted-use area by using the 1/r ratio.

Direct radiation $DR = D \cdot (SFi \cdot FTi \cdot SFo \cdot FTo)$

where:

- D - dose [mSv/y] at the distance of 1 m from the surface of the building;
- SFi,o - shielding factor indoors and outdoors;
- FTi,o - fraction of time spent indoors and outdoors;
- r - distance of the critical group from the reactor.

For a person who lives 100 m from the reactor, the DR dose is:

$$DirectRadiation = \frac{1}{100} \cdot 1 \cdot (0.1 \cdot 0.5 + 1 \cdot 0.5) = 5.5 \mu Sv / y$$

In the opinion presented in Chapter 11 of the environmental impact documentation for the UK EPR reactor[71], it is assumed that all releases of radioactive materials occur in a continuous manner, with the same intensity throughout the year, and that they continue for 50 years.[72] The maximum gaseous and liquid releases from an EPR power unit are shown in **Błąd! Nie można odnaleźć źródła**

odwołania. and **Błąd! Nie można odnaleźć źródła odwołania.**, while the spectrum used to evaluate the isotope content of radionuclides is shown in **Błąd! Nie można odnaleźć źródła odwołania.** i **Błąd! Nie można odnaleźć źródła odwołania.**.

Making a number of simplifications resulting in pessimistic results, the designers of the EPR reactor calculated the doses for the most exposed family equal, as shown in the table below, to approx. 63 mSv a year. The designers referred to this stage of evaluation as stage 2. However, once more precise data was used, it turned out that the calculated values were much too high. More accurate evaluations, referred to as stage 3, are shown below in sections 7.3.1.3 – 7.3.1.11.

Table 3.3.1. Total dose for the critical group caused by an EPR rector and received through different exposure paths (µSv.y$_{-1}$), calculated based on simplified data which lead to excessively high results

Exposure path	Dose
Air, family living close to a nuclear power plant	11.4
Family of a fisherman living at the shore	46.1
Family living close to a nuclear power plant, exposed to direct radiation	5.5
Total dose for the critical group [µSv/y]	63.0

3.3.1.3 Location characteristics

A set of location characteristics needed to conduct the assessment of the impact of a nuclear plant on the environment is shown in **Błąd! Nie można odnaleźć źródła odwołania.**. The characteristics are selected so as to assure the possibility of locating an EPR reactor in many areas, in particular taking into account the typical geographical conditions and the impact of the plant in both coastal and inland regions. The parameters determining the dispersion of gaseous releases and liquid releases are presented below.

3.3.1.3.1 Parameters of gaseous releases

The receiving points of radiation impact on people and on food are located at the distance of 500 m from the emission point from the reactor. The effective height of the ventilation stack is assumed to be equal to 20 m. This is due to the conservative approach to the analysis of atmospheric dispersion parameters. The height of the EPR reactor building is approx. 60 m, and the ventilation stack extends several meters above the building. Due to air swirling in the wake of the building, the effective height of emission from the stack is lower. In the safety analysis for an EPR reactor[71], safe stack height is assumed to be 1/3 of the height of the building (hence the height of 20 meters).

The predominant weather category is assumed to be the D class of atmospheric stability which is characteristic of coastal locations. The standard sweeping and deposition coefficients and roughness of the surface typical of farming regions were selected in accordance with the guidelines set forth in the RP 72 document.

3.3.1.3.2 Liquid releases dispersion parameters

Local waters, referred to as local area, are defined based on the most restrictive values of each parameters for each of the potential locations. The smallest volume occurs together with the largest depth, the longest shoreline, the smallest mass exchange coefficient, the smallest deposit load, and the highest deposition speed.

Table 3.3.2. Location parameters of a nuclear power plant with an EPR reactor

Location characteristics	Parameter value
Receiving point for releases into the atmosphere [m]	500
Receiving point for food products [m]	500
Location boundary [m]	100
Category of wind stability according to the Pasquille scheme	70 % D
Deposition speed [m/s]	$1*10^{-3}$, $1*10^{-2}$ (I), 0 (inert gases)

Sweeping coefficient [s^{-1}]	$1*10^{-4}$
Surface roughness [m]	0.3
Local area depth [m^3]	$3*10^{8}$
Local area depth [m]	20
Length of local area shoreline [m]	$3*10^{4}$
Rate of volume exchange for local area [m^3/y]	$1.1*10^{10}$
Local area load with suspended deposits [Mg/m^3]	$5*10^{-6}$
Rate of deposition in the local area [Mg/m^2/y]	$1*10^{-2}$
Density of deposits in the local area [Mg/m^3]	2.6
Rate of bioturbation in the local area [m^2/y]	$3.6*10^{-5}$
Rate of diffusion in the local area [m^2/y]	$3.15*10^{-2}$

3.3.1.4 Yearly doses from gaseous releases from an EPR reactor for the most exposed member of the public

3.3.1.4.1 Critical group

It was assumed that the critical group, i.e. the group most likely to receive the highest exposure, is a farmer's family living 500 m from the point of release from the nuclear power plant. It was assumed that adults and children spend a significant part of their time outdoors.

Table 3.3.3. Data for evaluation of the consequences of gaseous releases from an EPR reactor

Parameter	Adult	Child	Baby
Shielding factor[73] for gamma radiation from the cloud	0.2	0.2	0.2
Shielding factor for gamma radiation from the deposits	0.1	0.1	0.1
Time during the year [h/y]	8,760	8,760	8,760
Fraction of time spent indoors	0.5	0.8	0.9
Speed of breathing [m^3/h]	1.12	0.64	0.22

The exposure paths considered are:

- Internal irradiation caused by inhalation of radionuclides located in the radioactive cloud and inhalation of nuclides which settled on the ground and were lifted up again;
- External irradiation from radionuclides located in the radioactive cloud;
- External irradiation from radionuclides settled on the surface of the ground;
- Internal irradiation caused by consumption of food containing radionuclides deposited on the ground.

3.3.1.4.2 Consumption of food

A farmer's family consumes two types of food with the highest contamination level in the largest possible quantities and all other land-based foods in accordance with the NRPB-W41. It is assumed that the two food products are made 100% locally and that all other food products are 50% made locally and 50% imported from other regions which are not contaminated.

It turns out that the largest share in the dose comes from consumption of cow milk and vegetables. Therefore, these two types of food are considered as the "top two" most contaminated and most often consumed types of food products.

Table 3.3.4. Rate of consumption of food products exposed to air-path radioactive contamination from an EPR reactor

Parameter	Adult	Child	Baby

Fraction of food produced locally – "Top 2"	1	1	1
Fraction of food produced locally – all other food	0.5	0.5	0.5
Consumption of green vegetables [kg/person/year] – average values	35	15	5
Consumption of root vegetables [kg/person/year] – average values	60	50	15
Consumption of fruit [kg/person/year] – average values	20	15	9
Consumption of mutton [kg/person/year] – average values	8	4	0.8
Consumption of offal [kg/person/year] – average values	5.5	3	1
Consumption of beef [kg/person/year] – average values	15	15	3
Consumption of milk [kg/person/year] – average values	95	110	130
Consumption of dairy products [kg/person/year] – average values	20	15	15
Consumption of green vegetables [kg/person/year] – critical values	80	35	15
Consumption of root vegetables [kg/person/year] – critical values	130	95	45
Consumption of fruit [kg/person/year] – critical values	75	50	35
Consumption of mutton [kg/person/year] – critical values	25	10	3
Consumption of offal [kg/person/year] – critical values	20	10	5.5
Consumption of beef [kg/person/year] – critical values	45	30	10
Consumption of milk [kg/person/year] – critical values	240	240	320

3.3.1.4.3 Yearly dose from air-path exposure for the most exposed person in the critical group

The consumption of grains is not analyzed because there is no information that the grains are grown, milled, and consumed locally. Dairy products are not considered to be the "top two" products because they include cheese, which usually is not produced locally, and milk beverages which are included in the cow and sheep milk.

Table 3.3.5. Yearly dose for the most exposed persons from a farmer's family due to releases into the atmosphere from an EPR reactor

	Dose from breathing [µSv/y]	Dose from land-based food consumption [µSv/y]	Dose from external exposure from the cloud [µSv/y]	Dose from external exposure from the cloud [µSv/y]	Total dose [µSv/y]
Adult	2.4E-01	3.6E+00	4.7E-02	3.9E-02	4.0E+00
Child	1.9E-01	4.2E+00	3.0E-02	2.0E-02	4.4E+00
Baby	1.3E-01	7.7E+00	2.4E-02	1.3E-02	7.8E+00

In the case of a farmer's family, the total dose for the different age groups is, respectively, 3.9, 4.4, and 7.9 µSv/year. The largest share of the dose comes from food, which contains carbon-14 (milk – 62% and vegetables – 17%).

3.3.1.5 Yearly doses for the most exposed members of the public due to water leaks

3.3.1.5.1 Critical group and environmental parameters

The most exposed group is members of a fisherman's family where the adults spend time fishing near the shore and the children play on the shore. The characteristics of the family according to the NRBP-W41 and ICRP66 are as follows:

Table 3.3.6. Characteristics of the habits of a fisherman's family taken into consideration in the evaluation of doses from liquid releases from an EPR reactor.

Parameter	Adult	Child	Baby
Fraction of time spent in the local area	1	1	1
Fraction of time spent in the regional area	0	0	0

Fraction of sea food caught in the local area	1	1	1
Fraction of sea food caught in the regional area	0	0	0
Time spent on the beach [h/y]	2,000	300	30
Speed of breathing on the sea [m^3/h]	1.69	1.12	0.35

3.3.1.5.2 Exposure paths

- Consumption of sea fish, crustaceans, and bivalves caught in the local waters;
- Inhaling the suspension of sea water drops in the air during stay on the beach;
- External exposure to deposits on the beach (three age groups) and to deposits on fishing equipment (adults only).

3.3.1.5.3 Consumption of food

The fisherman's family eats food from the sea in the maximum quantities, as shown in the table below:

Table 3.3.7. Habits of a fisherman's family pertaining to food from the sea assumed in the calculation of doses from liquid releases from an EPR reactor

Parameter	Adult	Child	Baby
Consumption of sea fish [kg/person/year]	100	20	5
Consumption of shellfish [kg/person/year]	20	5	0
Consumption of bivalves [kg/person/year]	20	5	0

3.3.1.5.4 Results of calculations

Table 3.3.8. Yearly doses for the most exposed fishermen's families [μSv/y] for various exposure paths from EPR reactors

	Dose from consumption of sea food (μSv y^{-1})	Dose from external exposure (μSv y^{-1})	Dose from inhaling sea splatter (μSv y^{-1})	Total dose (μSv y^{-1})
Adult	1.4E+01	3.2E+00	1.7E-09	1.7E+01
Child	4.2E+00	4.8E-01	2.2E-10	4.7E+00
Baby	1.4E+00	4.8E-02	1.5E-11	1.4E+00

3.3.1.6 Yearly doses for the most exposed members of the public received from all releases

The following three possible scenarios were taken into account to determine the maximum doses:

- A critical group of people living inland who also consume sea food with moderate intensity;
- A critical group of fishermen who also consume locally produced land-based food with moderate intensity;
- The most exposed person: a local inhabitant exposed to releases into the atmosphere and into the water.

3.3.1.7 Persons living inland who also consumes sea food

The dose from consuming sea food caught locally is defined with the assumption that:

- the fraction of sea food caught in the local area is equal to 1;

- the rate of consumption of sea food is moderate, as stated in the table below.

Table 3.3.9. Rate of seafood consumption

Parameter	Adult	Child	Baby
Consumption of sea fish [kg/person/year]	15	6	3.5
Consumption of shellfish [kg/person/year]	1.75	1.25	0
Consumption of bivalves [kg/person/year]	1.75	1.25	0

3.3.1.7.1 Results of calculations

Table 3.3.10. Dose received as a result of consumption of sea and land-based food in the vicinity of an EPR reactor

	Dose from consumption of sea food (average) (mSv y^{-1})	Dose from the land path of exposure (mSv y^{-1})	Total dose (mSv y^{-1})
Adult	1.9E+00	4.0E+00	5.9E+00
Child	1.2E+00	4.4E+00	5.6E+00
Baby	1.0E+00	7.8E+00	8.8E+00

3.3.1.8 Fishermen's families also consuming land-based food

It is assumed that 50% of food grown inland comes from local sources and all food is consumed in moderate quantities. The persons are not exposed to a radioactive plume by way of inhalation or exposure to external radiation from the plume and radionuclide deposits released to the atmosphere.

Calculation results:

Table 3.3.11. Dose received as a result of consumption of sea and land-based food in the vicinity of an EPR reactor

	Dose from consumption of land-based food (average) (µSv y^{-1})	Dose from the sea-path exposure (µSv y^{-1})	Total dose (µSv y^{-1})
Adult	1.4E+00	1.7E+01	1.8E+01
Child	1.6E+00	4.7E+00	6.3E+00
Baby	2.3E+00	1.5E+00	3.8E+00

3.3.1.9 The most exposed inhabitant

It is assumed that the family (adults, children, and babies) who lives the closest (500 m) from a nuclear power plant is exposed to releases into the atmosphere and into the sea. Therefore, the dose for the critical group is the sum of the radiation dose from the atmosphere and the dose received due to eating sea food.

Table 3.3.12. Comparison of the maximum exposure of critical group in different categories of inhabitants of the vicinity of an EPR reactor

	Fisherman's family (µSv y^{-1})	Farmer's family (µSv y^{-1})	Local inhabitant (µSv y^{-1})
Adult	1.7E+01	4.0E+00	2.1E+01
Child	4.7E+00	4.4E+00	9.1E+00
Baby	1.5E+00	7.8E+00	9.3E+00

3.3.1.10 The dose from direct radiation

Outside of buildings, the dose to the public is limited to 1 mSv per year. This value is based on the assumption that a work year is equal to 2,000 man-hours: hence the 0.5 µSv/h value. For simplicity's sake, it was assumed that this dose is present at the distance of 1 m from the external surface of buildings. The dose for a receiver located at the r distance can be calculated using the 1/r[74] function, i.e. by assuming that the relation between the dose and the distance from the reactor is inversely proportional. It turns out that the value of the dose is 0.001 µSv/h.

In order to calculate the yearly dose from direct radiation per person in the critical group, one must evaluate the shielding effect of his or her house. In the United Kingdom, the proper location (shielding)[73] factor is equal to 0.1 (according to the IRA methodology, table D). The total yearly dose for the critical group is equal to the value of the dose in the receiving person, multiplied by the stay time, taking into consideration the reduced value of the dose during the receiving person's stay indoors.

$\text{Dose} = D \times (LF_i \times O_i + LF_o \times O_o)$

where:

- D - value of the dose in the location with the highest radiation level on the land [µSv/h];
- LFi,o – Location (shielding) factor taking into account the ration of radiation values indoors and outdoors;
- Oi – time of stay indoors [h/y];
- Oo – time of stay outdoors [h/y].

It is assumed that adults spend 50% of their time outdoors, working in the field adjacent to the lot on which the nuclear power plant is situated. The anticipated dose is 4.8 µSv/y, as shown below:

$Dose = D\times (LF \times O + LF_o \times O) = 0.001\times (0.1\times 4380 + 1\times 4380) = 4.8\ \mu Sv/y$

Children spend 20% of time outdoors. Thus, the expected yearly dose is 2.5 µSv/y, as shown below:

$Dose = D\times (LF \times O + LF \times O) = 0.001\times (0.1\times 7008 + 1\times 1752) = 2.5\ \mu Sv/y$

Babies spend 10% of time outdoors. The anticipated dose for babies is 1.7 µSv/y, as shown below:

$Dose = D\times (LF \times O + LF \times O) = 0.001\times (0.1\times 7{,}884 + 1\times 876) = 2.5\ \mu Sv/y$

Table 3.3.13. Yearly dose for people exposed do direct radiation from an EPR reactor

Parameter	Adult	Child	Baby
Yearly dose for people who are the most exposed do direct radiation [µSv/year]	4.8	2.5	1.7

The maximum anticipated exposure due to direct exposure in the critical group is 5 µSv/year for people who live 500 m from a nuclear power plant. The value can be compared to the exposure to external radiation from Earth and space sources, which is equal to 700 µSv/year.

Table 3.3.14. Yearly dose for the critical group in the vicinity of an EPR reactor

	Local inhabitant ($\mu Sv\ y^{-1}$)	Direct radiation ($\mu Sv\ y^{-1}$)	Critical group ($\mu Sv\ y^{-1}$)
Adult	2.1E+01	4.8E+00	2.58E+01
Child	9.1E+00	2.5E+00	1.16E+01
Baby	9.3E+00	1.7E+00	1.10E+01

The assumption that the critical group of adults will consume the maximum quantity of sea food, milk, and vegetables results in a large safety margin and is very unlikely. Moreover, the parameters used in the calculation are very exaggerated which results in a dose which is slightly larger than 20 µSv/year.

3.3.1.11 Conclusions

The largest possible yearly dose is 25 µSv/year for an adult in a critical group. This value demonstrates that the radiation hazard from an EPR reactor is within limits for the public defined by the ICRP (1,000 µSv/year) and within the limits defined by the nuclear regulatory authorities (300 µSv/year). It must be remembered that we all receive an average yearly radiation dose equal to 3,400 µSv/year.

3.3.2 Nuclear power plants with AP 1000 reactors

The yearly doses resulting from exposure through the air leak during operation of an AP1000 reactor at the boundary of the restricted-use area (800 m) are equal to 0.021 mSv/year for gamma radiation and 0.1 mSv/year for beta radiation. The doses were determined based on the average yearly atmospheric dispersion coefficient $\chi/Q = 2{,}0 \times 10^{-5}$ s/m^3. The doses are lower than those allowed according to the US regulations 10CFR50, Appendix I, which are equal to 0.1 mSv/year for gamma radiation and 0.2 mSv/year for beta radiation.

3.3.3 Nuclear power plants with ESBWR reactors

During normal operation of an ESBWR reactor, the effective yearly dose for the critical group at the nuclear plant site is equal to 0.53 mSv and at the boundary of the restricted-use area – 0.002 mSv from the water path exposure and 0.01 mSv from the air path exposure.[75]

3.3.4 Reference nuclear power plant for conditions present in Poland according to the requirements set forth in the Atomic Energy Act

According to the requirements set forth in the draft of the modified Atomic Energy Act, the maximum dose that a critical group of people living at the boundary of the restricted-use area can receive is equal to 0.3 mSv/year.

The review of the yearly doses caused by normal operation of EPR, AP1000, and ESBWR reactors presented above demonstrates that at the distance of 800 m from the reactor the doses are lower than the permissible value (0.3 mSv/year).

The calculated anticipated total dose for an adult in the critical group is equal to

0.025 mSv/year **for an EPR reactor** (taking into account all exposure paths, for persons consuming sea and land-based food products contaminated with radiation and living 500 m away from the nuclear plant);

for an AP1000 reactor: air path exposure: 0.021 mSv/year for gamma radiation and 0.1 mSv/year for beta exposure (in total: 0.121 mSv/year);

for an ESBWR reactor: 0.002 mSv from water path exposure and 0.01 mSv from air path exposure (in total: 0.012 mSv/year).

The above three reactors have been recommended for Poland and are being considered by the investor. Thus, it can be assumed that the future Polish nuclear power plant will emit a dose larger than 0.3 mSv/year at the boundary of the restricted-use area 800 m away from the reactor. For other types of reactors that may be recommended in the future, it will be necessary to conduct similar analyses and demonstrate that the value of their radiation doses is not larger than those mentioned above.

As the above discussion indicates, the doses emitted during regular operation of an EPR reactor are very low. If we consider the input from atmospheric emissions, deposits on fields and the contaminated food produced on land, as well as fish exposed to radiation coming from nuclear power plants, inhabitants of highest-risk areas within 500 m around the reactor will be exposed to radioactive doses amounting to about 26 microsieverts, i.e. much less than the difference in annual doses between average towns and cities in Poland. For instance, the average dose of external radiation in Kraków is higher by 390 microsieverts than in Wrocław. This means that by moving to Krakow, an inhabitant of Wrocław would receive an additional 10 times larger radiation dose, compared to the dose he would have received if a nuclear power plant was built in Wrocław so close to her home that the plant's fence would be next to her window.

A comparison of the maximum dose received from an EPR reactor with the difference of doses in different cities in Poland is shown on **Błąd! Nie można odnaleźć źródła odwołania.**.

Still, nobody in their right mind would shy away from going to Kraków for fear of higher radiation. By the same token, we are not afraid of going to Zakopane, where radiation levels are even higher. Thus, it can be concluded that the small additional radiation present in the close vicinity of a nuclear power plant during its normal operation is not a problem for the ecosystem or for the health of people.

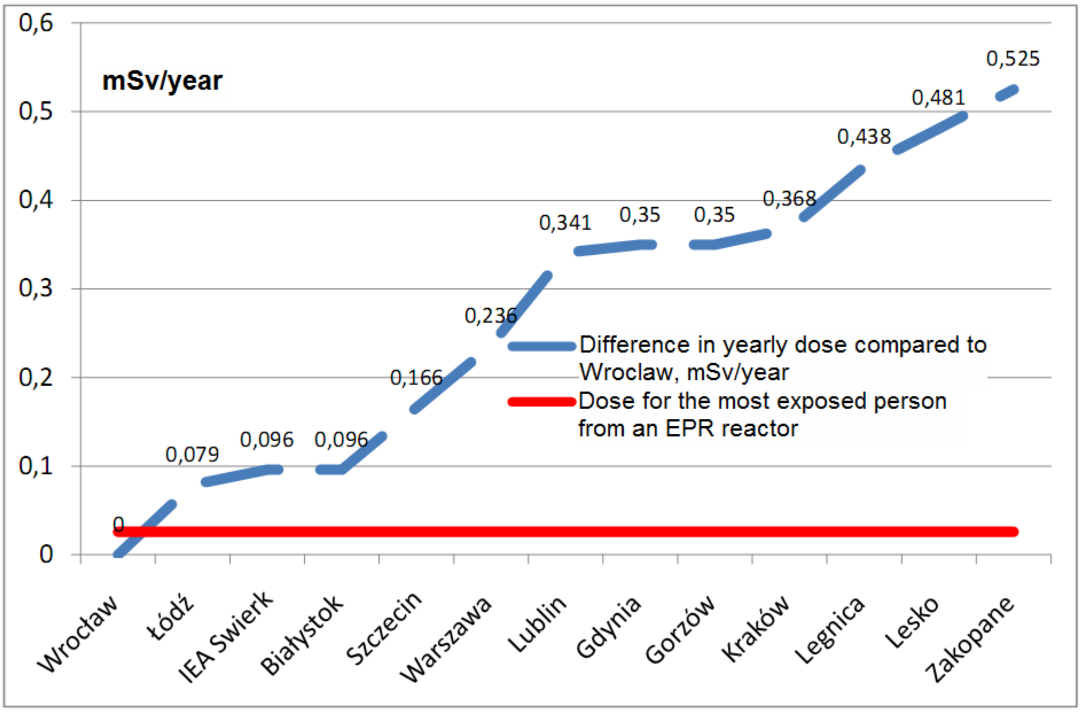

Figure 3.3.1. Comparison of the different external radiation doses in different cities in Poland with the additional radiation dose that may be received by the most exposed person from all exposure paths due to the operation of an EPR reactor.

3.4 Impact in transient and accident conditions

3.4.1 Nuclear power plants with EPR reactors

3.4.1.1 Assumptions for dose calculations

- The releases were evaluated using conservative methods and based on conservative assumptions regarding the primary activity, the rate of failure of fuel jackets, etc.

- When calculating the radiological effects (the doses), one makes realistic assumptions, so as to obtain fairly reasonably conservative assessment of the radiological effects of the transient conditions in question.
- The calculations of the effective doses cover all potential exposure paths, external exposure to radiation from clouds and deposits, internal exposure from inhalation and consumption of contaminated products. The value of the effective dose is calculated for a period of 50 years.
- After 7 days. The doses in this phase correspond to the exposure of the most exposed person located in the direct vicinity of the reactor during release of radioactive substances. The value of the effective dose received by inhalation and external exposure to radiation from clouds and deposits on the ground has been calculated for an EPR reactor at the distance of 500 m from the reactor. This must be underscored because the radius of the restricted-use area planned for Poland is 800 m, which means that the doses will be relatively smaller. Moreover, the equivalent dose to the thyroid by inhalation is calculated for an adult and for a 1 year old baby.
- After 50 years. The dose represents the integrated effects over the lifetime of the exposed person. In addition to the dose received during the passage of the cloud, it also considers the doses received due to the long-lasting contamination of the ground. Persons who live near a power plant are exposed to external radiation from deposits on the ground and to internal radiation resulting from consumption of contaminated food for 50 years. The dose is calculated for locations 2 km away from the plant.

3.4.1.2 The principles of radiation protection adopted in the EPR design in reference to design-basis accidents

In accordance with the general principle, when considering design-basis incidents and accidents, the more often an occurrence may take place, the least extensive its radiological consequences must be. In observance of this principle, the EPR reactor has been designed so as to significantly reduce the releases in transient conditions during incidents and accidents.

Each of the four types of occurrences has the following associated radiation protection objectives:

In PCC1 operation conditions (normal operation conditions) and in PCC2 transient conditions, the normal operating limits, namely the yearly dose of 0.3 mSv, must not be exceeded.

The radiological objectives are the same for PCC3 and PCC4 accidents; they are based on the principle that intervention measures should be unnecessary, i.e. the requirements set forth in the EUR document must be met. However, restrictions in the use of food coming from the surrounding area may be required.

Intervention measures at the early stage of an accident include staying in a shelter, evacuation, and administration of iodine pills. The ICRP recommends staying in a shelter when the avoided dose is in the range of 5 to 50 mSv; it recommends administering iodine pills when the equivalent avoided dose to the thyroid is in the range of 50 to 500 mSv. During accidents of this type, long term intervention measures, such as resettling of the population, are not allowed.

The 2008 safety analysis of the UK EPR reactor states that the French government adopted threshold values of 10 and 50 mSv (effective dose), respectively, for staying in a shelter and for evacuation, and the dose of 10 mSv (equivalent dose to the thyroid) for administering iodine pills. In the decree issued in December 2009[76], the Minister of Health of the French Republic defined the following doses at which intervention measures are undertaken.

Staying in a shelter – effective dose 10 mSv;

Evacuation (temporary) - effective dose 50 mSv;

Administration of stable iodine - equivalent dose to the thyroid 50 mSv.

The restriction on consumption of food are the same as in other European Union countries.

Thus, for class 3 and class 4 of an accident, the EPR design states an effective dose and an equivalent dose to the thyroid.

3.4.1.3 Atmospheric dispersion factors adopted in the calculations for the EPR reactor

The values of the doses are strongly dependent on the atmospheric dispersion factor (ADF). According to the data included in the US EPR reactor safety report, the values of the ADF for the American option are preliminarily assumed to be the same as those mentioned in the safety report of the Flamanville 3 power unit. The values are stipulated below.

Table 3.4.1. Atmospheric dispersion factors - χ/Q

Place and time where dispersion is to be determined	Value
Maximum average value during the year (800 m – boundary of the restricted-use area)	≤4.973E-06 s/m^3
Accident conditions	
0-2 h (800 m)	≤1E-03 s/m^3
0-2 h (2,400 m)	≤1.75E-04 s/m^3
2-8 h (2400 m)	≤1.35E-04 s/m^3
8-24 h (2400 m)	≤1.00E-04 s/m^3
1-4 day (2400 m)	≤5.40E-05 s/m^3
4-30 day (2400 m)	≤2.20E-05 s/m^3

Please note the high value of the atmospheric dispersion factor χ/Q= 1E-03 s/m3 assumed for the calculation of hazard after accidents of an EPR reactor at the boundary of the restricted-use area (radius 800 m) in the period of 0-8 hours after the accident. The anticipated values of the factor for typical conditions in Poland are, as shown above, for 1000 m - approx. χ/Q= 1E-04 s/m3; and for 500 m – approx. 2,5 E-4 s/m^3. What this means is that in Poland, at the distance of 500 m from the reactor, the anticipated dose within 8 hours after an accident in an EPR reactor is approx. 4 times less than that calculated in the analyses of the UK EPR reactor for the ADF χ/Q= 1E-03 s/m^3.

Similarly, a high value of the ADF was assumed in the calculations for the UK EPR reactor for the distance of 2,400 m.

Why do the safety analyses for the EPR reactor assume such high χ/Q values? This does not mean that EPR reactors cause high χ/Q values. The values characterize the location of a nuclear power plant and not the reactor type. Such high χ/Q values mean that all locations where the χ/Q values are smaller than those listed in **Błąd! Nie można odnaleźć źródła odwołania.** are suitable for the construction of an EPR reactor from the point of view of radiological restrictions on the doses received from the air after reactor accidents.

For the period of 24 hours after an accident and the distance of 800 m the χ/Q value is not stipulated because, according to US regulations, calculations are performed for 2 hours periods only. Nevertheless, for the distance of 2,400 m, it is stated that extension of the time from 2 hours to 24 hours results a 1.75 times increase of the ADF value. In the case of the Darlington nuclear power plant, the reduction of the ADF when the time is extended is even larger. Thus, the ADF for 800 m defined in Poland for 24 hours will be at least 1.75 times smaller than that for 2 hours.

3.4.1.4 Results of calculations

The doses received by the critical population group in the case of class 2, 3, and 4 design-basis accidents in a UK ERP reactor are shown in **Błąd! Nie można odnaleźć źródła odwołania.** [77] .

Table 3.4.2 . Doses received by the critical population group in the case of design-basis accidents in a UK ERP reactor

Occurrence		Distance 500 m, short-term dose, 7 days		Distance 2 km, long-term dose, 50 years
Incidents - Category 2:				
	Dose	Adult (Sv)	Child (Sv)	Adult (Sv)
Loss of vacuum in the condenser	Effective To the thyroid	$1.9\ 10^{-5}$ $2.2\ 10^{-4}$	$2.5\ 10^{-5}$ $4.0\ 10^{-4}$	$6.9\ 10^{-5}$ $1.7\ 10^{-5}$
Accidents – Category 3"				
Primary loop pipeline rupture outside of safety containment	Effective To the thyroid	$5.6\ 10^{-6}$ $1.7\ 10^{-5}$	$6.0\ 10^{-6}$ $2.9\ 10^{-5}$	$6.8\ 10^{-6}$ $1.3\ 10^{-6}$
Pipe rupture in steam generator – 1 pipe	Effective To the thyroid	$1.9\ 10^{-4}$ $3.3\ 10^{-4}$	$2.0\ 10^{-4}$ $5.9\ 10^{-4}$	$1.2\ 10^{-4}$ $2.5\ 10^{-5}$
Accidents – Category 4:				
Severe accident involving loss of coolant during operation	Effective To the thyroid	$2.9\ 10^{-4}$ $2.4\ 10^{-4}$	$2.3\ 10^{-4}$ $3.9\ 10^{-4}$	$1.4\ 10^{-4}$ $1.9\ 10^{-5}$
Loss of coolant when reactor shut down	Effective To the thyroid	$2.3\ 10^{-5}$ $9.3\ 10^{-5}$	$2.2\ 10^{-5}$ $1.5\ 10^{-4}$	$1.4\ 10^{-4}$ $7.0\ 10^{-6}$
Multiple failures in auxiliary building during earthquake	Effective To the thyroid	$3.8\ 10^{-4}$ $2.1\ 10^{-4}$	$3.8\ 10^{-4}$ $3.1\ 10^{-4}$	$7.3\ 10^{-5}$ $1.7\ 10^{-5}$
Pipe rupture in steam generator – 2 pipes	Effective To the thyroid	$4.6\ 10^{-4}$ $1.1\ 10^{-3}$	$4.8\ 10^{-4}$ $1.9\ 10^{-3}$	$5.0\ 10^{-4}$ $8.6\ 10^{-5}$
Accident during refuelling	Effective To the thyroid	$5.5\ 10^{-3}$ $1.8\ 10^{-4}$	$5.5\ 10^{-3}$ $2.7\ 10^{-4}$	$6.1\ 10^{-4}$ $2.0\ 10^{-5}$

As the data above shows, the largest effective doses at the boundary of the restricted-use area adopted in the design of the EPR reactor occur after class 4 accidents. In the case of the most severe accident involving primary loop rupture, namely an accident where 2 heat exchange pipes in the steam generator are ruptured, the effects received within 7 days after the accident are equal to $4,8 * 10^{-4}$ Sv for a child and $4,6 * 10^{-4}$ Sv for an adult. These values are higher than those for an accident involving rupture of the main primary loop pipeline because when the primary loop pipeline is ruptured the fission products escape into the safety containment, whereas rupture of pipes in a steam generator result in the fission products from the primary loop escaping to the plant's surroundings through the safety valves of the primary loop and bypassing the safety containment. In safety analyses of Generation II PWR reactors, accidents involving rupture of pipes in a steam generator are considered to be potentially the worst and design-basis accidents assumed rupture of only one pipe. Rupture of two pipes was classified as hypothetical accident.

The analysis of such an accident assumes that the maximum concentration of iodine in the primary loop prior to the pipe rupture corresponds to the previous peak of iodine emission which causes the concentration of iodine in the primary loop coolant to reach the maximum value right before the accident; the maximum value is equal to 150 GBq/t in units of equivalent I-31 iodine activity (I131eq), which is defined as:

$$(I-131eq) = I131 + I132/30 + I133/4 + I134/50 + I135/10$$

The radiological consequences of this accident are effectively mitigated in the EPR reactor thanks to the following design improvements:

The pressure in the medium head safety injection system (MHSI) is below the tripping value for the safety valves in the steam loop, which lowers the quantity of water that may flow from the primary loop to the secondary loop in a defective steam generator.

The defective steam generator is identified based on a simple symptom of its condition, i.e. on the level of water in the generator. The resulting signal automatically initiates lifting of the tripping level of the main relief valves on the steam side, which eliminates the leak from the primary loop to the secondary loop. Prior actions of the operator, consisting in manual switching based on the level of activity in the defective steam generator, are possible but not included in the safety analysis.

The capacity of the steam generator on the secondary loop side is increased, which extends the time for taking actions to prevent filling of the secondary loop side of the steam generator with water.

Thanks to these safety measures introduced to the EPR reactor, an accident involving simultaneous rupture of 2 pipes is qualified as a design-basis accident (i.e. an accident where the design of the reactor guarantees that the safety of the surroundings of the reactor will be maintained); in fact, the effective dose within 7 days after such an accident is limited to 0.48 mSv. The maximum equivalent dose to the thyroid during such an accident is equal to 1.2 mSv for an adult and 1.9 mSv for a child. These values are much lower than the values where, according to the decree of the French Minister of Health**Błąd! Nie zdefiniowano zakładki.**, intervention measures must be undertaken.

The largest potential threat takes place in the case of an accident occurring during handling of fuel, since in such a case it is assumed that the whole fuel assembly fails as it is in danger of becoming damaged after the refuelling container is dropped. Because refuelling operations are conducted with the safety containment open, the released fission products are released into the atmosphere around the plant and are not trapped in the containment. At the distance of 500 m from the reactor, the maximum effective dose for a child within 7 days is equal to 5.5 mSv and the equivalent dose to the thyroid is equal to 0.27 mSv. Both these values are lower than the values that trigger intervention measures. Evidently, from the point of view of doses received after design-basis accidents of an EPR reactor that do not involve core meltdown, the radius of the restricted-use area could be less than 800 m and be just under 500 m.

The doses at the distance of 2 km from the reactor calculated for a 50-year period for an adult are equal to 0.61 mSv for a fuel handling accident and 0.5 mSv for an accident involving simultaneous rupture of two pipes in a steam generator. These values are much lower than the values triggering any intervention measures.

Moreover, according to the note made in the previous section, when the atmospheric dispersion factor values χ/Q for the actual location are lower than those assumed in the UK EPR design, the dose values will be lower than those stipulated in **Błąd! Nie można odnaleźć źródła odwołania.**.

Błąd! Nie można odnaleźć źródła odwołania. shows the doses received in the case of an accident involving rupture of the steam pipeline outside of the safety containment, analyzed in accordance with US requirements.

Table 3.4.3. Doses at the exclusion area boundary (EAB), low population zone (LPZ), and in the master control room (MCR) after an accident involving rupture of the steam pipeline outside of the safety containment of an EPR reactor, calculated according to the US NRC method (note: the values in parentheses are permissible dose limit values according to US regulations)

	Total effective dose (TEDE) (REM) and dose limit			
Receiving	Iodine peak prior	Simultaneous	Failure of 3.3% of fuel	Meltdown of

point	to the accident	iodine peak	jackets	0.58% of fuel
EAB	0.24 (25)1	0.27 (2.5)	5.3 (25)	5.8 (25)
LPZ	0.06 (25)	0.20 (2.5)	2.6 (25)	2.8 (25)
MCR	0.52 (5)	0.72 (5)	4.5 (5)	4.5 (5)

3.4.2 Nuclear power plants with AP 1000 reactors

3.4.2.1 Atmospheric dispersion factors assumed in the design of the UK AP1000 reactor

The atmospheric dispersion factors assumed in the design of the UK AP1000 reactor are shown in **Błąd! Nie można odnaleźć źródła odwołania.**[78].

Table 3.4.4. Atmospheric dispersion factors assumed in the analysis of the AP1000 reactor

Atmospheric dispersion factor - $X/Q_{(E)}$	
Exclusion area boundary - 800 m from the reactor (0-2 h)	5.1×10^{-4} s/m^3
Exclusion area boundary (average value during the year)	2.0×10^{-5} s/m^3
Low population zone boundary	
0 - 8 h ,	2.2×10^{-4} s/m^3
8 - 24 h,	1.6×10^{-4} s/m^3
24 - 96 h,	1.0×10^{-4} s/m^3
96 - 720 h,	8.0×10^{-5} s/m^3

The value of the χ/Q factor assumed for the exclusion area boundary is two times lower than the value assumed in the UK ERP design. On the other hand, the χ/Q values assumed for the UK AP100 reactor for the low population zone are slightly lower than those for the EPR reactor. This must be remembered when considering the results of the calculation of doses after the AP1000 reactor accidents.

3.4.2.2 Consequences of steam generator tube rupture in an AP1000 reactor[79]

The safety analyses distinguish two cases:

– when the iodine peak is caused by the accident;

– when the accident occurs at a time when the iodine peak has continued for 8 hours.

In the first case the effective dose within 2 hours after the accident at the exclusion area boundary does not exceed 11 mSv and at the boundary of the low population zone – does not exceed 8 mSv within 30 days after the accident. These are small fractions of the permissible dose for such cases according to US regulations[80] (250 mSv).

In the latter case, the doses are 22 mSv and 13 mSv respectively and are within the permissible dose limits according to US regulations.

If the anticipated atmospheric dispersion factor at the exclusion area boundary for a typical location in Poland, which is equal to 10^{-4} s/m3, were used, it would turn out that the dose from an AP1000 reactor is five times lower and is within the permissible dose limits according to the draft regulations to be adopted in Poland. However, in worse weather conditions, it may be necessary to enlarge the exclusion area beyond the 800 m radius.

3.4.2.3 Consequences of complete rupture of the steam pipeline outside of the safety containment of an reactor[81]

In the event that the iodine peak is caused by the pipeline rupture, the calculated total effective dose equivalent (TEDE) is 11 mSv at the exclusion area boundary within 2 hours after the accident and 20 mSv at the boundary of the low population zone within 30 days after the accident. The doses are small fractions of the permissible dose according to US regulations, which is equal to 250 mSv (10 CFR Part 50.34). A small fraction, according to the NCR guidelines (Standard Review Plan) is 10% or less. In the event that the iodine peak occurs prior to the accident, the TEDE values are 10 mSv at the exclusion area boundary and 8 mSv at the low population zone boundary.

3.4.2.4 Consequences of sudden rupture of the main pipeline of the primary loop in an AP1000 reactor

In calculations made on the basis of assumptions made according to the best knowledge, an accident involving rupture of the large diameter pipeline rupture in an AP1000 reactor does not lead to failure of the fuel jackets. This is in line with the results of many experimental studies.

The calculated maximum jacket temperature, which with 95% confidence will not be exceeded, is 1,002.78 oC; thus, the value is lower than the permissible value of 1,204.44 oC.

The maximum local depth of oxidation of the jacket is equal to 2.25% (whereas the permissible depth is 17%). The maximum oxidation of the jackets in the whole core is 0.2%, which is also less than the permissible value which is ≤ 1%. The geometry of the core remains intact to the extent that allows for continued cooling of the core.

The radiological consequences remain small, similar to accidents in an EPR reactor. On the other hand, given the assumptions imposed by US regulations, where, regardless of the operation of the emergency core cooling system, fuel meltdown will occur, such an accident is considered as a severe accident involving fuel meltdown in section 9.4.2.

3.4.3 Nuclear power plants with ESBWR reactors

3.4.3.1 Principles of classification of design-basis accidents in ESBWR reactors

The radiation hazard after accidents in ESBWR reactors has been evaluated in accordance with the requirements set forth in US regulations. Due to the fact that no safety reports have been elaborated for ESBWR reactors in accordance with EUR requirements, the present document uses data from a report published for the NRC, with the dose values recalculated to correspond to the anticipated requirements to be set forth in Polish regulations.

In the event of an accident according to the 10 CFR 50.34(a)(1), the total effective dose equivalent[82] according to the SRP 15.0.1 and RG 1.183 must be limited to 0.025 Sv, 0.063 Sv, and 0.25 Sv, depending on the category of the accident, as shown in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.4.5. Categories of accidents in ESBWR reactors and the corresponding permissible total effective dose equivalent values according to US regulations

Accident	0.025 Sv	0.063 Sv	0.25 Sv
Fall of spent fuel container		x	
Rupture of a small diameter tube containing primary loop coolant outside of the safety containment	x		
Rupture of the feedwater pipeline outside of the safety containment	x		
Rupture of the coolant cleaning loop and the after-shutdown cooling loop outside of the safety containment	x		

Fall of the control rod		x	
Rupture of the steam collector outside of the safety containment	x		
Rupture of the primary loop inside the safety containment			x
Fuel handling accident		x	
Leak from the radioactive gases system	x		

The atmospheric dispersion factor values assumed in the ESBWR reactor safety analysis are shown in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.4.6. Data for calculating the dispersion and the radiation doses in the case of an ESBWR reactor

A. Meteorology – the value of the atmospheric dispersion factor:	
Exclusion area boundary, 800 m	2.00E-03 s/m^3
External boundary of low population zone, 0–8 hours	1.90E-04 s/m^3
8 – 24 hours	1.40E-04 s/m^3
1 – 4 days	7.50E-05 s/m^3
4 – 30 days	3.00E-05 s/m^3

It must be noted that the value of the atmospheric dispersion factor at the exclusion area boundary used in the analyses of the ESBWR reactor is equal to $2*10^{-3}$ s/m^3, which it two times more than the value for the EPR reactor and four times more than the value for the AP1000 reactor.

3.4.3.2 Doses calculated for design-basis accident[83]s in ESBWR reactors

In the case of failure of 1,000 fuel rods, the dose at the exclusion area boundary (800 m away from the reactor) is less than 0.025 Sv.

Table 3.4.7. Results of calculation of doses after failure of 1,000 fuel rods in an ESBWR reactor

Exposure location and time	**Maximum effective dose calculated** REM / (mSv)	**Criterion of acceptance of effective dose** REM / (mSv)
Exclusion area boundary throughout the time of flow of radioactive plume	1.56E-01 /(1.56)	2.5 (25)
External boundary of the low population zone throughout the time of flow of the radioactive plume	5.94E-02/ (0.594)	2.5/ (25)

As **Błąd! Nie można odnaleźć źródła odwołania.** shows, defects which lead to failure of the jackets of 1,000 fuel rods in an ESBWR reactor cause doses at the exclusion area boundary (1.56 mSv) and at the low population zone boundary (0.594 mSv) which are lower than the permissible values defined in US regulations and lower than the permissible values designed in the draft Polish regulations. The analysis of the accidents assumes that fission products will be released from the jackets and that partial fuel meltdown will not occur.

Accidents in the radioactive gas system will also not result in doses that exceed the permissible values, as shown in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.4.8. Coefficients for failures leading to releases from the radioactive gas system

Data for calculation of dispersion of the dose	
A. Atmospheric dispersion factor	
At the exclusion area boundary, 800 m (s/m^3)	2.0E-03
In the reactor control room (s/m^3)	Table 2.0-1
B. Assumptions regarding conversion of the dose	RG 1.183

Table 3.4.9. Calculated radiation doses after a failure in the radioactive gas system

Exposure location and time	Maximum effective dose calculated REM / (mSv)	Criterion of acceptance of effective dose REM/(mSv)
Exclusion area boundary, 2 hours	7.2 E-02 / (0.72)	2.5 / (25)
External boundary of the low population zone, 30 days	7.2E-02 / (0.72)	2.5 / (25)

On the other hand, an accident with fuel container failure during manipulation with the safety containment open leads to doses which, given the large atmospheric dispersion factor values assumed in the ESBWR reactor safety analyses, exceed the values allowed in the draft Polish regulations. The calculations results are shown in **Błąd! Nie można odnaleźć źródła odwołania.**. Even higher are doses after accidents involving rupture of the steam loop outside of the safety containment. This is due to the relatively high concentration of fission products in the steam loop, which is the natural outcome of the operation of the ESBWR reactor which, unlike the EPR reactor or the AP1000 reactor, has one loop, instead of two. Consequently, the releases of iodine and other fission products dissolved in the steam from ESBWR reactors are much larger than from PWR reactors.

Table 3.4.10. Calculated doses after a failure during fuel handling in an ESBWR reactor

Exposure location and time	Maximum effective dose calculated REM / (mSv)	Criterion of acceptance of effective dose REM/(mSv)
Exclusion area boundary, 2 hours	3.6 / (36)	6.3 /(63)
External boundary of the low population zone throughout the time of flow of the radioactive plume	3.6 / (36)	6.3 /(63)
Dose received by the operator in the control room through the time of the accident	2.3 / (23)	5.0 /(50)

Table 3.4.11. Results of radiological analysis of consequences of steam collector rupture in an ESBWR reactor

Exposure location and time	Maximum effective dose calculated REM / (mSv)	Criterion of acceptance of effective dose REM/(mSv)
At the exclusion area boundary throughout the time of flow of radioactive plume		
With iodine activity peak prior to the accident	12,6 (126)	25 / (250)
With iodine activity in a balanced state	0,7 (7)	2,5 / (25)
At the external boundary of the low population zone throughout the time of flow of the radioactive plume		
With iodine activity peak prior to the accident	12,6 (126)	25 / (250)
With iodine activity in a balanced state	0,7 (7)	2,5 / (25)
Dose received by the operator in the control room through the time of the accident	4,5 (45)	5 / (50)

3.4.4 Reference nuclear power plant for conditions present in Poland according to the requirements set forth in the Atomic Energy Act

According to the recommended requirements included in draft Polish regulations, similar to the EUR requirements, nuclear power plants should be designed so that outside of the exclusion area, during a design-basis condition accident (without core meltdown) it is not necessary to implement any intervention measures. Regulation of the Council of Ministers of 27 April 2004[84] defines the doses at which appropriate intervention measures with specific effectiveness must be undertaken. The respective values are shown in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.4.12. Intervention levels according to the Polish regulations

Dose that may be received with no intervention measures			Type of intervention measures
Value	Type of dose	Time	
100 mSv*	Effective	7 consecutive days	Evacuation
10 mSv*	Effective	2 consecutive days	Instructions to stay in sealed indoor premises
100 mSv*	To the thyroid	-	Administration of stable iodine
30 mSv*	Effective	30 days	Temporary resettlement
10 mSv*	Effective	30 days, 2 years after the accident	Permanent resettlement
1000 mSv*	Effective	Lifetime**	Permanent resettlement
When the radioactive substance content in food exceeds the values stipulated in Annex 1 to the Regulation			Ban on consumption of contaminated food
When the content of caesium in animal feed or water exceeds the values stipulated in Annex 2 to the Regulation			Ban on giving contaminated feed and water to animals and on pasturing cattle on the contaminated land

** With the exception of the dose received with food*
*** Adults - 50 years; children – 70 years*

The basic evaluation criteria for the three types of reactors in question are the dose values at the exclusion area boundary in reference to the two types of intervention measures and levels defined in the aforementioned Regulation of the Council of Ministers, namely:

- staying in sealed indoor premises – the doses within 2 days after the accident may not exceed 10 mSv;
- evacuation – the doses within 7 days after the accident may not exceed 100 mSv.

As shown in sections 7.4.1 – 7.4.3, the doses at the exclusion area boundary after accidents which do not involve fuel meltdown are equal to:

EPR reactor: χ/Q (0-2 h) =$1*10^{-3}$ s/m3, the effective dose within 7 days equal is equal to 5.5 mSv in the case of refuelling accident; the dose to the thyroid is equal to 1.9 mSv in the case of simultaneous rupture of 2 tubes in the steam generator. In the case of rupture of tubes in the steam generator – which is the accident with the most extensive radiological consequences for the other two generator types - in an EPR reactor all factors that increase the hazard have been considered, to include the preceding peak of iodine emission into the primary loop.

AP1000 - χ/Q (0-2 h) = 1*10-3 s/m3, the effective dose within 2 hours after the accident is equal to 11 mSv for an accident involving rupture of the steam pipeline without prior peak of iodine emission into the coolant; or 10 mSv in the case of iodine emission prior to the steam pipeline rupture. At the distance of 2,400 m from the reactor, the doses within 30 days are 20 mSv and 8 mSv, respectively.[85]

ESBWR: χ/Q (0-2 h) = 2*10-3 s/m3, the effective dose within 2 hours after an accident involving failure of 1,000 fuel rod jackets at the exclusion area boundary is 1.56 mSv; after a fuel handling accident – 36 mSv; and after rupture of the steam loop with earlier iodine peak – 126 mSv (which is approx. 6 times more than in the case of an AP1000 reactor). Even though the atmospheric dispersion factor assumed for the ESBWR is two times larger than that assumed for the EPR reactor, it is evident that the consequences of steam loop rupture in the ESBWR reactor are severe. Considering the fact that in specific locations in Poland the value of the atmospheric dispersion factor is several times lower than the value assumed for the ESBWR reactor, such accidents would require people living at the distance of 800 m from the reactor to at least stay in sealed indoor premises and perhaps to be temporarily evacuated. The right decision can be made only after determining the characteristics of the atmospheric dispersion in a specific location. Of course, an ESBWR can be located in Poland without the need for evacuation, but it will require a significantly larger exclusion area.

Thus, the values shown in table 7.4.11 will be used as the reference values.

3.5 Impact in the event of severe accidents

3.5.1 Nuclear power plants with EPR reactors

3.5.1.1 Assumptions for evaluation of radiological hazards after accidents according to US regulations

With regards to accidents other than those involving rupture of the primary loop, the assumptions are more conservatives than those in regulations in force in most European Union countries and in regulations to be adopted in Poland. At the stage of licensing of a reactor design, the designer performs analyses which demonstrate the extent of defects caused by a given accident at which the doses in reference points will not be exceeded. Such reference points are usually:

– the exclusion area boundary located 800 m from the reactor;

– the low population zone boundary[86] located 2,400 m from the reactor;

– the reactor master control room located in the building adjacent to the safety containment for which conservative assumptions are made concerning the movement of air and the atmospheric dispersion factors.

Depending on the type of accident, one of these reference points is the location where the dose is close to the limit value defined in US regulations. In the other points, the anticipated dose is lower than the permissible dose. The permissible doses after severe accidents are not defined either in Polish regulations or in regulations of other EU countries; however, they are defined in US regulations. The permissible dose depends on the anticipated frequency of the accident; for the maximum accident, it is equal to 250 mSv and for more frequent accidents – 63 mSv or 25 mSv. These values are much higher than the doses for design-conditions accidents according to the EUR requirements, which is due to the formal requirements regarding the characteristics of the accidents in question. The main types of accidents in EPR reactors according to the US approach are shown below.

3.5.1.2 Characteristics of the main types of accidents considered in the design of the US EPR reactor

1. The loss of coolant accident (LOCA) in the US EPR reactor is considered in accordance with the assumptions defined in the RG 1.183 document.

It is assumed that a loss of off-site power (LOOP) occurs simultaneous with the loss of coolant, and that the time sequence of the releases conforms to the requirements of the RG 1.183, Table 4. US EPR reactors are licensed under the condition that leaks are detected before rupture of the primary loop. Despite this, the radiological consequences of an accident are determined as if this condition was not met. This is important, because it is assumed that in the first 305 seconds air will be removed from the space between the primary and the secondary safety containment. This process does not include filtration, which means that releases occurring immediately after an accident are removed into the surroundings on the outside of the plant.

The releases consists of the activity in the coolant at the moment of rupture of the pipeline (with the limit content of iodine isotopes corresponding, from the point of view of radiation hazard, to the dose equivalent of iodine-131 equal to 1 µCi/gm, the dose equivalent of inert gases equivalent, from the point of view of radiation hazard, to dose equivalent of xenon-133 equal to 210 µCi/gm) and of releases from the reactor fuel, in accordance with the course of releases defined in the RG 1.183 guidelines. In addition to releases from underneath the jacket for a period of 30 minutes, the releases from the fuel include releases from melting fuel for a period of 90 minutes. Thus, an accident of this type is a severe accident with fuel meltdown.

All releases occur to the primary atmosphere in the safety containment. Their elimination from the atmosphere in the containment occurs as a result of natural decay, settling on the wall and on the floor, escape in the first 10 seconds after the accident through the ventilation system, and escape through any openings in the remaining time of the accident. It should be noted that the designers of the EPR reactor did not take advantage of the possibility to increase the rate of elimination of iodine from the atmosphere inside the containment by using an encasement sprinkling system. The rate of the leaks from the containment is 0.25% per day for the first 24 hours and then it drops by 50% in the following days. The fact that fission products are stopped in buildings around the containment is not taken into account. The atmospheric dispersion factor values for the LOCA conditions are shown in **Błąd! Nie można odnaleźć źródła odwołania.**.

Table 3.5.1. Atmospheric Dispersion Factors (χ/Q) used in the safety report for the US EPR[87] reactor for LOCA accidents

Location and time	Value of the χ/Q factor
Maximum average value during the year (800 m – boundary of the restricted-use area)	≤4.973E-06 s/m³
Accident conditions	
0-2 h (800 m)	≤1E-03 s/m³
0-2 h (2400 m)	≤1.75E-04 s/m³
2-8 h (2400 m)	≤1.35E-04 s/m³
8-24 h (2400 m)	≤1.00E-04 s/m³
1-4 day (2400 m)	≤5.40E-05 s/m³
4-30 day (2400 m)	≤2.20E-05 s/m³

2. Rupture of a small diameter pipeline (sampling line, dia. 6 mm) outside of the safety containment does not lead to fuel meltdown or jacket failure because the leak is too small and the coolant replenishment system keeps the core under water and properly cooled. However, the rupture causes water with fission products to leak out (it is assumed that an iodine peak occurred before the rupture). The leak continues for 30 minutes before the operator intervenes. The accident results in the dose at 800 m (within 2 hours after the accident) and 2,400 m (within 30 days after the accident) to be 0.18 REM = 1.8 mSv and 0.3 REM = 3 mSv, respectively.

3. Rupture of tubes in the steam generator does not lead to fuel burnout because the core continues to be properly cooled. Two courses accidents of this type are assumed:

– Due to the prior iodine peak, concentration of iodine in the primary loop coolant increases to reach the maximum operating value of 60 µCi/gm DE I-131 (acc. to the RG 1.183, Appendix F);

– With iodine peak caused by the accident in question, it is assumed that iodine concentration increases for 8 hours, which corresponds to a 355-fold increase of the rate of iodine emission into the coolant (acc. to the RG 1.183, Appendix F).

4. Rupture of the steam pipeline outside of the safety containment causes steam to escape from the defective steam generator for 9 hours and from the other steam generators for 8 hours after the accident, i.e. until the water temperature in the secondary loop drops to 99 °C. The analysis takes into account a prior iodine peak or an iodine peak caused by the accident, a jacket failure due to heat exchange crisis and melting of the fuel centre in rods operating at the uneven thermal load coefficient equal to 1.7.

Various cases are also considered for this type of accidents:

- iodine concentration in the primary loop coolant at the time of accident is equal to 60 µCi/gm DE I-131;
- rate of iodine emission into the coolant increases 500 times;
- the jacket fails in 3.3% of fuel rods;
- 0.58% of fuel melts down.

The potential radiation consequences of such an accident that does not involve jacket failure and fuel meltdown are equal the limit values in the reactor control room. In the last two cases are considered, the doses in the control room reach 90% of the permissible dose. The radiological consequences of the accident are evaluated assuming that the whole uranium mass in the fuel rod melts and releases 100% of inert gases and 50% of halogens and alkali metals into the coolant.

The consequences of steam collector rupture are more severe than the consequences of feedwater pipeline rupture and, therefore, the latter case does not need to be considered.

5. Seizure of the rotor of the circulation pump leads to possible fuel rod failure due to heat transfer crisis. The purpose of the analysis is to determine the maximum fraction of jacket failures that does not lead to exceeding the level of 90% of the permissible dose in any of the receiving points. It turns out that the permissible fraction of jacket failure is equal to 9.5% and is limited by the dose at the distance of 800 m from the reactor.

6. Ejection of the control rod results in a sudden local power increase with simultaneous loss of tightness of the reactor vessel. The following two alternative scenarios are considered in accordance with the guidelines set forth in the SRP 15.0.3 and the RG 1.183:

- leaks through the safety containment into which the whole activity of radionuclides released from the failed fuel rod jackets and the overheated fuel escapes;
- leaks through the secondary loop into which the activity from the primary loop escapes due to the leaks in the steam generator tubes which are damaged in the plant's cooling phase (which occurs as steam is releases through the relief valves on the secondary side which are open due to the loss of the on-site AC power supply after the accident).

It is expected that during actual accidents leaks will occur simultaneously through both paths.

The analysis indicated that, due to the permissible doses at the distance of 800 m from the reactor, the fraction of failed fuel jackets may not be larger than 4%.

7. A fuel handling accident is considered with the assumption that it occurs at the beginning of refuelling, 34 hours after the reactor was shut down. It is assumed that a fuel assembly which has been used at the power peaking factor of 1.7 falls onto other assemblies, which leads to failure of all 265 fuel rod jackets in the dropped fuel assembly and to release of the whole quantity of gases and iodine contained in the gaps beneath the fuel rod jackets. It is assumed that the accident occurs either in the safety containment or in the fuel building. Other accidents occurring during handling of fuel (e.g. fall of the transport container into the fuel pool) are excluded thanks to proper design of the spent fuel transport equipment.

The fraction of released fission products from the gap beneath the fuel rod jacket correspond to the fuel with maximum burnup of 62 GW·d/tU (RG 1.183, Table 3, Footnote 11). The released activity flows through the 7 m deep layer of water which retains the alkali metals and reduces the release of halogens to less than 0.5% of the original value (RG 1.183, Appendix B, Section 2). The whole quantity of inert gases escapes into the atmosphere in the safety containment or in the fuel building. It is assumed that all releases into the plant's surroundings occur within 2 hours (RG 1.183, Appendix B, Section 4.1). This corresponds to the assumption that the air change rate is 2.5 times the building's volume per hour, which results in removal of 46.5% of the activity present in the air in the reactor building into the atmosphere within 15 minutes. This is equal to a release of 99.3% within 2 hours. It is assumed that the releases occur without filtration at the level of the ventilation stack base.

In US EPR reactor fuel with the maximum thermal load (radial peaking factor equal to 1.7), the maximum pressure of gases beneath the fuel rod jacket is less than the limit value of 8.4 MPa defined in the RG 1.25 document.

The period of cooling before the accident equal to 34 hours was selected so that the dose after the accident is less than 90% of the permissible value in the most exposed receiving point, which in this case is a person present at the distance of 800 m from a nuclear power plant. The dose received by the staff in the control room is fairly low, approx. 0.022 mSv, with continuous exposure throughout the time after the accident.

3.5.1.3 Protection of the foundation slab of the EPR reactor containment from melt-through in the event of a severe accident involving core meltdown

All Generation III reactors have a sturdy safety containment, whereas an EPR reactor has a containment which will withstand a collision with even the largest passenger aircraft. Moreover, nuclear power plants with EPR reactors have four safety systems located in four separate buildings, which provides an additional protection against attacks on the plant from the outside. However, the basic characteristic of Generation III reactors is the fact that, regardless of the extremely low likelihood of core meltdown as a result of an accident, it is assumed as a starting point that a core meltdown may occur and that appropriate reactor characteristics and technical measures are provided to protect the population against such a hypothetical accident.

All designs use safeguards against early sudden rupture of the safety containment, for example as a result of explosion of hydrogen emitted at high temperatures in chemical reactions between water and zirconium. A number of other systems ensure the reliable absorption of heat from the reactor and its safety containment. In AP1000 reactors, the shaft where the reactor is located can be filled with water in the event of a severe accident, in order to assure external cooling of the reactor vessel and, consequently, to prevent the glowing core from burning through the vessel. In EPR and ESBWR reactors, due to their larger power, such cooling would not be sufficient and, consequently, a concept of molten core catcher was introduced. The concept involves using a pool installed beneath the reactor vessel into which the molten core would leak and where it would spread over a large surface, thus facilitating the cooling of the molten layer of core materials.

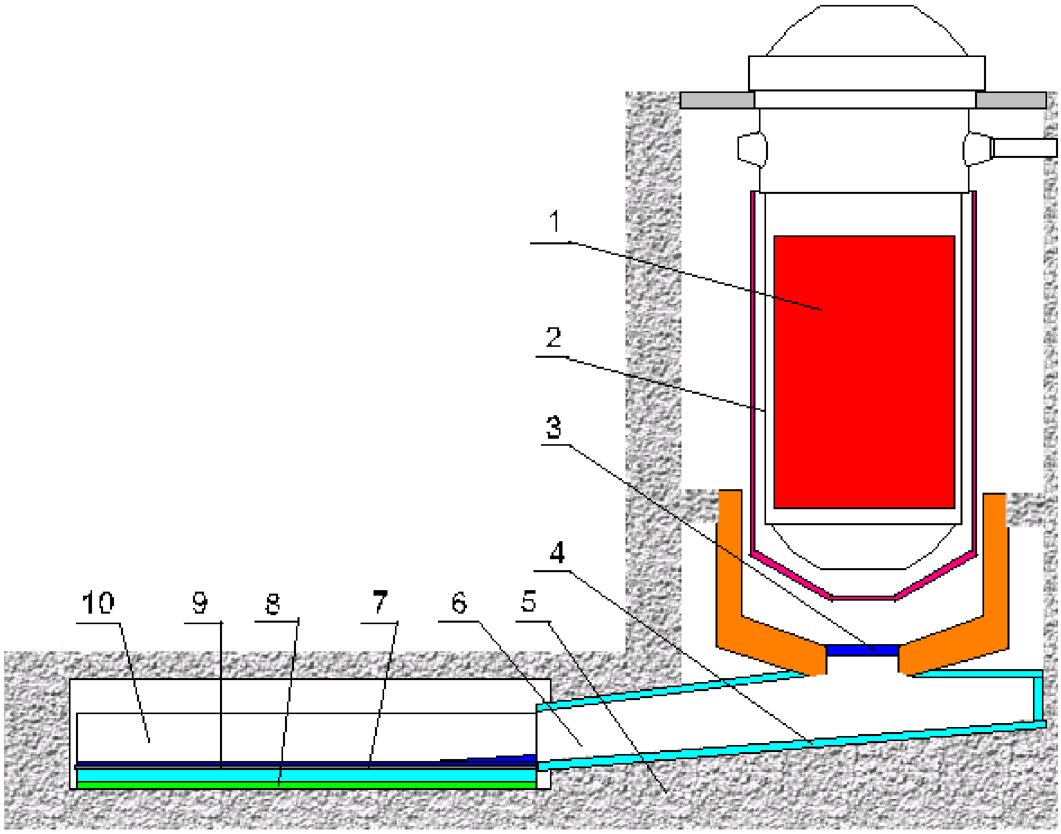

Figure 3.5.1. Core catcher in an EPR reactor

In the event of a severe accident involving core (1) meltdown and its escape from the reactor vessel (2), the molten core material melts through the lid (3) and flows through the channel (6) into the pool (10). The heat resistant material layer (4) protects the foundation slab (5) of the safety containment from being molten-through, and the pool (10) contains layers of concrete (7 and 9) which are cooled with water flowing through pipes (8).

3.5.1.4 Radiological effects of accidents with core meltdown (severe accidents) and without core meltdown in EPR reactors according to US regulations

Błąd! Nie można odnaleźć źródła odwołania. shows data on doses after severe accidents in EPR reactors.

Table 3.5.2. Radiological consequences of severe accidents with partial core meltdown in US EPR reactor (mSv TEDE[88])

Accidents without core meltdown and with partial core meltdown		Radiation dose, mSv (permissible value acc. to US regulations provided in the parenthesis)		
		800 m	2400 m	Control room
1. Loss of coolant accident (LOCA)		122 (250)	111 (250)	40 (50)
2. Rupture of small diameter pipeline outside of the safety containment		18 (25)	3 (25)	1 (50)
Steam generator tube rupture	3. with prior iodine peak	11 (250)	3 (250)	3 (50)
	4. with simultaneous iodine peak	7 (25)	5 (25)	6 (50)
Main steam line break	5. with prior iodine peak	2 (250)	1 (250)	5 (50)
	6. with simultaneous iodine peak	3 (25)	2 (25)	7 (50)
	7. with fuel jacket failure	53 (250)	26 (250)	45 (50)
	8. with partial fuel meltdown	58 (250)	28 (250)	45 (50)
9. Seizure of the rotor or breaking of the circulation pump shaft 2		23 (25)	9 (25)	13 (50)
10. Ejection of the control rod		57 (63)	35 (63)	43 (50)
11. Fuel handling accident		56 (63)	10 (63)	5 (50)

As one can see, the assumptions corresponding to severe accidents lead to a several-fold increase of the consequences of the same initiating occurrences which previously, when using the EUR methods, were possible to control with the safety systems to prevent core meltdown. In the event of a loss of coolant accident, when the emergency core cooling system is triggered, fuel meltdown is prevented and the effective dose for adults at the distance of 500 m within 7 days after the accident is 0.29 mSv and at the distance of 2,000 m within 30 days after the accident – 0.14 mSv. On the other hand, if the accident becomes a severe accident, the dose for adults at the distance of 800 m within 2 hours after the accident is 122 mSv.

The values of doses after other types of accidents change in a similar fashion. For example, steam generator tube rupture analyzed taking into consideration the operation of safety systems in accordance with the EUR methods results in an effective dose for adults at the distance of 500 m within 7 days after the accident equal to 0.19 mSv; if the accident becomes a severe one considered in US regulations, the dose at the distance of 800 m within 2 hours is equal to 11 mSv. The differences may be due to the values of releases and the assumed values of the atmospheric dispersion factor.

According to the EUR document, the frequency of severe accidents involving core meltdown must be less than one time in 100 000 years and the frequency of the ensuing releases of fission products must be less than one time in one million years. The maximum doses are equal to 250 mSv. In the opinion of designers of the EPR reactor, the frequency of accidents are lower than those set forth in the EUR; moreover, the radiation doses after such accidents will not exceed the permissible values according to the US requirements.

3.5.2 Nuclear power plants with AP 1000 reactors

3.5.2.1 Protection against burn-through of the reactor vessel in the event of a severe accident in an AP1000 reactor

The AP1000 reactor is designed so as to prevent the reactor vessel burn-through even if the core is not cooled inside the vessel and is melting. In such events, the vessel is cooled by the water that is poured into the reactor shaft, as shown on **Błąd! Nie można odnaleźć źródła odwołania.**.

The heat transferred from the vessel causes the water to evaporate. The steam condenses on the internal surface of the safety containment. Cooling of the external surface of the containment, described in Chapter 6, assures long-time heat transfer and safety of the population in the plant's vicinity.

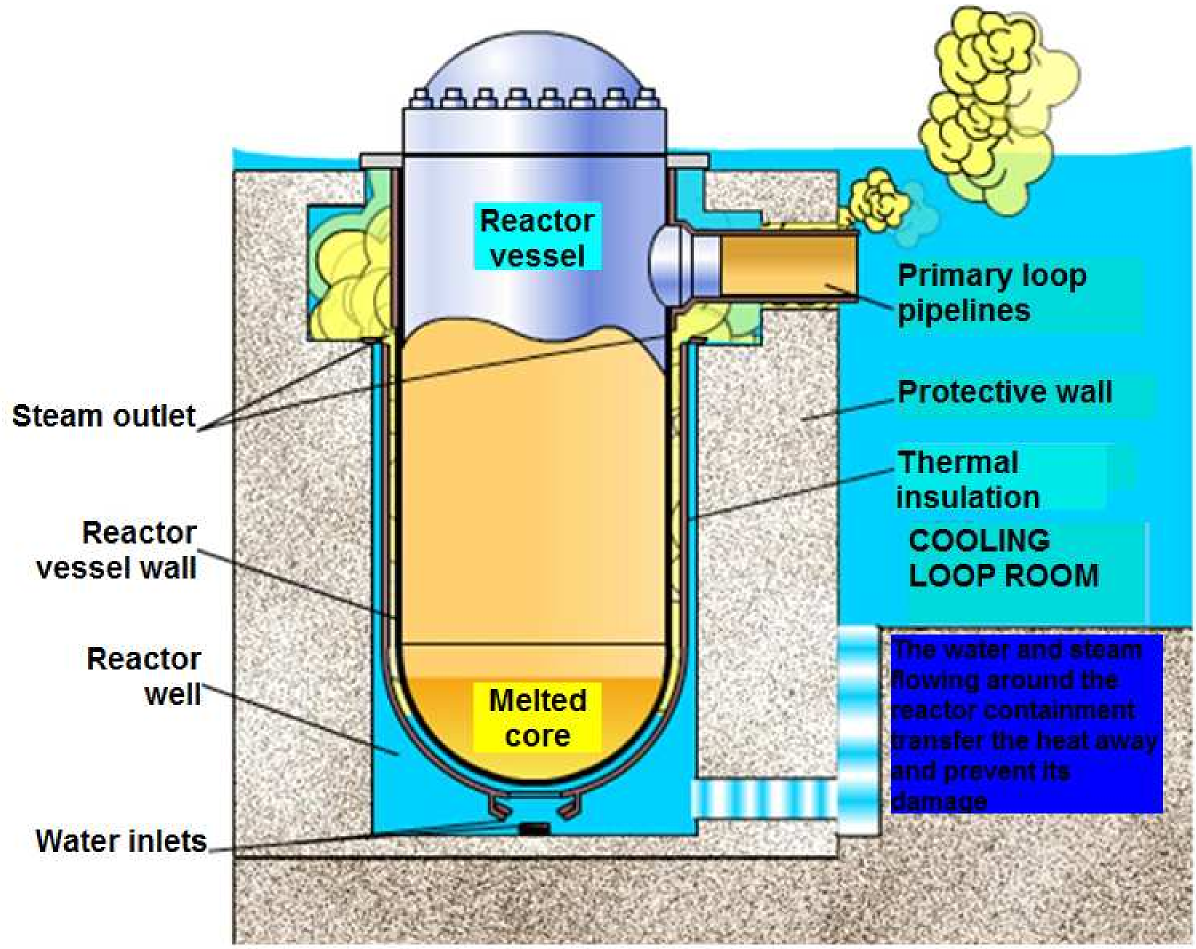

Figure 3.5.2. Diagram of heat transfer in the event of an AP1000 reactor accident, from the melted core through the reactor vessel to the water filling the reactor shaft

Nevertheless, according to the US regulations, for the purpose of evaluating the radiological consequences of an AP1000 reactor accident it is assumed that the core has melted and a part of the fission products are releases into the safety containment. This is an artificial assumption which was originally introduced to compare the effectiveness of safety containments and location conditions and not to determine the hazard to the population, but it may be used to evaluate the consequences of a severe accident, it one does occur in an AP1000 reactor.

3.5.2.2 Consequences of a severe accident in an AP1000 reactor

To distinguish the loss of coolant accident defined in accordance with US regulations with the accident defined in accordance with regulations in force in the UK and in other EU countries (to include Poland), the authors of the report for the UK AP100 reactor titled the accident analysis elaborated in accordance with US NRC regulations as “Radiological consequences of a loss of coolant accident with core meltdown” (table 15.6.5-3 in the UK AP1000 report).

Given the above-mentioned assumptions regarding releases during a severe accident and the assumed values of atmospheric dispersion factors, the effective dose received in 2 hours of stay in an exclusion area is equal to 246 mSv and the effective dose received in 30 days of stay after the accident on the low population zone boundary is equal to 234 mSv.

These doses are lower than the maximum permissible dose according to US regulations (250 mSv) but are much larger than the limit doses received during accidents that do not involve core meltdown according to the Polish regulations (10 mSv). Because the accident in question is a severe accident, one cannot assume that there is no need for “any intervention measures.” According to the

EUR and the proposed provision of the Regulation of the Council of Ministers, the limit values should refer to measures considered in the case of a severe accident, namely to evacuation (according to the Polish regulations the proposed value is 100 mSv) and to permanent resettling. However, it is evident that while according to US regulations an AP1000 reactor can be built on a site with the atmospheric dispersion factor at the boundary of the exclusion area equal to $5*10^{-4}$ s/m^3, according to the Polish regulations, such a site would be unacceptable (the atmospheric dispersion factor would have to be much lower).

The risk of reactor core failure and large radioactive releases in the case of the AP1000 reactor is very low. The total results for all accidents related to power supply shutdown, occurred due to external factors, fires, and floods are shown below:

Likelihood of core damage: 5 * 10-7/reactor-year

Likelihood of large releases: $6 * 10^{-8}$ /reactor-year[89]

3.5.3 Nuclear power plants with ESBWR reactors

The frequency of accidents involving core meltdown in an ESBWR is very low and equal to approximately:

CDF = $3 * 10^{-8}$/R-Y.

Thanks to the passive cooling system of the safety containment and the molten core catcher (*BiMAC*), the relative frequency of safety containment damage in the event of a core meltdown (*Contingent Containment Failure Probability - CCFP*) is only 2.5%, which means that the likelihood of a large release of fission products is extremely low, in the order of $7.5 * 10^{-10}$/R-Y.[90]

The low frequency of core failures and the low likelihood of safety containment failures guarantee that the radiation doses outside of the plant will remain on a very low level, even after severe accidents. **Błąd! Nie można odnaleźć źródła odwołania.** shows the radiation dose at the distance of 800 m from the reactor as a function of the likelihood for a typical location in the USA. As the figure shows, large releases of fission products do not occur even as rarely as one time per billion years.

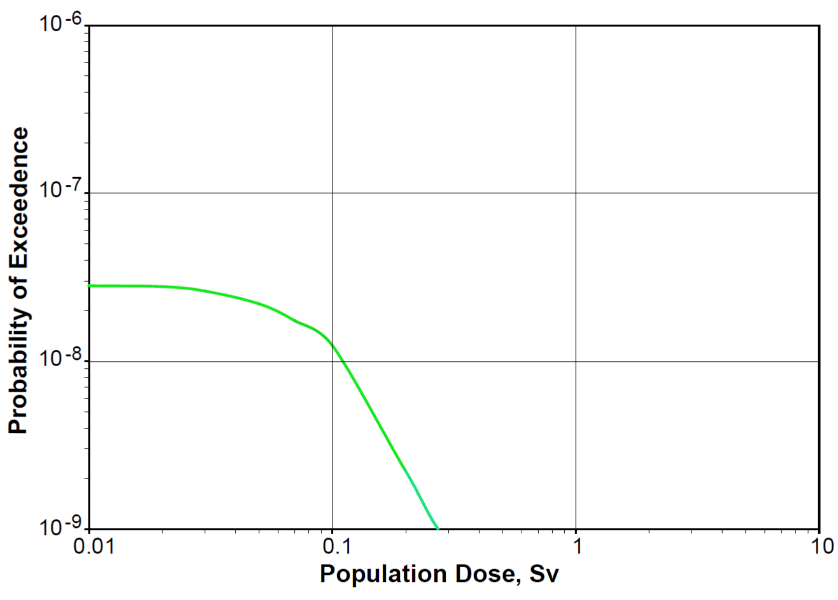

Figure 3.5.3. Radiation dose at the distance of 800 m from an ESBWR reactor as a function of likelihood for a typical location in the USA; source: description of the ESBWR reactor[90]

Błąd! Nie można odnaleźć źródła odwołania. shows the doses after an accident involving rupture of the main steam pipeline inside the safety containment.

Table 3.5.3. Calculated radiological consequences of a failure involving rupture of the cooling loop pipeline of an ESBWR reactor inside the safety containment

Exposure location	Meteorological conditions (s/m^3)	Maximum calculated effective dose (TEDE) (mSv)	Acceptance criterion acc. to 10 CFR 50.34(a)(1) TEDE (mSv)
Exclusion area boundary, 800 m	2.00*10^{-3}	130	250
Outer low population zone boundary	1.9*10^{-4} (0-8 h*) 1.4*10^{-4} (8-24 h*) 7.5*10^{-5} (1-4 d*) 3.0*10^{-5} (4-30 d*)	32 59 111 177	250

** The values shown in the table above do not take into account the additional 20 minutes of decay of fission products; therefore, the time shown in the table corresponds to the time from the beginning of the fuel failure and not from the beginning of the accident.*

3.5.4 Reference nuclear power plant for conditions present in Poland according to the requirements set forth in the Atomic Energy Act

In the event of a severe accident, emissions from Generation III reactors are limited thanks to the technical solutions and the built-in safety features, so that a long-term or severe exposure of the local population is not possible even for the core meltdown scenario assumed in the analysis. The special safety requirements adopted by the European power utilities (known as EUR – European Utility Requirements) assume that reactors must be safe not only during normal operation and design-basis accidents, but also during severe accidents involving core meltdown. he same requirements have been introduced in the proposed provisions of the Polish Atomic Energy Act and the related regulations of the Polish Council of Ministers. Reactors offered to Poland must conform to these requirements.

Thorough verification of all safety features is only possible after completion of an analysis of the reactor’s documentation by the nuclear regulatory authorities. However, for the purposes of this study it was assumed that the results of analyses of three reactor designs by the EUR Committee and the nuclear regulatory authorities in the USA, Finland, France, China and the UK will be sufficient. AP1000 and ESBWR reactors offer considerable reduction of the frequency of serious accidents and have special solutions to prevent early and significant releases of radioactive materials after the reactor core melts. They meet the requirements concerning reduction of the likelihood of accidents and reduction of the hazard in the event that a serious accident does occur despite all of the preventive measures.

In general, one can expect that the reactors to be built in Poland will meet the requirements of the Polish standards providing that in the event of a severe accident involving core meltdown, there is no need to take early and long–term intervention measures (such as evacuation or permanent resettlement) outside of the exclusion area whose radius has been initially defined as approx. 800 m (depending on the actual local weather conditions and the type of reactor). Intervention measures with limited and medium-term scope, including administration of stable iodine pills, may be required after a severe accident within the low population zone – about 3 km around the reactor according to the EUR requirements (also depending on the local weather conditions and the reactor type).

Błąd! Nie można odnaleźć źródła odwołania. presents a summary of the parameters of radiological impact on humans and the environment for the nuclear power plant proposed for Poland, with the envelope including the results for Generation III reactors, taking into account the standards proposed for Poland.[91]

Table 3.5.4. Parameters of radiological impact on humans and the environment for the nuclear power plant proposed for Poland defined for the boundary of the exclusion area

Parameter		Results in the analyses performed for: EPR	AP1000	ESBWR	Assumed for the nuclear plant in Poland
Atmospheric dispersion factor χ/Q for the distance of 800 m from the nuclear power plant and for the time of 2 h, s/m3		$1*10^{-3}$	$5.1*10^{-4}$	$2*10^{-3}$	$2.5*10^{-4}$
Radius of the restricted-use area, m		800	800	800	800
Annual dose during normal operation, mSv		0.025 mSv, 500 m from the plant	0.121 mSv, 800 m from the plant	0.012 mSv, 800 m from the plant	0.30 mSv, 800 m from the plant
Dose after an accident without core meltdown, 800 m from the plant, mSv	at χ/Q assumed in reports presented by suppliers of reactors	5	22	126	10
	at χ/Q assumed for the nuclear plant in Poland	1.4	10.8	15.8	
Dose after a serious accident with core meltdown, for 2 hours, for the assumed χ/Q, mSv	at χ/Q assumed in reports presented by suppliers of reactors	122	246	130	100
	at χ/Q assumed for the nuclear plant in Poland	30.5	120.6	16.3	
χ/Q for the boundary of a low population zone LPZ (2400 m) s/m^3					
0-2 h		$1.75*10^{-4}$	$2.2*10^{-4}$	$1.9*10^{-4}$	Data must be defined for the specific location, based on the annual cycle of meteorological measurements
2-8 h		$1.35*10^{-4}$	$2.2*10^{-4}$	$1.9*10^{-4}$	
8-24 h		$1.00*10^{-4}$	$1.6*10^{-4}$	$1.4*10^{-4}$	
24-96 h		$0.54*10^{-4}$	$1.0*10^{-4}$	$0.75*10^{-4}$	
96-720 h		$0.22*10^{-4}$	$0.8*10^{-4}$	$0.3*10^{-4}$	
χ/Q for the boundary of a low population zone LPZ s/m3, arithmetic average for 30 days		$2.63*10^{-5}$	$8.53*10^{-5}$	$3.87*10^{-5}$	
Dose after a serious accident with core meltdown, for 30 days, for χ/Q for the boundary of a low population zone LPZ, mSv		111	234	353	
Frequency of serious accidents involving high releases outside of the safety containment		Less than 10^{-6} /reactor-year	$6 * 10^{-8}$ /reactor-year	Less than 10^{-8} /reactor-year	Less than 10^{-6} /reactor-year

3.6 Case study – radiological impact of the Flamanville nuclear power plant on the ecosystem[92]

3.6.1 Radiological impacts in a maritime ecosystem

3.6.1.1 Surroundings of the Flamanville nuclear power plants with PWR reactors that have been in operation for 25 years

The description of the nuclear power plant with an EPR reactor is based on measurements conducted on reactors at the Flamanville plant, which have been in operation for over 25 years. Flamanville is located in France, at the west coast, in the vicinity of Cotentin, at the edge of rocky land. Its distinguishing features are large sand dunes cut by sharp protruding rocks in Cateret and Flamanville. The tides in this area are very strong. The maritime environment is of the oceanic type. The turbine condensers in the plant are cooled with sea water which is pumped through the inlet canal built on the shore and protected with two breakwaters. Wastewater from the plant's two power units are drained into the sea through underground tunnels over the distance of 500 and 600 m from the shoreline. The sea bottom in Flamanville drops sharply and reaches the bathymetric depth of -10 m CM[93] at the distance of 700 m and -20 m CM at the distance of approx. 4 km.

The radioecological study covers the shoreline from the town of Goury in the north to Catteret in the south and a fishing zone located approx. 5 km away from Flamanville.

Radioactivity in the environment was measured before and after the plant was commissioned. The purpose of the measurements was to determine the level of radioactivity and to detect radioactive deposits from the wastewater drained from the plant.

The reference conditions were determined between April 1981 and April 1982. The two power units of the Flamanville plant started operation in December 1985 and July 1986 respectively.

3.6.1.2 The measurement and assessment methods

Since 1981, a sampling and measurement campaign was conducted in the direct vicinity of the plant on a yearly basis. The studies were conducted by the Radiological Protection and Nuclear Safety Institute (Institut de Radioprotection et de Sûreté Nucléaire, IRSN). The information collected during the radioecology studies in 1996 and in the years 1997-2003 are presented below.

Before the operation of the nuclear power plant began, the condition of the maritime environment was determined in areas that were going to be affected by the radioactive wastewater drained from the plant. Most radioactivity was of natural origin. It comprised mostly K-40 isotopes and, to a lesser extent, Th-232 and U-238 isotopes.

Artificial isotopes present in the maritime environment included 14 radionuclides, of which Ru-106 and Cs-137 were the most common. The presence of these artificial radioisotopes was mostly due to the industrial wastewater from the nuclear installations operating at that time and from the atmospheric nuclear weapons tests conducted by the Chinese.

3.6.1.3 Inspections and measurements conduced at sea

Samples were collected in the maritime environment at the distance of 50 ma away from the wastewater discharge points, in open sea at the distance of 750 m from the wastewater discharge points, and in the groundwater in the area adjacent to the installations. Measurements of tritium did not demonstrate the presence of radionuclides above the detection level (37 Bq/l of water in 2003). The total beta activity was stable (approx. 11 Bq/l of seawater, maximum of 7 Bq/l of subsurface water in contact with seawater). This was mostly due to the activity of the K-40.

In the vicinity of Flamanville, radioactivity was also measured in the deposits as well as in caught fish, bivalves, and crustaceans.

In the years 1991-1995 the level of radioactivity did not change. The main component was K-40. Derivatives of the Th-232 and U-238 series were also detected. Be-7 of atmospheric origin was often detected in various organisms, with the exception of fish.

Artificial radioactivity was observed in the form of gamma emitters originating from the wastewater from the Flamanville nuclear power plant (Cs-137, Co-60, Ag-110m, Sb-125, and Mn-54), as well as from the spent nuclear fuel processing plant in La Hague and from nuclear weapons tests conducted in the previous years.

In 1991 a drop in the activity of artificial isotopes was reported, which indicated a reduction in the leaks from the spent nuclear fuel processing plant in La Hague and a reduced impact of the Chernobyl disaster. In the maritime environment, the presence of Co-60, Ag-110 m, Cs-137, and (more rarely) Ru-106 and Sb-125 was reported. The highest concentration of Ru-106 was detected on sea weeds.

In 1996, the presence of alpha radiation emitters was studied; Pu-238, Pu-239, and Am-241 was found in each of the 12 samples collected. The ratio of activity of the PU-238/PU-239 isotopes was between 0.25 and 0.70. It corresponded to a mid-range value between the nuclear weapons testing fallout in the past (0.05) and the ration characteristic of the processing of the spent nuclear fuel in La Hague (0.1 to 2.3).

3.6.1.4 Activity of radionuclides emitting alpha radiation

The activity of radionuclides emitting alpha radiation in different samples collected in the maritime environment was equal to:

- 77 to 1,251 mBq/kg of dry deposits,
- 58.5 do 250 mBq/kg of dry sea weeds,
- up to 25.9 mBq/kg of dry bivalves,
- 0.43 to 11.5 mBq/kg of wet crustaceans,
- 0.08 to 0.33 mBq/kg of wet fish.

3.6.1.5 Radionuclides emitting beta radiation

In some samples, beta activity caused by Sr-90 and Tc-99 was specifically searched for.

The concentrations of Sr-90 detected in bivalves and crustaceans were low and usually lower than the values measured before the nuclear power plant was commissioned. The activity of these radionuclides in the fish was lower than the sensitivity of the sensors. The Flamanville nuclear power plant does not emit Sr-90.

Of the artificial radionuclides, the highest activity level was measured in the case of Tc-99. It is a known fact that Tc-99 has high concentration levels in brown sea weeds and lobsters. The activity values measured in samples collected in the vicinity of Flamanville became gradually lower and were similar to the values measured in samples collected in the middle of the English Channel. Such activity is beyond doubt the result of the activity of the La Hague spent fuel processing plant.

3.6.1.6 Radionuclides emitting gamma radiation

Natural gamma radiation in different parts of the maritime ecosystem is caused mostly by K-40 as well as radionuclides from the U-328 and Th-232 series. The highest concentration of K-40 was found on brown sea weeds (1,280 to 2,230 Bq/kg of dry material). Be-7 is present in deposits, sea weeds, and bivalves. It was not found in fish and crustaceans. Natural radioactivity is on the same level as before the plant was commissioned.

In 1996, artificial radioactivity was clearly connected with the presence of the following radionuclides:

- Am-243 and Ru-106, originating solely from the La Hague plant;
- Cs-137, Co-60, Mn-54, and Sb-125, which are present in the wastewater discharge from the Flamanville plant, but also in other sources (rainfall after nuclear weapons tests and the Chernobyl disaster in the case of Cs-137; the La Hague plant in the case of the remaining radionuclides);
- Ag-110m, mostly released by the Flamanville plant. Very low activity values were detected for this radionuclide in crustaceans and bivalves (0.08 to 0.654 Bq/kg of wet material) and in sea weeds (0.54 Bq/kg of dry material).

Given such low values, it was not possible to differentiate the radionuclides that were discharged from the Flamanville plant from the background of other nuclear installations located near the English Channel.

3.6.1.7 Analyses conducted in the years 1997-2003

Spectrometric testing of all the collected samples was conducted each year. From 2000 on, the radioecological monitoring also covered the activity of free tritium in brown sea weeds.

Radioactivity of the samples collected in the maritime environment in the vicinity of Flamanville (deposits, bivalves, and fish) was caused mostly by the radionuclides generated in the Earth crust (K-40, series of derivatives of Th-232 and U-238) and in the atmosphere (Be-7). In dry sea weeds, the activity of K-40 may reach the level of 1,700 Bq/kg of dry material.

In the period in question, the radioactivity of deposits and fish was caused only by Cs-137 and Co-60. In sea weeds, bivalves, and crustaceans, the two radionuclides were associated with Ru-106, Am-241, and Ag-110m.

The trace quantities of Agb-110m detected in sea weeds (0.07 to 0.6 Bq/kg of dry material), bivalves, and crustaceans (0.05 to 0.11 Bq/kg of dry material) were due to the operation of the Flamanville plant. Between 1991 and 2003, the concentration of these radionuclides was reduced by a factor of 10. In 2002 and 2003 they were detected in only 1 out of 12 samples. With the exception of Am-241, Ru-106, and Ag-108m, which originated solely from the La Hague plant, the origin of other radionuclides was impossible to determine due to the large number of possible sources (the Chernobyl disaster, the spent fuel processing plant, industrial waste, etc.).

From 2000 on, the content of tritium in brown sea weeds was thoroughly tested. Its value was from 1.4 to 7.7 Bq/dm^3. The activity measured in the vicinity of Flamanville was slightly higher than the background level in this area.

The measurements of I-131 demonstrated that its activity is below the sensitivity level of the measurement equipment (less than 3 Bq/kg of dry material).

3.6.1.8 Assessment of the measured values

Since the Flamanville nuclear power plant was commissioned, the whole radioactivity in the maritime ecosystem comes from the radionuclides generated naturally in the geosphere and the atmosphere.

The maritime environment in the vicinity of Flamanville is characterized by the presence of artificial radionuclides from the La Hague spent nuclear fuel processing plant, from the fallout after nuclear weapons tests, from deposits discharged from the Flamanville plant, etc.

Any leaks from the Flamanville plant contribute to the presence of artificial radionuclides in sea water. The proportion of such radionuclides is difficult to estimate.

Activity of artificial radionuclides is gradually reduced, thanks to the efforts of nuclear installation operators to reduce the level of radioactivity in the wastewater, as well as to the decrease of radioactivity in remains of nuclear weapons tests.

3.6.1.9 The anticipated effects of the operation of a power unit with an EPR reactor in a maritime ecosystem

The new power unit with an EPR reactor will not be a source of releases of radionuclides into the environment. The results of the operation of the two power units in the Flamanville plant, as well as the experiences gained from the measurements conducted in the vicinity of the 4 power units at the Atlantic coast (Paluel – 2 power units with PWR reactors and Gravelines – 2 power units with PWR reactors) confirm this statement. Evidently, operation of nuclear plants leads to detection of artificial radionuclides in maritime environments. However, such radionuclides are present only in a few locations (mostly in deposits and in sea plants) and their activity level is very often below 10 Bq/kg of dry mass. In sea fauna (bivalves, crustaceans, and fish) the activity of artificial radioisotopes has not exceeded 1 Bq/kg of wet mass since the year 2000. Such levels of activity are much below the natural radionuclide content in sea organisms.

The strategy adopted in the measurements and tests conducted in the vicinity of the Flamanville plant assured a good description of the condition of the local maritime flora and fauna. A similar strategy, with yearly measurement campaigns and radioecological reviews repeated at 10 year intervals will be continued in the future.

The results of the tests performed in the vicinity of Flamanville have not demonstrated any links of the radioactivity of maritime flora and fauna to any leaks from the nuclear power plant. Leaks of chemicals from the Flamanville plant have not disrupted the maritime ecosystem in the plant’s vicinity, either. Irrespective of the chemical products discharged from the plant, the maximum concentration values of the leaks do not affect the maritime system because they constitute a small fraction of the natural contents of such products in the environment or are much lower than the reference values.

3.6.2 **Impact of the proposed EPR reactor on the land ecosystem**

3.6.2.1 Impact of the construction on the land ecosystem

No radioactive substances will be released into the environment at the construction stage.

3.6.2.2 Impact of the nuclear power plant’s operation on the land radioecology

The measurements conducted in the vicinity of the two existing power units with PWR reactors at Flamanville have demonstrated that nearly the whole radioactivity in the land ecosystem around the Flamanville plant originates from the radionuclides that are naturally present in the geosphere and the atmosphere.

The artificial radionuclides detected on the land around Flamanville originate mostly from continuously falling aerosols generated during nuclear weapons tests in the atmosphere and during the Chernobyl disaster. This is why trace quantities of Cs-137, Sr-90, transuranic elements, H-3, and C-14 are detected. Moreover, the last two radionuclides are generated naturally.

In addition to the radionuclides falling from the atmosphere, artificial radionuclides are periodically emitted in liquid form into the sea (Cs-137, C-60, Pu-238) and are deposited on the beach due to the sea foam effect and the use of algae as fertilizer in the fields. Since 1996 the actual activity of Cs-137 has not exceeded 30 Bq/kg of dry mass, C-60 – 5 Bq/kg of dry mass, and transuranic elements – 0.2 Bq/kg of dry mass. Those radionuclides could have been released from the Flamanville plant or from the La Hague plant. The share in these values of the PWR reactors operated in power units 1 and 2 was so small that it was not possible to determine it; in the future it will most likely be impossible to determine the impact of the EPR reactor.

The radioecological measurements in the vicinity of the Flamanville plant have not lead to a detection of any increase in radioactivity that could be ascribed to the gaseous releases from power units 1 and 2.

Operation of an EPR reactor will evidently result in an increased of discharged radioactivity, but the emission levels will be as small as those from power units 1 and 2 and, consequently, it will not be possible to measure them.

The releases of radionuclides from power units 1 and 2 have not made any impact on land organisms.

3.6.3 Conclusion

- the very small emissions of non-radioactive gases will have no detectable impact on the quality of air in the area of Flamanville,
- operation of the EPR will have no significant impact on the current radioecological conditions around the nuclear power plant,
- nuclear waste will be reprocessed and stored in the power plant building to make sure that containers will not leave the controlled area without prior control and approval,
- radioactive waste will be transported by rail or by road only in final containers that will meet the requirements defined by the nuclear regulatory authorities,
- methods of transport of containers with radioactive waste will meet all the applicable requirements for transport.

3.7 Impact of small doses of radiation on living organisms

3.7.1 Natural radiation on the Earth

Radiation is a normal element of our daily lives. On the planetary scale, radon emitted from the earth in the gaseous form causes approx. 50% of the average individual daily dose and the remaining 40% id due to cosmic radiation and radioactive materials contained in the soil and entering the human body. This is not at all due to any nuclear accidents: radiation has been there since days immemorial and when life started on the Earth the intensity of radiation was much higher than it is now. Perhaps this is why radiation is a necessary element of life and many experiments confirmed that a complete lack of radiation causes plants and animals to stop growing and breeding.

To understand the situation regarding the current radiological protection regulations, we need to know how radiation is measured. Radioactivity describes the intensity of the source of radiation. The unit of measurement of radioactivity is curie (Ci), which was called so to commemorate Maria Skłodowska-Curie who discovered radium. One curie is the radioactivity of 1 gram of pure radium. Usually radioactivity values are much lower and they are measured in picocurie (one millionth part of a one millionth part of a curie). In 1 picocurie only approx. 2 atoms per minute undergo decay and emit radiation. The US Environmental Protection Agency (EPA) has recommended a limit for potable water equal to 5 picocurie per litre. According to the relevant regulations, the radioactivity of water discharged from nuclear power plants may not be greater than 10 picocurie per litre. This appears to be reasonable.

However, one litre of regular sea water in which people swim when they go to the beach contains, on average, 350 picocurie. In other works, regular sea water is 35 times more radioactive than water discharged from a nuclear power plant. The average radioactivity of milk is 1,000 picocurie per litre. The radioactivity of salad olive is 5,000 picocurie per litre, which means that it is 1,000 times more radioactive than tap water, according to the EPA limit. Still, no one claims that sea water, milk, and salad olive pose a radiation hazard to the public.

Also, as far as the doses are concerned, the regulations limit the doses generated by human activities to values that are many times smaller than the natural radiation values present in nature. This is due to the caution of radiation protection experts who, in observance of the *primum non nocere* (first of all, do no harm) principle, are striving to assure that humans do not disturb the current natural balance. One must be aware, however, that radiation has been, is, and will be a natural phenomenon and it is not sure if its role is negative or that the opposite is true: radiation is beneficial and necessary for life.

The average natural background radiation in the world is 2.4 mSv/year[94] and the dose caused by humans (mostly by medical applications) is equal to 0.86 mSv/year. The operation of all the nuclear power plants in the world increases the average dose by a very minute value, approx. 0.006%.

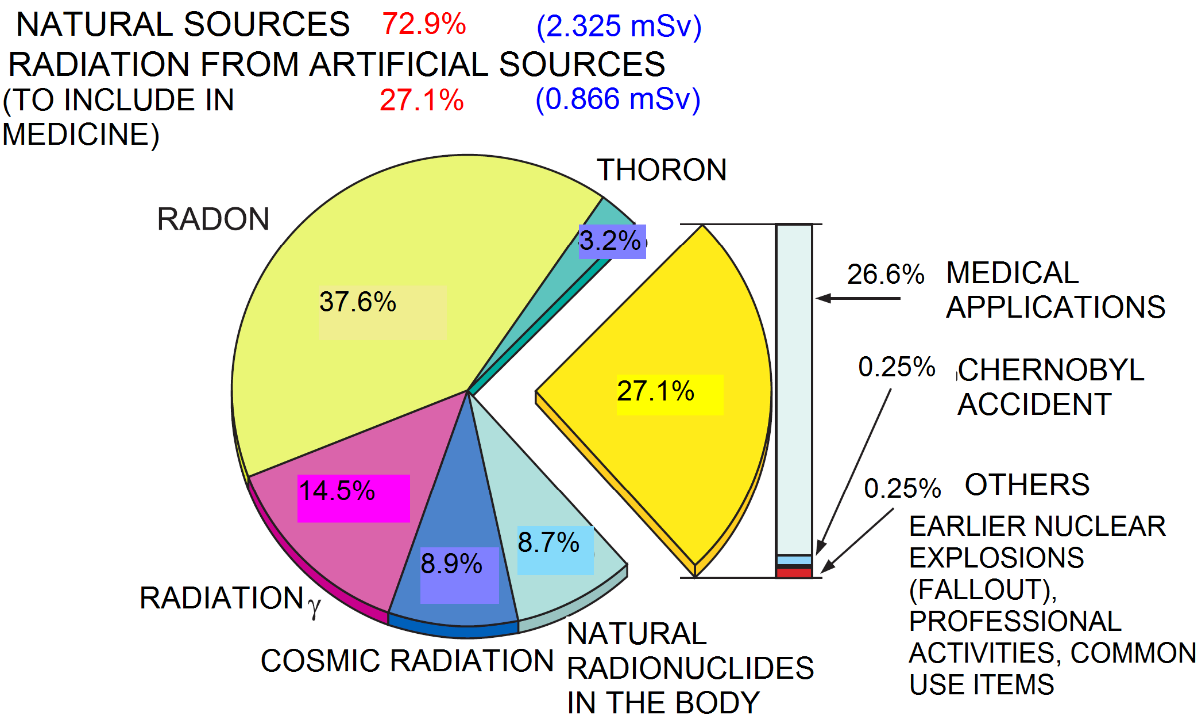

Fig. 7.7.1. Contribution of various sources of ionizing radiation to the average yearly effective dose (3.19 mSv) absorbed by the statistical inhabitant of Poland in 2009.[95]

The main components of natural radiation are:

cosmic radiation – its value is the larger the thinner is the layer of the atmosphere protecting people from radiation emitted by the stars – i.e. the higher the altitude at which a person is located. For example, in Zakopane, the yearly dose of cosmic radiation is 50% larger than that in Gdańsk. The dose at the sea level is 0.28 mSv/year;

soil radiation – soil contains radioactive elements which decay for millions of years, since the Earth formed; the average value in Poland is 0.46 mSv/year;

radiation from radon and the products of its decay - the values are very variable, depending on the composition of the soil; the global average value is 1.27 mSv/year;

radiation of radioactive elements – the elements are absorbed from food and beverages (such as potassium-40 or rubidium). This radiation causes human body to emit radioactivity. The dose from such external sources in human bodies is equal to 0.28 mSv/year.

The average value of natural radiation in Poland is equal to the average global values. The total effective dose in Poland is 3.19 mSv/year, of which 72.9% is natural radiation and 26.6 is radiation from sources used in medical applications. The effects of nuclear explosions in the atmosphere and the radiation caused by the Chernobyl disaster are equal to a total of approx. 0.5%. The contribution of the various sources of radiation to the total dose is shown in Fig. 7.7.1.

The fluctuations of background radiation values, caused mostly by differences in the content of radon in the soil, are very large, usually from 2 to 10 mSv; however, there are localities where the doses are much higher, up to several dozen mSv a year. For example, the background radiation in Sweden is twice as large as that in Poland and the background radiation in Finland - over 2.5 times larger.

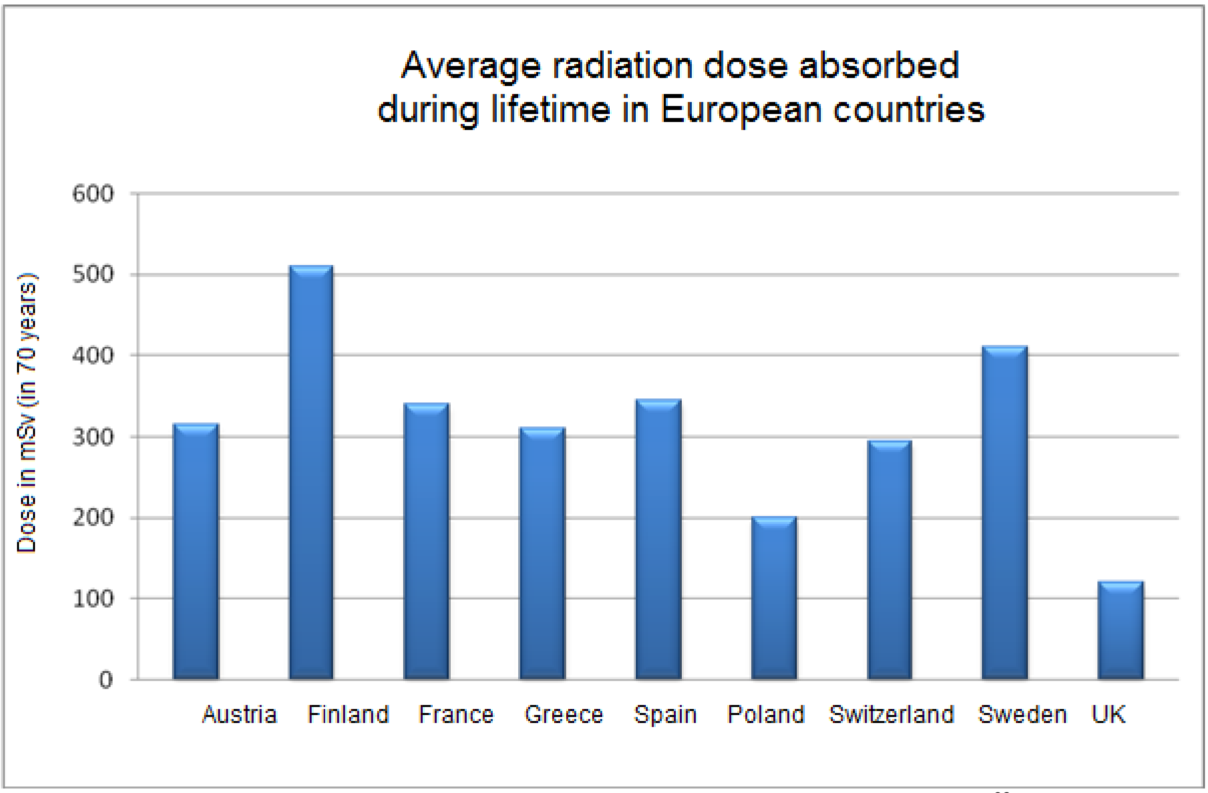

Fig. 7.7.2. Average doses absorbed by a person over a 70-year period in various countries of Europe [96].

In some areas in Brazil, India, and Iran, the yearly doses are much higher, up to 35 mSv (Kerala, India, and Guarapari, Brazil) or even 260 mSv (Ramsar, Iran).

Given such large differences, scientists have for many years conducted research in order to identify the negative consequences of higher natural background radiation to human health. So far, they have not been successful. Even in areas with the highest doses, the occurrence of cancer is not above average. To the opposite: surprisingly, at first site, it is often a little lower than average. This translates into difficulties in determining the scale of the effects of radiation – at small dozes the effects are simply unnoticeable! In order to have a basis for evaluations and comparisons, it is assumed (as a hypothesis) that the relation between the effects of radiation and the dose, as described below.

3.7.2 The hypothetical linear relation between the danger and the radiation dose

Given the lack of detectable effects of small radiation doses and striving to assure utmost care in handling radioactive substances as well as to stop nuclear weapons tests, the International Commission on Radiological Protection (ICRP) introduced the hypothesis, referred to as the linear no-threshold (LNT) model, according to which hazards from small doses are the same as from large doses multiplied by the ratio of the doses and the appropriate proportionality factors. This model assumes that both somatic effects (cancer) and genetic effects of small doses are the result of mutations caused directly by ionizing radiation. At small doses, there is no data confirming directly the presence of a hazard. Therefore, the data must be extrapolated from data pertaining to large radiation doses, specifically to the effects of sudden irradiation with large radiation doses of the populations of Hiroshima and Nagasaki.

The LNT model has become the basic model used in radiological protection. It was used as a basis for formulating the principle of limiting radiation doses *as low as reasonably achievable (ALARA)* and the establishment of a very effective, albeit costly, system of barriers to prevent the spread of radiation from nuclear power plants.

As many more recent observations may suggest, the extrapolation assumed in the LNT model is excessively pessimistic. Research conducted on cancer development processes clearly indicates that cancer is a multi-stage disease and, as such, its nature is not linear but rather it resembles a curve with a threshold.

The LNT hypothesis is in contradiction with natural phenomena; in particular, it does not take into account hormesis, i.e. the fact that many occurrences and phenomena are beneficial to living organisms in small doses, even despite their harmful effects in large doses[97]. There are numerous examples: aspirin, which is beneficial when taken at a rate of one pill a day, even though several hundred pills taken at one time would be harmful; vitamins and microelements, which are necessary in small doses and harmful in large ones; sunlight, or even temperatures, which are advantageous to human health when in the range of 20-25^{o}C and deadly when they exceed 100 ^{o}C. The situation with radiation may be similar, as described in the next section.

3.7.3 Hormesis – small radiation doses advantageous in cancer treatments

Radiation is a necessary element of life and organisms and experiments where living organisms were screened from radiation have demonstrated that they suffered from diseases and died, whereas small doses of radiation were beneficial to their development. The positive impact of radiation on growth and breeding is common knowledge and has been discussed in dozens of publications on small radiation doses.

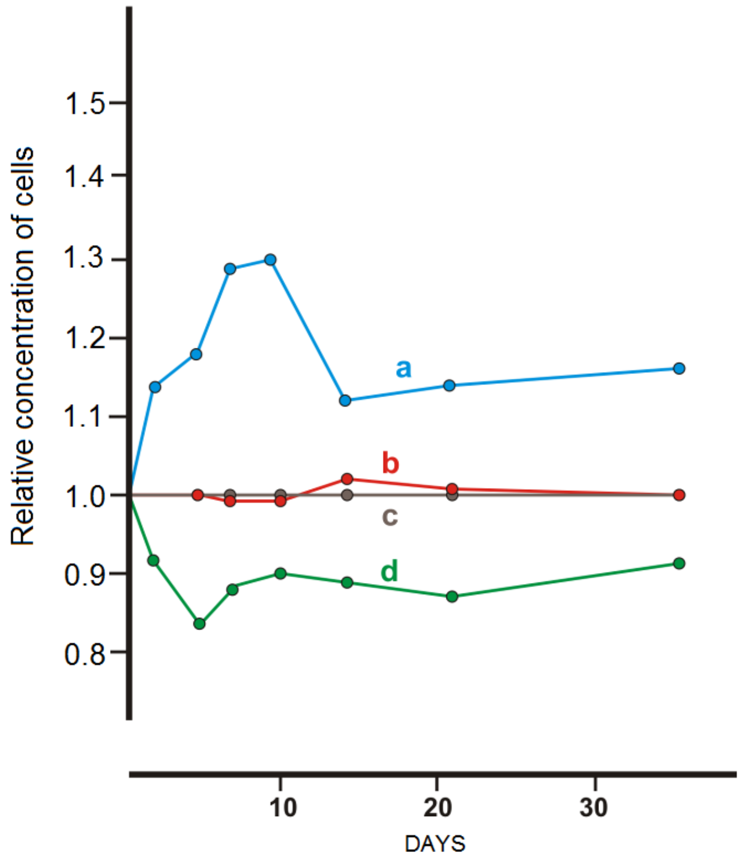

Fig. 7.7.3. Impact of screens blocking radiation, irradiation, and screens permeating some radiation on the relative concentration of Synechococcus lividus cells in experiments by professor Planel

a. Irradiated cells; b. Cells behind a screen but irradiated; c. Cells behind a screen and not irradiated.

The need for some radiation was demonstrated as early as 1960's when bacteria cultures were placed in environments without radiation – e.g. under 200 m thick rocks or behind 5-10 cm thick lead screens – and the K-40 isotope and other radioactive substances were eliminated from their nutrient medium. The yearly radiation doses were 1.65 mGy for the control group and 0.1 mGy for the cultures placed behind lead screens. It turned out that in the cultures that received no radiation the growth and breeding processes were stopped. After bacteria cultures were irradiated, with their location unchanged, the cultures began to breed normally[98].

Professor H. Planel and his team from the Medical Biology Laboratory in France conducted a series of such experiments; they used 5 or 10 cm thick lead screens[99]. The thicker were the screens, the slower was the growth of the tested bacteria and other organisms. An example of the results of their experiments is shown in **Błąd! Nie można odnaleźć źródła odwołania.**.

In another series of experiments, bacteria cultures were kept behind screens which blocked radiation. An clearly slower growth of the cultures was observed. Then, without changing the position of the cultures, approx. 1.5 mGy/year of radiation was introduced. As a result, the growth of the cultures returned to normal. In other experiments, the growth of plants and animals was demonstrated to be faster in the presence of radiation.

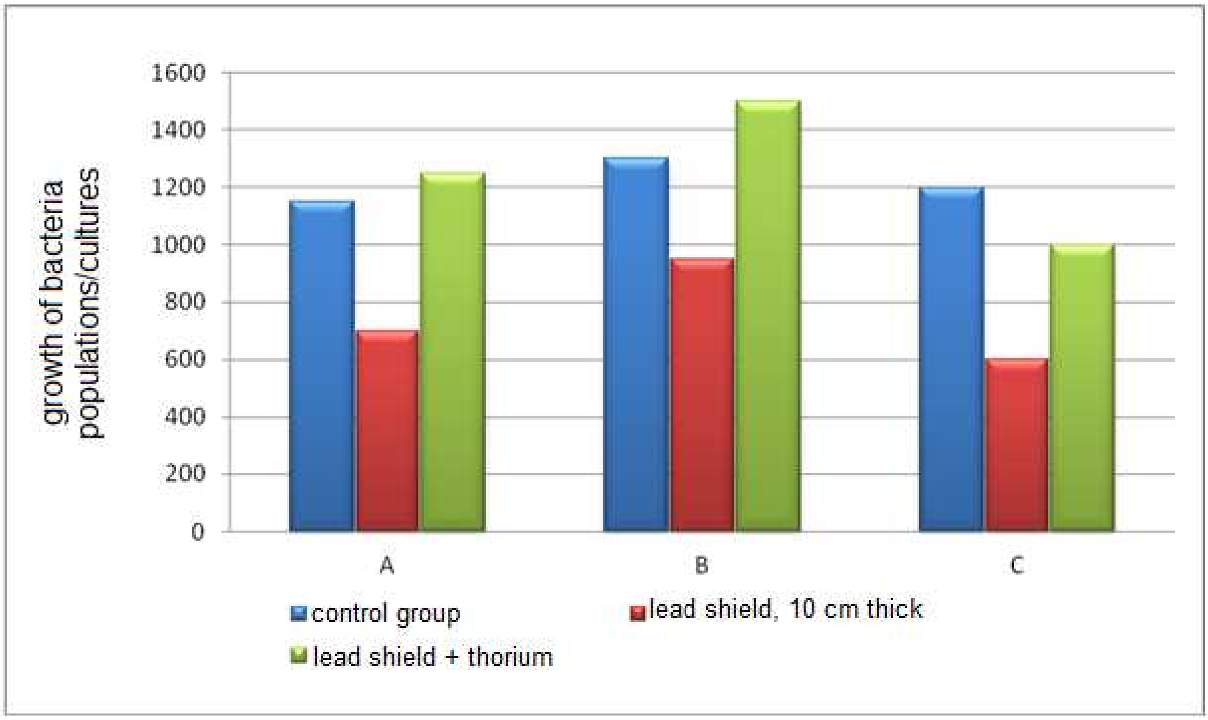

Fig. 7.7.4. Return of growth after radiation was reintroduced

Growth returned when bacteria cultures enclosed within lead screens received supplementary radiation from thorium equal to 1.59 mGy/year, which is comparable with a dose they would receive in natural conditions.

The scientists studying the role of hormesis emphasize that the LNT theory does not take into account the role of biological defence mechanisms that are stimulated by radiation. Life developed on Earth when the intensity of radiation from geological sources (uranium, thorium, potassium) and from internal sources in living organisms (K-40 potassium) was approximately 3.5 times higher than currently[100]. Thus, it is possible that our defence mechanisms work the most effectively in conditions where radiation values are much higher than they are now. In many experiences it was demonstrated that irradiation of organisms with small radiation doses enhances their immunity to cancer and is conducive to faster growth. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has recognized the importance of hormesis and has issued a special report which recommended further studies of the positive role of radiation[101].

Given that the theoretical relations should correspond to the actual phenomena present in nature, below we present a review of the research results obtained for various groups of people irradiated with small doses.

3.7.4 Impact of small radiation doses on large groups of people

3.7.4.1 Research conducted in the USA

In the USA, the correlation between the background radiation and cancer mortality rates has been the subject of many research programs. The research has demonstrated that in all the states with an increased background radiation levels, cancer mortality rates are lower than average. This was confirmed by the results of research conducted by scientists who were not connected with the nuclear energy sector and who enjoyed impeccable reputation for honesty, such as Frigerio and Stowe[102] (Quakers), Hickey[103] from Argonne National Laboratory, and, in late 1990's, professor Bernard Cohen[104].

Frigerio and Stowe studied the rates of malignant cancer mortality in the 50 US states as a function of the background radiation. Before the research, it was expected that cancer mortality would increase by approx. 350 deaths per 100,000 people for each additional each 1 mSv/year[105]. The results of their research proved the opposite.

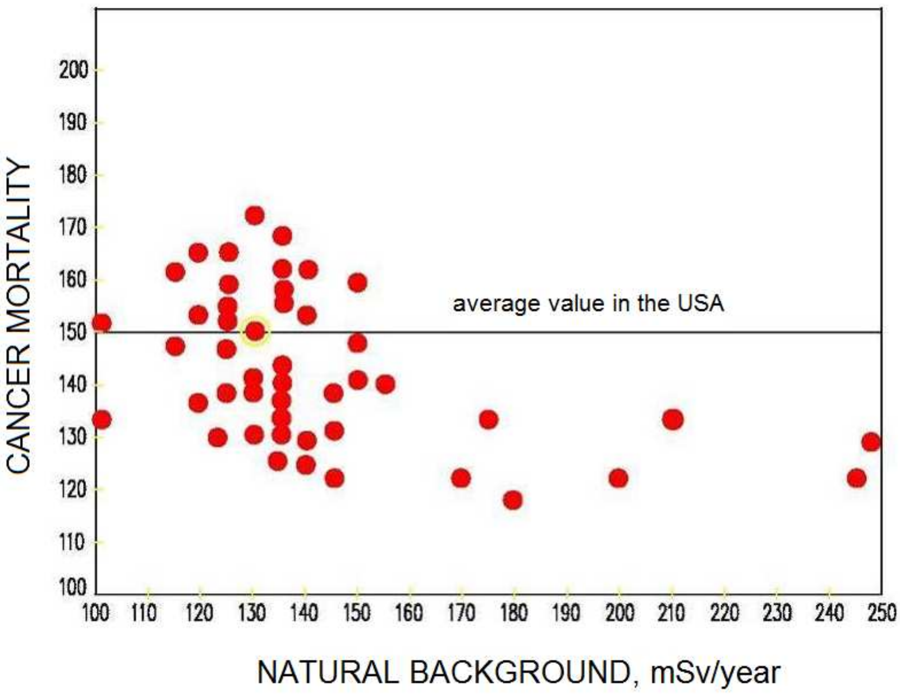

Fig. 7.7.5. Rates of cancer mortality as a function of the natural radiation background in various US states

The horizontal line and the circle indicate the average mortality and radiation background for the whole USA. Data from the work by Frigerio and Stowe, 1973.

As Fig. 7.7.5 shows, of the 14 states where the background radiation is higher than 1.4 mSv/year, **in 12 states the mortality rate was much LOWER than the average value** for the USE, in one – a little lower, and in one – a little higher.

Epidemiological research conducted in 1981 in 39 metropolitan areas and in 4 standard economic areas of the United States demonstrated that the rate of **lung and respiratory tract cancer mortality is lower in areas with the highest radiation levels**[103]**.**

Research of the impact of radon concentration in homes on lung cancer mortality [Cohen, 1995] covered 1,730 administrative districts in the USA inhabited by over 90% of the country's population. The results of Cohen's research demonstrated that **an increase in the concentration of radon does not lead to higher rates of lung cancer mortality** but rather the opposite: that cancer mortality is lower in areas with higher radon radiation levels.

In order to eliminate the impact of confounding factors, B. Cohen took into account those variables that may have an impact on the rates of lung cancer mortality, such as smoking, uncertainty of radon concentration data, impact of outliers, and 50 other socio-economic factors. Nevertheless, the slope of the curve remained negative for the scenarios which covered:

- only urban districts;
- only rural districts;
- the most wealthy districts or the poorest districts;
- the districts with the best or the worst health care services;

- and so on, for a total of 54 factors.

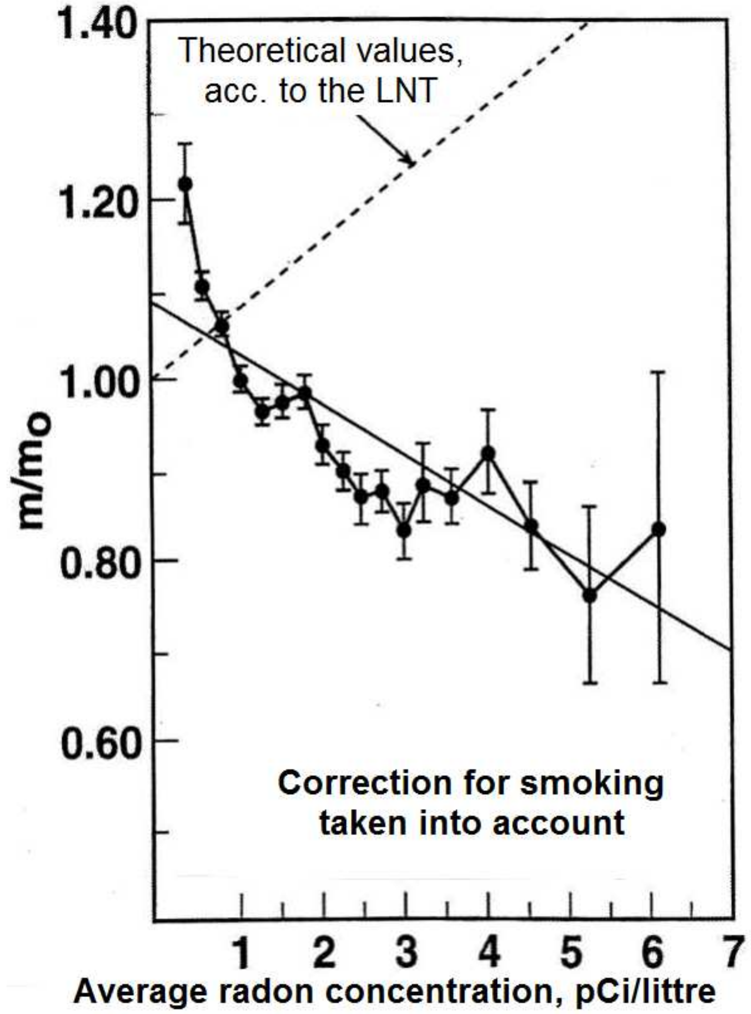

Fig. 7.7.6. Lung cancer mortality as a function of the average concentration of radon in USA administrative districts, compared to the mortality calculated in accordance with the LNT model presented in the BEIR IV report.

*- **m/mo** – the ratio of the mortality calculated in accordance with the LNT hypothesis and the mortality at 0 radon concentration, or the ratio of the mortality recorded during the research at the measured radon concentrations in homes to the mortality at the average radon concentration in homes in the USA equal to 1.7 pCi/litre.*

Cohen has also taken into account the impact of geography, altitude above the sea level, and the weather; nevertheless, the slope of the curve remained negative. Cohen's research raised a lot of interest among other scientists and efforts were made to call its result into question [Greenland, Robins 94][106], [Stidley Samet 93][107], [Lubin 02][108]. Nevertheless, Cohen was successful in refuting all the claims [Cohen] [109]. In particular, in response to the claim that introduction of averaging of the results for a large population is an example of an *"ecologic fallacy"* [110]. Cohen replied that his research was intended to answer the question of whether the LNT hypothesis is correct and that the very LNT hypothesis is based on integration of small or large doses for whole exposed populations, regardless of the doses' distribution. In Cohen's opinion, the results of his research clearly demonstrated that the LNG hypothesis does not correctly describe the reality and that calculating the number of hypothetical deaths caused in large populations by radiation is unreasonable.

An analysis of the radiation background on cancer mortality in the USA was presented by Jagger[111]. For the purpose of comparison, he selected three states with low background radiation levels

(Louisiana, Mississippi, and Alabama) and three states with high background radiation levels (Idaho, Colorado, New Mexico).

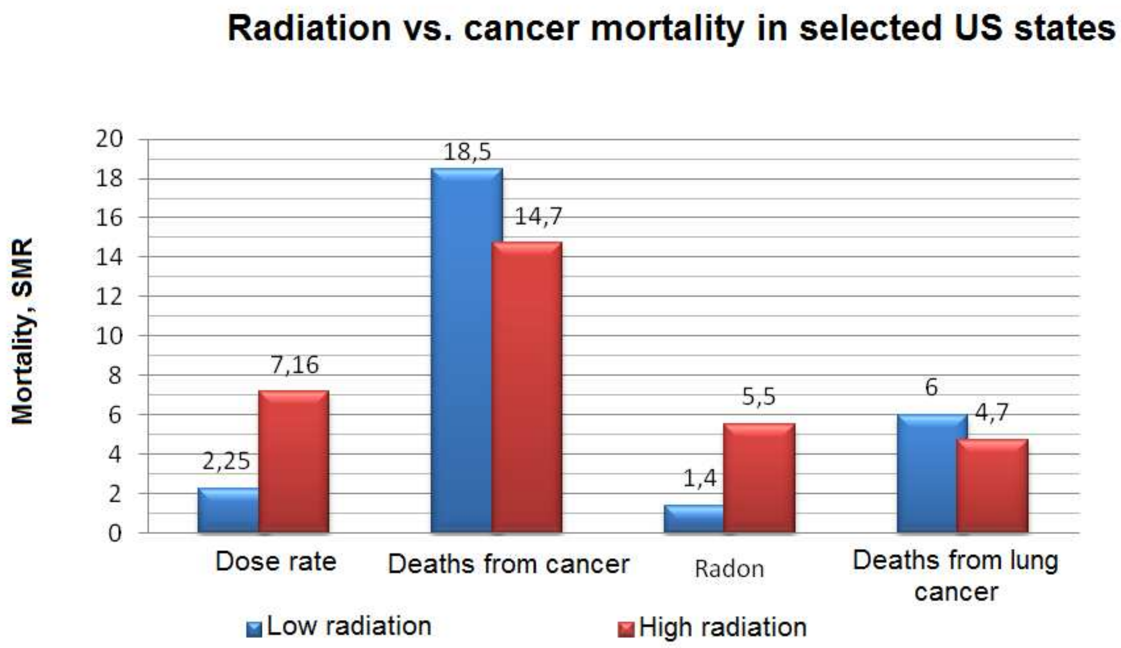

Fig. 7.7.7. Radiation vs. cancer mortality in selected US states

The average radiation doses in those states are, respectively 2.25 and 7.16 mSv/year, and the ration of radon concentration is 3.9 in open spaces and 5.2 in homes. According to the LNT hypothesis, one could expect that cancer and lung cancer mortality values would be higher in areas with high background radiation levels and high radon concentration values. In fact, the opposite is true, as shown on Fig. 7.7.7.

Another research[112] demonstrated that the actual lung cancer incidence in US states with the highest background radiation levels (CO, MT, ND, SD, UT, and WY) are, on average, 44 per year per 100,000 inhabitants, which is equal to only 14% of incidence calculated based on the LNT model. On the other hand, the incidence of the lowest background radiation levels (ID, OR, and WA), the average lung cancer incidence is 73 per year per 100,000 inhabitants, or 390% of the incidence anticipated according to the LNT model. Thus, the discrepancy between the actual numbers and the LNT model is huge: approximately 28 times larger or smaller. We would like to emphasize that “not only the reality is very different from the values anticipated according to the LNT model, but also the correlation with the background radiation is the opposite to that provided for in the LNT model.”

Thus, the results of the research conducted in the USA confirm that in populations exposed to small radiation doses due to higher background radiation values there are no noticeable negative health impacts. On the contrary: in areas with high background radiation, the cancer mortality values are small.

3.7.4.2 Health effects in populations exposed to low radiation levels in China[113]

Research has been conducted in the high background radiation area (HBRA) near Yangjiang in China since 1972. The research covers two neighboring areas with the total surface area of 500 km^2, inhabited by 95,000 people who are exposed to radiation from monazite sands with high content of thorium. In the vicinity of those areas there is an area with low background radiation levels, which was selected as the control area (CA). In the control area, the average yearly dose of gamma radiation from external sources is 2 mSv and the doses in the HBRA – from 4.8 to 6.2 mSv. The cumulative doses increase with age of the persons; consequently, 50 years old persons in the HBRA have absorbed the average cumulative effective dose of natural gamma radiation equal to approx. 274 mSv. Both areas are inhabited predominantly by farmers (93% and 94%). Their population structure is similar. All the environmental parameters are similar, too (e.g. the percentage of smokers in the HBRA is 37.9% and in the CA – 37.6%). Having taken into account the doses absorbed from food, the average yearly doses in the HBRA was determined to be equal to 6.4 mSv and in the control area – 2.4 mSv.

The cancer mortality values were 53.5/100,000 inhabitants in the CA and 6.3/100,00 inhabitants in the HBRA.

In order to better account for the effects of lengthy stay in areas with elevated background radiation levels, the cancer mortality (except for leukaemia) rates were compared for persons aged 40 to 70. The following values were determined:

- 168/100,000 inhabitants in the CA;
- 143.8/100,000 inhabitants in the HBRA.

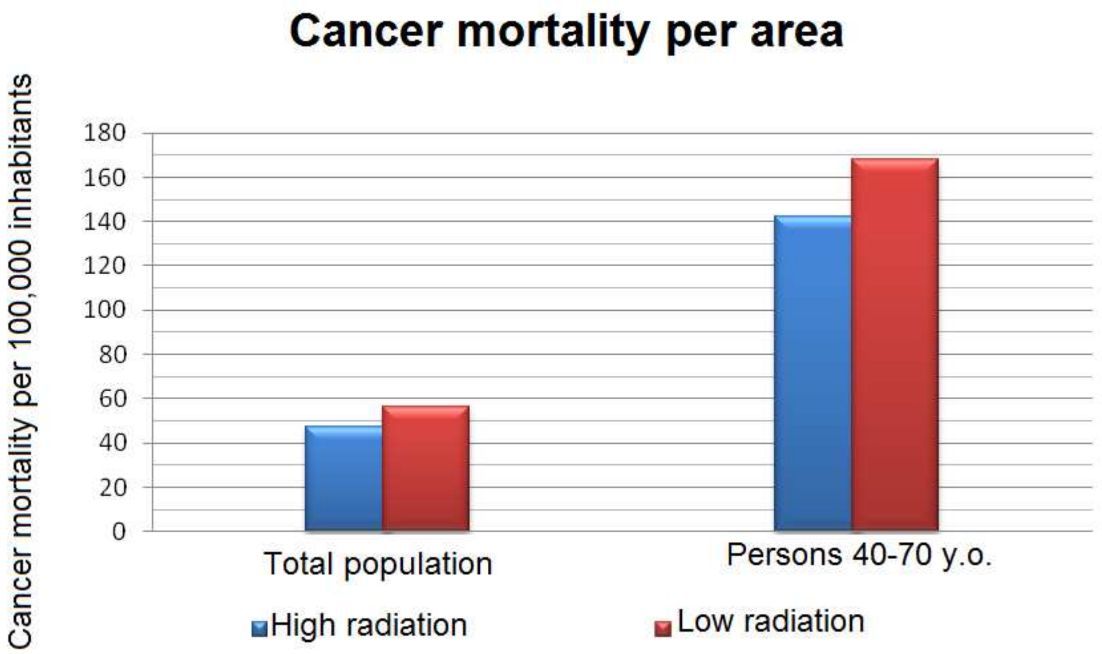

Fig. 7.7.8. Cancer mortality in the high (HBRA) and low (CA) background radiation levels in the vicinity of Yangjiang

Thus, the elevated radiation levels in the HBRA are associated with a REDUCED risk of death from cancer. Even though the research, conducted over the course of over 30 years, covered 100,000 persons, the differences turned out to be so small that they are statistically insignificant. It is beyond doubt that there is no increase in the risk of cancer.

A research conducted later[114] demonstrated that, even though no statistically valid conclusions can be drawn, further research conducted the previous research and strengthened the postulate that cancer mortality is lower in the HBRA than in the control area. An extensive research conducted by Chinese and Japanese scientists confirmed that inhabitants of the area with high background radiation levels absorb, over their lifetimes, an additional dose of external radiation equal to **320 mSv (6.4 mSv x 50 years).** No increase of cancer incidence was observed in this group; on the contrary, the value of the optimum factor to evaluate the additional risk (excess relative risk, ERR) caused by radiation, was negative **(ERR = -0.11).**

In the description of their results, the researchers add that the confidence interval[115] (95% CI: -0.67 to 0.69) overlapped the confidence interval for the evaluation obtained for the cohort of inhabitants of Hiroshima and Nagasaki, **ERR = 0.40** (95% CI, 0.31 to 0.51); consequently, further research is necessary to obtain a larger statistical material and to reduce the uncertainty interval. Nevertheless, the research conducted in China for many years systematically leads to results that suggest beneficial impact of ionizing radiation of human health[116].

3.7.4.3 Research conducted in other countries

Similar conclusions were reached in the research conducted in the Kerala region in India[117,118] where an area with the presence of monazite sands with high thorium content (125 km^2) is inhabited by approx. 400,000 persons exposed to background radiation levels as high as 13 mSv/year. In the Kerala state, 98 various types of development anomalies were analyzed in a group of 37,000 new born babies. No significant differences were identified between the 26,000 babies in the high radiation area and the 11,000 babies in the normal radiation area.

Further research covered 50,000 new born babies from an area with high background radiation. It was found, that the frequency of anomalies is equal to 1.46%, which is slightly better than the frequency of anomalies among the 72,000 new born babies in Chennai (1.6%0 and among the 95,000 newborn babies in New Delhi, Baroda, and Mumbai (1.6% to 1.86%)[119].

The cytogenetic tests of newborn babies have been conducted since 1986. A comparison of the 9,493 newborn babies from the high radiation level area with the 1,737 newborn babies from areas with normal background radiation has not demonstrated any significant differences in the occurrence of chromosome aberrations. No connection between the frequency of chromosome aberrations and the radiation level of 1 to 35 mGy/year was found, either. Tests performed on rodents inhabiting the area of high background radiation levels in Kerala have not demonstrated any genetic effects that could be attributed to radiation[120].

Research was also conducted in other areas with radon radiation sources.

E.g. in Misasa in Japan[121], where the radiation level is elevated due to the presence of sources with significant contents of radon and radium, the normalized values of mortality from stomach cancer and other cancers are lower than in the control area with low background radiation, as shown in Fig. 7.7.9.

Such resorts as Bad Gatstein (Austria) and Boulder (USA) are used by radiation experts who come there yearly for health recovery purposes.

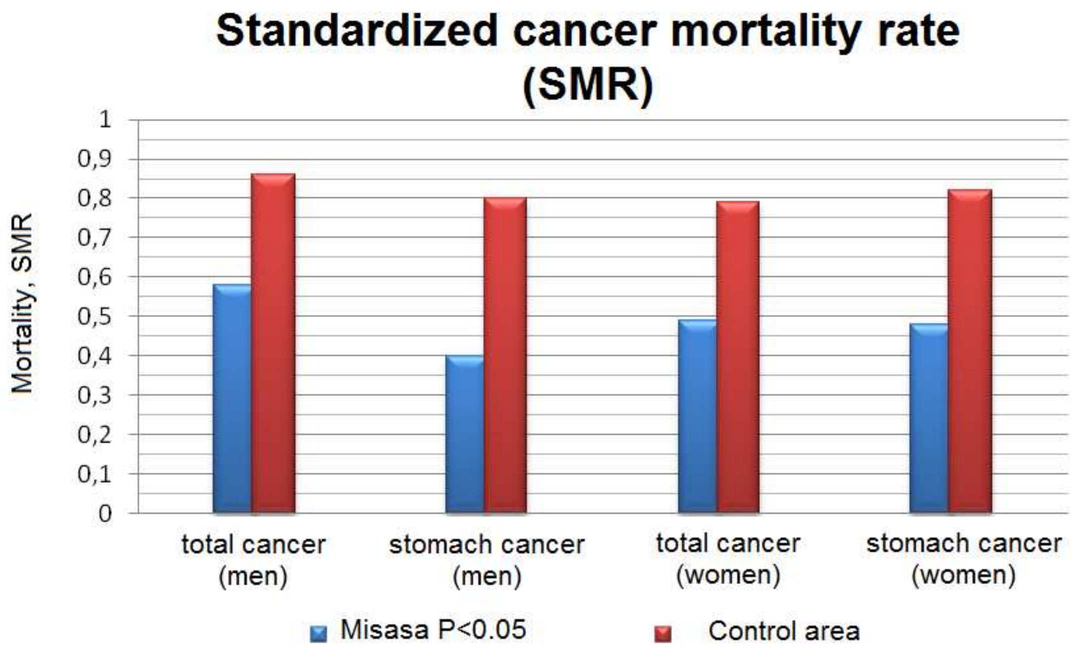

Fig. 7.7.9. Standardized cancer mortality rate for the Misasa radon resort and for the control area. Data acc. to Kondo[122]

Results that are not statistically sufficient to refute the hypothesis that all doses are harmful, but that demonstrate that mortality is lower in areas with elevated radiation levels are regularly obtained in research conducted in other countries. In no area with elevated background radiation level were higher cancer mortality rates detected. The incidence of chromosome mutations in the blood of inhabitants of such areas is sometimes elevated (but this is not a rule), but the incidence of cancer is lower than or the same as that in the control groups.

The relation between the chromosome aberrations and the value of the radiation dose has been tested in the high background radiation area near Ramsar, Iran. Approximately 2,000 persons received doses from 10 to 260 mGy/year, with the average value of 20 mGy/year. No positive relation between the chromosome aberrations and the value of the dose was identified. Also, no differences compared to inhabitants of nearby areas with low background radiation levels were found. Similar results demonstrating small significance of radiation compared with other factors were obtained in a high radiation level area in China[123].

According to the statement of the French National Academy of Medicine[124], certain data exists that confirms that elevated background radiation leads to a greater proportion of chromosome with aberration in the lymphocyte circulatory system, which constitutes a biological indicator of radiation exposure. One may not conclude, however, that this indicator pertains to health loss, as no increase of the risk of cancer, birth defects, or defects of newborn babies caused by cytogenetic effects was detected either in the thoroughly studied populations in the Kerala region in India or in the high background radiation level region in China. As the US NCRP[125] stated [NCRP 01], *"It must be concluded that cancer incidence in most populations exposed to low radiation doses is not significantly higher and in most cases the data indicates that it is lower."*

The hypothesis about the harmful effect of small radiation doses is based on the LNT model which has been questioned by many scientists and is contradictory to the experimental and epidemiological data. However, ecological research (conducted on large populations) does not allow for precise elimination of all the confounding factors and, so far, no research has been statistically valid, thus allowing it to eliminate the LNT hypothesis.

An excellent example demonstrating that elevated background radiation levels do not negatively influence people's health is shown in Fig. 7.7.10, which demonstrates the life expectancy for women in various countries as a function of electricity use. In Finland, where electricity use is high, people live much longer than in Poland, even though the background radiation there is among the highest in the world. As we can see, human health is not related to radiation levels.

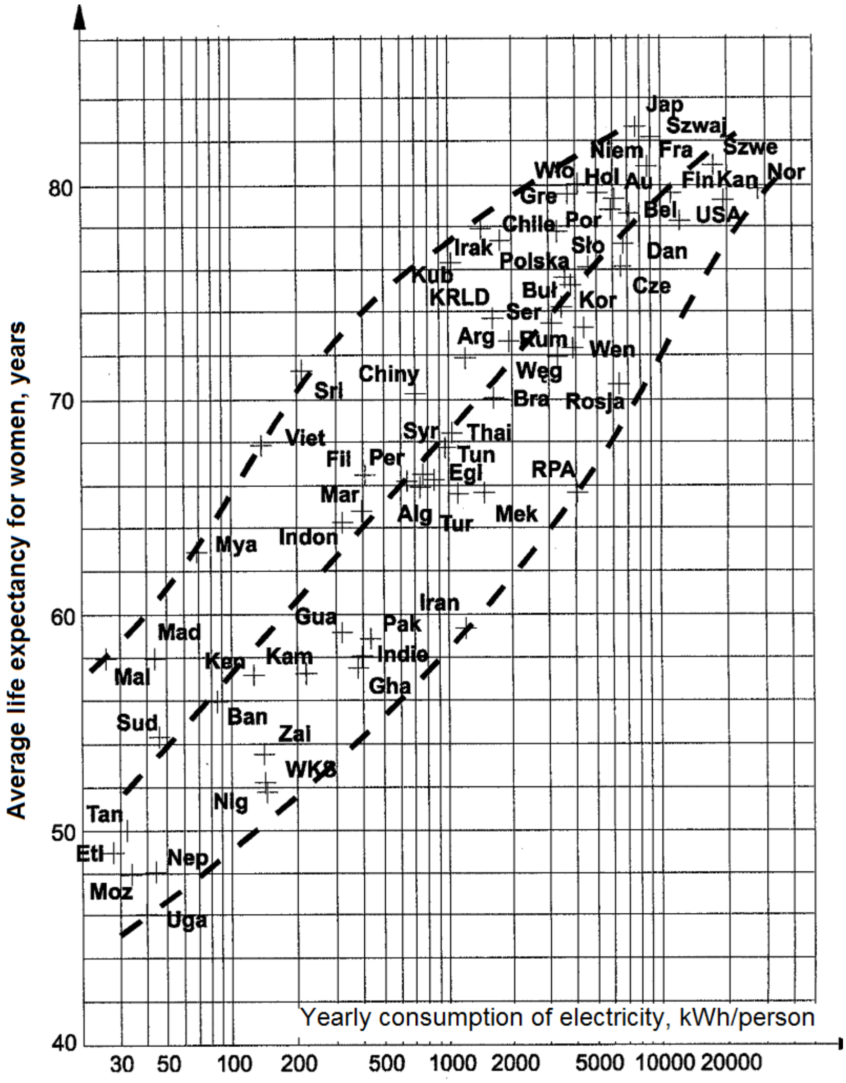

Fig. 7.7.10. Women's life expectancy as a function of electricity use

3.7.5 Research conducted on persons exposed to radiation at work

3.7.5.1 Lower cancer mortality rates among employees of the nuclear energy sector

Research involving 95,000 employees of the nuclear energy sector in the USA, Canada, and the United Kingdom, performed by the International Agency for Research on Cancer (IARC) demonstrated that within the range of small doses incidence of cancer does not increase, but rather decreases with the increase of the dose value by a factor of -7%/Sv. The relative mortality from cancer and leukaemia as a function of the cumulative dose absorbed in their lifetimes by employees exposed to ionizing radiation is shown in Fig. 7.7.11 prepared by the author based on the numerical data from the IARC work[126].

As one can see, an increase in mortality among employees exposed to radiation on their jobs occurred only in the case of very large doses, in the order of 400 mSv, and only with regards to leukaemia. This is a good example of the qualitative difference in the effects of small doses and large doses. The increase of incidence of for large doses is evident. However, doses emitted by nuclear power plants (1 mSv in a lifetime) do not cause any danger and the curves suggest that in this range of doses the mortality from cancer is reduced.

There are numerous statistically significant results of epidemiological research which demonstrate the hormetic effect of various factors, to include ionizing radiation. Based on the knowledge in the field as of 2005, it could be stated that "the hormetic model of the impact of a dose on the reaction of an organism is more common in toxicology than the threshold model"[127]. Despite the very large cohort and the many years of observation, the results of the IARC study have not achieved the statistical significance needed to prove that the LNT model should be abandoned. New data is being gathered systematically and will be published in the future. However, by now it is evident that small doses, which is what we are interested in with regards to radiation in the vicinity of nuclear power plants, there are no detectable negative effects on health.

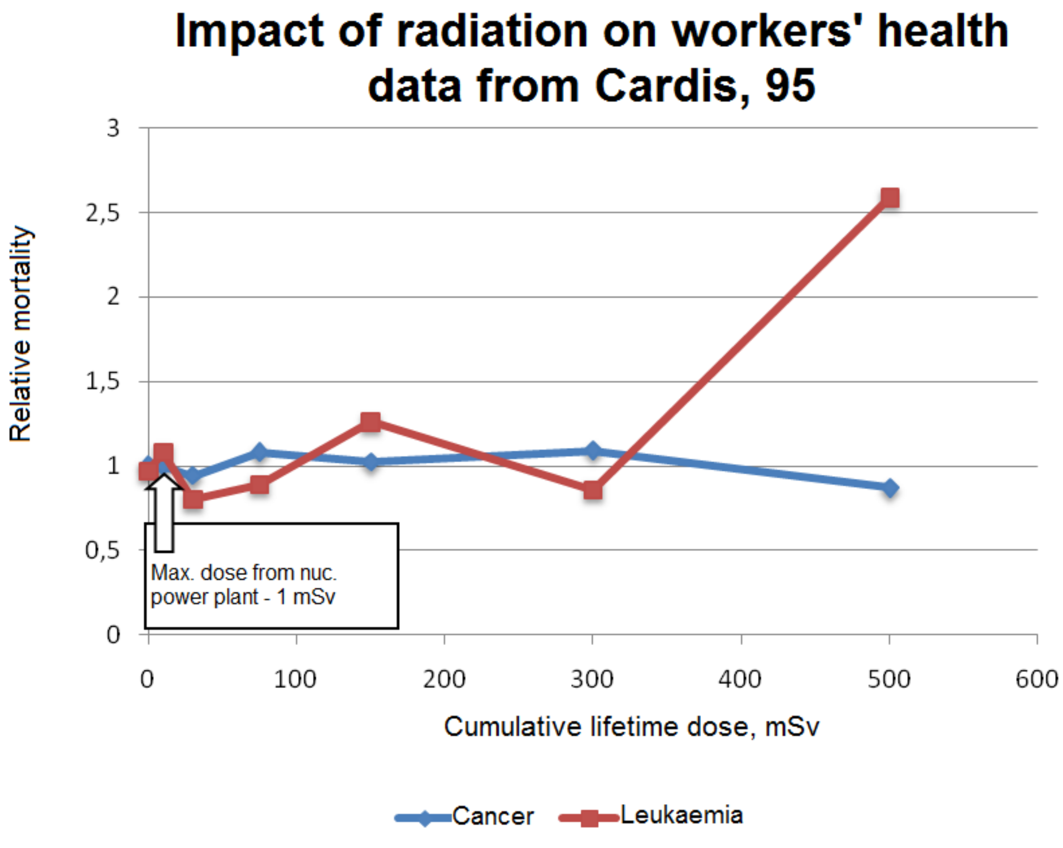

Fig. 7.7.11. Relative mortality (level „1" corresponds to the average mortality of employees not exposed to radiation) as a function of the additional dose absorbed in the course of work with radiation sources, accumulated during lifetime.

A research performed in Japan, covering 115,000 employees exposed to small radiation doses, demonstrated that both cancer incidence and general mortality in this population are lower than the average value for the corresponding group of men in Japan[128]. At the average cumulative dose of 13.9 mSv/person, the standardized mortality ratio (SMR) for the whole exposed population was SMR=0.83 for all the causes and SMR=0.89 for cancer. Thus, in Japan too cancer mortality among exposed employees is lower than the average.

Research of the impact of radiation on the health of employees of the nuclear sector are still performed as a part of international cooperation and the results from all countries are submitted to the International Agency for Research on Cancer (IARC). In 2007, the results of an analysis of deaths among 400,000 employees of the nuclear energy sector in 15 different countries were published. It turned out that the SMR ratio, as the average value of all the causes of deaths, was 62% for all deaths and for cancer among employees of the nuclear energy sector was only 19%, compared to 23% of all deaths[129] for the total population (see Fig. 7.7.12).

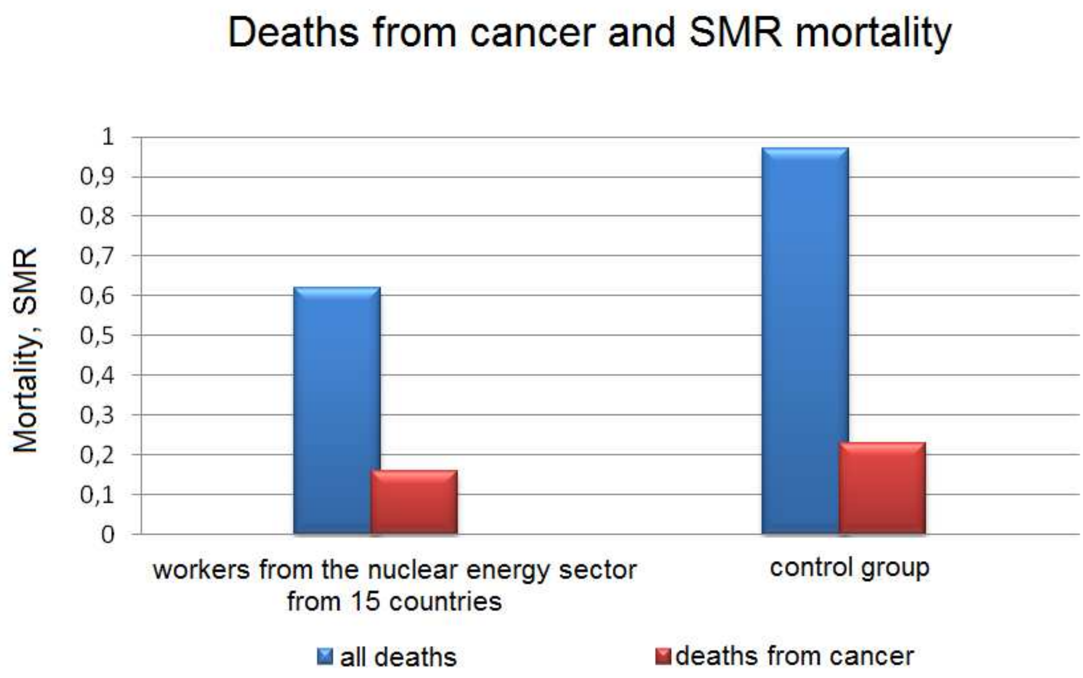

Fig. 7.7.12. Death from cancer and mortality (SMR) for employees of the nuclear energy sector from 15 countries and for the total population. Data from the IARC, figure based on the work by Fornalski and Dobrzyński[130] (with the authors' permission).

Thus, both the results of the research involving the 100,000 of employees presented in 1995 and the results of the research involving 400,000 employees presented in 2007 confirm that employees of the nuclear energy sector are more healthy and live longer than the average groups in the society of the same age characteristics. This is certainly a very encouraging facts for candidates for jobs involving work with radiation sources.

However, there are some doubts as to whether such good results are correlated with radiation or with other factors.

3.7.5.2 Can low incidence of diseases in persons exposed to radiation be explained using the healthy worker effect?

The supporters of the thesis that every dose of radiation is harmful claim that the low incidence of cancer among persons exposed to radiation is due to the healthy worker effect. The effect is the result of the fact that working persons are more healthy than the average person because persons who are ill do not work and are taken into account in comparisons between workers and the society as a whole.

The healthy worker effect can play a role in comparisons between groups of employees exposed to any factor with any external control groups, e.g. the total population of a country. It manifests itself in the reduced incidence of diseases among the persons covered by the study as a result of selection of employees to eliminate persons who are not healthy. As a result, persons with poor health do not become workers and the average mortality of workers is lower than the mortality of the whole population. Of great significance are also socioeconomic factors and, for example, education. Persons who are more wealthy and better educated generally take a better care of their health and are less exposed to harmful factors, such as alcoholism.

This thesis is reasonable, but there is one exception to it: there is no selection of employees on the basis of susceptibility to cancer or other genetic disorders. Routine tests administered to employees do not include tomography or genetic tests that may detect cancer or susceptibility to them. This is very important for the analysis of the impact of ionizing radiation, as cancer is the most important element of any analyses. The hypothesis that the healthy worker effect has an impact on the IARC results is criticized by many scientists; in Poland it was refuted by experts of the Institute for Nuclear Problems, professor L. Dobrzyński (member of the UNSCEAR) and mgr K. Fornalski**Błąd! Nie zdefiniowano zakładki.**.

In their work, they also discussed the healthy worker survivor effect (HWSE) connected with the fact that the SMR is the lower the longer the employment time is. This can be explained by the fact that workers with poorer health gradually quit their jobs, which leads to a reduced average mortality rate among the remaining workers. However, the weighted average number of deaths in 15 countries does not confirm a significant drop of the SMR with time of employment (see Fig. **7.7.13**).

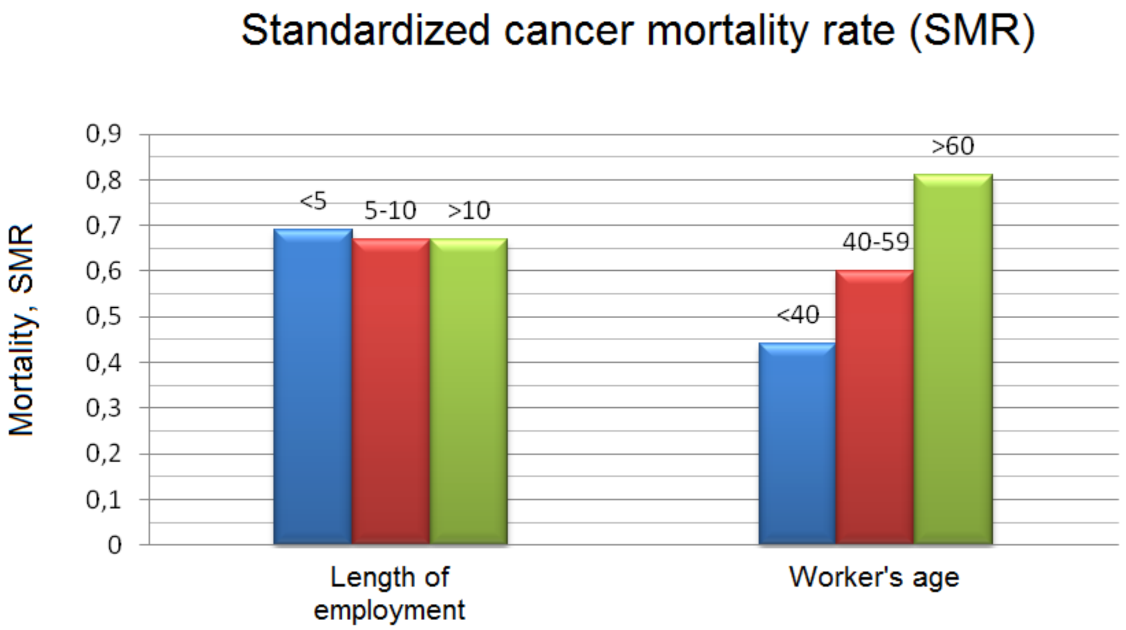

Fig. 7.7.13. Relation between the SMR and the time of employment and age of workers (figure based on the work by Fornalski and Dobrzyński[130], with the authors' permission)

This clearly proves that the HWSE does not exist in this cohort and, consequently, the HWE concept (which is related to the HWSE) is very dubious. Also, it can be seen that the SMR increases with the employees' age. This is not unusual, as it is related to the natural biological trend of every living creature.

Using the HWSE as an explanation for the reduction of the SMR appears to be unreasonable because it contradicts the claim that the HWE causes a greater reduction of the SMR at the early stages of employment than at late stages.

This leads to additional doubts as to the presence of the two effects.

The final argument against the HWSE is the fact described in the work by Berrington et al[131] who have analyzed mortality rates among British radiologists in the period of the last 100 years. The period is long enough to observe all the factors pertaining to deaths, in particular resulting from cancers, depending on the time of testing, time of employment, or the person's age. The work pointed at a drop in incidence of diseases for radiologists exposed to low doses. The control groups in all cases were selected to make the HWE factor neutral.

Another study, where the research groups and the control group were selected specifically to eliminate the healthy worker effect, was conducted to determine the impact of radiation on a large group of workers (28,000 persons) of the Shippingport shipyard. The whole research was designed, from the early stages, so as to avoid the impact of the HWE on the results. The US Department of Energy (DOE) has established a special committee for this purpose[132], and the list of its members – Professor Matanoski, Professor Cameron, etc. – is a guarantee that the works of the committee will be thorough and cohesive. The research has demonstrated that cancer mortality among persons irradiated with small doses (above 5 mSv) was 24% lower than in the control groups consisting of workers at the same shipyard who absorbed no radiation[133] (see Fig. 7.7.14).

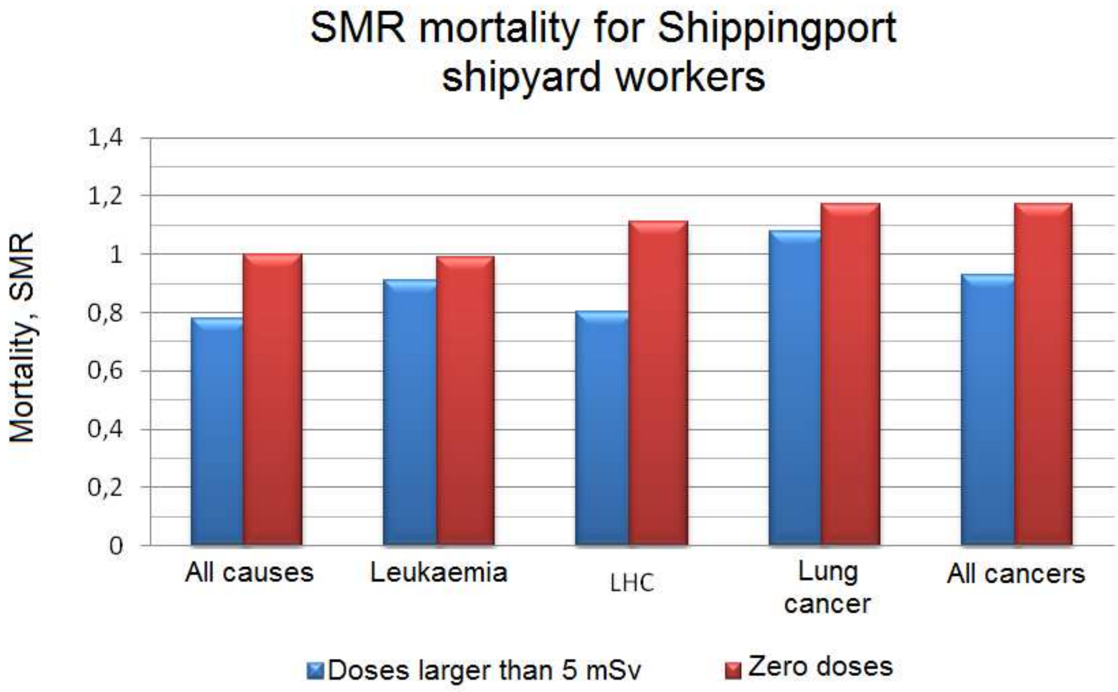

Fig. Mortality among shipyard workers at Shippingport

The selection of the control group from among the workers of the same shipyard has made it possible to eliminate the healthy worker effect. In the case of Shipingport, this effect could not have taken place as there are no reasons why workers of the same shipyard performing the same work (welding, erection, riveting, etc.) on nuclear ships could be “healthy workers” while the remaining workers are "unhealthy.”

3.7.5.3 Lower mortality among British radiologists

In the United Kingdom, extensive research among cancer mortality among radiologist has been performed. The research covered a period of 100 years (1897-1997) where the physicians absorbed various doses of radiation. As a result of the study, the standardized mortality ratio (SMR) was determined for deaths from all causes, deaths caused by cancer, and all deaths not caused by cancer for the radiologists involved. The SMR values were compared with the SMR values for the following three groups:

(i) all men in England and Wales;

(ii) all men in social class I (to which physicians belong);

(iii) all male physicians.

As a group, the radiologists registered after 1920 (1921-1979) do not demonstrate any significant differences in the SMR values for deaths caused by cancer compared to other physicians. However, radiologists have a significantly lower SMR value for deaths caused by cancer than other men (SMR-0,63; p<0.001) and men from social class I (SMR=0.82; p<0.01). Moreover, radiologists registered after 1920 have a lower SMR value for deaths from all causes than other male physicians (SMR=0.91; p<0.01), men from social class I (SMR=0.91; p<0.01), and all men (SMR=0.72; p<0.001) [134].

The SMR for deaths caused by cancer for radiologists registered after 1955 was lower by 29% (which is statistically not significant) than the SMR for other physicians, while the SMR for deaths from all causes was much lower than the SMR for other physicians. Why would radiologists be more healthy than other physicians? Dr. Cameron, a recognized authority in the field of research on impact of radiation on people, suggests that the hypothesis that the good health of radiologists may have resulted from stimulation of their immune systems by radiation is justified:

“The study on British radiologists will not resolve the controversies concerning the soundness of the hypothesis based on the LNT model, but it confirms the doubts concerning the assumption that small radiation doses have no beneficial effects on the human body. This contradicts the current dogma that “all radiation doses are harmful” [135].

3.7.6 Consequences of small radiation doses absorbed for medical purposes

Medical diagnostic procedures often involve irradiation with small radiation doses. Extensive studies conducted on adult patients exposed to radiation for diagnostic purposes have not demonstrated an increase in incidence of diseases. For example, the analysis of data of 34,000 persons in Sweden who were administered J-131, which covered 653,000 person-years, demonstrated that at the average total dose of 1,100 mSv, the incidence of thyroid cancer did not change[136].

The study of the effects of thyroid hyperfunction using radioactive iodine conducted recently by the University of Birmingham and published in "The Lancet" reveals numerous facts that contradict the LNT model. The study, which involved a group of 7,414 adult patients treated in Birmingham in the United Kingdom in the years 1950-1991, with average cumulative dose of 308 MBq of I-131, identified 683 cases of cancer and 448 deaths caused by cancer in the years 1971-1991 among the patients. These values can be compared with the British statistics concerning cancer incidences and deaths caused by cancer for corresponding age groups, genders, and periods, which are equal to 761 and 499, respectively. The standardized incidence ration was 0.83 (95% confidence interval 0.77-0.90) and the standardized mortality rate was 0.90 (0.82 – 0.98). “Higher incidence and mortality were observed for the small intestine and thyroid cancers, but the absolute risk related to these types of cancer was small.” The scientists summed up their study with the following statement: “A decrease of the overall incidence and mortality from cancer among persons treated for thyroid hyperfunction with radioactive iodine is an encouraging occurrence."

A cohort study, involving 64,172 Canadian patients treated with multiple irradiations with small doses, which amounted in total from over ten mSv to several Sv, but where the instantaneous dose values were moderate (0.6 mSv/s), demonstrated that, as the author of the study stated, “there is no relation between the risk of death from cancer and the dose” [137]. A comparison with the cancer mortality among the Japanese who survived the dropping of nuclear bombs on Hiroshima and

Nagasaki and received very large single doses demonstrated that the nature of the risk related to small doses is very different. Fig. 7.7.15 shows the mortality for groups of persons who have absorbed total radiation doses in the following ranges: Group 1: 0.01-0.49 Sv; group 2: 0.50-0.99 Sv; group 3: 1.0 – 1.99 Sv; group 4: 2.00-2.99 Sv; and group 5: above 3 Sv.

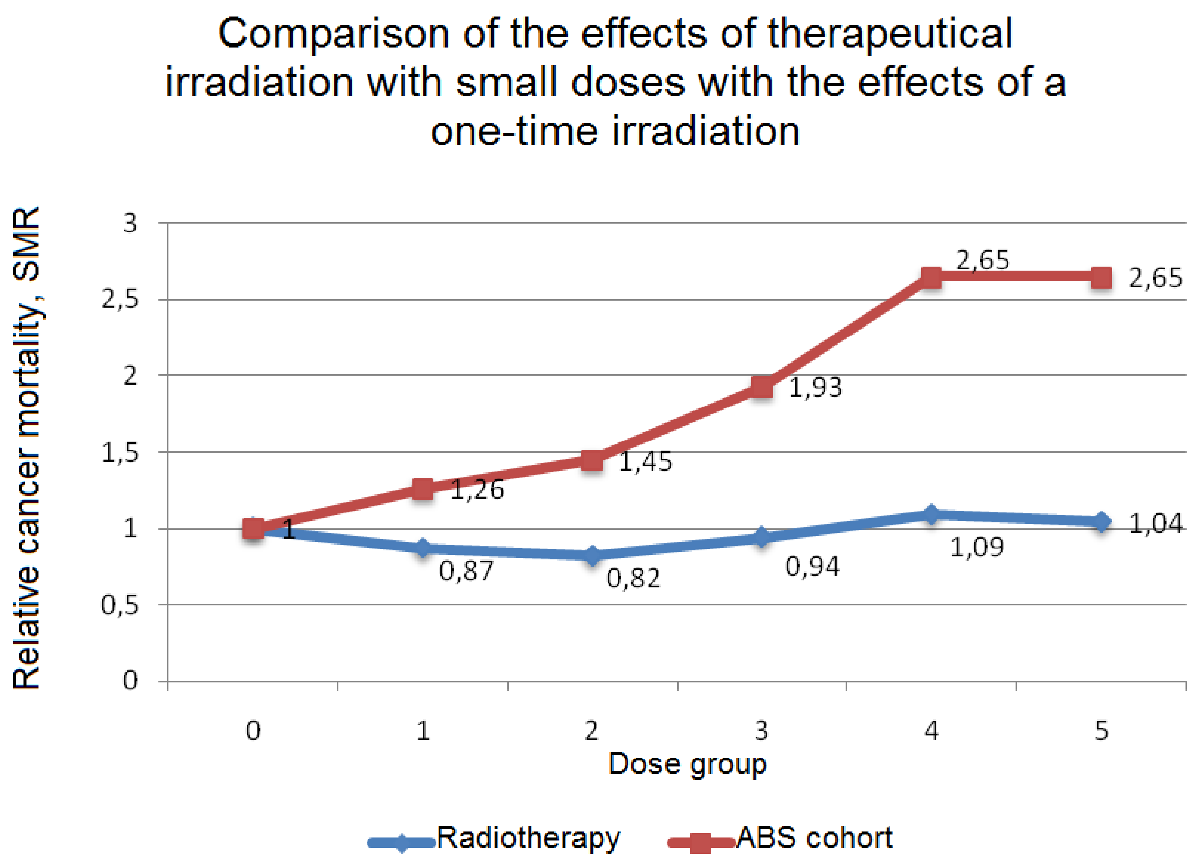

Fig. 7.7.15. Comparison of the effects of therapeutic irradiation with small doses with the effects of a single irradiation in Hiroshima and Nagasaki

In the case of the ABS cohort, the risk clearly increases with the dose. On the other hand, in the case of the cohort subject to radiotherapy with small dose rates, even though the total dose absorbed by the patients was the same as that in the ABS cohort, at small doses the cancer mortality values decrease. Only at high total doses the risk increases to levels above the average for periods who were not irradiated; however, it is still close to one, which is much lower than that for the ABS cohort. Similar results were obtained in a number of other studies.

3.7.7 The impact of irradiation with small doses on children

3.7.7.1 The impact of irradiation of parents on the health of children

In the group of children from Hiroshima and Nagasaki (1,263) who survived the explosions of the atomic bombs as foetuses and absorbed doses above 0.01 Gy (the average value was 0.309 Gy), there was no increase in the incidence of cancer and none of them died of leukaemia. In London and Edinburgh there were 9 cases of leukaemia among 39,166 irradiated children, while the number anticipated based on the average incidence of leukaemia in the United Kingdom (RR=0.86) was 10.5.

A large international epidemiologic study covering children that were begot by parents who, as children, underwent cancer treatment involving radiation, demonstrated that the incidence of genetic diseases among them is lower than that in the control group[138]. In the group of 5,559 children born in the USA and Denmark whose parents had been treated for cancer there were 239 of genetic defects (0.43%), while the number in the control group (6564 children) was 306 (0.446%). The authors of the study emphasized that even though large doses of ionizing radiation are the cause of inherited effects in Drosophila flies and in mice, there is no evidence that irradiation of a human foetus leads to genetic defects in children.

In the ABS cohort where, after irradiation in Hiroshima and Nagasaki, 70,000 children were born, no genetic effects were identified. The research presented in the work by Boice confirms that no such effects should be expected in human populations. The authors cautiously conclude that “radiotherapeutic treatment of cancer diseases is not connected with a significant risk, if any, from the point of view of genetic defects in children."

3.7.7.2 The effects of foetal irradiation

Supporters of the LNT thesis use the consequences of foetal irradiation, in particular the results of the “Childhood Cancer Oxford Study” as the proof of validity of the LNT model. However, it is unknown whether children that have been exposed to X-rays *in utero* have been selected for the procedure due to suspected congenital diseases, i.e. whether the Oxford cohort is representative for normal foetuses. At the same time, the research involving the cohort of the Japanese survivors of the Hiroshima and Nagasaki bombs, referred to as the ABS cohort (“A-bomb survivors”) has not demonstrated any carcinogenic effects of foetal irradiation, in the case of neither leukaemia nor solid tumours[139]. Similar experiments conducted on animals have not demonstrated carcinogenic effects of *in utero* irradiation with small doses. In numerous studies, the impact of X-ray radiation absorbed by foetuses *in utero* or by small children was analyzed. Doll and Wakeford concluded that *in utero* irradiation with doses equal to 5-10 mSv is connected with an increase of the incidence of leukaemia and solid tumours in children[140]. However, their work was subject to sharp criticism by Professor Mossman as early as mid-1990’s. Since then, 19 case-control studies and 6 cohort studies have been completed, which have not demonstrated any significant increase in the incidence of cancer caused by small X-ray doses absorbed by a child before or soon after the birth[141].

3.7.7.3 Impact of irradiation of children according to tests conducted in the United Kingdom

In November 1999, the United Kingdom’s National Radiological Protection Board stated that “The results of the new huge epidemiological study are not in line with the thesis that exposure of parents to radiation before conception of a child is the cause of leukaemia and non-Hodgkin lymphoma (LNHL) in children.”

This hypothesis was proposed by the Gardner group in 1990. In response, the Committee on Medical Aspects of Radiation in the Environment (COMARE), established by the British government, recommended conducting a detailed study[142].

The NRPB’s report titled “Cancer in the Offspring of Workers Exposed to Radiation” based on a study involving 36,000 children over a period of 30 years and an analysis of data concerning 120,000 workers exposed to radiation leads to the conclusion that the results of this study do not support Gardner's thesis[143].

In particular:

"No confirmation was found for higher risk for parents who absorbed a dose of 100 mSv or larger prior to conception or a dose of 10 mSv or larger within 6 months prior to conception.

Also, no relation between foetal irradiation and other categories of cancer in children was found**Błąd! Nie zdefiniowano zakładki.**. The both the 1994[144] report and the latest report[145] of the COMARE which uses the most sensitive statistical and mathematical methods confirm that “nothing indicates an increase in the incidence of any cancers in children within 25 km from nuclear power plants.”

3.7.7.4 Thyroid cancers in children treated with X-rays

The research on thyroid cancer in children treated with X-rays is described in the article by E. Ron et al.; however, the research did not pertain to small doses, as the linearity range extended from doses above 10 Gy down to 0.1 Gy[146]. The authors mentioned "even up to 0.1 Gy," which means that they do not indicate that their work covers the range of doses discussed in the book, i.e. several mSv and less. Moreover, the authors of the aforementioned article recognize the existence and effectiveness of repair processes in human bodies by saying that "spreading dose over time (from a few days to >1 year) may lower risk, possibly due to the opportunity for cellular repair mechanisms to operate." Evidently, respected experts, such as E. Ron, J.H. Lubin, R.E. Shore, K. Mabuchi, B. Modan, L.M. Pottern, A.B. Schneider, M.A. Tucker, and J.D. Boice Jr, recognize the importance of repair processes and can differentiate between the effects of low dose rates and the effects of one-time exposure to large doses.

3.7.8 Achievements in research on biological processes occurring after irradiation of people

3.7.8.1 Comparison of permanent mutations caused by irradiation and those caused by metabolic processes

An analysis of the processes taking place in the human body indicates that radiation is not the only process that causes cell damage. Much more important are the normal metabolic processes which cause the production of over 100 million free radicals a day in each cell, which may cause damage to the DNA. The free radicals cause approximately a million DNA nucleotides a day in each cell. There is also damage caused by normal division of cells and DNA multiplication, as well as the loss of nearly 5,000 of purine cations a day per cell of a human body due to the destruction of their bonds caused by the normal warmth of the human body. Metabolism causes ten million times more cell mutations (repaired and not repaired) than natural radiation.[147]

Table 7.7.1. Comparison of the number of cell damages caused daily by metabolic processes and by radiation with dose rate equal to 1 mSv/year.

	Metabolism	Radiation (1 mSv/year)
Number of free radicals created in the vicinity of the DNA	100,000,000	
Number of DNA defects per cell	1,000,000	0.005
Ratio of the number of unrepaired DNA changes or DNA changes repaired with errors to the number of DNA defects	1 per 10,000	1 per 500
Number of DNA unrepaired DNA changes or DNA changes repaired with errors per cell	100	0.000,01
Ratio of the number of permanent mutations that are unrepaired or repaired with errors to the number of DNA changes that are repaired or repaired with errors	1 per 100	1 per 100
Number of permanent mutations that are unrepaired or repaired with errors per cell	1	0.000,000,1
Ration of mutations caused by radiation to mutations caused by metabolism	1 to 10,000,000	

Given that the due to radiation two DNA spirals at a time may become damaged, the ration of the number of DNA changes that are not repaired or repaired with errors to the number of DNA defects is 20 times larger for radiation than for metabolic processes. This fact is always emphasized by supporters of the LNT hypothesis in discussions concerning the effectiveness of repair processes. However, even though the number of DNA defects caused by metabolism is so huge that after the repair process the number of unrepaired permanent mutations caused by radiation is only one ten millionth of the number of unrepaired permanent mutations caused by metabolism.

In order for the organism to survive, it must have very effective methods of removing free radicals and to repair and eliminate DNA defects. The methods are also an effective response to ionizing radiation.

3.7.8.2 Repair processes in living organisms

Over the last decade we witnessed huge progress in our understanding of biological processes that serve the purpose of protecting the cells and the human body from radiation hazards. As it turns out, the nature of the defence mechanisms is variable and depends on the value of the dose. The supporters of the LNT hypothesis used to claim that both small and large doses cause similar DNA defects and that repair processes may sometimes lead to errors and, consequently, initiate carcinogenic processes. Currently, the French Academy of Sciences emphasizes that even though DNA defects in cells occur identically regardless of the dose rate, the defence processes on the cell, tissue, and organism level are different according to the rate and value of the dose[148].

In particular, at very small doses (less than several mSv), activation of defence processes by radiation causes increased immunity of the body to other dangers present in normal metabolic processes. For example, the effectiveness of removal of toxins, such as active oxidants, increases, which protects DNA from becoming damaged. While the number of DNA defects caused by metabolic processes reaches a million a day per cell, the number of radiation defects per cells at low radiation rates, e.g. 1 mSv/year, is approx. 0.005 a day. Even though radiation damage includes a larger proportion of double damage of the DNA strands than damages caused by metabolic processes, increasing the effectiveness of the biological defence mechanisms in our bodies has effects that are many times greater than the minimum relative increase in the danger to the body caused by small radiation doses.

Moreover, at small doses, no negative effects of irradiation of tissues are noticeable because damaged cells are not being repaired but eliminated by way of apoptosis, i.e. programmed death of cells containing unrepaired DNA damages. From the point of view of the organism (when the proportion of damaged cells is very small) this is the safest solution. According to the French Academy of Sciences, "elimination of damaged cells protects the body from potential malignant tumours."

When the doses reach values exceeding several mSv, but less than approx. 100 mSv, defence mechanisms are activated and defective cells are eliminated or repaired in very effective processes. Such processes were first developed at the time life emerged on Earth; if it was not for them, no organism would endure the millions of cell defects per seconds. The effectiveness of the defence processes increases with the dose, so that in the range of over ten and several dozen mSv the hormesis effect may take place; the reduction cell defects caused by metabolic processes is much more important than possible imperfections of the repair processes. However, defects caused by radiation are of different nature than defects caused by metabolism: 1) the fraction of the double damage to DNA strands is larger; 2) there are clusters of defects caused by hydroxyl radicals; 3) the distribution of cell defects is more heterogenic. Such defects may be repaired with errors, although a number of studies indicate that the increase of effectiveness of defence processes is of the greatest importance[148].

At larger doses, above 100-200 mSv, the concentration of defective cells increases and the DNA repair processes may include errors, whose likelihood increases with the dose rate. If apoptosis is not initiated, errors in repair of the DNA may allow defective cells to survive and initiate the development of a neoplasm.

At doses above 500 mSv, the cell multiplication rate increases in order to compensate the loss of cells damaged by radiation. Fast division of cells interferes with the repair processes and the likelihood of erroneous repairs and development of a neoplasm increases.

Such differences in the repair processes explain why at small doses the impact of radiation on health may be positive, even though it is negative at large doses. Although the ICRP still supports the LNT hypothesis and it still constitutes the grounds for radiation protection regulations and comparative analyses, in the unanimous opinion of the French Academy of Sciences and the French National Academy of Medicine the current knowledge indicates that very small doses are not dangerous.

The French National Academy of Medicine emphasizes the fact that the most recent biological data indicates that the molecular and cellular processes that determine where a cell survives or undergoes mutagenesis depending on the dose value and rate are very complex and variable. Both the National Academy of Medicine and the Academy of Sciences, and many scientists alike, emphasize the fact that the hormetic model is the most suitable to describe the processes occurring after irradiation of people with small doses.

3.7.9 **Conclusion**

Long-term studies conducted in many parts of the world and among different populations have proven beyond any doubt that small doses of radiation – comparable to natural background radiation – have no negative impact on human health, including adults, children, and the offspring of persons exposed to radiation.

Still, until recently, comparative analyses would assume that every dose of radiation carries a risk that is proportional to the dose. All analyses performed until 2005, the results of which are quoted in this study, were based on this assumption.

The leading specialists in health protection call for additional studies and development of models that would explain the impact of small doses of radiation on human health. [UNSCEAR 1994, Sugahara, 1994]. Studies are underway, but in the meantime everyone agrees that small doses of radiation either have no negative impact at all or these impacts are undetectable even when studying the largest populations. On the other hand, many renowned scientists and most respectable institutions claim that the majority of results even suggest a beneficial effect of small doses of radiation. Thus, it is evident now that there are no reasons to be concerned about small radiation doses.

4 ANALYSIS AND ASSESSMENT OF OTHER PREDICTED SIGNIFICANT EFFECTS ASSOCIATED WITH OPERATION OF NUCLEAR POWER PLANTS

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4.1 Impacts at the Programme implementation stage

Due to the fact that a lot of place in the assessed Polish Nuclear Power Engineering Programme is devoted to the Programme implementation stage, potential impact associated with this stage was also examined. It aims at enabling construction of the first nuclear power plant in Poland, and the scheduled actions precede the construction itself by many years. Although the effects are not very significant in comparison to the construction and operation stage, they are however long-term and multi-aspect (they are to last until 2020), and their results will certainly have effect much longer. Also, their scope of impact will be greater than the one related to construction of the power plant itself (socio-economic aspect).

At the first stage of execution, the Programme assumes appointing proper units and creating legal framework to introduce nuclear power engineering in Poland. The actions will have far-reaching results, enabling development of a new branch of power engineering industry in Poland, and they will mainly be based on providing the conditions for safe application of nuclear power engineering (for humanity and environment).

Providing specialised staff is necessary for development of nuclear power engineering in Poland. The actions concerning investment in human capital, aiming at educating necessary Polish specialists in this field, are also planned in terms of the assessed Programme.

Furthermore, education of the entire society is planned by means of information and education campaigns.

4.2 Impacts at the construction stage

Impacts occurring at the nuclear power plant construction stage are identical to those usually related to construction of large-format facilities. In case of nuclear power plants, however, they are significant due to construction time, which is about 6-7 years. This chapter discusses in detail impacts on water and air, as being most significant. Other impacts are summarised in the summary table in chapter 0.

4.2.1 Impact on water

4.2.1.1 Construction stage

The greatest threat which may directly affect contamination of underground water and disturbance of water surface level will result from ground works at the investment site. This will be particularly important in the areas characterised by high and very high sensitivity to underground water pollution related to lack of rock insulation of aquiferous layer from the surface of the area. Hydrogeological analysis performed for potential nuclear power plant locations has shown very high diversity in the insulation level and depth of utility aquiferous layers. Impact of ground works on underground water may be particularly visible in the areas of shallow deposits of aquifers. Such a situation will necessitate intensive excavation pumping and thus creation of local cones of depression, which as a result may cause drainage of surface water reservoirs hydraulically related to underground water.

When examining probability of direct intervention in aquatic environment, three hydrogeological cases must be considered (Fig. 4.2.1):

- location of a nuclear power plant in the area where in the ground impermeable deposits are found (case 1) with thickness of at least several meters (e.g. moraine blocks made of clay) - guarantees protection against potential pollution of underground water,

- location of a nuclear power plant in the area where in the ground semi permeable deposits are found (case 3) with medium pollution permeation time enables taking relevant preventive actions in case of water pollution,

- location of a nuclear power plant in the area where in the ground permeable deposits are found (e.g. sandur plateaus made of sands and gravel) with short pollution permeation time (case 2) - the most unfavourable situation in case of pollution penetration in the ground; in short time, infiltration through the rocks and widespread aquifer contamination takes place, and in case of hydraulic connection with a main watercourse, contamination of further situated areas.

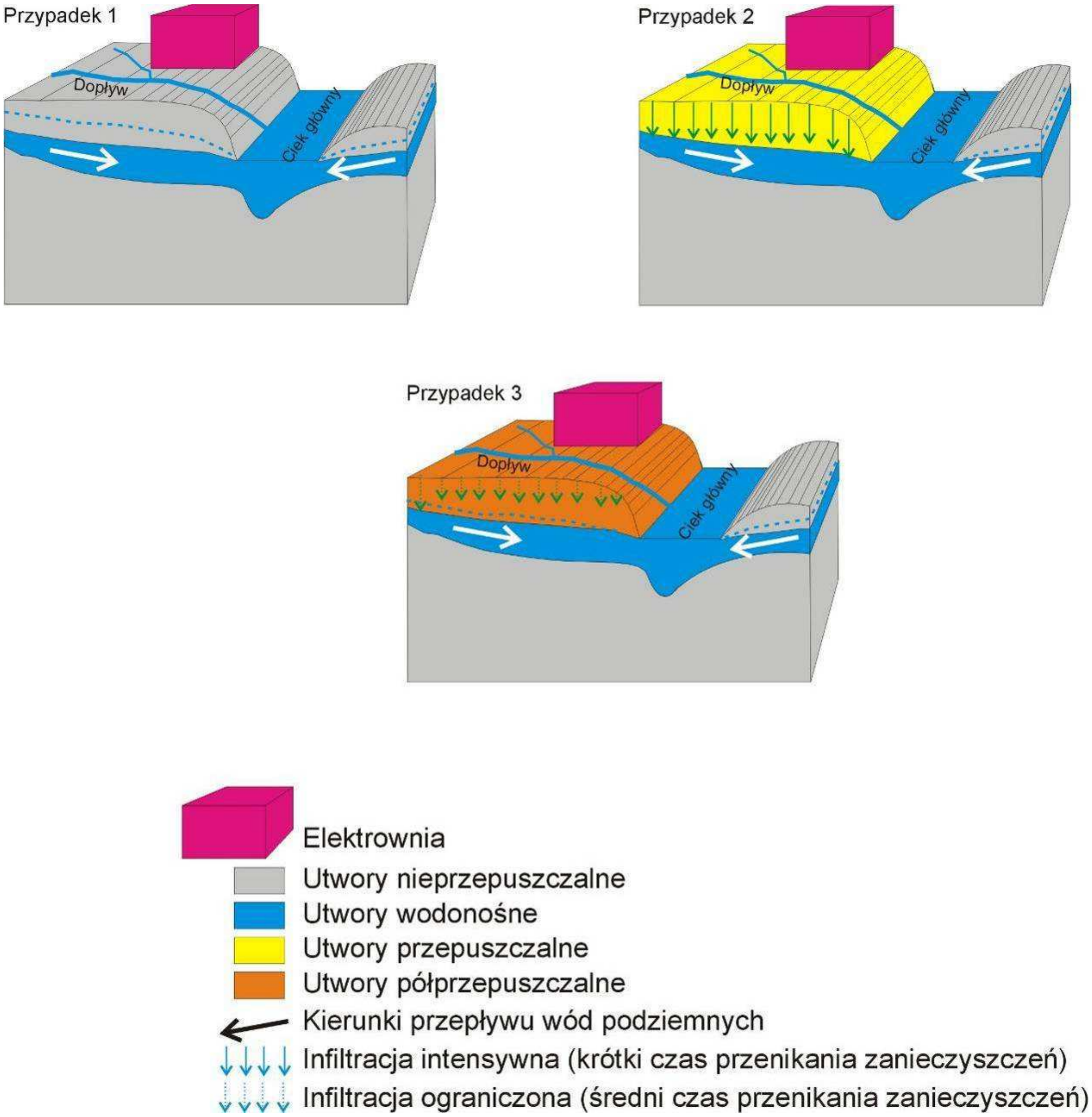


Fig. 4.2.1 Impact of potential pollution of underground water by a nuclear power plant depending on hydrogeological conditions.

[Przypadek – Case
Elektrownia – Power plant
Utwory nieprzepuszczalne – Impermeable formations
Utwory półprzepuszczalne – Semi-permeable formations

Kierunki przepływu wód podziemnych – Flow directions of groundwater
Infiltracja intensywna (krótki czas przenikania zanieczyszczeń) – Intense infiltration (short pollution penetration time)
Infiltracja ograniczona (średni czas przenikania zanieczyszczeń) – Limited infiltration (medium pollution penetration time)]

It may be assumed that the very basic safeguards during normal construction works will eliminate the risk of groundwater contamination with substances from the surface of the construction site. However, actual contamination hazard may occur in emergency situation related to uncontrolled leaks, e.g. oil derivatives and other compounds applied in construction. Therefore, provision of emergency water collection tanks and development of emergency procedures is a key element in the design and construction phase.

Sealing a large area by construction of a nuclear power plant and adjacent infrastructure may cause decreasing water surface, and thus local drainage of the area surface. On general level, it is difficult to determine whether location of a nuclear power plant may impact condition and quality of Main Underground Water Reservoirs. Determination of potential impact will only be possible at the moment of establishing specific location and performing a more detailed geological and hydrogeological study.

Regardless of geological construction, execution of piezometer network around the planned investment is necessary. Distribution and depth of piezometers should be planned at the stage of the investment environmental impact report in a specific location depending on local hydrogeological conditions. Water samples from piezometers will be taken before commencement of the construction in order to establish the existing background of underground water pollution. During investment execution and operation, samples should be taken regularly in order to detect potential substance leaks to aquiferous layers.

Generally however, during construction, temporary storage of chemicals should take place on hardened and sealed surfaces, and all construction actions should take into account ground and water protection against potential pollution. Therefore, besides unforeseen emergencies, the construction stage should not adversely affect the quality of underground water.

4.2.1.2 Test stage

A separate aspect in water impact analysis is the reactor commissioning stage with tests. It is related to potential emission of the following chemical compounds to the water: iron (Fe), phosphates (PO_4^{2-}), lithium hydroxide (LiOH), hydrazine (N_2H_4), boric acid (H_3BO_3), morpholine ($HNCH_2CH_2OCH_2CH_2$), sodium (Na), sulphates (SO_4^{2-}), bromoform ($CHBr_3$). Among the mentioned substances, the potential impact on water quality is displayed by boron compounds and iron. Boron is used in cooling cycles, and its leaks are related with first temperature increase tests in those cycles. Iron may also come from cooling cycles and production of demineralised water. The quantities of substance releases were specified in UK EPR report[149] on the basis of conducted tests. Maximum daily release values are 40 kg of iron and 1250 kg of boric acid. However, actual values depend on installed cooling systems and local water intake and discharge conditions, therefore they should be specified in detail for a specific investment location.

4.2.2 Impact on the air

4.2.2.1 Construction stage

4.2.2.1.1 Dustiness

Ground works, soil mass and construction materials transport, concrete production and loose material storage cause dust emission into atmosphere. However, there are effective methods of dust prevention, such as water sprinkling of roads and material processing areas (e.g. cutting, crushing), which should be planned prior to commencement of construction and consistently applied in its duration. Impact of dustiness may only be assessed at the stage of environmental assessment of power plant construction in its specific location, taking into account current air quality and assessing potential additional effect of dust emission resulting from the planned construction.

4.2.2.1.2 Exhaust emission from machines and vehicles

In relation to construction, transport of construction materials and workforce will take place, resulting in exhaust emission (containing, i.a., carbon monoxide, dust particles, hydrocarbons and nitrogen oxides). Impact of those emissions remains closely dependent on selection of investment location and charting transport routes to a construction site. At the preparation stage of the environmental impact report, distribution of pollutions should be examined in detail.

4.2.2.2 Test stage

A the test stage, first commissioning of the entire installation takes place, along with its first heating to high temperature, which in turn may cause releasing formaldehyde and carbon monoxide to the atmosphere. Quantities of these releases were specified in UK EPR report[149] based on identification of potential emission quantities and modelling distribution in the atmosphere of significant emissions. Assuming the most unfavourable scenario, the emission value was specified at 1230 g of formaldehyde (at release rate 0.0342 g/s) and 1152 g of carbon monoxide (at release rate 0.032 g/s). The report states that the emissions have no significant impact on air and do not have to be modelled in detail.

4.2.2.3 Impact on the ground surface

In construction of power facilities and related transmission infrastructure, impacts during construction will be mainly based on land take and changes in soil structure (thickening, removal of humus layer etc.) in direct vicinity of planned investments. Such impacts may occur also in temporary storage sites of construction materials and structural elements. Potential impacts also include soil contamination with petroleum derivatives, which may penetrate soil due to lack of tightness/failure of mechanical vehicles. However, such impacts only refer to the nearest neighbourhood of the investments and due to their scale they usually do not require recultivation activities. Other impacts with examples are presented in the first part of the table, in the section 5.3.

4.3 Impacts in conditions of normal operation of the nuclear power plant

The figure below (Fig. 4.3.1), illustrates impact of nuclear power plant in operation stage on individual elements. This Chapter discusses these impacts one by one, with the exception of radiological impacts – they have been discussed earlier in chapter 7).

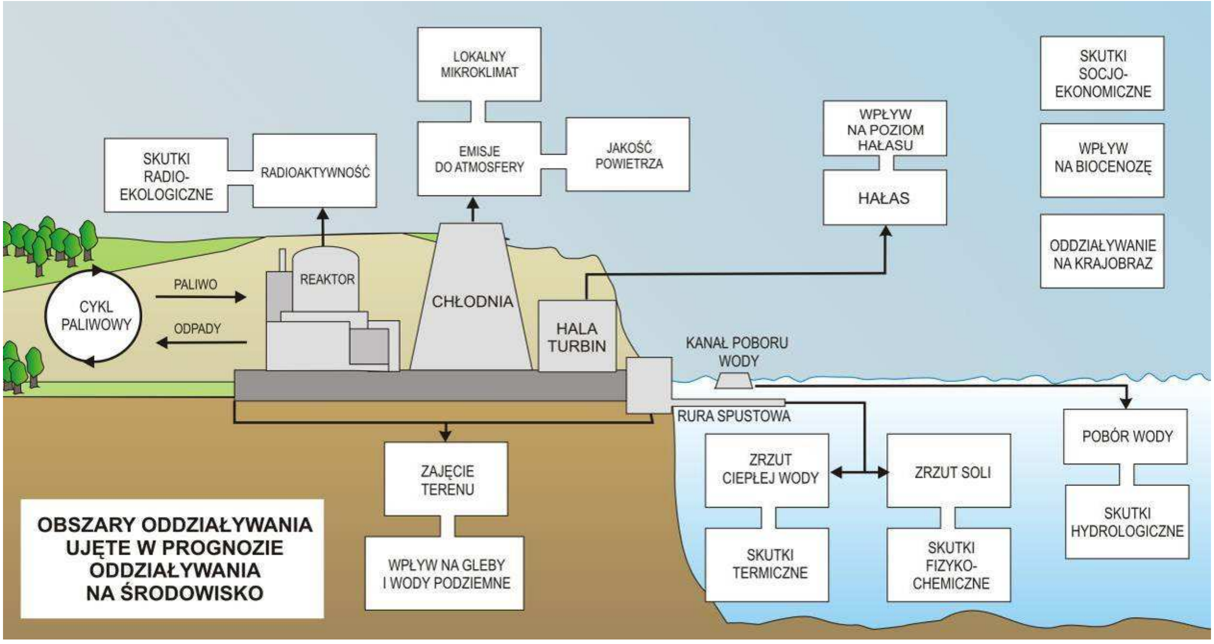


Fig. 4.3.1 Illustration of environmental nuclear power plant impact aspects and their mutual relations [own study based on [UK EPR: PCER, Chapter] [150]

[OBSZARY ODDZIAŁYWANIA UJĘTE W PROGNOZIE ODDZIAŁYWANIA NA ŚRODOWISKO – IMPACT AREAS INCLUDED IN THE ENVIRONMENTAL IMPACT FORECAST

Cykl paliwowy – Fuel cycle
Paliwo – Fuel
Odpady – Waste
Reaktor – Reactor
Radioaktywność – Radioactivity
Skutki radio-ekologiczne – Radiological and environmental effects
Chłodnia – Cooling tower
Emisje do atmosfery - Emissions to atmosphere
Lokalny mikroklimat – Local microclimate
Jakość powietrza – Air quality
Zajęcie terenu – Land take
Wpływ na gleby i wody podziemne – Impact on soils and groundwater
Hala turbin – Turbine room
Hałas – Noise
Wpływ na poziom hałasu – Impact on noise level
Skutki socjoekonomiczne – Socio-economic effects
Wpływ na biocenozę – Impact on biocoenosis
Oddziaływanie na krajobraz – Impact on landscape
Kanał poboru wody – Water intake channel
Rura spustowa – Discharge pipe
Zrzut ciepłej wody – Warm water discharge
Skutki termiczne – Thermal effects
Zrzut soli – Salt discharge
Skutki fizyko-chemiczne – Physicochemical effects
Pobór wody – Water intake
Skutki hydrologiczne – Hydrological effects]

4.3.1 Impacts related to the fuel cycle

Fig. 4.3.2 schematically presents simplified fuel cycle of a nuclear power reactor, including three basic elements:

„Preliminary part” of the fuel cycle *(„front-end”)*, consisting of:

- uranium output and uranium concentration production in form of "yellow cake" – containing 70-90% triuranium octoxide U_3O_8;
- chemical conversion to uranium hexafluoride (in gaseous form) U_3O_8, → UF_6;
- uranium enrichment with isotope U235 (to ca. 4%);
- nuclear fuel production: conversion to uranium dioxide (in powder form) UF_6 → UO_2, production of fuel pellets (powder sintering UO_2 and forming pellets), assembly of fuel elements and sets.

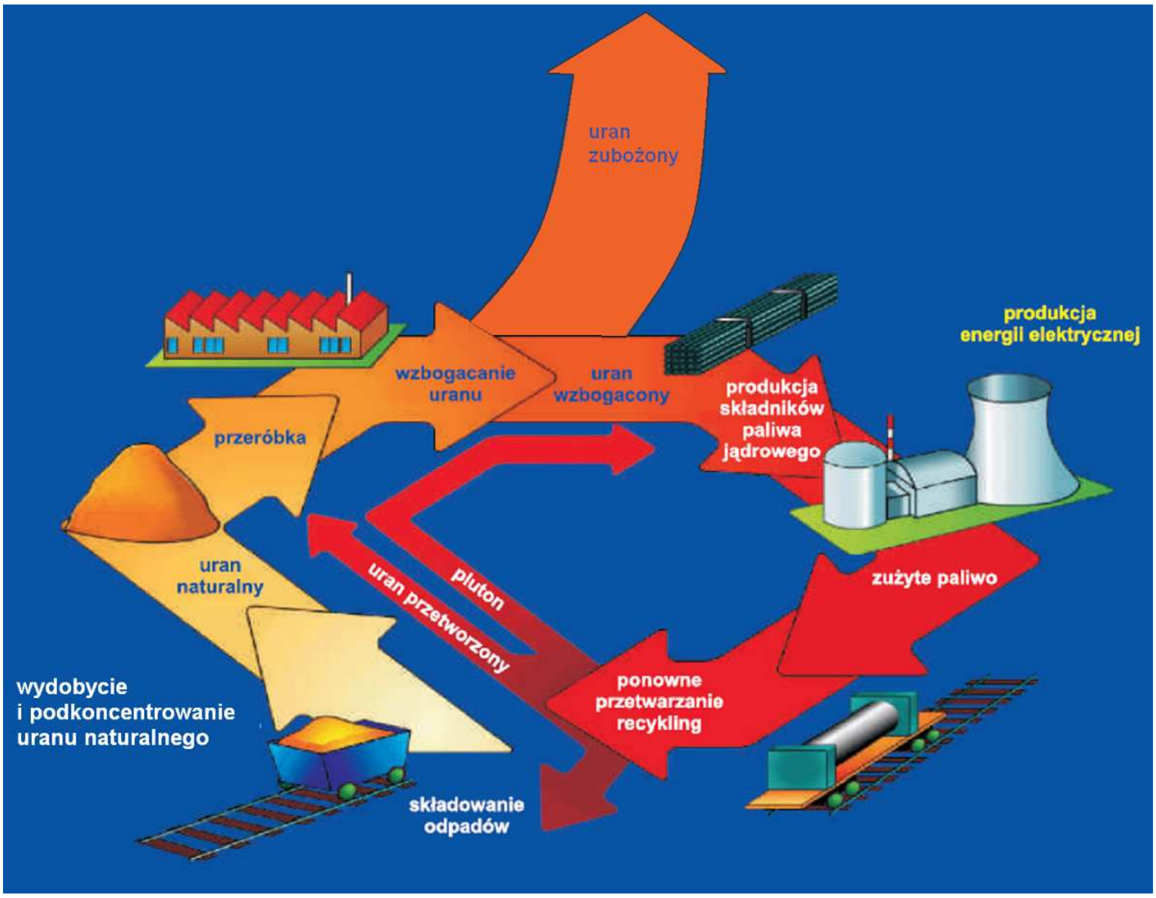


Fig. 4.3.2 Fuel cycle of nuclear power reactor [EDF][151].

[Wydobycie i podkoncetrowanie uranu naturalnego – Extraction and sub-concentration of natural uranium
Uran naturalny – Natural uranium
Składowanie odpadów – Waste storage
Przeróbka - Processing
Wzbogacanie uranu – Uranium enrichment
Uran wzbogacony – Enriched uranium
Uran zubożony – Depleted uranium
Produkcja składników paliwa jądrowego – Production of nuclear fuel components
Zużyte paliwo – Spent fuel
Ponowne przetwarzanie, recycling – Reprocessing, recycling
Produkcja energii elektrycznej _ Electricity production
Pluton – Plutonium

Uran przetworzony – Reprocessed uranium]

Middle part of the cycle: fuel combustion in the power reactor when producing electricity, involving, among others, the following issues:

- long-term optimising planning of nuclear fuel demand - on the basis of electricity production plans;
- commissions, transport and storage of fresh fuel on the plant premises;
- planning fuel campaigns with optimisation of core loading for individual campaigns *(in-core fuel management)*;
- fuel reloading, fuel campaign supervision and temporary storage of burnt nuclear fuel on the plant premises.

„Final part" of the fuel cycle *(„back-end")*, consisting of:

- transport of burnt fuel to a processing plant or deep geological waste dump,
- processing the burnt fuel with recycling of recovered uranium (directed to chemical conversion and enrichment) and plutonium (used in uranium-plutonium MOX fuel production after mixing with depleted uranium - being a waste product of enrichment process);
- rendering harmless and storage of the high-activity radioactive waste from burn fuel processing process.

This chapter briefly characterises the middle part of the fuel cycle: fuel combustion in the reactor - also including nuclear fuel supply, fresh fuel transport and storage on the plant premises, and temporary storage on the plant premises and disposal of burnt fuel.

4.3.1.1 Options of securing the raw material for uranium concentrate production

The analyses below are based on materials from the report ***„Assessment of possibility of uranium mineralisation in Poland on the basis of the results of geological and search works"*** prepared by the interdisciplinary team of specialists, composed of: A. Solecki, W. Śliwiński, I. Wojciechowska, D. Tchorz-Trzeciakiewicz, P. Syryczyński, M. Sadowska, B. Makowski. The basis of the report was agreement no. 330/2009/Wn-07/FG-sm-tx/D of 28th January 2009, concluded between Minister of Environment, National Fund for Environmental Protection and Water Management and WS Atkins – Polska Sp. z o.o. Also a part of materials by A. Solecki, were used, not included in the final report version. The report, completed in April 2010, in the final corrected version was accepted in October 2010. Therefore, some data were updated on the basis of sources published in the second half of 2010.

The fundamental fact which must be taken into account when considering fuel supply of nuclear power plants planned in Poland is uranium demand, which in 60 years may reach 72.240 Mg of natural uranium[152], which equals 85.191 Mg U_3O_8 being the main component of "yellow cake", the basic trade form of concentrate of this raw material.

The second fact is price of metallic uranium, which in the last decade fluctuated between: 18.45 $/kg U at the end of 2000 to 354 $/kg U in June 2007. In December 2010 the price was 134 $/kg U [153].

Purchase of metallic uranium, necessary to provide fuel for the planned nuclear power plants at a price 134$/kg means expenditure of 9.7 billion $. It should be emphasised that this is an initial phase of fuel cycle, consisting of: uranium output and uranium concentrate production in form of "yellow cake", containing 70-90% of triuranium octoxide U308. Further stages usually require an expensive enrichment procedure in order to increase 235U isotope content in nuclear fuel. The enrichment takes place in plants with expensive equipment, the construction of which requires international community supervision due to the threat of nuclear weapon production. At the assumed scale of development of nuclear power engineering in Poland and lack of significant natural uranium resources, building such plants does not seem to be economically justified. With large-scale fuel production, currently taking place in global power engineering, costs of uranium enrichment and fuel production are low. In total, fuel costs including all phases of fuel cycle amount to approximately 10-15% of the entire electricity cost.

Assuming that future documentation of uranium resources in Poland sufficient for profitable operation would be possible, we may obtain complete independence from import of uranium, since fuel cycle services are offered by various countries and do not pose any obstacles in developing nuclear power engineering. In the discussed case (which currently is hypothetical), future development of domestic nuclear power industry could be based on reactors using natural (non-enriched) uranium. Currently, such reactors do not meet European standards and are not considered for Poland.

4.3.1.1.1 Options of obtaining uranium from domestic deposits

During developing the report by Solecki's team (2010), balancing criteria were used from 2008 presented in Table 4.3.1.

Table 4.3.1 Balancing criteria from 2008

Parameter	Unit	Marginal value
Maximum depth of deposit documentation	m	1000
Minimum content of U_3O_8 in the sample outlining the bed	% U_3O_8	0,03 (0,01)*
Minimum mean content of U_3O_8 in the bed profile with barren interlayers	% U_3O_8	0,03 (0,01)*
Minimal bed abundance (U_3O_8)	kg U_3O_8/m^2	1,2 (0,8)*
* in brackets parameters for extra-balance resources		

Until the preparation of the above mentioned report, the most up-to-date published diagnosis of status and prospects in terms of searching for uranium deposits in Poland was presented by Nieć [154]. Comparison of the diagnosis conclusions with report results was presented in Table 4.3.2.

Table 4.3.2 Status and prospects of search for uranium deposits in Poland according to Nieć (2009) and Solecki et al. (2010)

Deposit	The most optimistic variant (Nieć 2009)		REMARKS resulting from the team report (Solecki et al. 2010)
	Resources estimated (t)	Content ppm U_3O_8	
Rajsk	1444	295	From the resources documented in 1976, 470 Mg meet the balancing criteria from 2008 (according to checking calculations performed in terms of this study ca. 450 Mg). One may take into account double increase in resources upon examining the area adjacent from SE. At large depth of deposition (544 m) and low resources, only pit mining remains, requiring developing new technologies
Podlaskie depression			Among the prospective resources documented in 1977, none meets balancing criteria from 2008
Grzmiąca	789	637	776 Mg of resources meet balancing criteria
Okrzeszyn	935	590-1180	Content of U_3O_8 meets the criteria, but since the strata

Deposit	The most optimistic variant (Nieć 2009)		REMARKS resulting from the team report (Solecki et al. 2010)
			are very thin (0.1-0.2 m) , the richness does not meet the balancing criteria, option of pit mining or surface mining of "highwall mining" type may be considered, performed from the surface or from shallow dip headings.
Radków Wambierzyce	217	118-354	Too low content and richness
Radoniów	131		Irregular and very diverse deposits
Podgórze	81		Irregular and very diverse deposits

The presented summary indicates, that currently a bit more than 450 tonnes of uranium in Rajsk deposit and 776 tonnes of uranium in Grzmiąca deposit may be deemed documented. Those resources are so small that potential mine construction is not profitable.

The currently known uranium deposits and mineralisations occur in the area of the following Polish geological units:

- Precambrian platform (podlaskie sink hole - Ordovician dictyonemic shales and Peribaltic Syneclise - Lower Triassic sandstone);
- Lower Silesian block (Sudety - both Variscan subsoil and Post-Variscan platform);
- Horst of Świętokrzyskie Mountains and lower San (Świętokrzyskie Mountains - tectonic zones within the block and cap);
- Śląsko morawska structure (Zagłębie Górnośląskie-Upper Carboniferous series);
- Palaeozoic platform (Foresudetic monocline - Lower Triassic sandstone);
- Carpathian Mountains - Oligocene menilite shales.

Podlaskie synecline-Ordovician dictyonemic shales

In the series of Ordovician dioctynemic shales from the resources documented [155] in 1976, only 470.683 Mg U_3O_8 meet the balancing criteria from 2008. According to the checking calculations performed in scope of the report by Solecki's team (2010), it is only 450.316 Mg U_3O_8. One may take into account potential double increase in resources upon examining the area adjacent from the south to Rajsk 1 hole.

At large depth of deposition (544 m) and low resources, only pit mining remains, requiring developing new technologies. Despite relatively high average uranium content in the entire series of shales, especially its black variation, the deposit quality is determined by secondary mineralisation processes, probably related to the tectonic zone. Therefore, prospective resources documented in 1977 [155] should be deemed not meeting current criteria, although in this area there are certain chances of finding secondary enrichment zones.

The significant global resources of rock with similar uranium content, being revealed on the surface (phosphorites from Morocco and USA, dictyonemic shales from Estonia) make it difficult to expect future economic conditions suitable for uranium mining from the Podlasie shales, except for secondary enrichment zones. One may hold certain hopes in case of combining the search and extraction works on uranium ores with works concerning shale gas. Upon completion of gas extraction, application of pit method should be considered, combined with combustion (or microbiological oxidation) and gasification of organic substance and leaching the residues in order to mine uranium. However, this is the issue of long-term works on development of new technologies.

Lower Triassic sandstone of Peribaltic Syneclise

In Lower Triassic sandstone of Peribaltic syneclise, uranium ore resources have not been documented so far. The obtained results create prospects of documenting the resources meeting balancing criteria from 2008. However, it is necessary to examine hydrogeological conditions, critical for underground leaching process. Lithological conditions of deposition are unfavourable and require serious modification of existing technologies.

Lower Silesian block (Sudety - Variscan subsoil and Post-Variscan platform);

Among the deposits documented in the past, only Grzmiąca deposit has the resources amounting to 810 tonnes of metallic uranium in three strata. The current criterion of U_3O_8 content is met by all sections taken to calculate resources. The richness criterion is met by most sections.

In the opinion of the report's authors (Solecki et al. 2010) good deposit recognition status and favourable geological conditions predispose Grzmiąca deposit for potential exploitation with underground leaching method. [156] [157] The following support it:

a) occurrence of mineralisations in porous and permeable detritic sediments;

b) presence of moderately regular silty formations isolating uranium layers from barren formations;

c) frequent location of neighbouring uranium strata within one clastic bank.

With Okrzeszyn deposit, the content of U_3O_8 meets the balancing criteria, but since the strata are very thin (from 0.1 to 0.2 m), richness is unsatisfactory. The following constitute additional impediment with potential deposit exploitation: multi-layer character of the deposit, unresolved method of uranium recovery from carbon and probably necessity of repeating a part or majority of geological works on this deposit. Pit mining or underground open pit mining of "highwall mining" type may be potentially considered, performed from the surface or shallow dip-headings.

Uranium mineralisations of Radków-Wambierzyce region are characterised with much too low content of U_3O_8. The deposits in the area of Variscan mass of Sudety Mountains are mostly fully depleted, and resources remaining in Radoniów are small and difficult to mine due to high deposit variability.

Option of discovering new deposits is related to examining tectonic zones and their intersection (especially related to albitisation processes).[154] The analysis (Solecki et al. 2010) indicates the possibility of relation of mineralisation of the Sudety Mountains Variscan mass rather with tectonic zones than with grantoids, which may result in new search strategies in the Fore-Sudetic block and Fore-Sudetic monocline.

There are certain hard to specify options of finding deposits associated with the secondary infiltration enrichment zones in permocarbonic and Cretaceous sediments.

Horst of Świętokrzyskie Mountains and lower San

Uranium ores were mined as accompanying mineral during pyrite exploitation in Staszic mine. Lack of detailed information on the remaining resources. Świętokrzyskie Mountains should be treated as a region enabling positive assessment of options of finding mineralised tectonic zones in the substrate of Palaeozoic platform cap on Fore-Sudetic Monocline.

Palaeozoic platform (Fore-Sudetic Monocline - Lower Triassic sandstone);

Uranium concentrations in zechstein formations do not meet current balancing criteria. It is a fact that even with uranium content of several dozen ppm, at the current scale of copper ore mining, according to simple mathematical operations astounding quantities of uranium may be obtained, but those quantities have no significance when costs of potential uranium recovery are taken into account.

The uranium ore resources have not been so far documented in Lower Triassic sandstone of Fore-Sudetic Monocline, despite some interesting local anomalies in the area of Nowa Sól. Lithological conditions of mineralisation deposition are unfavourable and require serious modification of existing technologies.

Śląsko-morawska structure (mineralisation in Carboniferous coal of Górnośląskie Zagłębie Węglowe)

Lack of documented resources in Carboniferous coal of Górnośląskie Zagłębie Węglowe. They have never been mined. There are certain prospects of finding richer, mineralised sections in leap zones of peripheral sections of Zagłębie Górnośląskie and perhaps Lubelskie. The global experience of uranium exploitation from coal up to date is not optimistic.

Carpathian Mountains

In Carpathian Mountains, uranium mineralisations are related to the series of Oligocene menilite shales. Probably, a part of menilite series from Bezmiechowa region meets current balancing criteria.

Taking into account thickness of uranium shales, falling between 2-5 m, with average content of U_3O_8 238 ppm for volume density 2 Mg/m^3, one may except capacity from 0.95 to 2.4 kg U_3O_8 /m^3. Exploitation of those rocks was considered in the 1990s for the purpose of obtaining shale oil and even then, the enterprise was barely profitable. In Synowódzkie region (presently Verkhnye Synyovydne, Ukraine) even before World War II „Wspólnota Interesów Górniczo-Hutniczych w Katowicach" made an attempt at industrial menilite shales exploitation for the purpose of shale oil production, later continued by the Ukrainians. In current economic conditions, combined uranium and shale oil recovery should be considered, including the pit mining method, combined with burning organic substances, gas generation and leaching the residues in order to mine uranium.

To sum up, it must be stated that resources of uranium currently available in Poland are scarce, and many years of exploration and prospecting works will be required to find new uranium deposits (if any). Therefore, the only solution seems to be importing nuclear fuel.

4.3.1.1.2 Options of obtaining uranium from import

In the World War II period and right after, uranium became a strategic raw material, due to works on nuclear weapon. Until the 1960s, economic issues were secondary in terms of uranium production. After creating a basic nuclear arsenal, rapid decrease in uranium production down to 30 thousand tonnes per year took place, which completely secured not only the military demand, but also nuclear power engineering.

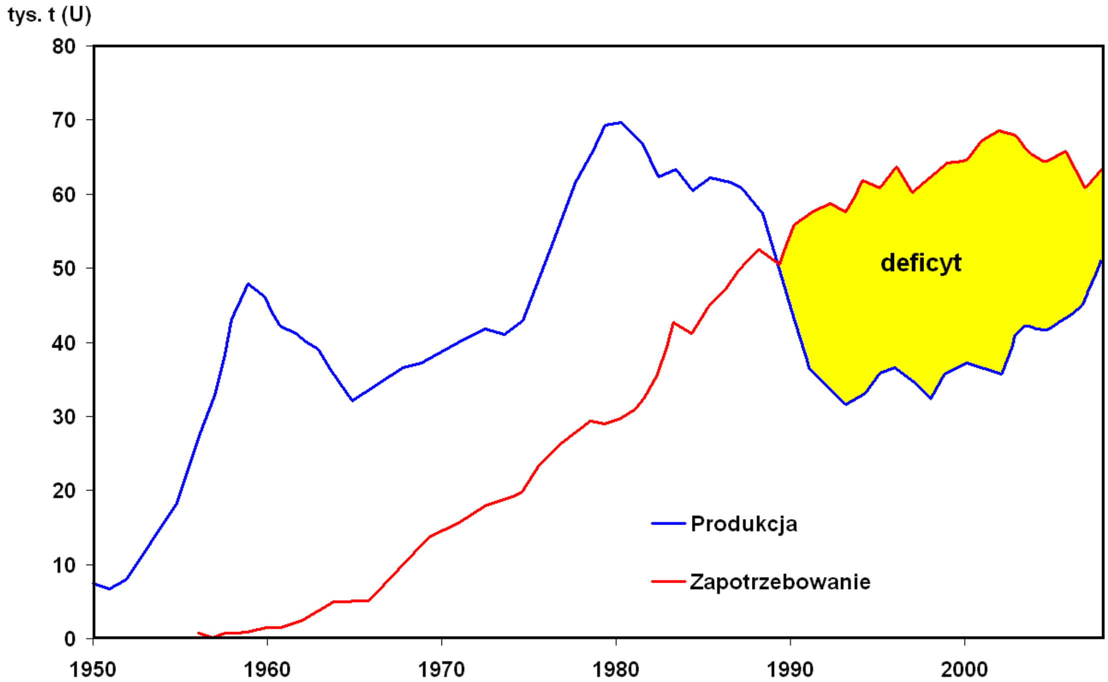


Fig. 4.3.3 Global uranium demand and production in 1950-2006 based on the data of WEC 2010

[Deficyt – Deficit
Produkcja – Production
Zapotrzebowanie – Demand
Tys. t – Thousand tonnes]

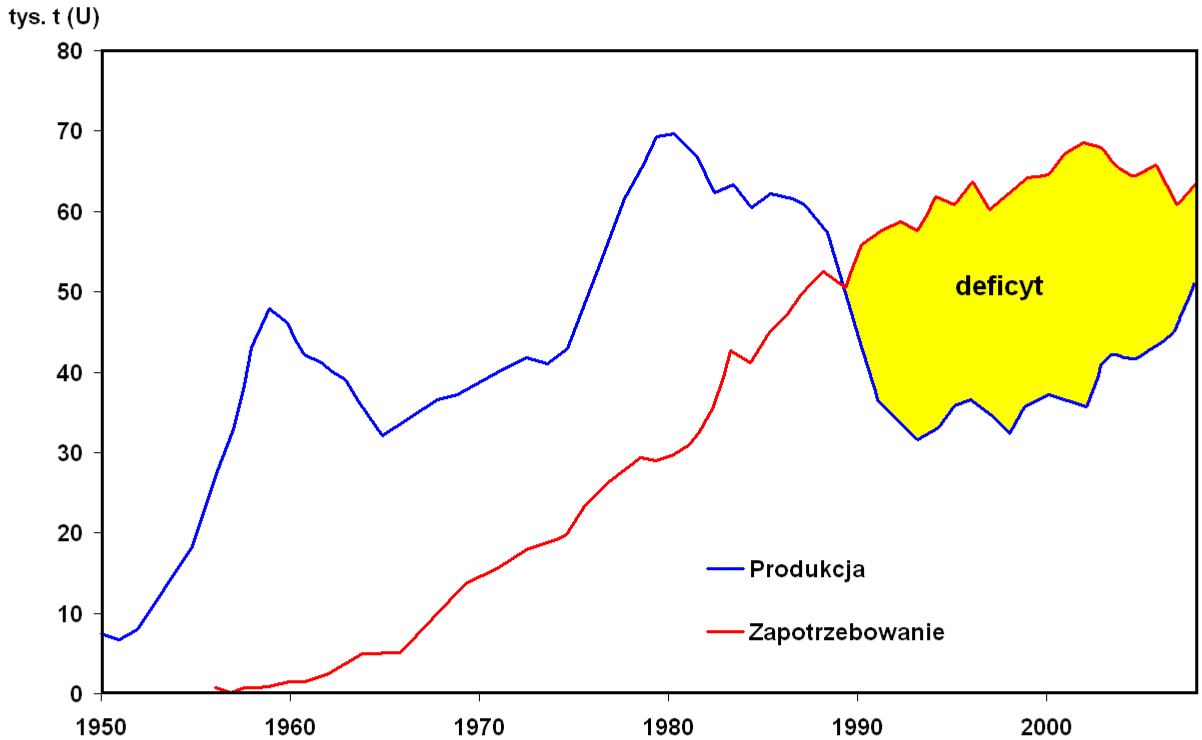


Fig. 4.3.4 Global uranium demand and production in 1950-2006 based on the data of WEC 2010

Increase in petroleum prices in the 1970s caused rapid development of nuclear power engineering, and consequently demand for uranium. Subsequent decrease in petroleum prices and Chernobyl failure affected the decrease in interest in nuclear power engineering development, which had its effect on development of mining industry. In 1995-2005 global uranium production dropped to 30-40 thousand Mg, which meant a deficit in the market for this raw material.

Since 1990 the deficit (several tens of thousands of tonnes) was covered from secondary sources, among others from recycling of Soviet warheads and recycling of fuel and processing the accumulated dumps, which kept uranium prices on relatively low level. Price of uranium reached its record low of 18.45 $/kg at the end of 2000. From 2001, increase in price occurred, additionally stimulated by failures in mines exploiting Olympic Dam and McArthur River deposits. Price increase caused increased interest of extractive industry and increase in production to the level of 52 thousand Mg in 2006. In June 2007 the prices reached their record high: 354 $/kg. Since then in 18 months prices dropped to 138$/kg[158] and stabilised. As it was mentioned previously, price of uranium in December 2010 was 134 $/kg. Currently, forecasts for nuclear power engineering and uranium mining indicate increase in demand to the level of 94 or even 122 thousand Mg/year in 2030.[158]

Currently, the indentified worldwide resources of uranium extracted at a price lower than $130/kg amount to 5.5 million tonnes[169]. Known resources of uranium ore extracted at about $130-260/kgU amount to 0.9 million tonnes. The resulting 6.4 million tonnes of uranium ore will satisfy the demand (at the current level of production) for more than 100 years. With the introduction of breeder reactors and fuel recycling technologies that considerably increase the energy efficiency of nuclear fuel, the same resources will suffice for several thousand years (at the current level of electricity production).

Other, conventional uranium resources, possible to document in commonly exploited deposit types, are estimated at approximately 10 million Mg. Additionally, the size of resources possible to obtain from phosphorites (at a cost of 60-100$/kg) and black shales is estimated at 10-22 million Mg of uranium. In the 1990s, until the decrease in raw material prices, recovery of this element from phosphorites was started in the USA, Belgium and Kazakhstan. With significant increase in prices (above 210-260 $/kg) it also becomes profitable to obtain uranium from sea water, where ca. 4 billion Mg of this stock is dispersed.[159] [160] As it can be seen, prices of uranium in long-term perspective should not increase, since with their increase it becomes profitable to extract huge resources from new types of deposits (phosphorites, black shales, sea water).

Existence of unconventional resources raises doubts concerning the sense of searching for uranium deposits in Poland. At the same time, we cannot forget about hundreds of thousands of tonnes of phosphorites processed in our country. Uranium contained in phosphorites is mostly found in phosphates obtained in production, where it forms an unwanted component. It seems appropriate to undertake works on recovering uranium from the same source as with significant import scale (458.92 thousand Mg[161]) it could lead to obtaining approximately 50 tonnes of U per year, with simultaneous positive ecological effect.

4.3.1.2 Environmental effects of preliminary hazard related to securing raw material for production of uranium concentrate

Mining related to extraction and processing of uranium ores until the stage of obtaining "yellow cake" is associated with significant environmental impact. This impact depends on the type of deposit, parameters of the surrounding area, and the adopted mining technology.

As the processing of uranium ore involves a chemical separation of this element, it may lead to migration of radioactive isotopes deposited in uranium ore during millions of years.

Among those isotopes, the highest environmental migration ability is displayed by radium Ra-226 and radon Rn-222, the radioactive progeny of which are, among others: bismuth Bi-214 (main emitter of gamma radiation in the series of uranium U-238 decay) and highly radiotoxic polonium Po-210.

Migration of these isotopes may be reduced by using the optimum extraction and processing technologies. In terms of the extraction process itself, extraction with underground headings may be considered as the least burdensome. The ore is then transported to a processing plant, and environmental changes in the mine area do not vary from those occurring with any other type of mineral extracted in underground mines. The mine drainage and ventilation system may release increased concentrations of radium and radon to the atmosphere, but taking into account uranium ores in regions with naturally increased content of uranium and its derivatives, this phenomenon should not significantly increase the natural radiation level in mining areas.

A more significant problem is mechanical and chemical ore processing. Waste from this process is made up of radioactive isotopes, accumulated in the ore for millions of years, as a result of uranium decay. The best solution is waste deposition in special dumps, rendering the isotope migration difficult. We must note that these activities will not lead to any increase in the amount of radioactive elements in the lithosphere, and the only risk is related to their relocation or easier migration to water and air. A properly designed radioactive waste depository (using mining pits whenever possible) will ensure permanent neutralisation of natural radioactive isotopes in a manner that is not much different from their original state. It must be emphasised that migration of radium, radon, and other products of uranium decay is a natural process, and radium and radon waters are commonly found in the lithosphere and sometimes used for medical purposes.

In case of surface mining, environmental impact of the mining process itself is more significant, but the increase is related with the nature of this sort of mining, causing significant changes in the landscape, regardless of the type of mineral.

In case of application of underground leaching method (ISL) with acidic or alkaline solutions pumped through drill holes, most environmental changes are localised in rock medium, at the depth from several tens to several hundreds of meters. This extraction method requires natural hydrogeological insulation around the mineralised bed. Therefore, risk of contamination of adjacent water-bearing layers is small. With such a method, a part of chemical process takes place in natural rock medium and only uranium recovery from the leaching solution takes place in a processing plant. Some amounts of radium, radon and other undesirable elements pass into the solution, but in favourable geological conditions, the process may be limited.

Uranium mining and pre-processing takes place in areas where the quantities of radioactive elements are naturally higher, and their negative impact on the environment should not be exaggerated. For instance, average uranium content in granite is 3-10 grams per tonne, which means that in the area of one hectare, in ten-meter layer of this rock, there are 600-2000 kg of uranium and the entire set of accumulated decay products. In case of natural phosphorite occurrences, average uranium content is ca, 100 grams per tonne, which in turn means that uranium content in 10-meter layer in one hectare area reaches 20 tonnes. In case of phosphorites commonly processed into chemical fertilizers, uranium recovery would be a process improving environment.

The isotope enrichment process taking place after the "yellow cake" stage is a source of significant amount of depleted uranium, often treated as waste. This uranium is not different in terms of its radioactivity from natural uranium. Due to high density, it is sometimes used as cores of armour piercing shells and weights in industry. Coloured uranium salts are used for colouring ceramic products gold. With common introduction of breeder reactors, this uranium may be used as nuclear fuel.

4.3.1.3 Fuel campaigns and cycle of the reactor

A 3rd generation reactor of nuclear power unit with electric power of ca. 1000 MW_e uses less than **20 tonnes** of nuclear fuel per year - i.e. one train car per year. For comparison purposes: in a boiler of thermal power station unit with the same power, fuelled with hard coal, at least ca. 3 million tonnes of coal must be combusted per year (daily average ca. 160 cars)

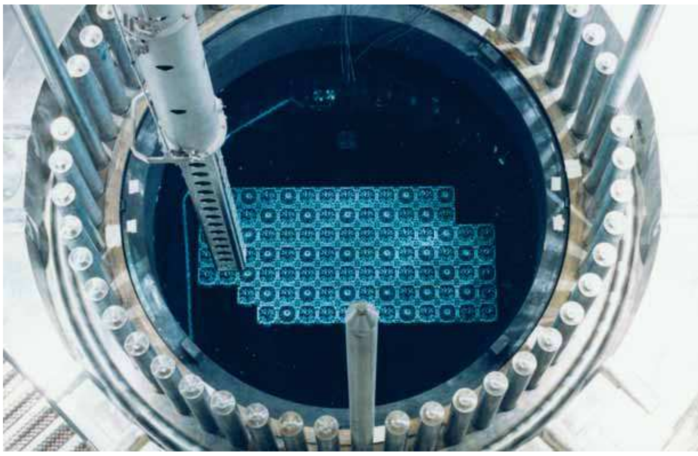


Fig. 4.3.5 Reloading nuclear fuel [AREVA: U.S. EPR Nuclear Plant]

In nuclear tank reactors - like light-water reactors, which will probably be erected in Poland - nuclear fuel is reloaded **periodically**, with the reactor *off-line*, after cooling the reactor, dismounting the tank lid and structures inside the tank above the reactor core, and then flooding the upper part of reactor shaft with water. Fuel reloading is performed with a special reloading machine, under a several-meter water layer, forming a shield against radiation. During fuel reloading, typically taking several days to one month, current overhaul of the nuclear unit is simultaneously performed. The period of fuel combustion in the reactor during operation between fuel reloading is called **fuel campaign**.

III and III+ generation reactors were designed to enable flexible planning of fuel campaigns, lasting from 12 to 24 months[162] and obtaining mean burn-up of nuclear fuel unloaded from the reactor at the level of ca. 60 MW·d/kgU. Depending on enrichment, nuclear fuel remains in the reactor from 3 to 5 years. During this time, most of the fissile U-235 is subject to "burn-up" (however, there still remains ca. 1%), and from nuclear transformations of U-238 and U-235 transuranic element isotopes are created, of which plutonium is particularly significant (fissile isotopes Pu-239 and Pu-241). At the end of a fuel campaign, ca. 35% of energy is created from fissions of plutonium isotopes, and their content in the fuel reaches ca. 1%. Other transuranic elements are also created, significant from the perspective of processing burnt-up fuel and disposal of radioactive waste, the so-called rare actinides (isotopes of neptunium, americium and curium)[163], as they are long-lived radioactive isotopes. The fission creates isotopes, mostly radioactive, called "fission products" (specific "ash" from fuel burn-up), some of the isotopes have long radioactive decay period (long-lived fission products)[164].

During reloading - depending on strategies of nuclear fuel management – $^1/_3$ or $^1/_4$ of the most burnt-up fuel sets (assemblies) are reloaded, which were in the reactor core for 3 subsequent campaigns. Other assemblies are properly relocated in order to obtain core arrangement providing meeting various physical (neutron-physical characteristics) and thermal and flow restrictions - resulting from safety requirements, and at the same time to generate the quantity of electric power planned for the period of a given fuel campaign (at the lowest possible fuel cost). **The most typical** for III and III+ generation reactors are **18-month campaigns**, where during reloading $^1/_3$ of the (most burnt-up) fuel assemblies are replaced with fresh fuel, and the remaining $^2/_3$ of the assemblies are rearranged. Presently, core loadings are designed with low neutron leakage *(low-leakage core)* – see Fig. 4.3.6.

The advantage of such core configurations - characterised with high gradient of radial power distribution - is possibility of obtaining higher fuel burn-up and simultaneously reducing neutron radiation of the structural elements of the reactor (pressure tank and certain structures inside the tank)[165]. However, a significant safety restriction is relatively high power density in the middle reactor core zones.

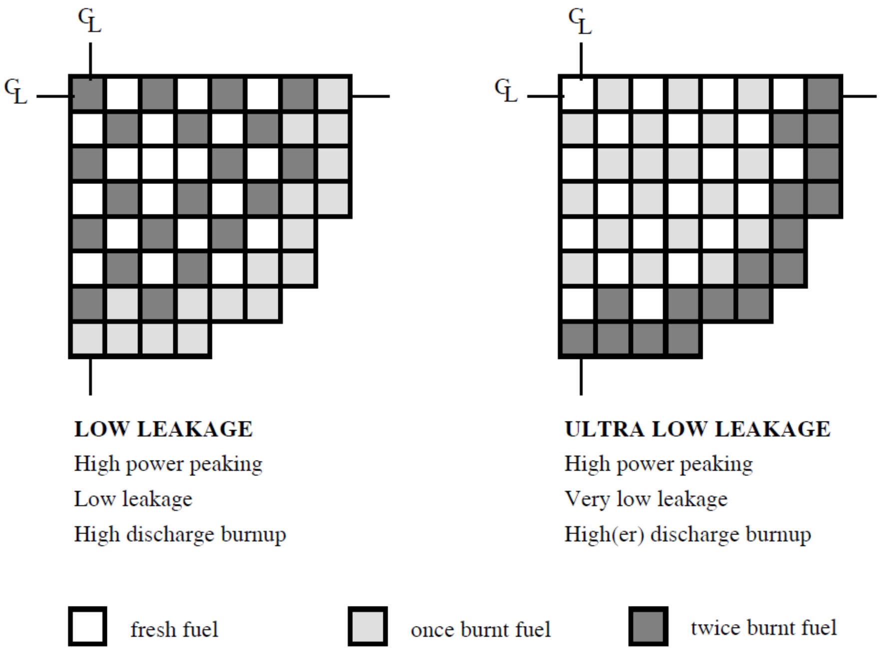


Fig. 4.3.6. Diagrams of reactor core configuration with low neutron leakage (configuration of ¼ of the core was presented)

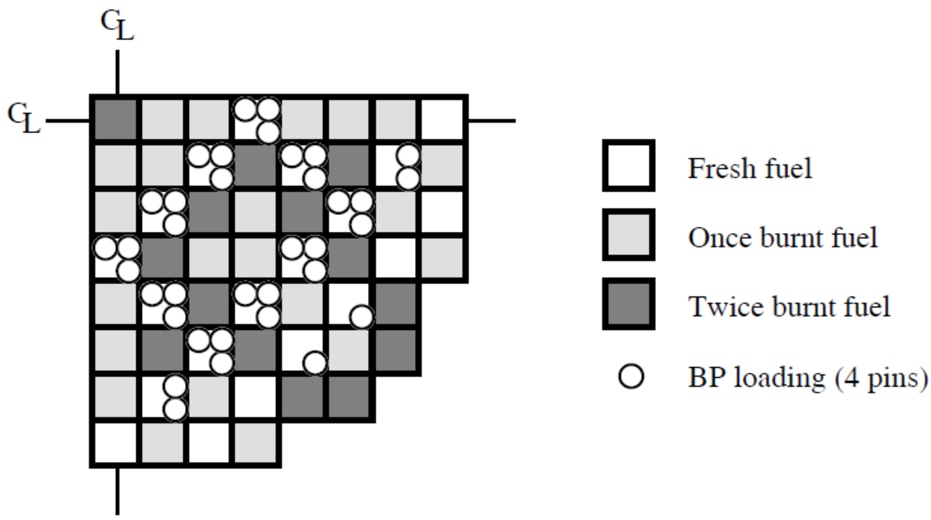


Fig. 4.3.7 Model core loading with BP – burnable poisons

Recently, in order to compensate high reactivity excess in power reactors[166] in the beginning of fuel campaign, the so-called "burnable poisons" were introduced - materials absorbing neutrons (usually gadolinium in form of Gd_2O_3) contained in fresh fuel assemblies (from several to several dozens of rods containing burnable poisons per fuel assembly). In the duration of the campaign, as a result of neutron absorption, the "poisons" are gradually burnt-up - i.e. their negative reactivity effect decreases. Due to application of burnable poisons, the highest local thermal loads (power density) in the core may also be decreased, (see Fig. 4.3.7).

4.3.1.4 Nuclear fuel management

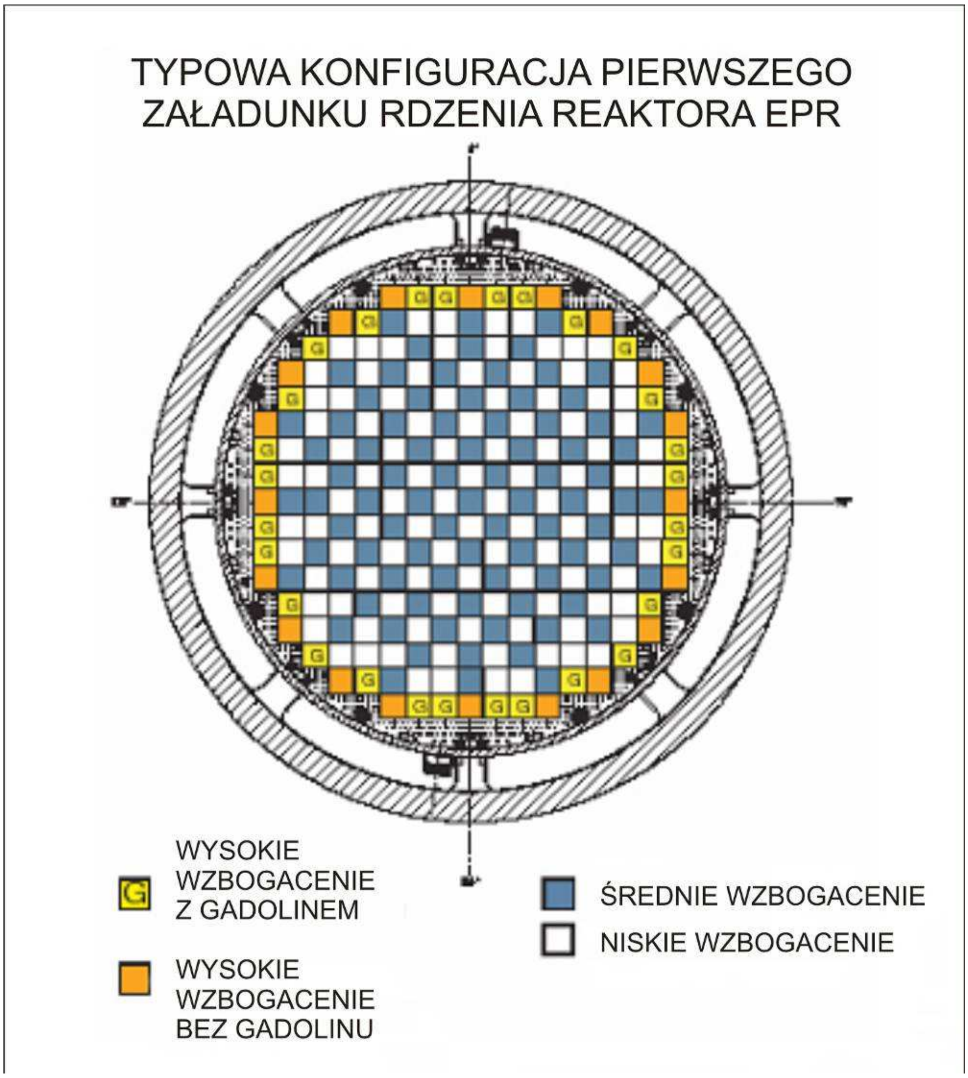


Fig. 4.3.8 Typical configuration of first charging of the EPR reactor core (24 fuel assemblies) [AREVA]

[TYPOWA KONFIGURACJA PIERWSZEGO ZAŁADUNKU RDZENIA REAKTORA EPR – TYPICAL CONFIGURATION OF FIRST CHARGING OF THE EPR CORE
Wysokie wzbogacenie z gadolinem – High enrichment with gadolinium
Wysokie wzbogacenie bez gadolinu – High enrichment without gadolinium
Średnie wzbogacenie – Medium enrichment
Niskie wzbogacenie – Low enrichment]

Economically optimal designing subsequent fuel campaigns (minimising fuel costs for specific amount of energy planned for generation), meeting all **requirements and physical , thermal and flow and material constraints** is a very complicated and hard to solve mathematical issue. As a result of optimisation calculations, a number of necessary fresh fuel assemblies of individual types is specified (enrichment, content of burnable poisons, MOX fuel), as well as core configuration for a specific fuel campaign (places of charging fresh fuel assemblies and manner of rearrangement of partially burnt-up assemblies).

The reactor core contains several hundred fuel assemblies of various enrichment and burn-up, distributed in a regular grid of cells - square in Western reactors or hexagonal - in Russian reactors (whereas identical-enrichment assemblies may be burnt-up to a different extent, depending on their locations in the core during campaigns).

Due to core symmetry, calculations are made for the section - in Western reactors: 90° (a fourth of the core), in Russian reactors: 60° (1/6 of the core). Still, the number of possible permutations of fuel assembly locations is huge (may even reach 10^{100}). Thus, it is a difficult discrete optimisation issue, requiring application of special advanced algorithms, based rather on **stochastic optimisation methods** (such as: simulated annealing method, genetic algorithms, pseudo-heuristic methods) than on more conventional methods (such as: linear, square or dynamic programming). There are commercial software packages for optimisation of nuclear fuel management, in particular based on stochastic methods[167].

Planning fuel campaigns with optimising calculations must be performed on a rolling basis with at least five years in advance (on the basis of long-term plans for electricity production). Results of the planning will provide data necessary to place orders for nuclear fuel. Since production of nuclear fuel for potential nuclear power plants is not planned in Poland in a foreseeable time perspective, it should be assumed that ready-to-charge fuel assemblies will be imported.

The most apparent and probable nuclear fuel suppliers are obviously suppliers of reactors of a given type (as a standard, the first core loading is supplied in terms of a "turnkey" contract for construction of a nuclear power plant). However, it is also possible to order fuel from other supplier (although sometimes it may involve some technological problems). For instance, for the Czech nuclear power plant Temelin[168] and South Ukrainian nuclear power plant[169], equipped with Russian reactors (pressurized water reactor type WWER-1000) fuel is supplied by Westinghouse, and for British nuclear power plants with gas graphite reactors (AGR) the fuel is recently supplied by Russian company TVEL[170].

Supply of ready-to-charge fuel assemblies is provide by all leading global nuclear technology suppliers, including French AREVA and American companies: Westinghouse (a part of Toshiba Corporation) and General Electric, and Canadian AECL. Nuclear fuel is also manufactured by British BNFL and Russian TVEL. Currently dominating global position in the nuclear fuel market is occupied by the following 3 groups (satisfying ca. 80% of demand): French **AREVA**, American **Westinghouse** (Toshiba Corporation) + Spanish **Anusa**, and American-Japanese **BNF Genusa** (GE + Toshiba + Hitachi). The highest (ca. 40%) contribution in supplies of fuel for light-water reactors (excluding WWER of Russian construction) is provided by AREVA, supplying fuel to 134 of 308 PWR and BWR reactors operating globally, of which $^{2}/_{3}$ are reactors designed by AREVA (formerly Framatome), and the remaining $^{1}/_{3}$ – by its competitors.[171]

Fig. 4.3.9 Fresh nuclear fuel storage in Finnish nuclear power plant Loviisa. [Imatran Voima Oy: Loviisa Power Plant]

If necessary, it is possible to accumulate a fresh fuel supply in a nuclear power plant for many years. The only limitation is current capacity of fresh fuel storage, which may be expanded if needed.

Fresh fuel is transported (by water, rail, road) in special containers, of which each contains 2 or 4 fuel assemblies. Container structure provides protection against mechanical damage, as well as subcriticality (i.e. it protects against accidental creation of critical mass) in case of falling into water as a result of transport accident. A fresh fuel storage is also designed to exclude creation of critical mass in case of flooding with water.

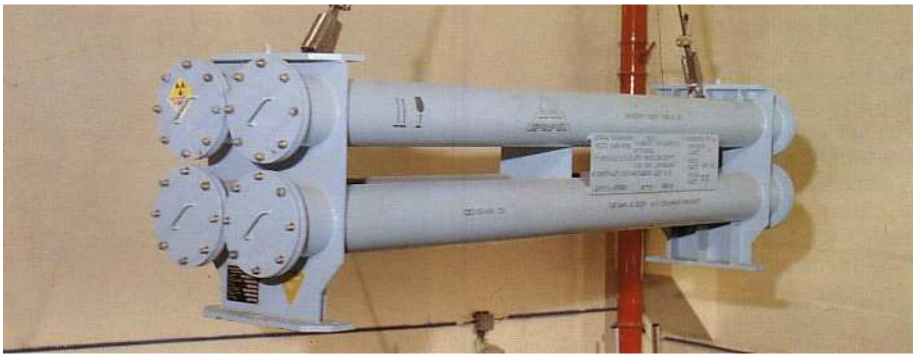


Fig. 4.3.10 Fresh fuel transport container to pressurized water reactors of Russian construction, type WWER-440.[Imatran Voima Oy: Loviisa Power Plant]

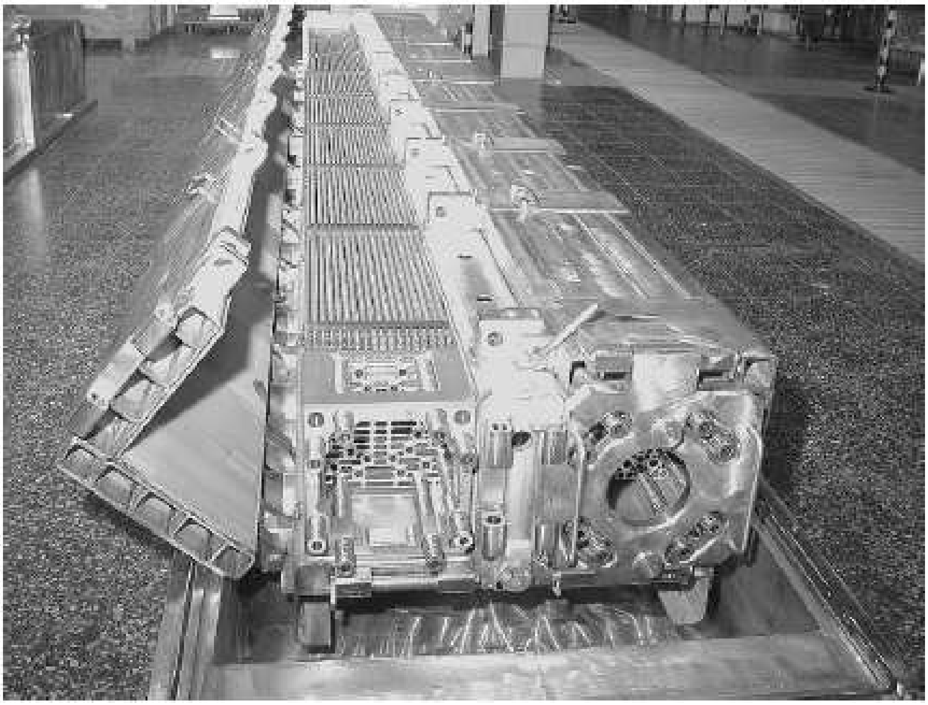


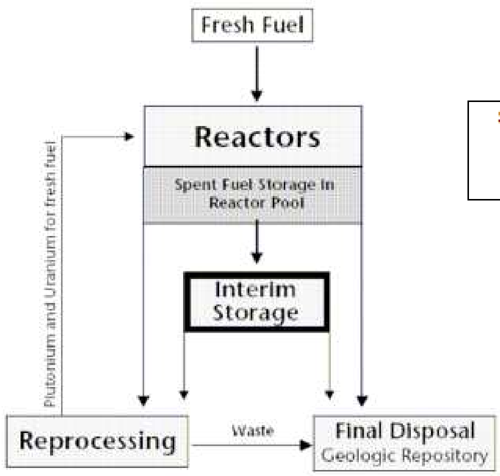
Fig. 4.3.11 ANF-18 type container for transporting fresh fuel to PWR reactors, loaded with two fuel assemblies.[172]

Ionising radiation emitted by fresh uranium fuel is insignificantly small, so no radiation shields are necessary. However, uranium-plutonium MOX type fuel is much more radioactive and therefore it must be transported and stored in shielded containers. Transport of fuel, both fresh and burnt-up, is subject to physical protection, which is required by International Convention of Physical Protection of Nuclear Materials.[173]

4.3.1.5 Handling burnt-up nuclear fuel

Burnt-up fuel discharged from the reactor is placed in **burnt-up fuel tank** filled with water, located in the auxiliary reactor building or fuel building (adjacent to the reactor containment), where it remains for at least 3 years (usually 7-10 years). During this time, it is cooled down and de-activated by tens of per cent. Then, if spent fuel is not reprocessed, it is moved to **the interim storage facility** (usually located on site) - wet or dry,[174] where it can be stored for additional 40-50 years.

The next step is deposition of spent fuel in **the repository in geological formations,** for its periodical *(reversible geological disposal)* or final storage *(final geological repository)* - see Fig. 4.3.12.



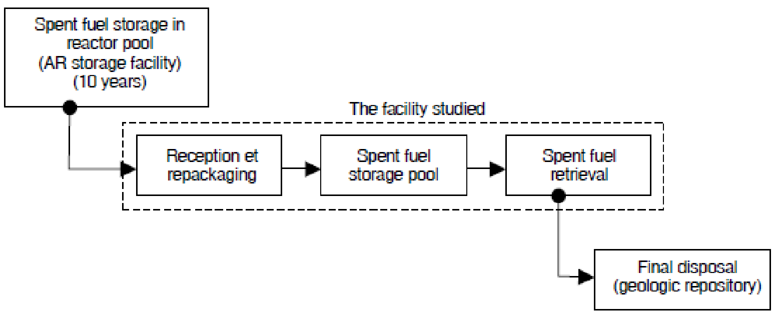


Fig. 4.3.12 Variants of handling burnt-up nuclear fuel [AREVA][175].

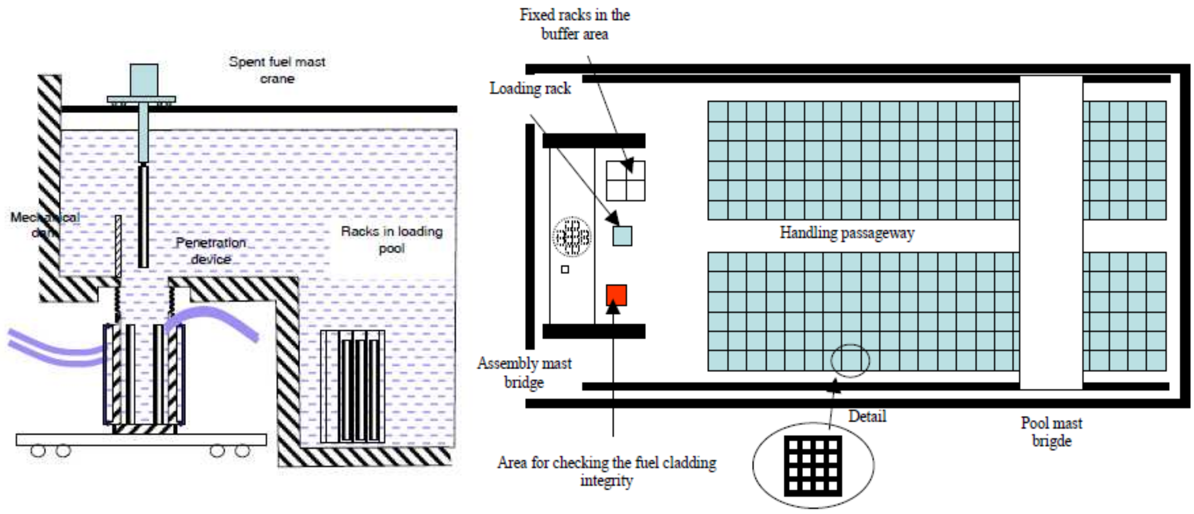


Fig. 4.3.13 Construction diagram of a wet interim storage facility for burnt-up fuel, estimated for 3400 fuel assemblies and 100 years of use [AREVA: UK EPR]

Spent fuel removed from the reactor is highly radioactive and emits heat generated as a result of radioactive decay - mainly fission products and rare actinides. The vast majority of radioactivity of the burnt-up fuel is related to radioactive decay of short and medium-lived fission products, most of which are subject to decay within several years after fuel discharge from the reactor.

As it can be seen in the diagram (Fig. 8.3.14) after approximately 4 years, the activity of fission products contained in spent nuclear fuel declines by 4 times. After about 10 years, the fuel activity is mainly related to radioactive decay of two isotopes: caesium Cs-137 and strontium Sr-90. After ca. 300 years, in case of processing the spent fuel combined with recycling of transuranic elements, activity of fission products decreases 1000-fold and they become practically harmless since [Hannum et al].[176]

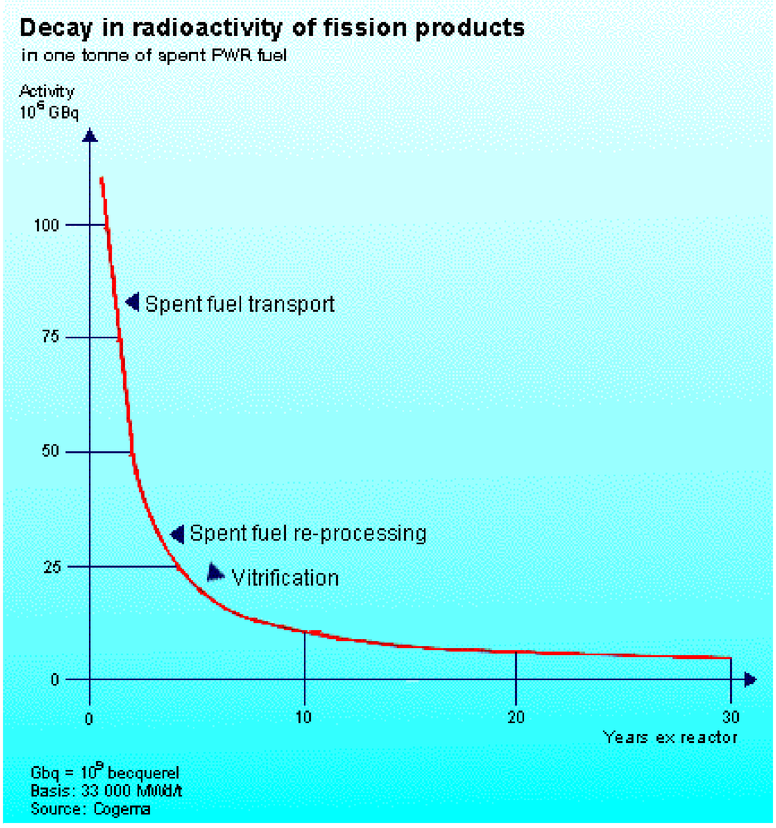


Fig. 4.3.14 Decrease in activity of fission products contained in 1 t of spent fuel PWR (spent fuel transport, reprocessing, vitrification)

Isotopes of transuranic elements (plutonium and rare actinides - including especially americium), although they comprise only about 1% of the spent fuel mass, due to their long-livedness (half-lives reaching tens of thousands years) and high radiotoxicity - constitute a significant problem in terms of long-term storage of spent fuel. It is necessary to provide removal of heat generated due to radioactive decay and its isolation from environment for the period of 10 thousand years. Therefore, plutonium and other actinides should be separated from fission products designated for final repository and "disposed of". The easiest and most effective "disposal" method is using them in reactors as nuclear fuel - then, in the fission process they transform into fission products or, as a result of neutron radioactive capture[177] and further radioactive transformations they transform into short-lived or stable isotopes.

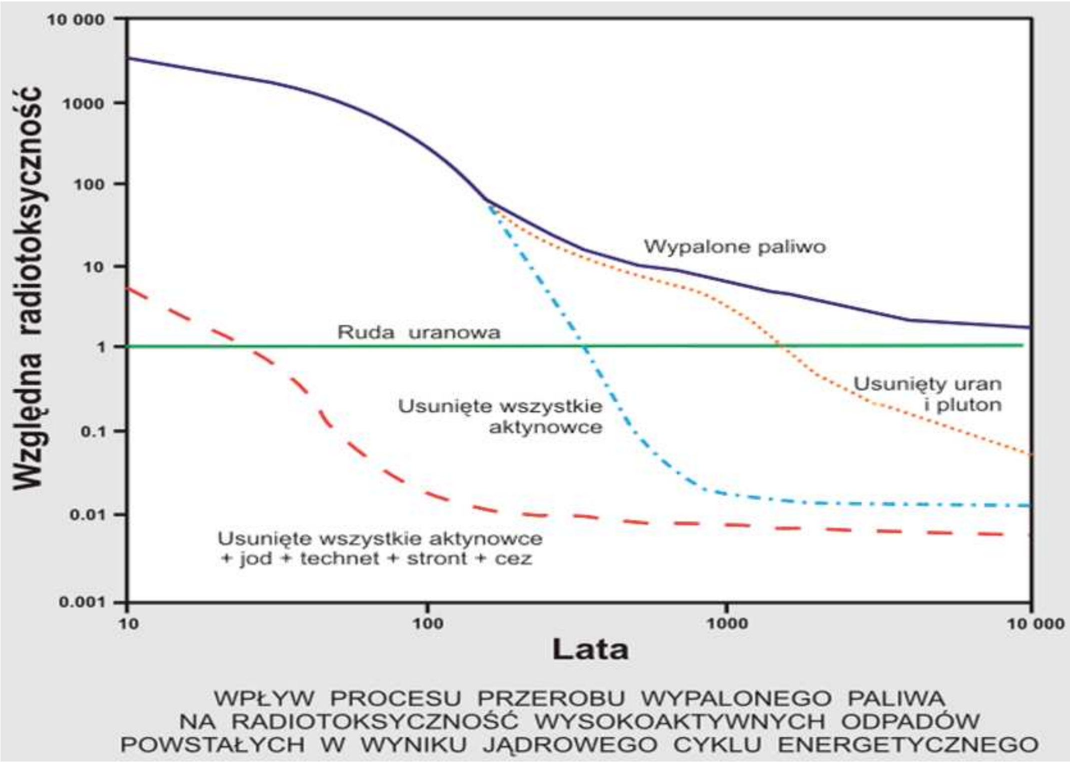


Fig. 4.3.15 Impact of spent fuel reprocessing on radiotoxicity of waste generated in the fuel cycle.[178]

[Względna radiotoksyczność – Relative radiotoxicity
Wypalone paliwo – Spent fuel
Ruda uranowa – Uranium ore
Usunięte wszystkie aktynowce – All actinides removed
Usunięty uran i pluton – Uranium and plutonium removed
Usunięte wszystkie aktynowce + jod + technet + stront + cez - All actinides removed + iodine + technetium + strontium + caesium
Lata – Years
WPŁYW PROCESU PRZEROBU WYPALONEGO PALIWA NA RADIOTOKSYCZNOŚĆ WYSOKOAKTYWNYCH ODPADÓW POWSTAŁYCH W WYNIKU JĄDROWEGO CYKLU ENERGETYCZNEGO – IMPACT OF SPENT FUEL REPROCESSING ON RADIOTOXICITY OF HIGH-LEVEL WASTE GENERATED IN NUCLEAR POWER CYCLE]

Activity of "light" radioactive waste (i.e. without plutonium and other actinides), after approximately 100 years decreases much faster than activity of the spent fuel, and after ca. 300-400 years it reaches the value below uranium ore activity (see Fig. 4.3.15). In this case - with elimination of plutonium and rare actinides - the required period of radioactive waste isolation from environment is decreased to ca. 500 years (see: Fig. 4.3.15).
Spent fuel may be reprocessed even after approximately 3 years from discharge from the reactor. In practice, fuel reprocessing takes place 5 to 25 years after discharge.[179] Early processing of spent fuel is economically profitable, since the duration of fuel cycle is shortened (fuel circulation is faster), but it involves additional difficulties caused by large amount of generated heat and high fuel activity. On the other hand, after a longer period of spent fuel storage, it generates more americium Am-241 isotope (as a result of decay of β isotope of Pu-241 with half-life of 13 years), which creates an additional problem in terms of manipulation with MOX fuel (increases exposure to gamma radiation).

Fig. 4.3.16 illustrates the transformations of fuel isotopes during burn-up of standard uranium fuel in form of uranium dioxide (UO_2), with 4% enrichment in isotope U235, in a typical light water reactor (LWR).[180]

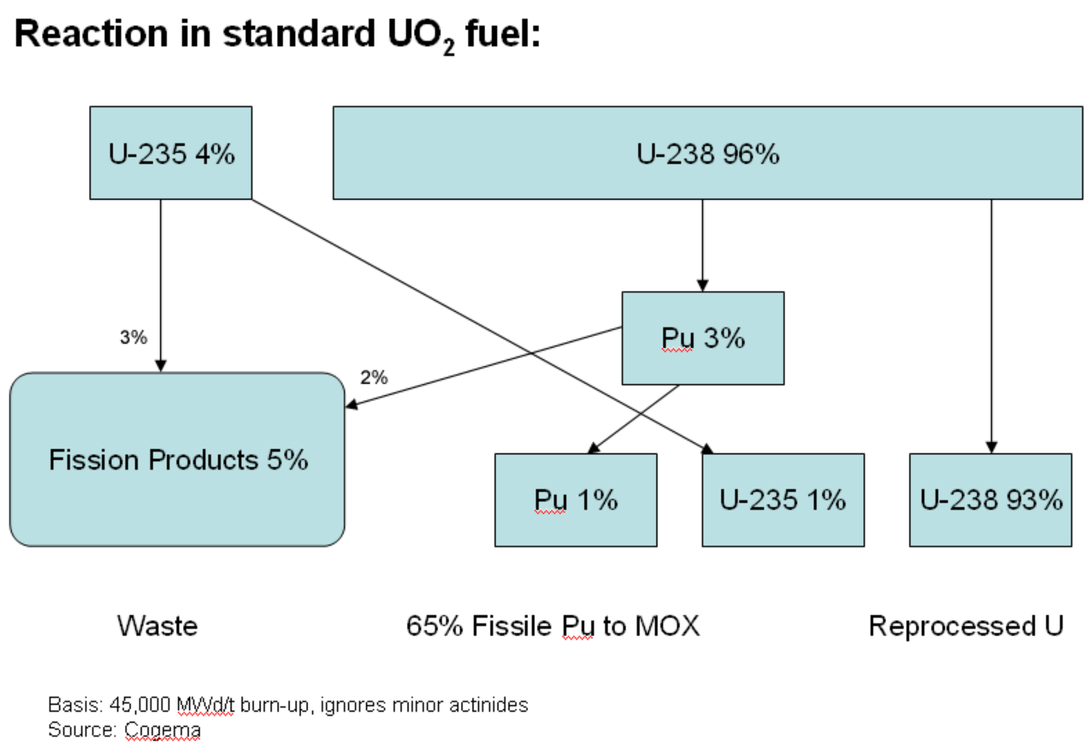


Fig. 4.3.16 Diagram of fuel isotope transformations during burn-up of uranium fuel in PWR

As it is shown in this diagram, in the spent nuclear fuel ca. 93% U-238, 1% U-235 remains (more than in natural uranium), 1% Pu (of which ca. 65% are fissile isotopes: Pu-239 and Pu-241), and ca. 5% are *fission products*. In spent fuel, approximately 200 various fission products are created, in fact they are only "ash" created as a result of nuclear fuel burn-up. Among fission products, approximately 2.9% are stable isotopes; 0.3% caesium and strontium; 0.1% iodine and technetium; and 0.1% long-lived fission products. The content of rare actinides is about 0,1%[181].

Every year, spent fuel is discharged from a typical large LWR with power of 1000 MWe (in the amount of ca. 30 Mg), therefore it contains ca. 300 kg U-235 and plutonium. Fissile isotopes, as well as "fertile"[182] U-238, may be recovered in *reprocessing* and reused in power reactors (recycling of uranium and plutonium).

If fuel is used only once in a thermal reactor(*once-through cycle*), the energy-generating potential of fuel materials is utilised to a very limited extent. Reprocessing spent fuel with recycling of uranium and plutonium - in particular for generation of uranium-plutonium fuel (MOX) allows for increased application of fuel energy potential and saving ca. 30% of fresh uranium [Hannum et al].

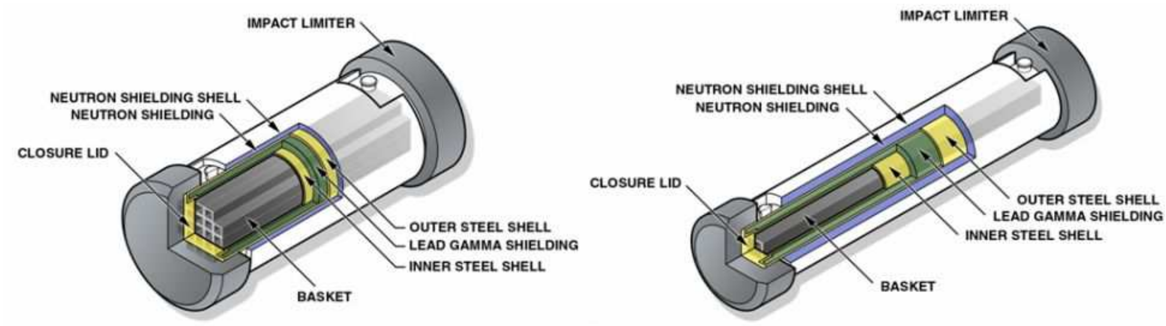


Fig. 4.3.17 Structure of a typical container for transport of spent fuel: on the left - railway container, on the right - road container.

Fuel reprocessing also allows significant reduction of volume of highly active waste. According to the data from AREVA[183] volume of highly active waste may be reduced even 4-5 times, and radiotoxicity of long-lived isotopes approximately 10 times. Taking into account saving of "fresh" uranium - costs of MOX fuel (0,177 €c/kWh) are only about 5% higher than costs of standard uranium fuel (0.168 €c/kWh). With increase of uranium concentrate prices, reprocessing spent fuel will become more profitable.

Spent nuclear fuel is transported in special containers that ensure protection from radiation and absorption of heat, meeting the strict safety requirements specified in MAEA[184] (Fig. 4.3.17).

4.3.1.6 Storage of radioactive waste

As it results from "Programme of Polish Nuclear Power Engineering" (point 14.2 and 14.3), currently studies are conducted concerning radioactive waste management in Poland, coordinated by the Team for development of *National plan of handling radioactive waste and spent nuclear fuel*. The team has already started the works and commissioned analyses concerning estimation of real costs of application of various radioactive waste and spent nuclear fuel management methods. These analyses, forming a basis for recommendations regarding an approach to spent nuclear fuel (whether spent fuel should be processed or, ultimately, fully stored in Poland), taking into account costs and advantages of application of each of the two solutions.

The issue of spent fuel from research reactors was solved by means of concluding agreements with the USA and Russia, which provide disposal of highly radioactive fuel from research reactors to Russia. However, development of nuclear power engineering in Poland in the near future poses an obligation to develop a strategy for radioactive waste management, whose main objective will be to specify a manner of handling radioactive waste derived from various activities and to suggest an approach to spent nuclear fuel and assumptions and recommendations concerning further works in this field.

Activities of the aforementioned Team do not refer directly to construction of a deep underground repository for high-activity waste and spent fuel. As it results from experiences of other countries, the need to build such a repository will occur about 30-40 years from commissioning the first nuclear power plant - that is no sooner than around 2050. Until then, spent nuclear fuel (unless it is reprocessed earlier) will be kept in water pools next to the reactor (for 10 years) and then moved to a wet or dry interim storage facility on site, where it can be stored for 40-50 years[185]. It must be emphasised that also in case of reprocessing spent fuel, the problem of high-activity waste storage will not disappear - however quantity and activity of the waste directed to repository will be decreased multiple times and required time of its isolation from environment will shorten drastically (see: point 0).

The radioactive waste management plan should be adopted by the Council of Ministers in 2011, following the adoption of the Polish Nuclear Programme.

The most urgent task in terms of radioactive waste management is building a new domestic repository of low and mid-activity waste, needed due to filling up of KSOP in Różan (expected in ca. 2020-2022).

For the next 2 years, intensive works on selecting location for the new domestic repository of low and mid-activity waste will be conducted, as a result of which 3 most advantageous locations will be chosen, from among which - after detailed research and analysis in 2013 - the most optimal location will be selected. Subsequently, design and construction works will be conducted, so that in 2020 at the latest the new repository cab ne put into service. This is important due to the fact that the introduction of nuclear power will lead to magnification of the scale of activities in terms of low and medium activity waste disposal.

Medium and low-activity waste will be processed and conditioned in individual nuclear power plants (decrease in volume, solidification and chemical binding, packing) to the form required in transport and storage - according to the provisions in force. Radioactive waste so processed may also be temporarily stored in surface repositories on site.

Types of radioactive waste

High-activity radioactive waste from a nuclear power plant is mainly spent nuclear fuel, consisting of ca. **99%** of entire waste activity, or waste from fuel processing. The remaining ca. **1%** of activity is contained in **medium and low-activity** waste. The following are included among them: filter inserts from contaminated process media and air treatment systems, sewage from decontamination of devices, rooms, showers and protective clothing laundry, used protective garments and certain decommissioned devices. Medium and low-activity waste is stored similarly to medical and industrial waste, as they do not differ much. A technical and economic problem is mainly the spent fuel, which contains high-activity and long-lived radioactive isotopes. Furthermore, with disassembly of a nuclear power plant, it is necessary to secure some devices and materials which constitute radioactive waste.

The time needed for decreasing activity of radioactive waste contained in spent fuel depends on whether we apply recycling or separation of fissile materials and their reuse as fuel in the reactor.

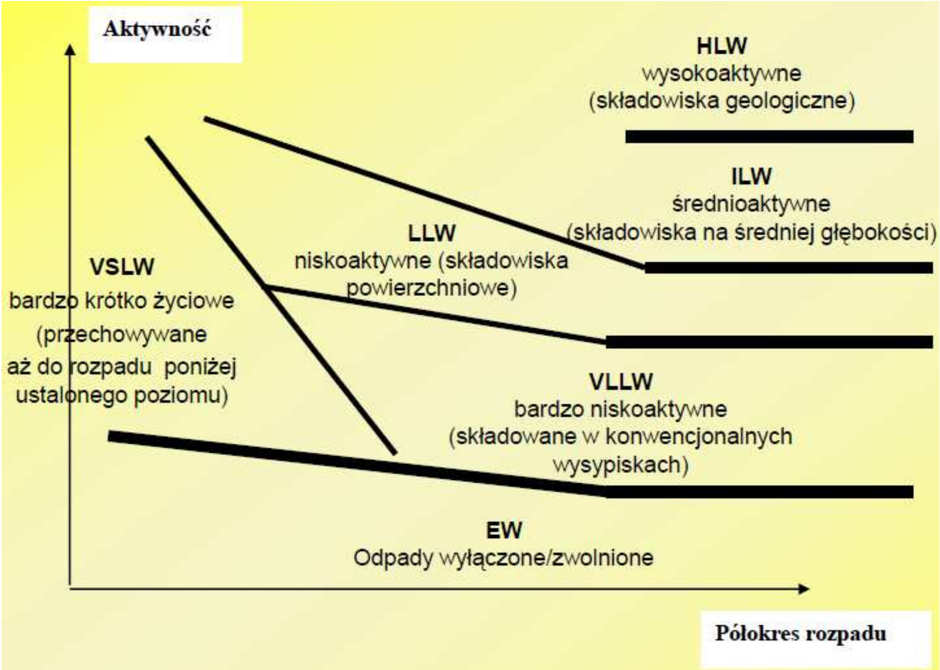


Fig. 4.3.18 Half-life periods of various types of radioactive waste

[Aktywność – Activity
Półokres rozpadu – Half-life
Wysokoaktywne (składowiska geologiczne) – High-level waste (geological repositories)
Średnioaktywne (składowiska na średniej głębokości) – Intermediate-level waste (repositories at medium depth)
Niskoaktywne (składowiska powierzchniowe) – Low-level waste (surface repositories)
Bardzo niskoaktywne (składowane w konwencjonalnych wysypiskach) – Very low-level waste (stored in conventional landfills)
Odpady wyłączone/zwolnione – Excluded waste
Bardzo krótko życiowe (przechowywane aż do rozpadu poniżej ustalonego poziomu) – Very short-lived waste (stored until decay below established level)

Radioactive waste from a nuclear power plant is relatively **small in volume**, which greatly facilitates careful preservation. Nuclear power plant with capacity of 1000 MW_e consumes up to 20 Mg of uranium per year (in form of UO_2), generating radioactive waste of total volume **ca. 180 m^3**, including:

- ca. **3 m^3** of high-activity waste - after processing spent fuel (or ca. 13 m^3 of unprocessed spent fuel),
- ca. **10-22 m^3** of medium-activity waste,
- ca.**155-160 m^3** of low-activity waste,

4.3.1.7 Transport of radioactive materials

Radioactive materials are transported by air, railway, road and sea[186] (Fig. 4.3.19, Fig. 4.3.20). Most transported shipments contain very small amounts of radioactive substances. However, one always must consider the risk of exposing people. In order to minimise this risk, the UN Social and Economic Council authorised the International Agency of Atomic Energy (IAAE) to prepare and recommend provisions and standards concerning safe transport of radioactive materials.

Fig. 4.3.19 Loading a container with spent fuel on a ship, Japan (photo John Mairs/IAEA)

Fig. 4.3.20 Transport of radioactive waste by road in Germany (photo Philipp Schulze)

Radioactive materials are transported in various packaging, guaranteeing integrity of shipment and radiation protection specified in the regulations.
Type of radioactive material packaging mainly depends on type of the material, its volume, amount, physical form and activity. Therefore, individual packaging types must be constructed differently and have different resistance and material parameters. Some of them prior to being permitted for use are subject to very strict tests: mechanical (squeezing, fall from height), thermal (resistance to increased temperature), immersion etc.

B type packaging (Fig. 4.3.21)

Type B is characterised by increased mechanical and thermal resistance, because it has to provide tightness and protection of the load even in serious transport accidents. They are used for shipping most radioactive materials (spent nuclear fuel, radioactive sources of very high activity, e.g. used in telegamma therapy or high-activity radioactive waste). B-type packaging is subject to particularly strict mechanical, thermal and immersion tests. Furthermore, they must be authorised, i.e. they must obtain a certificate issued by competent nuclear inspection and radiological protection bodies in a given country.

A type packaging (Fig. 4.3.21)

This packaging must provide load tightness and protection in case of smaller transport accidents. They are also subject to resistance tests, but not as strict as in case of B type packaging; they must be resistant to rain and potential fall from a vehicle. It is however assumed that the packaging may be damaged in transport and its content may be released. Therefore, regulations specify maximum amount of radioactive substances which may be transported in this type of packaging. Risk of irradiation or contamination - even in case of releasing such substance to environment - is very small.

Type A

Type B

Fig. 4.3.21 Containers for transport of radioactive waste type B and A

Transport packaging of radioactive waste must meet rigorous international requirements specified in IAEA regulations (IAEA Safety Standards. Publ. 1255 Safety Requirements TS-R-1, Regulations for the Safe Transport of Radioactive Materials, 2005 Edition, IAEA, Vienna, 2005.) - depending on waste category.

Containers with radioactive waste are designed to provide safety not only during regular transport but also after failures, and design failures are selected to be more serious than failures which can be expected on the basis of experience and pessimistic forecasts.

B type containers for road or water transport of spent fuel must be resistant to all possible transport accidents. Test series for B and C type containers includes the following tests:

- Impact of a train at full speed against concrete dam
- Impact of a train against the container side
- Fall of B container from 9 m to hard concrete surface
- Resistance to piercing with a metal rod
- Fire

- Sinking the container.

The risk associated with accidents during transport of spent fuel and radioactive waste is well known and low. High level of safety was achieved due to the following factors:

- Strict safety requirements in designing, construction, tests and operation of transport containers, specified in international regulations, commonly recognised as mandatory.
- Container tests at a full 1:1 scale in the conditions of most serious failures.
- Increasingly improved computational and computer models of packaging behaviour in emergency.
- Reconstructions of emergencies during transport accidents, which did not refer to radioactive material, in order to check behaviour of protection containers in such situations.
- Physical protection of transported nuclear materials.

By observing these safety standards, no radiological threats have occurred so far for the society or environment, which would be caused by failures of shipments with radioactive materials. Statistics show that transport of radioactive materials has been performed successfully for ca. 60 years, and currently about 50 million of radioactive shipments are transported per year. Nobody has lost their life or health due to release or radiation of transported radioactive materials.

Storage of radioactive waste

Proper handling of radioactive waste may effectively protect people and environment against harmful impact of emitted ionising radiation. Therefore, during disposal and storage of waste, certain principles are in effect:

- minimising the amount of generated waste;
- proper sorting (separation of liquid, waste, waste for break-up, waste for compaction, incineration etc.);
- decreasing volume (compacting, evaporation etc.);
- solidification and packing to obtain chemical and physical stability;
- waste storage in locations with proper geological structure and application of all possible technologies and barriers which effectively isolate the waste from people and environment [Włodarski][187].

Radioactive waste is deposited depending on its activity and radioactive half-life period in surface waste sites (low-activity and short-lived) and underground repositories (medium and high-activity) (Fig. 4.3.22).

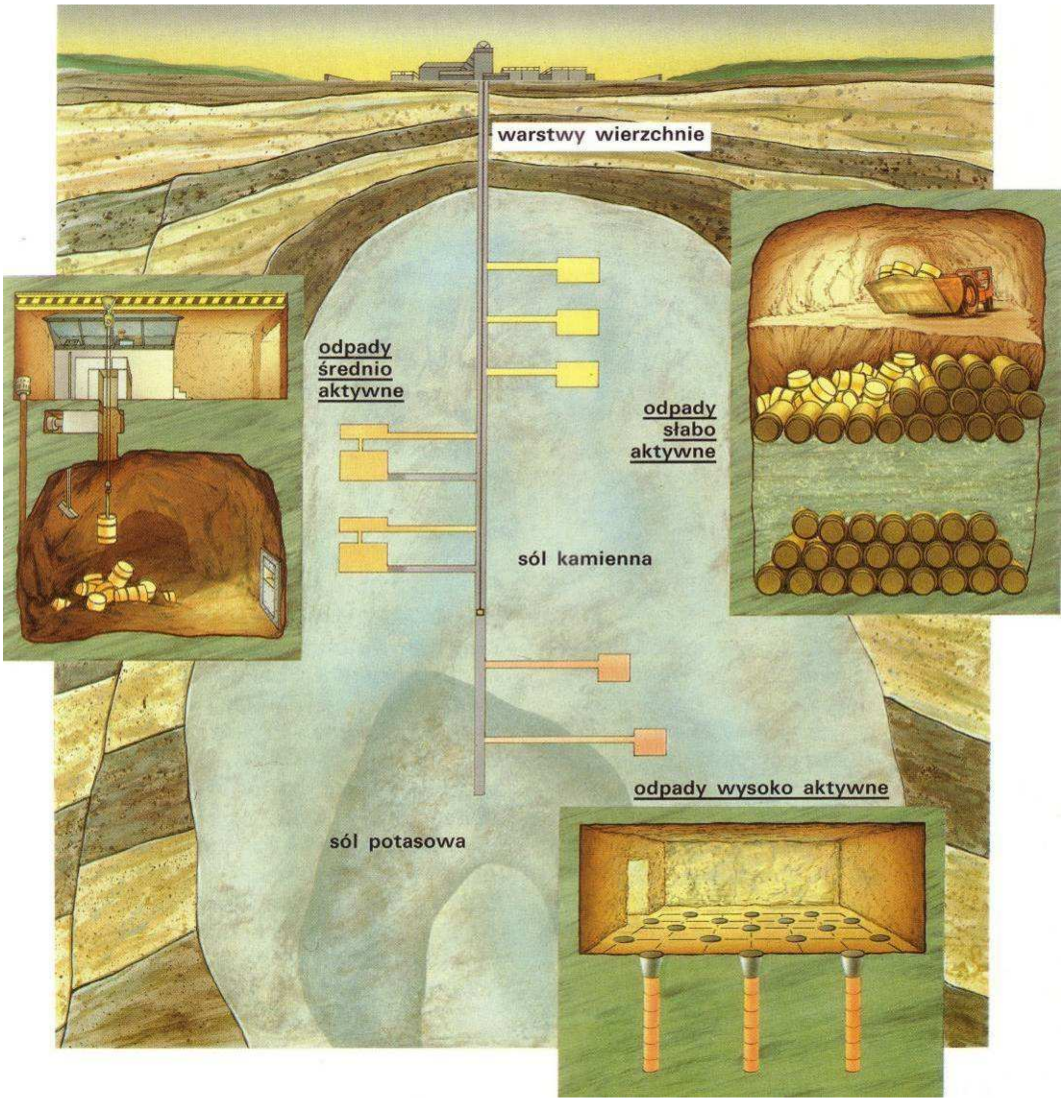


Fig. 4.3.22 Diagram of underground radioactive waste storage [Erich Übelacker: „Nuclear energy"]

[Warstwy wierzchnie – Surface layers
Odpady średnioaktywne – Intermediate-level waste
Odpady słaboaktywne – Low-level waste
Sól kamienna – Rock salt
Odpady wysokoaktywne – High-level waste
Sól potasowa – potassium salt]

Costs of disposal of radioactive waste only slightly affect the price of electricity from nuclear power plants, as they are ca. 1% of total electricity generation costs - it mainly results from economic analyses performed by the American Massachusetts Institute of Technology (MIT 2009[188]).

High Level Waste

Modern approach to the fuel cycle is the reason for the fact that with increasing frequency spent fuel is not treated as burdensome high level waste, but as a precious raw material for reprocessing and recycling fuel materials. It provides many times greater application of energy contained in fissile materials and at the same time it radically diminishes the problems related to disposal of radioactive waste.

Plutonium contained in spent fuel has a very long half-life period, which means that waste containing plutonium and rare actinides must be stored for tens of thousands of years. Therefore, the countries applying an open fuel cycle, in which spent fuel is removed to underground radioactive waste repository - were forced to developed waste storage methods ensuring their isolation from the environment for a very long time. The task was successfully solved in several countries.

Direct radiation from radioactive waste does not pose a threat – several meters of soil are enough to confine this radiation underground. Radioactive waste is usually stored several hundred meters below the surface. Therefore, the only risk is that radioactive waste could be washed up to the surface by water. Radioactive substances could be dissolved in water, reach the surface, and be consumed by people, which will cause a radiological threat. To reduce this threat, when storing spent fuel, a number of successive physical barriers are used to contain the possible spread of radioactive substances and absorb radiation. This barrier system consists of:

- ***Making slow-dissolving chemical compounds*** (concentrates) binding radioactive isotopes.
- ***Using a binding material* (binder),** for waste solidification, which prevents spilling, dispersion, spraying and washing out radioactive substances. A binder may be concrete (simultaneously acting as a biological shield), asphalt, organic polymers and ceramic mass.
- ***Waste packaging**,* protecting against mechanical damage, impact of weather conditions and exposure to water. Solid or solidified waste is usually closed in metal or concrete containers and transported and stored in this form.
- ***Concrete repository structure,*** forming an additional waste protection against impact of weather conditions, preventing corrosion of packaging and migration of radioactive substances from their storage place.
- ***Geological structure of an area*** determining the location of storage site. The repository area must be aseismic, unfloodable (e.g. during floods), of low economic utility and removed from human agglomerations. Appropriate geological and hydrological conditions must prevent propagation of radionuclides in soil and their penetration to ground and surface water.
- ***Impregnating bituminous layer*** covering the top concrete layer, which reduces, among others, water migration, slows down corrosion of packaging and washout of radioactive substances.

The effectiveness of these barriers depends on their multi-stage design that prevents radioactive substances contained in nuclear waste from getting released, scattered, sprayed, or washed away with water. Therefore, the degree of exposure of the environment to the negative effects of ionising radiation emitted by nuclear waste is very small, even if we assume a worst-case scenario.

The barrier systems used globally are different depending on geological conditions of repository location, but they have several common characteristics. Below, a model system of barriers is presented: vitrified material binding radioactive material, copper fuel container, flexible bentonite clay surrounding the container, and stable geological formation (Fig. 4.3.23). If one barrier fails, the others take over.

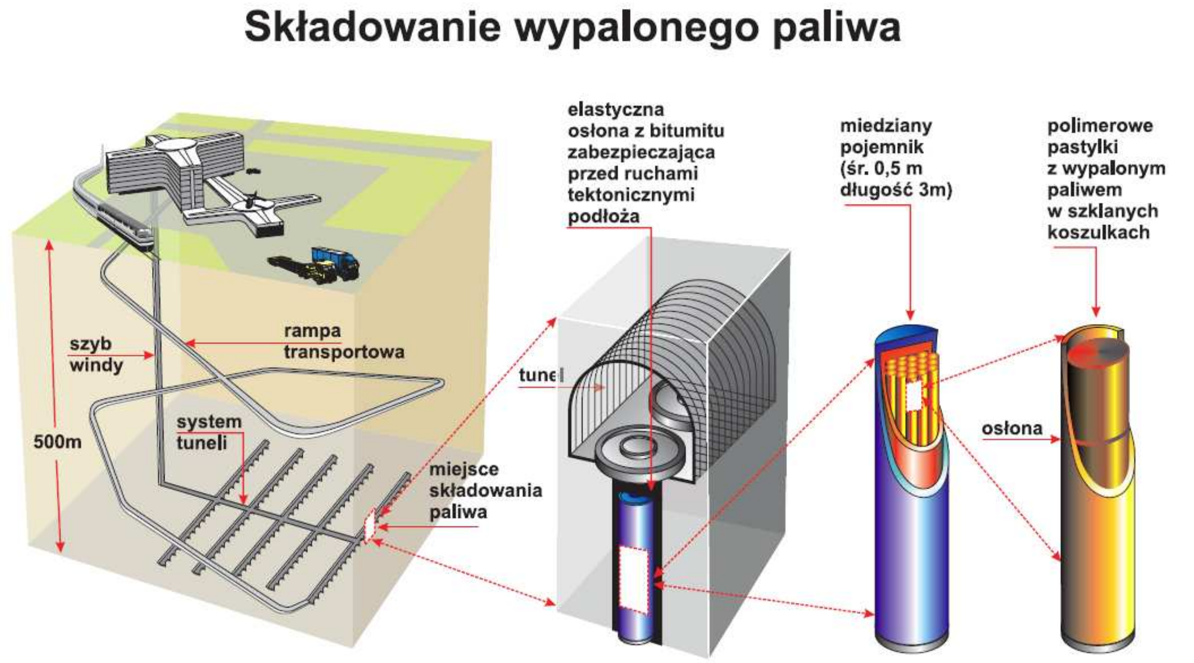


Fig. 4.3.23 System of barriers protecting spent fuel in underground storage [189].

[Składowanie wypalonego paliwa – Spent fuel storage
Szyb windy – Elevator shaft
Rampa transportowa – Transport ramp
System tuneli – Tunnel system
Miejsce składowania paliwa – Fuel storage location
Tunel – Tunnel
Elastyczna osłona z bitumitu zabezpieczająca przed ruchami tektonicznymi podłoża – Flexible bituminous casing protecting against substrate movements
Miedziany pojemnik (śr. 0,5 m, długość 3 m) – Copper container (diameter 0.5 m, length 3 m)
Osłona – Casing
Polimerowe pastylki z wypalonym paliwem w szklanych koszulkach – Polymer pellets with spent fuel in glass cladding]

First of all, melted fuel is drowned in glass with high resistance to washing out. Resistance of such vitrified material is counted in tens of thousands years. Vitrified fuel is surrounded with the first barrier, being a copper container. Its task is to isolate the fuel from the environment. As long as the container remains tight, no radioactive release may occur. The greatest threat to the whole of the container is corrosion (mainly caused by oxygen and sulphur compounds dissolved in underground water), as well as rock movements, which may cause breaking the container. Copper is a material which withstands effects of aggressive substances in underground water very well. Cast iron inserts allow withstanding very high mechanical load.

The container is surrounded by a layer of bentonite clay referred to as a buffer, as it protects the containers against small movements of rock layer and keeps it in place. The buffer has two additional functions. Bentonite absorbs water and increases its volume, which practically excludes penetration of ground water through the clay layer to the container. At the same time, bentonite acts as a filter. Radionuclides adhere to the surface of clay particles. In a very improbable case of damaging the container, huge majority of radionuclides will remain in the container. Most of those leaking out will be captured in bentonite. Thus, we delay transport of radionuclides to the surface, which ensures further natural radioactive decay and reduction of activity.

A rock, where a repository is located plays an important role in delaying radionuclide transport. Its main task is to protect the container and buffer against mechanical damage and to provide stable chemical medium. It is important that underground water does not contain dissolved oxygen, which could corrode the container. Moreover, low rate of water flow in the rock is an advantage in terms of maintaining barrier integrity. The following countries have developed fuel storage containers and repository designs: Switzerland, Finland (Fig. 4.3.24), Sweden, USA and France. Tests of underground rocks were performed successfully in those countries. It appeared that technical problems had already been solved and that the selected locations offered good conditions for waste isolation for thousands of years.

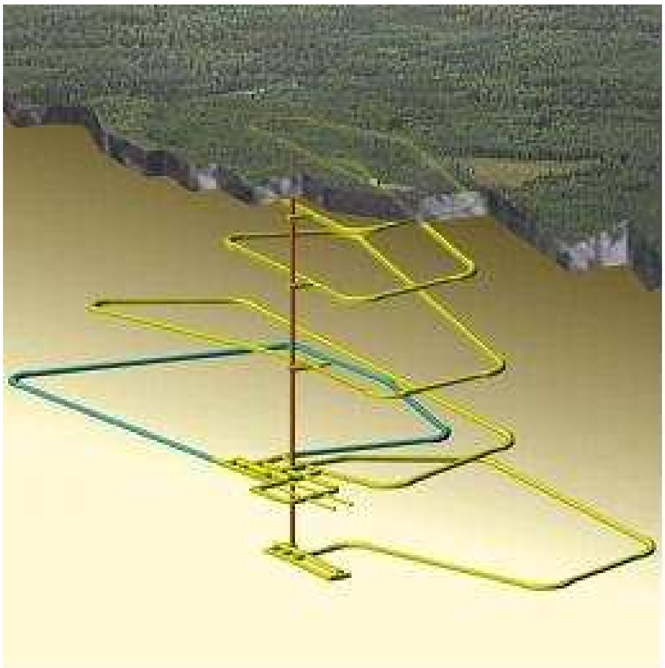


Fig. 4.3.24 Diagram of the deep radioactive waste storage in Onkalo, Finland[190]

Geologists concur that the waste washout processes are very slow and even if the waste was not in containers and was not vitrified, it would not penetrate to the surface from the depth of 500 m earlier than in 20-100 thousand years.

In Finland, construction of a deep repository in Onkalo was initiated; it will be put into service in 2020.

Medium and low level waste

Storage of medium and low activity waste is conducted in all countries where radionuclides are used in medicine and industry. Such repositories operate in the entire European Union, also in Poland (in Różan on Narew). Introduction of nuclear power engineering means expanding the scale of activities and not substantial quality changes in commonly applied and very effective waste disposal methods.

Medium and low level radioactive waste is stored in **surface** repositories(low level and short-lived) or **underground medium-deep** repositories (medium level) - in stable geological formations: salt domes, argillaceous rocks or igneous rocks.

Especially salt deposits are useful for repositories, because salt is characterised with very high tightness and thus it well prevents penetration of radioactive substances to the environment, and especially to ground water.

Before being transported to the storage, waste must be properly processed and conditioned in order to meet specific conditions of radiological safety in transport and storage. The conditions - compliant to IAEA requirements - are specified in relevant Polish regulations.[191]

Radioactive waste processing methods depend on its physical form and chemical composition. In particular, the following methods are applied (Fig. 4.3.25) [Włodarski]:

Liquid waste:

- treatment with application of non-organic sorbents,
- concentration on evaporator,
- membranes
- ion exchange filters,
- solidification (cement, asphalt, plastics),
- vitrification

Solid waste:

- fragmentation,
- compaction,
- fixing (cement, plastics).

Biological waste:

- setting in urea-formaldehyde resins.

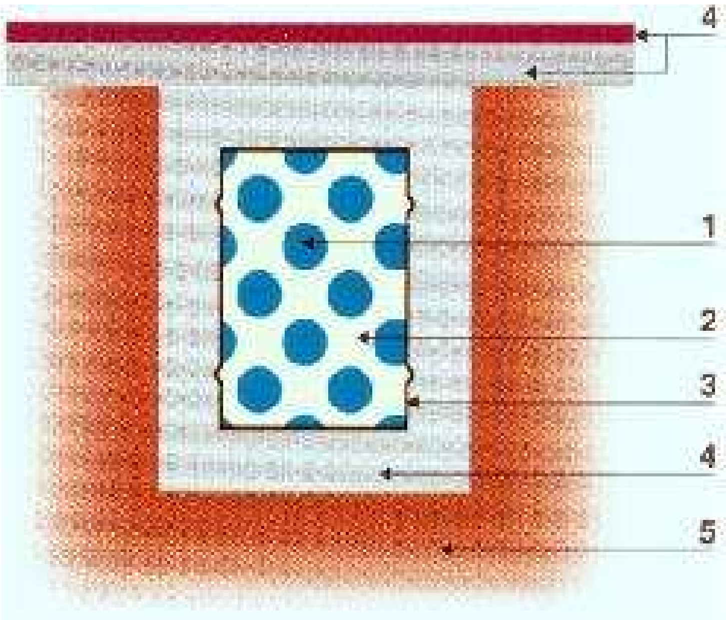


Fig. 4.3.25 Protective barriers in radioactive waste storage (ZUOP Świerk)

1- chemical, 2-physical, 3- I engineering, 4- II engineering, 5- natural

In Poland, the problem of radioactive waste disposal occurred in 1958, upon commissioning of the first research nuclear reactor EWA in Świerk and commencement of production of artificial radioactive isotopes for science, medicine and industry. In 1961, after proper engineering and technical preparations, radioactive waste repository in Różan on Narew was put into service. It still operates successfully.

This storage was located in the former military fort from 1905-1908, with thick (1,2 - 1,5 m) concrete walls and ceilings, which provide full biological protection to the waste located within (Fig. 4.3.26).

Ground water is found under the layer of clay with very low permeability and a layer of soil with sorptive properties at the depth of several meters below the storage. Soil composition effectively prevents waste migration which could penetrate the soil due to unfortunate events.

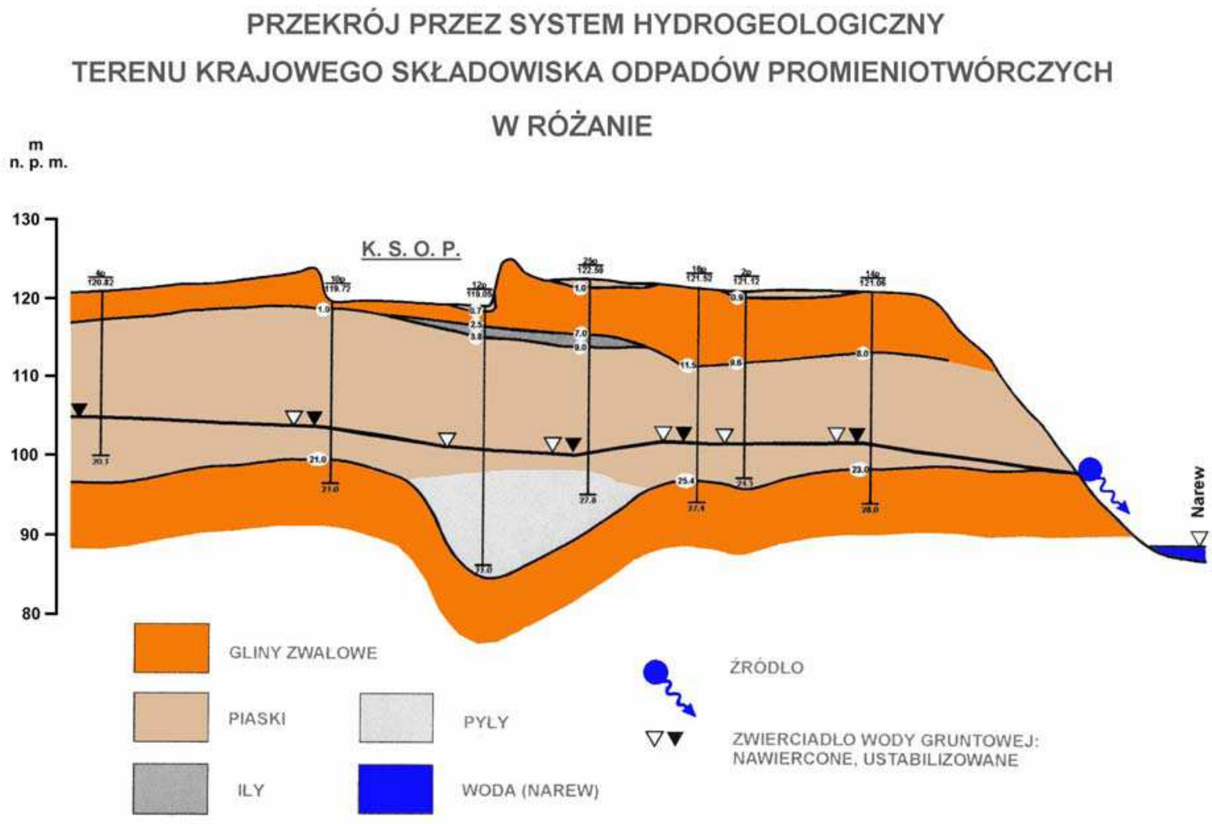


Fig. 4.3.26 Cross-section of hydro-geological system of National Waste Storage in Różan

[PRZEKRÓJ PRZEZ SYSTEM HYDROGEOLOGICZNY TERENU KRAJOWEGO SKŁADOWISKA ODPADÓW PROMIENIOTWÓRCZYCH W RÓŻANIE – CROSS-SECTION OF HYDROGEOLOGICAL SYSTEM OF NATIONAL RADIOACTIVE WASTE REPOSITORY IN RÓŻAN
M n.p.m. – Meters above sea level
Gliny zwałowe – Boulder clay
Piaski – Sands
Iły – Silts
Pyły – Dust
Woda (Narew) – Water (the river Narew)
Źródło – Source
Zwierciadło wody gruntowej: nawiercone, ustabilizowane – Groundwater surface: drilled, stabilised]

Although radioactive waste has been stored in Różan for half a century, adverse health effects were not stated among the local community. On the contrary, mortality due to neoplastic diseases in Różan commune is among the lowest in Poland. This indicates lack of adverse effect of the repository on the environment and residents.

Fig. 4.3.27 Low level radioactive waste prepared for transport to the storage [ZUOP Świerk].

4.3.1.8 Assessment of environmental effects of storage and production of radioactive waste

Selection of fuel cycle type and the best (in Polish conditions) radioactive waste storage method will be discussed and developed in terms of **National Plan of Handling Radioactive Waste and Spent Nuclear Fuel [Krajowy Plan Postępowania z Odpadami Promieniotwórczymi i Wypalonym Paliwem Jądrowym]** (**KPPzOPiWPJ**). It will be one of the main challenges facing the Government Representative for Polish Nuclear Industry. KPPzOPiWPJ should include all actions related to processing, relocation, storage and deposition of radioactive waste, including removal of radioactive waste and decommissioning of a nuclear facility.

This study attempts not to avoid the issue of generation, transport and storage of radioactive waste. However, it should be emphasised that this part of fuel cycle is not included in the discussed scope of environmental impact forecast of Polish Nuclear Programme.

KPPzOPiWPJ like the Polish Nuclear Energy Program will be subject to strategic environmental assessment, which will assess the environmental effects of its introduction, and thus the environmental effects of transport, storage and disposal of radioactive waste, including removal of radioactive contamination and nuclear decommissioning.

This approach also arises from Article 5.2 of SEA Directive:

„Report[…], made according to excerpt 1, contains information which may be rationally required, including […] content and level of specification of a plan or programme, its stage in decision-making process and scope in which certain issues may be more appropriately evaluated at various process stages, <u>In order to avoid multiplication of assessment</u>."Impact related to operation of cooling systems

4.3.2 Impact of cooling systems

4.3.2.1 Applied cooling system installations

Below, two basic types of cooling systems for turbine condensers and auxiliary devices are presented: open (flow) system - without cooling tower[192], and closed (circulation) system with cooling tower (wet with natural draft or hybrid).

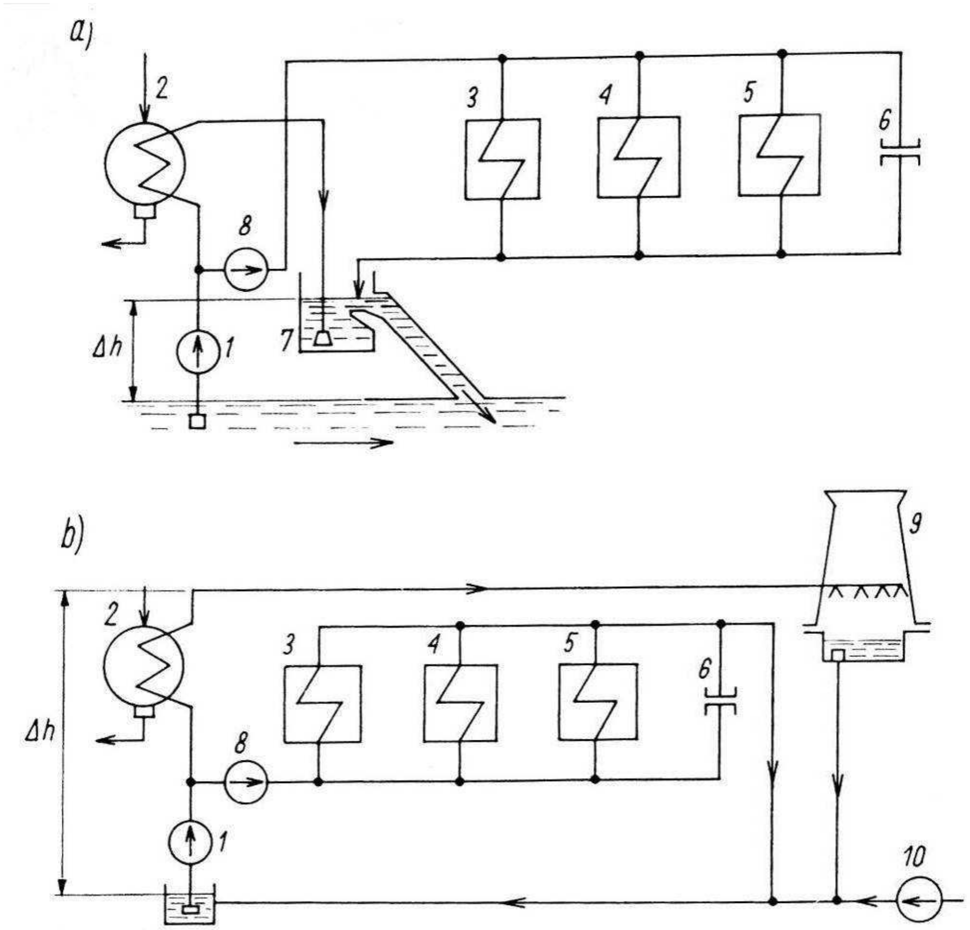


Fig. 4.3.28. Basic types of cooling systems for turbine condensers and auxiliary devices [193].

a) open system - flow cooling, b) closed system with cooling tower - circulation cooling:

1 – cooling water pump, 2 – condenser, 3 – coolers for hydrogen, air and cooling water for generator stator, 4 – oil coolers, 6 – bearings of auxiliary devices, 7 – siphon well, 8 – service water pump, 9 – cooling tower, 10 – make-up water pump.

The type of cooling system has significant effect on efficiency of electricity generation and consumption for internal load. Increase of final cooling water temperature by 1°C will cause decrease in efficiency by ca. 0.4% (temperature in closed cycles is typically higher by 5°C as compared to closed cycles, which may result in decrease in deficiency by 2%).

On the other hand, typical electricity consumption by a cooling water system [BAT[194]] is ca.:

- kWe/MW$_t$ for an open system (intake by cooling water pumps),
- 15 kWe/MW$_t$ for a closed system with a natural-draught wet cooling tower (increased consumption by cooling water pumps),
- 23 kWe/MW$_t$ for a closed system with a hybrid cooling tower (increased consumption by cooling water pumps + intake by cooling tower fans).

At this stage, **designs of cooling systems** for nuclear power plants in Poland have not been developed yet. They will be developed for specific locations selected by the investor.

Upon commission of PGE Energia Jądrowa S.A., BSiPE „Energoprojekt Warszawa" S.A. conducted in 2010 a more specific study of the following 6 locations (from 28 proposed)[195]: Żarnowiec, Lubatowo-Kopalino, Choczewo, Kopań, Warta-Klempicz and Nowe Miasto. Based on this study, the Investor has selected 3 locations for preliminary closer assessment: Żarnowiec (closed cycle) and Lubatowo-Kopalino and Kopań (open cycle - cooling with sea water). According to Polish Nuclear Programme[196], the final selection of location for the first nuclear power plant will be made by the end of 2013. One of the selection criteria will be information in this forecast.

4.3.2.1.1 Open (flow) cooling systems without cooling tower

This cooling system in a nuclear power plant may be used in locations with an access to large reservoirs of cooling water, without hydrothermal limitations.

In practice, this option is possible only for the following locations: coastal, on the river - in lower course of big rivers, and situated at the estuaries of big rivers (including bays).

For a nuclear power unit with net capacity of **1000 MW_e** expenditure of cooling water, with 10 K heating, is ca. **50.2 m^3/s** (with 12 K: ca. 41.8 m^3/s).

Option of sea water cooling is attractive due to lower temperature, which allows for deeper vacuum in turbine condensers and obtaining higher energy generation efficiency) and practically no limits in terms of resources and hydrothermal limitations.

However in technical terms, sea water intake and discharge presents technical problems due to:

- low depth in coastal zone and sandy bed;
- dynamic effect of sea water in coastal zone (variable sea currents, waves);
- intense rubble movement along the coast;
- tendencies for changing coastal line and embacles.
- Basic parameters of Baltic Sea:
- area: 415,266 km^2;
- capacity: 21,721 km^3;
- temperature of surface water in coastal zone: from -0.5°C (in winter) to +18÷20°C (in summer).

Cooling water intakes are planned at the depth of 10 m, in the following distance from the coast: 400-500 m (Kopań), 500-800 m (Lubatowo-Kopalino)[197]. Discharge of cooling water should be in the distance of ca. 1-2 km from the intake in the direction of dominating sea currents - in order to avoid re-suction of heated water.

Fig. 4.3.29 presents a model design solution of sea water intake and discharge executed in South Korea for Shin-Kori 2 & 4 APR-1400 reactor (thermal power: 3983 MW_t, gross capacity: 1455 MW_e, net capacity: 1350-1400 MW_e). Water intake is at the depth of 20 m, and water is fed and discharged via drain adits (6.3 m in diameter).

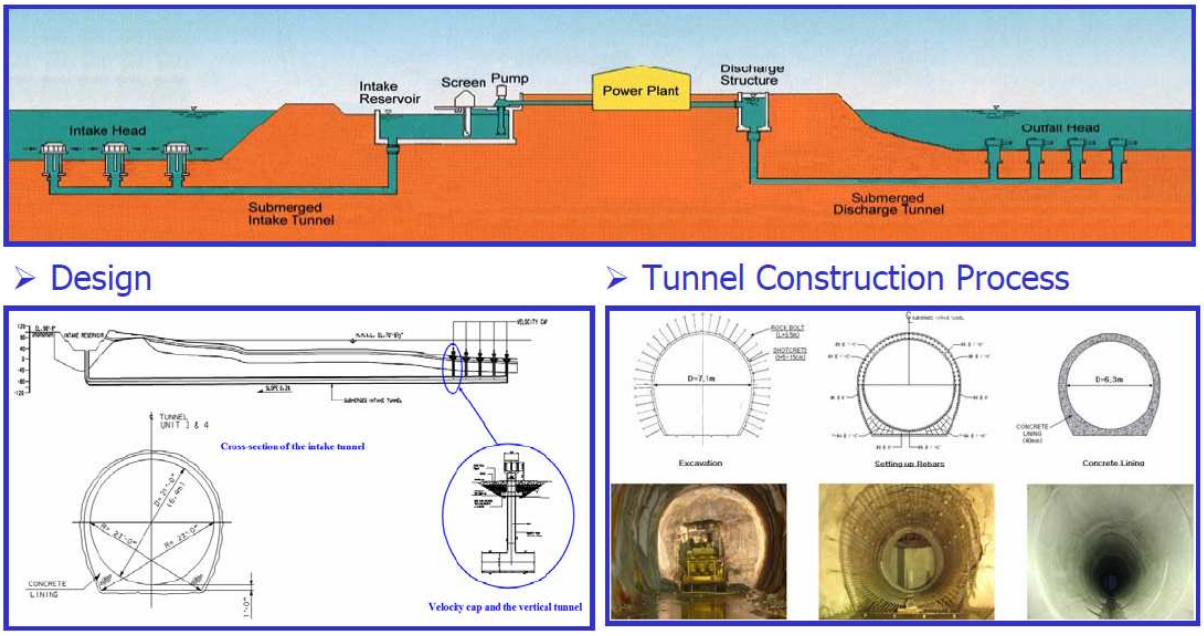


Fig. 4.3.29 A model concept of sea water intake and discharge at Shin-Kori 3 & 4 (South Korea)[198]

When taking advantage of rivers for cooling power plants in open cycle, one must take into account hydrological and hydrothermal constraints. Flow rate in rivers and water temperature change during a year; the fluctuations are smaller in lowland rivers. The highest intake of cooling water cannot exceed 1/3 ÷ 1/2 of mean minimum flow (SNQ), and water temperature after mixing cannot exceed 26°C.

Irrecoverable losses of cooling water due to additional evaporation depend on temperature and air humidity, wind velocity, cooling zone (cooling water heating scale), and season and fluctuate between **0.4% and 0.6%** of cooling water flow rate [Andrzejewski][199]. Irrecoverable losses practically are not an issue in big rivers, however a significant constraint can be caused by hydrothermal conditions - especially in upper and mid-course of the rivers, including Wisła. Still, irrecoverable losses are always very significant for lake water balance.

Hydrotechnical devices for cooling water intake and discharge (from/to river or bay) for nuclear power plant will be substantially similar to the technical solutions currently applied in large thermal power plants, namely river water is fed through the bank pumping station channel - with grates, screens and intake, from where it is pumped to the power plant via reinforced concrete or steel pipes. Water discharge takes place through steel pipes to siphon wells and then via an open channel to the river.

4.3.2.1.2 Closed-cycle cooling systems with cooling tower

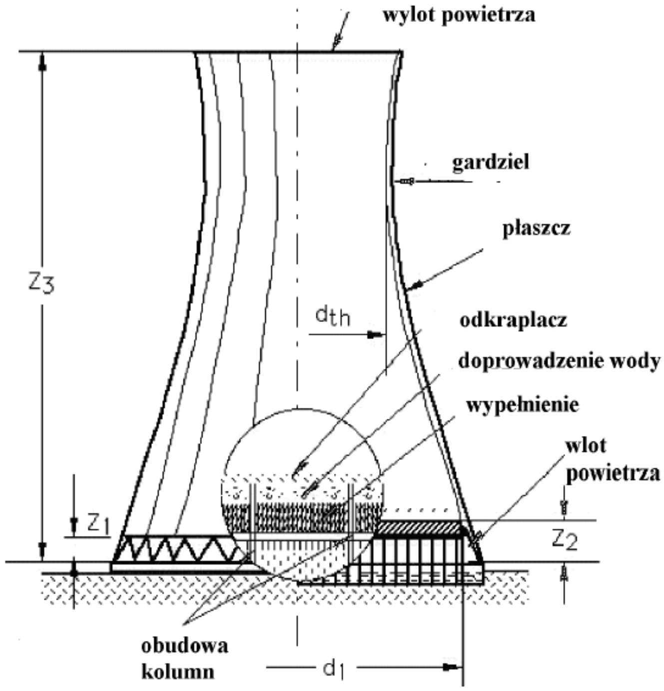


Fig. 4.3.30 Wet natural-draught cooling tower [BAT]

[Wylot powietrza – Air outlet
Gardziel – Throat
Płaszcz – Jacket
Odkraplacz – Condenser
Doprowadzenie wody – Water supply
Wypełnienie – Fill
Wlot powietrza – Air inlet
Obudowa kolumn – Column casing]

For cooling large power units - including nuclear units localised in places where water resources are not sufficient for open-cycle cooling, closed-cycle cooling systems are applied with the following cooling towers:
1) **natural draught wet cooling towers**

2) **hybrid cooling towers** with fan-forced draught.

So far, in Poland only **natural draught wet cooling towers** have been used. The largest operated cooling towers are located in:

- Bełchatów power plant - one per 2 units 370 MW_e: height 132 m, diameter at the base 105.5 m, outlet diameter 57.9 m; hydraulic load 80 000 m^3/h = 22.2 m^3/s, thermal load 3500 GJ/h = 972 MW_t;

- Łagisza power plant – new unit 460 MW_e: height 133.2 m, diameter at the base 98.8 m, outlet diameter 55.08 m.

However, the largest cooling tower will be the one designed for the new unit of Ostrołęka power plant (Ostrołęka C), with capacity of 1000 MW_e: height 185.0 m, diameter at the base 145.0m;

hydraulic load 95 500 m^3/h = 26,5 m^3/s, thermal load 950 MW_t, cooling zone 9K), total water intake estimated at ca. 0.57 m^3/s).[200].

The biggest cooling towers in the world were applied in **nuclear power plants**. In particular wet natural draught cooling towers:

- in Germany, nuclear power plant with Konvoi reactor – Isar II (3950 MW_t, 1475 MW_e gross, 1400 MW_e net): height 165 m, diameter at the base 153 m, outlet diameter 86 m, hydraulic load 216 000 m3/h = 60 m3/s; and Elmstad (3950 MW_t, 1400 MW_e gross, 1329 MW_e net): height 152 m;
- in France in nuclear power plant with N4 reactors (4250 MW_t, 1560 MW_e gross, 1500 MW_e net) – Civaux (2 units) and Chooz B (2 units): height 180 m, diameter at the base 153 m, outlet diameter 85 m.

Fig. 4.3.31 Nuclear power plant Isar II (Germany) with wet natural draught cooling tower.

Fig. 4.3.32 Nuclear power plant Civaux 1&2 (France) with wet natural draught cooling tower.

The highest wet cooling tower in the world was built in Germany, in Niederaussem thermal power station. Brown-coal fuelled K Unit with supercritical parameters (1012 MW_e gross, 965 MW_e net): height: 200 m, diameter at the base: 152.54 m, outlet diameter: 88.41 m; hydraulic load: 91 000 $m^3/h = 25.3\ m^3/s$.

Fig. 4.3.33 Niederaussem power plant (Germany) with the tallest wet natural draught cooling tower in the world (200 m)

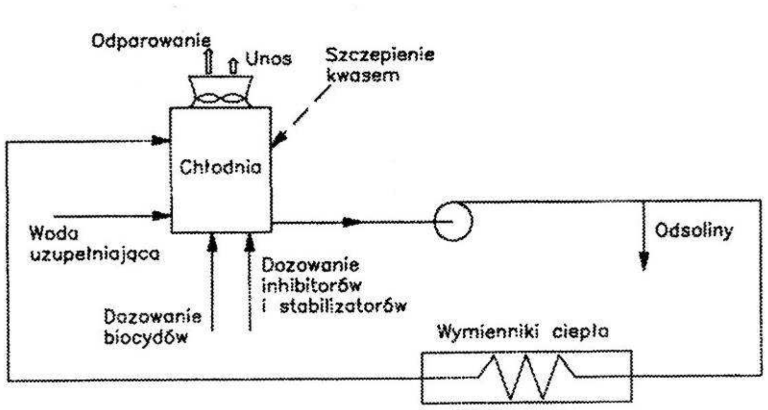


Fig. 4.3.34 Diagram of closed-cycle cooling system with cooling tower[201]

[Odparowanie – Evaporation
Unos – Windage
Szczepienie kwasem – Acid grafting
Chłodnia – Cooling tower
Woda uzupełniająca – Makeup water
Dozowanie biocydów – Biocide dosing
Dozowanie inhibitorów i stabilizatorów – Dosing inhibitors and stabilisers
Wymienniki ciepła – Heat exchangers
Odsoliny – Blowdown]

During water cooling with air stream in a cooling tower, partial water evaporation takes place (evaporation loss), as well as water drops capture by air stream (windage loss) - this water is irreversibly lost (evaporation and windage loss together constitute irreversible losses). Furthermore, in order to prevent salt content thickening in the cycle due to water evaporation, some water is discharged as blowdowns (blowdown discharge). Water deficits in the cycle are made up with water from the cooling basin. In order to prevent creation of carbonate deposits (calcium and magnesium carbonates), the make-up water is treated. Treatment includes decarbonisation (with lime) and grafting (with hydrochloric or sulphuric acid). It also allows to significantly decrease water loss on blowdown. (see diagram: Fig. 8.3.34).[201]

Hybrid cooling towers, with fan-assisted draught were introduced in the 1980s. A hybrid cooling tower has a special structure enabling decrease in cooling water consumption and vapour generation. It is a combination of a wet and dry cooling tower. Depending on external air temperature, a hybrid cooling tower may be operated exclusively as a wet tower or as a combined wet and dry tower.

Heated cooling water passes through the first dry section of the tower, where hot part is discharged by air stream, partially sucked by a fan. After passing through the dry section, water is cooled down in wet section, similarly to a wet natural draught cooling tower. In the upper tower section, heated air from the dry section is mixed with wet section vapours, thus decreasing its relative humidity before leaving the tower, which (almost) completely reduces vapours over the tower. Optimisation oh a hybrid tower is based on optimisation of amount of heat exchanged in the dry zone in order to meet the requirements concerning reduction of vapours. At the same time, basic cooling takes place in the wet zone.

To ensure effective operation of a hybrid cooling tower, many auxiliary devices are used:

- fans with regulated rotation speed;

- devices closing air inlets (such as shutters or flaps);
- water flow valves in dry and wet tower zones;
- shunt systems;
- auxiliary pumps (in special construction types);
- devices for mixing dry and humid air.

Hybrid cooling towers are characterised by low cooling water consumption - even ca. 4 times lower than wet natural draught cooling towers (assuming 75% operation in dry mode) [BAT, Table 3.3][202] i [203] and they are at least 3 times lower, with similar diameter. It has significance not only due to much lower water consumption and hence lower environmental impact, but also due to the fact that such a cooling tower disturbs landscape to a much lesser extent - is less visible and vapours above it are almost imperceptible (which may be very important, particularly for local community). Technical parameters of hybrid cooling towers are similar as with wet cooling towers. Their disadvantage is additional power consumption (apart from consumption by cooling water pumps, ca. 15 kWe/MWt, which is at the same level as for a wet cooling tower) for fan drive – 8 kW_e/MW_t. [BAT]

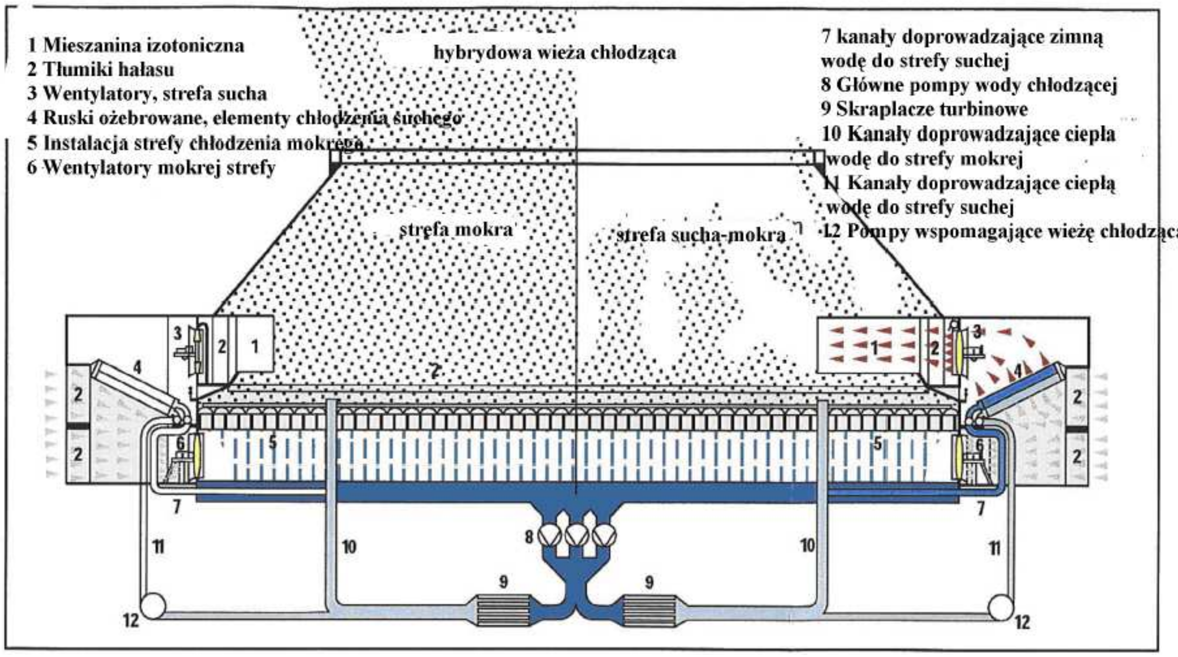


Fig. 4.3.35 Hybrid cooling tower [BAT]

[1 Isotonic mixture
2 Noise attenuators
3 Fans, dry zone
4 Ribbed pipes, dry cooling elements
5 Wet cooling zone installation
6 Wet zone fans
7 Channels feeding cool water to dry zone
8 Main cooling water pumps
9 Turbine condensers
10 Channels feeding warm water to wet zone
11 Channels feeding warm water to dry zone
12 Cooling tower support pumps
Hybrid cooling tower

Wet zone
Dry-wet zone]

The largest hybrid cooling tower was constructed in Neckarwestheim-2 power plant (with Konvoi reactor: 3850 MW_t, 1395 MW_e gross, 1310 MW_e net) in Germany: height 51.22 m, diameter at the base 160.0 m, outlet diameter 73.6 m, thermal load 2500 MW_t, 64 fans.
As we can see, currently cooling water systems are operated with single cooling towers in nuclear power units with capacity similar to capacity of an EPR reactor unit.

Fig. 4.3.36 View of Neckarwesheim power plant (Germany) with a hybrid cooling tower in unit II (unit I is cooled in open cycle from the river Neckar with auxiliary fan cooling towers)

Fig. 4.3.37 Close-up view of hybrid cooling tower in Neckarwestheim-2 power plant

Currently,[204] using hybrid cooling towers is planned in particular in Calvert Cliffs power plant 3 & 4 in the USA – Maryland[205] (unit U.S. EPR: 4590 MW_t, 1710 MW_e gross, 1600 MW_e net), North Anna nuclear power plant 3 (APWR 1700 MW_e, MHI) in the USA – Virginia, and for cooling a new unit in Swiss nuclear power plant Beznau.

Calvert Cliffs cooling towers will have the following parameters: height 54.0 m; diameter 166.4 m; hydraulic load 187 390 m^3/h = 52 m^3/s; power consumption by fans ca. 20 MW_e[206].

Fig. 4.3.38 View of hybrid cooling tower in new nuclear power plant Bezanu (Switzerland) – visualisation.

4.3.2.2 Cooling water demand

$Q_W = \frac{P_{tw}}{C_W \cdot \rho \cdot \Delta t} \cdot 10^3$ - cooling tower hydraulic load [m^3/s],

$P_{t,w}$ – thermal power discharged in cooling water [MW_t],

c_w = 4.19 kJ/kg·deg – specific heat of water,

ρ = 998.2 kg/m^3 – water density at 20°C,

Δt = 10 K – cooling zone (typical value).

Below, calculations were performed **for wet natural draught cooling towers** [Andrzejewski] [Kozioł, Stechman].[207]

$p = p_1 + p_2' + p_2''$ - total water consumption (% Q_w),

$p_1 = \alpha \cdot \Delta t$ - evaporation loss (% Q_w),

Table 4.3.3 Values of α coefficient [Andrzejewski]

SEASON OF THE YEAR	COEFFICIENT α
Summer	0,15 ÷ 0,16
Spring and autumn	0,10 ÷ 0,12
Winter	0,06 ÷ 0,08

$p'_2 =\leq 0.01$ - windage loss (% Q_w) – in state-of-the-art cooling towers with windage eliminators [BAT],

p''_2 - blowdown loss (% Q_w),

Due to evaporation, water thickening in the cooling cycle occurs. In order to maintain constant salt concentration in cooling water, amount of salt discharged with windage and blowdown must equal amount of water fed with makeup water, that is:

$$s \cdot p = K \cdot s \cdot p_2,$$

where:

s – salt content in makeup water [mg/l],

K = s_o/s – acceptable water thickening in the cooling cycle (s_o – acceptable salt content in the cooling cycle, mg/l),

$$p_2 = p'_2 + p''_2;$$

which gives the following dependence:

$$p = \frac{K}{K-1} \cdot \alpha \cdot \Delta t.$$

In practice, values K = 3 ÷ 6 are assumed, then amount of blowdown sewage is 20 ÷ 50% of irreversible loss[208].

According to [BAT, Table 3.3] average water consumption is, for:

open cycle wet cooling towers: 2 $m^3/h/MW_t$ = 0.55 $m^3/s/1000\ MW_t$ (2% Q_w);

open cycle wet-dry (hybrid) cooling towers: 0.5 $m^3/h/MW_t$ = 0.14 $m^3/s/1000\ MW_t$ (0.6% Q_w) - assuming 75% operation time in dry regime.

Assuming (conservatively): upper values of α and K = 3, from the above relations we can calculate individual components of water consumption by wet cooling towers.

Table 4.3.4 Characteristics of wet natural-draught cooling tower

	Summer	Spring and autumn	Winter	Year
α coefficient	0,16	0,12	0,08	0,12
Evaporation loss p_1 (%Q_w)	1,60	1,20	0,80	1,20
Windage loss p'_2 (%Q_w)	0,01	0,01	0,01	0,01
Irreversible loss $p_1 + p'_2$ (%Q_w)	1,61	1,21	0,81	1,21
Water demand p (%Q_w)	2,40	1,80	1,20	1,80

Blowdown discharge p'_2 (%Q_w)	0,79	0,59	0,39	0,59

It results from Table 4.3.4 that mean yearly water consumption indicator by wet natural draught cooling tower is at the level of 1.80% of cooling water expenditure, of which 1.21% is irreversible loss, and 0.59% is blowdown discharge. Maximum values (in summer) are, respectively: 2.40%; 1.61% and 0.79%.

The tables below present selected basic parameters of various types of nuclear power units offered in Poland (Table 4.3.5) and cooling water consumption by those units with cycle cooling with wet natural draught cooling tower or dry-wet hybrid cooling tower (Table 4.3.6)

Table 4.3.5 Basic parameters of nuclear power units

Unit type	Thermal power [MW_T]	Gross electrical capacity [MW_E]	Net electrical capacity [MW_E]	Thermal power discharged in cooling water [MW_T]	Water expenditure in cooling system [m^3/s]
EPR	4590	1710	1600	2880	68,9
AP 1000	3400	1200	1117	2311[209]	55,3
ABWR	3926	1371	1350	2555	61,1
ESBWR	4500	1600	1550	2900	69,3

Table 4.3.6 Cooling water consumption by nuclear power units of various types with cycle cooling with cooling towers: wet natural draught and wet-dry hybrid at K=3

Unit type	Cooling tower hydraulic load [m^3/s],	Cooling tower type	Water demand [m^3/s]		Irreversible loss [m^3/s]		Blowdown discharge [m^3/s]		Irreversible loss per net electrical capacity indicator [$m^3/s/1000\ mw_e$]		Water consumption per discharged thermal power indicator [$m^3/s\ /1000\ mw_t$]	
			summer	year	summer	year	summer	year	summer	year	summer	year
EPR	68,9	wet	1,65	1,24	1,11	0,83	0,54	0,41	0,70	0,53	0,57	0,43
		hybrid	0,58	0,43	0,39	0,29	0,19	0,14	0,24	0,18	0,20	0,15
AP 1000	55,3	wet	1,33	0,99	0,89	0,67	0,44	0,33	0,80	0,60	0,57	0,43
		hybrid	0,46	0,35	0,31	0,23	0,15	0,11	0,28	0,21	0,20	0,15
ABWR	61,1	wet	1,47	1,10	0,98	0,74	0,48	0,36	0,73	0,55	0,57	0,43
		hybrid	0,51	0,38	0,34	0,26	0,17	0,13	0,25	0,19	0,20	0,15
ESBWR	69,3	wet	1,66	1,25	1,12	0,84	0,55	0,41	0,72	0,54	0,57	0,43
		hybrid	0,58	0,44	0,39	0,29	0,19	0,14	0,25	0,19	0,20	0,15

For comparison purposes: The planned average yearly water consumption for **„Warta" nuclear power plant in Klempicz** (4 x WWER-1000/W-320, $P_{e,net}$ = 4x963[210] = 3852 MW_e, $P_{t,w}$ = 7828 MW_t, Q_w = 187 m^3/s, 8 cooling towers) [Widmoski [211]]:

- raw water demand (p): 4.0 m^3/s (2.14% Q_w),
- irreversible water loss ($p_1 + p'_2$): 2.7 m^3/s (1.44% Q_w),

- blowdown discharge (p''_2): 1.3 m^3/s (0.70% Q_w) – which constitutes 48.3% of irreversible loss $p_1 + p'_2$.

Value K may be calculated based on the following relation: $K = \frac{p}{p - p_1}$; assuming windage loss p'_2 = 0.2% Q_w (for older cooling towers), we obtain for „Warta" power plant: K ≅ 2.4 – these are very low water thickening values (with windage 0.01% Q_w K ≅ 3,0). Mean yearly irreversible loss per net electrical capacity estimated for „Warta" power plant: **0.70** $m^3/s/1000\ MW_e$ – this is a value similar to those obtained from the above calculations (0.53 – 0.60 $m^3/s/1000\ MW_e$), slightly higher probably due to higher windage loss in older cooling towers.

The environmental impact study for **Visaginas nuclear power plant** (new Ignalina power plant) presents the value of irreversible loss **0.45** $m^3/s/1000\ MW_e$ – this value however seems underrated (with reference to cycle cooling losses - as the same value was assumed as with open-cycle cooling).

The concept of water supply for „Warta" power plant[211] assumes that irreversible loss will be covered from current flow of the river Warta exceeding invariant flow (for hydrobiological reasons). Invariant flow in water intake cross-section is 20.7 m^3/s. Statistical hydrological data on the river Warta in 1951-85 show that minimal flow of the river Warta may approach the invariant flow only during several days in a dry year, with mean recurrence period once per 20 years. In order to maintain the invariant flow and full power plant capacity also in this period, water retention was assumed with capacity of ca. 5 million m^3. Such retention would allow covering irreversible water loss on mean yearly level (2.7 m^3/s) for ca. 20 days. Percentage values of decrease of characteristic flows in the river Warta in water intake cross-section due to irreversible water loss were estimated as follows:

- mean low flow SNQ = 45.7 m^3/s, decrease by 5.9%;
- medium flow SNQ = 122.0 m^3/s, decrease by 2.2%;
- mean high flow SNQ = 368.0 m^3/s, decrease by 0.7%;

In **Bełchatów power plant** the cooling water system (of currently operated 12 thermal units with total installed power 4 440 MW_e) consists of 6 wet natural draught cooling towers (one per 2 units), each with hydraulic load 80 000 m^3/h (22.2 m^3/s) and thermal load 3500 GJ/h (972 MWt). Irreversible water losses in Bełchatów power plant amount to 2.08 m^3/s[212] -which is **1.56%** Q_w, and water intake 2.30 m^3/s. Water consumption per discharged thermal power index is **0.39** $m^3/s/1000\ MW_t$[213] – this is the value approaching the value obtained from the above calculations **0.43** $m^3/s/1000\ MW_t$ (Table 10.3.4).

<u>**Assumption**</u>: nuclear power plant in each site should have net electrical capacity ca. 3000 MW_e, therefore it should consist of **2 EPR units** (3200 MW_e), or **ABWR units** (2700 MW_e) or **ESBWR units** (3100 MW_e), or of **3 AP 1000 units** (3350 MW_e).

With the above assumption, cooling water consumption by a single nuclear power plant was calculated (2- or 3-unit, respectively), with cycle cooling – Table 4.3.7

Table 4.3.7 Cooling water consumption by nuclear power plant with cycle cooling with wet or hybrid cooling tower.

Power plant configuration	Cooling tower type	Water demand [m^3/s]		Irreversible loss [m^3/s]		Blowdown discharge [m^3/s]	
		summer	year	summer	year	summer	year

Power plant configuration	Cooling tower type	Water demand [m^3/s]		Irreversible loss [m^3/s]		Blowdown discharge [m^3/s]	
2 x EPR	wet	3,31	2,48	2,22	1,67	1,09	0,81
	hybrid	1,15	0,86	0,77	0,58	0,38	0,28
3 x AP 1000	wet	3,98	2,98	***2,67***	2,01	1,31	0,98
	hybrid	1,39	1,04	***0,93***	0,70	0,46	0,34
2 x ABWR	wet	2,93	2,20	1,97	1,48	0,97	0,72
	hybrid	1,02	0,77	0,69	0,52	0,34	0,25
2 x ESBWR	wet	3,33	2,50	***2,23***	1,68	1,10	0,82
	hybrid	1,16	0,87	***0,78***	0,58	0,38	0,29

On the basis of calculation data presented above, it may be estimated that for river sites, minimum water resources in summer should be sufficient to consume (irreversible losses with 100% margin):

- <u>for nuclear power plant with 3 AP 1000 units</u>: **2.9 m^3/s** (wet cooling towers) or **1.0 m^3/s** (hybrid cooling towers – minimum);
- <u>for nuclear power plant with 2 units of any type</u>: **2.5 m^3/s** (wet cooling towers) or **0.9 m^3/s** (hybrid cooling towers – minimum);

In case of big rivers (Wisła, Odra, Warta, Bug), especially in their mid and upper course, uptake of such amounts of water to makeup cooling cycle is not a problem.

Then, assuming time of application of installed power 8000 h/a (which corresponds to installed power use index 91.3%), yearly water consumption by a nuclear power plant in the above configuration was calculated, with cycle cooling and wet natural draught cooling tower or hybrid cooling tower.

The value is particularly significant for assessment of sufficiency of cooling water resources in lake sites and for specification of discharged salt load (Table 4.3.8).

Table 4.3.8 Yearly cooling water consumption by nuclear power plant with cycle cooling with wet or hybrid cooling tower.

Power plant configuration	Cooling tower type	Annual water demand [million m^3/a]	Annual irreversible loss [million m^3/a]	Annual blowdown discharge [million m^3/a]
2 x EPR	wet	71,4	48,0	23,4
	hybrid	24,9	16,7	8,2
3 x AP 1000	wet	85,9	57,8	28,2
	hybrid	30,0	20,1	9,8
2 x ABWR	wet	63,3	42,6	20,8
	hybrid	22,1	14,8	7,2
2 x ESBWR	wet	71,9	48,3	23,6
	hybrid	25,1	16,8	8,2

Nuclear power plant site should have water resources covering annual water demand of a closed cooling water cycle for 3 AP 1000 units or at least 2 units of other type. It results from calculation data presented above that those minimum required water resources (only for covering irreversible losses, assuming that blowdown may be discharged to the same reservoir) with 10% margin are:

- <u>for nuclear power plant with 3 AP 1000 units</u>: **64 million m^3/a** (wet cooling towers) or **22 million m^3/a** (hybrid cooling towers);

- for nuclear power plant with 2 units of any type: **53 million m^3/a** (wet cooling towers) or **18 million m^3/a** (hybrid cooling towers);

4.3.2.3 Preliminary assessment of sufficiency of cooling water resources

So far **detailed site analyses have not been performed** for any potential nuclear power plant site in Poland (even for 3 sites initially selected by the investor, PGE S.A., i.e.: Żarnowiec, Lubiatowo-Kopalino and Kopań), **including** in particular **optimisation technical and economic analysis of cooling system variants**, applicable in individual locations.

With regard to the above and due to deficiencies in hydrological data for some sites, a fully credible assessment of sufficiency of water resources for all locations - at the current stage and within a month - is practically unfeasible. Thus, the assessments below must be treated as **very preliminary**, based on incomplete hydrological data and expert knowledge.

The problem of insufficiency of cooling water resources does not apply to **coastal** locations where seawater will be used for cooling.

In case of **river** sites, located **on lower Wisła and Odra** (including Zalew Szczeciński) open-cycle cooling systems are planned, however such an option is not determined: as long as detailed hydrological and hydrothermal analyses are not conducted[214] and water-legal permit is not obtained (in terms of an integrated permit).

With **lake** sites – with existing hydrological and water legal constraints - open-cycle cooling systems seem unfeasible (especially if a nuclear power plant were to have more than 1 unit - which is proposed). Therefore, a closed-cycle system (rather with hybrid cooling towers) should be planned.

For **other river** and **inland** sites, closed-cycle cooling systems are planned - principally with wet natural draught cooling towers, optionally with hybrid towers. There are not any hydrothermal constraints, however in some cases available (in a reasonable distance of ca. 35 km) cooling water resources to make up irreversible losses may be insufficient - however, without relevant hydrological data it cannot be ascertained with certainty and authority.

The preliminary assessment of cooling water sufficiency was made with an assumption that the resources should suffice for max 3 AP 1000 units (with net capacity of ca. 3350 MW_e)[215], according to data specified in points **4.3.2.1.1** and **4.3.2.2**, i.e.:

- In open cooling cycle: ca. **168 m^3/s**;
- In closed cooling cycle (makeup of irreversible losses):
- with wet natural draught cooling tower: max (in summer) - **2.9 m^3/s**; annual irreversible losses:
  ca. **64 million m^3**;
- with hybrid cooling tower (minimum consumption – at 75% operation in dry regime): max (in summer) - 1,0 m^3/s; annual irreversible losses: ca. 22 million.

Table 4.3.9 Results of cooling water sufficiency assessment for individual potential nuclear power plant sites

No.	Name	Geographical data	Site type	Cooling cycle	Cooling / raw water source	Hydrological data	Sufficiency of cooling water
1	**Chełmno**	Commune Chełmno, District Chełmno, Province Kujawsko-Pomorskie	River - Wisła	Open	River Wisła km 806+800	SSQ = 1,013 m^3/s SNQ = 382 m^3/s	Sufficient
2	**Nieszawa**	Commune Nieszawa, District Aleksandrów Kujawski. Kujawsko-Pomorskie	River - Wisła	Open	River Wisła (after Mień estuary)	SSQ = 929 m^3/s SNQ = 309 m^3/s	Sufficient
3	**Gościeradów**	Commune Gościeradów, District Kraśnik, Province Lubelskie	Inland (5 km from Wisła)	Closed (wet cooling towers)	River Wisła or San (13 km) – better water quality	SSQ = 408 m^3/s (Wisła, Zawichost) SNQ = 258 m^3/s (Wisła, Zawichost) SSQ = 123 m^3/s (San, Radomyśl) SNQ = 81 m^3/s (San, Radomyśl)	Sufficient
4	**Chotcza**	Commune Chotcza, Province Mazowieckie	Inland (5 km from Wisła)	Closed (wet cooling towers)	River Wisła, Iłżanka (add.)	SSQ = 408 m^3/s (Wisła, Zawichost) SNQ = 258 m^3/s (Wisła, Zawichost)	Sufficient
5	**Bełchatów**	Commune Kleszczów, District Bełchatów, Province Łódzkie	Inland	Closed (hybrid towers?)	River Warta (Raduczyce, 36 km), Widawka, Krasówka	No data: currently, closed cooling cycle of Bełchatów power plant is supplied mainly with KWB drainage water (this source will not be available in the future).	? Lack of sufficient hydrological data.[216]
6	**Karolewo**	Commune Nowy Duninów, District Włocławek, Province Kujawsko-Pomorskie	River - Wisła	Open	River Wisła	SWQ = 5020 m^3/s SSQ = 1140 m^3/s SNQ = 352 m^3/s NNQ = 216 m^3/s	Sufficient
7	**Kozienice**	Commune Kozienice, District Kozienice, Mazowieckie	River - Wisła	Closed (wet cooling towers)	River Wisła	SWQ = 2,922 m^3/s SSQ = 502 m^3/s SNQ = 166 m^3/s NNQ = 115 m^3/s	Sufficient
8	**Małkinia**	Commune Zaremby Kościelne, District Ostrów Mazowiecka,	Inland (2 km from Bug)	Closed (wet cooling towers)	River Bug (Dębe dam area)	SSQ = 120 m^3/s (Bug, Frankpol) SNQ = 96 m^3/s (Bug,	Sufficient

No.	Name	Geographical data	Site type	Cooling cycle	Cooling / raw water source	Hydrological data	Sufficiency of cooling water
		Mazowieckie				Frankpol)	
9	**Nowe Miasto**	Commune Nowe Miasto, District Płońsk, Mazowieckie	Inland	Closed (wet cooling towers)	Zalew Zegrzyński (32 km) – basic River Wisła (33 km) – reserve	Zalew Zegrzyński: 30 km^2, 94.3 million m^3, tributary from Bug and Narew >20 m^3/s; River Wisła SWQ = 5020 m^3/s SSQ = 1140 m^3/s SNQ = 352 m^3/s NNQ = 216 m^3/s	Sufficient
10	**Wyszków**	Commune Zabrodzie, District Wyszków, Mazowieckie	Inland	Closed (wet cooling towers)	River Bug (Kamieńczyk region, 10 km)	SSQ = 163 m^3/s (Wyszków) SSQ = 127 m^3/s (Wyszków)	Sufficient
11	(podlaskie)	During assignment					
12	**Choczewo**	Commune Choczewo, District Wejherowo, Pomorskie	Sea	Open	Baltic Sea (8 km) Raw water: basic - Lake Żarnowieckie (10 km), serve - river Łeba (30 km)	Baltic Sea: 414 266 km^2, 21 721 km^3, temp.: -0,5°C (winter) ÷ 18-20°C (summer) River Łeba (above outlet to Lake Łebsko): SWQ = 48.30 m^3/s SSQ = 15.90 m^3/s SNQ = 9.95 m^3/s NNQ = 8.30 m^3/s	Sufficient
13	**Lubatowo-Kopalino**	Commune Choczewo, District Wejherowo, Pomorskie	Sea	Open	Baltic Sea (on the sea) Raw water: basic - Lake Żarnowieckie (10 km), reserve - river Łeba (27 km)	Baltic Sea: as in point 12 River Łeba (above outlet to Lake Łebsko): as in point 12	Sufficient
14	**Tczew**	Commune Tczew, District Tczew, Pomorskie	River - Wisła	Open	River Wisła km 908+600	SSQ = 1,046 m^3/s SNQ = 441 m^3/s	Sufficient

No.	Name	Geographical data	Site type	Cooling cycle	Cooling / raw water source	Hydrological data	Sufficiency of cooling water
15	**Żarnowiec**	Commune Krokowa, District Wejherowo, Pomorskie	Lake - Lake Żarnowieckie	Closed (hybrid towers)	Lake Żarnowieckie, additionally: river Łeba (35 km) Raw water: underground water intake	Lake Żarnowieckie: 14.31 km^2, 114.5 million m^3; depth: average – 8.4 m, max – 16.0 m, retention layer: 29.4 million m^3, River Łeba (Cecenowo): SSQ = 11.0 m^3/s SNQ = 8.95 m^3/s NNQ = 4.46 m^3/s	Sufficient
				Open	Baltic Sea (10 km) Raw water: Lake Żarnowieckie	Baltic Sea: as in point 12	Sufficient
16	**Połaniec**	Commune Połaniec, District Staszów, Świętokrzyskie	River - Wisła	Closed (wet cooling towers)	River Wisła	SSQ = 253 m^3/s (Wyszków) SNQ = 155 m^3/s (Wyszków)	Sufficient
17	**Pątnów**	Commune Konin, District Konin, Wielkopolskie	Lake - Lake Pątnowskie	Closed (wet or hybrid towers?)	5 lakes (total ca. 12 k^2): Gosławskie + Pątnowskie + Licheńskie + Wąsowsko-Mikorzyński e + Ślesińskie River Warta (7 km)	Lake Gosławskie: 4.54 km^2; depth: average - 3.0 m, max – 5.3 m Lake Pątnowskie: 3.07 km^2; depth: average - 2.6 m, max – 5.4 m Lake Wąsosko-Mikorzyńskie: 2.45 km^2; depth: average - 11.9 m, max – 38.0 m Lake Ślesińskie: 1.48 km^2; depth: average – 7,5, max – 25.7 m	? Lack of sufficient hydrological data. Currently, 5 lakes are used for cooling (in open cycle) of Pątnów and Konin power plants (1448 MW_e)[216].
18	**Warta-Klempicz**	Commune Lubasz, District Piła, Wielkopolskie	Inland	Closed (wet cooling towers)	Warta (7 km) km 178 (4 km below Obrzycko)	SWQ = 368.0 m^3/s SSQ = 118.0 m^3/s SNQ = 53.4 m^3/s NNQ = 39.1 m^3/s	Sufficient
19	**Kopań**	Commune Darłowo, District	Sea	Open	Baltic Sea (3	Wieprza:	Sufficient

No.	Name	Geographical data	Site type	Cooling cycle	Cooling / raw water source	Hydrological data	Sufficiency of cooling water
		Sławno, Zachodniopomorskie			km) Raw water: Wieprza (6 km) – basic, Słupia (25 km) – reserve	SWQ = 60.50 m^3/s SSQ = 14.20 m^3/s SNQ = 7.68 m^3/s NNQ = 5.60 m^3/s	
20	**Krzywiec**	Commune Marianowo, District Stargard Szczeciński, Zachodniopomorskie	Inland	Closed (hybrid towers?)	Stawy Dzwonowskie, river Krąpiel, Lake Miedwie (22 km)	Lake Miedwie: 35 km^2, depth max – 43.8 m Complex of 36 Dzwonowskie Ponds: in total 2.78 km^2	? Lack of sufficient hydrological data.[217]
21	**Lisowo**	Commune Marianowo, District Stargard Szczeciński, Zachodniopomorskie	Inland	Closed (hybrid towers?)	Lake Marianowowskie, stawy Lutkowskie, river Krępa, Lake Miedwie (30 km)	Lake Marianowskie: 0.82 km^2 Stawy Lutkowskie: 0.43 km^2 Lake Miedwie: as in point 20	? Lack of sufficient hydrological data.
22	**Wiechowo**	Commune Marianowo, District Stargard Szczeciński, Zachodniopomorskie	Inland	Closed (hybrid towers?)	Lake Szadzko, Wiechowskie and Marianowskie; rivers Krępa and Pęzinka; Lake Woświn (20 km) Lake Miedwie (26 km)	Lake Szadzko: 0.78 km^2, depth max – 2.6 m Lake Wiechowskie: 0.19 km^2, Lake Woświn: 8 km^2, 75.84 million m^3; depth.4 m, max – 28.1 m, Lake Miedwie: as in point 20	? Lack of sufficient hydrological data.
23	**Pniewo**	Commune Gryfino, District Gryfino, Zachodniopomorskie	River	Open	River Odra	SSQ = 620 (Gozdowice) SNQ = 536 m^3/s (Gozdowice)	Sufficient
24	**Pniewo-Krajnik**	Commune Gryfino, District Gryfino, Zachodniopomorskie	River	Open			Sufficient
25	**Dębogóra**	Commune Widuchowa, District Gryfino, Zachodniopomorskie	River	Open			Sufficient

No.	Name	Geographical data	Site type	Cooling cycle	Cooling / raw water source	Hydrological data	Sufficiency of cooling water
		skie					
26	**Krzymów**	Commune Chojna, District Gryfino, Zachodniopomorskie	River	Open			Sufficient
27	**Stepnica 1**	Commune Stepnica, Zachodniopomorskie	Zalew	Open	Zalew Szczeciński	911.8 km^2 (457.3 km^2 in Polish territory); 2.75 km^3; average depth 4m; average annual Odra outflow 16.3 km^3; salinity 0.5-2.0 ‰	Sufficient
28	**Stepnica 2**	Commune Stepnica, Zachodniopomorskie	Zalew	Open			Sufficient

Explanations: SSQ – average annual flow; SNQ – average low flow value per year; SWQ – average high flow value in a year; NNQ – the lowest observed flow value

4.3.2.4 Raw water demand

Annual water demand of a PWR unit with net electric capacity of **1000 MW_e** (estimated on the basis of data for EPR[150]– **total 195 000 m^3/a** (which corresponds to average intake ca. 530 m^3/d = 22 m^3/h = 0.0062 m^3/s), of which:

Make up water for process cycles (except for a cooling water cycle) - demineralised: ca. **94 000 m^3/a** (demineralised water demand of the unit falls between ca. 256 m^3/d – during normal operation, and ca. 694 m^3/d – during start-up);

Water for other process purposes, not requiring treatment: ca. **72,000 m^3/s**;

Treated (potable) water for household needs (drinking, sanitary - WC and showers, preparing meals)[218] and industrial purposes (laundry, labs, washing electrolysers, air conditioning etc.): **29,000 m^3/s**;

<u>For comparison purposes</u>: raw water intake (underground water from the second water-bearing layer of Quaternary) for **"old" Żarnowiec power plant** (1830 MW_e gross, ca. 1700 MW_e net) has maximum capacity exceeding 500 m^3/h = 0.14 m^3/s, i.e. per 1000 MW_e net: 294 m^3/h = 0.08 m^3/s.[219]

Therefore, raw water demand of a nuclear power unit with net capacity **1000 MW_e** is relatively small (on average ca. 530 m^3/d) and **it will not restrict a nuclear power plant location.**

The sources of raw water for filling and making up process systems will be - depending on availability and hydrological and hydrogeological conditions at a specific site - surface or underground waters (from Quaternary or Tertiary formations).

4.3.2.5 Impacts of waste heat discharge into water

According to the Ordinance of Minister of Environment[220], discharge of cooling water (from open and closed cooling cycles) with temperature ≤35°C (for lakes and their affluents the limit specified in Water law[221] is 26°C)

This ordinance also specifies acceptable parameters of pollution of discharged cooling water and sewage.

The regulations currently in force do not specify separate requirements concerning introducing cooling water to the sea, however provisions of Water law are applicable to: inland waters, internal sea waters and territorial sea waters (art. 7 excerpts 1 and 2). Thus - since the Ordinance was issued pursuant to Water law (art. 45, excerpt 1, point 1 and 3) – it should be assumed that the limit of 35°C also refers to cooling water discharged to the sea.

Moreover, it should be emphasised that pursuant to the relevant Ordinance of Council of Ministers[222], introduction to water or soil of cooling water with temperature exceeding 26°C is charged with proper fees, according to differentiated rates depending on temperature and updated annually by Minister of Environment.[223].

Amount of heat discharged in cooling water from nuclear power plants is ca. **2100 MW_t/1000 $MW_{e,net}$**.

Amount of heat emission to surface water depends on a cooling system type. In open-cycle systems, heat id discharged in total by cooling water to a reservoir, whereas in closed systems with cooling towers, ca. 98.5% is given up to the air, and remaining ca. 1.5% is discharged with water (blowdown).

In an open-cycle system, with typical heating of cooling water ("cooling zone") by 10 K, discharge of **1 MW_t** heat stream requires expenditure of ca. **86 m^3/h** of cooling water**.** Discharge of **1000 MW_t** requires expenditure of ca. **23.9 m^3/s** of cooling water (with 12 K: 19.9 m^3/s). **For a nuclear power** unit with net capacity of **1000 MW_e** expenditure of cooling water is ca. **50.2 m^3/s** (with 12 K: 41.8 m^3/s).

In power engineering, tests were conducted on factors significant in dispersing large amounts of heat in surface waters. Calculations should include a number of physical phenomena, such as:

- seasonal differences in temperature of water receiving the discharge stream
- seasonal differences in water level in rivers and differences in current velocity,
- degree of mixing discharge water with dispersing water (in place of cooling water discharge and in a distance from it),
- condition of a coast and sea currents
- and convection movements in water and air.

Although ultimately the entire heat emitted by a power plant is passed into atmosphere, the large part of it is passed through aquatic environment. During heat transfer, the following physical processes take place:

- eddy diffusion,
- heat convection in water,
- flow of liquid of various density,
- evaporation, radiation and convection of heat in the air.

The amount of discharged heat and type of environment determine which process will be decisive in heat exchange and distribution process. When describing processes occurring in discharged cooling water, two characteristic areas must be distinguished: the first - in the direct vicinity of discharge and the second - remote from discharge. Before water is cooled down, heat contained in it may affect aquatic ecosystem, which should be avoided.

Direct vicinity of discharge is an area where complete mixing of heated cycle water with river water does not occur. Water temperature in this area depends on the degree of mixing discharge water with water in the receiving medium. Water heating in this area may be reduced by proper devices for quick mixing discharge water and receiving water.

The area distanced from discharge is where water was mixed at full depth. This area is a background for further emissions. Temperature increase in the remote area is gradually reduced by inflow of external water and heat exchange with the atmosphere.

In **atidal seas** (Baltic Sea) processes occurring in heated water zone mainly depend of stratified flows. Temperature drops there quickly due to mixing caused by friction and turbulence between layers. In such waters (as well as **in lakes**) dispersion or transfer of cooling water largely depend on currents caused by wind and thermocline conditions. It is estimated that **for 1MW_e 1 ha of water surface is needed.**

Assessment of water heating **in river** related to warm water discharge from a power plant is a complex issue. Water cooling process in a river is mainly associated with heat exchange between a river and atmospheric air. Thermal energy flow between water surface and atmosphere changes significantly depending on weather conditions and time of day. For better distribution and mixing of heated water at the **distance of several tens to several hundred meters**, distribution structures are located along the entire width of a river. If water discharge takes place along the river bank, complete **natural water mixing occurs at the distance of several kilometres**.

Re-suction of heated water should be avoided. In case of discharge to the sea or estuary, a degree of heated water return to the system should be reduced to minimum in order not to decrease efficiency and safety of power plant operation.

Location and construction of water intake and discharge should be designed to prevent recirculation of cooling water. Preliminary tests usually allow designing a construction of water intake and discharge and devices which will prevent recirculation and provide thorough and quick mixing of heated water. Such tests are based on physical (hydraulic) and numerical models. Using those tools in assessment of environmental impact of the planned facility ensures that **acceptable values of maximum water heating in mixing area or water temperature after mixing will not be exceeded**.

Heat emissions to surface water **may have negative environmental impact**. Factors shaping such impact are for example: Possible dispersion capacity of receiving cooling water, actual temperature and the ecological status of surface waters. Emissions of heat in heated cooling water may cause exceeding environmental quality standards (for temperature during warm summer seasons). An important factor in terms of impact of heat emission on environment is not only water temperature but also temperature increase at the border of mixing zone as a result of heat discharge to water.

Temperature increase may lead to **increased respiration and biological growth (eutrophication).** Cooling water discharge to surface waters affects the entire aquatic system, and in particular **fish population**. The temperature of water has a direct impact on all living organisms and their physiological processes, and an indirect impact on **oxygen balance in water**. Water heating **decreases amount of oxygen** dissolved in water and facilitates decomposition of organic matter, which leads to faster consumption of oxygen.

4.3.2.5.1 Case study - analysis of discharge heat emission impact for referential facility Flamanville nuclear power plant.

Analysis of discharge heat impact on surface waters: Flamanville nuclear power plant

Impact of heat discharged in heated cooling water on water reservoirs will be modelled with 3D models. Due to the fact that heat impact analyses are based on complicated calculations, perfumed on the basis of data specific for a given site and that simplified calculations do not give reliable results, **analyses may be performed only for a specific site**, in order to specify impact of discharged heat on local aquatic environment (sea, river, lake).

Such analyses have not been yet performed for any nuclear power plant site in Poland[224]; they will be performed in future only for selected sites.

Assessment for a specific site will refer to impact of heat releases on water temperature in a reservoir: near cooling water discharge and in more remote locations. 3D modelling will be used for assessment of various possible configurations of water discharge in various hydrodynamic conditions. The data needed for 3D modelling include: data on temperatures of surrounding water, temperature of discharged cooling water and flow intensity, geometrical data, data on currents and bathymetric data. The analyses will specify the scope of thermal impact (temperature growth isotherm by 1°C), temperature distribution (surface and stratification), maximum temperatures in least favourable conditions, temperatures in specific locations (particularly in the area of water intake). After discharge of heated water into cooler reservoir water, heated water rises, therefore thermal impact is located on and near reservoir surface, hence the greatest temperature increases occur **in surface layer**.

Furthermore, aquatic ecosystem will be monitored during nuclear power plant operation in order to specify the scope and character of impact of discharged heat.

Below, as an example, some analysis results for the sea location (Atlantic Ocean) of **Flamanville power plant** in France are presented. The analyses were performed with 3D Telemac model (developed in France). Of course, they were performed for specific site conditions (with strong tides, among others) and therefore the conclusions should not be projected onto other sites.

Simulations were performed for maximum cooling water heating (cooling zone) **14°C**, with minimum flow intensity **58 m^3/s** (in normal operation conditions the parameters are 12°C and 57 m^3/s), for neap tide and spring tide conditions. Typical water outflow velocity from the distribution structures on discharge: **4 m/s**.

First, impact analyses were performed during operation of unit FA3 with EPR alone, and then with operation of 2 already existing units (with "P4” reactor) with capacity 1300 MW$_e$ each - for each unit, discharge of water heated by 15°C, with flow intensity 45 m^3/s was assumed.

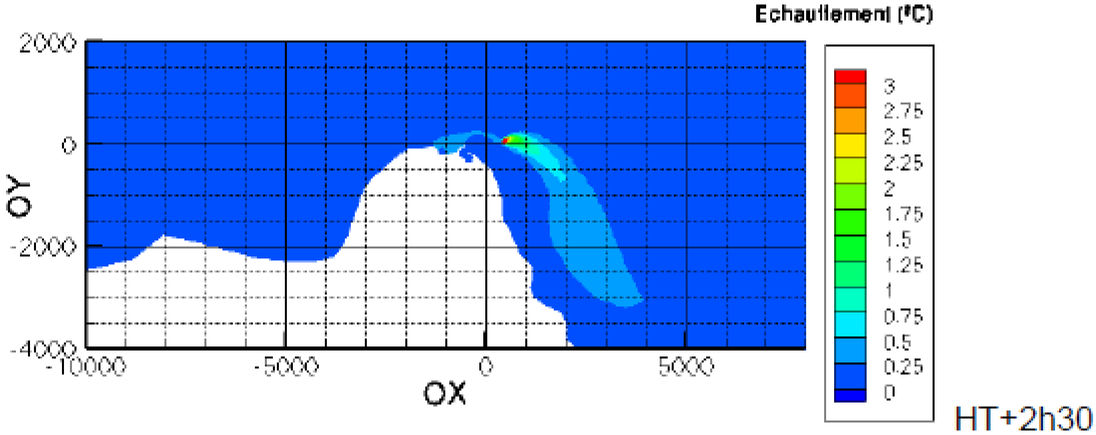
During operation of FA3 unit alone it was stated that:

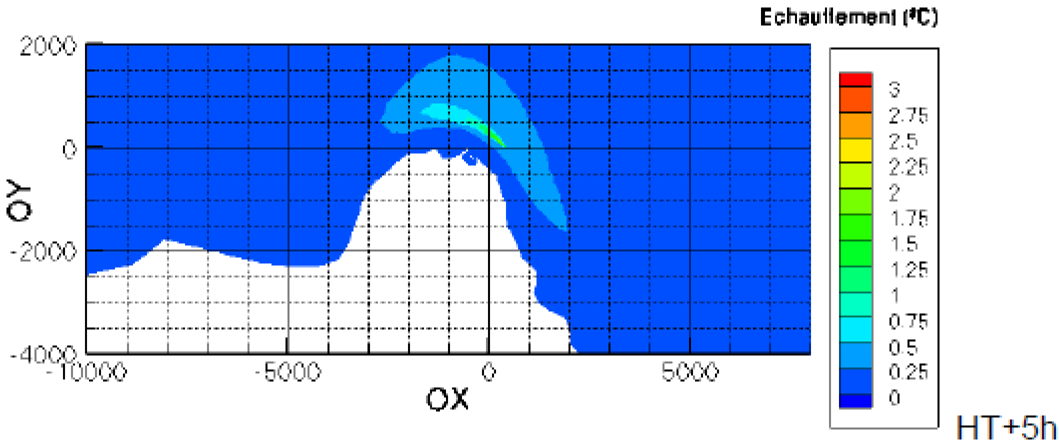
Maximum water heating in the intake area and at the shore will be ca. 0.5.

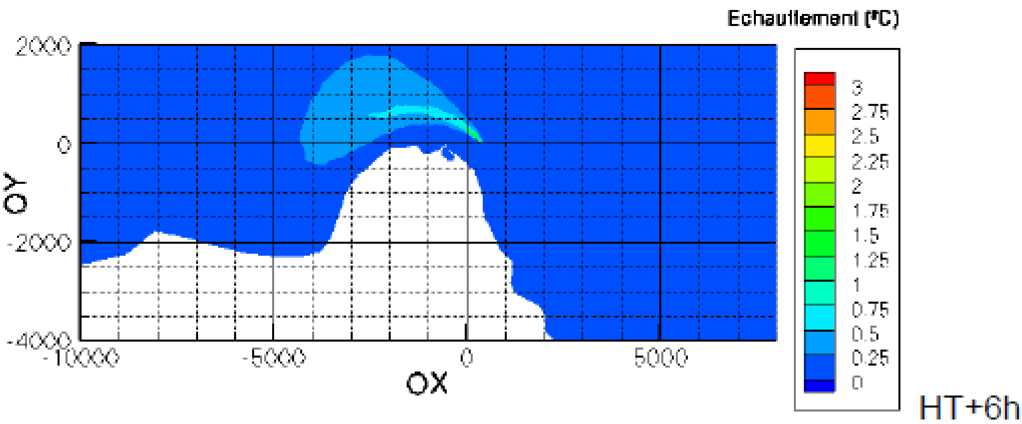
"Thermal cloud" displays vertical stratification, but becomes homogenous at a distance from discharge location.

"Thermal cloud" corresponding to increase in surface temperature by 1°C covers the area of: ca. 0.4 km^2 - in mean spring tide conditions and 0.6 km^2 - in mean neap tide conditions; whereas maximum **temperature increase at the distance of 50 m from discharge** is lower than: 6.3°C - in mean spring tide conditions, 6.3°C - in mean neap tide conditions.

Below, graphic results of simulation of maximum "thermal cloud" range are presented, +1°C with operation of FA3 unit alone, in mean neap tide conditions.



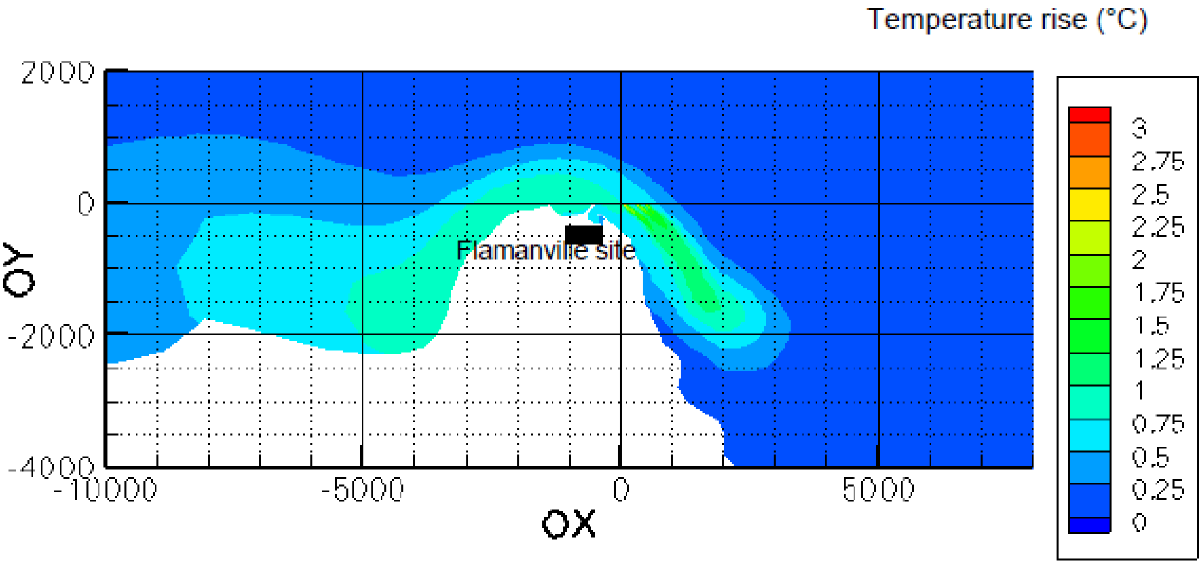




During operation of 3 units it was stated that (see figures below):

Separate "thermal clouds" from three discharge locations quickly blend together (at the distance of less than 500 m from the discharge locations).

In least favourable conditions, maximum water heating in the intake area and at the shore will be ca. 1.2□.



- "Thermal cloud" displays vertical stratification, but becomes homogenous at a distance from discharge location.

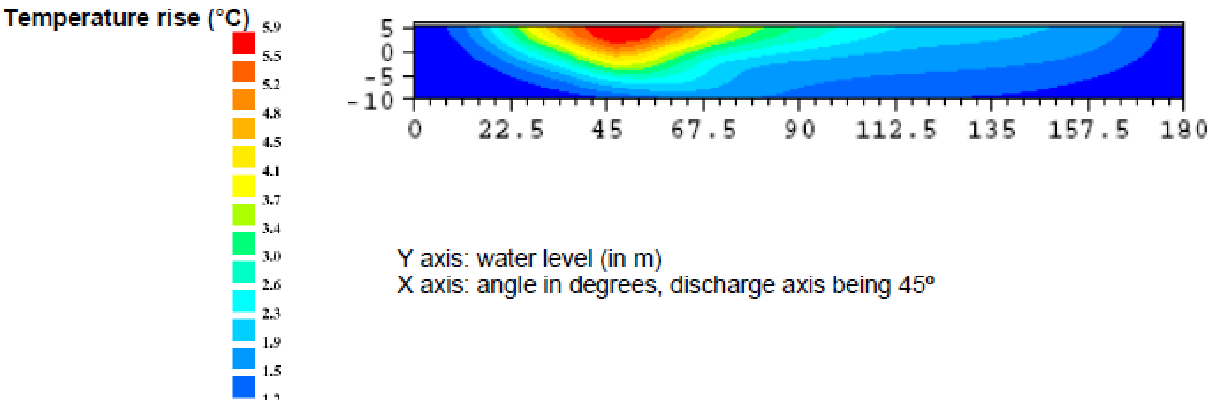
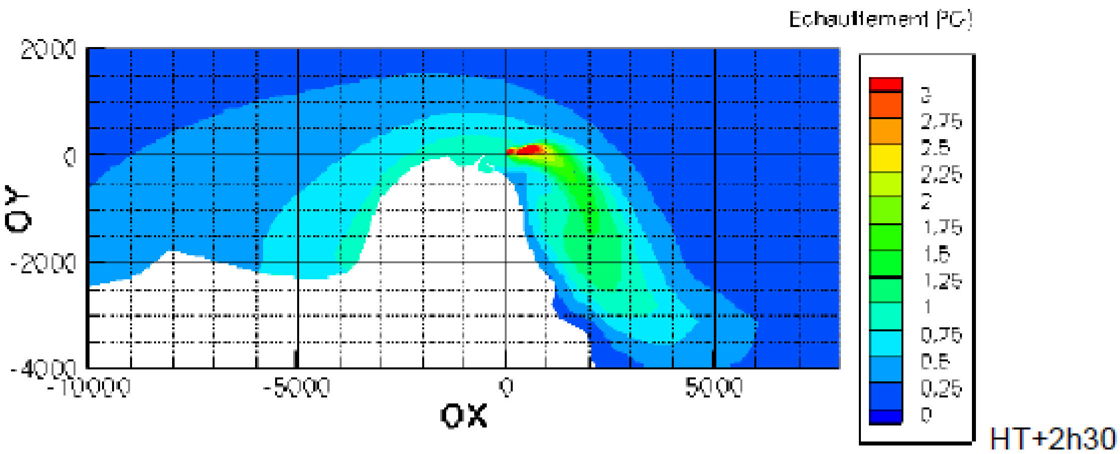
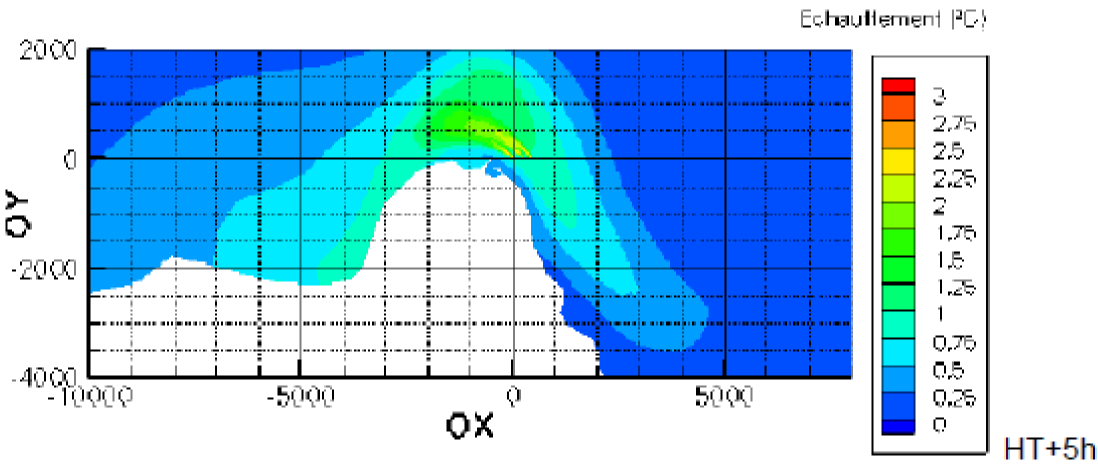
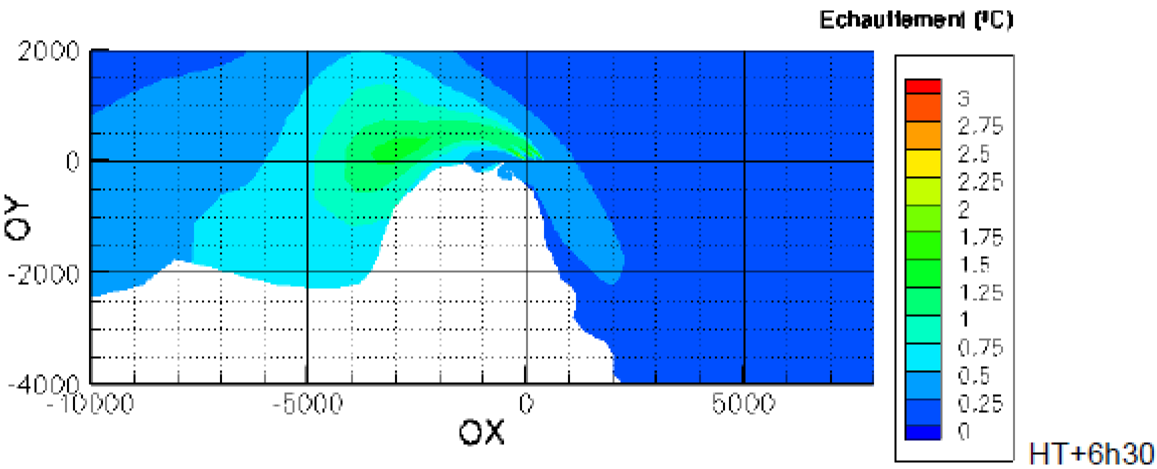


Figure 12.2-c: Temperature rise at 50 m from discharge point 3 (EPR), cross section, HT+3h30

"Thermal cloud" corresponding to increase in surface temperature by 1°C covers the area of: ca. 2.5 km^2 - in mean spring tide conditions and 8.5 km^2 - in mean neap tide conditions; whereas maximum **temperature increase at the distance of 50 m from discharge** is lower than: 6.7°C - in mean spring tide conditions (max temp. occurs in the discharge area from unit 2, which is affected by FA3), 7°C - in mean neap tide conditions (in the discharge area from unit 2).







4.3.2.5.1.1 Analysis conclusions

During operation of 3 units, water heating at the intake and at the shore, as well as in the distance o 50 m from discharge sites is the same as in case of 2 units with capacity 1300 MWe. Discharge from FA3 has partial impact on temperature at unit 2 discharge, however it contributes to temperature increase by no more than 0.3°C. therefore, adding FA3 unit does not significantly change temperature increases.

The main effect of heat discharge from FA3 is increase in heat impact surface: the surface of +1°C "thermal cloud" increases from 2.5 km^2 to 8.5 km^2.

Temperature increases, mainly observed on the surface, have minimal impact on marine ecosystem, mainly consisting of bottom-dwelling species.

Hydrobiological monitoring conducted for the last 20 years for Paluel nuclear power plant (4 units) and Gravelines (6 units) did not detect any impact of discharged heat on marine ecosystem, therefore probably adding EPR (FA3) unit at Flamanville site will not adversely affect the ecosystem.

4.3.2.6 Impacts of waste heat discharge into atmosphere

Regardless of cooling manner, all waste heat is ultimately transferred to atmosphere. In case of cooling towers, heat is directly transferred to atmosphere. In case of open-cycle cooling connected with a river, sea or lake, heat is transferred into atmosphere through the surface of water reservoir receiving discharge, which takes place on a large area and with some delay, depending on local conditions.

4.3.2.6.1 Open-cycle cooling systems

In open-cycle power plants, withy unit operating at rated power, water is usually heated by ca. 10 K. In such a system, discharged water is gradually cooled down by mixing with receiving water. Heat is then transferred to atmosphere by means of three basic processes: evaporation (35 to 45% of released energy), radiation from water surface (25 to 35%) and penetration into air (20 to 30%).

Amount of energy discharged due to evaporation corresponds to 20 kg/s of steam per 100 MW_t of discharged heat stream. The **only atmospheric phenomenon which may occur in the vicinity of water outlet is creation and maintenance of fog**. It happens due to high temperature difference, however the scope is limited.

It is worth mentioning that in the same conditions, temperature of fog creation and disappearance is higher in case of saltwater than in case of fresh water. It is beneficial for power plants located at estuaries or near the sea.

4.3.2.6.2 Closed-cycle cooling systems

In power plants with closed cycle equipped with wet cooling towers, heat is directly discharged into atmosphere. Heat discharge occurs in a concentrated manner on a small area.

Cooling towers transfer into atmosphere 70% of heat in form of latent heat (saturated steam) and 30% in form of sensible heat. It results that amount of steam discharged to atmosphere is, more or less, twice as large as with an open cycle. Humid air gets absorbed into atmosphere, with temperature exceeding ambient temperature by ca. 10 - 20 K. Outflow velocity in case of natural draught cooling tower is 3 - 5 m/s, and in case of forced draught cooling tower the velocity is twice as high. The humid air, cooled down by mixing with external air, may cause **a vapour cloud**. Shape and volume of a visible vapour cloud are affected by temperature and relative humidity of atmospheric air as well as wind speed. The colder and more humid surrounding air, the more stable is a vapour cloud. Therefore, this problem may occur mainly in winter.

The risk of **ground level fog** due to settlement of humid vapour when it is cold, humid and without wind, may occur mainly in case of forced draft towers, due to their smaller height, i.e. (40-50 m). However, using **hybrid cooling towers** usually prevents **creation of vapours**. The taller the tower, the more rare the phenomenon. It may be assumed that on the plains, settlement of vapours occurs only in exceptional situations, when a cooling tower is 50-75 m tall, depending on local conditions. With nuclear power plants, wet cooling towers will be much taller (certainly above 160 m) - which practically **eliminates the risk**.

In winter in the cooling tower area there may also occur **frost build-up** due to settling vapours of water splashed at the tower base coming into contact with frozen ground surface. However this phenomenon is only limited to **direct vicinity of a cooling tower** within the radius of several meters. The result of large amount of vapours and condensation in extreme weather conditions may also be **icy roads**.

The main climatic change related to wet cooling tower operation is **increased haze in the vicinity of cooling towers** due to generation of vapours. As a result, decrease in insolation may occur.

4.3.2.7 Protection of living organisms from being sucked into the cooling system

When cooling water is pumped, small living organisms (algae or plankton) as well as animals found in water (molluscs and fish) are sucked into the cooling system. Plankton passes through the grid of rotating filters with mesh size between 1 and 5 mm. Such a filter stops crustaceans and fish, which are flattened out on filtration panels, and then collected and ejected with filter washing water. The tests show that aspiration into cooling systems mainly refers to small organisms, such as: larvae and fry.

In the last several years, many repellent systems and devices were designed and applied, mounted on inlets to hydroelectric and thermal power plants, among others:

- In fresh water, energized screens deter some fish species, but they do not work on fingerlings, or even draw them;
- Air bubble curtains generally produced poor effects;
- Light is partially effective with certain organisms, but fish may get used to it and then the deterrent effect is only temporary;
- In some cases, acoustic deterrent systems produced good results, in some other cases - just the opposite.
- In large water inlets equipped with sliding filtration screens, organisms are removed with fish pump or low-pressure water nozzles (1 bar).

Furthermore, cooling water pumping stations are designed to reduce algae aspiration and risk of clogging the devices.

4.3.3 Impacts of chemical substance emission to water

Emission of chemical substances to surface water was estimated for a PWR reactor unit with net capacity **1000 MW$_e$**, on the basis of available data for EPR units [UK EPR: PCER, Chapter 12][225] and AP 1000 [UK AP1000 Environment Report][226], specified for typical sites of new nuclear power plants in Great Britain (on the sea or at estuaries - with open-cycle cooling). The data include emissions due to (raw) water treatment for process and maintenance purposes and due to fighting biological sediments in cooling system.

Operation of nuclear power plant generates liquid waste due to: the process itself, conditioning and maintenance/overhauls of process systems, leaks and maintenance/overhauls of power plant facilities and premises. Liquid waste may be divided into:

Radioactive waste water: containing chemical substances from processes in nuclear section (reactor and its auxiliary systems); they are processed, stored and monitored before discharge;

Non-radioactive waste water from conventional section, including sewage, mainly from:

- Raw water demineralization and potable water treatment;
- Chlorination of cooling water and generation of sodium hypochlorite;

- Products generated in cooling water chlorination (organo-halogenated compounds);
- Precipitation water from drainage and treated sewage from sewage treatment station;
- Oiled water and process sewage from engine room building.
- Below, emissions of non-radioactive substances are described.

4.3.3.1 Discharges from demineralization station

Substances produced during raw water demineralization:

Iron: partially originates from raw water, but mainly is introduced as iron chloride added as a coagulant to the settling tank. Most iron is precipitates in coagulation and flocculation processes, which are the initial stage of raw water processing. Mainly, it is in form of liquid sludge from the settling tank or washing sand filters.

Solid particle suspension: this is sludge from demineralization station and solid particle suspension from washing sand filters.

Sulphides: they are introduced during ionite regeneration with sulphuric acid or neutralisation of alkaline sewage with sulphuric acid in neutralising well.

Sodium: introduced in three stages: 1) during dosing sodium hypochlorite at the outlet from raw water storage tanks, 2) during ionite regeneration with sodium hydroxide, and 3) during sewage neutralisation from demineralization station in neutralising well.

Chlorides: introduced during dosing iron chloride and sodium hypochlorite to raw water.

Waste water from demineralization station (after neutralization) are discharged to sewage system.

Maximum annual amounts of substances discharged from water demineralization for PWR unit with net capacity **1000 MW_e**, estimated on the basis of data for EPR unit [UK EPR: PCER, Chapter 3]:

Solid particle suspensions: 1010 kg/a;

- Iron: 530 kg/a;
- Chlorides: 2,260 kg/a;
- Sulphides: 7,330 kg/a;
- Sodium: 8,450 kg/a;
- Detergents: 195 kg/a.
- Brine with 70 g/l concentration is discharged to discharge channel with flow intensity ca. 94 m^3/s).

4.3.3.2 Discharge from chlorination of cooling water

Cooling water cycles are protected against bio film and biological sediments by chlorination, performed when seawater temperature exceeds 10°C. Sodium hypochlorite is produced from seawater by means of electrolysis. Chlorination is related with discharge to sea of both residual oxidizers (both unbound and as chlorine compounds) and tribromomethane (bromoform). Also chlorides from washing devices are discharged into sea.

Regular chlorination: with active chlorine concentration **0.5 mg/l**, sequential dosing every 30 minutes for each cooling water channel.

In exceptional cases: when change in water quality may cause excessive biological sediments, which requires **1 mg/l** concentration for 10 days for each unit, to chlorinate various service water cycles. Apart from that, some service water cycles may need shock chlorination at concentration **6 mg/l**.

The amounts of discharge due to eradication of bionic sediments estimated for PWR unit with net capacity 1000 MW_e, estimated on the basis of data for EPR unit [UK EPR: PCER, Chapter 3]:

Realistic concentrations in discharge tank:

- Residual oxidizers: 0.14 mg/l.
- Bromoform: 0.0027 mg/l.

Estimated maximum concentrations in discharge tank:

- Regular chlorination:
- Residual oxidizers: 0.5 mg/l.
- Bromoform: 0.02 mg/l.

Exceptional chlorination:

- Residual oxidizers: 1 mg/l.
- Bromoform: 0.04 mg/l.

Shock chlorination:

- Residual oxidizers: 0.72 mg/l.
- Bromoform: 0.0244 mg/l.

Annual estimated weight of discharged chlorides: **1,630 kg/a**.

Total residual oxidizers (TRO) occur in cooling water cycle chlorination against biological sediments. Estimated TRO concentration in discharge tank is 0.5 mg/l. The assumed EQS is **10 µg/l** (although this is not the value specified by regulations).

As a result of dilution with cooling water and additional demand for oxidizers generated by chlorine, TRO level in the receptor water is significantly decreased. Assessment of TRO concentration in discharge tank does not include the dilution and disintegration processes.

4.3.3.3 Discharges from sewage system

Typically, sewage system accumulates:

- Precipitation from power plant premises;
- Sewage ("black" and "grey") from toilets and showers, after treatment in treatment plants, the content of discharged substances is specified by BZT_5 (**<35 mg/l**);
- Process waters not polluted with hydrocarbons or deoiled;
- Waste water from water demineralization and potable water treatment.

Phosphates or nitrogen-containing substances are not discharged into sewage system.

4.3.3.4 Discharges containing oils and hydrocarbons

Water accumulated from the unit, which may contain oil (from transformers, engine room, oil and lubricant storage) are directed into oiled sewage system, equipped with oil separator, where oil and sludge are separated before discharge into rainwater sewage system, which reduces hydrocarbons discharged to surface waters.

Water containing hydrocarbons is treated on scrubbers and oil filters, content of hydrocarbons in discharged water is below **5 mg/l**.

Furthermore, there is a subsystem collecting other polluted water (from extinguishing fires or accidentally contaminated with chemicals) to a retention tank, where its chemical composition is controlled. The water is treated in the power plant premises, if possible, or if necessary, transported to external treatment plants.

4.3.3.5 Other hazardous substances

Liquid chemicals[149] used for conditioning (cleaning) process systems may contain pollutions such as mercury, cadmium and arsenic. Nuclear power plant operators however in their specifications indicate very rigorous levels of pollutions, which must be met by suppliers. Cadmium and arsenic are not acceptable in cooling water in order to prevent corrosion and activation of those pollutions in the reactor. Therefore, they may only occur in trace amounts in chemicals used for cycle conditioning, such as phosphoric acid.

waste water before being directed to retention tanks are filtered and treated on ion-exchange columns. It may be assumed that only small fraction of pollution introduced to the cycles will get to discharge tanks and be discharged to surface waters. Therefore, it may be stated that these substances, introduced temporarily to the systems in trace amounts, may be found in liquid discharge only in trace amounts.

Silver[149] may occur **in trace amounts** as Ag110m, as control rod corrosion product. Impact of those releases is included and assessed in terms of radioactive releases. Occurrence of silver in chemicals applied in power plant is not expected. Chemical specifications concerning content of other contaminations (e.g. arsenic in boric acid) serve as indicators of total pollution content in chemicals (including silver). Analyses of those indicators have shown that in chemicals for conditioning **measurable traces of silver do not occur.**

4.3.3.6 Assessment of total amounts of chemicals discharged into surface waters

Substances discharged into cooling reservoir during operation of EPR or AP 1000 unit, for which acceptable environmental quality standards were specified (EQS) are: ammonia or ammonium hydroxide, boron, iron, copper, chromium, nickel, zinc, lead and total residual oxidizers (TRO).

- Ammonia / ammonium hydroxide is dosed into secondary cycle (steam-water) to obtain pH value at which corrosion is lowest.
- Boron is needed in various process cycles as neutron-absorbing substance.
- Metal contamination as a result of material wear in process cycles can be found in liquid waste related to radioactive releases. These are metals of pipelines or certain devices (iron, nickel, zinc, copper, chromium and lead). The main factor reducing the amount of metal pollution is maintaining proper chemical regime conditions. Despite the fact that liquid discharge is filtered and treated on ion-exchange columns, still small amounts of those metals are found in discharge water reservoirs.

- Iron comes from chemical conditioning (cleaning) of process cycles and from water demineralization.
- Sodium perchlorate is a biocide for eradication of biological sediments in open seawater cooling cycle (AP 1000).
- Ammonium chloride is used for eradication of algae in open seawater cooling cycle (AP 1000).
- Hydrazine is used for removing oxygen in primary cycle during cold unit start (AP1000).
- Monoethanolamine is used for chemical correction (pH) in secondary cycle (AP1000).
- Lithium hydroxide is used for chemical correction (pH) in primary cycle (AP1000).
- Zinc acetate is used as corrosion inhibitor in primary cycle (AP1000).
- Total residual oxidizers (TRO) are produced due to water processing in cooling cycle to eradicate biological pollution.

The table below (Table 4.3.10) presents maximum annual amounts of discharged substances during operation of PWR unit with net capacity **1000 MW_e**, estimated on the basis of data for EPR unit [UK EPR: PCER, Chapter 12] and AP 1000 [UK AP1000 Environment Report].

Table 4.3.10 Maximum annual amounts of discharged substances during operation of PWR unit with net capacity 1000 MWe.

Substance	Cycle conditioning [kg/a]	Production of demineralised water [kg/a]	Annual amount discharged to environment [kg/a]
Ammonia (non-ion) [EPR]	104	-	104
Ammonium hydroxide [AP1000]	26 300	-	26 300
Boric acid [EPR – AP1000]	4 375 – 6 970	-	4 375 – 6 970
Boron* [EPR – AP1000]	765 – 1 220	-	765 – 1 220
Hydrazine [AP1000]	330	-	330
Monoethanolamine [AP1000]	99,4	-	99,4
Lithium hydroxide [AP1000]	5,7	-	5,7
Zinc acetate [AP1000]	1,1	-	1,1
Iron [EPR]	10,2	530	540,2
Copper [EPR]	0,1	-	0,1**
Nickel [EPR]	0,1	-	0,1**
Zinc [EPR]	1,8	-	1,8**
Lead [EPR]	0,06	-	0,06**
Chromium [EPR]	2,43	-	2,43***
Aluminium [EPR]	1,54	-	1,54***
Magnesium [EPR]	0,96	-	1,54***

Trace metal contamination from chemicals [AP1000]	2,9	-	2,9
Ammonium chloride - algaecide [AP1000]	5 610	-	5 610
Sodium hypochlorite - biocide [AP1000]	120 400	-	120 400

** Boron contained in H_3BO_3*
*** Among metals for which EQS was specified, emission amounts are insignificant for copper, nickel, zinc and lead; despite that impact assessment is performed.*
**** Emissions of metals for which EQS was not specified (aluminium and magnesium) are insignificant.*

In environmental impact assessment, only the substances were included for which environmental quality standards (EQS) were specified – Table 4.3.11. Impact of other substances is assessed in reference to a specific site.

Table 4.3.11 Environmental quality standards (EQS)

Substance	Type of eqs	Eqs [µg/l]
Ammonia (non-ion)	-	21*
Boron	Total average annual	7 000
Iron	Dissolved average annual	1 000
Copper	Dissolved average annual	5
Nickel	Dissolved average annual	30
Zinc	Dissolved average annual	40
Lead	Dissolved average annual	25
Chromium	Dissolved average annual	15
Mercury	Dissolved average annual	0,3
Cadmium	Dissolved average annual	2,5
Arsenic	Dissolved average annual	25
Total residual oxidizers (TRO)	Maximum acceptable concentration	10

** Value proposed in IPPC H1 guidelines (July 2003).*

Table 4.3.12 Assessment of emission of substances to surface waters during operation of PWR unit with net capacity 1000 MWe. [UK EPR: PCER, Chapter 12] and [UK AP1000 Environment Report]

Substance	Annual discharge [kg/a]	DC** [µg/l]	EQS [µg/l]	DC/EQS [%]	PC** [µg/l]	PC/EQS [%]
Ammonia (non-ion) [EPR]	104	0,08	21	0,4	0,015	0,075
Ammonium chloride [AP1000]	5 610				≤11	
Boron [EPR – AP1000]	765 – 1 220	0,58	7 000	0,008	0,12 - 0,19	0,002 - 0,003
Hydrazine [AP1000]	330		-		0,3	
Monoethanolamine [AP1000]	99,4		-		0,09	
Lithium hydroxide [AP1000]	5,7		-		≤0,005	
Zinc acetate [AP1000]	1,1				$<3.4x10^{-5}$	
Iron [EPR]	540	0,41	1 000	0,04	0,08	0,008
Copper [EPR]	0,12	0,0001	5	0,002	0,00002	0,0004
Nickel [EPR]	0,13	0,0001	30	0,0003	0,00002	0,00007
Zinc [EPR]	1,7	0,0013	40	0,0033	0,0003	0,0007

Lead [EPR]	0,09	0,00007	25	0,0003	0,00001	0,00005
Chromium [EPR]	2,43	0,002	15	0,0122	0,0004	0,002
Trace metal contamination from chemicals [AP1000]	2,9		Table 10.3.9		0,0027	
Ammonium hydroxide - algaecide [AP1000]	26 300		-		≤11	
Sodium hypochlorite - biocide [AP1000]	120 400		10 (TRO)		≤200	≤2000
Total residual oxidizers (TRO)* [EPR]	-	500	10	5000	100	1000

** Value estimated according to assumptions below.*
*** For all metals, the discharge concentration refers to total content and not to dissolved fraction, therefore discharge assessment is conservative, as EQS for metals refer to dissolved fraction.*

If **concentration in discharge reservoirs DC** (Discharge Concentration) and **discharge concentration after dilution PC** (Process Contribution) of a given substance are lower than 1% of environmental quality standard (EQS) , its environmental impact is not analysed.

<u>Conclusion</u>: The forecasted **DC and PC are below 1% EQS** for all substances except TRO. Therefore, their impact on receptor reservoir environment is insignificant. Thus, more precise assessment of their environmental impact is not necessary, except for TRO.

4.3.3.1 Impacts of salt discharge into water

Using surface waters for cooling is connected with **emission of chemicals to environment**.[227] These may be, in particular:

- agents for protection against scale settlement in cooling systems with cooling towers;
- agents for eradication of biological sediments, and reaction products of some of them;
- corrosion products of heat exchangers and pipelines;
- substances suspended in the air, introduced via a cooling tower.

The common materials in heat exchangers, channels, pumps, and screens are carbon steel, cupro-nickel and various stainless steel variations; titanium is used increasingly often. For surface protection, paints and coats are used.

In case of **marine environment**, to maintain proper purity of systems and provide their proper operation, **biocides** are used. In seawater cooling systems, prevention from mollusc growth is most important. Currently, **chlorine** is used for this purpose (in form of sodium hypochlorite). It is usually produced on site in seawater electrolysis. It allows avoidance of hazards related to transport of NaOCl.

Chlorination may be constant and periodical (seasonal) depending on many factors, such as weather, water quality, cooling system structure or typology of biological sediments (settlement periods and rate of growth). Usually, chlorine is applied in small doses so that concentration of free chlorine in system outlet is within **0.1 and 0.5 mg/l** (sporadically 0.7 mg/l). However, when chlorine reacts with some organic compounds, it may create organo-halogenated substances (in seawater mainly bromoform). Tests show that bromoform concentration in heated water zone near cooling water outlet from a power plant located on the coast is very low (ca.15 µg/l).

Chlorination with sodium hypochlorite is a chemical treatment method which protects against sediments and is **commonly** applied for system protection **in coastal power plants**. Another successfully applied oxidizer is chlorine dioxide.

For many years, coastal power plants have been using alloys with titanium for construction of heat exchangers. For this reason, corrosion in those systems is insignificant or non-existent. In standard designs of III and III+ generation nuclear power plants stainless steel of titanium alloys were used for turbine condenser pipes.

In **river power plants** effect of chemicals largely depends on the type of cooling system and various biological factors.

In closed-cycle cooling system scale settlement occurs, which requires application of a proper manner of **makeup or cooling water treatment**. The following treatment methods may be applied:

- makeup water softening (decarbonisation) with lime,
- water processing (grafting) with acid in cooling cycle,
- processing with precipitating retardant,
- combination of the following treatment types: acid grafting and inhibitors of scale settlement or softening with lime and acid grafting.

Selection of treatment method depends on many criteria. Among them are the following:

- cycle thickening coefficient (K);
- river water chemical composition;
- cooling system structure.

With high thickening coefficient (3 to 7) **makeup water softening with lime** is used, which can be **supplemented with light acid grafting** (in most cases, sulphuric acid is used).

The aim of softening makeup water with lime is to increase water pH to 10 in order to precipitate calcium and some magnesium in form of carbonate and hydroxide. At the decarbonizer outlet, concentration of residual calcium is between 0.5 and 1 [mequivalent]. However, it is combined with carbonate which is responsible for high settlement of scale from treated water. To maintain balance in decarbonised water, sulphuric acid grafting is often performed.

Softening with lime causes **generation of large amounts of sludge** (mainly containing calcium carbonate $CaCO_3$ and magnesium hydroxide $Mg(OH)_2$). Moreover, due to pH increase, softening with lime may cause precipitation of certain heavy metals, which will be present in discharge water.

Sludge resulting from precipitation in softening process collects at the bottom of settling tank. It is usually pumped to sludge thickener, where due to further settlement, concentration of solid particles increases. The process is usually aided by feeding polyelectrolyte. Clear water returns to settling tank, and concentrated sludge is further dried in vacuum drum filters or band filters. Granulated sludge generated from drying with water content at ca. 50% is removed to dumps. No adverse environmental effect from sludge collected on dumps after water softening was noted.

Desalination of closed cooling cycle does not result in introduction of additional salt into the reservoir from which makeup water is taken. On the contrary: it is a smaller amount, as in decarbonisation process, significant amounts of calcium and magnesium are removed, which then as removed as sludge.

Constant **chlorination of cycle systems**, aiming at elimination of biological sediment on **condenser tubes** was eliminated a long time ago and replaced with mechanical methods (Taprogge, Techno systems etc.). Despite that, chlorination is still an effective treatment method. In practice, five chlorination methods may be used:

- end of season chlorination: for example constant chlorination with low concentration (0.5 mg/l) for 2-4 weeks at the end of period of settlement of freshwater clams Dreissena polymorpha (zebra mussel);
- periodical chlorination: several periods of constant biocide adding during the settlement period;
- irregular chlorination: frequent short-term dosing (e.g. once per day or three days, for several minutes to one hour);
- constant chlorination with low concentration during clam settlement;[228]
- semi-constant chlorination is based on short dosing periods (15-60 minutes) and identical periods without dosing.[229]

Intense chlorination (shock dosing) is a special method developed to remove fibrous algae occurring in open reservoirs and cooling tower fills. Concentration at dosing point is 5 to 25 mg Cl_2/l. To avoid releasing chlorine to environment, outlet pipes are closed for several hours. They are open when free chlorine concentration in water decreases below maximum discharge concentration. Depending on local requirements, the value may be from 0.1 to 0.5 mg TRO/l.[230] Some local requirements are specified according to flow rate. This treatment method is not applied in all facilities. Frequency of intense dosing largely depends on water quality, thickening coefficient and general cycle purity. It may be used weekly, monthly or quarterly.

Chlorine reaction with hummus and fulvic substances creates **organo-halogenated compounds**. In fact, concentration of bromide ions in river water is small. In such conditions, only organo-halogenated compounds are created. There are also such volatile compounds as chloroform, dichloromethane, (POX) and adsorbable organically bound halogens (AOX).

However, similarly to seawater, presence of halogenated carbohydrates in surface inland waters is not only caused by chlorination in cooling systems. Other possible sources are particularly agriculture and natural processes. In clean lakes, e.g. in Sweden - concentration of adsorbable organohalogens (AOX) is from 10 to 190 µg Cl/l. The highest concentrations were noted in very eutrophic lakes.

Chlorination in open-cycle cooling systems does not cause significant increase in halogenated carbohydrates. It is because the exposure time is very short - max. ca. 10 minutes, and free chlorine concentration is low. Depending on applied chlorination method, measured peak concentrations of POX and AOX are respectively 0-10 µg Cl/l and 20-150 µg Cl/l. The values correspond to free chlorine concentration at dosing point between 0.5 and 10 mg/l.

Chlorination in closed cycle may lead to higher concentrations of organo-halogenated compounds. The following factors play a negative role in this process:

- longer exposure time
- circulation increases precursor concentration.

It should also be mentioned that pH increase related to release of CO_2 favours creation of POX. These are easily transferred to atmosphere via cooling towers.

With free chlorine concentration at dosing point between 5 and 25 mg/l and with exposure time 2-70 hours, POX concentration is 0-10 µg Cl/l, and AOX 200-2,500 µg Cl/l.

It should be mentioned however that presence of small amount of ammonium ions in natural water may significantly reduce concentration of POX and AOX. It happens because kinetics of reaction Cl-NH_4^+ ids faster than kinetics of reaction between chlorine and aromatic compounds.

Area exposed to concentration of TRO (total residual oxidizers) > 10 µg/l will be limited to direct surroundings of discharge location. Moreover, it is improbable that aquatic organisms suffer negative effects from TRO discharge. Sea bottom-dwelling organisms will not be in the discharge cloud, fish (and other mobile organisms) will not remain within the discharge cloud for a long period of time, before its dilution. Chlorine dosing and TRO discharge estimation largely depend on specific site, information on water quality and thermal cloud modelling are necessary. Thus, assessment of impact of TRO discharges will be performed in future for specific sites.

4.3.4 Impacts of chemical substance emission to atmosphere

In considerations regarding air, long-term forecast of air quality change must be included at national scale for main power engineering pollutions – SO2, NOx and PM10 and PM 2.5 – included in air quality assessment.

4.3.4.1 Emissions to atmosphere from cooling towers

Wet or wet-dry cooling towers may emit pollution by lifting and escape of chemical substances for water treatment, in particular biocides. It is known that escape of chemical substances increases with temperature increase, but the mechanism leading to emission of pollutions is more complex and dependent on many factors. Therefore, it is difficult to specify quantitatively, Quality and quantity of direct pollution emission from cooling towers is specific for each case and depends on treatment substances, their concentration in circulating water and effectiveness of mist elimination.

However, pollution emissions are significantly reduced by windage eliminators, mounted in all modern wet cooling towers; they allow reduction of water lift to 0.01% or less with regard to entire flow.

An attempt was made at estimation of pollution emission with a simplified model[231]. It results from the data that emission concentrations are low (µg/m^3), but should not be neglected and that structure and location of cooling tower outlet are important - due to location of air inlets to A/C systems or other cooling installations.

Water drops released from wet cooling towers may be contaminated with chemical substances for water treatment, micro-organisms or corrosion preventing products. Using windage eliminators and optimised water treatment program will allow for decreasing potential risk.

Forming vapours is also taken into account where fog effect occurs or where a risk occurs that the vapours will reach ground level.

Emission to atmosphere occurring in wet cooling towers becomes particularly significant in direct vicinity of urban areas, however compared to other industrial air pollutions, it may be deemed relatively insignificant.

The problems which may occur during operation are as follows:

- water drops containing certain water treatment substances,
- growth of bacteria (leading, e.g. to legionellosis) in case of improper water treatment with biocides and improper maintenance of a cooling tower.

4.3.4.2 Gas emissions related to the process

During normal operation, potential sources of non-radioactive emissions are chemical releases, including vehicle exhaust emissions.

In terms of chemical releases, the following main groups were identified:

- sulphur and nitrogen oxides contained in exhaust gases from emergency generator motors, supplying power during their periodical tests;
- formaldehyde and carbon monoxide emitted by insulation to ventilation system and released via ventilation chimney;
- ammonia released from steam generators during temperature increase accompanying power unit start-up.

According to H1 methodology[232] and conservative assumptions, it was stated that:

- emissions of formaldehyde, nitrogen oxide and ammonia should not have significant impact on air quality, further impact modelling is not justified;
- emissions of sulphur and nitrogen oxides are above significance limits for environment, therefore they require further assessment - at the stage of detailed environmental impact assessments at specific sites.

With regard to unpleasant odours, sources of odour emissions exist during construction and operation stages (diesel exhausts, formaldehyde, ammonia), but they occur for short periods of time. Therefore their significant adverse effects seem improbable.

4.3.4.2.1 Emissions during emergency tests of diesel generators

Maximum emissions for PWR unit with net capacity **1000 MW_e** were estimated on the basis of data for EPR unit [150] with 4 emergency diesel generators (*"Emergency Diesel Generators"* – to supply 4 groups of security systems) each with capacity 7.5 MW_e, and additional 2 generators (*"Ultimate Emergency Diesel Generators"* – in case of failure of power supply from external grid) each with capacity 2.5 MW_e. <u>For comparison purposes</u>: AP 1000 unit has 2 generators with capacity 4 MW_e each and 2 generators 35 kW each.

Total annual test duration for each generator is estimated at less than 20 hours.

Estimated emissions of sulphur and nitrogen oxides:

- sulphur dioxide: annual emission - 517 kg/a, emission intensity – 1.63 g/s,
- nitrogen oxides: annual emission - 5,425 kg/a, emission intensity – 17.13 g/s,.

4.3.4.2.2 Emissions due to heating of new insulation materials

Some pipelines in reactor building have insulation made of materials from which after heating - due to thermal decomposition - steam is released, containing formaldehyde, which in turn may produce carbon monoxide.

Estimated gas release rate: formaldehyde – 15.2 mg/s; carbon monoxide - 14.3 mg/s.

Ammonia emissions

Ammonia emissions from steam generators during unit start-up are estimated with a conservative assumption that all hydrazine contained in water will disintegrate into ammonia and that 2/3 of ammonia in water will be released to atmosphere.

Annual amount of released ammonia: 12.5 kg, maximum release rate: 1.95 g/s (estimated duration of ammonia emission - 88 hours).

4.3.4.3 Reduction potential of atmospheric pollution emissions

One of the outcomes of the Programme will include the partial replacement of electricity generation in coal-fired power plants with electricity production in nuclear power plants. As the emissions of pollutants to the air are much lower for nuclear power plants, the Programme will reduce the emissions of pollutants in the atmosphere resulting from electricity generation. This Chapter attempts to estimate the possible reduction of these emissions. To estimate them, one has to assume the amount of produced power which will be replaced with nuclear power engineering. Polish power engineering policy until 2030 assumed contribution of nuclear power in total power production above 10%. In Polish Nuclear Programme, contribution of nuclear power in fuel structure in 2030 was assumed at 15.7%. Emission reduction potential in nuclear power plants should result from proportion of nuclear power plant contribution in covering the amount of power production. Decrease in production of coal-fired power plants must be included [assumption: 141 TWh(2008) – 110 TWh(2030)] and increase in gross demand for power [217 TWh(2030) – 141 TWh(2010)]. This means that power demand of 107 TWh will be covered by other sources than coal-fired power plants, being nuclear power plants, OZE and gas power plants. It results from the share proportion of the sources in 2030 assumed in the Programme, that ca. 38% of this demand will be covered by nuclear power engineering, which gives ca. 40TWh. Such amount of power can be produced by the designed power units with total capacity ca. 5000 MWe[1], because III generation power plants are characterised with very high installed power consumption coefficient (ca. 92%). Should the Programme not be implemented, the power would be generated by coal-fired power plants, which would generate larger emissions to atmosphere. To sum up, ca. 18% of power produced in 2030 will be replaced with nuclear power engineering (40TWh/217TWh=0.18). It should be emphasised that the calculated amounts are estimated values, calculated on the basis of the above assumptions and serve to show the order of magnitude and not precise figures. On current stage due to limited technical data, more precise analyses are not feasible.

4.3.4.3.1 Reduction potential of greenhouse gas emissions

Nuclear power plants (NPP) during power generation do not directly produce CO_2. Small CO_2 emissions are related to construction, operation and decommissioning of NPP. Main part of carbon dioxide emission by nuclear power industry is related to fuel cycle (uranium extraction and processing, fuel production and disposal of radioactive waste).

Nuclear power plants will not have adverse impact on climate, on the contrary – their implementation will reduce emission of CO_2 by avoiding emissions from power plants fuelled with fossil fuel. Emissions from individual power plants of various types are presented in Table 4.3.13. Data presented in the table refer to the entire life cycle, therefore they include emission from fuel extraction and processing through power plant operation to its construction and decommissioning. They are taken from a German study[233], in which the authors analysed emission and raw material consumption for various power sources on the basis of material and power flow modelling for a lifecycle of power production from various primary sources. The analyses show that definitely lowest

[1] It seems realistic, since the investor – PGE S.A. – plans building 2 nuclear power plants with total capacity ca. 6000 MWe.

emissions related to power production cycle are generated by nuclear power plants; they are 17 kg CO_2/MWh. It should be emphasised that this amount corresponds to emissions during the entire life cycle, including:

- 8 kg/MWh – related to fuel cycle;
- 5 kg/MWh – related to power plant operation (mainly transport and accompanying infrastructure);
- 4 kg/MWh – related with stages of construction and decommissioning.

Additionally, the table presents data quoted from the document by the European Commission[234], which divides power production-related emissions from individual sources into direct emissions (related to power production) and indirect emissions (related with operation of auxiliary infrastructure, fuel cycle and stage of construction and decommissioning).

Table 4.3.13 Emission of CO_2 from individual power plant types [233] [234]

POWER PLANT TYPE	CO_2 EMISSION [kg/MWh] acc. to [Marheineke, 2000] 233	CO_2 EMISSION [kg/MWh] acc. to [COM, 2008,744] [234]
Brown coal-fuelled power plants	829 - 1054	820-960*
including direct emissions	791-998	725-850 *
Hard coal-fuelled power plant	740-897	
including direct emissions	679-766	
Gas-fuelled power plant	370-417	420-640
including direct emissions	349	350-530
Nuclear power plant, EPR	16-17	15
including direct emissions	5	0

**emissions are given in total for coal-fuelled power plant, without division into brown and hard coal combustion*

Discrepancies in the quoted emissions according to various sources may result from the dates of material publications and available technologies assumed in calculations. Also in case of NPP, emissions largely depend on applied technologies, in case of NPP it involves particularly applied uranium enrichment technology. The quoted study 233 from 2000 is not fully up-to-date, as technological progress in this period allowed for further emission reductions, e.g. AP1000 reactor needs twice less materials that 2nd generation reactors. When quoting emissions of CO_2 in the entire nuclear cycle, literature sources present significant discrepancies from 4 to 20 kg CO_2/MWh. The upper limit is due to diffusion enrichment, consuming a lot of power and thus causing large releases of CO_2 (large for nuclear cycle). The lower limit corresponds to centrifugal enrichment, which requires much less energy. Currently, centrifugal enrichment becomes a preferred technology mainly due to the fact that it is much cheaper and besides emission indicator for CO_2 for nuclear cycle decreases. Therefore, we may assume that in 2020 centrifugal enrichments will be applied as the only technology and emissions will remain at the lowest forecast level.

However, even calculating emission reduction unfavourably for nuclear power engineering - the potential is very significant. Production of 1 MWh in Poland with current power production structure (chapter 6.1: 54% - hard coal, 37% - brown coal, 2% - natural gas) results in emission (OZE emission assumed at 0, conventional power industry emissions at the lowest level possible - assumption of retrofitting production cycles) at the level of ca. 714 kg CO_2. If, according to the Programme ca. 18% of power production will be replaced with nuclear power production, the emission will decrease by ca. 125kg/1MWh, taking into account the entire power production cycle in NPP. It should be emphasised that this is the minimal emission reduction potential (due to the assumptions). However, according to the presented uranium resources and technological capabilities (chapter 4.3.1.1), the initial nuclear cycle phase, producing largest emissions, will be executed outside Poland, therefore **actual reduction of CO_2** emission in Poland would be higher, exceeding **127 kg CO_2/1MWh. Therefore, execution of the Programme indicates potential of reduction of CO_2 emission by ca. 18% in relation to current emission.** Assuming the demand for gross power in 2030 in the amount of 217 TWh – **the entire emission reduction potential** in Poland due to Programme implementation would exceed **27 Tg ($27*10^{12}$g = 27 million t) CO_2.**

With assumptions presented in Polish Power Engineering Policy until 2030, assuming construction of first NPP units in 2020 and obtaining power until 2030 from NPP at the level exceeding 10% of domestic power production and more than 15% share of renewable power, forecast for changes in CO_2 emission to atmosphere shall be as presented in Fig. 4.3.39.

The data in Fuel and Power Demand Forecast until 2030 indicate that despite growing demand for final power, CO_2 emission will be decreasing by 2020 in order to slightly increase later. Growing consumption of renewable power and cogeneration largely affect this state of matters. Introduction of nuclear power in 2020 and constant expansion until 2030 (up to 4.8 GW) will allow to maintain emission in this period by ca. 8.5% below the state from 1990.

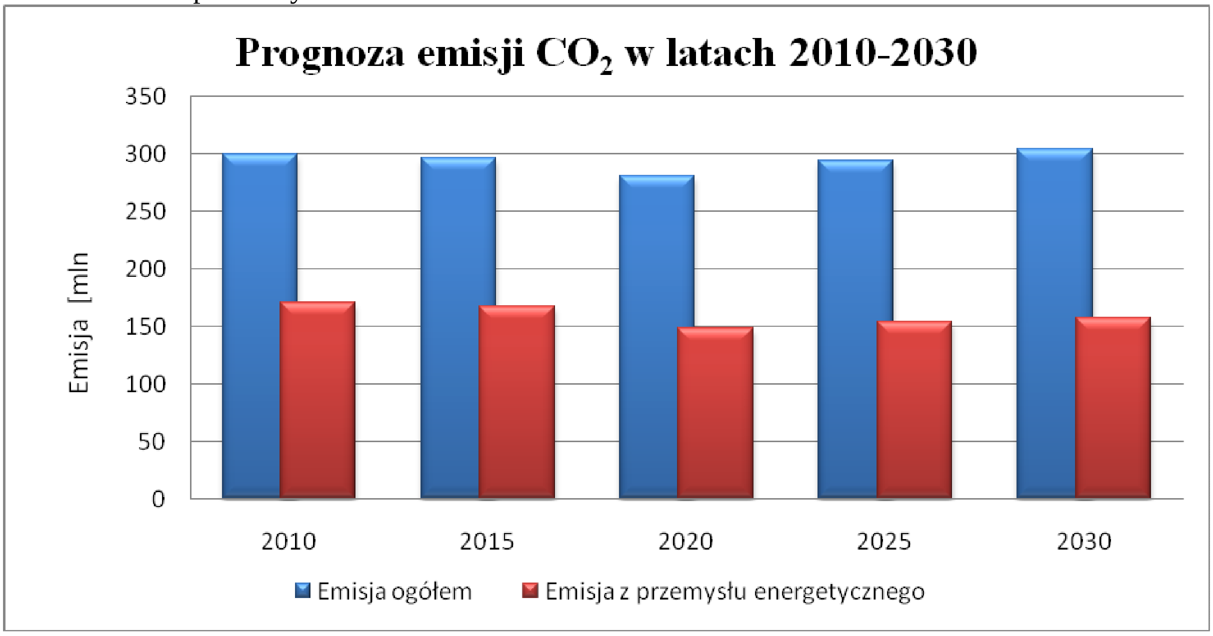


Fig. 4.3.39 Forecast of CO_2 emission based on Fuel and Power Demand Forecast by the year 2030

[Prognoza emisji CO2 w latach 2010-2030 – Forecast of CO2 emission in 2010-2030
Emisja [mln] – Emission [million]
Emisja ogółem – Total emission
Emisja z przemysłu energetycznego – Power industry emission]

In the assessment of potential of greenhouse gas emission reduction in Poland by 2030**Błąd! Nie zdefiniowano zakładki.**, 5 scenarios were presented for potential of reduction of CO_2 emission in power industry. 3 of them forecast introduction of power engineering, the other two focus on gas and renewable power industry. The highest reduction potential is forecasted for variants including construction of nuclear units in Poland. The most effective CO_2 reduction, according to the forecasts, would be achieved according to the scenario providing natural decommissioning of coal-fuelled units and covering the increase in demand for power mainly with: nuclear power - 6 GW (more than provided for in Polish Power Production Policy by 2030) and power from renewable resources - 16 GW (more than provided for in Polish Power Production Policy by 2030). Reduction potential in this case is 120 Tg $C0_2$. The second place with regard to CO_2 reduction belongs to **the scenario executing the assumptions of Polish Power Production Policy by 2030 with forecasted reduction of 97 Tg $C0_2$ (=97 million t CO_2)**.

4.3.4.3.2 Potential of reduction of emissions to atmosphere – SO_2, NO_x and dust

Besides reduction of greenhouse gas emissions, nuclear power plants will contribute to reduction of other emissions to atmosphere, such as: NOx, SO_2 and dust. As with CO_2, during normal operation of nuclear power plant significant emissions of harmful substances do not occur. Those emissions, caused by nuclear power engineering - relatively small compared to plants using fossil fuels - are mainly related to uranium extraction and processing and production of nuclear fuel. Differences in individual emissions during an entire cycle from individual types of power plants are presented in Table 4.3.14. Data presented in the table refer to the entire life cycle, therefore they include emission from fuel extraction and processing through power plant operation to its construction and decommissioning. They are taken from a German study[235], in which the authors analysed emission and raw material consumption for various power sources on the basis of material and power flow modelling for a lifecycle of power production from various primary sources. The analyses show that the lowest emissions of all analysed pollutions related to power production cycle are characteristic for nuclear power plants. It must be emphasised that in terms of total low NPP emissions, their very small part is related directly to NPP operation. Most emissions are related to fuel cycle, mainly ore extraction and enrichment, which will mostly take place outside Poland.

Table 4.3.14 Emissions to atmosphere from individual power plant types [233]

POWER PLANT TYPE	DUST EMISSION [mg/kWh]	NOx EMISSION [mg/kWh]	SO2 EMISSION [mg/kWh]
Brown coal-fuelled power plants	222-263	354-830	232-401
including direct emissions	12-20	300-763	150-318
Hard coal-fuelled power plant	56-197	414-1529	275-1762
including direct emissions	11-20	284-551	142-207
Gas-fuelled power plant	19-75	279-497	80-215
including direct emissions	0	208	0
Nuclear power plant, EPR	25	44-47	66-72
including direct emissions	5	12	18
fuel cycle	14	19-22	30-35
construction and decommissioning	7	12	18

In calculating emission reduction, the most favourable emission parameters for conventional power engineering (assuming its dynamic modernization) and the least favourable parameters for nuclear power engineering were conservatively adopted. Production of 1 kWh in Poland with current power production structure (chapter 6.1: 54% - hard coal, 37% - brown coal, 2% - natural gas) gives emission (OZE emission assumed at 0) at the level of ca. 141 mg of dusts, 349 mg NO_x and 228 mg SO_2. If, according to the assumptions, ca. 18% of power production will be replaced with nuclear power production, the emission will decrease by ca. 21 mg/kWh of dusts, 54 mg/kWh NO_x and 28 mg/kWh SO_2, taking into account the entire power production cycle in NPP. However, according to the presented uranium resources and technological capabilities (chapter 4.3.1.1), the initial nuclear cycle phase, producing largest emissions, will be executed outside Poland, therefore **actual emission reduction** in Poland would be higher, exceeding **23 mg/kWh of dusts, 58 mg/kWh NOx and 34 mg/kWh SO_2**. Therefore, execution of the Programme indicates **potential of dust emission reduction by ca. 16%, NO_x emission by ca. 17% and SO_2 emission by ca. 15%.** Assuming power demand in 2030 at 217 TWh – **the total emission reduction potential** in Poland due to Programme implementation would be ca. **5 Gg (5* 10^9g = 5 thousand t) of dust, 12.6 Gg (12.6* 10^9g = 12.6 thousand t) NOx and 7.4 Gg (7.4* 10^9g = 7.4 thousand t) SO_2.**

The data in Fuel and Power Demand Forecast by 2030 indicated expected large decrease in SO_2 emission. According to those forecasts, we can be almost certain that in 2010 SO_2 emission will be below the emission limit resulting from 2nd Sulphur Protocol, which assumes that by that year we will decrease general SO_2 emission to below 1398 thousand Mg/year. Limits for large fuel combustion facilities adopted during accession negotiations according to Directive 2001/80/WE may be harder to obtain. In 2008, we failed in Poland to keep the limit below 454 thousand Mg/year limit in 2008 r. resulting from stocktaking was ca. 500 thousand Mg[236]) but forecasts in Fuel and Power Demand Forecast by 2030 show a chance for keeping the limits in next years (426 thousand Mg/year in 2010 and 358 thousand Mg/year in 2012). Reduction of SO_2 emission will be largely affected by desulphurization installations mounted in coal and gas power plants and introduction of low emission power sources such as renewable power sources and nuclear power plants. It is expected that by 2030 emissions from large combustion sources will drop to 312 thousand Mg/year.

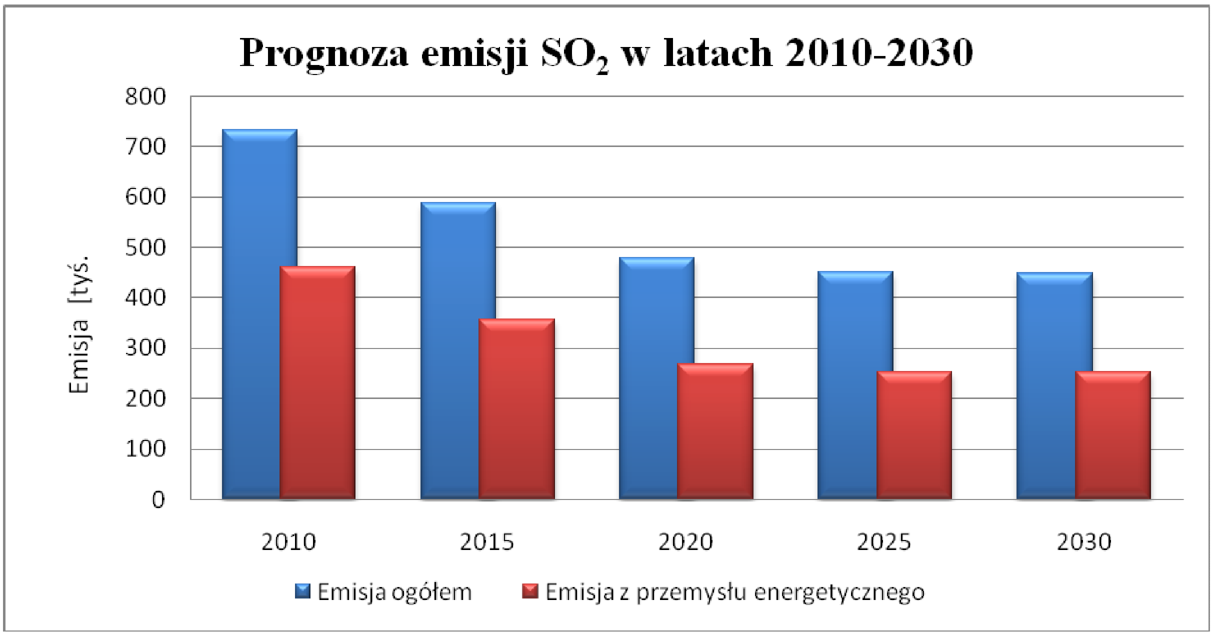


Fig. 4.3.40 Forecast of SO_2 emission based on Fuel and Power Demand Forecast by the year 2030

[Prognoza emisji SO2 w latach 2010-2030 – Forecast of SO2 emission in 2010-2030
Emisja [tys.] – Emission [thousand]
Emisja ogółem – Total emission
Emisja z przemysłu energetycznego – Power industry emission]

Limits of domestic NO_x emission, similarly to SO_2 emission will be kept. 2nd Nitrogen Protocol specifies acceptable 880 thousand Mg in 2010, and expected emission is ca. 786 thousand Mg. In terms of emissions from large power fuel combustion sources, the limit specified in UE Accession Treaty in 2008 was kept (the limit was 254 thousand Mg, and emission in 2008 was ca. 243 thousand Mg[236]). Keeping the limit in the following years (2010 - 251 thousand Mg, 2012 - 239 thousand Mg) is related to forecasted economic slowdown, due to which power demand will fall[237]. Only after 2015 significant reduction of NO_x emission will be visible, caused among others by introduction of increasing number of renewable energy sources and first nuclear units in 2020.

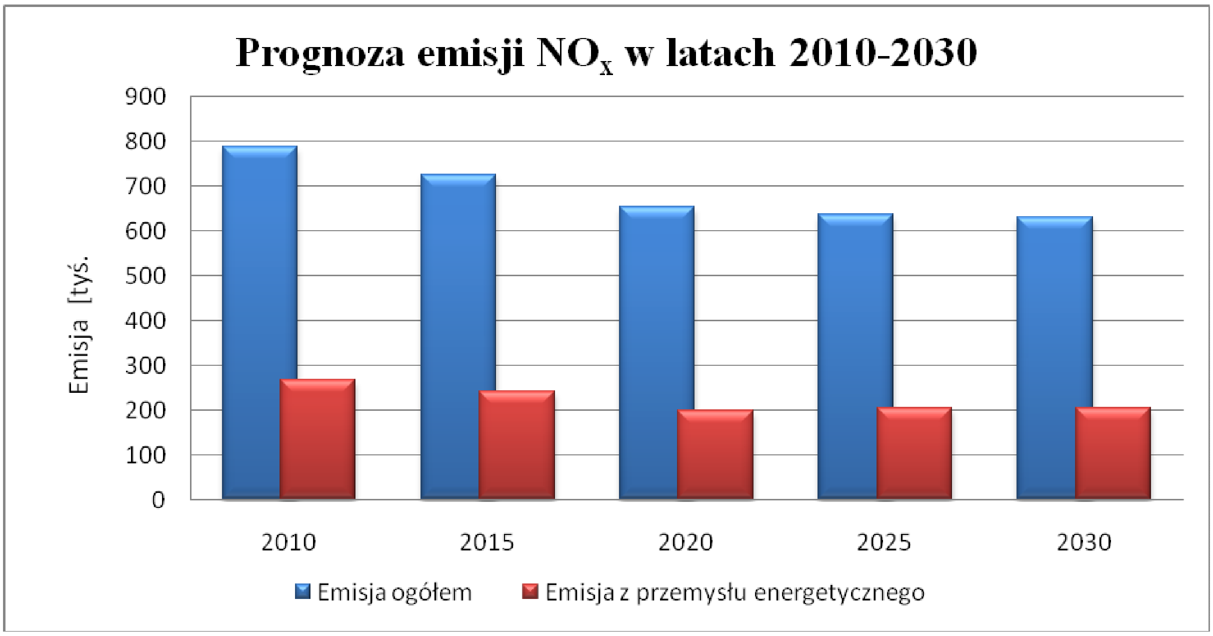


Fig. 4.3.41 Forecast of NO_x emission based on Fuel and Power Demand Forecast by the year 2030

[Prognoza emisji NOx w latach 2010-2030 – Forecast of NOx emission in 2010-2030
Emisja [tys.] – Emission [thousand]
Emisja ogółem – Total emission
Emisja z przemysłu energetycznego – Power industry emission]

In the following years, dust emission will decrease every year. The factors causing those changes will be similar as with SO_2 reduction. However, the percentage share of power industry in general emission will increase. This is due to significant emission reduction outside the power industry, among others by decreasing coal consumption in small combustion sources.[237]

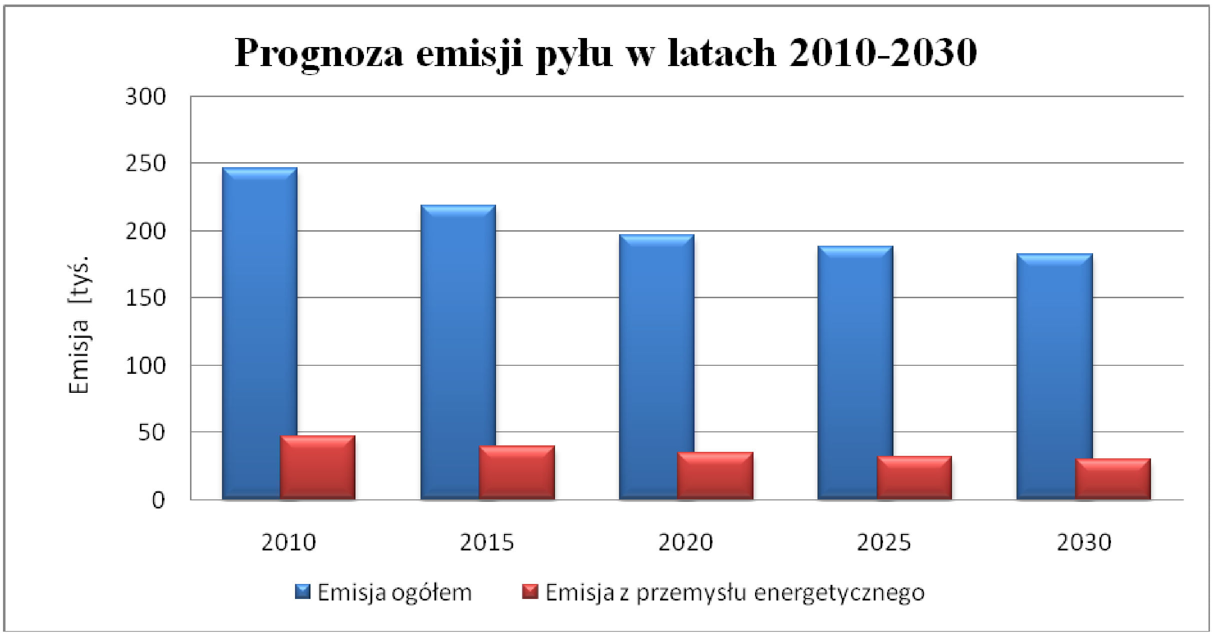


Fig. 4.3.42 Forecast of dust emission based on Fuel and Power Demand Forecast by the year 2030

[Prognoza emisji pyłu w latach 2010-2030 – Forecast of dust emission in 2010-2030
Emisja [tys.] – Emission [thousand]
Emisja ogółem – Total emission
Emisja z przemysłu energetycznego – Power industry emission]

4.3.5 Impact of noise

For EPR unit (for Europe, Flamanville 3 – FA3 is referential) it was assessed that noise level during operation, not including noise background and specific topography, will not exceed **45 dB(A) in the distance of 350 m** from primary noise sources. **Therefore, operation of the nuclear power plant will not increase the level of noise in the environment to a considerable extent.**

Noise emission is a local issue for large natural draught cooling towers and all mechanical cooling systems. Levels of non-attenuated sound fall between 70 dB(A) for natural draught cooling towers to ca. 120 dB(A) for mechanical draught towers. Those discrepancies are due to various types of equipment and various measurement places, since the measurement produces different values at air inlet and outlet.

Three main noise sources in cooling systems are:

- fans (rotor, transmissions, drive) - all forced draught cooling towers;
- pumps - all cooling water systems;

- liquid drops falling on water surface in water pans - only in wet cooling towers.

Noise generation may be direct or indirect. Sound is directly generated by:

- air intakes;
- air discharges.

Indirect sources are:

- fan drive motors;
- outlet screens from fans and linings in cooling towers.

In wet cooling towers, noise is generated only due to falling water drops (with natural draught or falling drops and operation of mechanical equipment. Generally, non-attenuated nose from fans dominates compared to noise generated by falling drops. Noise emission does not depend on the size of wet towers.

In case of wet natural draught cooling towers, the noise **in the 100 m radius** may reach **60 dB(A)**, and in case of hybrid cooling towers, noise level at the same distance reaches **70 dB(A)**.

4.3.6 Impacts related to the land take

4.3.6.1 Exclusion of biologically active area and reduction of water infiltration

A nuclear power plant is a facility that occupies a large area. Therefore, its construction and operation involves exclusion of a large bioactive area. Depending on a specific NPP site, it usually is an agricultural area or meadow ecosystem. Deforestation may be also necessary in the area of the planned development.

The actual built-up area depends on the adopted technology – the type of reactor and installation of cooling towers. The largest area occupation takes place in case of installation of EPR reactor. The figures below present the planned land development for a power plant with EPR and AP1000 reactor (Fig. 4.3.43, Fig. 4.3.44).

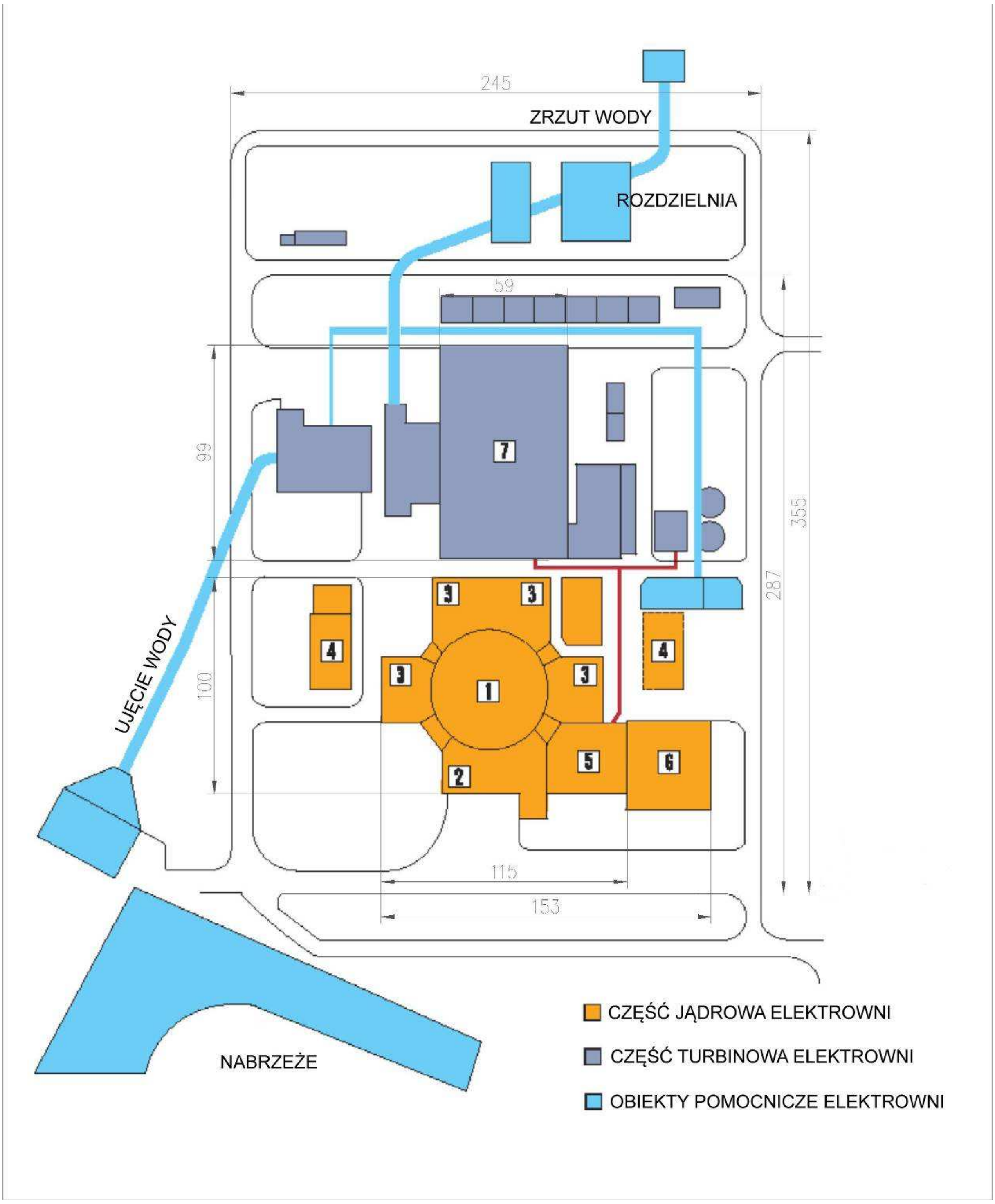


Fig. 4.3.43 Model land development for a nuclear power plant area with EPR reactor

1 - reactor building; 2 – fuel building – fresh and spent fuel; 3 – safety system buildings – UACR and emergency makeup water; 4 – emergency diesel generator and emergency power supply buildings; 5 – auxiliary nuclear building; 6 – waste building, 7 – engine room.

[Zrzut wody – water discharge
Rozdzielnia – Switching station
Ujęcie wody – water intake
Nabrzeże – Shore
Część jądrowa elektrowni – Nuclear section
Część turbinowa – Turbine section

Obiekty pomocnicze – Auxiliary facilities]

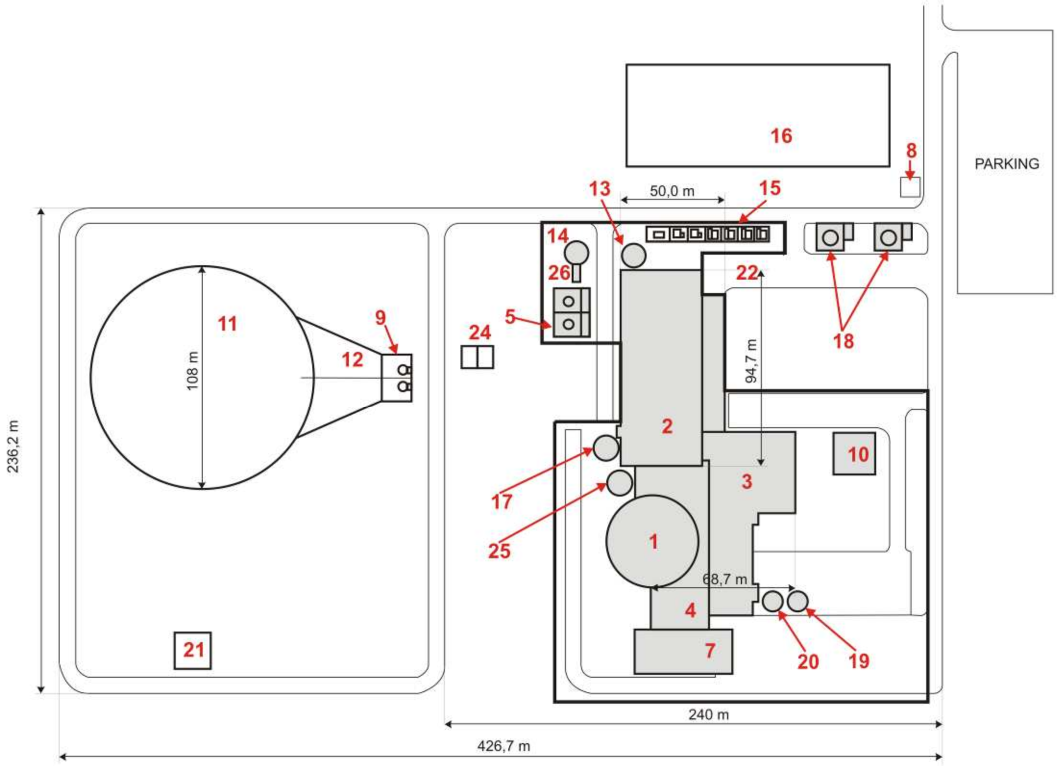


Fig. 4.3.44 Model land development for a nuclear power plant area with AP1000 reactor

1 – Containment / containment building, 2 – engine room, 3 – additional building (outhouse), 4 – auxiliary building, 5 – service water system coolers, 7 – radioactive waste building, 8 – entrance to power plant premises, 9 – water intake for cooling water cycle pumps, 10 – diesel generator building, 11 – cooling tower of cooling water cycle, 12 – water intake channel for cooling water cycle, 13 – fire water storage tank /settling tank, 14 – – fire water storage tank, 15 – transformer zone, 16 – switching station, 17 – condensate storage tank, 18 – diesel oil storage tank for generators, 19 – demi water storage tank, 20 – boric acid storage tank, 21 – hydrogen storage tank zone, 22 – engine room deposition zone, 24 – waste water retention tank, 25 – auxiliary water storage tank for passive containment cooling, 26 – diesel fire water pump / railing.

On the basis of presented model diagrams, it may be estimated that minimum (estimated) area demand (per 1 power unit) is as follows:

- EPR (Fig. 4.3.43): $245m \times 355m \approx 9ha$
- AP1000 (Fig. 4.3.44): $240m \times 236m \approx 6ha$
- cooling tower (Fig. 4.3.44): $236m \times 187m \approx 4ha$

For instance, 1 EPR OL3 unit in Finland occupies ca. 12 ha. It may be assumed that the entire power plant area, assuming construction of 2 EPR units with infrastructure will take ca. 40ha. As no detailed location analyses have been performed yet including the determination of land use, these are only estimates based on previous projects involving the construction of similar installations.

Due to sealing a significant area, infiltration will be limited, which may lead to decrease in underground water resources. Assuming estimated hardened surface to be 40 ha, mean annual precipitation in Poland at 600mm, and mean infiltration for Poland at 18%, estimated decrease in underground water supply was calculated at ca. 43.2 thousand m^3. The value should be calculated separately for specific data upon site and NPP construction technology selection, since for a specific site, annual precipitation and soil infiltration may differ, whereas technology selection determines the size of occupied area.

Amount of water by which the underground supply will be decreased will mainly get to surface water reservoirs. Rain water management is as follows:

- the power plant area is drained - usually with a ditch, then water is discharged to a lake or river);
- NPP area is drained with drainage ditches and rainwater sewage system;
- roof drainages and building drainages are usually directed to this sewage system, as well as neutralized sewage from treatment station (potable and demi water);
- rain water from sewage system is treated in rain and industrial water treatment station, after treatment water is discharged to the reservoir.

Therefore, for a specific site, impacts must be considered related to limiting underground water supply and additional surface water supply, including existing hydraulic connections between individual water-bearing levels.

4.3.6.2 Impact on availability of natural resources

When examining impact of nuclear power engineering development in Poland on natural resources, one must consider two direct impact options: limiting access to mineral deposits due to foundation of the entire power plant complex and direct impact on natural resources demand and application in power industry.

Due to the growing power demand in Poland and planned construction of a nuclear power plant, an issue arises of nuclear fuel supply to power plants. The balancing and availability analysis of radioactive deposits in Poland indicates that they are rather limited and economically non-viable, and the demand will rather be covered from external sources. We can expect that the development of nuclear power will result in a significant reduction in the demand for fossil fuels – which may decrease from 20% to 25% depending on the adopted option [238].

When planning investment sites, one should include an option of mineral deposits in the area of future investment. Upon analysing the available distribution maps for hard, brown coal and peat deposits, petroleum and natural gas deposits, metal ore and chemical deposits, solid rock and ceramic and refractory material deposits, it may be concluded that in the planned investment area, utility mineral deposits do not occur.

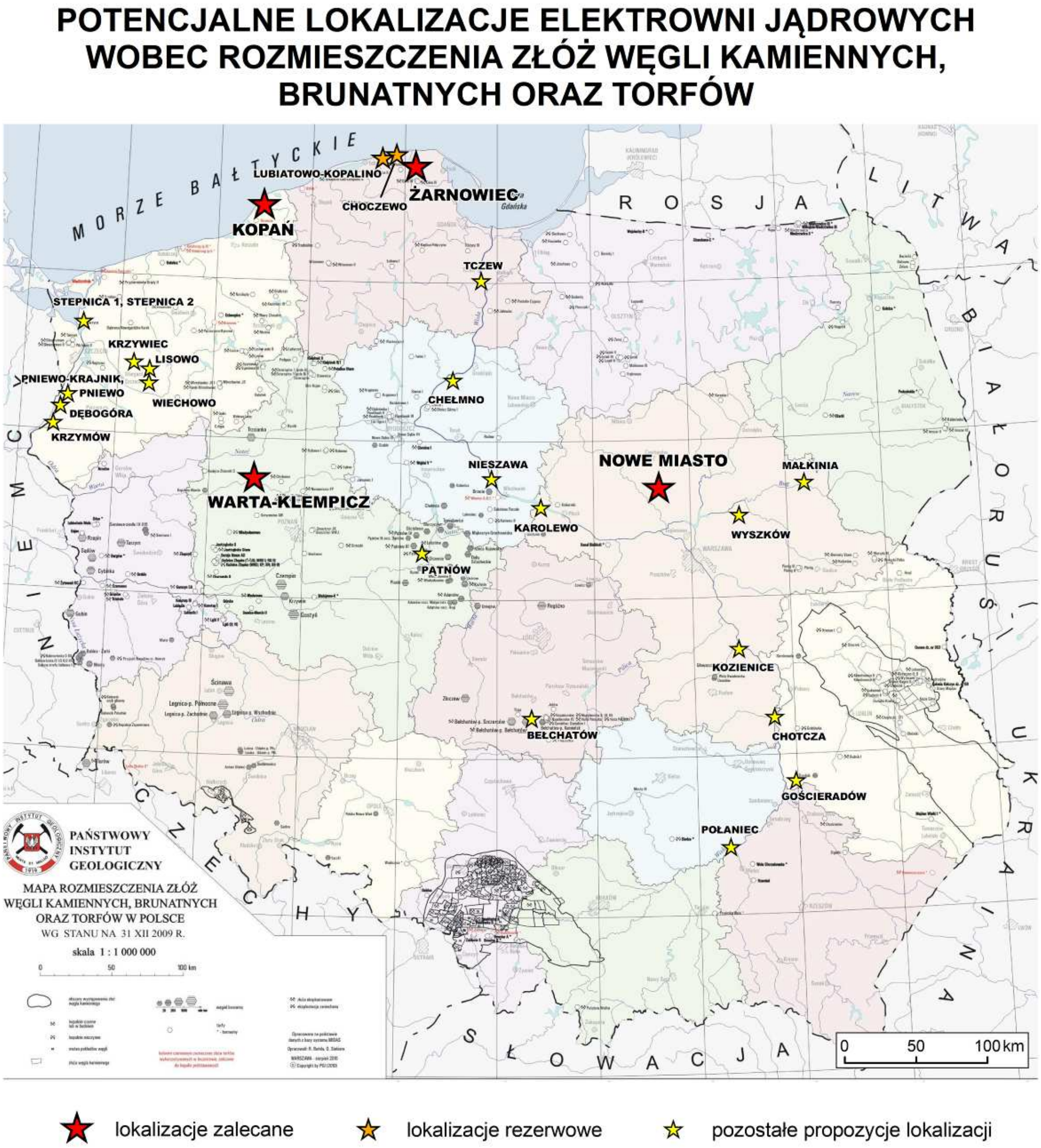


Fig. 4.3.45 Distribution map of hard coal, brown coal and peat deposits in terms of potential nuclear power plant sites (source: http://old.pgi.gov.pl/surowce_mineralne/).

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST DISTRIBUTION OF HARD COAL, BROWN COAL AND PEAT DEPOSITS
Recommended locations
Reserve locations
Other location proposals]

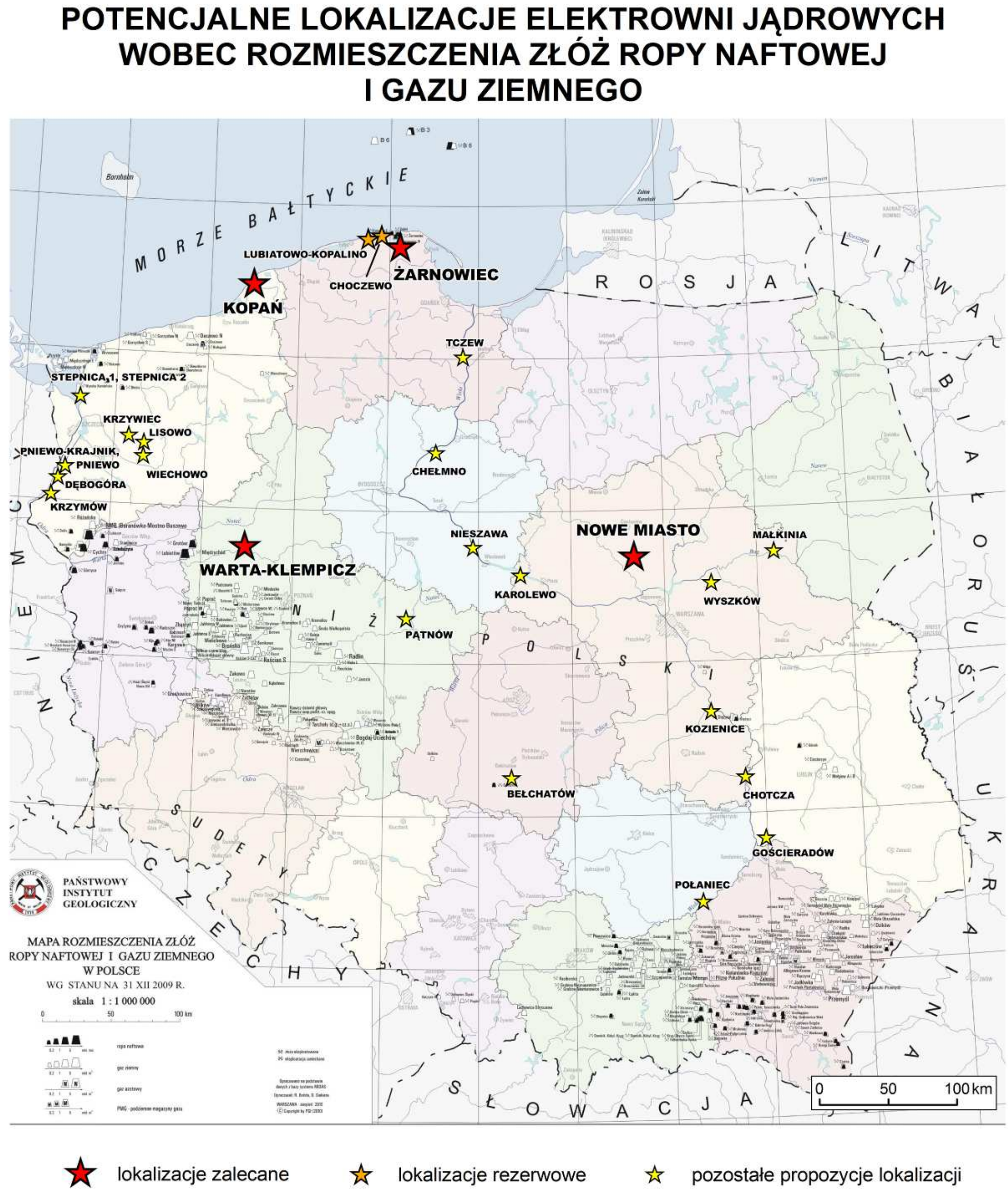


Fig. 4.3.46 Distribution map of petroleum and natural gas deposits in terms of potential nuclear power plant sites (source: http://old.pgi.gov.pl/surowce_mineralne/).

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST DISTRIBUTION OF CRUDE OIL AND NATURAL GAS DEPOSITS
Recommended locations
Reserve locations
Other location proposals]

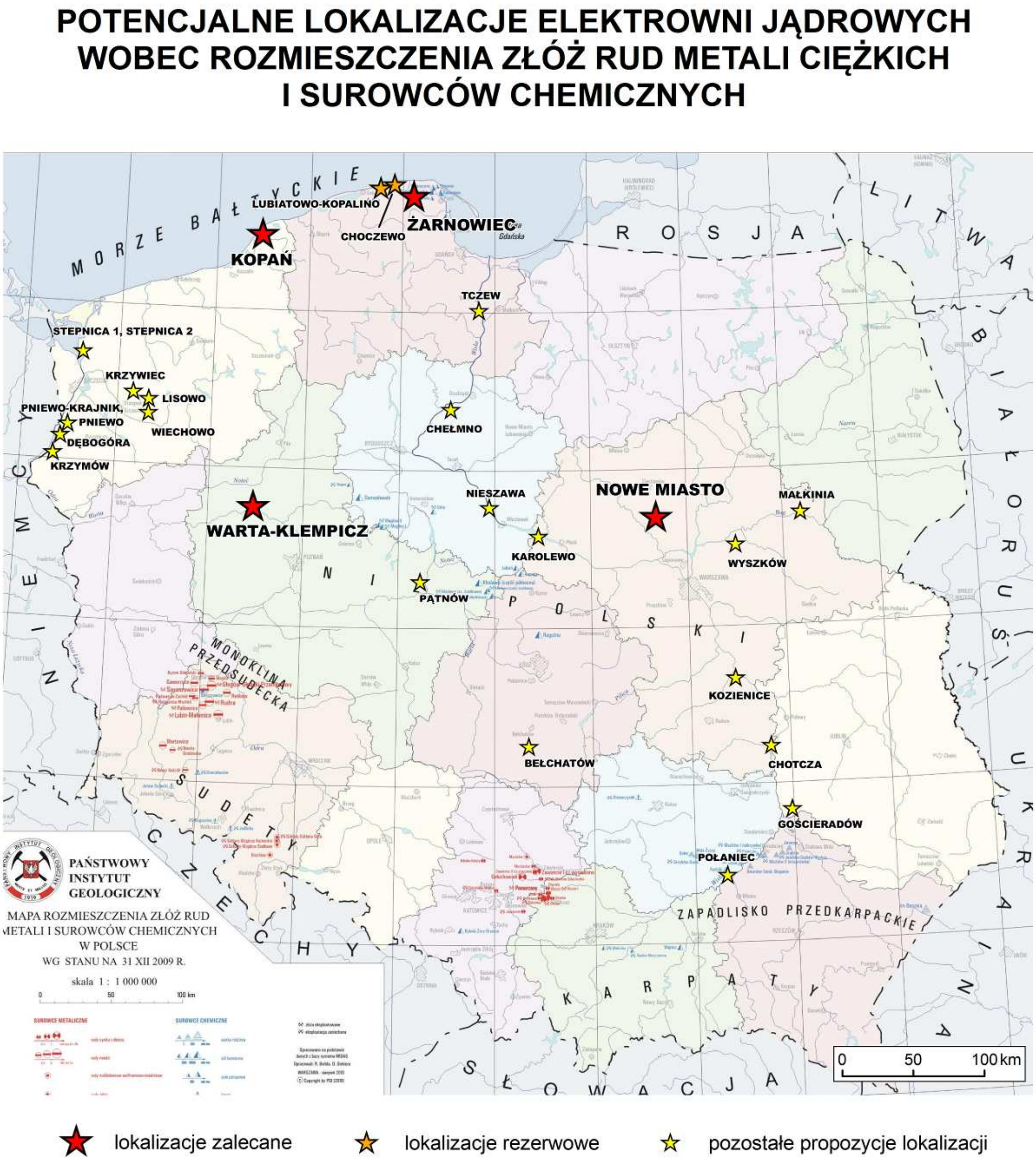


Fig. 4.3.47 Distribution map of metal and chemical deposits in terms of potential nuclear power plant sites (source: http://old.pgi.gov.pl/surowce_mineralne/).

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST DISTRIBUTION OF HEAVY METAL ORE AND CHEMICAL DEPOSITS
Recommended locations
Reserve locations
Other location proposals]

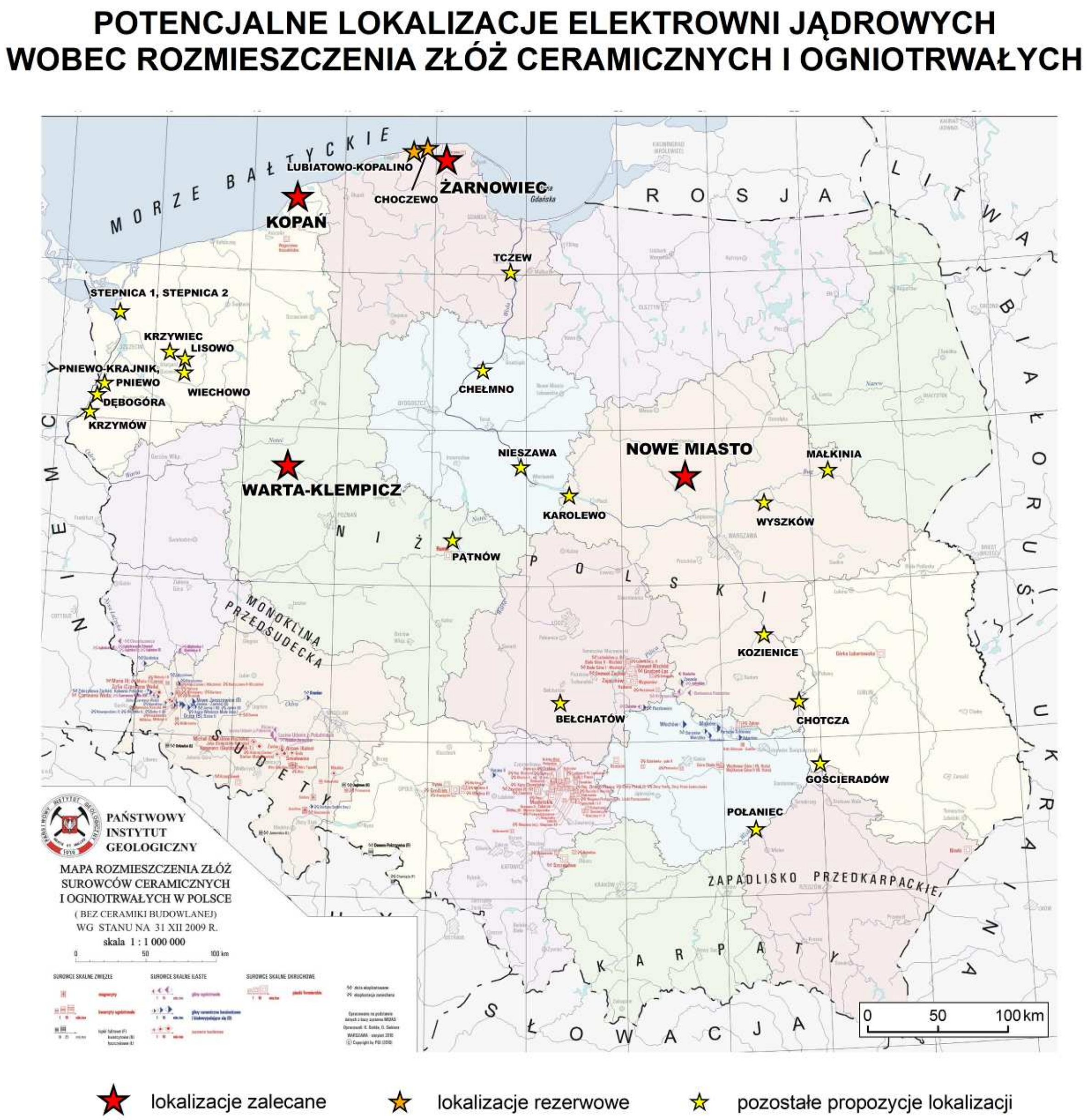


Fig. 4.3.48 Distribution map of ceramic and refractory deposits in terms of potential nuclear power plant sites (source: http://old.pgi.gov.pl/surowce_mineralne/).

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST DISTRIBUTION OF CERAMIC AND REFRACTORY DEPOSITS
Recommended locations
Reserve locations
Other location proposals]

Fig. 4.3.49 Distribution map of firm rock deposits in terms of potential nuclear power plant sites (source: http://old.pgi.gov.pl/surowce_mineralne/).

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST DISTRIBUTION OF FIRM ROCK DEPOSITS
Recommended locations
Reserve locations
Other location proposals]

4.3.7 **Impact of the infrastructure development**

4.3.7.1 Condition of Polish infrastructure and necessary directions of changes (specified in PSE strategy)

Polish high-voltage power supply grid is made up by grid infrastructure (Fig. 4.3.50 state as of 2009), including the following facilities:

- 236 lines with total length of 13053 km, including one 750 kV, 114 km long, 68 lines with 400 kV voltage of total length 5031 km and 167 lines with 220 kV voltage, of total length 7908 km,
- 106 high voltage stations; 174 LV/110 and LV/LV kV transformers with total capacity of 38 450 MVA.

Fig. 4.3.50 Power supply grid in Poland

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST EXISTING HIGH VOLTAGE POWER SUPPLY GRID
Recommended locations
Reserve locations
Other location proposals]

Territorial scope of power supply transmission system covers entire Poland. The greatest grid density occurs in southern part, and the lowest - in north-eastern part.

Needs in terms of transmission grid expansion result from forecasts of increase of power demand, requirements of recipients in terms of power supply reliability and investments necessary for power connection and output from new production units. Needs in terms of transmission grid expansion also result from EU directives concerning RES share in power production and requirements related with expansion of cross-border connections. The future costs of transmission system operation in market conditions will be highly affected by decisions made today, concerning the expenditures on its development. The aim should be to minimize total power production and transmission costs.

Difficulties in expansion of transmission grid caused that grid density in the North and in relation from The North to central part of the country is insufficient. Electric power market based on the concept of trading "above actual grid", implemented at a later time, introduced price competition disturbances and lack of stimuli for rebuilding and diversification of generation sources. To reduce the effects of this situation, transmission grid operator initiates and performs works aiming at improvement and development of market mechanisms. In long-tem perspective, the most significant directions of development of market mechanisms should include sending multi-component economic signals to production source investors and implementation of principles of power trade consistent with actual, physical character of power supply system.

Taking into account:

- total length of 220 kV line - 7908 km,
- plans of voltage change on those lines to 400 kV,
- commonly known regulatory obstacles,

actions are necessary aiming at acceleration of rebuilding and retrofitting 220 kV line and simplification of formal and legal procedures in the investment process.

In large sets of lines, facilities and devices, decreasing technical condition takes place gradually with their age. Also, age of facilities is related to materials and technologies used in their construction (affecting ability to perform functions in the predicted life cycle of a facility). Therefore, the basic parameter in synthetic assessment of technical condition is age of a line, facility or device, including its ability to operate.

400 kV transmission lines.

Most lines were built in the 1970s and 1980s. Some grids exceeding the age of 40 require urgent modernization. Modernization is difficult due to lack of option of line shutdown.

220 kV transmission lines.

Age structure of 220 kV lines indicates necessity of modernization. Expansion and modernization programmes prepared by PSE Operator SA are based on the concept of 400 kV grid development along the routes of existing 220 kV lines. After their execution, structure of line length according to voltage will be changed.

Transformers

In age structure o transformers, 30, 40-year old units have large part. In previous years, a stage programme of transformer units replacement was executed. Further replacement is being planned, together with the programme of adding transformer units and purchase of new generation transformers. this is necessary in order to renew the transformer population, to cover the demand and increase reliability of power supply to recipients.

The analyses show that most facilities may be operated for another several years. This expected useful life is safe in the case of network facilities such as transformer stations, switches, and 400 kV line components. However, it is too short for 220 kV lines.

Implementation of power network investments, including (but not limited to) the connection of nuclear power plants, needs several years to complete the preparation and implementation phase. According to regulations currently in force, this period is about 7 years.[239]

4.3.7.2 Infrastructure necessary for proper operation of nuclear power plants

4.3.7.2.1 Power supply grid

Power outlet

In construction of a nuclear power plant we must include necessity of incurring significant grid investments related to expansion, modernization and construction of new 400 kV lines and construction of appropriate 400 kV power plant stations.

New grid investments for the purposes of power outlet from nuclear power plants require several years of preparation and execution. In view of current legal regulations, about 7 years will be needed to conduct the entire process.

To lead out 1600 MW from a nuclear power plant, the following are needed:

1) construction of 400 kV station

2) construction of two 400 kV lines

Internal load supply during construction and regular operation

During nuclear power plant construction and regular operation, power supply at the proper level is necessary by means of local power supply grid and from emergency power supply systems (*"Ultimate Emergency Diesel Generators"*). Substations are needed to provide required voltage during construction and operation stages.

4.3.7.2.2 Analysis of environmental impact due to expansion of power supply infrastructure

Power supply infrastructure of a NPP mainly consists of 400/110 kV power stations and 400kV lines (power outlet) and 110 kV lines (emergency internal load supply). With 1600 MW unit, to provide power supply safety and power outlet, the following are necessary:

- construction of 400/110 kV station,
- construction of at least two transmission lines 400 kV and a 110 kV line.

Apart from that, feeding fail proof power supply from MV grid (1o kV) is also necessary, as well as construction of proper power supply grid at construction site.

Positive impacts of these investments include the creation of favourable conditions for electricity transmission.

Negative impacts in the implementation phase will include an increase in the level of noise, exhaust gases and dusts generated by construction machinery and equipment, as well as the removal of trees and shrubs along the route of the power line and in sections of construction sites.

In the operation phase, 400kV and 110 kV equipment may generate the following environmental impacts:

- permanent area occupation for construction of power poles and stations 400kV and 110kV,
- creation of limited use zones,
- constant electromagnetic field emission,
- disruptions of radio and TV reception,

- generation of acoustic noise (maximum measured noise for 400 kV line is 48 dB).
- permanent and significant changes in the landscape (the poles will be 35-60 m tall, and the smallest possible distance of working cables from the ground is 7.67 m),
- permanent hazard to birds and bats.

Acceptable levels of electromagnetic fields and manners of observing them are specified by Ordinance of Minister of Environment of 30th October 2003 on acceptable electromagnetic levels in environment and manners of verification of observance of the same (Journal of Laws No. 192 item 1883).

The alternative could be to apply 400 kV cable lines, laid in special channels and properly insulated. This is however very costly and thus unrealistic at a larger scale. Sometimes at small distances cables are used - between unit transformers and power plant power station, when it is necessary due to specific spatial arrangement of a line (e.g. crossing). In cable technology, we eliminate the electric shock hazard or negative impact of lines on the landscape, but at the same time we increase exposure to electromagnetic fields and potential disruptions in operation of electronic devices.

Necessary expansion of 400 kV grid is described in other chapters of the Forecast and mentioned in Chapter IX of Polish Nuclear Programme; it tackles the issues of preparation and required changes in domestic transmission system. Due to the scope of changes, a document must be updated titled "Development Plan in terms of covering current and future power demand for the years 2010-2025".

The document will be subject to strategic assessment of environmental impact, in terms of which environmental impacts of infrastructure expansion will be evaluated. This approach also arises from Article 5.2 of SEA Directive:

„Report[…], made according to excerpt 1, contains information which may be rationally required, including […] content and level of specification of a plan or programme, its stage in decision-making process and scope in which certain issues may be more appropriately evaluated at various process stages, <u>in order to avoid multiplication of assessment</u>"

In environmental impact forecast for development plan in terms of meeting current and future power demand, particular attention must be paid to collision with Natura 2000 areas and analysis of potential alternatives.

Moreover, during the investment process procedure of environmental impact assessment will be performed, including N2000 areas. This multi-stage procedure should guarantee minimising potential significant impacts. The procedure should examine both effects of grid expansion and effects of nuclear power plant construction.

4.3.7.3 Other infrastructure

4.3.7.3.1 Water intake

Construction of a power plant (not only nuclear) requires providing sufficient amount of cooling water.(**For a nuclear power** unit with net capacity of **1000 MW$_e$** expenditure of cooling water, with 10 K heating, is ca. **50.2 m^3/s** (with 12 K: ca. 41.8 m^3/s).

4.3.7.3.2 Transport

Expansion of local road grid and railway transport to a power plant.

Technical transport for NPP. During investment process, significant intensification of heavy road and railway transport will occur in the NPP area. After the power plant commissioning, traffic intensity will decrease. Transport of utility parts and periodical transport of spent fuel to a processing plant or deep geological repository will continue (3rd generation reactor of nuclear power unit with capacity of ca. 1000 MW_e uses less than **20 tonnes** of nuclear fuel **-** i.e. one train car per year).

Passenger transport. Operation of one unit will employ ca. 800 people. Therefore, if we choose French reactors with capacity 1600 MW, the employment will include ca. 1500 people in one power plant. If we decide to use American reactors with capacity 1000 MW, the employment will include ca. 2500 people.

The construction will also stimulate the economy. Construction of a nuclear unit in Olkiluoto, Finland employs 1500 companies and 4000 people, many of them from the nearby commune.

In case of NPP sites near big rivers and sea coasts, there is an option of building harbours capable of reception and unloading large-size and heavy devices and structural elements.

4.3.7.3.3 Social facilities.

During construction and regular operation, construction of facilities providing proper operation of the entire site back-up facilities will be necessary, also at the further stage of regular power plant operation.

4.3.7.3.4 Analysis of environmental impact due to expansion of other infrastructure

Development of the infrastructure will require the use of certain environmental resources (especially water and energy), just as for any other large industrial plant. Passenger and technical transport vehicles will generate additional emissions of exhaust gases to the environment. However, these amounts will not be considerable. We should note that passenger traffic will be more intensive than traffic of technical vehicles, given the low demand for raw materials but high demand for workforce (high number of employees on site).

Operation of the infrastructure will also produce waste. Annual amount of conventional waste for PWR unit with net capacity **1000 MW_e** were specified on the basis of estimates for EPR unit [UK EPR: PCER, Chapter 3]. They are:

- 294 Mg of chemically neutral and municipal waste,
- 63 Mg of hazardous (non-radioactive) waste.

4.3.8 Impacts on the landscape

Operation of a nuclear power plant must be examined in terms of its impact on the landscape. Definition of a landscape seems intuitively clear for everyone, however specialists debate the proper specification of this basic notion. According to Ostaszewska[240], in Polish the word "landscape" has two meanings: firstly, it denotes the earth surface as seen from a certain point (surrounding view), secondly - presentation of real (or fantastic) world in any technique. The quoted author reviewed several functioning definitions of landscape, suggesting referring to landscape as a system of connected natural components occurring on and near Earth's surface. In this concept, examining landscape issues should involve both its abiotic components (geological structure, relief, soils, water) and biotic components (flora, fauna), creating a certain local geocomplex. Since in the Report on nuclear power industry impact on individual environment components they are subject to separate evaluation, the landscape will be treated as a whole, in compliance with older views, rather as a subjective impression of an observer. In such an approach, landscape was referred to by Jermołajew (cf.: Kalesnik[241]) as geographical space or geosphere.

Impact of the nuclear power plant on landscape is closely related to the location of the project and type of land use in the neighbouring areas. Therefore, it depends on the scale of the investment, cubage of buildings and facilities, and the associated infrastructure, as well as the urban layout and components of the natural environment in the area. Therefore, the expected impacts cannot be precisely defined at this stage. Still, we may analyse impacts recorded for the adopted reference projects.

We may venture a statement that impact of nuclear power plants on landscape is somehow an individual matter for a recipient, depending on their aesthetic notions and preferences. It is believed that the so-called beauty models are not constant, they remain specific for specific cultural cycles and period of creation. Also historical changes of the notion of ugliness are closely related to analogous changes in perceiving the notion of beauty. Here however, we enter the sphere of unresolved philosophical reflections. The notion of supremacy of natural beauty over manmade creations is also popular and perhaps true. However, the situation of actual shaping natural elements by humans, since historical times, poses further questions concerning the meaning of this statement. Polish legislation formulates the definition of landscape values. Pursuant to Environment Protection Act of 16 April 2004[242] these are ecological, aesthetic or cultural values of the area and related relief, formations and components of nature, shaped by natural forces or human activity.

It seems beyond any doubt that all large investments in the power sector change the existing spatial arrangement. These changes include single point, surface, and linear objects (such as roads or transmission lines). Their vertical range (and thus visibility from a distance) is also diversified. Given that a qualitative evaluation of this interference is difficult, we could use quantitative data for a project with a comparable or generally high electricity production capacity (e.g. in terms of the area occupied by the project or the area where raw materials are extracted). The following examples (Fig. 4.3.51) illustrate different methods of presentation of various projects and how it influences the way we perceive these projects. Supporters and opponents of various types of investments often use quite different images – photographs of landscapes.

In Poland, some areas with high landscape values are protected as landscape parks and, to a lesser extent, natural and landscape complexes[243]. Landscape parks serve not only protection of natural values (including landscape values - maintaining their characteristics), but also historical and cultural values. In those places, economic activity is allowed, although limited, e.g. enterprises of significant environmental impact are prohibited, as well as ground works permanently distorting the area or building new structures in the 10m wide area from the river banks, lake shores and other water reservoirs (except facilities for water tourism, water management or fishery). The domestic landscape parks created so far are not directly adjacent to the recommended and reserve nuclear power plant sites (see site variant analysis). Those structures should not therefore result in deterioration of quality of those areas. Another section of the Report also discusses landscape parks and forms of environment protection in Poland.

POWER PLANTS FIRED WITH BROWN COAL

Fig. 4.3.51 Landscapes in the area of various types of power plants – examples of one-sided presentation[244].

To some extent, operation of a nuclear power plant depends on good communication – including transport by road or rail and power lines. The first two problems seem marginal, given that fuel deliveries and removal of spent fuel are not too frequent, and the number of people who come to work at the power plant is not too high. However, high-capacity transmission lines and the associated infrastructure will definitely change the original spatial arrangement. Still, this effect is observed for all large electricity-generating facilities, irrespective of the technology, and in all places where transmission lines are installed – even if there is no power plant in the area. The following photographs illustrate examples of the siting of large facilities (nuclear power plants) in the surrounding landscape, in accordance with the principle of keeping the negative impacts on the landscape at a minimum.

Fig. 4.3.52 Nuclear power plant in Neckarwestheim (Germany)

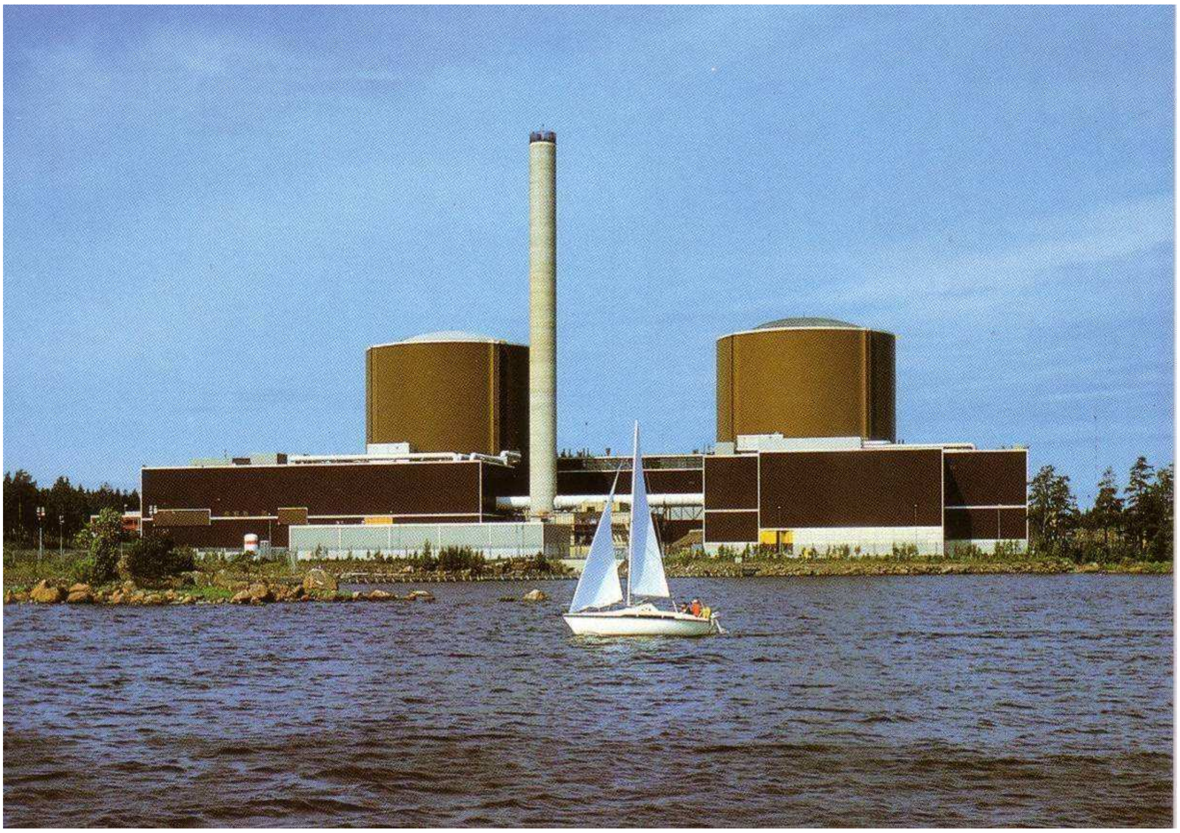


Fig. 4.3.53 Nuclear power plant in Loviisa (Finland)

Experience of other countries indicates that construction of nuclear power plants, even in attractive, historically significant regions, does not have to decrease the value of those areas, on the contrary, it may increase tourism, and due to improvement of road infrastructure it may improve access to those areas. An example can be the power plant in Belgium, erected in the vicinity of historical town of Huy, on the opposite bank of the river Meuse. According to town authorities, adverse effect on tourism was not observed. In fact, it was just the opposite. Trips organised by the power plant authorities attract new category of people to the town, which affects development of trade and services. It was also shown that those people come to the region as holidaymakers[245]. Also in France, country where main source of power in nuclear power, may power plants are situated in culturally valuable regions, e.g. in the valley of the river Loire with historical castles and nearby power plants in the towns of Chinon, Saint-Laurent, Dampierre and Belleville.

Fig. 4.3.54 Belleville power plant situated in the valley of the river Loire (source: Areva)

4.3.9 Socio-economic effects

The impact of a nuclear power plant must be also analysed in terms of its operation as a very important production facility. Certainly, its construction will have high economic significance for the commune where it is located and for adjacent communes, in terms of:

- higher value of land in the area,
- increased income of the municipality,
- improved infrastructure,
- lower unemployment rate,
- economic revival in the region,
- increased safety of power supply in the region.

4.3.9.1 Higher value of land in the area

At first, location of a nuclear power plant may cause decrease in land value - people, fearing harmful effects of the power plant will not settle in the neighbouring villages and municipalities. However, taking onto account that construction of a power plant involves employment of large numbers of workers, both at the construction and operation stage, and that the residents will not be able to satisfy the employment demand, inflow of population is expected and, what follows, increase demand for land and residence. This will increase value of real estate. Furthermore we may assume that increasing awareness of Polish society in terms of actual threats of nuclear power plant operation will bring about increase perception of advantages of living in the area.

The power plant in the Belgian town of Huy may serve as an example. In October 2009, the Senate Office conducted a questionnaire directed to the parliaments of the European Council member states and Canada, USA and Israel, concerning the attitudes of local communities to location of nuclear power plants in their area.

Authorities of Huy stated in response that in this area, value of real estate, including apartments and land, increased due to economic boost caused by location of the power plant.[245].

4.3.9.2 Increased income of the municipality

Construction of the power plant will greatly improve financial condition of the municipality. Even the Polish example shows that mining and power industry affect income of the municipalities. In 2007, the richest commune in Poland was Kleszczów in Łódzkie province. Its income was three times higher than the commune in the second place. Kleszczów receives high income due to its brown coal mines and the power plant located there.[246]

There are many examples of increasing income of administrative units where a nuclear power plant was located. In Europe, the Belgian town of Huy may serve as an example, with its significant increase of income on tax, related to increase in population, increase in salaries of the power plant employees, development in building engineering and fees paid by the power plant, which annually pays ca. 30 million Euros of national and regional taxes, half of which goes to municipal budget. Operator of nuclear power plant in Olkiluoto (Finland) paid more than 4.2 million Euros in tax in 2007 on real estate title, the nuclear power plant in Flammanville (France) pays 25 million Euros every year in local taxes.

The situation is similar in the USA. Until 2002, budgets of the counties located near Indian Point NPP and state budget received more than 49 million dollars on taxes paid by the power plant and taxes paid by other companies related with power plant commissions and investments.[247]

4.3.9.3 Improved infrastructure

Construction of a nuclear power plant involves expansion of necessary infrastructure, such as roads, water and sewage system, power supply grid. These investments are necessary for the power plant operation, but at the same time they increase comfort of life for the residents. Temelin, Czech Republic may serve as an example. Two waste treatment plants were built there on the river Vltava for the needs of the nuclear power plant.

4.3.9.4 Lower unemployment rate

Construction of a nuclear power plant will largely contribute to an increase in employment in the local labour market and lower unemployment rate. The population may be permanently employed in the power plant and subcontracting companies, and temporarily employed during maintenance works. The previously discussed Kleszczów commune may be referred to as an example of employment growth due to industry development. In 1977, there were 81 work places in the municipality. Construction of a mine, power plant and associated companies expanded the labour market to 17,600 work places in 2009. this is 4 times more than residents of the municipality.[248]

Preliminary estimates show that in the USA, 800 employees of various levels are employed in one unit with net capacity of 1000 MWe.

Table 4.3.15 List of job positions in a nuclear power plant [249]

TYPES OF POSITIONS	NUMBER OF EMPLOYEES
Civil engineers	5
IT engineers, electricians, electronics engineers	20
Mechanical engineers	15
Nuclear engineers	25
Design and maintenance engineers	30
Control system and equipment operators	75
Chemical technicians	20
Maintenance technicians	135

Radiological protection and radioactive waste management technicians	35
Physical security staff	70
Training staff	35
Other staff	335
Total	800 (+/-300)

Additionally, project execution stage will require employment of 3000-4000 people for construction works, plus employment in construction of associated investments, such as: Power lines, access roads etc.[249]

In Europe, nuclear power plants are main employers in their locations. Belgian power plant Huy employs 950 own employees and additionally 500 subcontractors. Additionally, town authorities state that the number of people whose employment is related to the power plant is three times bigger than the power plant staff. The next example is French nuclear power plant Flammanville, employing directly 680 staff and ca. 2000 outside people, employed during scheduled overhauls and maintenance. Most of them (especially permanent workers) live in the neighbouring municipalities.

American power plant Indian point employs more than 1600 workers (as of 2002), of which 80% live in the area of five neighbouring counties.

4.3.9.5 Economic revival in the region

The power plant will directly and indirectly affect economic revival in the region. Orders placed with surrounding companies by the power plant will greatly affect their activity and development. Additionally, influx of well-earning new residents and increase in life standard of present ones will contribute to development of local trade. Huy power plant purchases various goods and services for 100 million Euros per year, Flammanville power plant annually places orders for 37 million Euros with local suppliers, Indian Point power plant (new York state, operator: Entergy company) executes 30% of their orders in neighbouring counties - by 2002 their value was almost 450 million $.[247]

To sum up: analysis of impact of nuclear power plant construction on the aforementioned aspects indicates, that location of a nuclear power plant may largely and positively affect material situation of its municipality and neighbouring municipalities.

4.3.9.6 Improved energy security of the country

Introduction of nuclear power engineering in Poland will constitute a new method of power production. It will diversify domestic power sources, presently mostly based on coal (see chapter **Błąd! Nie można odnaleźć źródła odwołania.**). Dependence of the entire power sector on only one primary material cannot provide permanent power engineering security or sustainable state development. Introduction of uranium as additional primary power source has significant potential for long-term stabilisation of power prices at low level and providing reliable power supplies (see chapter 4.3.1.1 and 6.1). Providing cheap and reliable power supply is an inherent condition of economic progress and improvement of the nation’s quality of living. Introducing an additional power production source will therefore positively affect population and material goods.

4.3.9.7 . Development of modern technologies

Introduction of new power production technologies in Poland will give an impulse for development of scientific and technological base. Due to technological advancement of solutions and necessity of installation of state-of-the-art security systems, power engineering is the most demanding power production sector. Therefore it forces dynamic development in various related and accompanying domains. Certainly, introduction of power engineering in Poland will have an inspiring impact on development of modern technologies at the highest level.

4.3.10 Natural threats to the operation of a nuclear power plant

Natural threats are understood as the impact of nature's forces that poses a threat to human life and health or to human-made infrastructure. As a rule, these are extreme or abnormal phenomena. They include extreme weather conditions (storms, tornados, droughts, etc.), hydrological phenomena (storms, floods, low water, etc.), seismic events (earthquakes, rock bursts), mass movements (avalanches, landslides, mud and debris flows), as well as events in the biotic world (such as locust swarms etc.). They are rather unpredictable, occur suddenly, and have serious consequences for the economy. However secular, slow-operating processes, although uninterrupted, may also pose a threat to environment. Among them are for instance land creep or atmospheric pollution. It must be emphasised that even the events at exceptionally large scale or occurring extremely rarely are completely normal from the perspective of natural environment, excluding those caused directly by human activity. Also, threats are not equivalent with the notion of risk. Usually risk is specified with the formula[250]:

$R = H \cdot V$, where *R* – risk, *H* – hazard, *V* – vulnerability. It means that with application of proper protections (increasing resistance to damage or decreasing vulnerability), risk does not necessarily grow with increase of hazard.

Natural hazards, which must be included due to development of nuclear power engineering are specified in the draft of Ordinance of Council of Ministers on requirements for a nuclear power engineering project. The list includes:

1. Earthquakes and active tectonic faults.
2. Geotechnical and hydro geological hazards,
   - instability of slopes or embankments,
   - collapse, settlement or elevation of the surface,
   - Liquefaction of ground materials,
   - behaviour of ground materials with static and seismic loads,
   - condition and chemical properties of ground water (potential aggressiveness towards concrete and reinforcing steel).
3. Weather events,
   - extreme weather phenomena (maximum wind velocity, maximum daily precipitation of rain and snow, extreme air temperature, storm swelling of a water reservoir),
   - rare weather phenomena (atmospheric discharges, tornadoes).
4. Floods and floodings due to precipitation and other natural causes.
5. Other external events or hazards: extreme temperatures of cooling water, depletion of reservoir water resources (natural causes), drought, blocking the flow in the river, the excessive growth of aquatic organisms, ice phenomena which may cause blocking the water intake or distort the functioning of a closed cooling cycle (including the cooling tower due to icing).

It should be noted that these project hazards include both natural aspects, and engineering solutions for potential investments. At the stage of development of the Forecast and with no concrete data on the adopted engineering solutions and the selected location, we are not able to refer directly to all the points of the presented list. Still, the key factors connected with natural hazards to nuclear power facilities and the associated infrastructure are described.

4.3.10.1 Seismic hazards

Comprehensive discussion of seismic factors in Poland and therefore issues related with tectonic movements and earthquakes can be found in another chapter of the Forecast. As Poland is not a seismically active area (although it is not fully aseismic, as some studies state), it may be assumed that the seismic factor will not be of key significance for conditions of power plant operation. The largest perceptible earthquakes recorded in the last millennium did not exceed the magnitude of 6. It means that no strong, large or extreme earthquakes have been recorded in Poland – only moderate earthquakes that can affect only buildings in a bad technical condition, and only to a limited extent.

Maintaining the construction standards prescribed by the International Atomic Energy Agency (IAEA), selection of proper building materials, and technical control and proper maintenance of nuclear power facilities under operation should guarantee absolute safety of nuclear power plants in Poland as regards their resistance to seismic shock.

4.3.10.2 Geotechnical and hydro geological hazards

Geotechnical and hydro geological threats should be eliminated by the proper analysis of ground conditions during preparatory works for the project and by using top-quality building materials and techniques. In Poland, young Quaternary sediments display high lithological diversity even at the small area, which results in various usability of the land for founding buildings. The so-called quicksand is an extreme obstacle, in engineering geology construed as fine loose sediment, e.g. sand or sludge mixed with water, poorly bound with land, behaving like thick liquid. Also frost susceptible soil, susceptible to cryogenic processes (water freezing and changes in volume) also is not favourable for construction of buildings. Therefore, detailed analyses of the geology of sub-surface layers and the system of groundwater are of key importance. Accurate determination of the existing hydro geological and geological conditions and application of the proper building technologies will guarantee stability of the nuclear power plant when its operation starts.

4.3.10.3 Meteorological threats

For Poland, there is an abundant collection of data concerning exceptional weather events, presented in many scientific studies. Weather conditions that may pose a threat to safety in a nuclear power plant include mainly snowfalls and rainfalls (and also hail) – their intensity, frequency, and time; wind – its speed and gustiness; atmospheric discharges; extreme temperatures; and other phenomena, such as tornados.

Despite Poland's location in moderate climate, the specifics of the region where masses of continental and oceanic air come into contact causes significant contrasts and amplitudes of weather factors. According to the information provided by Institute of Meteorology and Water Management (IMGW) the highest temperatures in Poland were 40.2°C (Prószków near Opole, 29 July 1921) and 39.5°C (Słubice, 30 July 1994). Heat waves and drought periods also occurred several times, e.g. in July 1994 or July 2010. The lowest recorded temperatures are −41.0°C (Siedlce, 11 January 1940) and −40.6°C (Żywiec, 10–12 February 1929). The most intense rains were recorded in Szychowice near Hrubieszów (35.3 mm in 2 minutes, 13 June 1956), Ryczów near Zawiercie (80.0 mm in 10 minutes, 19 June 1956) and in Sułoszów near Olkusz (180 mm in 60 minutes, 18 May 1996). Recorded wind speed may exceed 288 km/h in the mountains (Kasprowy Wierch) and 162 km/h in the lowlands (Gdańsk, 25 November 1993). Besides gales, for instance hurricane Cyryl in southern Poland in 2007, also tornados and waterspouts are observed in Poland. Tornados, although their scale is incomparably smaller than famous tornados in the USA, may damage poorly secured buildings. This happened on 20 July 1931 near Lublin, m20 August 1946 near Kłodzko, 25 August 1956 near Szczecin, 20 May 1960, 20 August 2006 in Kraśnik District (Lubelskie). Recently, records of such events have increases significantly, also due to development of communication techniques. In terms of number of days with atmospheric discharges, records are from mountain regions (Kasprowy Wierch - up to 54 stormy days a year). The values given should be deemed measured extremes. Slight exceeding of extremes could have occurred, but they were not recorded in measurement grid points.

Adverse weather conditions will affect mainly the safety of the associated infrastructure of a nuclear power plant during its operation, including electricity transmission lines. They can be expected especially in winter months. In the winter of 2009–2010, HV power lines would break down under the weight of ice. However, the problem concerned mainly old lines that had not been properly maintained. It may be expected that a properly designed, constructed, and managed nuclear power plant will be resistant to extreme weather conditions. The same applies to the related associated services, including proper organisation of transport of fuel and spent fuel.

4.3.10.4 Hydrological threats

Hydrological threats are important for all potential nuclear power plants, which will be located t the bottoms of river valleys and in direct vicinity of rivers and water reservoirs. The specificity of the technological process that requires water for cooling eliminates the possibility to move a nuclear power plant at a large distance from water intake points.

High water is one of hydrological threats that require special attention. The increase in water level due to oversupply of water or a blockage along the river course is generally considered the highest risk in Central Europe. In Poland, floods – defined as high water that affects people's lives – occur in various rivers each year and practically during all seasons. The most serious floods affecting a large part of major river basins occur in the warmer seasons of the year. Floods are also a problem in the melting season – in spring and mid-winter. There is one another category – floods that are caused by the build-up of ice or slush-ice, affecting mainly rivers in lowlands (such as the annual ice build-up in the Włocławek part of the Vistula). Issues related to floods are discussed in the subchapter on condition of environment in Poland.

In hydrological literature, high water is divided into regular - reaching the shore water level (full-bed state, without water overflow to flood plane) or low high water (with overflow to flood plane) and catastrophic high water, exceeding medium high water. Punzet[251], when studying the Vistula river basin, divided high water into catastrophic (with culmination flow $Q_{kulm}>Q_{5\%}$), large ($Q_{5\%}>Q_{kulm}>Q_{10\%}$), medium-large ($Q_{10\%}>Q_{kulm}>Q_{50\%}$) and regular ($Q_{50\%}>Q_{kulm}>(Q_{śr}+Q_{50\%})/2$). There is also standard high water, referred to as maximum probable flood . This term means the largest flood which may occur during simultaneous occurrence of adverse factors responsible for water supply and wave culmination[252]. Estimation of probability of maximum water levels and flows is burdened with an error and is reviewed during greatest floods, which was proven by events of July 1997 in the Odra river basin or spring 2010 in the Vistula river basin. Specification of actual flood risk is also made difficult by incompleteness of studies on flood threats for all river basins, which is Polish obligation imposed by the European Union[253] according to *Directive 2007/60/WE of the European Parliament and the Council of 23 October 2007 on assessment and management of flood risk*.

Hydrological threats must be included during designing nuclear power plants and analyses in proper amount of detail. With the currently available building technologies and engineering solutions, it would be possible to protect a nuclear power facility against the negative effects of even the highest water levels. A well-designed nuclear power plant and the associated infrastructure should not be affected by floods.

Another issue concerns low water, i.e. decrease in level of surface and underground water, also treated as hydrological extremes. A nuclear power plant must have access to sufficient water resources. If this water comes from surface water courses, its level must not drop below the minimum flow limit that is required by organisms living in that water course[254].

4.4 Non-radiological impacts at the nuclear decommissioning stage

Non-radiological impacts related to NPP decommissioning will not deviate from the impacts of decommissioning of other facilities of similar area. Demolition works will certainly produce higher emissions of dusts into the atmosphere and higher noise levels. These emissions may be considered a nuisance by inhabitants of the surrounding area. However, they will be only temporary and should not be particularly problematic, given that nuclear power plants are located away from residential areas. Designation of access route to demolition site is also important, as this is the transport route of obtained materials for land reclamation, and transport of heavy machinery and workforce.

Increased noise emission and air pollution emission will also take place on this route. Its course should be designated at a maximum possible distance from residential development areas.

Decommissioning of a nuclear power plant will produce large amounts of waste that should be reused or recovered to the highest degree possible or neutralised. Providing high degree of recovery of demolition materials will reduce adverse effect on natural resources (in form of using raw materials) and ground surface (in form of its occupation by waste storage).

NPP buildings should be completely demolished, and the area must be cleaned and recultivated. If these works are successfully completed, the impact of the decommissioning stage is considered positive – it removes ‘foreign’ elements from the landscape. Removal of the large hardened surface will also have a positive impact on soils and waters in the area, leading to the restoration of biologically active surfaces and the natural circulation of water by allowing its infiltration into the ground. Those impacts will be possible in case of choosing a natural reclamation direction (forest, meadow, agriculture). Selection of recultivation method may however be different - industrial, allowing for using the hardened area, possibly also some buildings for industrial purposes, if such demand exists in a given area. This recultivation method would not have positive impact on soils and water. Depending on the manner of area use, the impacts may be neutral or negative.

4.5 Impact on biodiversity, including biological resources protected under the Natura 2000 network

4.5.1 Impact on biodiversity, including biological resources protected under Natura 2000 network

Individual identified impacts on plants, animals, biological diversity and Natura 2000 areas generated by construction of a nuclear power plant according to the Programme mostly have broad spectrum and overlap. To avoid multiplication of impacts regarding animals, plants etc., the impacts are described collectively for all level environmentally significant levels, dividing them into individual stages of investment:

- construction stage,
- operation stage,
- decommissioning stage.

4.5.1.1 Impacts at construction stage.

Construction stage is a part of investment process generating the most adverse impacts. For this stage, the following actions were diagnosed which have negative impacts on environment:

- Area occupation for permanent and temporary construction facilities, machines and devices used in construction, area occupation for construction backup facilities, access roads, construction material storage, resulting in:
    - damaging integrity of the areas or their properties.
    - loss or decrease in population of protected plant and animal species due to destruction of feeding grounds, breeding grounds etc.
    - direct lethality of animal species due to collision with buildings and machinery (birds, bats)
    - loss of plant communities

- Waste storage from ground works and the site, resulting in:
  - destruction of natural communities (e.g.: sand dunes, haughs, river valley habitats)
  - animals settling on temporarily stored soil masses (sand martins and other burrow-dwelling species) and resulting species endangerment
- Dust generation during construction activities, such as: transport of soil, reloading sediments and soil, construction of facilities and road foundations etc., resulting in:
  - dust settlement, adversely affecting plants and animals
- Construction of buildings, access roads and parking spaces (with hardened surface), resulting in:
  - soil erosion and water quality changes - possible sediment emission to water and disruption of aquatic ecosystem balance
- Drainage and surface run-off due to ground works and displacement of soil, resulting in:
  - possible destruction of plant communities by contaminants running-off with water (e.g. machine oils)
  - soil erosion and water quality changes - possible sediment emission to water and disruption of aquatic ecosystem balance
- Application of natural surface water for production of concrete, washing machines and equipment, resulting in:
  - impact on quality of surface and ground water and on habitats, plant and animal species and Natura 2000 areas
  - possibility of contamination of local water courses and related endangerment of plant and animal species and protected Natura 2000 areas
  - impact on amount of surface water due to decreasing the level of ground water locally
- Drainages for excavation works, resulting in:
  - disruption of local water relations and impact on neighbouring ecosystems, including plants, animals and entire communities and their protective areas
  - impact on quality of surface and ground water and on habitats, plant and animal species and Natura 2000 areas
- Installing cooling water intake and discharge infrastructure, resulting in:
  - direct interference in aquatic ecosystems due to violation of bottom structure in water reservoirs
  - worsening living conditions of aquatic organisms due to stirring and dislocation of sediments onto plant and animal organisms
- Accidental fuel, petroleum, chemicals, concrete, cement spills etc., resulting in:
  - contamination of ground water, surface water (deterioration of water quality), contamination of natural plant communities and poisoning animals or worsening their living conditions by deterioration of habitats

- Vehicle traffic, resulting in:
    - direct lethality of animals due to collision (birds) or road kills
    - scaring animals
- Noise and vibrations from explosive works, piling, foundation drilling and tunnelling or laying pipeline for cooling water intake as well as from construction machines, means of transport and other vehicles, resulting in:
    - decreasing the values of breeding grounds, feeding grounds, rest areas (birds) or migration routes for several species of animals
    - disturbing fish and aqueous and semi-aquatic mammals
    - disturbing land animals dwelling in the neighbouring areas
- Light emission during construction works (area, machine and vehicle illumination), resulting in:
    - disruption of animal environment (preying bats, resting birds etc.)

4.5.1.2 Impacts at operation stage

Operation stage, being relatively stable in terms of executed tasks and their scope, generates relatively few negative impacts. For this stage, the following actions were diagnosed which have negative impacts on environment:

- Area occupation for power plant building and associated buildings and devices, resulting in:
    - direct lethality of animal species due to collision with buildings and machinery (birds, bats)
- Vehicle traffic, resulting in:
    - direct lethality of animals due to collision (birds) or road kills
    - scaring animals
- Area occupation for access roads and parking spaces (with hardened surface), resulting in:
    - soil erosion and water quality changes - possible sediment emission to water and disruption of aquatic ecosystem balance
    - contamination run-off (oil, lubricants etc.) to ground and surface water, resulting in deterioration of plant communities and living conditions of animals
- Area occupation for aerial contact line, resulting in:
    - direct lethality of birds and bats due to collisions
    - possibility of changing bird migration route due to barrier effect (numerous, dense and landscape-crossing power lines)
- Noise and vibrations from transport and vehicle traffic, resulting in:
    - decreasing the values of breeding grounds, feeding grounds, rest areas (birds) or migration routes for several species of animals

  - disturbing fish and aqueous and semi-aquatic mammals
  - disturbing land animals dwelling in the neighbouring areas
- Light emission (area, machine and vehicle illumination), resulting in:
  - disruption of animal environment (preying bats, resting birds etc.)
- Water intake to the cooling system, resulting in:
  - direct animal lethality due to suction
  - disruption of aquatic ecosystem balance
  - underwashing and local substrate changes causing indirect impacts on flora and fauna
- Warm water discharge from cooling systems, resulting in:
  - disruption of balance in aquatic ecosystems (change in population of various species depending on environmental preferences)
  - impact on bird migration habits (possibility of wintering of water fowl and risk of increase lethality in case of rapid weather changes)

4.5.1.3 Impacts at decommissioning stage

This stage implies necessity of repeated ground works, although due to environmental values already decreased at construction stage, the impacts are smaller.

For this stage, the following actions were diagnosed which have negative impacts on environment:

- Area occupation for permanent and temporary construction facilities, machines and devices used in decommissioning, area occupation for decommissioning backup facilities, access roads, demolition material storage, resulting in:
  - direct lethality of animal species due to collision with buildings and machinery (birds, bats)
- Waste storage from ground works and demolition, resulting in:
  - animals settling on temporarily stored soil masses (sand martins and other burrow-dwelling species) and resulting species endangerment
- Dust generation during demolition activities, such as: transport of soil, reloading sediments and soil, demolition of facilities and roads etc., resulting in:
  - dust settlement, adversely affecting plants and animals
- Drainage and surface run-off due to ground works and displacement of soil, resulting in:
  - possible destruction of plant communities by contaminants running-off with water (e.g. machine oils)
  - soil erosion and water quality changes - possible sediment emission to water and disruption of aquatic ecosystem balance

- Application of natural surface water for washing machines and equipment, resulting in:
    - impact on quality of surface and ground water and on habitats, plant and animal species and Natura 2000 areas
    - possibility of contamination of local water courses and related endangerment of plant and animal species and protected Natura 2000 areas
    - impact on amount of surface water due to decreasing the level of ground water locally
- Disassembly of cooling water intake and discharge infrastructure, resulting in:
    - direct interference in aquatic ecosystems due to violation of bottom structure in water reservoirs
    - worsening living conditions of aquatic organisms due to stirring and dislocation of sediments onto plant and animal organisms
- Accidental fuel, petroleum, chemical spills, resulting in:
    - contamination of ground water, surface water (deterioration of water quality), contamination of natural plant communities and poisoning animals or worsening their living conditions by deterioration of habitats
- Vehicle traffic, resulting in:
    - direct lethality of animals due to collision (birds) or road kills
    - scaring animals
- Noise and vibrations from explosive works, demolition of buildings, pipeline for cooling water intake as well as from construction machines, means of transport and other vehicles, resulting in:
    - decreasing the values of breeding grounds, feeding grounds, rest areas (birds) or migration routes for several species of animals
    - disturbing fish and aqueous and semi-aquatic mammals
    - disturbing land animals dwelling in the neighbouring areas
- Light emission during demolition works (area, machine and vehicle illumination), resulting in:
    - disruption of animal environment (preying bats, resting birds etc.)

4.5.2 **Impact on protected areas, including Natura 2000 areas**

Implementation of the Programme involves construction of two nuclear power plants and related infrastructure in Poland, in form of aerial transmission grids, roads etc. These actions may adversely affect Natura 2000 network in Poland, depending on selected sites. Degree of environmental impact of specific final locations will be assessed at the stage of EIA. This document analyses, solely on the basis of literature, potential impacts on Natura 2000 areas of power plant location in proposed sites, divided into two groups - i.e. recommended and reserve sites and other proposed sites. One of the criteria of site assessment was adherence of location within the area created pursuant to Birds Directive or Habitat Directive. The diagrams below present possible collisions with SAC and SPA areas in case of power plant construction in one of the analysed locations.

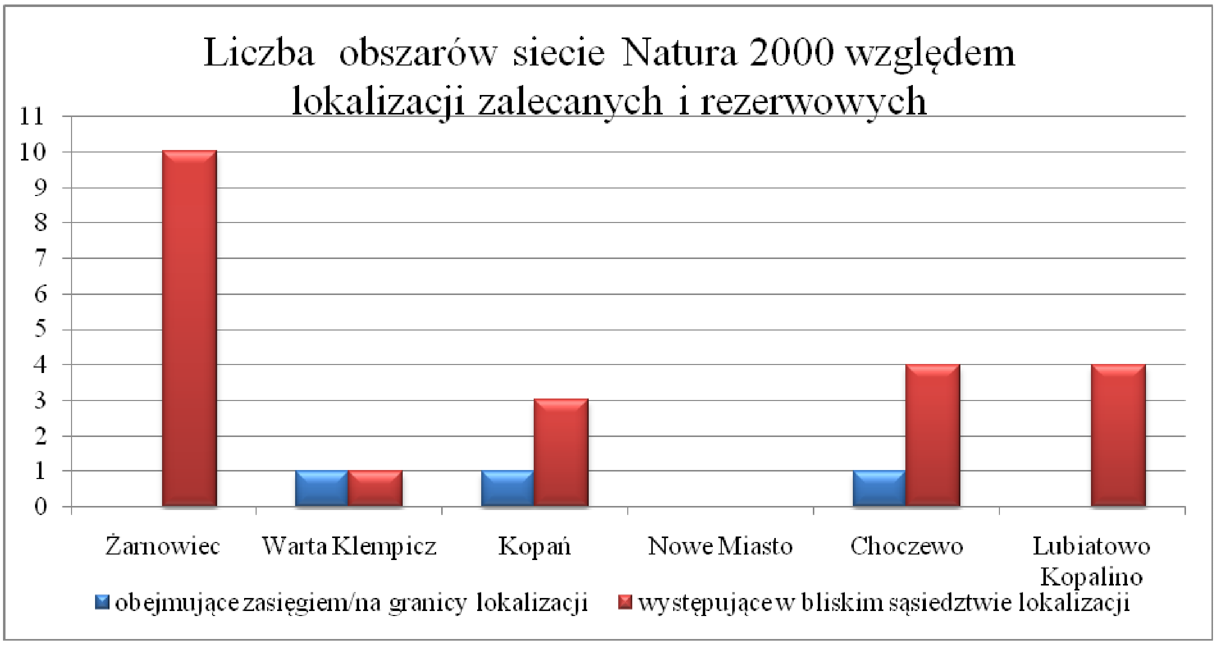


Fig. 4.5.1 Location and number of Natura 2000 areas in relation to the assessed recommended and reserve locations

[Number of Natura 2000 sites with regard to recommended and reserve locations
In their range/bordering
In the close proximity of the site]

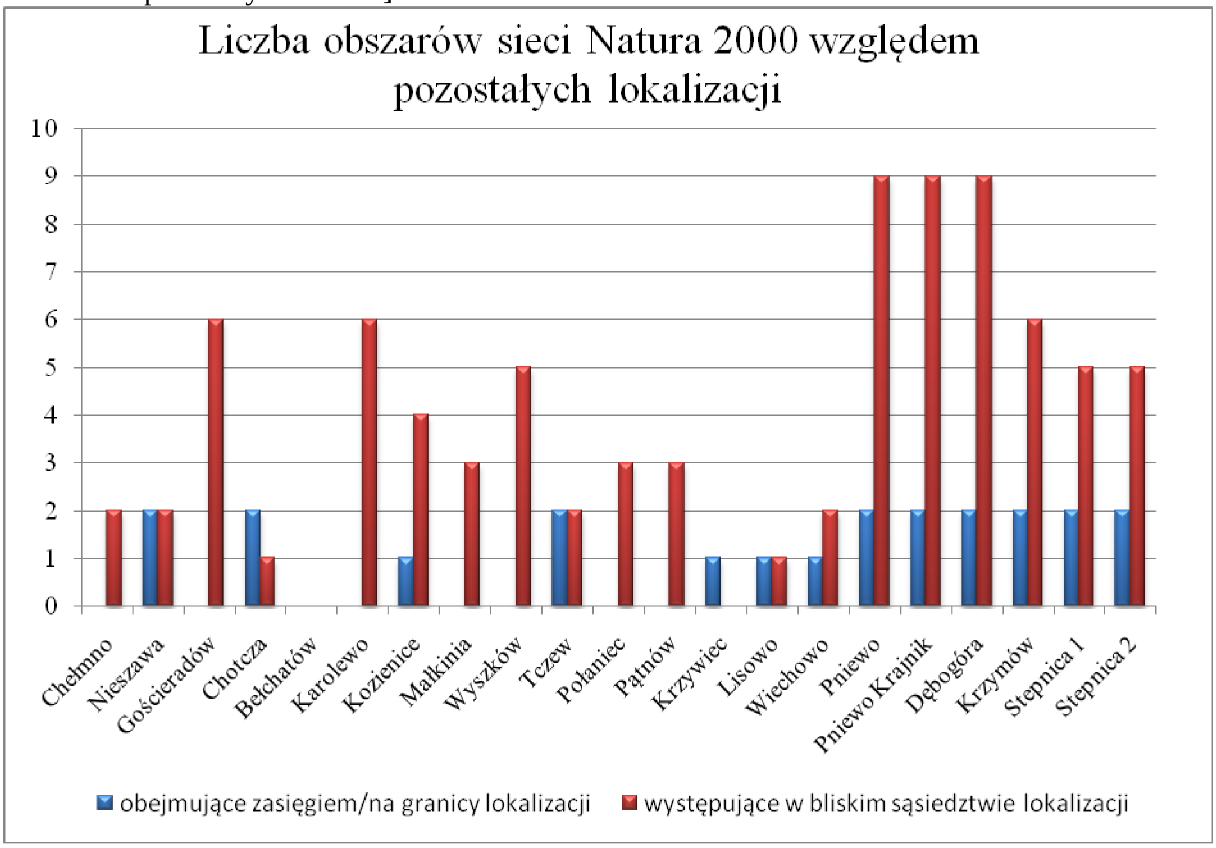
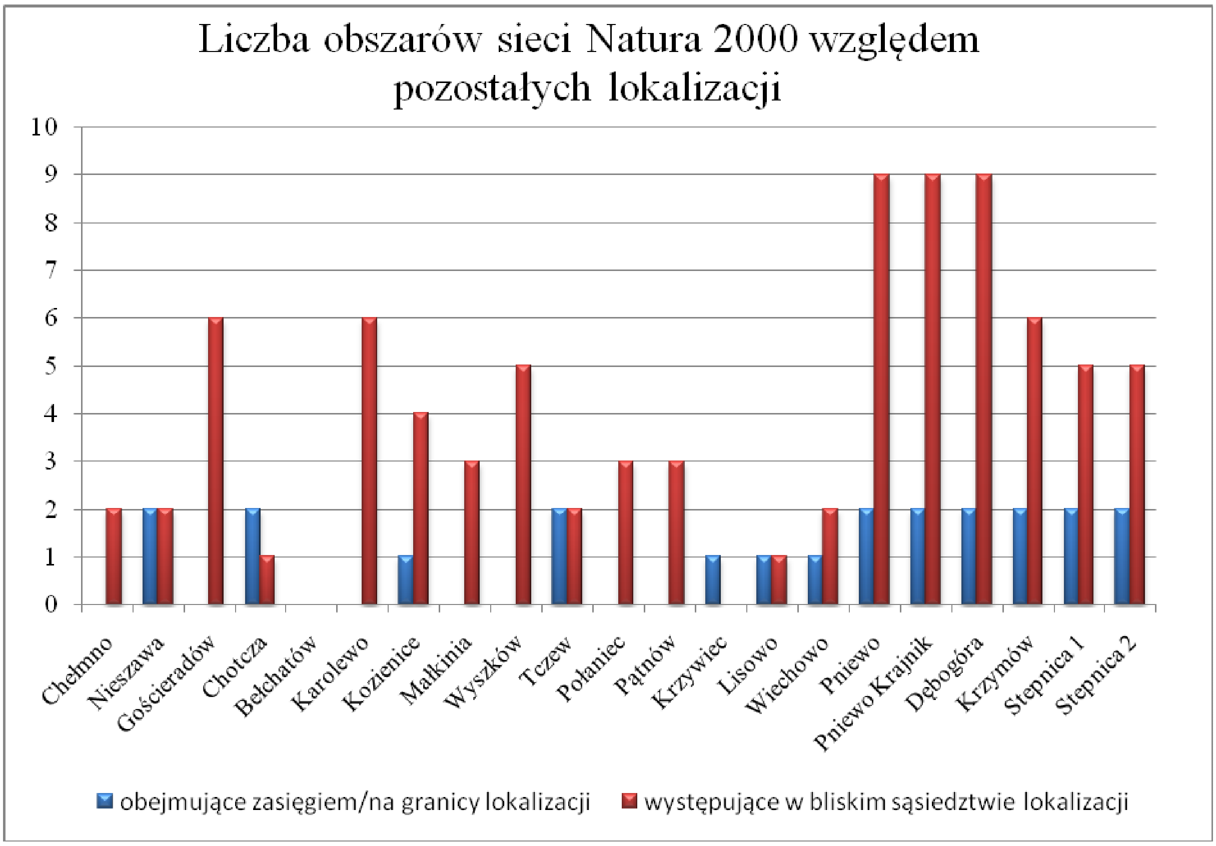


Fig. 4.5.2 Location and number of Natura 2000 areas in relation to the assessed recommended and reserve locations

[Number of Natura 2000 sites with regard to other locations
In their range/bordering
In the close proximity of the site]



As it can be seen, most analysed locations are in or in the neighbourhood of Natura 2000 areas - except for sites in Nowe Miasto and Bełchatów. In other cases, more or less apparent collisions may occur. In case of selection of sites in sensitive areas, integrity of Natura 2000 area may be violated and execution of objectives may be threatened. EIA procedure, conducted properly and according to good practice at the subsequent Programme stages should prevent such negative impacts.

Also, expansion of contact line grid resulting from the Programme may impact Natura 2000 areas due to deforestation, ground works at construction stage and increased bird mortality in its course areas at operation stage.

4.5.3 **Impacts on biodiversity**

Biodiversity may be examined according to various criteria and on various precision levels.

From the perspective of nature organisation, biodiversity is examined on three basic levels:

- intraspecific diversity - or genetic diversity, including i.a. diversity of subspecies, varieties, forms, in order to increase (or not decrease) diversity on intraspecific level, a grid of wildlife corridors was created (particularly for migrating animals).
- species diversity - includes diversity of species, but in a broader sense this is also taxonomic diversity, including supraspecific diversity of higher-rank taxa, to which individual species belong - i.e. genera, families etc.
- supraspecific diversity - diversity of species groups and their habitats but not in taxonomic aspects, but as communities,, sets created by species. Such diversity is best recognised and commonly analysed and included in the aspect of nature protection with regard to plants. In contrast to plant species diversity including flora, plant diversity is also analysed in terms of plant

communities, i.e. syntaxonomic units distinguished in this aspects, i.e. associations, relations, orders and classes of vegetation. Plant types currently are protected similarly to species. Plant communities occur in landscape complexes involving various communities related in spatial and dynamic aspects and they form a basic landscape component. Thus, landscape is the highest level of biological diversity.

Analysis of potential impact of nuclear power plants in Poland in the context of biodiversity was performed on species and supraspecific level. Analysis for intraspecific level in relation to the preliminary assessment stage (of strategic character) and to lack of proper and sufficiently precise data was not performed.

Analysis on species level may be conducted for various groups of organisms, and analyses for plants and animals were performed in this aspect. Analysis of supraspecific impact was performed for plant communities, and more precisely for types of protected habitats specified in Annex 1 to Natura 2000 Habitat Directive. Precise data were included in location analysis for individual potential sites. Synthetic discussion of results for animals, plant species and their community was presented in separate, dedicated chapters.

Undoubtedly, programme execution may impact biodiversity, though mainly in local aspect. Level of impact on biodiversity will depend on selected nuclear power plant location.

4.5.4 **Impact on animals**

Significant impact of the Programme on environmental components may refer to selected animal species. Programme execution may directly affect the species or may affect them indirectly due to changes of habitats.

Nuclear power plant construction in Poland as the main environmentally burdensome effect of the Programme is related to possible increased direct mortality of animals due to collisions with facilities such as buildings, devices and vehicles, mortality due to construction works (particularly ground-dwelling and aquatic invertebrates). Moreover, necessary expansion of aerial transmission grids threatens migrating birds and bats, both in terms of increase mortality due to collisions and due to the barrier effect (transmission lines concentrated in the vicinity of power plant may affect correction of established migration routes).

In power plants taking cooling water from reservoirs and rivers, there is a hazard of animal mortality due to suction into cooling systems. Also discharge of heated water to natural reservoirs may lead to deterioration or improvement (depending on species requirements) of environmental conditions and related species population.

Deterioration of the functions of a wildlife corridor is also possible due to location of a nuclear power plant within. As a result, migration may be reduced (mainly for mammals), which increases the risk of isolation of animal population.

Depending on a selected site (and its natural values) impacts may vary in terms of their specifics, intensity and duration, therefore it is important to properly select a site and diagnose hazards at the EIA stage.

4.5.5 **Impact on plants**

The basic aspect of analysis of potential impact of nuclear power plant construction on plants was analysis of potential negative impact on biodiversity of plants on species and community level. Rare and endangered taxa and syntaxa, legally protected, were selected as potentially most susceptible to negative impacts and most valuable for impact assessment in methodological sense. From the syntaxonomic perspective, analysis was performed according to types of habitats specified in Annex

1 of Habitat Directive, being in different rank, i.e. not only plant associations, but also higher units, including classes.

The preliminary biodiversity analysis on the basis of available literature shows that individual sites are highly diverse in this regard. Basic data collected in the tables allow for numerous analyses in various variants, however in general it can be stated that although differences between sites are significant, diversity analysed with various selected criteria gives mutually correlated results. It is understandable, as in locations with large diversity of habitats, greater diversity of species also occurs, and what follows - greater probability of rare species. With regard to the above, basic analyses for selected criteria are presented below, allowing for assessment of potential significant impacts on biodiversity of plants and flora. Plant species from Annex 2 to Habitat Directive, usually very rare, are an exception. There are no more than 5 of them in a given location, so that form a non-representative group. Therefore, despite occurrence of those species, biodiversity of a much broader group of rare and protected species was analysed. A group of frequent species was excluded from protected plants, as they appear in most locations, have larger populations and usually appear with more frequency and coverage. Therefore they have much less value differentiating sites with respect to their negative impact on plants, and they are less susceptible to such impacts. The results for plants and habitat types are presented in Fig. 4.5.3 - Fig. 4.5.5.

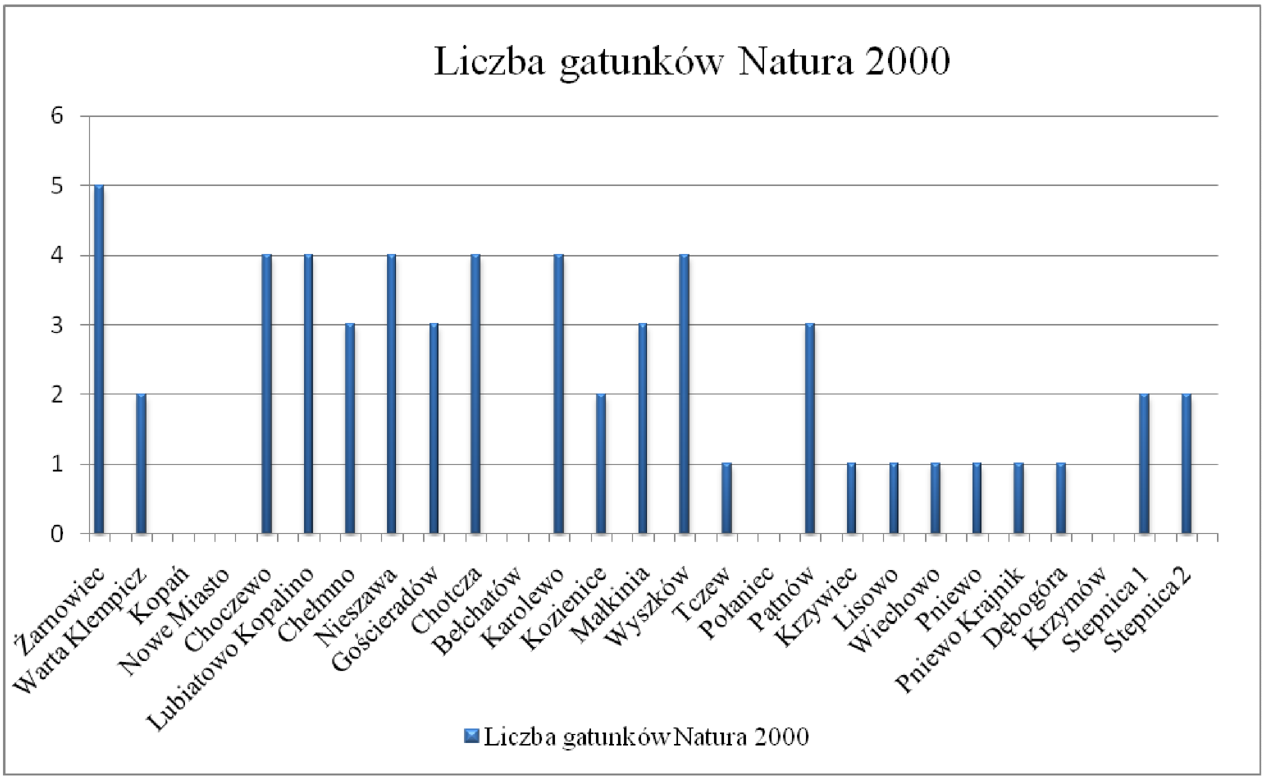


Fig. 4.5.3 Occurrence of the species from Annex 2 to Habitat Directive in the area of proposed site and in the area of surface environment protection forms in its vicinity.

Fig. 4.5.4 Occurrence of the rare and endangered species under strict protection in the area of proposed site and in the area of surface environment protection forms in its vicinity.

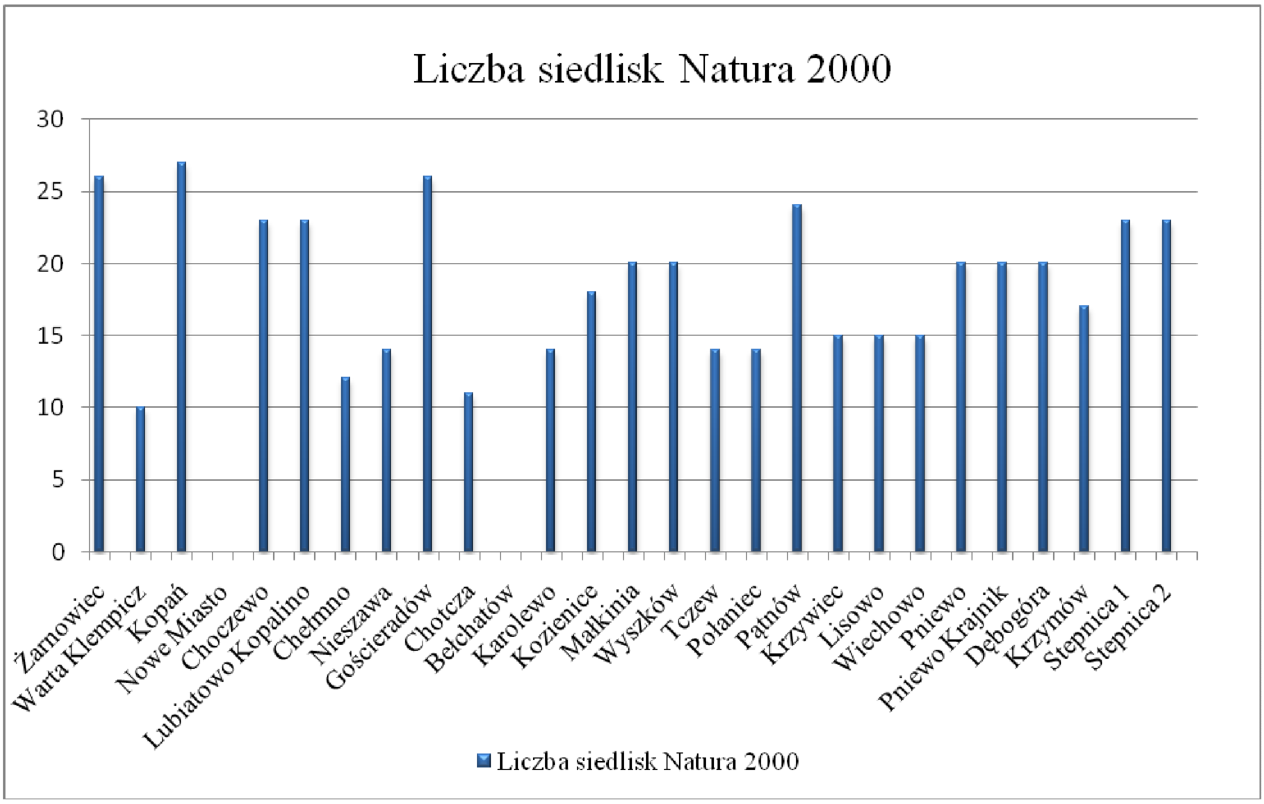


Fig. 4.5.5 Occurrence of habitats from Annex 1 to Habitat Directive in protected areas within potential sites

In case of plant species and plant communities, one of the basic factors which may potentially adversely affect their diversity is their direct destruction due to construction of a power plant and related infrastructure. Therefore, intensification of predicted impacts at the current stage of analysis is assessed on the basis of number of protected and rare species and habitats in a given site area. Therefore, the greater the diversity of vegetation in all aspects, the greater the power plant impact may be. Negative impact to a smallest extent may be expected in places where diversity and occurrence of rare and protected taxa is the lowest. As the differences in this regard, according to the analyses, are significant, from the perspective of impact on plants, it may be clearly indicated that potentially smallest risk of impacts occurs in Nowe Miasto site among recommended sites and in Bełchatów among reserve sites; however, it must be emphasised that new sites will probably be added to the assessed ones, not included in this analysis.

4.5.6 Analysis of premises mentioned in art. 34 of the Environment Protection Act of 16 April 2004

The forecast for the draft of Nuclear Power Engineering Programme includes a habitat assessment, concluded with a statement of **possibility of potential** impact of the drafted document on Natura 2000 areas. Thus, pursuant to art. 55 of the Act on environmental information and protection, participation of society in environmental protection and assessment of environmental impact (EIA Act), the draft of the document cannot be accepted, unless premises occur from art. 34 of the Environment Protection Act of 16 April 2004 (Journal of Laws 2009 Nr 151, item 1220 as amended), pursuant to which

1. If justified by requirements of overriding public interest, including requirements of social or economic nature, and the absence of alternatives, the competent local regional director of environmental protection, and in marine areas - the director of the competent maritime authority may authorize the implementation of the plan or action that could significantly adversely affect the conservation objectives of Natura 2000 area or areas on the list referred to in art. 27, excerpt 3 point

1, ensuring implementation of environmental compensation necessary to ensure consistency and proper functioning of the Natura 2000 network.

2. Where a predicted significant impact relates to the priority habitats and species, a permit referred to in excerpt 1, may be granted only for the purpose of:

1) protection of human life and health;

2) providing common safety;

3) obtaining beneficial results of primary significance for

environment;

4) resulting from requirements of overriding public interest, upon obtaining the opinion of the European Commission.

The premises are as follows:

1) Lack of alternatives and 2) necessary requirements of public interest, which, pursuant to the Act, include social or economic requirements.

In case of impact of the draft of Nuclear Power Engineering Programme on priority species protected in terms of Natura 2000 network, the premises were limited to objectives related to:

1. protection of human life and health;
2. providing common safety;
3. obtaining beneficial results of primary significance for environment;
4. and other objectives resulting from requirements of overriding public interest, upon obtaining the opinion of the European Commission.

In order to assess whether the premises occur in the discussed case and whether they will enable approval of the document pursuant to art. 34 of the Environment Protection Act, they must be semantically and legally analysed in detail,

The key premise for initiation of the assessment of occurrence of a category of objectives from art. 34 of the Environment Protection Act is the premise of "lack of alternatives".

Alternatives described in the EIA procedure should include alternative sites or trails (routes in case of line investments), different scales and sizes of investment or project design solutions, and the timetable or the organization of construction work, construction methods, as well as decommissioning method and alternative processes[255]. Assessment of alternative solutions should always be through the prism of the conservation objectives of a given Natura 2000 area, its integrity and contribution to the overall coherence of Natura 2000 network. Zero option also must be considered[256]. The term "non-existence of alternatives" means that there are not any solutions that enable the achievement of the objective in a different, less environmentally damaging way, although the choice of one of the selected opportunities does not have to be based on the ones which have the least negative impact on the area.

The impact forecast analyzes the potential sites from a list of the Ministry of Economy with the proviso that none of those locations is determined (see Chapter 10.3) and possible technological and structural solutions, as well as examines the possibility of securing its energy needs through other sources, including renewable energy (see chapter 10.1). In the analysed case, also assessment analysis of zero option was performed, i.e. effects of failure to execute the drafted document, although it should be emphasised that the political decision on introducing nuclear power engineering in Poland was made on the basis of another document, i.e. State Energy Policy until 2030 with the strategic environmental impact assessment (see chapter 2). Pursuant to art. 5.2. of SEA directive, work schedule was not included in the forecast (both in terms of logistics and construction) due to the fact that the term was "given" in State Energy Policy until 2030.

It should also be noted that due to the need to carry out the procedure to obtain a decision on the environmental conditions for the three possible equivalent locations guarantees proper approach to variant analysis guarantee that the chosen location will have the minimum possible impact on the environment and that the variant analysis performed at the environmental decision stage will allow assessment of the existence or nonexistence of alternatives.

The following remarks - without prejudging in any way on recognition of the existence/nonexistence of alternative solutions focus only on the premise of the necessary requirements of overriding public interest.

In order to assess what is or could be regarded as such a premise, one needs to indicate interpretation of the term "legal interest" in doctrine and judicature.

The concept of public interest is subject to constant interpretation in the doctrine and judicature, mainly due to the fact that there is no general definition of interest as a normative category[257]. (In legal language there is the category of "private interest" (individual), "public interest", "general interest" or "social interest" (general social), "state interests" (of the state)).

For the purposes of this paper it is worth quoting only the selected views, which may contribute to the subsequent interpretation of the concept of "overriding" public interest[258].

Judicature accepts that the public interest relates "essentially to matters related to the functioning of the state and other public bodies as a whole, especially with the functioning of the basic structure of the state. Effective action in the public interest is associated with the possibility of real influence on the functioning of certain state institutions in a broad sense"[259], and that the interpretation of the term "public interest" should take into account the values shared by society as a whole, this particularly refers to justice, security, citizens' trust in public authority[259]. Moreover, according to the ruling of the Constitutional Tribunal, public interest (common good) to be upheld, should have an established axiological base in the consciousness of individuals, which implies a particular normative imperative. The concept of public interest cannot be treated as the notion that gives the legislature an opportunity to treat it randomly, because it has no blanket character. Therefore, it is legislature's obligation to identify its content with regard to constitutionally protected standards.[260]

In summary, the concept of legal interest is a classic legally indeterminate phrase, which does not have a precisely defined content, and therefore it does not have a precisely defined legal meaning. Therefore, we should agree with the view of M. Wyrzykowski that it is most favourable to present the public interest in descriptive terms, i.e. **as the best response to the situation in the conditions of existence of all interests and in a way that respects the values generally accepted in the society**[261]**.**

In this context, the question arises whether, and if - in what extent - the concept of public interest includes protection of the environment on the one hand and energy security - on the other. The answer can be found in the provisions of the Polish Constitution[262], more precisely art. 31, excerpt 3, which mentions specific manifestations of public interest, including environmental protection and safety[263]. Similarly, art. 5 of the Constitution indicating functions of the state, i.e. fundamental directions and objectives of its activity. The elements expressed therein comprise interest of the state[264].

Similarly, art. 3 p. 13 of Environment Protection Law (i.e. Journal of Laws 2008 No. 25, item 150 as amended), which construes the notion of environment protection as *taking or failure to take action to preserve or restore the natural balance; this protection is, in particular:*

a) rational shaping the environment and management of environmental resources in accordance with the principle of sustainable development,

b) preventing pollution,

c) restoration of the natural elements to the proper state.

Thus, it should be assumed that management of resources (including non-renewable energy resources) is not opposed to the popular meaning of "protection" of the environment but - if it is compliant with the principle of sustainable development and takes place in a rational way - is a component of the concept. This means that the objectives of environmental protection and resource management are not contradictory. The question is, however, how one may reconcile them with satisfying needs for energy supply. The answer can be found in art. 1 of the Energy Law[265], pursuant to which

1. The Act defines the rules of the state energy policy, terms and conditions of supply and use of fuels and energy, including heat, and the activities of energy companies, and also defines the competent authorities in matters of fuel and energy.

2. The purpose of the Act is to create conditions for sustainable development of the country,

energy security, economical and rational use of fuels and energy, the development of competition, counteracting negative effects of natural monopolies, integrating environmental protection requirements, the obligations arising from international agreements and balancing the interests of energy companies and consumers of fuels and energy.

The concept of energy security should be understood as the possibility of ensuring stable supplies of fuels and energy at a level guaranteeing meeting national needs at the prices accepted by the economy and society, assuming optimal use of domestic energy resources, and through diversification of sources and lines of supply of crude oil, liquid and gaseous fuels . Energy security is also the security of technology, guarantee of sector investment profitability and continuity of supply.[266]

According to the jurisprudence of the Constitutional Court, ensuring **energy security** of the country, in other words striving to meet both existing and projected energy needs, is the duty of public authorities[267]. Ensuring energy security should take place in conditions specified in art. 74, excerpt 1 of the Constitution, taking into account the ecological security of current and future generations

In light of the definition of "energy security" and "public interest" understood as the best response to the situation in the conditions of existence of all interests in a way that respects the values generally accepted in the society[268] it must be recognized that energy security is in the public interest. Such a position is also confirmed by the doctrine[269] and case law, in particular the judgment of Regional Administrative Court in Warsaw VI SA/Wa 1893/07 of 2008-04-07 recognising energy (including fuel) security as public interest.

Since energy security can be considered as public interest, one should consider whether it constitutes a category of "overriding" public interest. Environment Protection Act, nor the Habitats Directive, nor the Court of Justice of the European Union [270] define "necessary requirements of overriding public interest". However, art. 34, excerpt 2, p. 1-3 Environment Protection Act lists the human health, public safety and beneficial consequences of primary importance for the environment[271], as examples of the necessary requirements of overriding public interest. Undoubtedly, however, the term "necessary requirements of overriding public interest" also includes other than the above mentioned types of social or economic interest. Surely this "overriding public interest" is an interest of a social or economic nature, but "qualified" in relation to the interests specified in art. 34, excerpt 2, p. 1-3 Environment Protection Act. According to the Court of Justice judgment in case of *Leybucht Dykes*, it must include interest exceeding the value of natural resources, for the protection of which a given area was created[272].

The overriding public interest can be regarded as strengthening the competitiveness of the region, better conditions for trade development, ensuring adequate quality of transport, the beneficial social effects in the short-and long-term scale, environmentally friendly alternative transport[273]. It results from the examples discussed in the amended version of the study "Managing Natura 2000 sites" that **potential overriding requirement for the necessary public interest can also be: prevention/minimization of unemployment, reducing greenhouse gas emissions, air pollution** and new jobs (all these arguments can be taken into consideration in connection with the planned nuclear power plant**)**, and the competitiveness of specific European industry and region, the demand for drinking water, etc.[273] Examples taken from the Commission's opinion indicate that the requirements of the overriding public interest may also be included in the area of priority infrastructure projects, approved by the EU itself[274]. Necessary public interest requirements also apply to situations in which it can be proved that the planned projects are necessary to protect human life and property[275].

Public interest should be deemed overriding, if it is a **long-term interest,** both economic and other interests bringing only short-term benefits to society, do not seem to be sufficient to dominate the natural long-term interests protected by the Directive.[276] Ensuring national energy security by building a nuclear power plant should certainly be treated as long-term interest.

For these reasons it should be considered that energy security can be regarded as an overriding public interest.

Another premise is the recognition whether conditions arising from an overriding public interest are **„necessary requirements**”. Due to the lack of interpretation of this concept in EU law and national law, the jurisprudence of the Court of Justice and the Commission communication relating to the concept of "service provided in general economic interest" may be applied in auxiliary capacity.

Primary EU law uses the term "service of general economic interest" cited in art. 106 TFEU (former art. 86, excerpt 2 TEC) as an exception to the competition rules laid down for companies providing such services. In its Communication on services of general interest in Europe the Commission, taking into account the case law on this matter, gave the following definition of services of general economic interest: *"These include commercial services of public utility, based on specific principles of public services specified by the member states. This applies in particular to services provided in transport, energy sector and communication networks"* [277] This clearly demonstrates the recognition by EU institutions of the services in the energy sector as services of general economic interest, which can render them explicitly as falling within the premise of the necessary requirements of overriding public interest.

In practice, the assessment of the premise of necessary requirements of overriding public interest is made by the administrative body which according to the ruling of the Regional Administrative Court in Warsaw IV SA / Wa 2319/06 "must consider the existence of alternatives *in concreto*, also taking into account the environmental or social costs of implementing alternatives. The existence of alternative solutions should be considered, bearing in mind the particular need for protection of goods subject to special forms of environment protection (e.g. areas of international importance under the Natura 2000 network), not forgetting at the same time the need for balancing the issues of reasonable protection of these areas with other considerations (such as social considerations or conservation of natural resources not covered by specific forms of protection), without neglecting the principles of sustainable development"[278].

This means that it is possible to adopt a document on the basis of art. 34, excerpt 1 of the Nature Conservation Act - as falling within the premise of the objective arising from the necessary requirements of overriding public interest. At the same time, if the competent authority selects the location of a nuclear power plant, the assessment of the impact on specific Natura 2000 areas (including perhaps - priority species) will be carried out *in concreto* as environmental impact assessment for the planned project. Then, if necessary, the implementation of the project will be possible on the basis of art. 34, excerpt 2 p. 4 of the Nature Conservation Act - as falling within the premise of the objective arising from the necessary requirements of overriding public interest, after obtaining the opinion of the European Commission. At the same time, it seems, a positive opinion in this regard would be the obvious consequence of the adoption of EU law documents such as climate and energy package, 6 action program for environmental protection along with the thematic strategy on air pollution and the Thematic Strategy on the sustainable use of natural resources for 2006-2013 as well as secondary legislation.

5 IDENTIFICATION AND CHARACTERISTICS OF EXPECTED ENVIRONMENTAL IMPACTS OF PROGRAMME IMPLEMENTATION

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Summary of significant identified impacts

This summary does not include "impacts on the biotic elements of the environment", since they have been described in detail in subsection 4.5. Text structure applied therein is compatible with the following layout of content.

PHASE	DESCRIPTION OF EXPECTED IMPACTS
5.1.1	**Impact on humans**
CONSTRUCTION	**Impact of noise** It will be minimal due to required selection of a site not adjacent to a developed area. Transport will be also a source of noise. The selected transport route should minimise any nuisance factors for the local population. **Impact of dust emission** The increase in dust, intrinsically linked with the construction of large surface facilities, can be effectively minimized through preventive action. **Additional jobs** The creation of new jobs is a positive impact on people.
OPERATION	**Emission of radiation** The highest possible doses of radiation associated with normal operation of EPR, AP1000 and ESBWR reactors for adults from critical group - estimated at a conservative approach - are, respectively, 25µS/year, 121µS/year and 12µS/year, which falls within any of assumed standards (the maximum dose for a critical group according to Atomic Law is 300µS/year). These doses are incomparably smaller than the current average annual radiation dose rate of 3400 µS/year, associated mainly with the natural radiological background, medical applications, and emissions from other industries. Additional radiation dose from a nuclear power plant is also much lower than the difference between doses in individual Polish towns and cities, which means that an inhabitant of Wrocław who decides to move to a city like Kraków will be exposed to a much higher dose of radiation than they would be exposed to in Wrocław if a nuclear power plant was built right in front of their house. Detailed calculations and data on the emission of radiation are provided in chapter 3.1 - **Błąd! Nie można odnaleźć źródła odwołania.**. Chapter 0 discusses radiation effects for a reference facility, which in 20 years did not cause negative impacts on people and ecosphere related to emission of radiation.
	Impact of small radiation doses Impact of low doses of radiation which may be emitted during normal power plant operation, has been described in detail in chapter **Błąd! Nie można odnaleźć źródła odwołania.**. Based on years of research of population and selected groups of workers or patients it was concluded that low doses of radiation (comparable to the size of natural background) do not cause adverse health effects. Quite on the contrary, most studies indicate that the impact of small doses of radiation is even positive for living organisms, including humans, as they have an anti-cancer effect (radiation hormesis hypothesis).
	Noise emission Noise is emitted by plant and machinery operated on site (see chapter 4.3.5). The nuisance level depends mainly on the actual location of a nuclear power plant. It may be higher in case of a power plant with *closed-cycle cooling system*, because basic noise emission results from operation of cooling towers. The noise level in a radius of 100m from the cooling towers can reach 60-70 dB (A). However the level of noise emitted by the power plant unit (with EPR) was estimated at 45 dB(A) at a distance of 350 m. The noise will therefore not be a substantial burden on the people, especially since no one will reside in the area of limited use, whose radius is estimated at about 800 m.
	Supply of electricity and improvement of the natural environment The introduction of nuclear energy in Poland is one of the actions that will improve energy security of the country (diversification of sources, reducing fossil fuel consumption, relatively low cost - ch. **Błąd! Nie można odnaleźć źródła odwołania.**). Energy production at nuclear power plants is associated with lower emissions to the atmosphere (Chapter 4.3.4.3), so its introduction will improve the quality of the environment by reducing emissions from existing energy sector.

Failures

In the event of a nuclear reactor breakdown, the key threat is connected with radioactive substances released to the environment through air (mainly) or water. These substances may be either inhaled or ingested by humans (see chapter **Błąd! Nie można odnaleźć źródła odwołania.**). Therefore, all reactors have an entire system of safeguards and protections – including devices and solutions that prevent the potential release of significant quantities of radioactive substances to the environment (see chapter **Błąd! Nie można odnaleźć źródła odwołania.**). But the fact is that the potential severe failure, which would result in significant release of radioactive substances into the environment, mainly into air, and (in much smaller quantities and less likely) to the water, could pose a significant threat to human health (maximum dose, in case of the most serious failure with core melt is 246mSv/2h (AP1000 reactor, estimate with conservative assumptions) - ch. **Błąd! Nie można odnaleźć źródła odwołania.**). However, the occurrence of such a failure, due to the applied security and planned use of the latest improved technologies with III and III+ generation reactors to build even first nuclear power units in Poland, in fact almost completely exclude the risk of such an accident (the frequency of such events is estimated at less than once in a million years of reactor operation). Radiological protection procedures have been defined and will be followed in any emergency situation. These intervention measures (see chapter **Błąd! Nie można odnaleźć źródła odwołania.**) will minimise any potential negative health effects.

In case of third-generation reactors, constructed so as to meet the safety requirements specified in the proposed Polish regulations and generally adopted European energy requirements, the risks in the event of design failure will not require interventions outside the restricted-use zones (about 800 m), and in case of severe failure early or long-term intervention will not be needed outside this zone. Theoretically, one may need to undertake medium-term interventions (administration of stable iodine), which will not cause impairment of normal life. The probability of such a failure is less than one in a million years of reactor operation.

DECOMMISSIONING

Emission of radiation

Dose size and power of the emitted doses during and after the decommissioning of NPP are not a threat to humans (Ch. **Błąd! Nie można odnaleźć źródła odwołania.**). Employees working on nuclear decommissioning will be exposed to doses of radiation that are comparable to normal radiation doses emitted during normal operation and maintenance of a nuclear power plant, and these doses will not cause any harm to their health – as confirmed in a study involving 500,000 people working in the nuclear power sector.

Impact of noise

It will be minimal due to required selection of a site not adjacent to a developed area. Transport will be also a source of noise. The selected transport route should minimise any nuisance factors for the local population.

Additional jobs

The creation of new jobs is a positive impact on people.

5.1.2 Impact on surface waters

CONSTRUCTION

There will be no significant negative impact on surface waters in the construction phase. We may only expect local changes in water circulation caused by the fact that ground waters will be pumped out of excavations and trenches and released to surface waters.

OPERATION

Heat emission to surface waters

Eventually, all the waste heat discharged from power plants is transferred to the atmosphere, but using *open-cycle cooling systems*, this heat is transferred through the surface waters - inland or sea. Before the water, after discharge of the heated water is re-cooled, heat contained in it may have a negative impact on the aquatic ecosystem. Heated water mixing processes, transmission and giving up waste heat are described in detail in chapter 4.3.2.5. The acceptable heat emissions to surface waters are limited by law. The introduced heated water must not exceed 35°C for rivers and seas, and 26°C for lakes and their tributaries.

An excessive rise in temperature of surface waters can lead to increased intensity of respiration, increased biological production and, consequently, eutrophication of surface waters. The temperature of water has a direct impact on all living organisms and their physiological processes, and an indirect impact on oxygen balance in water. If water is heated up, it affects the solubility of oxygen and facilitates decomposition of organic matter, which leads to faster consumption of oxygen.

The value of the temperature increase in the reservoir water, which will receive the waste heat, can be calculated only on the basis of a detailed computational model for a particular location for the investment. Such detailed analysis will be performed after the selection of investment location, and on that basis one can determine precisely the degree of water heating near the discharge of cooling water and in the distance from the point of discharge. An example of such an analysis for the selected reference facility is presented in chapter 4.3.2.5.1. The water reservoir used for cooling purposes will be analysed in detail during the operation phase to determine the scope and type of impacts caused by the release of heat.

Pollution with chemicals

Chemical pollutants are released to water from: products used to prevent depositions on the surface of elements of the cooling water system, biocides, and products of corrosion in heat exchangers and piping.

In *nuclear power plants on river sites*, makeup water used in the cooling system or cooling water must be treated, based on: lime decarbonisation, acid grafting, application of precipitation retardant. The application of these methods depends on the design of the cooling system and the quality of water used (see chapter 4.3.3). Due to decarbonisation, sediments of $CaCO_3$ and$(OH)_2$ are created, with which some heavy metals may be precipitated. The precipitate is collected in special settlers, concentrated, dried and disposed of in landfill. Deposition of this type of waste has no negative impacts on the environment. As calcium and magnesium are removed in the form of deposits, mineralisation is lower in water released to surface water compared to water that is taken in.

In *nuclear power plants on coastal sites* chlorine (biocide) must be used to maintain the required purity of water used in water circulation systems. Chlorine reacts with organic compounds and forms organo-halogenated compounds. Concentration of those compounds is higher with chlorination in *closed-cycle cooling systems*.

Due to the value of the discharge concentrations of chemicals released into water, which do not exceed 1% of environmental quality standards, their impact can be regarded as negligible (see chapter 4.3.3.6). The only substances in excess of the standard are TRO (total residual oxidants). However, the area of potential exceedences for these compounds will be limited to the immediate surroundings of the discharge point due to dilution and degradation processes of these compounds.

Failures	A potential release of radioactive substances to surface waters may occur only as a result of a very serious accident (with reactor core melt). However, third generation reactors include additional systems and structures that protect the integrity of the safety containment and the foundation slab. As a result, the risk of an accidental release of radioactive substances is reduced practically to zero. However, in the event of an accidental release of radioactive substances to the atmosphere, radioactive particles will slowly deposit on the surface of the ground, or will be washed away quickly by rain or snow and will finally get to surface water bodies. Depending on the existing weather conditions, potential pollution of surface waters is therefore possible.
DECOMMISSIONING	No significant negative impact on surface waters is expected in the nuclear decommissioning phase.

5.1.3 Impact on ground waters

CONSTRUCTION		**Pollution of waters** During the construction phase there is the greatest threat of groundwater pollution. This will be particularly important in the areas characterised by high and very high sensitivity to underground water pollution related to lack of rock insulation of aquiferous layer from the surface of the area. The most favourable area in terms of securing aquifers are impervious moraine deposits with slow infiltration of depth. Such a location ensures protection of groundwater also in potential emergency situations. **Change in water relations** Impact of ground works on underground water may be particularly visible in the areas of shallow deposits of aquifers. Deep excavations require intensive drainage, resulting in local depression craters, which may affect the drainage of adjacent areas. However, in the case of nuclear power plants excavation depth is not particularly large[2], since the lowest level of foundation of the most sunken buildings (containment) is -14.00 m (EPR). Sealing large areas of land through the construction of power plants and adjacent infrastructure may locally influence lowering the surface of shallow groundwater, and thus drainage of the surface.
OPERATION		**Potential pollution of groundwater** NPP structures, systems and devices will be constructed under strict quality control standards, environmental standards, supervision standards, and standards of BAT (Best Available Techniques), which will minimize potential unplanned releases of hazardous substances to the soil. Storage containers, storage areas for chemical substances, fuel unloading areas and areas of other works that could cause environmental pollution will be located on hardened surfaces or confined with leak proof barriers that will contain any possible releases of harmful substances. Retention zones will be designed to prevent contact of spills with the ground and then with groundwater. Therefore, operation of the nuclear power plant will have no impact on the quality of the ground and groundwater – unless an unforeseen accident occurs. During normal operation there is no likelihood of direct or indirect release into the groundwater of the following substances: hydrazine hydrate, bromoform, hydrocarbons, metals, phosphates, ammonia, nitrates. In order to control the quality of groundwater from piezometers network surrounding the NPP water samples will be collected, in order to monitor groundwater quality and detect any possible contamination.
		Potential changes in groundwater level The level of groundwater may be subject to slight changes due to sealing a large area surface, which prevents infiltration to approximately 43 thousand m^3 (chapter 4.3.6.1). The level of groundwater will be controlled by a network of piezometers. It will be used to determine the impact of buildings on the local hydro geological conditions (changes in groundwater flow in the surroundings of the buildings).
	Failures	**Release of radioactive substances** A potential release of radioactive substances to surface waters may occur only as a result of a very serious accident (with reactor core melt). However, third generation reactors include additional systems and structures that protect the integrity of the safety containment and the foundation slab. In the EPR reactor measures protecting containment foundation slab before melting are a central element of the reactor safety system. The AP1000 reactor foundation slab protection system is different, but also tested and reliable. Polish regulations provide that reactors cannot be built without these systems that ensure proper protection of the safety containment. As a result, the risk of an accidental release of radioactive substances is reduced practically to zero. **Release of non-radioactive substances** The real threat of groundwater pollution (other than radioactive substances) may occur due to uncontrolled leakage. Therefore, provision of emergency water collection tanks and development of emergency procedures is a key element in the design and construction phase. In the event of any accidental release of pollutants, an emergency procedure will be launched to detect and neutralise source of the leakage and the contaminated area in order to prevent the pollution of groundwater.

[2] Compared with such facilities as large scale hydro stations.

DECOMMISSIONING	Complete removal of buildings and the associated infrastructure, including all hardened surfaces, will have a positive impact on water resources by increasing the infiltration area.

5.1.4 Impact on the air

CONSTRUCTION	**Emissions during the production of materials** Quantities of materials and equipment needed for third-generation nuclear power plants are relatively small (converting into unit of energy production). As a result, emissions of sulphur dioxide, nitrogen oxides, dusts, heavy metals, and CO_2 during the construction of a power plant and production of the associated equipment are much lower for nuclear power projects than for other sources of electricity (chapter 6.1.2.4). **Dustiness** As a result of the construction works dust emissions into the atmosphere will increase. However, it can be effectively reduced by, e.g., spraying. Quantities of materials are relatively small (converting into unit of energy output), therefore values of dust emission in the area during construction are also correspondingly small (about 7 mg of dust per 1 kWh of power (Table 4.3.14)). **Exhaust emission from machines and vehicles** The construction phase will involve an increase in heavy machinery traffic and the related increase in the emissions of exhaust gases to the air. This impact will depend on the location of the construction site and the selected access route.
OPERATION	**Reduction potential of atmospheric pollution emissions** Potential reduction of air pollution resulting from the introduction of nuclear power in Poland was evaluated based on the analysis of emission volumes from various energy sources for the entire electricity production cycle (from the extraction of raw materials up to the deposition of waste). The data are presented in chapter 4.3.4.3. They show that NPP has definitely the lowest emissions of CO_2 (ca. 50 times lower compared with coal power plants), as well as the lowest emissions of dust, NO_x and SO_2. According to calculations (chapter 4.3.4.3) minimal potential for emission reductions resulting from implementation of the objectives of Polish Nuclear Power Programme, is 127 kg of CO_2/1MWh, 23 mg of dust/kWh, 58 NOx mg/kWh and 34 mg SO_2/kWh, which gives, respectively, 18%, 16%, 17% and 15% of current emissions. Given the projected demand for energy, the total emission reduction potential in Poland, associated with the implementation of the Programme would be more than 27 Tg ($27*10^{12}$ g) CO_2, and ca. 5 Gg ($5*10^9$ g) of dust, 12,6 Gg ($12,6*10^9$ g) NOx and 7,4 Gg ($7,4*10^9$ g) SO_2.
	Emissions from cooling towers With *closed-cycle cooling systems*, moisture emitted into the atmosphere from cooling towers may (in case of improper water treatment system) include chemical pollution with water treatment agents or microbes. These problems should be eliminated by an effective water treatment system, and their impact will be only marginal.
	Exhaust emissions Potential emissions, mainly sulphur and nitrogen oxides are associated with the transport and operation of emergency power generators. Their impact will be only temporary and will depend on the specific location and the transport infrastructure on site. Emissions related to the transport of fuel and waste (in small amounts) will be limited compared to the transport of employees.
	Other emissions of chemical substances There are potential ammonia emissions from steam generators and formaldehyde and carbon monoxide from the ventilation system. The significance of these emissions can be considered negligible.

	Failures	In the event of a serious accident, a potential release of radioactive substances to the atmosphere will be the most likely source of radioactive pollution. Impact of the radioactive cloud and its spread in the air will depend on the weather conditions. Calculations for dispersion coefficients of radioactive streak in the air are presented in detail in chapters **Błąd! Nie można odnaleźć źródła odwołania.**-**Błąd! Nie można odnaleźć źródła odwołania.**.
DECOMMISSIONING		The decommissioning phase will involve an increase in heavy machinery traffic and the related increase in the emissions of exhaust gases to the air. This impact will depend on the location of the construction site and the selected access route.

5.1.5 Impact on the climate

CONSTRUCTION		Emissions of greenhouse gases (mainly CO_2)) are related to the operation of construction equipment and transport of building materials and the workforce to the construction site. These emissions will not be burdensome to the local environment. For the global balance these are not important added variables, as they relate solely to the construction and decommissioning phase (short-term impact).
OPERATION		**<u>Reduction potential of greenhouse gas emissions</u>** Production of electricity in nuclear power plant does not cause emissions of CO_2, and so participation of NPP in energy production will reduce production of this greenhouse gas, which can have a positive impact on the climate. Very low emissions of CO_2 will be generated in the construction and decommissioning phase, as well as during the fuel cycle. The total carbon footprint is estimated at approximately 17kg CO_2/MWh (for comparison, in the case of coal-fired power plants, this figure is approximately 1054kg CO_2/MWh, and for gas power plant – 417kg CO_2/MWh) (chapter 4.3.4.3.1).
		<u>Heat emission to the atmosphere</u> Ultimately waste heat, generated as a by-product of electricity production is transferred to the atmosphere. With *<u>open-cycle cooling systems</u>*, heat may be transferred through water environment, and it is released to the atmosphere gradually (evaporation, radiation from water surface, and absorption in air). Given the large temperature differences, these processes may produce fog in the area where heated water is discharged. The area covered by fog will be limited. In power plants with *<u>closed-cycle cooling systems</u>* heat is transferred directly to the atmosphere via the cooling tower in the form of latent heat (70%) and sensible heat (30%). Cooling towers will release humid and heated air into atmosphere. This air cools down and produces a cloud of vapour. The cooler and more humid the surrounding air, the longer the cloud will remain in the air. This process, as well as the process of deposition of the cloud on the surface of the ground, will depend on the weather and design of the cooling tower (see chapter 4.3.2.6). Fogging may also be more intensive in the surrounding areas.
	Failures	No major impacts.
DECOMMISSIONING		Emissions of greenhouse gases (mainly CO_2) are related to the operation of construction equipment and transport of building materials and the workforce to/from the site. These emissions will not be burdensome to the local environment. For the global balance these are not important added variables, as they relate solely to the construction and decommissioning phase (short-term impact).

5.1.6 Impact on the Earth's surface

CONSTRUCTION

Impacts on the Earth's surface will be diverse, depending on the scale and phase of the project. The key impacts will include exclusion of the biologically active surface and changes in the ground structure (compaction, removal of a humus layer, etc.). The potential impacts also include the pollution of soil with petroleum products that mat be released into the ground due to leakage or breakdowns of mechanical vehicles.

OPERATION

Land take

The size of the surface occupied by NPP and the accompanying infrastructure depends on the adopted technological solutions (ch. 4.3.6.1) and may reach ca. 40 ha. Sealing of the area will reduce the biologically active area and the infiltration of water.

Production of solid waste

- radioactive waste – 30 Mg/year (for reactor with capacity 1000MWe) (ch. 4.3.6.1)
- chemical and inert waste – 294 Mg/year
- hazardous (non-radioactive) waste – 63 Mg/year

Failures

In the event of an accidental release of radioactive substances to the atmosphere, radioactive particles will slowly deposit on the surface of the ground as the radioactive cloud spreads out, or will be washed away quickly by rain or snow, depending on the weather conditions. As a result, contamination of soil is possible

DECOMMISSIONING

Complete removal of all facilities and infrastructure of the nuclear power plant and proper recultivation of the area that restores the former condition of land will have a positive impact on the Earth's surface.

5.1.7 Impact on the landscape

CONSTRUCTION

Impacts on the landscape will depend on the specific location and the type of land use in the neighbouring areas. In the construction phase, it is also of key importance to select the most optimum route for the transport of building materials.

Impacts on the landscape will result not only from the construction of the nuclear power plant, but also the associated infrastructure, including access roads, overground power lines, and water intake and discharge piping. The implementation phase (e.g. due to the use of large cranes) will probably be more unfavourable to the landscape than the exploitation phase of the investment.

OPERATION

Power plant buildings

Impacts on the landscape will depend on the specific location and the type of land use in the neighbouring areas.

For cycle-cooled power plants presence of the cooling tower is an additional detriment to the landscape. Wet natural draft cooling towers, whose raw (hyperboloid) form generally is not blatant, are very high and visible from afar, especially in the open. Hybrid cooling towers, whose appearance is more questionable, have the advantage that they are generally lower than other major power plant facilities and, above all, do not emit large plumes of vapour, visible from a distance. Examples of impacts of referential facilities are shown in ch. 4.3.8.

Coastal power plants and power stations on inland waters do not have a cooling tower, so that their interference in the landscape is significantly smaller.

Associated infrastructure

Power lines connected to the nuclear power plant will be a key element of the associated infrastructure. They intersect natural systems and developed anthropogenic systems, jointly forming specific landscape complexes. The scale and type of impacts caused by power lines will depend mainly on their linear layout and technical parameters (i.e. height of facilities, type of structures – tubular poles or lattice towers) that will clearly stand out in the landscape.

Failures

A potential accident will have no impact on the landscape. However, protection of the area after a breakdown may affect the environment.

DECOMMISSIONING

It is expected that nuclear decommissioning, involving the complete dismantling of all facilities and structures and restoration of the area to the condition as close to the original state as possible, will have a positive impact on the landscape.

5.1.8 Impact on natural resources

CONSTRUCTION

Construction of a nuclear power plant will involve the consumption of large amounts of water and mineral resources used to build power generating units and the associated infrastructure. At the same time, it will generate large amounts of waste: (including inert, construction, and municipal solid waste and sewage).

Analysis of maps of natural resources (chapter 4.3.6.2) shows that none of the variants of localization jeopardizes exploitation of the useful mineral deposits.

OPERATION

Securing supplies of nuclear fuel for NPP

In the foreseeable term, manufacturing nuclear fuel in Poland is not expected. Fuel - as fuel assemblies ready for loading into the reactor - will be purchased from foreign suppliers of NPP technology or from another manufacturer (as far as economic reasons make it beneficial). Production of nuclear fuel in Poland is not a feasible alternative given the relatively limited scale of the nuclear power projects and current prices of uranium ore. The balancing and availability analysis of radioactive deposits in Poland indicates that they are rather limited and economically non-viable, and the demand will rather be covered from external sources.

However, in the future with the large scale development of nuclear energy and an increase in market prices for uranium, the exploitation of domestic resources can be cost effective. Similarly, domestic execution of some fuel cycle processes may develop (e.g. the final stage of fuel production).

Reduced consumption of raw materials

We can expect that the development of nuclear power will result in a significant reduction in the demand for fossil fuels – which may decrease from 20% to 25% depending on the adopted option[279].

Failures

No major impacts.

DECOMMISSIONING	No direct impacts of the nuclear decommissioning phase on natural resources were identified. However, disposal of materials from demolition sites will have an indirect impact on the consumption of environmental resources. These materials should be re-used or recycled as much as possible (positive impact on environmental resources). If, however, they are treated as waste and disposed of, this will involve the negative impacts on environmental resources.

5.1.9 Impact on historical buildings

CONSTRUCTION	A nuclear power project will have the same impact on the country's historical heritage as any other large building covering a similar area. The most serious problem is related to the destruction of archaeological sites, but it is rather unlikely – any works performed in areas that include documented archaeological sites will be supervised and approved by the Regional Building Conservation Officer. In addition, construction works covering such a large area may actually lead to the discovery of new undocumented sites of cultural significance and their subsequent exploration.
OPERATION	At this stage, the impact on historical monuments is difficult to predict, since the actual location for the project has not been selected yet. However, given the nature of the investment it is not expected to have any impact on the movable monuments and the potential locations exclude impact on the UNESCO World Heritage sites. Therefore, focus should be on immobile monuments and archaeological sites.[280] More precise impact will be determined only in the EIA Report prepared for the specific location where the nuclear power plant will be built. Possible impacts for potential location options currently under consideration are presented in ch. 6.1.
	No negative impact on historical buildings and other cultural resources is expected in the operation phase. On the contrary, we may venture to say that the project will reduce the pollution that may have a negative impact on the structure of historical buildings and other cultural assets. By obtaining energy from the proposed power plant there will be no need for location of new coal or gas power plants in the area. Moreover, the number of conventional power plants currently operating in Poland may be reduced, which will be associated with reduction of harmful emissions into the air. When combined with water, substances emitted by coal-fired power plants cause acid rains that dissolve and change the surface of stone buildings and structures. This risk applies in particular to structures made of limestone and marble – they are composed mainly of calcite that is dissolved relatively quickly in light sulphuric acid or nitric acid.
	Failures: No major impacts.
DECOMMISSIONING	No significant negative impacts on cultural assets is expected in nuclear decommissioning phase. Impacts will be comparable to those caused by the dismantling of any other facilities covering a similar area. In the areas adjacent to places of historical and cultural significance, the site may be brought to the state that corresponds to the land use in the surrounding areas.

5.1.10 Impact on material assets

CONSTRUCTION	Construction of a nuclear power plants will require significant investments. Therefore, in a short-term perspective it will consume material assets. Only after the construction phase is completed can we expect a positive impact in the context of the economic balance.

OPERATION		Based on the analysis of reference sites (see chapter 4.3.9) positive impact of NPP operation on material goods has been shown in form of: - increased value of land in the area of the investment (the initial drop is only possible at the beginning of the construction/operation phase) - increased income of the municipality - improved infrastructure - lower unemployment rate - economic revival in the region
	Failures	Any potential accident will cause significant material losses suffered by the investor and the adjacent areas – which must be partially compensated in accordance with the current provisions regarding the liability for nuclear accidents.
DECOMMISSIONING		Nuclear decommissioning will be financed with funds deposited in a special bank account during the operation of the nuclear power plant, in accordance with draft amendment to the Atomic Energy Act. The impact on material assets will depend on how the area of the former nuclear power plant will be managed.

5.1.11 Impact on biodiversity, including biological resources protected under the Natura 2000 network

CONSTRUCTION		Like any other large investment, construction of a nuclear power plant will have an impact on the natural environment. Selection of an optimum location is the key as regards the impacts. If the selected location is not recommended for reasons related to environmental protection, the integrity and objectives of Natura 2000 sites may be affected, functions of ecological corridors undermined, habitats fragmented, and valuable species endangered (both at the domestic and international level). When selecting a less sensitive location, the impact of the investment on biodiversity resources and Natura 2000 sites will be much smaller.
OPERATION		In the operation phase, expanded overhead traction network will have crucial significance, as in some locations it may be a source of increased mortality of large numbers of migrating birds, as well as a permanent threat to the birds occurring in the Natura 2000 areas (in case of power line routing through the area). Other significant impacts will include discharges of heated water to rivers or other water bodies, which may lead to changes in ecosystems and affect biodiversity (a two-way impact involving both negative and positive aspects).
	Failures	As the risk of a radioactive leakage in nuclear power plants that are allowed in Poland is negligibly small, the release of a radioactive cloud is the key threat. Depending on the weather conditions, it may lead to contamination that will affect living organisms to a greater or lesser extent and cause increased mortality in the contaminated area.
DECOMMISSIONING		The complete decommissioning of a nuclear power facility and restoration of the environment to the state as close to natural as possible will ultimately have a positive impact on the natural environment. However, demolition work itself may have a negative impact on Natura 2000 sites (in sensitive locations), as it will generate vibrations, noise, possible contamination of surface and ground waters, and may also temporarily affect functions of the ecological corridor.

5.2 Description of impacts

The identified environmental impacts may differ in terms of their source and origin (direct and indirect, secondary, accumulated), duration (short-, medium, and long-term), and frequency (permanent and temporary), as well as the probability of their occurrence.

The nature of impacts in terms of source and mode of action is defined as:

- **direct** – impacts resulting from direct interaction between the action to be taken under the project, and the environment of the project;
- **indirect -** impacts resulting from other activities taking place in connection with the project or the impact on one element of the environment through impacts on the other one;
- **secondary -** impacts resulting from the direct or indirect impacts, resulting from subsequent interactions with the environment;
- **accumulated** – impacts occurring in conjunction with other interactions (including the related existing or planned activities of third parties), concerning the same resources or subjects of impact as the draft.

The duration of impact is shown in the following way:

- **short-term -** short duration associated with the stage of the project;
- **medium-term -** impacts at the project operation stage;
- **long-term -** impact remaining after decommissioning of the project.

The frequency of impacts, that is the nature of occurrences in time can be defined as:

- **permanent** – acting on a continuous basis;
- **temporary** – acting in intervals or limited periods of time.

The possibility of the occurrence of impacts, i.e. the probability of their occurrence can be defined as:

3	certain impact (inherent to a specific activity, and thus will certainly occur)
2	probable impact (there is a possibility of impact depending on occurrence of other external factors)
1	unlikely impact (impact occurrence is allowed, but only in certain cases)
0	impact almost impossible (considered within the worst, very unlikely eventuality)

Individual impacts have also been classified in terms of their scale, which were marked in the table with different colours:

(dark green)	significant positive impacts(both improving the properties of the element and change in its characteristics are observed, which as a result of subsequent interactions can have a positive impact on other environmental components)
(light green)	moderate positive impacts (basic properties of the element are not changed significantly, although improvement of their size or quality is observed, this is without significant effect on other environmental components)
(white)	no significant impacts or neutral impact
(light orange)	moderate negative impacts (basic properties of the element are not changed significantly, although deterioration of their size or quality is observed, this is without significant effect on other environmental components)
(dark orange)	significant negative impacts(both deterioration of the properties of the element and change in its characteristics are observed, which as a result of subsequent interactions can have a negative impact on other environmental components)
(yellow)	indeterminable impact (dependent largely on the specific location of the investment)

5.2.1 Characteristics of impacts - construction stage

Table 5.2.1 Tabular summary of the characteristics of the impacts associated with construction of NPP

TYPE OF IMPACT	SCALE OF IMPACT		NATURE			DURATION			CONTINUITY		PROBABILITY OF OCCURRENCE
	NEGATIVE	POSITIVE	DIRECT	INDIRECT	SECONDARY	SHORT-TERM	MEDIUM-TERM	LONG-TERM	PERMANENT	TEMPORARY	
IMPACT ON PEOPLE											
nuisances due to noise emission and dustiness			v			v				v	2
nuisances due to intensity of heavy machinery and transport traffic			v		v	v				v	3
additional jobs			v	v	v	v			v		3
radiation hazard (also refers to a critical group, e.g. employees)			v	v	v	v				v	0
IMPACT ON SURFACE WATERS											
local disruption of aquatic relations				v	v	v			v		2
IMPACT ON GROUND WATERS											
potential water pollution			v		v			v	v		1
changes in aquatic relations				v	v		v		v		2
IMPACT ON AIR											
dustiness			v			v				v	3
exhaust emission from machines and vehicles			v			v				v	3
IMPACT ON CLIMATE											
greenhouse gas emission				v	v	v				v	3
IMPACT ON EARTH'S SURFACE											
potential land pollution			v		v		v		v		1
exclusion of biologically active area				v	v		v		v		3
waste generation				v	v			v	v		3
IMPACT ON LANDSCAPE											
deterioration of aesthetics of adjacent areas				v	v	v			v		2
IMPACT ON NATURAL RESOURCES											
consumption of natural resources (water, construction materials, power)				v	v			v	v		3
limitation of access to natural resources			v				v		v		1

TYPE OF IMPACT	SCALE OF IMPACT		NATURE			DURATION			CONTINUITY		PROBABILITY OF OCCURRENCE
	NEGATIVE	POSITIVE	DIRECT	INDIRECT	SECONDARY	SHORT-TERM	MEDIUM-TERM	LONG-TERM	PERMANENT	TEMPORARY	
IMPACT ON HISTORICAL BUILDINGS											
potential destruction of archaeological sites within the area of nuclear power plant site	*impact substantially dependent on selection of investment site*										**1**
IMPACT ON MATERIAL GOODS											
financial investments				v	v	v			v		**2**

5.2.2 Characteristics of impacts - operation stage

Table 5.2.2 Tabular summary of the characteristics of the impacts associated with operation of NPP

TYPE OF IMPACT	SCALE OF IMPACT		NATURE			DURATION			CONTINUITY		PROBABILITY OF OCCURRENCE
	NEGATIVE	POSITIVE	DIRECT	INDIRECT	SECONDARY	SHORT-TERM	MEDIUM-TERM	LONG-TERM	PERMANENT	TEMPORARY	
IMPACT ON PEOPLE											
provision of energy supplies			v				v		v		**3**
general improvement of environment quality				v	v			v	v		**3**
radiation hazard (also refers to a critical group, e.g. employees)			v	v	v		v			v	**3**
in emergency: - potential necessity of evacuation - release of radioactive substances to environment			v				v			v	**0**
IMPACT ON SURFACE WATERS											
consumption of surface water resources			v				v		v		**3**
discharge of waste heat - increase in temperature			v		v		v		v		**2**
potential water pollution			v				v			v	**1**
in emergency: - contamination of surface waters			v				v			v	**0**

TYPE OF IMPACT	SCALE OF IMPACT		NATURE			DURATION			CONTINUITY		PROBABILITY OF OCCURRENCE
	NEGATIVE	POSITIVE	DIRECT	INDIRECT	SECONDARY	SHORT-TERM	MEDIUM-TERM	LONG-TERM	PERMANENT	TEMPORARY	
IMPACT ON GROUND WATERS											
consumption of groundwater resources			v				v		v		1
potential water pollution			v		v		v			v	0
potential radiological contamination			v	v	v			v	v		0
changes in groundwater level				v	v			v	v		2
in emergency: - contamination of groundwater			v	v	v			v	v		0
IMPACT ON AIR											
decreasing gas emission to atmosphere				v	v			v	v		3
decreasing dust emission to atmosphere				v	v			v	v		3
discharge of waste heat (cooling towers)					v		v		v		2
in emergency: - radioactive emission to atmosphere				v	v			v		v	1
IMPACT ON CLIMATE											
reduction of greenhouse gas emission				v	v			v	v		3
discharge of waste heat (cooling towers)				v	v		v		v		2
IMPACT ON EARTH'S SURFACE											
land take							v		v		3
reduction of biologically active area							v		v		3
waste generation				v	v			v	v		3
IMPACT ON LANDSCAPE											
reducing development of conventional power plants (chimneys - industrial landscape)				v	v			v	v		2
nuclear power plant as a new anthropogenic element of landscape	*impact substantially dependent on selection of investment site and manner of incorporation into surrounding area*										*3*
IMPACT ON NATURAL RESOURCES											
consumption of uranium ore resources								v	v		3
reduction of fossil fuel consumption				v	v			v	v		3

TYPE OF IMPACT	SCALE OF IMPACT		NATURE			DURATION			CONTINUITY		PROBABILITY OF OCCURRENCE
	NEGATIVE	POSITIVE	DIRECT	INDIRECT	SECONDARY	SHORT-TERM	MEDIUM-TERM	LONG-TERM	PERMANENT	TEMPORARY	
IMPACT ON HISTORICAL BUILDINGS											
reduction of harmful impact of atmospheric pollutions on buildings				v	v			v	v		2
IMPACT ON MATERIAL GOODS											
increase in land value and income of municipality				v	v			v	v		2
improved infrastructure			v					v	v		3
decreased unemployment and economic revival			v	v	v			v	v		3
improved energy security of the country.			v		v			v	v		3

5.2.3 Characteristics of impacts - decommissioning stage

Table 5.2.3 Tabular summary of the characteristics of the impacts associated with decommissioning of NPP

TYPE OF IMPACT	SCALE OF IMPACT		NATURE			DURATION			CONTINUITY		PROBABILITY OF OCCURRENCE
	NEGATIVE	POSITIVE	DIRECT	INDIRECT	SECONDARY	SHORT-TERM	MEDIUM-TERM	LONG-TERM	PERMANENT	TEMPORARY	
IMPACT ON PEOPLE											
nuisances due to noise emission and dustiness			v			v				v	2
nuisances due to intensity of heavy machinery and transport traffic			v		v	v				v	3
additional jobs			v	v	v	v			v		3
radiation hazard (also refers to a critical group, e.g. employees)			v	v	v	v				v	0
IMPACT ON SURFACE WATERS											
local disruption of aquatic relations				v	v	v			v		0
potential water pollution			v		v	v			v		0
IMPACT ON GROUND WATERS											
potential water pollution			v		v			v	v		1

TYPE OF IMPACT	SCALE OF IMPACT		NATURE			DURATION			CONTINUITY		PROBABILITY OF OCCURRENCE
	NEGATIVE	POSITIVE	DIRECT	INDIRECT	SECONDARY	SHORT-TERM	MEDIUM-TERM	LONG-TERM	PERMANENT	TEMPORARY	
restoration of natural water relations			v		v		v		v		2
IMPACT ON AIR											
dustiness			v			v				v	3
exhaust emission from machines and vehicles			v			v				v	3
IMPACT ON CLIMATE											
greenhouse gas emission				v	v			v	v		3
IMPACT ON EARTH'S SURFACE											
potential land pollution			v		v		v		v		1
restoration of biologically active area				v	v		v		v		3
waste generation				v	v			v	v		3
IMPACT ON LANDSCAPE											
Improving the aesthetics of the adjacent areas due to land reclamation				v	v			v	v		2
IMPACT ON NATURAL RESOURCES											
consumption of environmental resources (disposal of demolition material as waste)				v	v			v	v		2
reduction of the use of environmental resources (recovery of demolition material)				v	v			v	v		2
IMPACT ON HISTORICAL BUILDINGS											
no significant impacts	*impact substantially dependent on selection of investment site*										1
IMPACT ON MATERIAL GOODS											
financial investments				v	v	v			v		2

5.3 Characteristics and summary of impacts on the biodiversity resources, including those protected under the Natura 2000 network

Impacts on flora, fauna, biodiversity and Natura 2000 sites mentioned in the chapter below have a wide spectrum of impact and apply to all listed natural assets.

Expected significant impacts identified in the table below have been described due to their nature (direct, indirect, secondary, accumulated), duration (short, medium, long-term) and due to the frequency of impact (permanent and temporary). Information was also added about the likelihood and strength of the identified negative impacts.

Table 5.3.1 Tabular summary of the characteristics of impacts on biodiversity resources

Designed action	Possible impact	Nature of impact
• Seizure of land for permanent and temporary construction works, machinery and equipment used during construction	• Loss or reduction of populations of protected species or vegetation communities due to the seizure of land and destruction of habitats needed for feeding • Direct lethality of animal species due to collision with buildings and machinery	• Direct/indirect • Long-term and medium term • Permanent
• Expansion of the overhead traction network	• Direct lethality of birds and bats due to collisions • Possibility of influencing the change of bird migration route, due to the barrier effect	• Direct • Long-term • Permanent or temporary
• Uncontrolled waste storage from ground works and the site	• Destruction of natural habitats • Possibility of water pollution, poisoning of animals	• Direct • Long-term • Permanent or temporary
• Production of dust during construction activities.	• Deposition of dust on the leaves of plants and on the surface of aquatic organisms	• Indirect • Short-term • Temporary
• Hardening of large surface areas (roads, parking lots)	• Soil erosion and changes in water quality. Possible emissions of sediments to water and disturbance of aquatic ecosystems	• Direct • Long-term • Permanent
• Surface runoff from construction site	• Soil erosion, with possible destruction of plant communities by contaminants running off with water (e.g. machine oils)	• Direct • Long-term • Permanent and temporary
• Storage of spoil from excavations and underground workings	• Animals settling on temporarily stored soil masses (sand martins and other burrow-dwelling species) and resulting species endangerment	• Direct • Short-term • Temporary
• Use of surface water for construction work • Drainages for excavation works.	• Change in local water relations • Possibility of contamination of watercourses	• Direct • Short-term • Temporary
• Noise and vibration	• Disturbance of aquatic mammals, fish and	• Direct • Short-term, medium

Designed action	Possible impact	Nature of impact
	bottom invertebrates • Disturbance of other land animals living in proximity	term • Temporary
• Light emission during construction, demolition, and at the stage of operation (from lighting facilities, vehicles, machinery)	• Disruption of animal environment (bats, resting birds etc.)	• Direct • Short-term • Temporary
• Accidental fuel, petroleum, chemicals, concrete, cement spills etc.	• Contamination of groundwater and surface water, contamination of natural plant communities, animal poisoning	• Direct • Short to long term • Permanent or temporary
• Vehicle traffic	• Direct lethality of animals due to collision or road kills	• Direct • Long-term, medium term • Temporary
• Cooling water uptake	• Disruption of aquatic ecosystem balance • Possible aspiration of living organisms	• Direct • Long-term, medium term • Permanent
• Warm water discharge from cooling systems	• Disruption of aquatic ecosystem balance • Impact on change in bird migration habits	• Direct • Long-term, medium term • Permanent

5.4 Analysis of the likelihood of cumulative impacts

Occurrence of cumulative impacts can be understood in two ways:

1) as overlapping impacts associated with the implementation of various investments, for which the impacts zones overlap, therefore accumulation of negative impacts occurs in these places

2) as an accumulation of negative impacts associated with the operation of the investment in question for the various environmental elements (impact on the individual elements may be insignificant, while analyzing the cumulative occurrence, accumulated impacts to entirety of the environment may be significant).

Regarding the first aspect, one cannot at this stage rule out the possibility of accumulation of impacts, due to lack of choice of specific location, hence the lack of knowledge of the detailed plans for development of neighbouring areas. But certainly, each location will entail the expansion of power network and accompanying infrastructure, so one can expect the accumulation of impacts on landscape and animated nature, particularly in the context of Natura 2000 sites. However, any additional impacts, such as associated with the expansion of the grid, will be the subject of separate studies including forecasts for the development of energy infrastructure, and therefore in this paper this problem is only indicated, not specifically addressed. Industrial plants are listed in the analysis of location variants (subject to availability of relevant information). In these cases, one can consider the potential accumulation of impacts at the stage of environmental impact assessment before a decision on the environmental conditions. It should become the subject of detailed analysis during the preparation of environmental impact report for a particular investment location.

Regarding the second aspect, on the basis of table in chapter 0 and 5.3 numerous impacts on various environmental elements can be identified. In particular, for construction phase and a possible failure it is clear that there are many negative environmental impacts in various aspects. During the construction phase, negative impacts on people, air, surface, natural resources and nature accumulate. But these are mostly short-term or temporary impacts associated with construction phase only. Similar impacts, albeit in a narrower spectrum, are also associated with decommissioning stage. However, the accumulation of potentially the most serious negative impacts may occur as a result of a failure. Concomitant negative impacts on various environmental elements can have serious consequences (accumulation of radiological contamination and increase in doses of radiation by various routes of exposure on living organisms). However, the situation has been examined and detailed calculations of radiation doses in the event of possible failures were made. Calculations with the results and their interpretation are presented in chapter **Błąd! Nie można odnaleźć źródła odwołania.**. The occurrence of these impacts, however, is highly unlikely due to numerous safety systems, which aim to prevent accidents, even in the worst-case scenarios (see chapter **Błąd! Nie można odnaleźć źródła odwołania.** and **Błąd! Nie można odnaleźć źródła odwołania.**).

The likelihood of cumulative impacts includes the construction of Polish nuclear energy Programme together with the implementation of other strategic documents in the country. The reference is to the documents assuming diversification of energy sources and promoting sources other than nuclear power as it is provided in *National development strategy 2007-2015*, *National Strategic Reference Framework 2007-2013 supporting economic growth and employment. National Cohesion Strategy*, *Polish Climate Policy. Strategies for reducing greenhouse gas emissions in Poland by 2010* and other documents. As pointed out earlier in the Forecast, almost all investments related to the development power industry are associated with potential impact on the environment. Thus in the process of diversification of energy sources, which is a goal of strategic Polish documents, where development of nuclear energy, promoting the expansion and modernization of energy infrastructure (e.g. networks capable of absorbing the increased transmission of electricity) will be included, are closely related. These activities must meet the needs. At the same time as stated in all strategic documents maintenance of strict environmental protection requirements is required, including the components of animate and inanimate nature. This is a guarantee that even the accumulation of impacts will not be standing in opposition to the current assumptions of II National Ecological Policy and other environmental documents and legislation.

5.5 Information on possible cross border impact of the Programme on the environment

5.5.1 Basics of cross-border environmental impact assessment

The basic legal acts that govern cross-border environmental impact assessment are respectively:

- The Convention on Environmental Impact Assessment in a Transboundary Context, drawn in Espoo on 25 February 1991 (Journal of Laws of 3 December 1999)
- European Parliament and Council Directive 2001/42/EC of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment
- Act of 3 October 2008 on provision of information on environment and its protection, public participation in environmental protection and environmental impact assessment

The Convention on Environmental Impact Assessment in a Transboundary Context, drawn in Espoo on 25 February 1991 (Journal of Laws of 3 December 1999)

Convention requires signatory states to take all appropriate and effective measures to prevent, reduce and control significant, harmful, transboundary environmental impact resulting from planned activities.

Pursuant to art. 1 of the Convention:

"transboundary impact" means any impact, not of global nature, within an area under jurisdiction of the party, caused by a planned activity whose physical origin is situated wholly or partly within the jurisdiction of another party.

The term "impact" means any effect of the planned activities on the environment including: health and safety of people, flora, fauna, soil, air, water, climate, landscape and historical monuments or other structures or the interactions among these factors; it also includes effects on cultural heritage or socio-economic conditions due to changes in these factors;

The basic method of preventive fulfilment of obligations under the Convention is to carry out within the state, which intends to undertake the activities causing such impacts, procedures for environmental impact assessment (EIA) of the proposed action, and thus in accordance with Article 3 and 4 of the Convention:

3. *The Party of origin*[281] *shall ensure that in accordance with the provisions of this Convention performance environmental impact assessment*[282] *takes place before deciding whether to approve or undertake a proposed activity listed in Annex I, which may cause significant adverse transboundary impact*.

4. *The Party of origin shall ensure, in accordance with the provisions of this Convention, that the Parties affected will be notified of any planned activity listed in Annex I, which may cause significant adverse transboundary impact*.

According to Annex I, "Summary of activities" the facilities that require discussion include thermal power stations and other combustion installations with heat output of 300 megawatts or more and nuclear power stations and other nuclear reactors ... "

1. *For the planned activities under the Annex I, which may cause significant adverse transboundary impact, the Party of origin in order to ensure adequate and effective consultations under Article 5, shall notify any Party which it considers a possible affected Party as early as possible and no later than informing its own public opinion about the proposed activity*.

8. *Parties concerned will ensure that the public of the affected Party in the areas likely to be affected, is informed of the proposed activity and that it has the opportunity to express their comments or objections to the planned activities and an opportunity to submit these comments or objections to the competent authority*[283] *of the Party of origin, either directly or, if appropriate, through the Party of origin*.

European Parliament and Council Directive 2001/42/EC of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (SEA Directive)

The SEA Directive sets out requirements for the implementation of environmental impact assessment of plans and programs in the European Union. The main objective of the Directive is that the environmental aspects of the preparation and adoption of plans and programs are included at the earliest possible stage so as to achieve a high level of environmental protection.

Pursuant to Article 7 of the SEA Directive:

If a Member State considers that the implementation of the plan or program being prepared in relation to its territory may potentially cause a significant impact on the environment in another Member State, or when requested by a Member State, which potentially can be significantly affected, that Member State on whose territory the plan or program is prepared prior to its adoption or submission to the legislative procedure, forwards a copy of the draft plan or program and the relevant environmental report to another Member State.

Act of 3 October 2008 on provision of information on environment and its protection, public participation in environmental protection and environmental impact assessment (*EIA Act*);

EIA Act defines, inter alia, the principles and procedures in cases of transboundary environmental impact, and so in accordance with Article 104:

If there is any possibility of a significant transboundary environmental impact originating in Polish territory as a result of implementation of projects, policies, strategies, plans or programs, investigation shall be carried out investigation of transboundary environmental impact. Such proceedings shall be carried out also at the request of another Member State whose territory may be affected by execution of the draft document.

Procedure on transboundary impact originating in Polish territory in case of projects of policies, strategies, plans and programs is described in section 3 of the EIA Act.

5.5.2 Assessment of the possible transboundary impact of the Programme on environment

At this stage of a strategic document (the Polish Nuclear Programme), the assessment of environmental impacts in neighbouring countries can be only preliminary. To evaluate these impacts, an analysis was conducted to decide which countries could be affected by the potential impact in the operational phase of the planned nuclear plant in Poland.

Pursuant to art. 36F of the draft of Atomic Law, a restricted use area around the nuclear facility covers the area, outside of which:

- in operation conditions of a nuclear facility covering normal operation and anticipated operational events annual effective dose of all routes of exposure will not exceed 0.3 milisievert (mSv);
- in case of failure without melting the core annual effective dose of all routes of exposure does not exceed 10 milliSievert (mSv).

It can therefore be assumed that if land adjacent to the Polish state will be in the above specified limited use area, it will be directly exposed.

The analysis should therefore determine the extent of the areas depending on the dosage level for normal operation and after failures without melting the core. But this is not possible at the stage of detail of Polish Nuclear Energy Programme.

Reactors intended for Poland must meet the requirements of EUR. According to these requirements the boundary of the limited use area proceeds 800 m from the reactor and boundary of emergency planning zone 3000 m from of the reactor. Currently, works are in progress on the Ordinance of Council of Ministers on requirements for nuclear safety and radiological protection included in the project. The draft of the mentioned Ordinance § 6.4 provides that the design of a nuclear facility should provide for a limitation of radioactive releases outside the reactor containment in emergency situations so that:

- in the event of design failure no interventions are required at a distance greater than 800 meters from the reactor;
- In case of occurrence of extended design conditions it is not necessary:
- to make early intervention during the radioactive releases in containment at a distance greater than 800 m from the reactor,
- to make medium-term intervention at any time at a distance greater than 3 km from of the reactor.
- to make long-term interventions at a distance greater than 800 m from of the reactor.

According to analyses carried out in Chapter 7, the EPR, the AP1000 and the ESBWR reactors, which are currently planned for installation in Poland, meet these requirements.

The Espoo Convention requires that the people of neighbouring countries have the same rights as people of a country where a power plant is built:

6. *According to the provisions of this Convention, the Party of origin shall provide the public in the areas that may be exposed the opportunity to participate in the relevant procedures of environmental impact assessments for the planned activities, and ensure that the opportunity to participate in these procedures, provided for the public of the affected Party, is the same as the option provided for the public of the Party of origin*.

In light of this formulation, it is important that the zone of the planned medium-term interventions according to the provisions of current proposals of Polish regulations and according to EUR requirements the third generation reactors reaches no further than 3 km from the nuclear power plant. Outside this area there is no need to provide e.g. the necessity of evacuation routes or emergency planning for NPP areas in Poland, so even with location of nuclear power plants in a small distance from the border there will also be no need to agree on interventions with the administrative authorities of the neighbour state.

Threat assessment is often subjective. It is also indicated by the result of the CBOS report, developed at the request of the Ministry of Economy, in which the question was asked concerning acceptance of a nuclear power plant location near the place of residence. Test results indicated that the term "near" is a purely subjective because the differences in the responses ranged from approximately 1 kilometre to 500 kilometres. The average of the reported values was 92 kilometres. This would mean that for the majority of the society an acceptable distance that does not raise concerns and negative emotions is 92 kilometres. It can be assumed with likelihood that the societies in which nuclear power plants already exist, and such are most societies in the neighbouring countries, have the same if not more liberal approach to these distances. Thus, the table indicates also the locations which are closer than 92 km from the Polish border, as the distance resulting from the concerns of society.

Thus, for further analysis it was assumed that if a State is at a distance less than 3000 m from of the reactor, it is directly exposed, and if it is closer than 92 km, its society might want to participate in the cross-border procedure of environmental impact of the Polish Nuclear Programme .

5.5.3 **Analysis of possible cross-border impacts of the programme**

In 2009, the Ministry of Economy devised a list of 27 potential sites for nuclear power plants. Locations are shown in Fig. 5.5.1. In 2010, commissioned by the Ministry of Economy a document was prepared entitled "The study on the siting criteria for nuclear power plants and preliminary assessment of the agreed locations", which analyzes the locations in the ministerial list. The study recommended six potential sites: Żarnowiec, Nowe Miasto, Kopań, Warta-Klempicz and Choczewo and Lubiatowo-Kopalino. Use of other locations (except for Kozienice) in foreseeable term is unlikely, especially for the construction of the first two nuclear power plants - as is clear from the information obtained from the Ministry of Economy and PGE S.A.

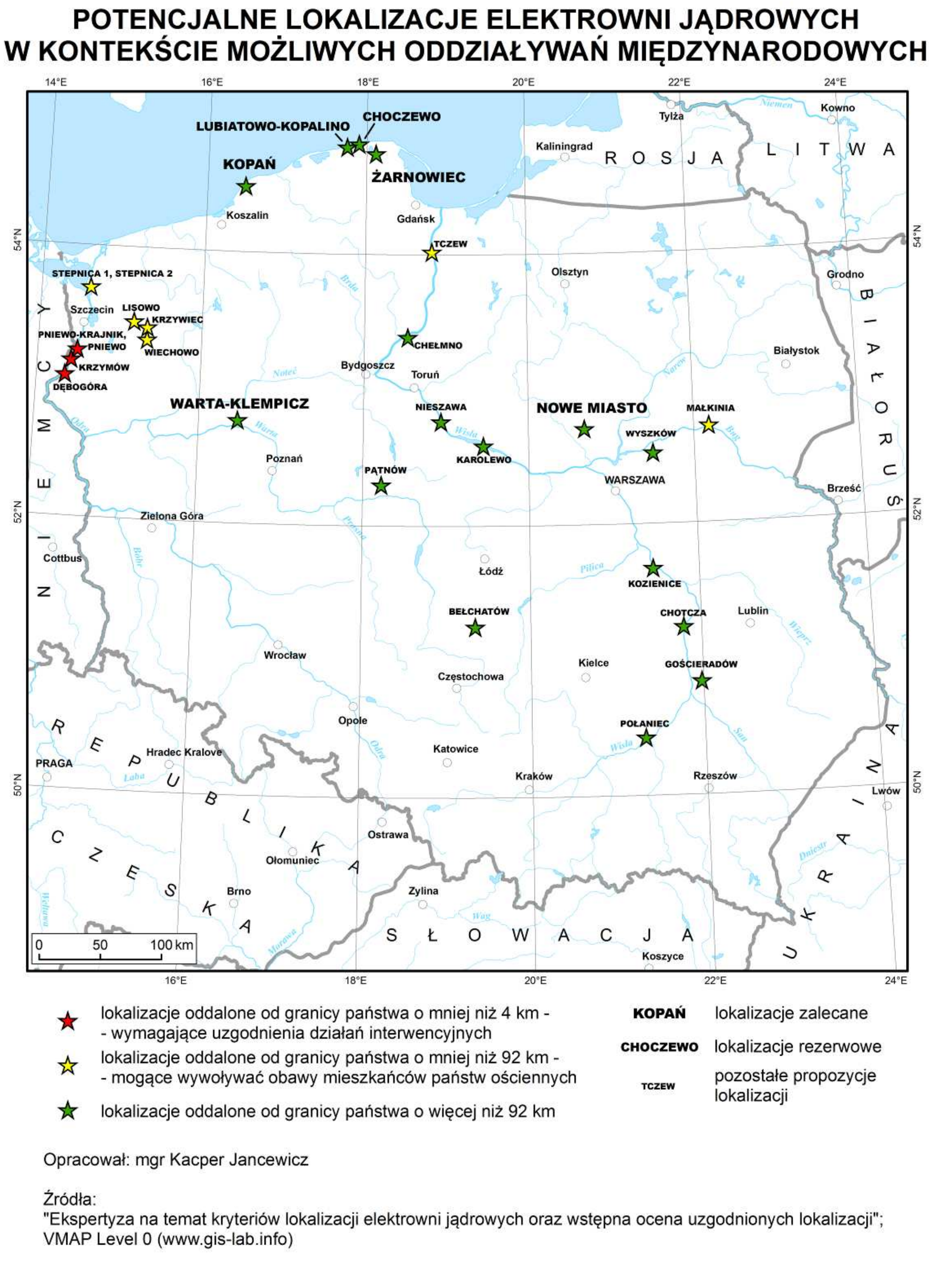

Fig. 5.5.1 Nuclear power plant sites in Poland in the context of possible international impacts

[POTENTIAL NUCLEAR POWER PLANT SITES IN THE CONTEXT OF INTERNATIONAL IMPACTS

Locations less than 4 km away from the border – requiring agreement on interventions
Locations less than 92 km away from the border – they may cause fear in residents of neighbouring countries
Locations more than 92 km away from the border
Recommended locations
Reserve locations
Other site proposals
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
VMAP Level 0 (www.gis-lab.info)]

For all locations, a table was developed with distances to the nearest Polish borders. The table marks the locations which are closer than 92 km from the Polish border and those whose limited use area goes beyond the State boundary. In the latter case the locations were also marked which are not in the immediatelimited use area, but are very close.

Table 5.5.1 Approximate distances of potential sites of nuclear power plants in Poland from the borders of the state.

		Distance [km]							
No.	**Location**	**Baltic Sea***	**Germany**	**Czech Republic**	**Slovakia**	**Ukraine**	**Belarus**	**Lithuania**	**Russia**
1	Bełchatów	329,6	300,5	154,9	184,3	299,4	287,4	412,3	354,4
2	Chełmno	107,6	272,4	338,9	426,2	398,6	334,4	284,5	139,1
3	Choczewo	0,3	257,6	460,1	589,7	523,2	377,0	245,9	120,0
4	Chotcza	369,8	470,9	270,6	199,5	129,5	128,6	322,7	343,5
5	Dębogóra	48,9	2,3	233,3	499,4	650,3	599,2	524,2	373,2
6	Gościeradów	416,3	488,4	260,0	156,2	124,3	136,3	360,8	389,2
7	Karolewo	181,7	324,9	280,0	332,1	306,6	255,4	296,4	206,5
8	Kopań	2,7	159,8	395,4	573,1	575,5	461,4	342,5	204,6
9	Kozienice	316,1	447,7	281,3	246,9	151,8	135,2	289,0	294,4
10	Krzymów	62,0	1,2	220,9	492,3	652,3	602,5	534,0	382,5
12	Krzywiec	43,8	54,7	269,1	497,8	606,5	550,1	462,1	311,4
13	Lisowo	52,5	61,0	265,9	490,7	597,9	542,8	456,8	305,7
14	Lubatowo-Kopalino	0,0	251,6	456,5	589,7	527,0	382,6	252,1	125,4
15	Małkinia	247,0	510,3	399,6	365,5	156,9	80,6	164,3	180,5
16	Nieszawa	163,9	291,8	285,5	354,2	345,9	292,4	309,8	193,1
17	Nowe Miasto	189,3	408,5	336,0	355,5	236,2	176,3	231,5	183,2
18	Pątnów	226,9	238,6	222,9	312,2	379,8	337,5	380,2	257,7
19	Pniewo	41,2	3,1	240,7	503,5	649,0	597,1	518,3	367,6
20	Pniewo-Krajnik	42,7	3,3	239,3	502,7	649,1	597,4	519,3	368,5
21	Połaniec	442,2	450,6	197,6	108,0	134,2	201,3	419,0	433,2
22	Stepnica -1	2,5	19,6	293,4	542,3	654,3	587,9	488,8	341,8
23	Stepnica -2	4,0	21,2	293,7	541,6	652,7	586,2	487,2	340,1
24	Tczew	36,5	300,7	410,1	493,0	419,7	306,6	224,2	72,0
25	Warta-Klempicz	155,6	125,9	213,5	392,0	506,1	457,7	433,7	281,9
26	Wiechowo	55,8	60,3	259,4	484,6	595,4	541,0	459,3	307,8
27	Wyszków	236,1	462,4	354,0	341,3	177,8	117,2	209,2	200,1
28	Żarnowiec	10,3	267,1	458,1	579,1	507,7	362,4	234,8	104,9

* distances for the Baltic Sea including the Szczecin and Vistula Lagoon

Analysis of results:

Recommended and reserve (basic) sites:

- None of the primary locations is close enough to the border to make it necessary to coordinate interventions with the administrative authorities of the neighbouring state. Thus, in accordance with approved methodology, no State will be directly affected by the choice of one of the primary locations.
- None of the primary sites is located closer than 92 km from the border, therefore it can be assumed, in accordance with accepted methodology, that societies of neighbouring States will not feel fear as a result of the selection of one of the primary sites.

Other sites (for which there is little likelihood of location of the first nuclear power plants in Poland):

The following sites from this group will require arrangements on intervention, (they will be directly affected):

- Dębogóra site – 2.3 km from border with Germany
- Krzynów site – 1.2 km from border with Germany

Moreover, because of the distance close to the border, the following were qualified to this group:

- Pniewo site – 3.1 km from border with Germany
- Pniewo-Krajnik site – 3.3 km from border with Germany

The following sites are closer than 92 km from the border, therefore it can be assumed, in accordance with accepted methodology, that the societies of those States may feel fear as a result of selection.

- Krzywiec site – 54.7 km from border with Germany
- Lisowo site – 60.1 km from border with Germany
- Małkinia site – 80.6 km from border with Germany
- Tczew site – 72.0 km from border with Russia
- Stepnica 1 site – 19.6 km from border with Germany
- Stepnica 1 site – 21.2 km from border with Germany
- Wiechowo site – 60.3 km from border with Germany

Conclusions

- Considering the small likelihood that the first nuclear power plants in Poland will be built in one of the locations defined as “other” in the Programme, we can conclude than none of the neighbouring countries will be exposed to any impacts (direct or indirect).

- However, if we assume that any “other” location is selected, Germany will be exposed to direct impacts from the Polish nuclear power plant.
- Germany, Belarus and Russia are the countries whose societies may be potentially interested in the participation in social consultations (given the distance from the potential sites).

5.5.4 The experience of neighbouring States in cross-border environmental impact assessment

In the context of the analysis of transboundary impacts it should be also pointed out that Poland is not a pioneer in the nuclear power sector. Apart from Lithuania and Belarus, all other neighbouring countries operate nuclear power plants in their territory. Schematic location of nuclear power plants in the vicinity of Poland is shown in Fig. 5.5.2

Fig. 5.5.2 Distribution of nuclear power plants in the vicinity of Poland

[DISTRIBUTION OF NUCLEAR POWER PLANTS IN THE VICINITY OF POLAND
Active nuclear power plants
Developed by: mgr Kacper Jancewicz
Source: www.insc.anl.gov; VMAP Level 0 (www.gis-lab.net)]

In the countries neighbouring with Poland, namely Slovakia (case of NPP Mochovce units 3 and 4) and the Czech Republic (Temelin case units 3 and 4) before deciding to build these units, the appropriate Ministry for the Environment appointed a responsible and competent organization, which was to carry out discussion of environmental impact assessment and present the conclusions of this discussion, to the ministry for a decision. This competent organization was not Nuclear Supervision, although the Nuclear Supervision in the course of the discussion presented its assessment of the safety and radiological protection around the proposed power plant. n case of NPP Mochovce materials were prepared in Slovakian and English, but they did not cover the entire environmental impact assessment, and only a summary of that assessment. The same was true in case of Finland[284].

The public discussion first took place in Bratislava, with the participation of about 200 people from Slovakia and four activists from Austria, and later in Vienna. The whole course of the discussion was recorded and forwarded to the competent Slovakian organization which has prepared conclusions for the Ministry of Environment. Similarly, the discussion takes place on Temelin.

The case of Temelin is important due to the fact that the discussions have already been conducted before selecting a specific reactor, specifying only that it will be a reactor with water under pressure. This means that if a final decision on the construction of NPP in Poland is made, a similar discussion can also be conducted, specifying only boundary parameters of the releases of radioactivity from the reactor during normal operation and emergencies.

After receiving conclusions from the discussion, the government body of the country building a power plant declares that it became familiar with the course of discussions, questions, objections and responses, and believes that the answers were satisfactory - or not. In the first case, it decides to approve the application of the investor from point of view of nuclear power plant impact on the environment, in the second - to reject the application. Regardless of that, nuclear power plant security analysis must be performed by nuclear supervision and only if positive decisions in both of these processes are made, construction of a power plant can begin.

5.6 Analysis of potential social conflicts

5.6.1 Potential social conflicts in Poland in the light of existing data and official documents

In the discussed draft of the Polish Nuclear Energy Programme (p. 95) it is provided that "social support for nuclear power is one of the most important pre-conditions for the Polish Nuclear Programme" and that "steady and conscious support (or at least acceptance) of the majority of the society is a condition precedent to the introduction of nuclear power that will prevent the Programme being used as a subject of political debates". The draft gives a figure for the support declared by the Polish society for the introduction of nuclear power at 40-50%. At the same time, it was emphasised that this support is unstable and to a large extent it is not based on the society's knowledge of nuclear power, which is an outcome of 20 years of education negligence.

When actions towards the development of nuclear power in Poland were resumed, social conflicts became a fact and the public opinion was divided from day one. It is all happening despite the fact that for quite some time articles in the press have been forecasting an ever-increasing demand for electricity and potential problems with electricity production in the future[285]. Some environmental organizations provide negative opinions on potential locations and the desirability and security related to the construction of nuclear power plants. At the same time, fierce protests of environmentalists reported in the media, combined with actions taken to disrupt the implementation of major infrastructural projects important for the country or local communities (even those that are reasonable and based on sound argumentation), trigger protests from other groups of the society. In the worst-case scenario, the significance of environmental initiatives may be undermined by the excessive and stubborn focus on single elements of the natural environment of relatively minor importance for the entire ecosystem.

Social conflicts are an inherent part of any large project. In holds true in particular in the case of investments in the energy sector. Not a long time ago, environmentalists voiced their protests against projects such as construction of Niedzica dam on the Dunajec River, the man-made Czorsztyn Lake, or Niedzica – Sromowce Wyżne Hydroelectric Power Plants. Major protests carried out in the 1980s and 1990s subsided after 1997, when the erected dam significantly contributed to the reduction of losses during the July flood (on the official opening of the barrier on 9 July 1997 the water level on the Dunajec River surpassed the record of 1934). Czorsztyn reservoir has also contributed to the construction of sewage treatment plant, to supply of drinking water to nearby towns (before construction of the dam this area had serious water shortages during droughts, and it was one of the main reasons for the construction of the reservoir), to stabilization of the level of the river (so that the traditional rafting down the Dunajec valley takes place without obstacles.)

In more recent years, wind power projects are the source of serious conflicts. Wind farms projects with wind turbines were rejected by the inhabitants and local authorities in many regions of Poland. Villages in the Kłodzko Valley or the Kaczawskie Foothills are just one example. In addition to the significant impact on the landscape and risks for birds and bats, opponents of wind power projects claim that wind turbines may have an impact on people’s health and well-being. Not without significance are also issues of cost-effectiveness of investment and its efficiency in the Polish power grid (power drops during interruptions in operation due to lack of wind at the time of greatest energy demand - during heat and frost). Opponents of wind farm locations organize pickets and create websites. In many places around the country they are effective, influencing local authorities and eventually discouraging investors.

Projects of new open-pit mines and brown-coal mining projects for the purposes of electricity generation are just as controversial. The plans of relocation of villages north of Legnica encountered a backlash from the protesting local communities. An initiative called ‘STOP the PIT’ was set up[286]. Inhabitants of these areas reject the proposed compensatory payments and refuse to relocate. The subject of huge damage related to the functioning of the excavation is also taken up. As in few other cases, the situation in Legnica region showed the incompatibility of interests of different levels of authority.

Public opinion on nuclear power in Poland and other electricity production methods and technologies is summarised in a Report of CBOS (Public Opinion Research Centre) published in September 2009, titled: “Public Opinion on Nuclear Power. Quantitative Research Report”. Respondents were requested to evaluate the efficiency of the following sources of energy: hard coal, brown coal, petroleum, natural gas, nuclear energy, biofuels, hydropower, solar power, wind power, geothermal power.

Findings presented in the CBOS Report are as follows:

- social support for the nuclear power plant project in Poland is increasing, but its supporters include usually well-educated people;

- lack of knowledge of nuclear power gives rise to fear and concerns that are expressed in the form of protests against the construction of a nuclear power plant or location of a radioactive waste depository;
- arguments of opponents always focus on irrational fears and general concerns;
- information and argumentation must be targeted mainly at social groups with a lower education level and inhabitants of rural areas, as well as young people (aged 15–17 lat) whose knowledge of nuclear power is simply a disaster;
- a radioactive waste depository raises more concerns than a nuclear power plant;
- any location for a radioactive waste depository will be accepted only on condition that it is properly protected with safety measures, but at the same time we may expect that the effectiveness of these safety measures will be questioned;
- there is a wide social support for compensatory payments for inhabitants of areas close to a nuclear power plant – they should include a number of elements, with special focus on health care and reduced electricity charges;
- the self-assessment of the respondents' knowledge of nuclear power is very low – Poles are well aware of the fact that their knowledge is poor; at the same time, data clearly indicates that the level of knowledge corresponds to the level of acceptance. The knowledge of nuclear power comes mainly from the media: the press, TV, and radio. Less than 1/5 of respondents declare that they gained this information from school, university, or work.

Findings presented in the CBOS Report are very interesting. Special attention should be given to the society's low level of knowledge of nuclear power, as well as the sources of this information – the public media rather than school curricula or specialist publications. Still, public approval for nuclear power in the period 2008–2009 increased by nearly 70%, and nuclear energy ranked second (after renewable sources) among all suggested options for the development of the energy sector. It results from the Research Report of 2009 entitled "Ecological awareness of Poles - sustainable development" made by the Institute for Sustainable Eco-Development in the framework of Active education program for sustainable development Eco-Hercules. According to the quoted report, recorded promotion of nuclear power occurred at the expense of all other solutions, with the largest decrease in the indications concerning energy saving (this can be considered as a sign of lower propensity to save). There is still extremely relatively low acceptance of coal as an energy source. Quite rationally, respondents did not consider power industry based on oil and natural gas. It should be added that in contrast to the results from 2008, not every the socio-professional group put raw materials and renewable sources in the first place. Nuclear power is preferred by members of households with incomes *per capita* exceeding 1500 PLN (45.3% indications to 36.7% for renewables) as well as those with higher education (40.4% versus 39.7%). Group of respondents which to a much lesser extent are convinced by this direction of energy policy are:

- persons with primary education - 11.9%
- unskilled workers, the unemployed and farmers - 12.1%
- persons with the lowest incomes (below 500 PLN) - 12.9%,
- women - 14.9%,
- rural residents - 18.9%,

- people aged 35-44 - 19.0%.

Results of studies conducted throughout the country echo the unofficial the results of the smaller polls, published in local media. For example, according to the portal *trzcianka.info*, based on the collected votes of Internet users, 60% of respondents said YES to a nuclear power plant in Klempicz, 33% said DEFINITELY NO to a nuclear power plant in Klempicz, (5% said YES to a nuclear power plant, but not in Wielkopolska, 2% had no opinion)[287]. Although a group of Internet users is not entirely conclusive and the vote was attended by just 43 people, the result is part of a noticeable trend in the country.

Information on the feedback to nuclear power in other countries, especially in countries where nuclear power plants are in operation, is presented in the Study no. OT-575 titled “Reaction of the local European communities to the proposed location of a nuclear power plant in their close vicinity” prepared by the Analyses and Documentation Office, Analyses and Topical Papers Unit of the Chancellery of the Polish Senate in October 2009. This study, as it is said in the introduction, attempts to answer the question: is location of a nuclear power plant in tourism-attracting region possible and acceptable and what consequences will result for the local community. The basis for the answers are the experiences of other European countries. Regions that are attractive for tourists often overlap with regions of high natural or scenic value, and therefore this study has a deeper meaning.

To perform the analysis, the Office of Analysis and Documentation turned, through the European Centre for Parliamentary Research and Documentation (ECPRD), to the parliaments of the Member States of the Council of Europe and Canada, the U.S. and Israel, with questions on this issue. A cover letter and a survey of five questions were prepared in order to obtain answers to a given topic from the experience of specific communities, rather than popular opinion. In response to the survey materials were received from 27 of 49 countries which were sent the questions. Tabular summary of information included in the study is presented below:

Table 5.6.1 The issue of location of nuclear power plants in Europe, in countries having, building or planning investments according to the survey conducted by the Office of Analysis and Documentation of the Chancellery of the Sejm. Applies to areas attractive for tourism. The table is a shortened version of the table contained in the original study.

State	Location in the attractive area (examples)	Attitude to construction of nuclear plants based on: General public opinion polls Local public opinion polls Other opinions	Loss or benefit of local government in connection with the location of a nuclear power plant
Belgium	No[288] (Huy-Tihange3)	positive a, b – no research c – opinion of local government	increased tourism, influx of people, increased employment, increase of financial assets in the region, development of education, building evacuation roads
Czech Republic	acceptable (Temelin)	positive a - yes[289] b - yes[290]	construction of two sewage treatment plants, supplying heat and hot water to local residents
Finland	no	–	no data
France	yes[291] (Tricastin, Flamanville)	positive a - yes[292] b - yes[292]	new infrastructure and development, increased employment, tax revenues,
Netherlands	no[293]	no data	no data
Lithuania	no data	no data a - no data b - yes[294]	no data

Germany	No[295] (Lumin[296])	negative[297]	tax revenues
Russia	no data	fearful14	no data
Slovakia	No[298]	no data	no data
Switzerland	no data	no data	no data
Sweden	no[299] (Ringhals, Oskarhamm, Forsmark[300])	lack of visible negative impact. Based on ranking of tourist resorts of Swedish Tourist Agency. a, b – no research20[301]	new jobs, also seasonal jobs. Tax revenues.
Turkey	yes[302] (Akkuyu)	no research	–
Great Britain	no[303]	–	no data
Italy	–	Recently published surveys on the return of nuclear energy: 45.75% - against 38.7% - for 8.2% not in my neighbourhood.	–

The study concludes that no examples were found that location of a nuclear power plant will adversely affect tourism in a given village/town. It also underlines the positive impact of nuclear power projects on the development of municipalities in the area. It was found that persons who live in an area where a nuclear power plant actually operates are in support of nuclear power. The remaining respondents, who do not benefit from nuclear power projects in their region, are usually against a nuclear power plant in the area where they live. Respondents (e.g. from the UK) agree that new nuclear power plants could be built in the same location as old nuclear facilities that are dismantled, and respondents who work for the nuclear sector, either directly or indirectly, actually expect that a new nuclear power plant will be built after the old one is decommissioned. The same applies to radioactive waste depositories. On the other hand, the study also indicates that there are signs of clear opposition against the development of nuclear power in Germany.

5.6.2 Organisations opposing the development of nuclear power in Poland and their initiatives

The draft Polish Nuclear Power Programme and its assumptions are clearly in opposition to the assumptions and objectives of a number of environmental organisations that do not accept the development of nuclear power in Poland or anywhere in the world. The one organisation that stands out in particular is a group called Anti-Nuclear Initiative (Inicjatywa Antynuklearna) – it identifies very strongly with anti-nuclear protests in Germany where the police regularly fight with the opponents of nuclear power on the streets or with groups of protesters who block transport routes leading to nuclear power plants. A group of scientists also voice their protests against nuclear power, including a number of scientists who are published in the press. Among those familiar to public service media due to their anti-nuclear convictions is Mrs. J. Czarnołęska-Gosiewska, president of Environmental Citizens' Club "Czuwanie"[304] and Dr. J. Jaśkowski (publicly branded for his grossly inaccurate statements by the Polish Society of Medical Physics[305]).

Arguments against the development of nuclear power in Poland are focused on a number of key areas. The vast majority of these arguments is based on the economic viability of nuclear power projects (with frequent questions like: "how many wind turbines can be built for the price of 1 nuclear power plant"[306]). Other arguments result from concerns about a possible terrorist attack, a breakdown or a serious accident in a nuclear power plant and the potential environmental pollution that could pose a threat for humans. The example of Chernobyl is showcased regularly, but often based on wrong interpretation of data or even on information that is simply not true[307]. Usually the arguments do not include technological progress and developed security standards[308]. Other arguments include the examples of other countries that do not use any nuclear power or do not build any nuclear power plants. Unfortunately, also in this case untrue data are frequently presented, which will be mentioned further in the chapter.

Unfortunately, many initiatives against nuclear power, which are often followed in the Internet remain anonymous, which makes serious discussion very difficult. In contrast to those involved in promoting the development of NPPs their authors remain unknown. The best example is the Portal of Antinuclear Initiative. How different is the manner of acting of the people involved in the development of nuclear energy can be seen on the Nuclear Energy site[309].

Characterization of all environmental organizations or initiatives bringing together the opponents of nuclear energy development is not necessary. Below, you may find a brief presentation of those organisations and their main assumptions and documents that are most familiar to the public.

Table 5.6.2 Selected organizations and associations against development of nuclear energy in Poland and their programs and documents concerning the issues discussed - the summary (the order of these organizations is not significant).

Organizations	Programs and documents relating to nuclear energy
WWF Poland WWF is one of the world's largest organizations for environmental protection[310]. The organization was founded on 11 September 1961. The idea for its establishment came from the Director-General of UNESCO, Sir Julian Huxley Switzerland became the seat of the organization. In time, also national divisions of the foundation were founded in many countries. In Poland, WWF works to protect rivers, forests and endangered species, including large predators and Baltic mammals (so-called umbrella species). It conducts educational activities and promotes legal solutions to prevent climate change. It fights animal smuggling and illegal trade in endangered species.	Document **„Atomic energy is a wrong answer"**[311] • The published document refers to the nuclear power industry in the world, it does not take into account the Polish reality; • The main theses of the document: *- nuclear power is dirty energy (referring to radioactive waste);* *- nuclear energy is economically unviable and inhibits the fight against unemployment,* *- nuclear power is dangerous,* *- nuclear energy is useless to us.*
Inicjatywa Antynuklearna [Antinuclear Initiative] As stated on the website of the organization[312], *Inicjatywa AntyNuklearna was established as a reaction to the Polish government adopting energy policy objectives, in which the construction of nuclear power plants, is regarded as a necessity*. According to the Organization *construction of nuclear power plants entails risks and a lot more damage than potential benefits*. The aims of the organization are to *overcome one-sidedness of official media, the public presentation of critical analysis on nuclear energy, calling an open public debate and promoting alternatives*.	Arguments raised[313]: • *Polish economy is 3-4 times more energy consuming than in Western European countries;* • *The measure of society development is not the amount of energy consumed;* • *High actual costs of building a nuclear power plant;* • *A nuclear power plant poses an immediate threat to the environment;* • *Production of energy from fission of an atom is a threat to human health and the environment also at the stage of obtaining the fuel;* • *Energy source that produces deadly waste cannot be called pure or "ecological". It is immoral is to leave future generations with a problem in the name of an ad hoc profit of business groups. Some of the waste generated at nuclear power plants will be dangerous for hundreds of thousands to millions of years;* • *Disassembly of nuclear installations is expensive and takes many years, radioactive waste disposal is expensive and paid for by taxpayers;* • *Development of nuclear energy in Poland will block efforts to develop energy conservation and renewable energy sources (budget is not*

Organizations	Programs and documents relating to nuclear energy
	unlimited); • *construction of nuclear power plants will not stop climate change and reduction of CO_2 emission;* • *Nuclear power plants are the perfect target for terrorists;* • *Construction of nuclear power plants is a further restriction of civil rights, including right to information.*
Instytut na rzecz Ekorozwoju [Institute for Eco-Development] Instytut na rzecz Ekorozwoju (InE) is a non-governmental *think-tank* organization founded in 1990 at the initiative of several members of the Polish Ecological Club, active in the foundation formula[314]. InE promotes and implements the principles and solutions for sustainable development of Poland. The Institute works on the European Forum at the European Environmental Bureau and in the country in coalitions of social organizations, among others Climatic, EU Funds, Polish Rural Forum.	**The position of Instytut na rzecz Ekorozwoju on the draft of "Polish Nuclear Program" dated 16 August 2010 prepared by the Government Plenipotentiary for Polish nuclear energy in the Ministry of Economy.**[315] General conclusion: *Nuclear power, whose development is proposed by the government, will not solve the basic problems of power industry in Poland in the required time, i.e. satisfying growing needs for electricity in the perspective of 15-20 years and reducing greenhouse gas emissions under the EU's commitments current and expected in the future. At the same time the costs of nuclear power, which according to the assessment of many experts are underestimated by 50-65% with the necessary guarantees from the state are a very expensive and risky option of meeting the energy needs ...*
Koalicja Klimatyczna [Climatic Coalition] Koalicja Klimatyczna is an association of non-governmental organizations interested in the actions for the protection of global climate[316]. The Coalition was founded June 22, 2002, during the conference, "Stop global warming" in Kazimierz Dolny. The mission of the Coalition is a joint action to prevent human-induced climate change for the good of the people and the environment. In the cited websites there is a list of 20 committee members, which include among others WWF, Greenpeace, Klub Gaja, Nature Protection League, and others.	**Position of Climate Coalition on the draft "Polish Nuclear Energy Programme"**[317] (selected fragments): *... Climate Coalition maintains a negative position on nuclear power development in Poland. Shape and direction of this development proposed in PNEP confirms the earlier concerns of the Coalition that the decision to build nuclear power plants in Poland, undertaken by the government unexpectedly in 2009 without the necessary economic and strategic analysis, is detrimental to Poland.* *... Essential remarks:* *To justify the development of nuclear energy PNEP presents four arguments ...* *... According to the Climate Coalition, none of these arguments has merit ...* *... Submission for public discussion an incoherent, self-contradictory program may be evidence that government agencies do not take seriously this document and public consultation ...*
Greenpeace Polska According to information posted on the organization website[318], Greenpeace is an international non-governmental organization working for environmental protection. The organization focuses its efforts on the most important, global threats to biodiversity and the environment ... Greenpeace offices are located in over 40 countries worldwide. The organization says that in order to preserve its independence it does not accept grants	**Assessment of Polish Energy Policy draft until 2030.**[319] Main theses: • *According to the report, "An Energy Revolution for Poland (Report ER-1), prepared by independent experts, in 2030 it is possible to reduce electricity production from coal to 30% and 46% coverage of demand for electricity from renewable energy sources (RES).* • *Implementation of the document in such a shape*

Organizations	Programs and documents relating to nuclear energy
from governments, political parties and corporations.	*will impede development of renewable energy in the period 2020-2030.* • *The draft does not contain a clear vision of systemic support for the development of RES. Although the current system of support for RES turned out to be inefficient and did not give a sufficient stimulus for the intensive development of this sector, the draft does not provide for its revision.* • *The draft does not contain a program that could effectively reduce the energy consumption of Poland to the present level of the EU average ... Moreover, the document envisages an increase of demand for primary energy by 21% by 2030. This is in contrast with an assumed zero-energy goal of economic growth assumed in the same document.* • *decision on the development of nuclear energy will halt development of renewable energy and energy efficiency, to which Poland is obliged by EU directives.* • *With 10 times less assets one can obtain half from the planned production of energy in nuclear power plants.* • *Postulates of changes in the Polish Energy Policy until 2030 proposed by Greenpeace, were backed by more than 10 thousand people.*
71 NGOs, participating in the meeting / conference organized by **FERSO Foundation** (Fundacja Edukacji i Rozwoju Społeczeństwa Obywatelskiego [Foundation for Education and Development of Civil Society]) The aim of FERSO Foundation is to support sustainable development of civil society through education, art and multimedia technologies. The Foundation pursues its objectives, in particular through the organization and financing of lectures, seminars, symposia, workshops and trainings[320]. The first meeting of a group of people interested in setting up the Foundation was held in early 2003.	**The position of environmental NGOs on the government's plan to introduce nuclear energy in Poland**[321] (Meeting of the Ecological NGOs – eKolumna 2010, Spała, 15 May 2010 r.), content of the position: *We found that the Polish government for several terms have sought to run a nuclear power program without thorough public debate and information about environmental, social and economic risks associated with it. Development of nuclear power will not prevent the country's energy problems, but will block the development of the renewable energy sector and measures to improve energy efficiency.* *We postulate the introduction of legal and financial instruments to facilitate:* • *reducing the energy consumption of the economy;* • *increasing the efficiency in the economy through modernization of existing energy infrastructure;* • *development of renewable wind, solar, biomass, geothermal energy sources;* • *research on other ways compatible with sustainable use of energy and solutions for climate protection and their implementation.* *Unanimously, we urge to withdraw from the program for nuclear energy and issuing public funds for its promotion. We demand a general social and national debate and real consultation on the future Polish energy policy.*

In addition to creating the above documents, the organizations opposing the construction of nuclear power plants in Poland also collect signatures of persons who identify with previously prepared petitions. An example of such a petition is presented below[322]:

Petycja przeciwko budowie w Polsce elektrowni jądrowych
Inicjatywa AntyNuklearna www.ian.org.pl

Ja niżej podpisany, jestem przeciwny budowie w Polsce elektrowni jądrowych (EJ). Nie zgadzam się też na jednostronność medialnej kampanii informacyjnej dotyczącej energetyki. Jako alternatywy dla EJ stanowczo domagam się - dla dobra mieszkańców Polski i przyszłych pokoleń, a także dla dobra środowiska naturalnego:

- oszczędnego korzystania z już produkowanej energii (m.in. usprawnienia sieci przesyłowych, zmniejszanie energochłonności procesów produkcyjnych, zapobieganie urbanistycznemu rozrostowi miast, właściwa izolacja budynków itd.);
- decentralizacji systemu produkcji i dystrybucji energii;
- przechodzenia gospodarki na odnawialne źródła energii (jako znacznie bardziej ekologiczne i zdrowsze oraz tworzące zielone miejsca pracy - np. biogaz, biomasa, energia słoneczna, energia wiatru), a odchodzenia od paliw kopalnych i szybko wyczerpywalnych;
- zaprzestania marnotrawienia moich podatków na subsydiowanie korporacyjnych zysków przemysłu jądrowego, wprowadzającego tylnymi drzwiami nieefektywne rozwiązania energetyczne, jakim jest budowa EJ;
- powszechnej, rzetelnej i rzeczowej debaty społecznej na temat planów wielkich strategicznych inwestycji mogących zagrozić zdrowiu mieszkańców, środowisku i ekologicznej gospodarce;

Chcę, aby Polska - wzorem innych krajów Europy (Austria, Dania, Grecja, Irlandia, Włochy, Hiszpania, Belgia, Niemcy, Holandia, Wielka Brytania, Szwajcaria) zrezygnowała z planów rozwoju przemysłu nuklearnego oraz, idąc za przykładem Austrii, zagwarantowała niepodejmowanie takich decyzji w przyszłości odpowiednim zapisem w konstytucji i przystąpiła do Nuclear Free Zone.

IMIĘ I NAZWISKO	ADRES	PODPIS

Authors of the petition do not mind the fact that in reality, most countries listed as a model for Poland, did not abandon their nuclear power plants, instead, they decided to build them (Italy, United Kingdom, Sweden, Switzerland, the Netherlands) or to continue operation of existing nuclear power plants (Germany, Spain).

Another manifestation of actions against the development of nuclear energy are the manifestations and protests. They are encouraged by such posters, taken from the websites of Nuclear Initiative:

Fig. 5.6.1 Posters of Antinuclear Initiative

Protests against the construction of nuclear power plants took place before indication of potential locations for the plants. An example might be a manifestation in Gryfino, organized in 2009 by a 40-person group of Polish and German Green party activists[323]. Recently, similar demonstrations were organized by Antinuclear Initiative Warsaw[324] (April 2010) and Gdańsk[325] (July 2010). However, protests from 1987-90 against the construction of a nuclear power plant in Żarnowiec went down in history.

Considering the events that take place beyond our western border and the fact that the Polish environmental organizations are inspired by their dynamically operating foreign counterparts / partners exacerbation of conflicts related to the implementation of the Polish Nuclear Programme cannot be excluded. Provocations by extremist activists seem particularly alarming.

We should note that the activities of Inicjatywa Antynuklearna and other environmental organisations are often propaganda-like. It applies in particular to the practice of presenting unverified or even false information.

However, some environmental organisations that promote cleaner environment and protection of nature also promote nuclear power. Environmentalists for Nuclear Energy (EFN) is one of them. It was established back in 1996 and now has about 9 thousand members around the world. In Poland, Stowarzyszenie Ekologów na Rzecz Energii Nuklearnej (SEREN) is the leading organisation of this type. Its objectives are to: create an association for the supporters of nuclear power for peaceful purposes, and to present to the society the complete and objective information on the power sector and its environmental impacts.

Considering the initiatives related to opting against nuclear power, we can also mention the relatively new phenomenon, which is integration of people with similar views on the online social networking sites. The most popular, Facebook, created in the US, has a profile „No to the Nuclear Energy = No to expensive electricity!”. On 12 December 2010, 51 other members of the same portal signed up in the profile. At the same time on the similarly operating profile, "Nuclear Power Plants for Poland" 610 people signed up.

Opinions expressed by Patrick Moore, co-founder of Greenpeace are also very suggestive. Moore changed his mind about nuclear power and now opposes the official position of his organisation. In an article published in 2006 in Washington Post, he states that nuclear power must complement the power generation sector based on renewable energy sources[326]. Other experienced environmentalists are of the same opinion: including Stewart Brand, author of the „Whole Earth Catalog[327]”, James Lovelock, originator of the Gaia Theory[328] (member of EFN), or the late British bishop Hugh Montefiore (founder and one of directors of Friends of the Earth[329]). Last year, they were joined by Stephen Tindale who had acted as the Executive Director of Greenpeace in the United Kingdom for many years (from 2000 to 2005). In 2009, he took a U-turn and with a group of other respected British environmentalists expressed his support for the development of nuclear power[330].

5.6.3 The overview of main problems related to the development of nuclear power – arguments for and against

The development of nuclear power in Poland will encounter a number of barriers: incompatibility of the Polish law, lack of clear vision of the future – how to meet the energy security requirements with the ever-increasing need to protect the natural environment and to meet the society's expectations, and different views expressed by various groups. The relatively low level of public knowledge of nuclear power and opinions based on inaccurate information will be also a major source of barriers.

Presented below is our review of the main problems related to the development of nuclear power in Poland that are discussed by the public and the media. These problems are discussed from the perspective of both the supporters and opponents of nuclear power – for each item, arguments and views for and against are presented. In this way we are trying to ensure an impartial approach to the problem.

Table 5.6.3 Arguments for and against the introduction of nuclear power relating to the feasibility of a nuclear power project in Poland.

AGAINST	PROBLEM	FOR
"With the current consumption, world's uranium reserves are sufficient until 2061. Expansion of the nuclear industry and the increasing energy consumption of our civilization may lead to depletion of those resources already in 2030"[331] "The expected bottlenecks in uranium ore supplies may become a more serious problem than we would expect – given the disproportion between countries that extract uranium ore and countries that use it. Of all countries in the world that operate nuclear power plants, only Canada and Republic of South Africa are not dependent on uranium imports. The largest 'atomic' countries either do not extract their own uranium ore (France, Japan, Germany, South Korea, Sweden, Spain) or have uranium ore resources that will not be sufficient for their reactors in a longer term (the USA, Russia). If we consider the problem of fuel supply for nuclear reactors, nuclear power cannot be the main source of domestic electricity production almost anywhere in the world. Russia in particular will soon face the first uranium supply crisis. This in turn may affect operators of nuclear power plants in the European Union that purchase about one-third of their nuclear fuel from Russia. China and India may also be forced to cope with a similar crisis if they continue to increase the number of their nuclear reactors, as they have declared."[332]	**Sufficiency of raw materials**	"The available resources of uranium depend strongly on its market price. Until 2001, the price of uranium ore was exceptionally low – about \$20/kgU. It was caused mainly by overproduction of uranium by 1990 and lack of social acceptance for nuclear power, resulting in overstocked inventories of uranium ore accumulated by power utilities. Nuclear disarmament reduced the prices even further by introducing cheap uranium from dismantled nuclear heads to the market. The inventory of uranium that came from disarmament has been almost used up by now, and the threat of a climate disaster put nuclear power back in the picture. As a result, the price of uranium has increased significantly. In 2005-2007, a 'uranium bubble' occurred – a sudden, exponential increase in the price of uranium, up to \$300/kgU. The current price (2009) is settled around \$100/kgU. This trend made it possible to explore uranium deposits that had been considered economically unviable before. With the increased outlays on the prospecting of new uranium ore deposits in 2001-2007, the known resources of cheap uranium increased by 40%. In 2007, the assured uranium resources that could be mined at less than \$80/kgU were estimated at 5,469,000 tonnes. IAEA estimates that these resources will suffice for at least 100 years of operation of nuclear reactors currently used, and the expected discovery of new deposits should extend this time frame up to 300 years. Civil nuclear power sector has been developing for 52 years only.(…). In the next 20-30 years, the introduction of Fast Breeder Reactors (that are currently developed as part of the Generation IV nuclear power programme) will make it possible to use both spent nuclear fuel produced by reactors currently under operation and the resources of depleted uranium left after the enrichment process. As a result, current resources of uranium will suffice for thousands of years."[333] "The security of supply of nuclear fuel for Polish nuclear power plants should not raise any concerns if we adopt the solutions developed in the European

AGAINST	PROBLEM	FOR
		Union. Still, when paving the way for the first nuclear power plants in Poland, we must actively follow the situation in the uranium market and fuel cycle services market. When doing so, we should use documentation prepared by the EURATOM Supply Agency and other global organisations (IAEA, OECD/NEA) and participate in the relevant long-term EU projects (especially SNE-TP). The focus on the uranium and fuel cycle services market in the coming years may give us valuable information well in advance as to the resistance of the future Polish nuclear power sector to potential disruptions in the fuel market in its first 'formative' years."[334]
"The question whether radioactive waste can be isolated from the biosphere for hundreds of thousands of even millions of years is a philosophical question. It just goes beyond our imagination. Only 5 thousand years have passed since the pyramids were built, and we must now think about how to safely deposit waste produced by German nuclear power plants in 2010 until 10010 or even 100010. However, we do not have a choice: because nuclear waste does exist and we cannot be 100% certain about the answer to this question, we must develop the most optimal technical solution to the best of our today's knowledge."[335] "In 2000, the amount of spent nuclear fuel deposited in the world totalled 220,000 tonnes. This amount increases at a rate of about 10,000 tonnes every year. Still, although many methods of deposition of spent nuclear fuel have been analysed for the past decades, including its deposition in space, the nuclear power industry has not found a solution to this problem yet. Most proposals for the management of highly radioactive waste involve its deposition in deep geological formations. However, we cannot predict whether containers, repository, or surrounding rocks will prove a sufficient barrier to radiation. An example of the repository foundation plan, which was a total fiasco is the project from Yucca Mountain, Nevada, USA. After twenty years of analyses and billions of dollars spent on the project, not even one gram of spent nuclear fuel was deposited in Yucca Mountain. The very fundamental	**Deposition of radioactive waste**	"...highly radioactive waste is deposited deep underground, e.g. at the depth of 500 meters, and radiation is no problem as long as its stays there – only several meters of the ground are enough to reduce radiation to undetectable levels. The only risk is the potential corrosion of containers caused by water, which may wash radioactive waste out of glass in which it was vitrified and move it up towards the surface and sources of potable water. Radioactive waste may become a threat only when ingested by humans. But, as an example, salt deposits would dissolve in water long time ago if water was able to penetrate through to them. And salt is dissolved in water much faster than glass! If we deposit containers with nuclear waste in salt layers, we can be sure that water cannot get through to them. But for how long? For much longer than the period during which nuclear waste remains hazardous. Our life is short compared to half-life of some radioisotopes, but geological changes take much longer time. The rate of removal of vitrified nuclear waste from glass will be slow, because methods of containment of waste used by the nuclear power industry are very effective. As a result, waste will be separated from the biosphere for a very long time, and even if it is removed from glass, the infiltration rate will be very slow. Moreover, the storage of nuclear fuel in tight containers will separate it from the environment for thousands of years! It is technically feasible and not difficult – the nuclear power industry is ready to build

AGAINST	PROBLEM	FOR
questions regarding the geological feasibility of this area were never answered. On top of that, it was discovered that scientific data had been manipulated, which triggered an investigation. Problems with radioactive waste deposition are not limited to highly active waste (i.e. the most radioactive waste generated in a reactor that can cause death on exposure). There are many examples of depositories for low-active nuclear waste that are a source of harmful radiation. Drigg in the UK and La Hague in France are just two of them. Nuclear waste emits radiation for tens, or even hundreds of thousands of years. No human language has survived for more than several thousand years, and no one can tell whether pictograms or other symbols will be interpreted correctly in the future. Therefore, there is no way of ensuring that the future generations are warned about radioactive waste repositories.[336]		this type of depositories for radioactive waste in a number of countries. How much land is needed to deposit highly radioactive waste? According to the EU studies, if nuclear power plants with the capacity of 30,000 MWe operate for 60 years without breaks and at full capacity, they will produce 5400 m^3 of high-active nuclear waste (after reprocessing of spent nuclear fuel). After this waste is vitrified and closed in cylinders (22 cm in diameter and 110 cm high), it may be deposited in 600 openings drilled in the area of just 0.4 km^2.[337]
Nuclear power plants are an attractive target for terrorist and military attacks, given their importance in the power sector, threats resulting from the release of radioactive substances, and their symbolic meaning. An attack targeted against a nuclear power plant may result in a disaster several times more serious than in Chernobyl. Nuclear facilities may be attacked during wars if they are allegedly used for military purposes. They may be attacked in a variety of ways – from the sea, land, or air. There is evidence that more and more terrorist groups are considering potential attacks on nuclear facilities. In this context, the decision of the nuclear power industry and governments of some countries to increase the number of nuclear reactors worldwide is a sign of their stupidity and recklessness.[338] "We may also assume with 100% certainty that none of the 436 reactors used at the beginning of 2010 around the world would withstand a targeted attack of a filled-up wide-body jet aircraft. In Western industrialised countries the risk of accidental crashes of small passenger or military aircraft was taken into account when building many nuclear reactors. However, accidental crashes of filled-up large passenger aircraft were considered so	**Terrorist attack**	"It may seem that nuclear facilities (including power plants) are an easy target for terrorists – it is enough to plant a bomb, throw a hand grenade, or crash an aeroplane. But in reality, nuclear facilities ensure ***the best possible protection against potential terrorist attacks*** – much better than for example chemical plants, water intake points, or coal-fired power plants(…). The system of protection of nuclear materials and facilities is a combination of administrative measures and a number of different types of physical barriers. This system consists of many interrelated elements: procedures for the personnel, methods of operation of equipment, plans of location of physical barriers in the expected sensitive areas in the facility, etc. (...). Terrorist attacks in New York proved that an external attack is easy. Therefore, certain measures are now more commonly introduced to prevent terrorist attacks such as destruction of physical barriers with armoured fighting vehicles filled with explosive materials, or a similar attack from the air or (potentially) the sea (as in Japan) in cases where nuclear facilities are located on coastal sites. In these cases, special coastal patrols are organised. Although a number of factors that may potentially lead to a nuclear accident have been considered

AGAINST	PROBLEM	FOR
unlikely that this scenario was not assumed by any country in the world and no effective procedures were developed. A planned attack using a passenger aircraft as a targeted missile was beyond the limits of imagination of nuclear reactor designers."[339]		since the early years of nuclear power, analyses indicate that older nuclear facilities that had been built in countries that used Soviet technologies, as well as the first nuclear reactors built in Western countries whose structural elements were affected by natural degradation, are not 100% resistant to this type of attacks. There are in urgent need of upgrades, just as certain facilities located near airports. In the United States, the mandatory safety zone of 10 miles around the reactor was introduced. If the damage caused by a terrorist attack is limited to one function or a single component of a nuclear reactor (e.g. a breakdown of the primary loop cooling system or external power failure), small corrective action will minimise this damage to a large extent. However, the situation is more serious if a number of elements are damaged. Structural design of a reactor building plays a major role in minimising the impact of a potential terrorist attack targeted at a nuclear facility with a reactor (power plants, research centres) – both external attack and internal sabotage. New buildings that house a reactor core have double walls (nearly 1 meter wide) made of reinforced concrete (with a free space of about 2 m between the walls that is monitored on an on-going basis) and additionally reinforced with a steel wall (several centimetres wide). The structure of this wall is similar to a ship's hull. Inside the building, a reactor core is placed in a safety containment made of steel and reinforced concrete (several meters wide). Simulations have proved that ***this structure can be damaged from the outside only by a major nuclear explosion***. This construction of the building can withstand strong earthquakes and hurricane-force storms (Three Mile Island plant in the US withstood 6.7 on the Richter scale and hurricane-force winds at 200 miles/h)."[340]
"It was calculated that a nuclear power plant emits 1/3 of CO2 (a greenhouse gas) compared to a modern gas-fired power plant with the same capacity. However, this ratio will be multiplied if we add emissions of greenhouse gases from deposited nuclear waste and from nuclear decommissioning after the nuclear power	**Nuclear power vs. climate**	"Nuclear power plants have less harmful impact on the environment than other commonly used sources of energy - they do not produce greenhouse gases, they do not release into the atmosphere any pollutants and waste generated during the production of energy is stored in secure locations and under strict control. One can

AGAINST	PROBLEM	FOR
plant is closed. Highly radioactive waste must be cooled down 24 hours a day, for thousands of years! One of the methods of management of low- and medium-active nuclear waste is to build underground repositories in rocks for concrete or steel containers with nuclear waste. All these energy-intensive processes are a source of greenhouse gases. Therefore, the relative benefits that may be expected only assuming a failure-free operation of nuclear power plants (which cannot be guaranteed), are neutralised by the damage caused by GHG emissions."[341] "Nuclear energy is the most expensive and most dangerous of all types of energy. The risk of proliferation of nuclear weapons, the problem of radioactive waste, the possibility of breakdowns and threat of terrorist attacks – these factors make it an unviable alternative. It is high time we stopped wasting public money on 'dirty' technologies and focus on renewable energy sources that are the only way to stop climate changes".[342]		often see big clouds of smoke rising from the chimneys of nuclear power plants, but this is water vapour, completely harmless to the environment, free from additional contaminants. In addition, nuclear power plants do not deplete valuable resources that can be used for other purposes. Moreover, they are able to generate high capacity using a relatively small area. Modern nuclear power protects the environment by eliminating some 2.4 Gt (or 2,400,000,000,000 kg) CO_2/year. Obviously, nuclear power will not eliminate CO_2 emissions altogether, but it sets the direction – how not to increase GHG emissions, at the very least. Just as an example: a coal-fired power plant with the capacity of 1000 MWe uses from 2 to 6 million tonnes of fuel per year (depending on the type of coal), and at the same time produces and releases 6.5 million tonnes of CO_2 (960 t CO_2/GWh) to the atmosphere. A similar gas-fired power plant uses 2 to 3 billion cubic meters of gas and produces 480 t of CO_2/GWh. An oil-fired power plant will use 1.5 million tonnes of fuel oil and produce 730 t of CO_2/GWh. A biomass plant with the same capacity will need an area of 6000 square kilometres as a source of biomass, a wind farm will cover an area of 100 square kilometres, and a solar power plant – 50 square kilometres. Unlike these facilities, an emission-free nuclear power plant with the capacity of 1000 MWe will use only 35 tonnes of fuel per year and will cover only several square kilometres. Only in the European Union nuclear power plants allow to save about 700 million tonnes of CO_2 per year, that is as much as all the cars of citizens of all Member States produce in a year."[343]
"The CapEx of a nuclear power plant construction project assumed in the Programme (3.0-3.3 billion euro/1000MW) is not up-to-date. Data presented by power utilities and rating agencies put the figure at 4.5 up to 5.4 billion euro/1000 MW. This data is confirmed by EDF. In its published results for Q2 FY 2010, EDF informed about the increase in the cost of construction of a nuclear power plant in Flamanville, France – from 3.3 to 5 billion euro. It suggests that the CapEx for nuclear power plant projects assumed in the Programme is	**Costs of nuclear power**	"The cost of electricity generated in nuclear power plant is 35 €/MWh, in coal fired power plant 64.4 €/MWh, in gas power plant 59.2 €/MWh, peat-fired plant 65.5 €/MWh and wood-fired plant 73.6 €/MWh (wood is not subject to tax on CO_2). Wind turbines can provide electricity at a price of 52.9 € / MWh, assuming that they are working at full capacity for 2200 h in the year and not incur any costs because of intermittent operation. In a nuclear power plant, investment outlays are the key element of costs, and the cost

AGAINST	PROBLEM	FOR
underestimated by as much as 60% and does not reflect the real costs of their construction. CapEx translated into electricity depends to a large extent on the interest rate on borrowings and the period of repayment of the construction loan. As nuclear power plants are commercial projects, cost analysis is based on data assumed for a typical commercial loan for the construction of a power plant. If we assume the interest rate on a loan at 7% and return on equity at 10.5% (1.5 x borrowing costs), and 70% of funds coming from borrowings, the average cost of capital will reach 8.05%. The cost of capital per 1 MWh of electricity produced in a nuclear power plant depends on the loan repayment period. Typically, loans are granted for 20 years, of which 5 years for construction and 15 years for operation of the project. In order to take out loan for a period longer than 20 years, especially for the construction of a nuclear power plant, state guarantees will be required. Still, even if a state guarantee is secured for the nuclear project and the period of loan repayment is extended, which is not possible under regulations currently in effect, this project will be economically unviable compared to other technologies. For a 20-year period of loan repayment, CaPex will reach 100 – 80 PLN/MWh for coal-fired power plants, 65.64 PLN/MWh for gas-fired power plants, and 282.61 PLN/MWh for nuclear power plants. For a 50-year period of repayment, these costs will reach, respectively: 66.90, 43.48 and 195.45 MWh – that is, three times higher when compared to coal-fired power plants and five times higher compared to gas-fired power plants. The Programme says virtually nothing about the operating costs in nuclear power plants. The complex technology and stringent safety requirements increase the OpEx in nuclear power plants. According to data from US nuclear power plants where production is managed at a very high level, these costs amount to 138 PLN/MWh. However, we must take into account total costs. Calculations were based on the following assumptions: 1 euro = 4 PLN, CO_2 = 30 euro/Mg, fuel cost: HC - 11.5zl/GJ. BC - 6.7 PLN/GJ; gas = 320 USD/1000mJ, atom 12.5 USD/MWh show that the energy from		of nuclear fuel is low. For other power plants, costs of fuel are the main cost component. Wind farms are an exception to this rule. In wind power plants, CapEx per one unit of peaking capacity is two times lower than in nuclear power plants, but much higher per one unit of average capacity during the year."[345] "Total cost of coal and CO_2 emissions will reach ***413 million euro/year.*** This figure is much higher than in a nuclear power plant, but CapEx in a nuclear power plant is much higher compared to coal-fired power plants. In the Flamanville nuclear power plant, CapEx amounts to 2450 euro/kW, i.e. ***3266 USD/kW***. We should note that the Flamanville 3 project is implemented without delays and in accordance with the adopted budget. CaPex of the first nuclear power plant in Poland may be higher than in nuclear power projects currently implemented in France, but to compare a number of plants we should assume average CapEx typically adopted around the world. The latest estimates of OECD assume 2.75 billion euro per 1000 MWe. For the second and every subsequent nuclear power plant in Poland, we may assume the positive effect of the learning curve in the nuclear power industry and lower investment costs. However, we will assume the worst-case scenario – CaPex will be higher than the latest OECD estimate and will be equal to CaPex of the second unit in the Florida nuclear power station in the USA – ***3220 €/kWe.*** These investment costs are higher than in Flamanville 3, because CapEx in the USA is always higher than in Europe (by about 20-30%) – not only for nuclear power projects, but also for coal-fired power plants. Therefore, CapEx assumed at 3220 €/kWe gives us a large safety margin. For coal-fired power plants in Poland, prices in 2008 reached from 1800 €/kWe to 2000 €/kWe. We will assume the cost of 1875 €/kWe, just as for the new power plant in the former Czeczot coal mine. The resulting difference in CapEx for the second and every subsequent nuclear power plant in Poland amounts to 1345 €/kWe. This is an amount equal to the difference in fuel costs and CO_2 emission charges that

AGAINST	PROBLEM	FOR
nuclear power plants is the most expensive and its cost is almost 100 Euros/MWh with a very long period of repayment. It is over two times higher than assumed in the Programme. Publication of underestimated costs of electricity production in nuclear power plants may be interpreted as an attempt to mislead the public opinion."[344]		must be incurred when burning imported coal instead of nuclear fuel during a 4-year period. Obviously, these findings should not be interpreted as a complete economic calculation, only as an illustration presenting the key elements that determine the final cost of electricity produced in nuclear and coal-fired power plants. As we can see, thanks to very low cost of nuclear fuel, ***nuclear power is an economically viable alternative despite the high capital expenditure"***[346]
"We don't need a nuclear accident to release radioactive substances to the air, water and soil. Everyday operation is enough, since government regulations allow such emissions. Radioactivity is measured in curium units. 1000 medical laboratories that use radioactive isotopes will contain the equivalent of 2 Ci. An average nuclear reactor in its core contains ca. 16 billion Ci, as much as long-term radiation from at least 1000 bombs dropped on Hiroshima. Pipework, valves and tanks of the reactor may have leaks. Leakages can be also caused by mechanical breakdowns or human errors. Ageing affects the entire reactor and its individual components, and leakages are more frequent with time. A portion of contaminated water is discharged on purpose from the reactor pool to reduce the amount of radioactive substances and corrosive compounds that would otherwise destroy valves and pipes. Water is filtered and then headed back to the cooling system or drained into the environment. A typical 1000 MW nuclear power plant with a PWR and a cooling tower needs 80 thousand litres of water from a river, lake or the sea per minute for cooling. This water is transported through 80 km of pipes. 20 thousand litres per minute are discharged back to the source, and the rest is released to the atmosphere as water vapour. A 1000 MW reactor without a cooling tower needs even more water – up to several million litres per minute. The water discharged after circulation is contaminated with radioactive elements,	**Radiation in the area of nuclear power plants**	"In the Flammanville nuclear power plant in France with two PWRs with the capacity of 900 MWe, the typical dose of radiation from all emissions from this power plant is 0.0003 mSv/year. The Souleau Committee appointed by the French government determined that the maximum doses of radiation corresponding to the allowed limits would amount to 0.3 mSv/year, and the actual dose of radiation measured outside of the power plant reached 0.01 mSv on average, i.e. 30 times lower than the adopted limits and 200 lower than the dose coming from natural background radiation. Also in the USA, the average radioactive emissions from all nuclear power plants are much lower than the acceptable maximum levels. Negative health effects caused by these low emissions have never been determined, and it is expected that they will never occur. Despite the claims presented in publications by anti-nuclear activists, a study by the US National Cancer Institute conducted on a wide scale (500,000 persons) confirmed that there are no signs of the increased cancer rate in the vicinity of nuclear power plants in the USA. Poles should not think that results recorded by the Swiss, Germans or Americans are beyond our reach due to some differences at the level of technical culture or social conditions. In the neighbouring country of Slovakia, a nuclear power plant was built in late 1980s with two WWER-440 reactors (similar to those planned in the Żarnowiec power plant in Poland). The political changes in Slovakia put the Mochovce project on hold for a couple of years, but the project was never abandoned and finally both reactors were put into

AGAINST	PROBLEM	FOR
whose concentration is neither known nor easy to measure, but it affects lives. Some radioactive gases expelled from the reactor cooling water are stored in decay reservoirs prior to release to the atmosphere through fans with a filter. Some gases are released inside the nuclear power plant buildings and are removed from time to time during what is known as 'airing'. These free gases will contaminate not only the air, but also water and soil. Radioactive leaks from a nuclear reactor that occur during normal operation are often not fully detected and not reported. Emissions from the accidents may not be fully verified or documented. For certain key side-products of a nuclear reactor (radioactive hydrogen – tritium, noble gases such as krypton and xenon), there are still no effective and economically feasible techniques of filtering and monitoring. Some liquids and gases are stored in tanks for decay of less durable radioactive materials before the release into the environment. Government regulations allow the discharge of radioactive water into the environment, containing "permitted" levels of pollutant concentrations. But 'acceptable' does not necessarily mean 'safe'. Detectors installed at reactors are set up to allow the release of unfiltered water that contains more pollutants than 'acceptable'. Detection of leakages and predicting the spread of radioactive pollution by US Nuclear Regulatory Commission is based on reports and computer models provided by operators of nuclear power plants. Much of the environmental monitoring data comes from extrapolation rather than from observation. There is simply no accurate analysis of all nuclear waste released into the air, water and soil from the entire production cycle of nuclear energy. This cycle includes: mining and milling of uranium ore, chemical processing, enrichment, fuel production, nuclear reactors, and pools, ditches and barrels in which the waste is stored. Growing as a result of deregulation of the electricity generating industry, economic pressures to reduce costs may further undermine the already tenuous monitoring and reporting of radioactive leaks. Delayed upgrades may increase the emissions of		operation – after the introduction of certain modifications. These reactors now produce electricity that is 50% cheaper than electricity produced in conventional power plants, and at the same time they meet all safety requirements adopted in the EU. Radiological analyses indicated that doses of radiation in the area are so small that they cannot be even measured. When measurements were finally taken, it turned out that in the period of 6 years since the opening of the Mochovce nuclear power plant, additional annual doses of radiation from this facility never exceeded one MILLIONTH of a sievert (ranging from 0.1 to 0.7 micro Sv)."[348]

AGAINST	PROBLEM	FOR
radioactive substances and the resulting risks. Many side-products of nuclear reactors are able to emit radioactive particles and rays for a very long time – defined based on their 'half-life'. Radioactive materials will emit harmful radiation for at least 10 half-lives. The half-life of one of the isotopes of iodine (iodine 129) is 16 million years, technetium 99 - 211 thousand years, and plutonium 239 - 24 thousand years. Noble gas xenon 135, is transformed into caesium 135, the isotope with half-life period of 2.3 million years. It is a scientific fact that low level radiation damages tissues, cells, DNA and other vital molecules, causing progressive cell death (apoptosis), genetic mutations, cancer, leukaemia, neonatal deformation, and disorders of reproductive, immunological and endocrine systems." [347]		
"Polish nuclear power plants will pose a threat of another Chernobyl disaster. The system selected by the Polish government is so hazardous that the British decided to ban the construction of this type of reactors. Polish experts have no experience and blindly believe the producers - the recognized nuclear energy expert warns. "The UK Nuclear Installations Inspectorate refused permission for the construction of EPR nuclear reactors (European Pressurised Reactor - a new reactor with a capacity of 1600MW), justifying this with concern about the safety of their operation," - explains in "Virtual New Industry" prof. Assoc. Eng. Wladyslaw Mielczarski, full professor at the Technical University of Łódź, a member of the European Energy Institute. And British experts are among the most experienced nuclear energy experts in the world. They claim that reactors that Poland intends to purchase have major safety issues. There are problems with maintenance of the optimum temperature and pressure. In case of problems the plant operation cannot be stopped quickly. In his opinion, there is no discussion in Poland on reactor safety, and the government presents the device as a super-safe. "Some time ago, people were convinced that they had built a super-reliable machine. It was a ship – and her name was the Titanic. Since that	**Safety**	"Since the very beginning of nuclear power, nuclear power plants in Western countries have been designed in such a way as to ensure that the effects of any potential (even very unlikely) accident do not exceed the acceptable level. A number of different and reliable safeguards were used, mainly based on natural mechanisms such as the force of gravity, safety systems with three or four redundant subsystems, large safety margins assumed in the design, and many other design and organisational measures described in the article "*Protection against threats from failures in nuclear power plants*" published in the September issue of PSE Public Information Bulletin. As a rule with respect to design failures it was assumed that the NPP safety systems must be sufficient to control failure in any NPP component, even if the failure occurs in the most inconvenient element for the operator and in the most unfavourable condition of NPP, and is accompanied by a single failure that can occur in any power plant system, even one that is designed to master this very failure. For such assumptions, the designer had to develop a failure scenario, assuming the most unfavourable assumptions, such that failure results in loss of electrical power from the external network (regardless of additional single postulated damage in any system) and prove that the existing safety systems in NPP are enough to provide

AGAINST	PROBLEM	FOR
time, nothing has been called super-safe or reliable. When I hear lobbyists singing praises about the safety of nuclear reactors, it is worthwhile to stop and think – maybe they are trying to sell us a ticket for the new Titanic?", said prof. Mielczarski. As suggested by Mielczarski, Polish experts have no experience. They have completed one-week courses and information from producers is all they have to rely on. And this information is not always true. That is why the decision regarding the selection of a particular type of a nuclear reactor for Poland in 2010 must be well prepared. Otherwise, the new Polish nuclear power plants may destroy Poland."[349]		power plant shutdown, cooling down and preventing the release of radioactive substances. We did witness one accident in a nuclear power plant that included a PWR core meltdown. It happened during a nuclear accident in the Three Mile Island (TMI) nuclear power station, where the power supply was not interrupted, but wrong decisions taken by operators caused the failure of the emergency core cooling systems and melting of the nuclear fuel. However, although the core and the entire nuclear reactor had been damaged to such an extent that the subsequent repair of the nuclear power station was not possible, the reactor pressure vessel maintained its integrity, and the safety containment prevented the release of fission products – as a result, the doses of radiation outside the nuclear power plant were negligibly small. Nobody lost their life or health as a result of the TMI accident. The TMI case proves that even 'old' reactors have safety margins that will ensure the containment of the effects of beyond-design basis accidents involving the nuclear core meltdown. At the same time, the TMI accident serves as a warning – human error is possible and fast and effective interpretation of the emergency processes may be difficult and may lead to very wrong decisions. Therefore, analyses were launched to determine whether effective rules of procedure can be developed to prevent human error on the part of operators. At the same time, additional safeguards were introduced to the planned and existing reactors to contain the release of radioactive substances in the worst-case scenario of the most serious hypothetical accidents. There works took many years, and the resistance of nuclear power plants to beyond-design basis accidents have improved over time. At the end of the 20th century, the EU Member States adopted the practice that safety features and systems in a nuclear power plant should be able to contain not only design-basis accidents, but also beyond-design basis conditions in order to prevent the release of large amount of radioactive substances outside of the safety containment. Now, after 25 years since

AGAINST	PROBLEM	FOR
		the TMI accident, both the EU and the USA have developed state-of-the-art reactor designs (Generation III reactors) that will guarantee safety for inhabitants of the local area even in the event of serious nuclear breakdowns with nuclear core meltdown."[350]

5.6.4 Educational and information programs concerning nuclear energy in Poland

The project to build nuclear power plants returns. We should take a look at how the approach of authors of development of nuclear energy to informing the society has changed, since the society has a right to be informed of any actions which can impact the environment.

It was included in the raft Polish Nuclear Programme that in order to increase the knowledge of society in terms of nuclear energy (including nuclear power industry), constant education and information actions are necessary. Both types of activities should be correlated and coordinated, conducted in parallel. The burden of educational activities should be distributed between the ministries responsible for education, training and promotion of science, collaborating with the Ministry of Economy, cooperating in the future with Nuclear Energy Agency. Educational activities should also be pursued by other bodies and institutions. Educational activities should be conducted from the lowest levels of education - from primary school level. They must also be supported by an investor/investors, both within their policy of CSR (Corporate Social Responsibility) and in cooperation with institutions training staff training for nuclear energy sector. Thus, the activities proposed by PEJ include:

- information campaign,
- education campaign.

According to PEJ society will be entitled to receive information on the operation of nuclear power sector, all the information will be available, unless legally protected in accordance with applicable regulations on protection of information covered by intellectual property rights recognized by the Investor/OEJ Operator as sensitive information concerning the physical protection of nuclear materials and security and those whose disclosure would endanger public safety. NEA will be required to protect data and information obtained from the Investor/OEJ Operator against access by unauthorized persons and entities, Nuclear Energy Agency (NEA) will be required to collect data and information on nuclear energy in Poland and abroad, to process and publish and share them with interested natural and legal persons.

Provisions quoted above correspond to the needs identified in the CBOS research results cited in the preceding subsections concerning low awareness of Poles about nuclear power. Informing the society is a necessary factor, which must accompany the development of nuclear energy. It is important that the principle of transparency recommended in the Draft is applied, allowing for social control and increase in public trust for conducted projects. In this scope, actions of potential Investors will also be crucial, as mentioned above. Achieving the objectives will be aided by "Human resources development plan", which according to PEJ should be adopted by the end of 2011.

Information action and dialogue concerning the plans to build nuclear power plants have already been started. The initiative is implemented by a series of meetings during the tour across the country on the so-called Atomic bus. As stated on the website of the Project[351] The main objective of the project "Atomic Bus - Mobile Lab" is to reach students in major academic centres and to provide reliable information on peaceful uses of nuclear energy in the context of the government's program of building nuclear power plant in Poland.

The educational project is run from November to December 2010 in collaboration with leading universities in selected localities. As part of the Project the university and polytechnic departments hold seminars on various aspects related to the introduction of nuclear power. Sample topics include the following: psychology of radiation; nuclear power reactors - construction, operation, operational safety, biological effects of ionizing radiation; staff for nuclear power industry, the prospects for applying thorium in nuclear reactors. A supplementary objective of the project is to attract and possibly deepen the knowledge of existing conditions and social attitudes and perceptions of nuclear power industry issues by students, residents of visited cities and local leaders. In direct conversations with students around the information and education booth and during seminars and open discussion, the staff of the Foundation offers free of charge, objective and most current knowledge in the field of radiation protection, the essence of radioactivity, used reactor construction technologies and security systems and the construction costs of the future nuclear power plant taking into account environmental aspects.

"Atomic Bus" is also a mobile information centre, equipped with a range of interactive teaching aids (audio-visual equipment, demonstration facilities and equipment and nuclear mini-laboratory) that are presented and made available to visitors. Foundation employees involved in the project, in addition to presentations and distribution of information materials and brochures, will be able to perform demonstrations and experiments in the field of nuclear physics and radiation protection, and demonstrate the performance of a typical nuclear power plant using a specially prepared model. In pursuit of the objectives of this Project, the experience with similar projects is taken into account.

The Atomic Bus Project also allows for substantive discussions of representatives of the Antinuclear Associations with representatives of Atomic Forum. For example, the presentation at Wroclaw University of Technology was closely observed by representatives of Stowarzyszenie Ekologiczne Eko-Unia who, by handing out information materials and discussions tried to present a quite different approach to the subject of nuclear energy. This kind of public confrontation of groups with two different views on nuclear energy in Poland allows persons not yet having to deal with this subject to refer to the arguments of both sides and fully consciously decide which arguments are correct and which side should be supported.

Popularization of knowledge of nuclear power industry is promoted by professional websites, being an increasingly frequent and easy source of knowledge. For this purpose the website „Nuclear energy[352]" was created in Poland. It deserves special attention as it is created in cooperation with the most prominent specialists in the field of energy, including nuclear power industry, of course. Thematic tabs include materials devoted to technology, security, ecology, law and current events that are related to the subject. A rich base of presentations, comprehensive publications and specialist publications can be found on the website. They are usually made available in form of PDF files.

6 ALTERNATIVES TO THE SOLUTIONS INCLUDED IN THE PROGRAM

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6.1 Alternative solutions for energy security

The structure of electricity generation in Poland (Fig. 6.1.1), by primary energy carriers consumed, is characterized by unique in the EU, and even in the world, dominance of coal (about 92% share), the total absence of nuclear energy and the small share of RES (4.6%). In contrast, in EU-27 states (Fig. 6.1.1), the structure of sources used for electricity generation is well-balanced: nuclear energy has the largest share - about 28%, then coal, ca. 27%, natural gas ca. 23% and RES ca. 18%.

We should realise that nuclear power is the main source of electricity in EU-15, while in Poland coal continues to dominate. Diversification of energy sources in Poland is therefore necessary and the society must be aware of the total real cost of the various energy sources to make an informed decision as to the directions of the country's development (cf. Chapter 5).

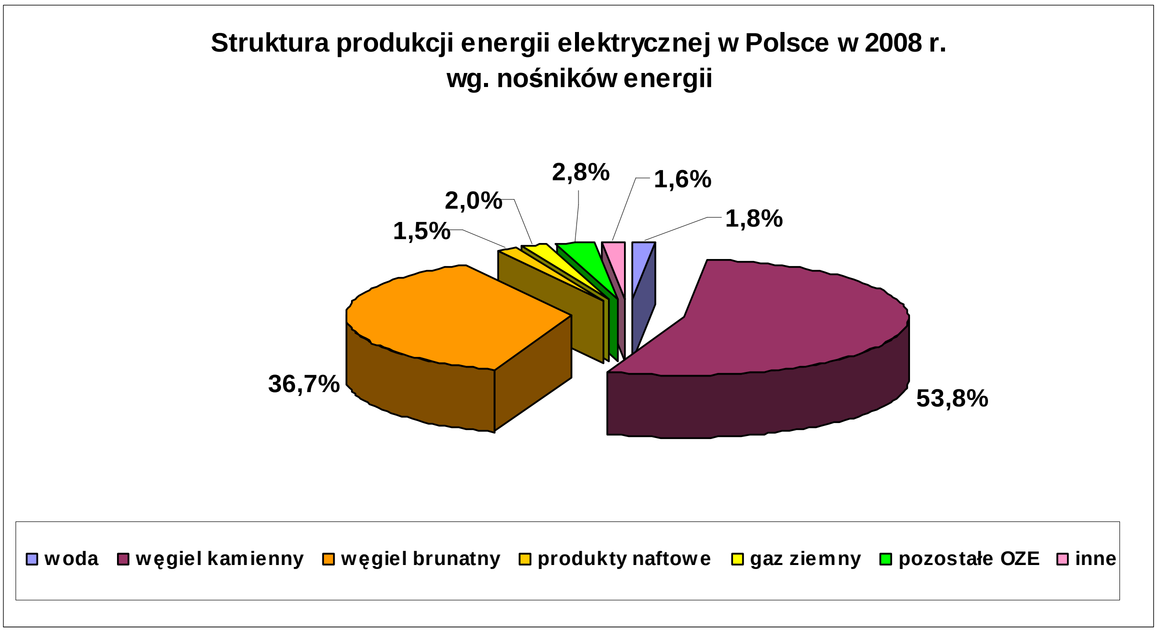

Fig. 6.1.1 The structure of electricity generation in Poland by primary energy carriers [own study based on Eurostat 2010 data].[353].

[Structure of electricity production in Poland in 2008 by energy carriers
Water
Hard coal
Brown coal
Petroleum products
Natural gas
Other RES
Others]

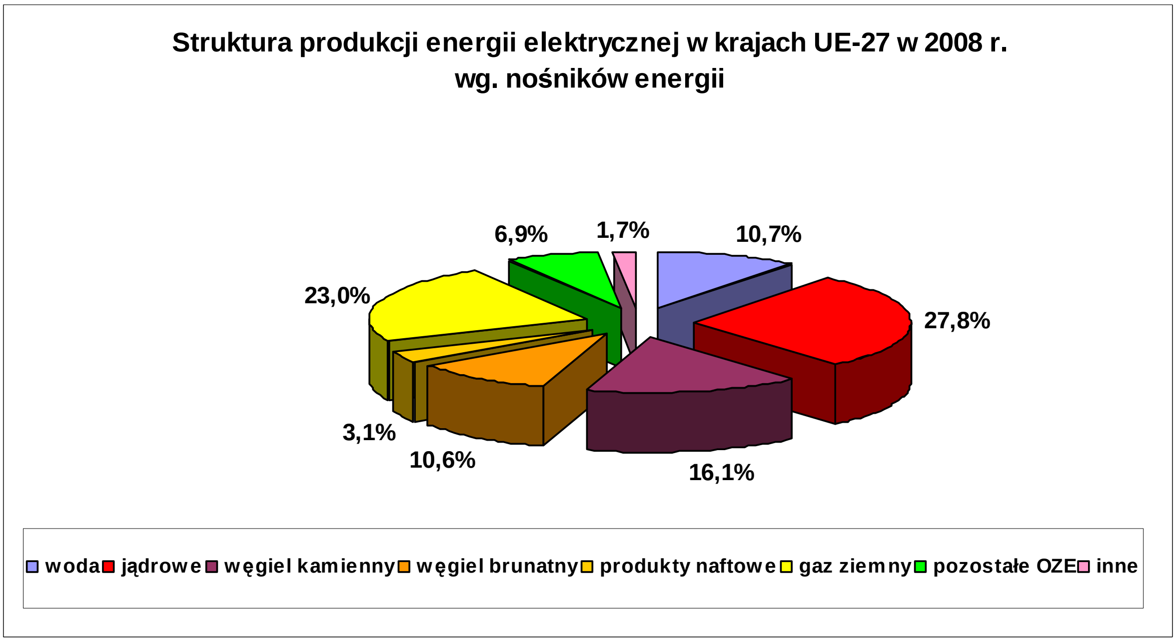

Fig. 6.1.2 The structure of electricity generation in EU-27 by primary energy carriers [own study based on Eurostat 2010 data]

[Structure of electricity production in EU-27 states in 2008 by energy carriers
Water
Nuclear
Hard coal
Brown coal
Petroleum products
Natural gas
Other RES
Others]

Poland needs to diversify its electricity production sources as soon as possible. On the one hand, the current structure of electricity generation has a number of negative environmental impacts (cf. Chapter 5); on the other, the country must become independent of the depletable resources of fossil fuels, which will guarantee energy security in a long-term perspective.

This Chapter discusses the potential outcomes of the implementation of the various alternatives for the strategy of development of the Polish energy sector.

6.1.1 Variant 1: Improving energy efficiency

Improvement of energy efficiency has a relatively high potential to reduce the emissions of greenhouse gases (by 29%) **Błąd! Nie zdefiniowano zakładki.**; and it will bring economic benefits, reduction of social costs, and potential reduction in the demand for electricity. However, energy savings alone are insufficient, both in terms of reduction of emissions and the ever-growing demand for electricity. Still, it must be noted that investments in this area are absolutely necessary and should be considered a top priority as the most effective method to achieve measurable results, especially in the form of reduced emissions.

Forecast of demand for fuel and energy by 2030 developed by ARE SA and adopted in "Polish Energy Policy until 2030"(Fig. 6.1.3)[354], predicts an increase in gross electricity demand by about **54%**: from 141.0 TWh (2010) do 217.4 TWh (2030). Very significant reduction in electricity intensity of GDP was assumed: from 137.7 MWh/PLN'07 in 2006 to 60.6 MWh/PLN'07. A similar estimate was adopted by McKinsey&Company**Błąd! Nie zdefiniowano zakładki.**; – assuming that all energy-efficiency initiatives are implemented (reduction of transmission losses, improvement of production efficiency), the demand for electricity will still increase from 157 TWh in 2005 to 198 TWh in 2030. (based on the forecast increase in GDP – as estimated by Global Insight) **Błąd! Nie zdefiniowano zakładki.**. This unavoidable increase in demand will need additional energy sources.

In order to produce these electricity volumes at reasonable cost and in an environmentally-friendly manner, Poland will need new energy sources based on different technologies with low emissions of CO_2, including high-capacity coal-fired, gas-fired and nuclear power plants, as well as renewable energy sources.

According to the above ARE forecast of power and fuel demand until 2030, taking into account the anticipated effects of the implementation of energy efficiency projects in the economy, the requirements of the European Union in reducing air emissions and fossil fuel prices forecast until 2030, there will be a **moderate increase in final demand for electricity** to ca. 172 TWh, i.e. by ca. **55%** compared to 2006 (that year was adopted in the forecast as the base year).

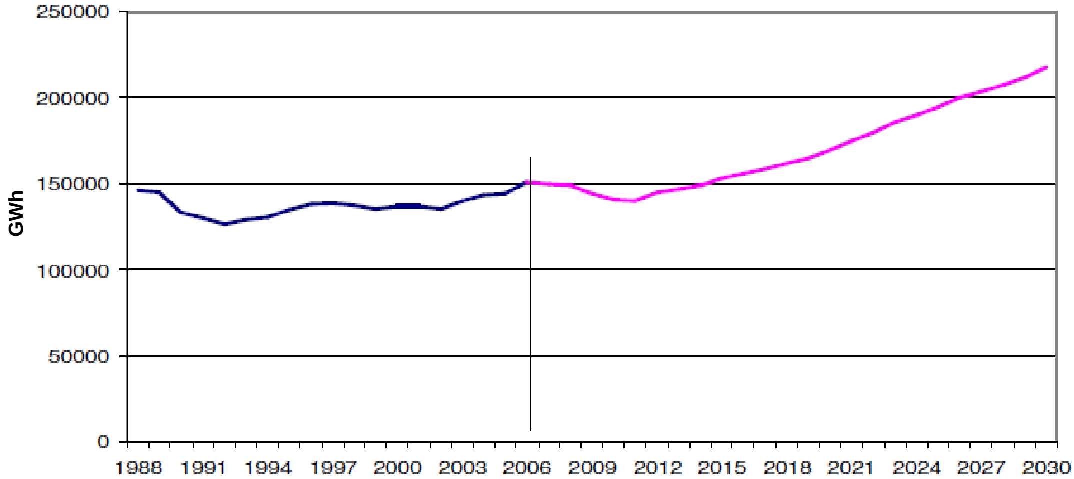

Fig. 6.1.3 Forecast gross consumption of electricity in Poland by 2030.[355]

6.1.2 Variant 2: Development of Renewable Energy Sources (RES)

Under the EU Energy and Climate Package, the share of RES in total consumption of energy (both heat and electricity) in Poland must reach 15% in 2020. Achievement of this target will be not only very difficult with the limited RES resources, but also expensive – considering the high cost of production of energy (especially electricity) from renewable energy sources. According to expertise developed by the National Agency for Energy Conservation [KAPE 2007][356]: "Total estimated potential of RES will not allow Poland to achieve the adopted target of 20% share of RES energy in the country's total balance of primary energy consumption".

In addition, the energy potential of RES has not been estimated in a reliable manner:

- [KAPE 2007]: "Results of assessments of the RES potential conducted to date are divergent. They have a limited scope and are often not based on the methodology adopted for scientific work"
- [ARE 2007] [357]: "The available studies on the potential of renewable energy sources present different results, which is caused mainly by the adoption of different definitions of the potential of RES. None of these analyses will answer the question what portion of this potential can be used in practice and, more importantly, at what cost and rate. Therefore, our Forecast assumes

the potential of RES based on the expert's assessment of the accuracy of data published in the relevant studies."

Various experts agree that **biomass and wind energy** have **the highest potential for growth** in Poland. The growth potential of hydropower, already the dominant source of electricity using renewable energy (about 2.3 TWh/a), is assessed as relatively small.

The analysis performed by ARE S.A.[357] (Fig. 6.1.4) presents the following potential of electricity production from these renewable energy sources usable until 2030:

– solid biomass (including co-firing with coal) and biogas: 29 TWh in total;
– wind power: 13 TWh;
– water: 1.5 TWh.

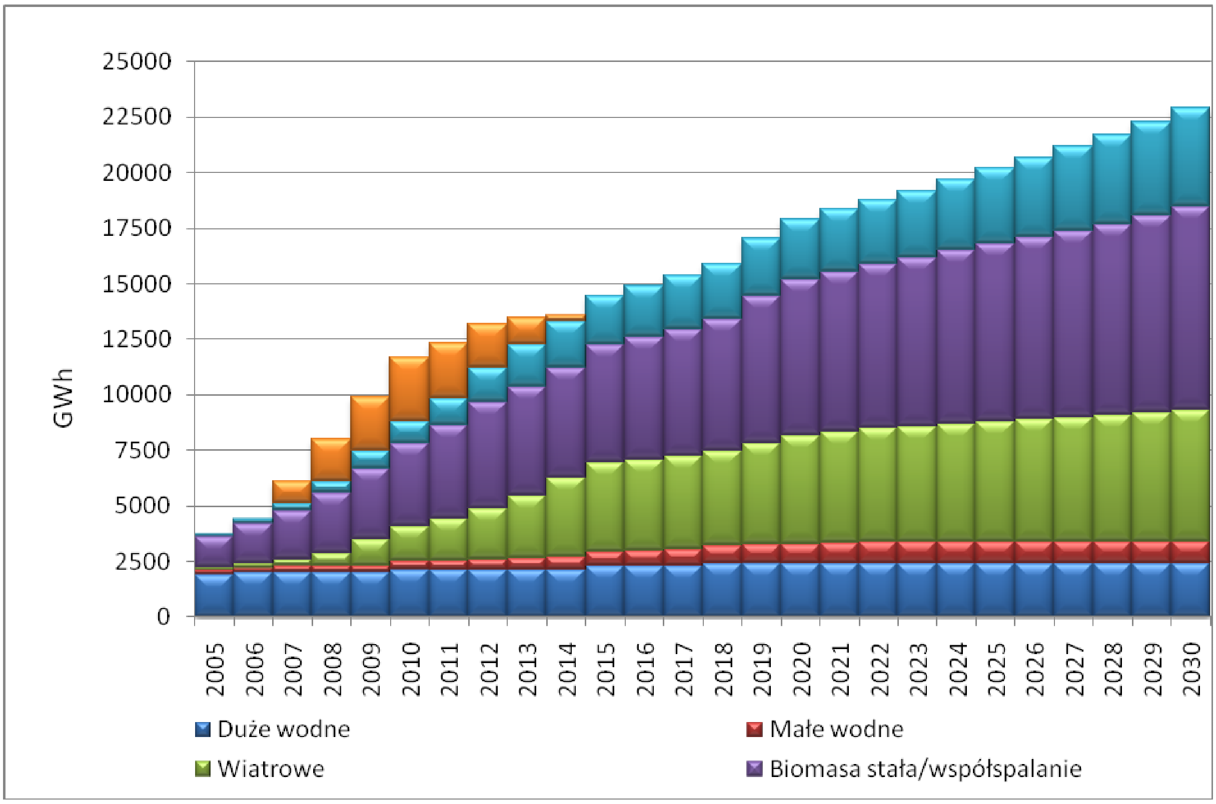

Fig. 6.1.4 Forecast production of electricity from RES by 2030 [ARE 2007].

[Large hydroelectric power plants
Wind power plants
Small hydroelectric power plants
Solid biomass/co-combustion]

Renewable energy sources are often presented as an alternative to nuclear power. Therefore, this Chapter discusses renewable energy sources that represent the highest potential for electricity production in Poland and attempts to define their environmental impacts and actual energy-generating capacity. Renewable energy sources may be broken down into two groups: The first group includes hydroelectric power, biomass and biogas. The second option is to build wind power projects. However, the average unit cost of wind power produced in Poland is much higher that the break-even point. The comparison of costs of electricity from different sources developed by ARE and shown in Fig. 6.1.5 indicates that the cost of wind energy exceeds 100 euro/MWh in all cases. Construction of wind turbines will therefore cause an increase in electricity production costs. [372] ARE prepared similar analyses for a longer-term perspective, i.e. 2030, 2040 and 2050. They clearly indicate that even after 2030, the cost of RES will still exceed costs of nuclear power.

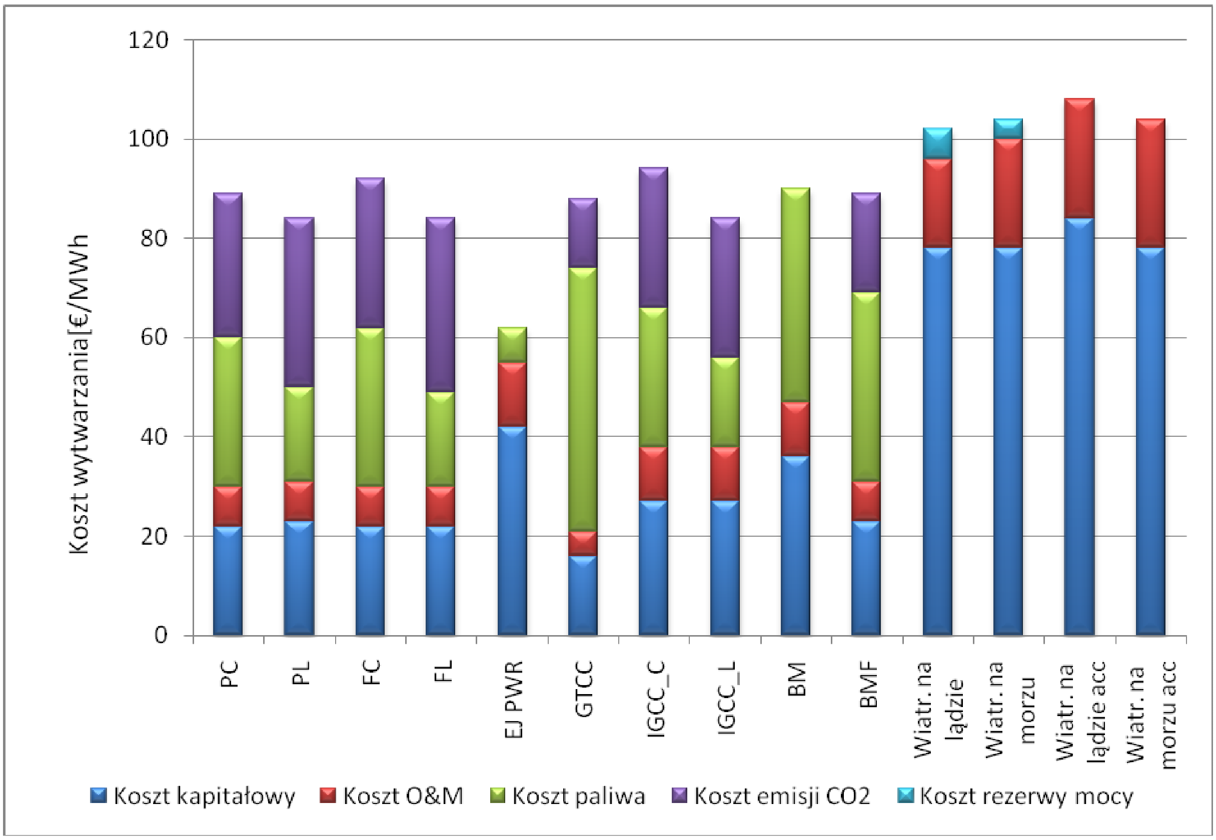

Fig. 6.1.5 Comparison of forecast costs of electricity production from various sources in 2020 [ARE 2009]

PC (pulverised coal) - condensing power plants burning black coal in pulverised coal-fired boilers with flue gas desulphurisation and denitrification systems;
PL (pulverised lignite) - condensing power plants burning brown coal in pulverised lignite-fired boilers with flue gas desulphurisation and denitrification systems;
FC (– fluidized coal) – condensing power plants burning black coal in fluidised bed boilers;
FL (– fluidized lignite) – condensing power plants burning brown coal in fluidised bed boilers;
PWR NPP – nuclear power plants with LWRIII reactors (III Generation Light Water Reactors) represented by power plants with Pressurised Water Reactors type PWR (nuclear power plant with a PWR);
GTCC (– gas turbine combined cycle) – steam and gas power plants – burning natural gas;
IGCC_C (– coal integrated gasification combined cycle) – power plants burning gas from the integrated coal gasification system;
IGCC_L (– lignite integrated gasification combined cycle) – power plants burning gas from the integrated lignite gasification system;
BM (– biomass integrated gasification combined cycle) – power plants burning gas from the integrated biomass gasification system;
PMF (– pulverised multifuel) – power plants with pulverised boilers that use biomass and coal co-firing;

[Generation cost [Euro/MWh]
CapEx
O&M cost
Fuel cost
CO2 emission cost
Power reserve cost]

6.1.2.1 Hydroelectric power plants

In 2008, hydroelectric power plants in Poland generated 2.2 TWh of electricity [358]. The total hydroelectric potential of Polish rivers (in accordance with the World Energy Council guidance) amounts to 23 TWh (theoretical), 12 TWh (technical), and 8.5 TWh (economically viable) [359]. As we can see, there is still room for further development of hydroelectric power, although to a limited extent. Poland's relatively low hydroelectric potential results from small total precipitation and its uneven distribution, high permeability of the ground, and the predominantly lowland area of the country.

Hydroelectric energy is a source of electricity that does not generate emission to the environment and does not use any natural resources. In addition, generation of electricity in hydroelectric power plants is relatively cheap – the cheapest of all renewable energy sources, and they are the most efficient and steady sources of electricity of all known RES technologies. Furthermore, barrages are an important element of the system of flood defences, regulation of hydrographic conditions, water supply for the population and the economy, and they make it easier or even make it at all possible to use the inland waterways network. They are also attractive for tourists. And lastly, barrages provide a passage over rivers and are used as bridges.

However, construction and use of barrages has a number of negative environmental impacts. Barrages undermine the natural ecosystems of rivers, both directly (interrupting the migration of aquatic species) and indirectly (changing the hydrological parameters of the entire river). The river flow after the barrage is regulated artificially and kept at a constant level, which is not natural for any river. It has a positive effect for people and their property as a protection against flooding, but at the same time may have a negative impact on the natural ecosystem of the river. The man-made reservoir below the dam also affects the groundwater system – the level of ground waters is increased before the dam and decreased after the dam. As artificial lakes cover a vast area of land in a river valley, they sometimes require permanent relocation of people which has a negative impact on the local population. However, the key environmental impacts affect the ecology of man-made reservoirs.

Given the high surface-to-volume ratio, man-made reservoirs in lowland rivers are especially sensitive to eutrophication. Bloom of toxic cyanobacteria (blue-green algae) is the most serious form of eutrophication regularly observed in man-made reservoirs. This problem applies to the majority of river-dam reservoirs in Poland, and in particular the Sulejów, Dębe, Goczałkowice, Włocławek and Jeziorsko Lakes. The main problems with water quality in man-made reservoirs are caused by sedimentation of suspended matter carried by the river, often from a vast drainage basin, as a result of a rapid reduction of its flow rate. Deposits contain organic matter, nutrients, and hazardous pollutants – including pesticides and traces of heavy metals. They may be re-circulated by living organisms – nutrients deposited at the bottom are released and made accessible to the phytoplankton, which additionally increases productivity (or eutrophication) of the lake and causes the so-called 'secondary pollution'. Mobilisation of deposits is facilitated by the variable water level, mixing by wind, activity of benthic organisms, and the existing anaerobic conditions at the deposit-water column point of contact (reducing environment – redox potential < 200mV and O_2 concentration < 2mg/l). [360] In these conditions, algae develop rapidly and create blooms, mostly of cyanobacteria, that produce and release toxins into the reservoir. Exposure to cyanobacteria toxins, including hepatotoxins and neurotoxins, may have harmful effects on human health: skin diseases, allergic reactions, paralysis, fever, poisoning, kidney and liver damage. A relation between liver cancer and consumption of potable water contaminated with cyanobacteria was also demonstrated. 360

However, the optimum design of man-made reservoirs will reduce these impacts to insignificant levels. All in all, despite these negative aspects of environmental impacts, hydroelectric power is still one of the most environmentally-friendly sources of electricity. This is demonstrated by the low level of external costs of hydropower generation (see: results of the European Commission study ExternE – Fig. 6.1.6).

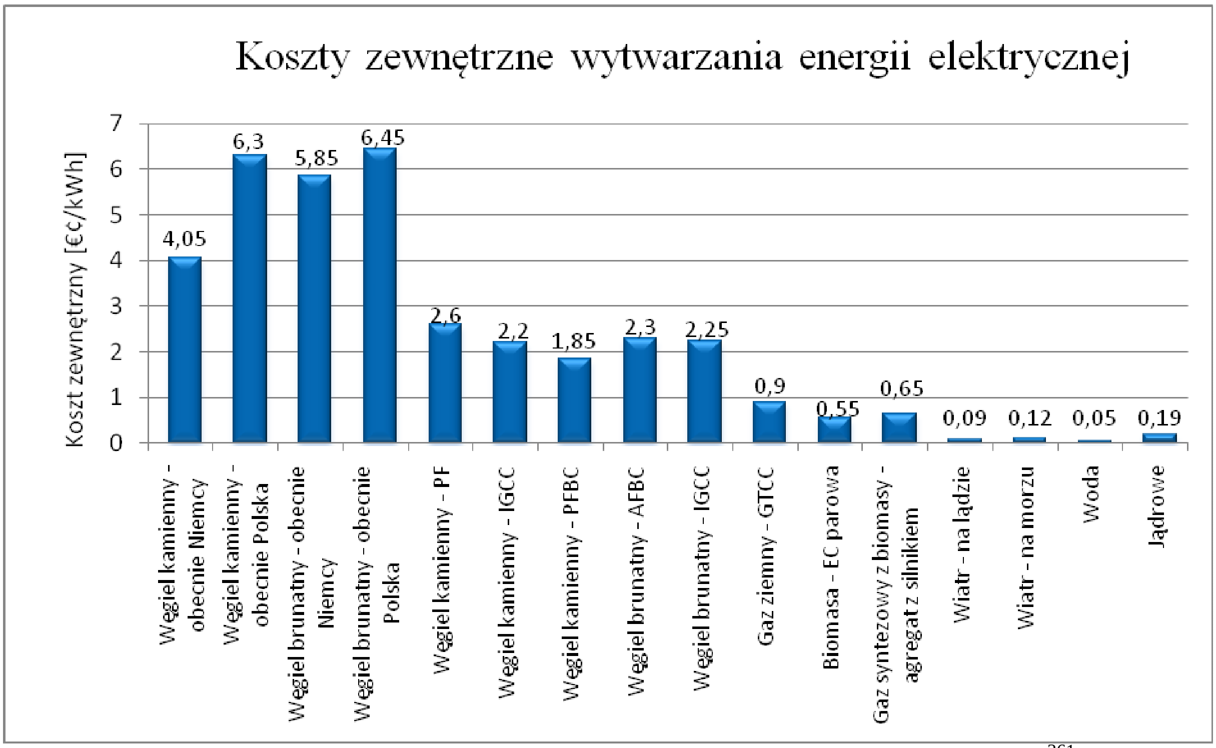

Fig. 6.1.6 External cost of electricity production in various technologies [own study based on ExternE-Pol][361]

[External cost (Eurocent/kWh)
Hard coal – currently Germany
Hard coal – currently Poland
Brown coal – currently Germany
Brown coal – currently Poland
Hard coal – PF
Hard coal – IGCC
Hard coal – PFBC
Brown coal – AFBC
Brown coal – IGCC
Natural gas – GTCC
Biomass – steam EC
Synthetic gas from biomass – generator with motor
Wind – on land
Wind – on sea
Water
Nuclear]

In addition, the vast majority of the discussed negative environmental aspects apply to large hydroelectric power plants that require an extensive area of man-made reservoirs and large dams. The environmental impact of small hydropower plants is much more positive, and their development should be a priority in this area. Development of small hydropower plants, and maintenance of energy production from large power plants at a constant level, is implied in "Polish Energy Policy until 2030", which is the overriding document in relation to the evaluated program. According to the data of Hydropower Plants Association (TEW) and the Society for the Development of Small Hydropower Plants (TRMEW) [362] electricity production in small hydropower plants (<10 MW) by 2020 can be increased by about 1.2 TWh in comparison to the level from 2009 (0.92 TWh). However, the potential of electricity production in hydroelectric power plants in terms of its quantity is so small vs. the country's total energy balance that is may be used only as a valuable addition in the energy sector, but cannot satisfy the ever-growing demand for energy in Poland. In 2030, the estimated electricity production volume in hydroelectric power plants will reach 3.2 TWh, using the potential of small hydropower units in 100%. [363]

6.1.2.2 Biomass and biogas burning

Production of electricity in biomass power plants is based on the supply of raw materials from local sources. Agricultural or forestry waste as well as energy crops produced in special plantations are used as fuels to generate electricity. The possibility to keep energy in store – in the form of raw materials (biomass), is of key importance. It offers a great advantage over other RES. Carbon dioxide released in the process of biomass burning does not represent additional GHG emissions – it is integrated in the biomass structure in the photosynthesis process. In this way the emission caused by combustion is balanced by absorption by plants during the assimilation of CO_2. Biomass is also characterized by much lower sulphur content than fossil fuels, thereby reducing the costs of flue gas desulfurization

Production of biomass and opening of smaller biomass-fired CHP plants would also offer a number of benefits for people, especially inhabitants of rural areas, including the creation of new jobs, additional market for agricultural products (also of inferior quality), and potential involvement of local communities in new projects. Development of biomass energy production will also de-centralise the production of electricity in Poland, thus improving the country’s energy security by reducing transmission losses and increasing diversification of energy sources, with biomass as a reliable and stable source.

However, despite all positive environmental aspects, the potential volume of energy produced from biomass is also limited to a large extent. Obviously, using the agricultural and forestry waste as biomass offers a number of environmental, social and economic benefits. But establishment of special plantations of energy crops involves certain negative impacts – including creation of plant monocultures and reduction of surface area for crops used in food production. On the other hand, land of inferior quality that is not suitable for typical agricultural production can be used to produce biomass.

Real chances and potential scale of development of the so-called "agroenergetics” were estimated by prof. Antoni Faber from the Institute of Soil Science and Plant Cultivation (IUNG) in Puławy [364] [365]. Prof. Faber has performed computational simulations for four scenarios of agricultural development in Poland, with different degrees of liberalization, namely: scope of intervention in agricultural market (price regulation), increasing farmers' income support (direct payments), support for areas with unfavourable management conditions and stimulation of the production of energy crops.

Simulations performed by prof. Faber show that for the purposes of biomass production, the agricultural sector could “…assign **the maximum of 830 thousand hectares**, assuming the self-sufficiency in food production at 97.2%, the required biodiversity, and carbon capture and storage. If this limit is exceeded, either the food production sector or the environmental value of agriculture will be affected. Therefore, biomass will become a scarce resource, especially given that after 2015 production of generation II liquid biofuels will start to develop and will also require lignin and celulose biomass." Moreover, analysis have shown that even in the most favourable scenario for the development of biomass, which is also a relatively favourable scenario for farmers, their income and social security will decrease.

We should also note that burning of biofuels apart from environmentally neutral CO_2 emissions, produces nitrogen oxides (NO_x) that are more difficult to eliminate than in the case of conventional energy sources. In addition, if biomass is contaminated with pesticides, plastic waste, or chlorine compounds, it may release toxic dioxanes and furans to the atmosphere on combustion.

Biogas burning technologies offer similar benefits. Biogas is a side-product of waste and sewage decomposition. Agricultural waste (manure), sludge, and landfills offer the highest biogas production potential in terms of its quantity. Combustion of biogas is environmentally beneficial in terms of greenhouse gas emissions as, although it produces CO_2, simultaneously emission of methane is limited, which is significantly more effective greenhouse gas than CO_2 (greenhouse effect of methane is about 32 times greater than for carbon dioxide[359]). If waste is decomposed naturally and the resulting biogas is not collected and burned, methane will be released to the atmosphere. However, just as in the case of biomass, biogas resources are limited in quantity and may be used successfully only in the form of dispersed energy sources supplying electricity to individual farms or elements of infrastructure, such as waste landfills or wastewater treatment plants; but their potential is not sufficient to satisfy the ever-increasing demand for energy for the industry or urban areas. The Polish Energy Policy until 2030, which is a document that takes precedence over the Programme, assumes very dynamic development of biogas burning applications – its potential is expected to be used in 100% already in 2020. A similar trend is expected for biomass – 100% of its potential is to be reached in 2030. [363]

6.1.2.3 Wind farms

Despite the necessary high investment costs, wind farms have been developing quite dynamically in Poland. It results from the fact that the development of RES is strongly supported by the state, and the imposed (regulatory) rules of operation of RES facilities are much less stringent than for other energy sources. This support includes guaranteed production subsidies, guaranteed purchase of any amount of electricity produced from renewable sources, and waiver of any liability for the costs of the balancing of differences from the planned electricity production schedules and costs of maintaining the required capacity reserves. Under EU directives, RES are given priority in the access to power grid – which means that electricity produced in RES facilities must be connected to the power grid first.

These regulations pose a number of problems for networks that include wind farms. Wind turbines operate at variable power, which is equivalent to work at full power for about 20% of the time (in Polish conditions, often less). As a result, the power grid that will receive this electricity must offer the capacity 5 times higher than usual, which is a source of high costs of network extension and which makes traffic planning and maintenance difficult. Because electricity supplies are not reliable, the network must include baseload plants – an independent source of constant and uninterrupted electricity supply. As a result, wind turbines destabilise the power grid and the operation of conventional power plants. The fact that wind farms offer intermittent capacity (equal to their full capacity for just about 20% of their time of operation) has two types of negative effects. First of all, conventional power plants must supply electricity to the grid for the remaining 80% of the time of operation, and so the apparently high capacity of wind farms reduces the demand for electricity produced by other power plants (baseload, coal-fired, gas-fired, or nuclear) only to a limited extent. And secondly, when the wind is gone or when stronger winds start it is simply not possible to switch baseload power plants on or off. They must operate continuously to secure the supply of electricity, because winds change so quickly that it is impossible to compensate these changes by regulating the output of coal-fired power plants. The problem is acknowledged even by strong supporters of wind power at Greenpeace[366]. Experience shows that not only coal-fired power plants, but also much more flexible gas-fired power plants cannot be switched on and off fast enough. In addition, it is impossible to predict wind speed in a precise manner in order to plan electricity production from different sources. As a result, it is necessary to keep a spinning reserve in the system, i.e. idle capacity or small capacity of power plants.

Unfortunately, maintaining a spinning reserve of power plants mean that their operation is far away from their optimum parameters, which will increase the cost of electricity production and emissions of gases and dusts. Consequently, the environmental benefits of wind power are reduced to a large extent when combining wind turbines and back-up power plants. The high costs of construction of wind power projects and investment outlays on the necessary baseload plants will still remain. In addition, most wind power plants introduce 'distorted' electric current to the grid (with waveforms much different from sinusoidal) and absorbs passive energy from the grid – which causes serious problems with the quality of electricity supplied to customers[367].

We must therefore remember that wind power is intermittent, needs large investments, and is expensive. The capacity of a power system must be sufficient to satisfy the needs of customers irrespective of the actual capacity of wind turbines, and therefore it is necessary to keep a spinning reserve in the system, i.e. idle capacity of power plants. Wind speed in Poland is unfavourable from an energy point of view, about 5 m/s in the most favourable region - around Łeba, which is relatively small compared with Denmark, Scotland and Ireland (about 8.5 m/s). Wind turbine load factor is relatively small, used power ranges from approximately 15% (Germany 1998-2003)[368] to ca. 24% (UK, 2003). [369]In 2007, wind turbines in Germany supplied electricity equal to 6.4% of the country's demand for power[370]. Given the number of wind farms in Germany (about 16 thousand turbines), their surface area, and significant (even if dispersed) impacts on people and the landscape, as well as the cost of the necessary investments, 6% of the country's demand for electricity seems rather disappointing. Denmark has recorded similar results. [372] In addition, Germany expects that in 2020 wind turbines will be able to replace only 2 GW of traditional energy sources, with the planned installed capacity in wind power plants of over 48 GW. [368]

A wind farm will remain in operation up to 20 years (compared to about 60 years in the case of nuclear power plants). Wind farm investment costs are 4.5 higher compared to the cost of construction of a nuclear power plant if we take into account the volume of produced electricity and time of operation. As these investment outlays include the cost of materials, the costs of use of environmental resources are certainly much higher for wind farms. These costs are ultimately borne by consumers, which is obviously a disadvantage from their point of view. According to estimates of Szczecin University of Technology[371] (assuming as a baseline ***the total volume of electricity produced*** throughout the entire life of a power plant, i.e. 40 years for nuclear power plants and 20 years for wind power plants), the typical indicators of the use of the natural environment and emissions for both types of power plants, after conversion to units of electricity, are as follows[372]:

- ***Land take*** is over 28 times larger for wind power plants;
- ***Emissions of CO_2***, including the period of construction and decommissioning, are two times HIGHER for wind power plants;
- ***Consumption of materials*** vs. total volume of electricity produced throughout the entire period of operation is more than two times LOWER for nuclear power plants! The result may come as a surprise: although nuclear power plants are commonly considered to be 'large and heavy', they need less than 50% of materials used by 'light and environmentally friendly' wind farms to produce one unit of electricity. As an example: a nuclear power plant with a AP1000 reactor will need 630 kg of concrete/GWh in the construction phase per one unit of electricity produced throughout the entire period of operation, compared to 10,000 kg of concrete/GWh in the case of a wind power plant. The same applies to iron – AP1000 will require 116 kg of iron/GWh while a wind power plant will need as much as 2200 kg of iron/GWh;
- The ratio of **total volume of electricity produced** throughout the entire period of operation vs. the cumulative energy expenditure in the construction phase is 4.5 times HIGHER for a nuclear power plant. Information presented by Greenpeace that wind farms produce 2.3 times more electricity per one unit of investment expenditure is therefore contrary to the impartial analyses of the German institute and the Polish university of technology;

- ***Demand for aluminium*** vs. total installed capacity in a power plant is 75 TIMES HIGHER for wind farms. Each of the many wind turbines has a turbo generator with controls and power evacuation systems, while a nuclear power plant has only one system (with redundancy) – a single system is an element that is missing in a wind power plant[373]. There are more examples of this kind, all in favour of nuclear power plants. Aluminium is a major problem, because its production generates high emissions of pollutants to the atmosphere. In Poland, an aluminium plant in Skawina was closed on this account many years ago. It is a good example of the impact of emissions generated even before a wind power farm is put into operation.

Another negative side of wind turbines is the fact that their investors and producers come from abroad. Construction of wind turbines is equal to the import of electricity at a high price[372]. No new jobs are created, because wind turbines are produced outside of Poland, e.g. in Denmark as the leading producer in Europe, As a result, development of wind power will not reduce the unemployment rate in Poland. In conclusion, wind power should be viewed with caution to avoid taking decisions that are not in the best interest of Poland's economy, just based on catchy slogans.

6.1.2.4 Conclusions

The cost curve for GHG reduction presented by McKinsey&Company indicates that costs related to the introduction of renewable energy sources are much higher than costs of nuclear power. However, this curve is based on market prices and does not include any state regulations (subsidies or taxes). In practice, investors in renewable energy sources pay much lower costs than market prices would suggest, which results from considerable state subsidies. In practice, this system means that costs of implementation of RES technologies are covered by taxpayers. However, the real cost (presented both by McKinsey and ExternE) reflects the actual expenditure related to RES projects, including the high consumption of natural resources and environmental impacts caused by the production and subsequent removal of these facilities.

It is a common misconception that RES offer ‘free’ energy in a way, because it comes from ‘free’ sources such as solar energy or wind power. However, to produce this energy it is necessary to built projects with relatively limited efficiency, and their manufacture, transport, operation, and decommissioning also deplete natural resources and release certain amounts of emissions to the environment.

The most fundamental problem concerning the large-scale use of RES is the fact that there are no technologies for the effective and efficient storage of energy, and renewable energy sources (especially wind power) produce electricity in an intermittent manner. Introduction of excessive amounts of electricity to the power grid will destabilise the system of electricity generation and transmission. However, some of these technologies may be unrivalled at a local level where electricity is consumed ‘on the spot’ and long-distance transmission is not necessary (for instance, a wind turbine for a single household, solar collectors installed on a roof of a residential building, production and burning of biomass for a single agricultural holding, or power supplied to traffic lights from photovoltaic cells). If this is the case, transmission losses are reduced, as is the demand of individual consumers for electricity from the power grid, thus reducing the overall demand for electricity and the growth in electricity production volumes in the country.

On the other hand, RES projects require substantial investments and consume considerable amount of materials in the construction phase. The amount of materials and equipment required by Generation III nuclear power plants are much lower than in RES technologies. The same holds true for energy intensity in the implementation phase. Much less energy is required to produce building materials and to build a nuclear power plant. As a result, emissions of sulphur dioxide, nitrogen oxides, dusts, heavy metals, and CO2 during the construction of a power plant and production of the associated equipment are much lower for nuclear power projects than for other sources of electricity. Long-term works under the EU's EXTERNE programme [377] have confirmed that nuclear power plants are the most environmentally-friendly and human-friendly of all sources of energy if we consider the entire period of their operation.

6.1.3 Variant 3: Development of conventional energy production and its modernization

Another alternative is to modernise the conventional energy production sector in order to increase its efficiency and reduce harmful emissions to the environment. In the past decade, considerable efforts were made in the Polish energy sector to reduce the environmental impacts of electricity production. In 2004, emissions of SO_2 dropped to 43.6%, NO_x – to 60.8%, and dusts – to 7.8% compared to 1990. [374375] Still, emissions of gaseous pollutants from power plants in Poland are much higher than in Western Europe. In 2009, total emissions from the Polish electricity production sector were as follows: [375]

- SO_2 – 335 thousand tonnes
- NO_x – 229 thousand tonnes
- Dusts – 20 thousand tonnes.

These figures indicate a considerable reduction in these emissions compared to previous years. But CO_2 emissions did not change significantly: from 150 thousand tonnes in 1990 to 149 thousand tonnes in 2004, and are expected to remain at this level in 2010. It is a natural consequence of the adopted structure of the Polish power sector, based primarily on coal.

However, current emission charges do not force the power sector to implement modernisation projects. As we can see in Table 6.1.1, they are not only much lower than external costs borne by the society, but also several times lower than unit costs of reduction of these emissions.

Table 6.1.1 Current unit rates of gas and dust emission charges[376]

Emission	Charge [PLN/Mg]
SO_2	410
NO_x	410
Dust	440
CO	110
CO_2	0.22
CH_4	0.22

It means that there are no economic incentives to reduce emissions in the Polish power sector. Implementation of technologies that reduce emissions to the atmosphere is expensive. As a result, it would be difficult to expect intensive actions to reduce the negative environmental impacts in the conventional electricity production sector.

There is a new promising technology offering the reduction of industrial emissions, based on capturing CO_2 and pumping it to underground geological structures, called carbon dioxide sequestration (CCS – Carbon Capture and Storage). CCS is still in the testing phase, and it is not known yet whether it will be introduced on an industrial scale by 2030. We should therefore assume that this technology is not yet proven, and it is disproportionately expensive. In addition, CCS projects will have only one positive impact in the form of reduced emissions, and only of CO_2. Emissions of other exhaust gases will not be reduced, and they often have more negative impacts on the environment than CO2 emissions. But most of all, CCS is not a power-generating technology. Therefore, investments in CCS will not improve the country's energy security or diversify its energy sources. The will reduce the negative environmental impacts of conventional energy sources, but only in the context of potential climate change related to CO_2 emissions. Other problems will remain unsolved – including emissions of other pollutants, supply of natural resources and impacts resulting from their extraction, transport, and the unavoidable depletion of non-renewable resources. Theoretical resources of coal and lignite in Poland are relatively large, but their extraction becomes more difficult with time (deposits are located deeper and are more complex in terms of their geology, for instance due to a threat of explosion), as well as more expensive, and exploration of new deposits is more difficult (social protests opposing the potential exploration of the Legnica deposit or the open-pit mine in Tomisławice near the Gopło Lake).

But even if the Polish programme of modernisation of the country's power sector is implemented in its entirety (assuming the best-case scenario), 47% of total volume of electricity in Poland will still be produced in coal-fired power plants in 2030 (according to the Programme). Therefore, the development of methods that will minimise their negative impacts on the environment is more than justified. Still, these methods cannot fully replace the planned introduction of nuclear power in any aspect.

6.1.4 Selection of the optimum alternative

We can conclude that the necessary modernisation of the Polish energy sector should not be limited to the introduction of nuclear power, as assumed in the Programme, but should also involve the development of RES (in an appropriate scale), investments aimed at the reduction of electricity consumption (energy efficiency projects), and modernisation of conventional energy sources (state-of-the-art electricity generation technologies and the so-called "clean" coal technologies, including possibly CCS), which is assumed in other strategic documents, including the Polish Energy Policy until 2030 that takes precedence over this Report (cf. Chapter 3). Considering the requirements related to the reduced emissions of greenhouse gases and the ever-growing demand for electricity, it is necessary to adopt a policy that promotes all these alternatives, as soon as possible. However, introduction of the Polish Nuclear Programme is still the key element of this policy, in the context of the necessary reduction of GHG emissions, diversification of energy sources, and reduction of the social cost of electricity production. This solution is justified by the fact that of all energy sources, nuclear power has the highest potential to reduce negative environmental impacts and to reduce social costs at the lowest cost of project implementation. Therefore, if the overriding objective of the currently updated energy strategy is to reduce emissions and ensure sustainable energy security combined with the reduction in social costs of electricity production at the lowest implementation costs possible, the development of nuclear power is the direction we should take (which is confirmed by the measurable outcomes of analyses based on the ExternE methodology and emission cost curve [377] **Błąd! Nie zdefiniowano zakładki.**).

6.2 Technological alternatives

6.2.1 Types of nuclear reactors

Structure of individual types of reactors (EPR, AP1000, ABWR, ESBWR) was discussed in detail in the initial section hereof in chapter **Błąd! Nie można odnaleźć źródła odwołania.** to enable the variant analysis in terms of the entire document. If environmental impacts potentially depend on the reactor type, individual impacts were discussed for different types of nuclear reactors. In particular, the type of reactor design will determine the release of radioactive substances to the environment. Emissions of radioactive substances during normal operation from different types of reactors (EPR, AP1000, ESBWR) are presented in chapter **Błąd! Nie można odnaleźć źródła odwołania.** - **Błąd! Nie można odnaleźć źródła odwołania.**, while comparison is performed in chapter **Błąd! Nie można odnaleźć źródła odwołania.**. Similarly, for transient and emergency conditions, possible emissions in the event of a design failure for the same three types of reactors were examined in ch. **Błąd! Nie można**

odnaleźć źródła odwołania.– Błąd! Nie można odnaleźć źródła odwołania., and their summary was presented in ch. **Błąd! Nie można odnaleźć źródła odwołania.**. Similarly, values of possible releases in case of serious failures were analysed for the discussed reactors in ch. **Błąd! Nie można odnaleźć źródła odwołania.– Błąd! Nie można odnaleźć źródła odwołania.**, and their summary was presented in ch. **Błąd! Nie można odnaleźć źródła odwołania.** . Detailed analysis broken down into various types of reactors was also performed on the impacts related to the discussed volumes of releases, based on calculations of radiation doses for exposed population:

- during normal operation of the nuclear power plant – comparison of impacts in Chapter 7.3.4;
- in transient and emergency conditions – comparison of impacts in Chapter 7.4.4;
- in the event of major accidents – comparison of impacts in Chapter 7.5.4.

Types of reactors were also analysed in terms of their energy parameters (Table 4.3.5), consumption of cooling water (Table 4.3.6, Table 4.3.7, Table 4.3.8) and land take.

6.2.2 Cooling system technologies

The analysis of individual environmental impacts also dealt with different systems of cooling, which can be alternatively applied to NPPs (description of the installations in ch. 4.3.2.1): open cooling systems (without the use of cooling tower) and closed cooling systems (using wet cooling towers or hybrid cooling towers). The installations display different environmental impacts in terms of size of demand for cooling water (Chapter 4.3.2.2), waste heat discharge to water or atmosphere (Chapter 4.3.2.5/4.3.2.6), chemical discharge to water or atmosphere (Chapter 4.3.3/ 4.3.4), noise emission (Chapter 4.3.5) and impact on landscape (Chapter 0).

6.2.3 Potential use of heat generated in nuclear power plants for heating and other purposes

A number of negative environmental impacts of nuclear power plants result from the necessary release of heat to the environment. Heat is a side product of electricity generation in a nuclear power plant. It is released to the environment via the hydrosphere (discharge of heated water) or the atmosphere (through cooling towers). Environmental fees are charged for the release of heat to the environment.

As an alternative, heat generated in nuclear power plants may be utilised. Heat may be collected from turbine extractions (for heating purposes) or from heated water in the cooling system (for other economic purposes). Utilisation of heat generated by the nuclear power plant may prove economically viable in certain locations, including Żarnowiec[378] (preliminary analyses conducted by PG indicate the supply of heat to the heating system in Trójmiasto (Gdańsk-Gdynia-Sopot) from the new nuclear power plant in Żarnowiec may be economically viable – collection of up to 250 MW_t was assumed)[379], or Warta-Klempicz (supply of heat to Poznań). It would be worthwhile to analyse the case study of the supply of heat from the planned power unit no. 3 in the nuclear power plant in Loviisa to the heating system in Helsinki (up to 1000 MW_t)[380]. There are examples of similar projects successfully implemented in other countries (e.g. in Sweden – a nuclear power plant supplying heat to Stockholm).[379] A nuclear power unit with gross power-generating capacity of 1400MW could produce up to 2885 MJ/s of heat, which is much more than the average demand for heat even in large agglomerations.[379] The project for the supply of heat to Warsaw potentially generated in a nuclear power plant is now being discussed. However, the nuclear power plant would have to be located north-east of Warsaw.[381]

Combined energy sources (producing electricity and heat at the same time) offer higher efficiency in the use of primary energy, which has a positive impact on natural resources. However, the potential customer base and demand for heat is a pre-condition for any CHP project. Nuclear power plants are usually located at the largest possible distance from densely populated areas, which makes it rather difficult to use CHP technologies. But the heat can be transferred on a fairly large distances without significant transmission losses (heat losses are approximately 8% which is usually, depending on water temperature, ambient temperature and the quality of the transmission network used approximately 1.5 do 3°C/10km of pipeline). As a result, it would be possible to supply heat to agglomerations located even 50km away from the nuclear power plant, at least in theory. But the problem of costs remains – the longer the distance, the higher the investment costs, especially related to the construction of a pipeline. [379] Therefore, the potential of heat application should be taken into account when selecting the most optimum location for a nuclear power plant in Poland. This alternative would ensure reduction of negative environmental impacts of heat releases to the environment, elimination of the resulting charges, more effective utilisation of primary energy sources, reduction of low emission in urban areas (from local building heating systems – which is one of the biggest environmental problems in Polish towns and cities), as well as reduction of final electricity consumption (electricity used to heat water and buildings).

6.2.4 Selection of the optimum alternative

At this stage of the SEA Report, we are not able to specify the most viable technological alternative as this decision will depend to a large extent on the actual location for the project. Combined generation of electricity and heat in the planned nuclear power plant should be the recommended alternative, but its viability will depend on the sufficient number of potential customers for heat. However, this alternative should be considered on a case-by-case basis in every EIA report for a given project.

As regards the choice of different types of reactors and different types of cooling systems, the final decision should be taken at the public procurement stage on the basis of the Best Available Technology principle, considering the many aspects of their environmental impacts, dependency on the actual location, and the continuous advancement in reactor design technologies. As this decision will not be taken in the nearest future, we should not form an opinion at this stage.

6.3 Location alternatives

This section focuses on the analysis of specific impacts arising from the specific context of location. In any case it does not exhaust the range of potential impacts that may result from the implementation of the Polish Nuclear Energy Programme and thus building the first nuclear power plants in Poland. This section cannot be read in isolation from the information contained in other chapters, in particular in Chapters 6,7,8 and 9. Thus, by reading only this subsection we cannot draw any conclusions about the potential impacts and their environmental effects.

Studies aimed at determining the location of the first nuclear power plant with a capacity of about 2,000 MW have been started in the 1960s. As a result of the location studies conducted in 1969 - 1970, in December 1972 the decision was made on the location of first nuclear power plant in Poland on Lake Żarnowieckie. Construction of Nuclear Power Plant "Żarnowiec" was launched in 1982. Simultaneously, research on finding another location continued. They ended in June 1988, when Governor of Pilskie Province decided to establish the site of second nuclear power plant Warta in the town of Klempicz. In parallel with the final phase of location study and research for the second nuclear power plant, localization studies were conducted in order to prepare the materials to begin the process of localization for the third and subsequent power plants. In the first stage macro-spatial analysis was performed in terms of site options for nuclear power plants throughout Poland; 62 potential areas of location were selected. The stage was completed in 1989. The second stage limited the list of locations to 29 areas. Further studies and research were interrupted due to the resignation from implementation of the development of nuclear energy. In 2009, the Ministry of Economy in consultation with local governments updated the nuclear power plant site proposals under consideration until 1990. Also, new offers were collected. On this basis, a list of 28 potential sites for nuclear power plants was prepared. These sites are presented in **Błąd! Nie można odnaleźć źródła odwołania.**

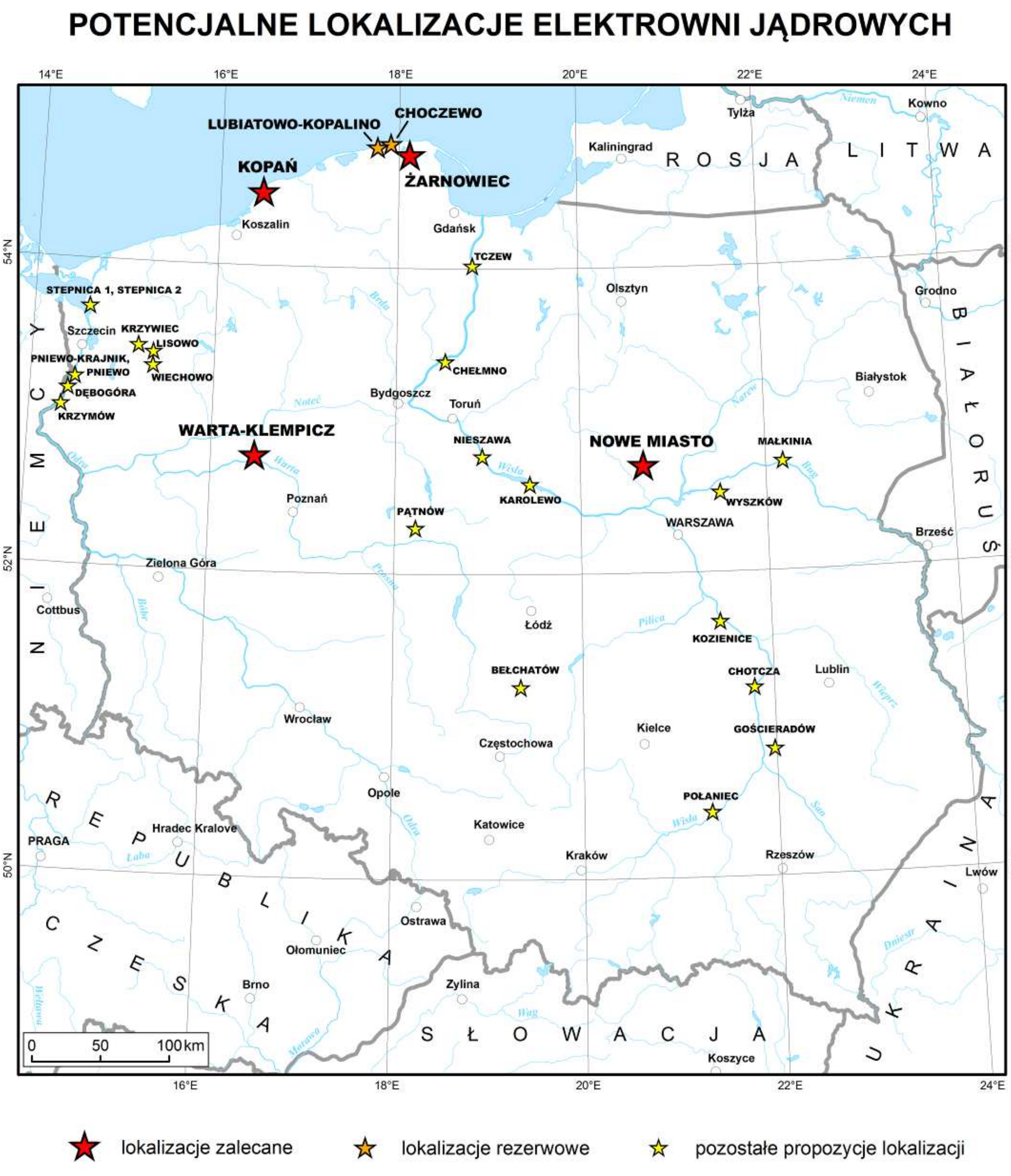

Fig. 6.3.1. Potential locations of nuclear power plants in Poland

[POTENTIAL NUCLEAR POWER PLANT SITES
Recommended locations
Reserve locations

Other site proposals]

6.3.1 Expert opinion on the siting criteria for nuclear power plants and preliminary assessment of the agreed locations

In 2010, commissioned by the Ministry of Economy, a document was prepared, entitled "The study on the siting criteria for nuclear power plants and preliminary assessment of the agreed locations". The ranking of locations was performed, taking into account the expert assessment of the 17 evaluation criteria (the last place in the ranking is the location for which no geographical coordinates were handed over, which due to formal reasons prevented its inclusion in the ranking). The expertise carried out as part of this study revealed the following sequence of the most favourable locations of the first Nuclear Power Plant in Poland (**Błąd! Nie można odnaleźć źródła odwołania.**).

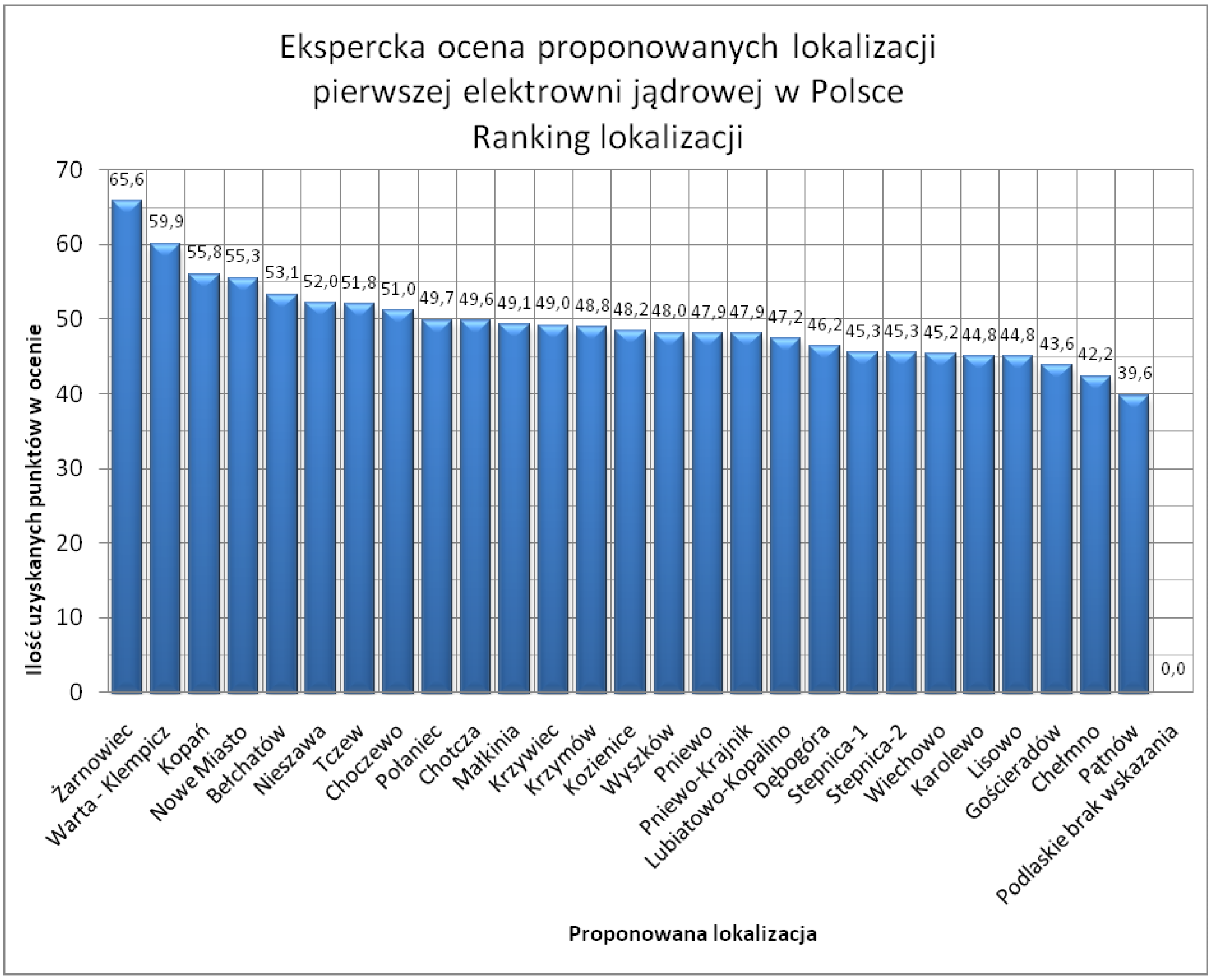

Fig. 6.3.2. Ranking of the proposed locations of nuclear power plant in Poland

[Expert assessment of proposed sites of the first nuclear power plant in Poland
Site ranking
Number of points obtained in the assessment
Proposed site
Podlaskie – no indication]

At the request of the Minister of Economy, funds were secured in the budget of the National Fund for Environmental Protection and Water Management to carry out further work on location analysis for nuclear power plants. According to information received at the Ministry of Economy, a company will be selected in the near future which will perform detailed fieldwork for three potential locations identified by the investor (the information obtained shows that these will be locations indicated by the expert opinion). This work should be completed by the end of the first half of 2013.

Returning to the results of the already developed site expertise, attention should be paid to the fact that Żarnowiec site was assumed (with vast majority) to be the site of the first nuclear power plant, recommended by the expertise authors. Żarnowiec was also recommended for further detailed studies of location.
The expertise also recommends another three (almost equivalent) locations: Warta-Klempicz, Kopań, Nowe Miasto for simultaneous location studies.. Additionally, Choczewo and Lubiatowo-Kopalino were added. On the basis of detailed studies and location expertise, other locations were excluded for various reasons and according to the information from Ministry of Economy and PGE S.A. it is very unlikely that they will be chosen as sites for two first nuclear power plants in Poland. This forecast analyzes several parameters characterising a given site and its potential impacts on individual aspects.

6.3.2 Description of location parameters

Selecting the most optimal location of nuclear power plant requires an analysis of many factors that can affect the attractiveness of the location or its disqualification. These factors were divided into four major groups - the basic environmental conditions, geological and hydrogeological structure, infrastructure and biota. In each group, several characteristic parameters were included.

In basic conditions of the environment the following parameters were taken into account:

- **population density** – density was assumed for a given municipality where construction of a nuclear power plant is planned. This is an important parameter indicating how many people may be exposed to the impacts associated with construction and operation of a power plant. The population density was referenced to the average population density in the country. The lower the density the lower the potential impact on the population as a whole.

- **limited use area** – area 800 meters from the planned nuclear power plant. In this area, permanent residence of people is not allowed, and thus, at the time of acquisition by the area of existing residential buildings or buildings intended for human residence, residents of these facilities should be relocated. It should be noted that the area has been designated based on the geographical coordinates of the position of power plants set out in the study by Energoprojekt [382]; these are only proposed locations, which are subject to change, and hence an area of limited use may change.

- **wind energy zone –** wind energy zone affects the accumulation of atmospheric pollutants from power plant or from facilities situated in the vicinity. The more favourable zone (the strength of winds in the area is greater), the less likely is accumulation of pollutants in the atmosphere and the location in this regard is more favourable. This analysis was done on the basis of information contained in the study by Energoprojekt[382].

- **sufficiency of water resources for cooling –** one of the conditions precedent for nuclear power plant location is the presence of sufficient water resources, which will be used in the cooling system. Depending on access to water, a closed or open cooling system was planned in power plants. Sufficient water resources study was conducted on the basis of information contained in the study by Energoprojekt[382], as well as on the basis of information obtained from specialists in this field.

- **impact on cultural goods –** because the impact of nuclear power plants on cultural goods will occur only during construction - with earthworks, and will concern possible violation of archaeological sites, in assessing this parameter only the presence of those posts was taken into account that have been found near the potential location of the plant. The occurrence of archaeological sites in specific sites was adopted in accordance with the data contained in the study by Energoprojekt[382].

- **impact on the availability of raw materials –** because construction of power plant occupies a large area, and no works will be allowed in the vicinity that could affect the stability of land, potentially occurring useful raw material deposits occurring in the vicinity of the site will not be used. In order to determine the occurrence of such an event, the presence of mineral deposits near the location has been analyzed. The analysis was based on maps of the raw materials developed by the Polish Geological Institute.[383]

Description of **geological and hydrological structure** was developed on the basis of data in the study by Energoprojekt[382] and literature. During the analysis, particular attention was paid to the geological structure of the substrate and susceptibility of lithology to infiltration rate, permeability, and cracking and discontinuous structures. In addition, attention was paid to the depth of groundwater levels and possible anthropogenic impacts.

Infrastructure related to electricity production and transmission is one of the most important factors affecting reasonable location of nuclear power plants. Here, accessibility of transmission grids, their current load as well as demand for electricity were analysed in the area which could be supplied in electricity from a nuclear power plant at a given site. Description of this factor uses an Expert assessment of the locations of nuclear power plants in Poland from the viewpoint of the possibility of connecting to the transmission network made for PSE S.A[384]. and data from the study by Enegroprojekt[382].

Factors affecting **fauna and flora** of a given site were described by experienced naturalists. Biodiversity in areas of individual locations was determined without field research, but only on the basis of literature data. The quality and accuracy of data in the source studies is relatively high, but the precision with which they can be accurately attributed strictly to the sites of the planned investments is approximate. Characteristics of diversity thus refer not to the point where a power plant is to be built, but to the area in which it is planned. It is difficult to precisely determine the boundaries of so adopted study, it may only be assumed that the established data refer to the area approximate in size to municipality or county. This should not however be a serious problem for two reasons: methodological and substantive. First of all, all the locations were analyzed in the same way, so regardless of their accuracy and possible errors, in all cases the data are comparable, and at this stage this is the main goal, i.e. comparison of locations. From the substantive point of view, extending the analysis from the scope of a specific place, which will be occupied by the plant, to closer or further surroundings is also justified, because construction of every plant is associated with infrastructure that can have a direct negative impact on diversity, even further away.

6.3.3 Recommended sites

6.3.3.1 Żarnowiec site

Basic environmental conditions

Żarnowiec site is a reserve location from the 1980s, additionally assigned by the Marshal of Pomorskie. Due to earlier work in this area associated with the construction of power plant (construction was halted pursuant to the resolution of the Polish Government of 04.09.1990) it is the most recognized terrain in terms of conditions associated with the location of nuclear power plants. Additionally, Żarnowiec has been positively assessed by the Mission of the International Atomic Energy Agency in 1990.[385]

The potential construction of Żarnowiec NPP would occupy the area located in the municipality Krokowa (District Puck) and the municipality Gniewino (District Wejherowo), Pomorskie. Exact location of the power plant is presented in **Błąd! Nie można odnaleźć źródła odwołania.**. The municipalities where the power plant is to be located have low population density (48 and 39 residents/km^2 at average population density in Poland 122 residents/km^2) due to which impacts of power plant construction and operation **will affect a small number of people**.

In the limited use area (800 m from the power plant) no residential buildings or other residential facilities are situated, **so there is no need for relocation** associated with power plant construction.

Near the site on the south-western shore of the lake facilities of "Żarnowiec" pumped-storage power plant (ESP „Żarnowiec") are located: drainage channel and engine room building. Upper reservoir (artificial hydrotechnical structure) of this plant is located on the plateau near the village Gniewino and is connected to the power plant with four steel derivation pipelines.

The surroundings of Żarnowiec NPP have a very favourable wind energy zone, due to which **there will be no accumulation of potential pollutions** emitted from the power plant and other facilities in vicinity.

Preliminary estimates suggest that the water resources of Lake Żarnowieckie allow for cooling of one large nuclear power plant unit (e.g. with EPR or AP1000 reactor) - using a closed cooling system with wet natural draft cooling tower. Possible use of wet-dry hybrid cooling towers with fan-assisted draft, from which the irreversible water losses are at least 4 times lower than with wet natural draft cooling towers would eliminate hydrological restrictions, but it also would involve a significantly increased internal load energy consumption, absorbed by the cooling tower fans. In addition, it must be remembered that the cooling towers require a large area, comparable to the area occupied by the main power plant buildings.

Therefore, selection of optimal cooling system has a key significance in case of „Żarnowiec" site. It will require an appropriate optimization analysis, taking into account size of the potentially available area, and possibly also the option to use sea water. As a result of this analysis, a number of power units will be specified with specific reactor types and certain cooling system solutions, possible to locate at that site.

The power plant area is limited to the west by Żarnowieckie Lake, and forested hills from the east with a height of up to approximately 100 m above sea-level. The main buildings of the new power plant will be located in the northern part of the former Żarnowiec NPP construction site, north of the abandoned main facilities of stage I of the previous construction, where after the necessary demolition work the supporting facilities will be situated.

To the north of the proposed site there is Seaside Landscape Park, but given the considerable distance and the presence of developments built between the park and the power plant, its functioning as a building **should not deteriorate landscape values** of these areas.

There are no archaeological sites in the construction area and its vicinity, **thus eliminating hazards to cultural heritage** during ground works or construction delays due to halting works for the period of work of archaeologists.

Northeast of the site there are operated oil and natural gas deposits (Mine Żarnowiec in Krokowa), but quite a distance from the planned investment to the deposits in no way **will impede access or operation of those deposits** (see: chapter 8.3.6.2).

Fig. 6.3.3. Proposed site of Żarnowiec NPP

[PROPOSED SITE OF ŻARNOWIEC POWER PLANT
Proposed power plant site

Limited use area
Area of interventions depending on reactor type and weather conditions
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

Geological structure and hydrogeology

The substrate on which the NPP is to be located mainly consists of boulder clay and fluvioglacial sand. The substrate contains a series of Tertiary Triassic outcrops within the chalk, whose tectonic conditioning is not specified. Neotectonic reactivation of this structure cannot be excluded. Mesozoic roof and Tertiary strata lay on the substrate. Historically, a small seismic quake was recorded several kilometres from the location, and maximum soil vibration acceleration is less than 0.02 g. In this area there are large area denivelations.

In the area of investment there is quaternary porous tank "Żarnowiec Fossil Valley" (GZWP 109), the average depth of groundwater intakes here is from 5 to 50 m. Depth to the main utility groundwater level varies between 2 and 5 m. The levels of aquifers show very high sensitivity to contamination. No insulation from the ground surface and the presence of sandy sediments of high permeability may cause **serious and widespread contamination** of groundwater in case of penetration of pollutions to water and ground.

Infrastructure

The site of Żarnowiec NPP has strong connections with national power supply system. 400/110 kV substation "Żarnowiec" was designed to connect to the NPS 4 pumped-storage units and 4 nuclear power plant units. This location is advantageous also due to network considerations, since this region of Poland does not have a large baseload power plant (except ESP "Żarnowiec"). Currently, this grid area has a **power production deficit** above 500 MW, and the existing transmission grid is loaded at less than 60%, which **gives the possibility to use existing transmission capacity** to evacuate power from the NPP. Connection of a new large power plant to "Żarnowiec" station would visibly improve the working conditions of the transmission grid in this region and contribute to reducing energy losses in the networks (including the transfer of energy for pumping at ESP "Żarnowiec") and improve the reliability of power supply to consumers. However, to enable the network connection to NPP, expansion of 100 to 250 km long transmission lines will be necessary. Expansion of the network will not interfere with any of the Natura 2000 areas and its course will be set away from urban areas. A detailed description of the impact of network expansion is described in chapter 8.3.7.

Site assessment made by PSE

From the viewpoint of the power balance in the NPS location is advantageous, which was emphasized with other nuclear power plant sites in the northern part of the country.

It should be noted, however, that in this case, difficulties should be expected with evacuation of full power (3200 MW) from the nuclear power plant into the NPS. In PRSP prepared by the TSO connection of the nuclear power plant to Żarnowiec node was considered. Results of analysis showed that in case of 1600 MW capacity, construction of an additional 2-track 400 kV line linking SE Żarnowiec with new station in the region of Gdansk is necessary. Expansion, however, was not sufficient for 3,200 MW and it is difficult to imagine the construction of other 400 kV lines from the node into the NPS. It is therefore proposed to consider this location for nuclear power plant with a capacity of not more than 1600 MW.

Moreover, for these locations attention should be paid to other factors that may adversely affect the location of nuclear power plant, associated with excess energy production in that area and with overloading of existing transmission networks:

- <u>Construction of wind farms in the north</u>. TSO (Transmission System Operator) has already issued the connection conditions for wind farms connected to SE Żarnowiec for the total power of 346 MW, and currently proceedings are pending concerning construction of further wind farms with a total capacity approximately 1600 MW (including a sea wind farm with capacity 420 or 1560 MW). It should also be noted that TSO issued the connection conditions for wind farms in neighbouring substations with total capacity ca. 1750 MW. Then there are proceedings pending at DSO (Distribution System Operator).

- <u>Construction of a gas power plant with a capacity of 250 MW</u> connected to SE Żarnowiec. At present it is difficult to judge whether the investment is feasible.

These areas due to former construction of NPP have been equipped with technical infrastructure, such as: deep water intakes, water and sewage and power supply network. The following are located in the vicinity of the site: high pressure gas pipeline, two 110/15 kV substations, 400/110 kV station.

Road grid was also rebuilt for "Żarnowiec" NPP< adjusting it to heavy and large machinery transport. The roads are still useful for transporting super-standard loads in terms of size and weight.

The distance between the NPP site and existing urban infrastructure is as follows: main roads - up to 5 km, municipal roads - up to 5 km, railway lines - up to 10 km, water transport routes - from 5 to 15 km, airports - 20-60 km, other urban infrastructure - up to 5 km. So developed communication network near the plant will allow for a diverse supply of goods during construction (building materials) and during operation of the plant (spare parts, uranium) supplied from other regions of the country or outside Poland.

<u>Fauna and Flora</u>

<u>Fauna</u>

Location in the coastal zone is certainly an increased risk of conflicts with birds - the zone is a very intensively used bird migration corridor. In bird refuges adjacent to the site (9-12 km away) nesting was stated (depending on the refuge) of 7 to 10 species from Appendix I of the Birds Directive (occurrence of at least 32 species was stated).

Key bird species found in three SPAs adjacent to the site:

whooper swan *Cygnus cygnus,* white stork *Ciconia ciconia,* black stork *Ciconia nigra,* common goldeneye *Bucephala clangula,* European honey buzzard *Pernis apivorus,* black kite *Milvus migrans,* red kite *Milvus Milvus,* white-tailed eagle *Haliaeetus albicilla,* short-toed snake eagle *Circaetus gallicus,* Western marsh harrier *Circus aeruginosus,* Montagu's harrier *Circus pygargus,* hen harrier *Circus cyaneus,* lesser spotted eagle *Aquila pomarina,* golden eagle *Aquila chrysaetos,* osprey *Pandion haliaetus,* red-footed falcon *Falco vespertinus,* peregrine falcon *Falco peregrinus,* hazel grouse *Bonasa bonasia,* common crane *Grus grus,* green sandpiper *Tringa ochropus,* wood sandpiper *Tringa glareola,* stock dove *Columba oenas,* short-eared owl *Asio flammeus,* Tengmalm's owl *Aegolius funereus,* Eurasian pygmy owl *Glaucidium passerinum,* European nightjar *Caprimulgus europaeus,* green woodpecker *Picus viridis,* black woodpecker *Dryocopus martius,* woodlark *Lullula arborea,* barred warbler *Sylvia nisoria,* red-breasted flycatcher *Ficedula parva,* red-backed shrike *Lanius collurio.*

Breed of 3 species from "Polish Red Book of Animals" was recorded (although 16 species were identified). Numerous migration of prey birds *Falconiformes* was observed, and common crane population during the autumn migration is estimated at 3,000. Because of the distance (about 9 km) to neighbouring refuges, the construction of power plant should not have a significant impact on the populations of birds nesting there (although the impact cannot be excluded and should be a part of detailed study concerning the choice of location), however, expansion of transmission networks associated with power plant (transmission network impact will be the subject of a separate study - see chapter 8.3.7.2.2) can constitute a serious threat to migratory birds in the area - this is a real risk especially to the observed abundance of migrating cranes. Due to the site surrounding with Natura 2000 refuges, expansion of aerial power lines may also affect the breeding birds of these areas. Although there are no accurate studies for this site, it can be assumed that in the immediate vicinity of the planned site there are also breeding birds refuges listed in Annex I of Birds Directive and/or the "Polish Red Book of Animals".

Possible discharge of heated water can disrupt the balance of aquatic ecosystems (invertebrates, fish), leading to eutrophication. Lake Żarnowieckie can become a place of bird concentration during harsh winters, which often is observed in the vicinity of the plants discharging heated water to the environment. It is difficult to determine whether such impact has positive or negative environmental effects.

In the Bielawskie Błota 2 species were found from Annex II of the Habitats Directive - great crested newt *Triturus cristatus* and dragonfly *Leucorrhinia pectoralis*.

Bielawa Reservation is an animal reservation inside Bielawskie Błota refuge, so it does not require a separate comment.

The site **can have significant effects on Natura 2000 sites, but does not interfere in the network of ecological corridors.**

There may be increased mortality risk of many migratory birds as a result of collision with overhead power transmission network, whereas the remaining NPP infrastructure (roads, buildings, etc.). because of the distance should not have significant effects on Natura 2000 areas.

More detailed analysis of the impact of NPP on Natura 2000 will be performed at the stage of preparing the Environmental Impact Report for construction of power plant when selecting a location, though it would be advisable to exclude this location because of the potential environmental effects of its implementation.

<u>Plants</u>

The proposed location is near the plant refuges IPA:

PL 96 – Białogóra.

PL 106 – Łąki piaśnickie.

The location is adjacent to many forms of nature conservation, including a number of Natura 2000 sites, has a rich and valuable flora and diverse vegetation.

<u>Flora</u>

Based on available published data the following list of species was established:

a) in closer proximity (approximately a few km):

- *Baeothryon caespitosum*

- *Carex chordorrhiza*
- *Carex limosa*
- *Centaurium litorale*
- *Corallorhiza trfida*
- *Dactylorhiza fuchsii*
- *Dactylorhiza maculata*
- *Dactylorhiza majalis*
- *Drosera anglica*
- *Drosera intermedia*
- *Drosera rotundifolia*
- *Dryopteris cristata*
- *Empetrum nigrum*
- *Epipactis palustris*
- *Erica tetralix*
- *Gentianella baltica*
- *Glaux maritima*
- *Goodyera repens*
- *Gymnadenia conopsea*
- *Hippuris vulgaris*
- *Juncus gerardii*
- *Juncus subnodulosus*
- *Lathyrus palustris*
- *Listera cordata*
- *Lycopodiella inundata*
- *Marrubium vulgare*
- *Myrica gale*
- *Pedicularis palustris*
- *Plantago maritima*
- *Polemonium coeruleum*
- *Potamogeton alpinus*
- *Pulsatilla vernalis*
- *Radiola linoides*
- *Ranunculus lingua*
- *Ruppia maritima*
- *Sparganium angustifolium*
- *Stellaria crassifolia*
- *Triglochin maritimum*
- *Utricularia australis*
- *Utricularia intermedia*
- *Utricularia minor*
- *Zannichellia palustris*

b) further (several km):

- *Ajuga pyramidalis*
- *Aster tripolium*
- *Atriplex litoralis*
- *Batrachium baudotii*
- *Betula humilis*
- *Blysmus rufus*

- *Campanula latifolia*
- *Carex buxbaumii*
- *Cephalanthera longifolia*
- *Cnidium dubium*
- *Coronopus squamatus*
- *Dactylorhiza incarnata*
- *Diantus superbus*
- *Epipogium aphyllum*
- *Eriophorum gracile*
- *Euphrasia nemorea*
- *Galium harcynicum*
- *Gentiana pneumonanthe*
- *Hieracium echioides*
- *Huperzia selago*
- *Iris sibirica*
- *Isoetes lacustris*
- *Juncus acutiflorus*
- *Koeleria pyramidata*
- *Littorella uniflora*
- *Lolium temulentum*
- *Najas minor*
- *Nuphar pumila*
- *Ophioglosum vulgatum*
- *Pyrola media*
- *Rubus chamaemorus*
- *Salsola kali ssp. kali*
- *Scheuchzeria palustris*
- *Spergularia salina*
- *Stachys arvensis*
- *Viola stagnina*
- *Zostera marina*

In the area of the proposed site and in the area of the above surface forms of nature conservation, position (5) are listed of the following species from the Habitats Directive Annex 2:

1902 *Cypripedium calceolus*

2216 *Linaria odora*

1903 *Liparis loeselii*

1831 *Luronium natans*

1528 *Saxifraga hirculus*

In the area of the proposed site and in the area of the above surface forms of nature conservation occurrence of ca. 79 species of rare and endangered plants under strict protection is possible.

<u>Plants</u>

In the area of the proposed location and protected areas in the vicinity, occurrence of the following habitats from the Habitats Directive Annex 1 is reported:

1130 - estuaries

1210 - nitrophilous strandline vegetation

2110 - initial stages of yellow dunes

2120 -yellow dunes (*Elymo-Ammophiletum*)

2130 - grey dunes*

2180 - mixed forests and forests on coastal dunes

2190 - humid depressions between dunes

3110 - Lobelia lakes

3130 - shores or drained reservoir bottoms with communities with *Littorelletea*, *Isoëto-Nanojuncetea*

3160 - natural dystrophic water reservoirs

4010 - humid heaths with Erica tetralix (*Ericion tetralix*)

4030 - dry heaths (*Calluno-Genistion*, *Pohlio-Callunion*, *Calluno-Arctostaphylion*)

7110 - high peat bogs with peat-generating vegetation (live) *

7120 - degraded high peat bogs, bur able to regenerate naturally and upon stimulation

7230 - lowland bogs of an alkaline marshes, sedges and mosses

7140 - Transition mires and quaking bogs (mostly with plants from *Scheuchzerio-Caricetea*)

7150 - depressions on peat substrates with vegetation from *Rhynchosporion*

6410 - Molinia meadows (*Molinion*)

6510 - lowland hay meadows used extensively (*Arrhenatherion elatioris*)

9110 - acidic beech (*Luzulo-Fagenion*)

9130 - fertile beech (*Dentario glandulosae-Fagenion*, *Galio odorati-Fagenion*)

9160 - Subatlantic broadleaved forest (*Stellario-Carpinetum*)

9190 - Pomeranian acidic birch-oak forest (*Betulo-Quercetum*)

91D0 - bog woodland*

91E0 - riparian willow, poplar, alder and ash

91F0 - riparian forests, oak-elm-ash (*Ficario-Ulmetum*)

* indicates priority habitat

The site area has one of the highest diversities of flora, including Natura 200 areas, and habitats. The location is adjacent to many forms of surface conservation. **Investment in this place has the potential to adversely affect vegetation**. **More detailed analyses of the impact of NPP on Natura 2000 sites should be performed on the stage of preparing the Environmental Impact Report for construction of the plant when selecting a site.**

Nearby are the following nature conservation areas:

Special areas of habitat protection (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Protected area: Choczewskie Lakes, Area code : PLH220096, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),
- Protected area: Opalińskie Buczyny, Area code : PLH220099, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),
- Protected area: Piaśnickie Łąki, Area code : PLH220021, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),
- Protected area: Trzy Młyny, Area code : PLH220029, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),
- Protected area: Bielawa and Bory Bażynowe, Area code : PLH220063, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),
- Protected area: Orle, Area code : PLH220019, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),
- Protected area: Białogóra, Area code : PLH220003, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),

Special areas of birds protection (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Protected area: Bielawskie Błota, Area code : PLB220010, Form of protection in terms of Natura 2000: special area of bird protection (Birds Directive),
- Protected area: Lasy Lęborskie, Area code : PLB220006, Form of protection in terms of Natura 2000: special area of bird protection (Birds Directive),
- Protected area: Puszcza Darżlubska, Area code : PLB220007, Form of protection in terms of Natura 2000: special area of bird protection (Birds Directive),
- Protected area: Białogóra, Area code : PLB220003, Form of protection in terms of Natura 2000: special area of bird protection (Birds Directive),

Landscape parks (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Nadmorski Park Krajobrazowy

Nature reserves (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Piaśnickie Łąki
- Długosz Królewski in Wierzchucin
- Zielone Bielawa
- Źródliska Czarnej Wody

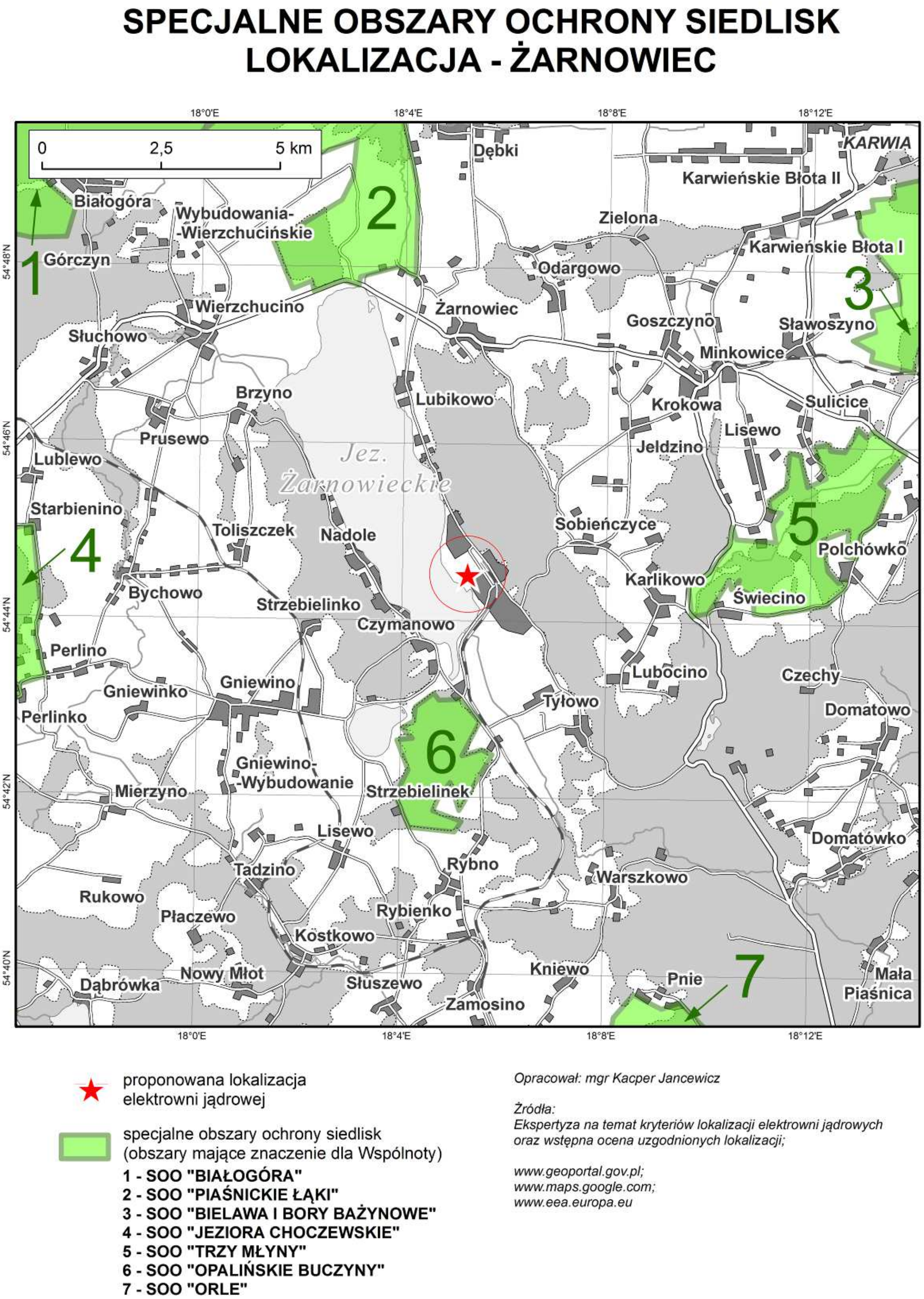

Fig. 6.3.4. Special habitat protection areas in the vicinity of Żarnowiec site

[SPECIAL HABITAT PROTECTION AREAS - ŻARNOWIEC SITE
Proposed power plant site

Special habitat protection areas (significant for the Community)
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

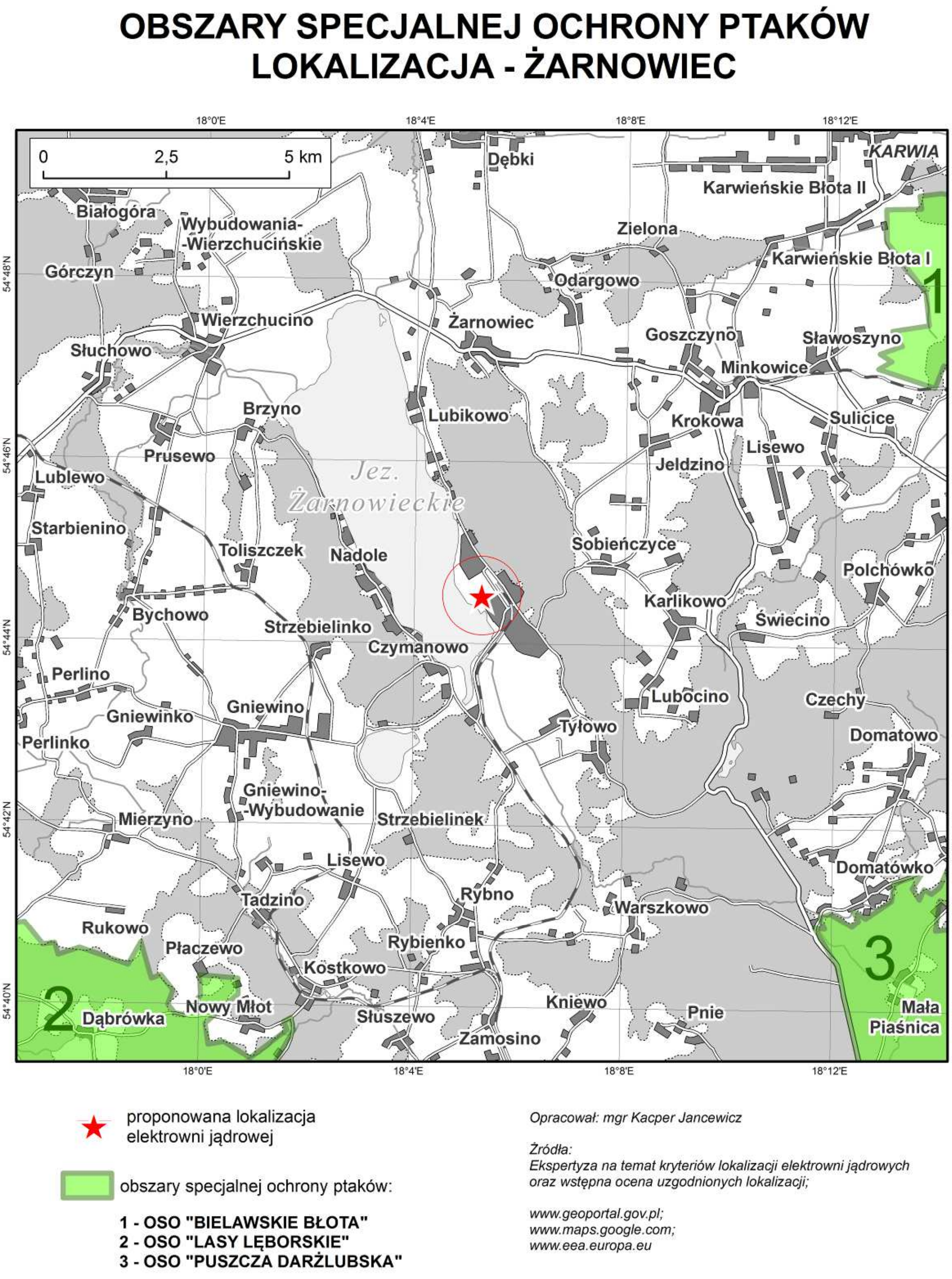

Fig. 6.3.5. Special bird protection areas in the vicinity of Żarnowiec site

[SPECIAL BIRD PROTECTION AREAS - ŻARNOWIEC SITE
Proposed power plant site

Special bird protection areas
Developed by: mgr Kacper Jancewicz
Sources:
“Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites”
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

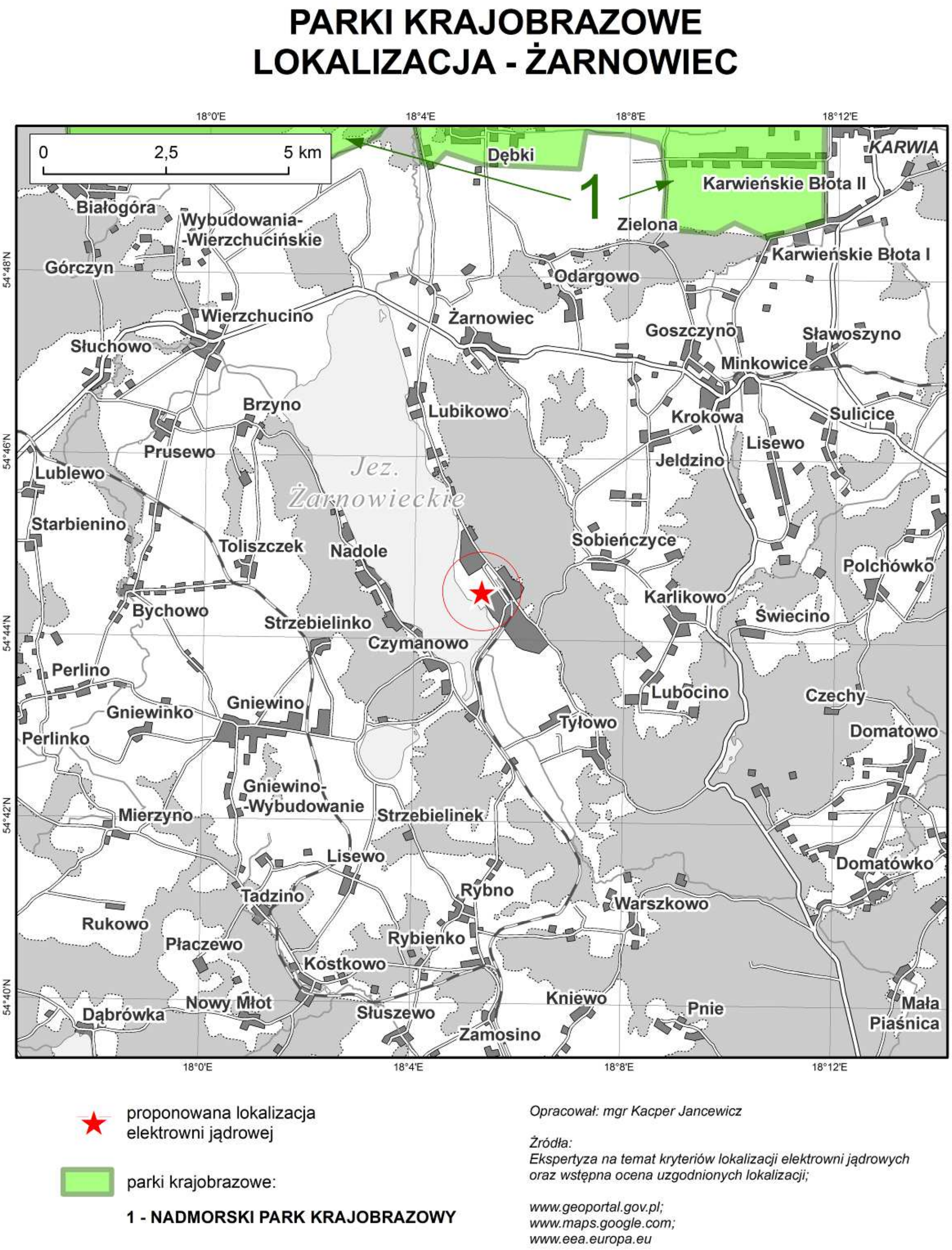

Fig. 6.3.6. Landscape parks in the vicinity of Żarnowiec site

[LANDSCAPE PARKS - ŻARNOWIEC SITE
Proposed power plant site

Landscape parks:
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

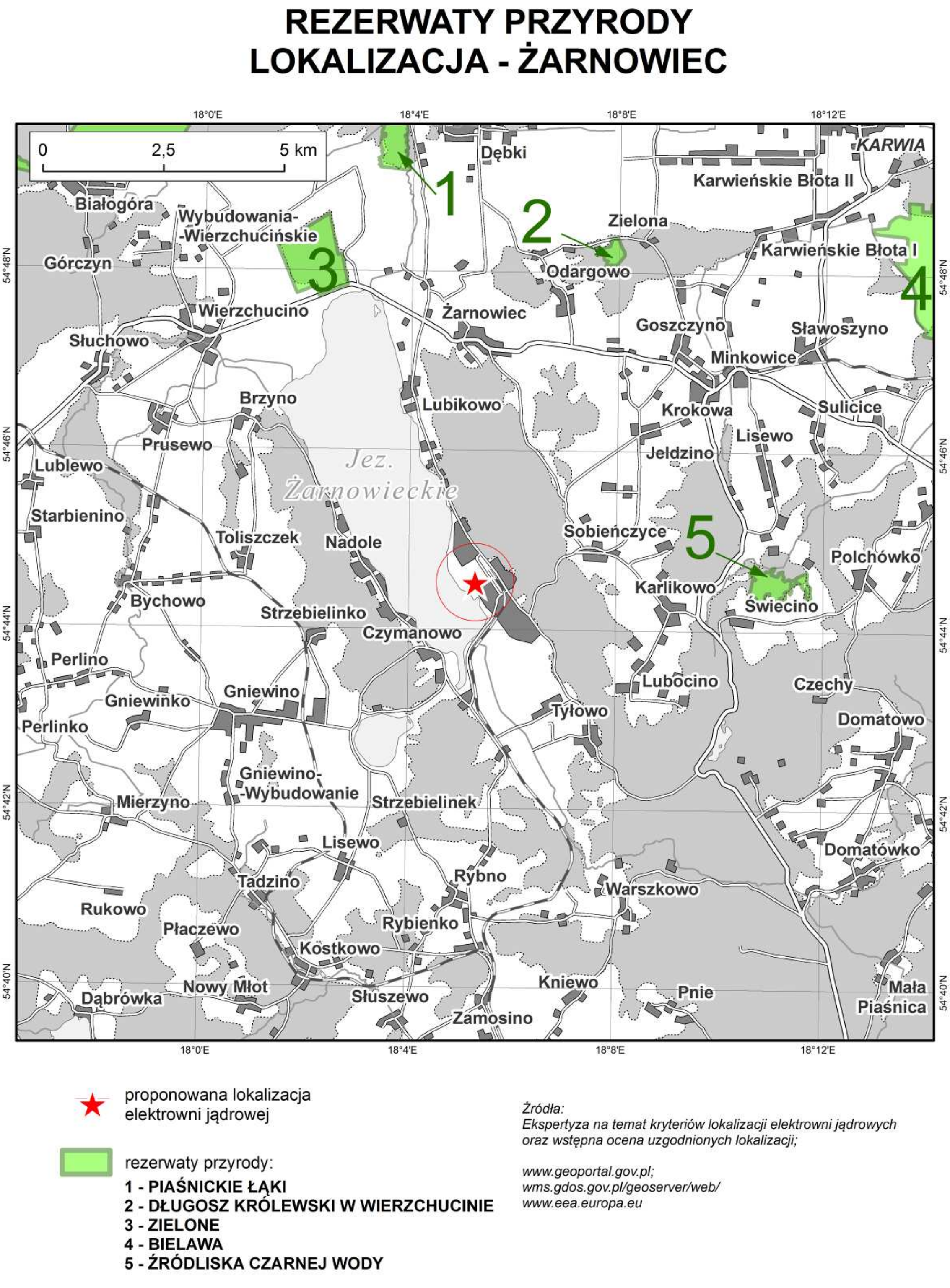

Fig. 6.3.7. Natural reserves in the vicinity of Żarnowiec site

[NATURAL RESERVES - ŻARNOWIEC SITE
Proposed power plant site

Natural reserves:
Developed by: mgr Kacper Jancewicz
Sources:
“Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites”
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

6.3.3.2 Site – Warta Klempicz

Basic environmental conditions

Warta-Klempicz site is a reserve location from the 1980s, additionally assigned by the Marshal of Wielkopolskie. It is located in the municipality Lubasz, district Czarnków-Trzcianecki on the Warta River, Wielkopolskie. The exact location of the power plant is shown in **Błąd! Nie można odnaleźć źródła odwołania.**. (coordinates of the location indicated in the study by Energoprojekt). The municipality where the power plant is to be located has low population density (43 residents/km^2 at average population density in Poland 122 residents/km^2) due to which impacts of power plant construction and operation **will affect a small number of people**.

In the limited use area (the area within 800 meters from the plant) there are currently no residential or other buildings intended for human residence. Therefore, **there is no need for relocations** due to power plant construction. However, it is also possible to locate the power plant in the area where it was supposed to be built and where preparatory works began in the late 80's. It was abandoned however in 1989 (one kilometre north of the currently indicated location). Then, depending on the exact location of construction site, the scope of limited use area could partially cover the western part of the village Klempicz and residents would be relocated from there.

The surroundings of Warta Klempicz NPP have a favourable wind energy zone, due to which **there will be no accumulation of potential pollutions** emitted from the power plant and other facilities in vicinity.

Preliminary analyses show that due to location in the vicinity of the river Warta and **sufficient water resources** (SSQ = 118 m^3/s, SNQ = 53.4 m^3/s) closed cycle cooling system can be used in the power plant. For this purpose, water intake is planned on 178th kilometre of the river (ca. 4 km below the town of Obrzycko, in the distance of ca. 7 km from the plant). The environmental impact of each cooling system solution has been discussed in detail in chapter 8.3.3

There are no archaeological sites in the construction area and its vicinity, **thus eliminating hazards to cultural heritage** during ground works or construction delays due to halting works for the period of work of archaeologists.

In the vicinity of the planned investments **occurrence of natural resources and other useful minerals** was not stated, therefore a threat of difficult access and exploitation of deposits does not exist (see: chapter 8.3.6.2).

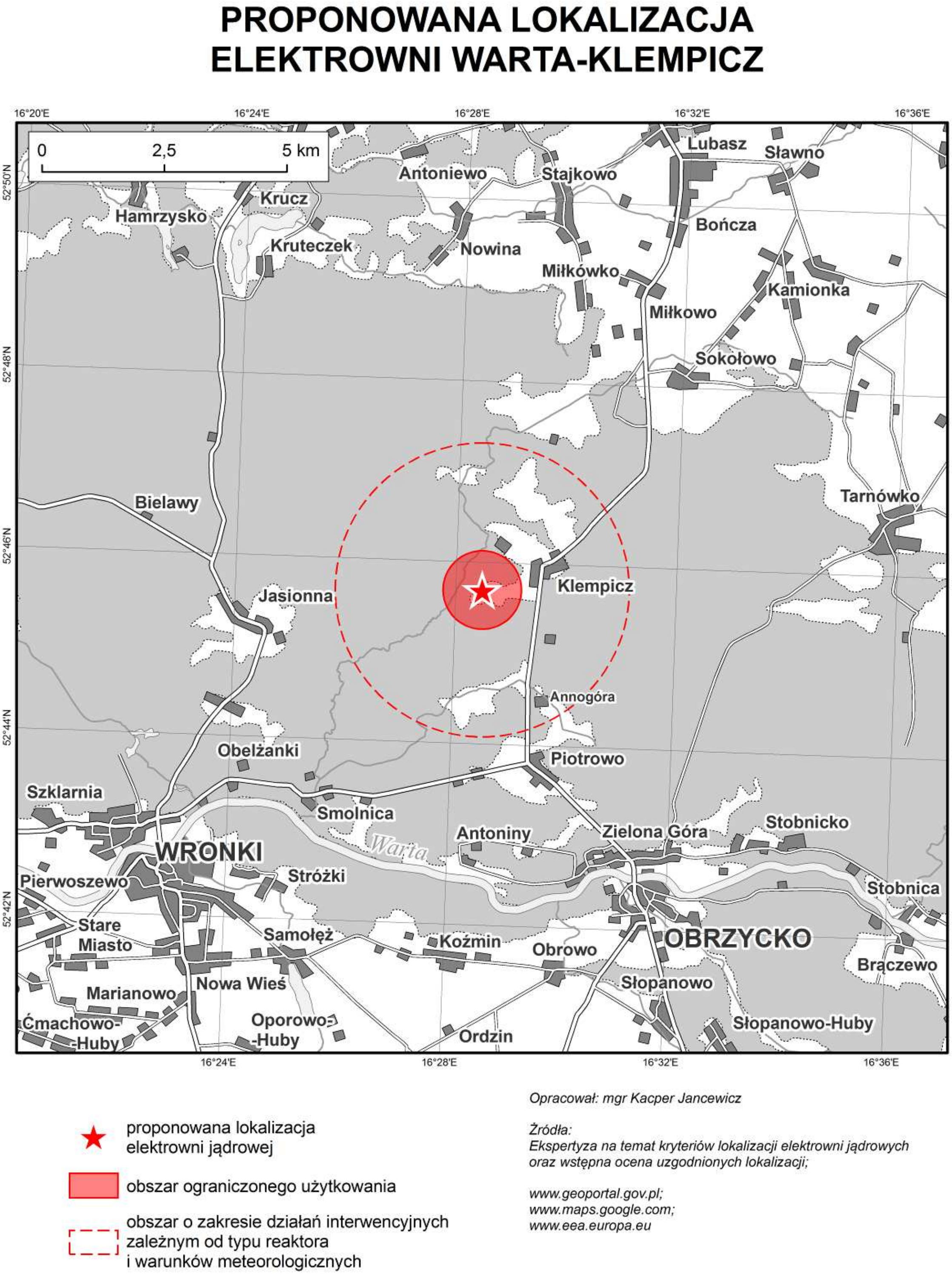

Fig. 6.3.8. Proposed site of Warta-Klempicz NPP

[PROPOSED SITE OF WARTA-KLEMPICZ POWER PLANT
Proposed power plant site

Limited use area
Area of interventions depending on reactor type and weather conditions
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

<u>Geological structure and hydrogeology</u>

The surface geological formations in an area where NPP is to be located mainly consist of fluvioglacial sands and gravels. In the vicinity (a few km) there is a Miocene rift with brown coal deposits, and a slip zone active in the Mesozoic- with partially piercing salt domes. Neotectonic reactivation of this structure cannot be excluded. Mesozoic roof and Tertiary strata lay on the substrate. Historically or currently, seismic shocks were not recorded, and maximum soil vibration acceleration is less than 0.03 g.

In the area of investment there is a Tertiary porous sub-tank „Jezioro bityńskie – Wronki – Trzciel" (GZWP 146). Depth to the main utility groundwater level varies between 2 and 5 m. The levels of aquifers show **medium sensitivity to contamination**. Groundwater runoff occurs in the NE direction. No insulation from the ground surface and the presence of sandy sediments of high permeability may cause contamination of groundwater in case of penetration of pollutions to water and ground.

<u>Infrastructure</u>

The location is in the network area, currently characterized by a deficit of electricity production above 500 MW. The existing transmission grid is loaded at less than 60%, which gives the possibility to use existing transmission capacity to evacuate power from the NPP. However, to enable the network connection to NPP, expansion of below 100 km long transmission lines will be necessary. Potential extension may interfere with the Natura 2000 site. In addition, it is necessary to build the LV/LV/110 station. A detailed description of the impact of network expansion has been described in Chapter 8.3.7.

<u>Site assessment made by PSE</u>

From the viewpoint of the power balance in the NPS **location is very favourable**, since this region has no large baseload power source. The nearest power plants: Dolna Odra and ZE PAK are not alternative to this site.

At present the state of the transmission grid does not allow the connection of nuclear power plant in this location. However, development plans of TSO involve converting an existing 220 kV line Dunowo - Żydowo - Piła Krzewina - Plewiska to 400 kV voltage and construction of 400 kV line Bydgoszcz - Piła Krzewina, through which power could be evacuated to NPS from the first unit with capacity of 1600 MW. Evacuation of 3200 MW power would require building additional 400 kV lines in the direction of Poznań, and in case of significant development of wind power industry in the north, construction of a new 400 kV line from Poznań to Wrocław would be necessary.

The investment is located near the water supply network, well developed transmission infrastructure, four sewage treatment plants. There is no gas supply grid.

The distance between the NPP site and existing urban infrastructure is as follows: main roads - up to 5 km, municipal roads - up to 5 km, railway lines - up to 10 km, water transport routes - from 5 to 25 km, airports - up to 60 km, other urban infrastructure - up to 5 km. So developed communication network near the plant will allow for a diverse supply of goods during construction (building materials) and during operation of the plant (spare parts, uranium) supplied from other regions of the country or outside Poland.

For the purpose of (primary) construction and operation of "Warta" NPP, expansion of transport infrastructure was partially performed in order to enable transport of large-size device components. Two sections of road No. 182 with a total length of 10 km were modernized (from the village Piotrowo to the border of municipalities Obrzycko / Lubasz - ca. 5.2 km, and from Piotrowo towards Wronki - ca. 4.8 km). The asphalt road in these sections was significantly widened (to more than 7 m).

Additionally, the original plan envisaged the construction of a railway siding with a length of 12 km to the station Lubasz and the reconstruction and modernization of the rest of the road No. 182 in the section Międzychód - Klempicz-Ujście and road No. 185 in the section Piotrowo - Szamotuły.

Fauna and Flora

Fauna

The location within the area of special protection of birds Puszcza Notecka. In close proximity there are no other Natura 2000 sites (the nearest SPA refuge Nadnoteckie Łęgi lies about 13 km from the planned location), or faunistic reserves.

In the refuge Puszcza Notecka 234 species of birds were found, of which 162 are nesting birds. Breed of 30 species from Annex I of the Birds Directive has been reported here, although a total of 38 species were found from this list. Also 12 species have been identified from the "Polish Red Book of animals."

Key bird species for the refuge Puszcza Notecka:

Eurasian bittern *Botaurus stellaris*, little bittern *Ixobrychus minutus*, white stork *Ciconia ciconia*, black stork *Ciconia nigra*, tundra swan *Cygnus columbianus*, bean goose *Anser fabalis*, greater white-fronted goose *Anser albifrons*, mallard *Anas platyrhynchos*, common goldeneye *Bucephala clangula*, smew *Mergus albellus*, common merganser *Mergus merganser*, European honey buzzard *Pernis apivorus*, black kite *Milvus migrans*, red kite *Milvus milvus*, white-tailed eagle *Haliaeetus albicilla*, Western marsh harrier *Circus aeruginosus*, Montagu's harrier *Circus pygargus*, osprey *Pandion haliaetus*, common crane *Grus grus*, spotted crake *Porzana porzana*, corn crake *Crex crex*, Eurasian coot *Fulica atra*, Eurasian curlew *Numenius arquata*, Eurasian eagle-owl *Bubo bubo*, Tengmalm's owl *Aegolius funereus*, European nightjar *Caprimulgus europaeus*, common kingfisher *Alcedo atthis*, grey-headed woodpecker *Picus canus*, black woodpecker *Dryocopus martius*, middle spotted woodpecker *Dendrocopos medius*, woodlark *Lullula arborea*, tawny pipit *Anthus campestris*, barred warbler *Sylvia nisoria*, red-breasted flycatcher *Ficedula parva*, collared flycatcher *Ficedula albicollis*, red-backed shrike *Lanius collurio*, ortolan bunting *Emberiza hortulana*.

Puszcza Notecka is one of the largest domestic refuges for nightjar, woodlark, red kite, black kite, black woodpecker and white-tailed eagle. In the region it is an important breeding ground for the crane, marsh harrier, black stork and white stork. Location in the bifurcation of Noteć and Warta makes this area important for migratory prey birds *Falconiformes*, ducks, coots and geese *Anser sp*. - autumn and winter concentrations reach 25 000 individuals here.

The forest is also included in the network of Polish ecological corridors, it is a place of permanent occurrence of wolves, but because of the vastness of the area, the possible investment **should not significantly impair the functions of the ecological corridor**. The world of animals leading water or surface water life is also rich - there are European beavers *Castor fiber*, European otter *Lutra lutra*, European pond turtles *Emys orbicularis* and five fish species from Annex II to Habitats Directive.

In addition to occupancy of land and the obvious nuisance arising from construction and operation of the facility, one must take into account **effect of the potential development of the traction network** (impact of transmission networks will be the subject of separate studies - see chapter 8.3.7.2.2) **on mortality of numerous migrating and nesting birds - in case of this site this is a significant hazard.**

The choice of this location is associated with a significant impact on the conservation objectives of Natura 2000 area as well as the impact on the integrity of the Natura 2000 site (construction of infrastructure necessary for the operation of NPP will directly affect the area). More detailed analysis of the impact of NPP on the Natura 2000 sites should be performed at the stage of preparing the Environmental Impact Report for construction of power plant when selecting a location, although for environmental reasons it is recommended to exclude the location from further proceedings already at the stage of strategic assessment.

Plants

Forest area (one of the largest in central and northern Poland); refuge for rare and endangered plant species, including the legally protected in Poland. The dunes are covered with monotonous, same-age forest, mainly pine, planted here after the great defeat in the interwar period, caused by the emergence of insect pests. Residues of natural forest stands are protected in the reserves.

Flora

Based on available published data the following list of species was established:

a) in closer proximity (approximately a few km):

- *Alchemilla glabra*
- *Allium ursinum*
- *Asperugo procumbens*
- *Botrychium multifidum*
- *Carex praecox*
- *Dactylorhiza incarnata*
- *Dactylorhiza maculata*
- *Dactylorhiza majalis*
- *Diantus superbus*
- *Dryopteris cristata*
- *Epipactis palustris*
- *Gentianella amarella*
- *Gladiolus imbricatus*
- *Hierochloe australis*
- *Najas minor*
- *Ophioglosum vulgatum*
- *Potamogeton alpinus*
- *Ranunculus arvensis*
- *Ranunculus lingua*
- *Scorzonera purpurea*
- *Scutellaria hastifolia*
- *Teucrium scordium*
- *Valerianella locusta*

b) further (several km):

- *Allium scorodoprasum*

- *Bromus secalinus*
- *Diphasiastrum tristachyum*
- *Drosera intermedia*
- *Gentiana pneumonanthe*
- *Hierochloe odorata*
- *Huperzia selago*
- *Kickxia elatine*
- *Marrubium vulgare*
- *Myosrus minimus*
- *Pedicularis palustris*
- *Pulicaria vulgaris*
- *Pulsatilla pratensis*
- *Pulsatilla vernalis*
- *Scheuchzeria palustris*
- *Trollius europaeus*
- *Utricularia intermedia*
- *Utricularia minor*

In the area of the proposed site and in the area of the above surface forms of nature conservation, positions are listed of the following species from the Habitats Directive Annex 2:

- 1477 *Pulsatilla patens*
- 1437 *Thesium ebracteatum*

In the area of the proposed site and in the area of the above surface forms of nature conservation occurrence of ca. 43 species of rare and endangered plants under strict protection is possible, including, e.g. 9 species of orchids.

<u>Plants</u>

In the area of the proposed location and protected areas in the vicinity, occurrence of the following habitats from the Habitats Directive Annex 1 is reported:

- 3270 - flooded muddy riverbanks
- 6410 - Molinia meadows (*Molinion*)
- 6430 - riparian tall herbs (*Convolvuletalia sepium*)
- 6510 - lowland hay meadows used extensively (*Arrhenatherion elatioris*)
- 7230 - lowland bogs of alkaline marshes, sedges and mosses
- 9170 - mid-European broadleaved forest (*Stellario-Carpinetum*)
- 9190 - Pomeranian acidic birch-oak forest (*Betulo-Quercetum*)
- 91E0 - riparian willow, poplar, alder and ash (*Salicetum albo-fragilis*, *Populetum albae*, *Alnenion glutinoso-incanae*, spring alders)*
- 91F0 - riparian forests, oak-elm-ash (*Ficario-Ulmetum*)
- 9110 - thermophilous oak forests (*Quercetalia pubescenti-petraeae*)*

* indicates priority habitat

The site is average with regard to flora and habitat diversity compared to others, however it is within the forest complex in Protected Landscape Area and is therefore unfavourable.

Near the site, the following sites protected due to the environment occur:

Special areas of habitat protection (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Protected area: Dąbrowy Obrzyckie, Area code : PLH300003, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),

Special areas of birds protection (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Protected area: Puszcza Notecka, Area code : PLB300015, Form of protection in terms of Natura 2000**:** special area of bird protection (Birds Directive),

Nature reserves (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Świetlista Dąbrowa

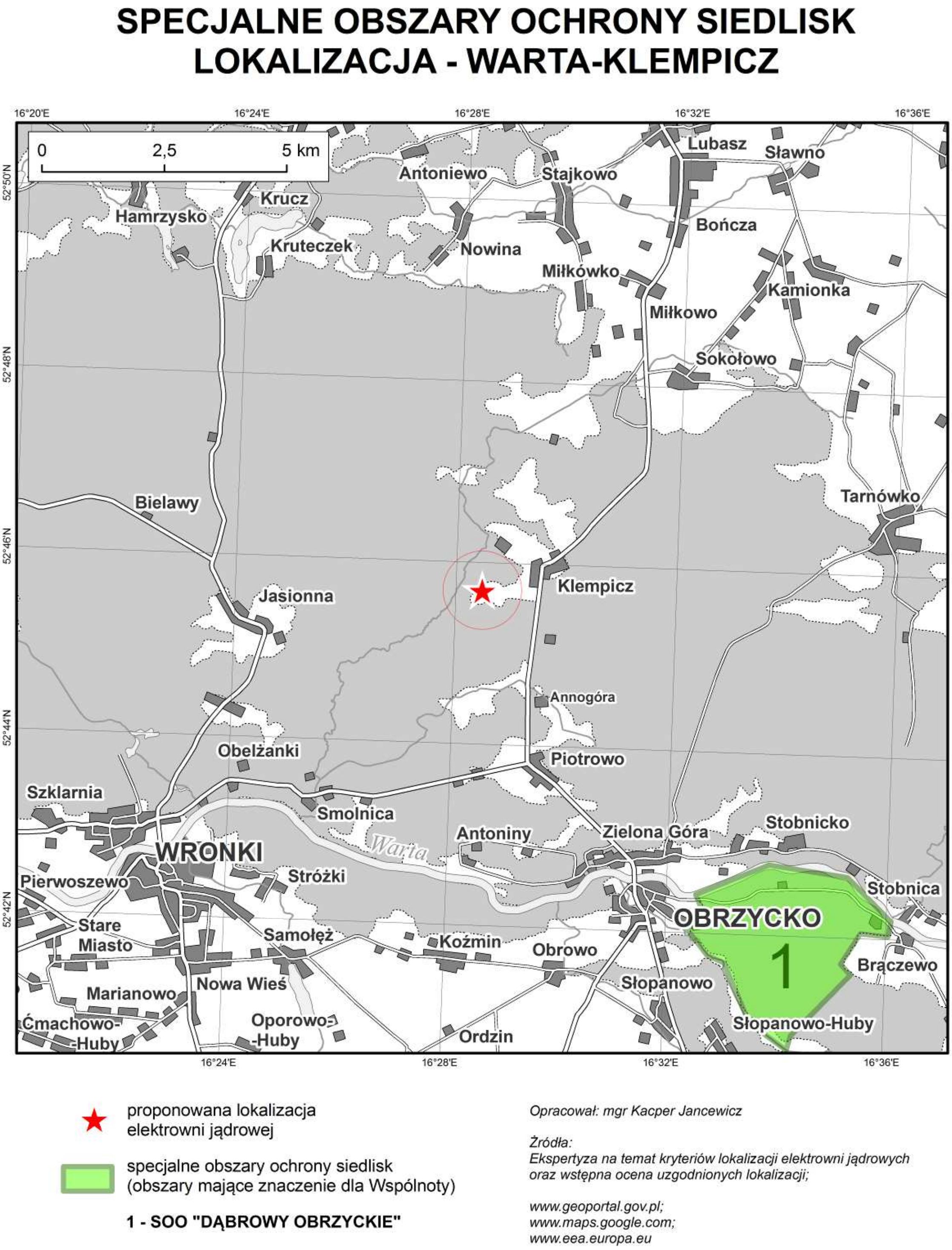

Fig. 6.3.9. Special habitat protection areas in the vicinity of Warta - Klempicz site

[SPECIAL HABITAT PROTECTION AREAS – WARTA-KLEMPICZ SITE
Proposed power plant site

Special habitat protection areas (significant for the Community)
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

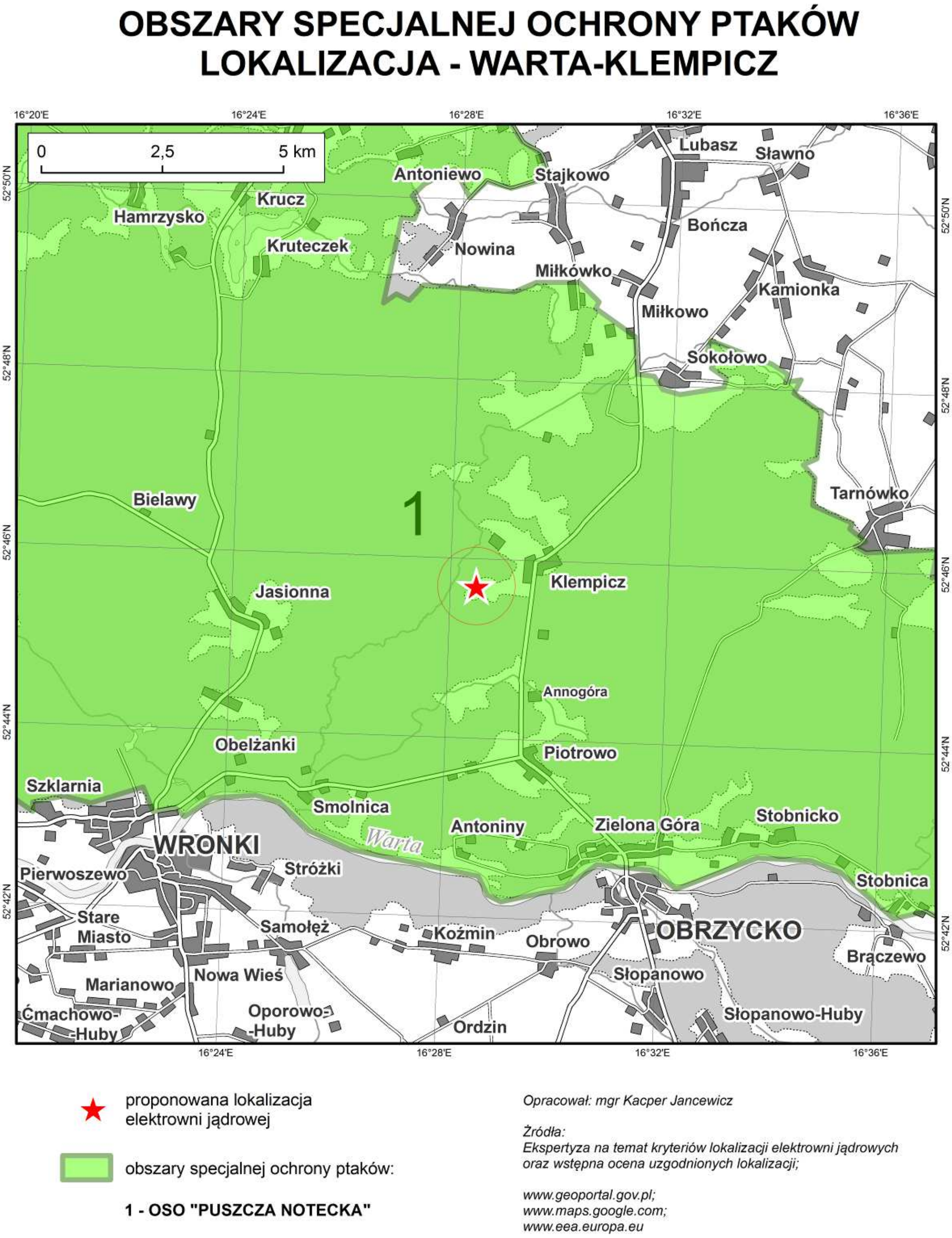

Fig. 6.3.10. Special bird protection areas in the vicinity of Warta - Klempicz site

[SPECIAL BIRD PROTECTION AREAS – WARTA-KLEMPICZ SITE
Proposed power plant site

Special bird protection areas
Developed by: mgr Kacper Jancewicz
Sources:
“Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites”
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

Fig. 6.3.11. Natural reserves in the vicinity of Warta - Klempicz site

[NATURAL RESERVES – WARTA-KLEMPICZ SITE
Proposed power plant site

Natural reserves:
Developed by: mgr Kacper Jancewicz
Sources:
“Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites”
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

6.3.3.3 Site - Kopań

Basic environmental conditions

Kopań site is a reserve location from the 1980s, additionally assigned by the Marshal of Zachodniopomorskie. It is located in the municipality of Darłowo, Sławieński district, Zachodniopomorskie Province. The exact location of the power plant is shown in **Błąd! Nie można odnaleźć źródła odwołania.**. The municipality where the power plant is to be located has low population density (28 residents/km^2 at average population density in Poland 122 residents/km^2) due to which impacts of power plant construction and operation **will affect a small number of people**.

In the limited use area (the area within 800 meters from the plant) there are currently no residential or other buildings intended for human residence. Therefore, **there is no need for relocations** due to power plant construction.

The surroundings of Kopań NPP have a very favourable wind energy zone, due to which **there will be no accumulation of potential pollutions** emitted from the power plant and other facilities in vicinity.

Preliminary analyses show that due to location in the vicinity of the sea coast (3 km) and Wieprza River (SSQ = 14.2 m^3/s, SNQ = 7.68 m^3/s) open cycle cooling system can be used in the power plant. The environmental impact of each cooling system solution has been discussed in detail in chapter 8.3.3.

In the surrounding area provided for the construction of power plant in Palczewice and Barzowice, there are 13 archaeological sites, but due to the distance from the places where ground works will be carried out, **we do not expect any risk to cultural assets** in the construction stage, or any delays if the project is suspended for the period of archaeological works.

In the vicinity of the planned investment **occurrence of natural resources and other useful minerals** was not stated, therefore a threat of difficult access and exploitation of deposits does not exist (see: chapter 8.3.6.2).

Fig. 6.3.12. Proposed site of Kopań NPP

[PROPOSED SITE OF KOPAŃ POWER PLANT
Proposed power plant site

Limited use area
Area of interventions depending on reactor type and weather conditions
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

Geological structure and hydrogeology

Geological structure of surface geological layers in which NPP is to be located is dominated by boulder clay with thickness of more than 30 m. This area is characterized by significant terrain denivelation. Although in the vicinity young and active faults have not been documented, the fault zone designated on the Baltic Sea may continue in the direction of this location. Mesozoic roof and Tertiary strata lay on the substrate. Historically or currently, seismic shocks were not recorded, and maximum soil vibration acceleration is less than 0.02g.

In this area, main groundwater reservoir does not occur. Depth to the main utility groundwater level varies between 15-50 m. The levels of aquifers show **low sensitivity to contamination.** Groundwater runoff occurs in the direction of NW, N. Good insulation from the ground surface with thick layer of aluminium sediments with low infiltration and movement of pollutants **should not cause** contamination of groundwater in case of contamination from the surface.

Infrastructure

The location is in the network area, currently characterized by **a deficit of electricity production** amounting to 100 ≤ dP < 300 MW. The existing transmission grid is loaded at less than 60%, which **gives the possibility to use existing transmission capacity** to evacuate power from the NPP. However, to enable the network connection to NPP, expansion of 100 to 250 km long transmission lines will be necessary. There is a possibility of interference of the expansion with two Natura 2000 sites and its course near urban areas. In addition, it is necessary to build the LV/LV/110 station. A detailed description of the impact of network expansion has been described in Chapter 8.3.7.

During emergency shutdown of the unit with capacity 1600 MW, **there may occur a threat to stable operation** of NPS and stable cooperation of NPS with systems in neighbouring countries.

Construction of NPP in this location will improve the conditions for cross-border trade.

Site assessment made by PSE

From the viewpoint of the power balance in the NPS **location is advantageous,** and is an alternative for three locations in Żarnowiec area and for Warta-Klempicz site.

Connection of nuclear power plant could be madeto the station Dunowo or Slupsk. TSO development plans assume a significant improvement in the connection of these stations to a 400 kV network. However, also in this case negative impact of wind energy on this location should be noted. Currently, terms of connection of wind farms with total capacity of 660 MW have been specified for Dunowo station, and proceedings are pending for another 468 MW. Terms of connection of wind farms with total capacity of 660 MW have been specified for Słupsk station, and proceedings are pending for another 345 MW.

As in case of the site to SE 400/110 kV Żarnowiec, considering capacity not exceeding 1600 MW for a nuclear power plant is proposed.

The following are located in the vicinity of the site: high pressure gas pipeline not supplying any municipality, 100/15 kV station.

The distance between the NPP site and existing urban infrastructure is as follows: main roads - up to 5 km, municipal roads - up to 5 km, railway lines - up to 10 km, water transport routes - up to 5 km, airports - more than 60 km, other urban infrastructure - up to 5 km. So developed communication network near the plant will allow for a diverse supply of goods during construction (building materials) and during operation of the plant (spare parts, uranium) supplied from other regions of the country or outside Poland.

Fauna and Flora

Fauna

In the vicinity (2 km) bird refuge Przybrzeżne Wody Bałtyku [Baltic Coastal Waters]. In this vast basin sea ducks winter in large numbers.

Key bird species for Natura 2000 Przybrzeżne Wody Bałtyku site:

red-throated loon *Gavia stellata*, black-throated loon *Gavia arctica*, horned grebe *Podiceps auritus*, long-tailed duck *Clangula hyemalis*, common scoter *Melanitta nigra*, velvet scoter *Melanitta fusca*, European herring gull *Larus argentatus*, common murre *Uria aalge* and razorbill *Alca torda*.

Approximately 12% of velvet scoters, 2% of common scoters i 35% of long-tailed ducks occurring within the Polish zone of Baltic sea gather here. Small crustaceans dominate the benthic fauna. Large marine mammals are rarely observed - grey seals *Halichoerus grypus*, ringed seals *Phoca hispida* and harbour porpoises *Phocoena phocoena*. The location is in the coastal zone, in the area particularly intensively used by migrating birds. At a distance of about 5 km from the planned location, Akcja Bałtycka bird-ringing camp has been operating for 50 years, organized here by the Bird Migration Research Station, the unit of the Department of Biology, University of Gdansk. This camp captures tens of thousands of birds every year in spring and autumn, both passerines *Passeriformes,* and prey birds *Falconiformes*, or owls *Stigiformes*. Despite lack of information on nesting birds from Annex I of the Birds Directive, this area is undoubtedly very important from the standpoint of migratory birds. In this context, **the question of possible expansion of overhead transmission networks** occurs again (impact of transmission networks will be the subject of separate study - see chapter 8.3.7.2.2) as well as resulting **high risk of significant direct mortality of birds due to collisions.** Possible discharge of heated water into the lake can affect the imbalance of the aquatic ecosystem and disrupt the structure of wintering of water birds.

The location potentially significantly affecting Natura 2000 sites, traction network can be a major threat to migratory birds, but without collisions with ecological corridors. **More detailed analysis of the impact of NPP on Natura 2000 sites will be performed at the stage of preparing the Environmental Impact Report for construction of power plant when selecting a location, though it would be advisable to exclude this location because of the potential environmental effects of its implementation.**

Plants

In the site area, numerous types of habitats were observed, particularly precious peat bogs and bog woodland. Species richness of flora on the basis of available data is smaller than the wealth of habitats.

Flora

Based on available published data the following list of species was established:

a) in closer proximity (approximately a few km):

- *Empetrum nigrum*
- *Erica tetralix*
- *Gagea spathacea*
- *Lathyrus palustris*
- *Orchis morio*
- *Pedicularis palustris*

b) further (several km):

- *Allium scorodoprasum*
- *Bromus secalinus*
- *Campanula latifolia*
- *Carex limosa*
- *Corallorhiza trfida*
- *Dactylorhiza majalis*
- *Drosera rotundifolia*
- *Dryopteris cristata*
- *Epipactis palustris*
- *Glaux maritima*
- *Goodyera repens*
- *Hippuris vulgaris*
- *Listera cordata*
- *Myosrus minimus*
- *Myrica gale*
- *Radiola linoides*
- *Scorzonera purpurea*
- *Triglochin maritimum*
- *Valerianella locusta*
- *Zostera marina*

Near the proposed site positions of plant species from Annex 2 of the Habitats Directive were not observed.

In the area of the proposed site and in the area of the above surface forms of nature conservation occurrence of ca. 26 species of rare and endangered plants under strict protection is possible.

<u>Plants</u>

In the area of the proposed location and protected areas in the vicinity, occurrence of the following habitats from the Habitats Directive Annex 1 is reported:

- 1130 - estuaries
- 1150 - bays and sea lakes (lagoons)*
- 2110 - initial stages of yellow dunes
- 2120 -yellow dunes (Elymo-Ammophiletum)

- 2130 - grey dunes*
- 2180 - mixed forests and forests on coastal dunes
- 3110 - Lobelia lakes
- 3150 - oxbow lakes and natural eutrophic reservoirs with the communities with Nympheion, Potamion
- 3160 - natural dystrophic water reservoirs
- 3260 - lowland and foothill rivers of Batrachion vegetation Ranunculion fluitantis
- 3270 - flooded muddy riverbanks
- 4030 - dry heaths (Calluno-Genistion, Pohlio-Callunion, Calluno-Arctostaphylion)
- 6120 - thermophilic, inland psammophilous grasslands (Koelerion glaucae)*
- 6430 - riparian tall herbs (Convolvuletalia sepium)
- 6510 - lowland hay meadows used extensively (Arrhenatherion elatioris)
- 7110 - high peat bogs with peat-generating vegetation (live) *
- 7120 - degraded high peat bogs, but able to regenerate naturally and upon stimulation
- 7140 - transition mires and quaking bogs (mostly with plants from Scheuchzerio-Caricetea)
- 7150 - depressions on peat substrates with vegetation from Rhynchosporion
- 7220 - limestone springs with the communities Cratoneurion commutati*
- 7230 - lowland bogs of alkaline marshes, sedges and mosses
- 9110 - acidic beech (Luzulo-Fagenion)
- 9130 - fertile beech (Dentario glandulosae-Fagenion, Galio odorati-Fagenion)
- 9160 - subatlantic broadleaved forest (Stellario-Carpinetum)
- 91D0 - bog woodland*
- 9190 - Pomeranian acidic birch-oak forest (Betulo-Quercetum)
- 91E0 - riparian willow, poplar, alder and ash (Salicetum albo-fragilis, Populetum albae, Alnenion glutinoso-incanae, spring alders)*

* indicates priority habitat

The location has a very high diversity of habitats and relatively small share of rare species, this may be partly an artefact resulting from the adopted methodology and the data available. The potential negative impact is possible.

<u>Near the site, the following sites protected due to the environment occur</u>:

Special areas of habitat protection (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Protected area: Słowińskie Błoto, Area code : PPLH320016, (outside the map), Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive), Area status : area proposed by the Government of Poland.
- Protected area: Kopań Lakes Area code : PLH320059, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),
- Protected area: Wieprza and Studnica valley, Area code : PLH220038, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),

Special areas of birds protection (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Protected area: Przybrzeżne Wody Bałtyku, Area code : PLB990002, Form of protection in terms of Natura 2000: special area of bird protection (Birds Directive),Area status : designated area [by Resolution of Minister of Environment]

Shadow List 2010 areas (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Protected area: Wicko Lake and Modelskie Wydmy, Area code : PLTMP551

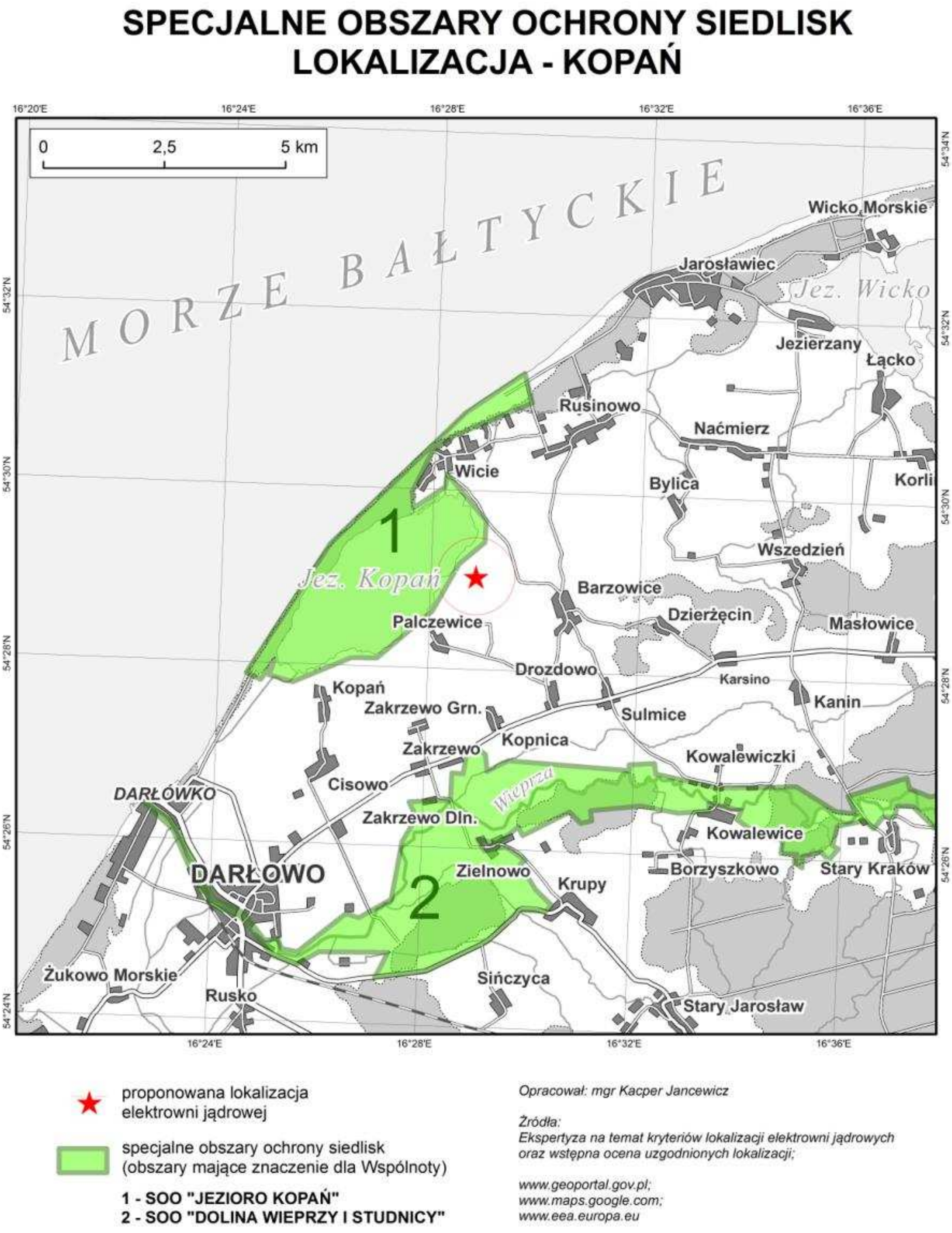

Fig. 6.3.13. Special habitat protection areas in the vicinity of Kopań site

[SPECIAL HABITAT PROTECTION AREAS - KOPAŃ SITE
Proposed power plant site

Special habitat protection areas (significant for the Community)
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

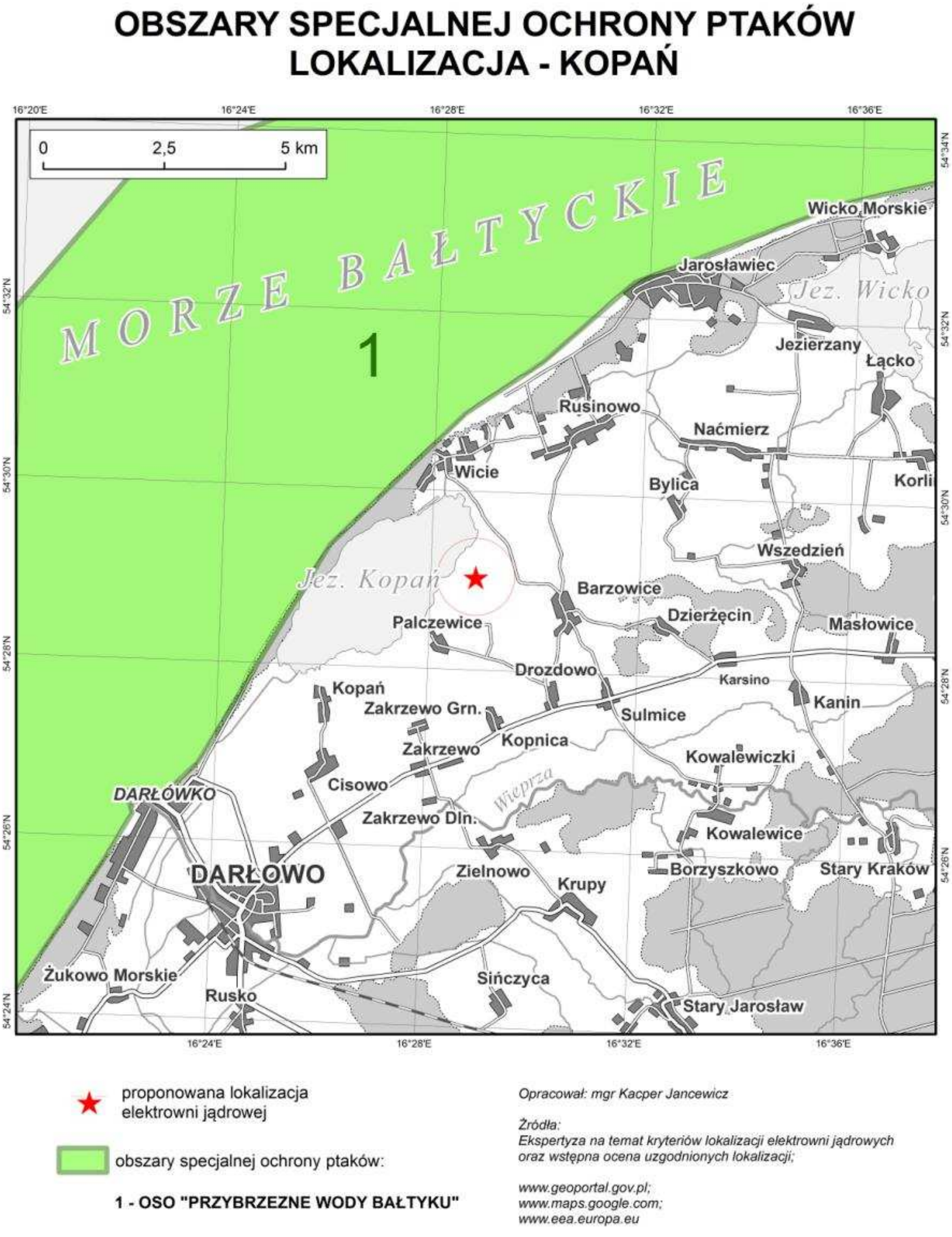

Fig. 6.3.14. Special bird protection areas in the vicinity of Kopań site

[SPECIAL BIRD PROTECTION AREAS - KOPAŃ SITE
Proposed power plant site

Special bird protection areas
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

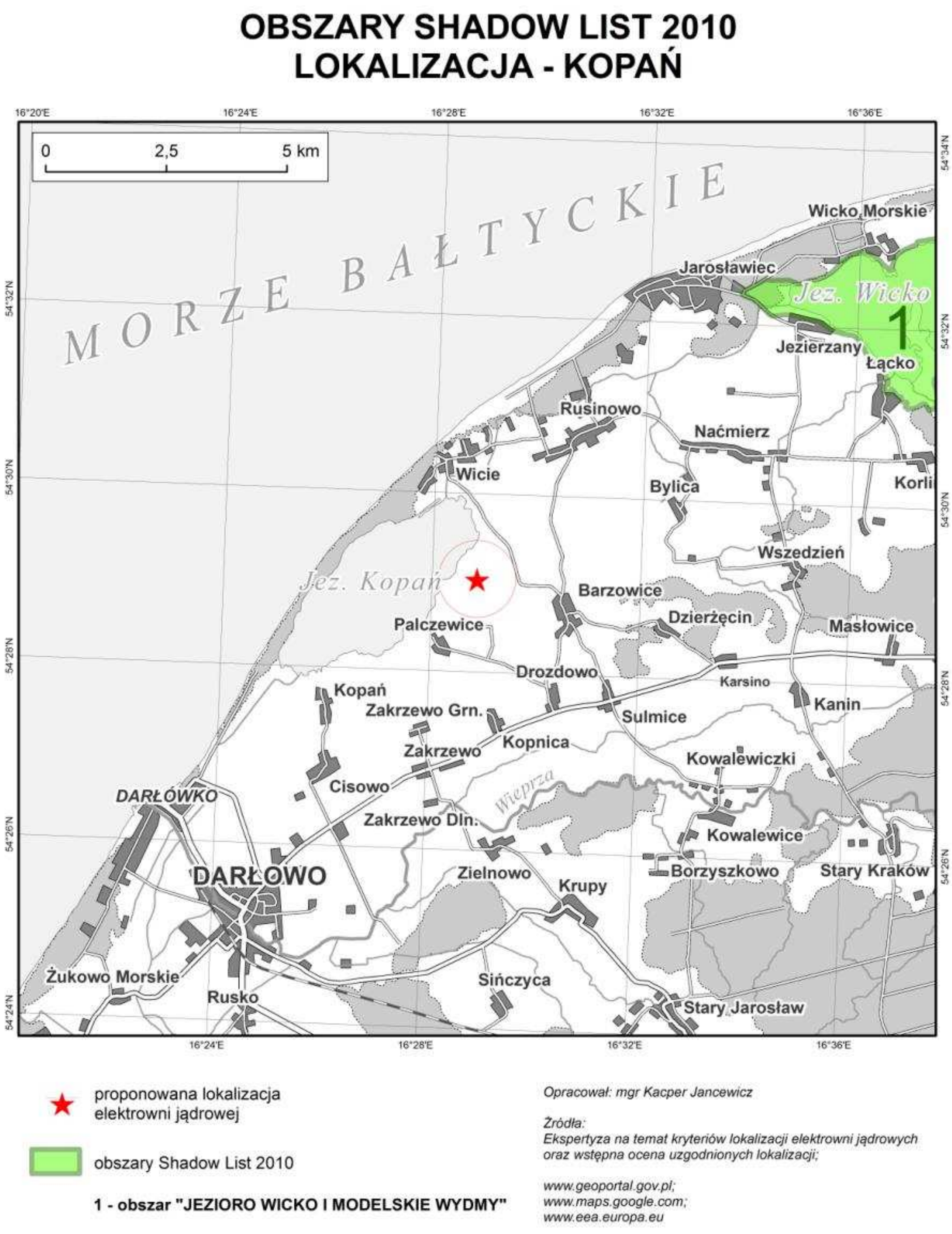

Fig. 6.3.15. Shadow List 2010 areas in the vicinity of Kopań site

[SPECIAL BIRD PROTECTION AREAS - ŻARNOWIEC SITE
Proposed power plant site

Shadow List 2010 areas
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

6.3.3.4 Site –Nowe Miasto

Basic environmental conditions

Nowe Miasto site is a reserve location from the 1980s. It is located in the municipality of Nowe Miasto, Płoński district, Mazowieckie Province. The exact location of the power plant is shown in **Błąd! Nie można odnaleźć źródła odwołania.**. The municipality where the power plant is to be located has low population density (42 residents/km^2 at average population density in Poland 122 residents/km^2) due to which impacts of power plant construction and operation **will affect a small number of people**.

In the limited use area (the area within 800 meters from the plant) there are currently no residential or other buildings intended for human residence (in Jurzyn and Spądoszyn) , **therefore there may be a need of relocations** due to power plant construction.

The surroundings of Nowe Miasto NPP site have a very favourable wind energy zone, due to which **there will be no accumulation of potential pollutions** emitted from the power plant and other facilities in vicinity.

Preliminary analyses show that due to location in the vicinity of Zalew Zegrzyński (distance 32 km area 30 km^2, capacity 94.3 million m^3) and river Wisła (distance 33 km, SSQ = 1140m^3/s, SNQ = 352 m^3/s) closed cycle cooling system can be used in the power plant. The environmental impact of each cooling system solution has been discussed in detail in chapter 8.3.3.

There are no archaeological sites in the construction area and its vicinity, **thus eliminating hazards to cultural heritage** during ground works or construction delays due to halting works for the period of work of archaeologists.

In the vicinity of the planned investment **occurrence of natural resources and other useful minerals** was not stated, therefore a threat of difficult access and exploitation of deposits does not exist (see: chapter 8.3.6.2).

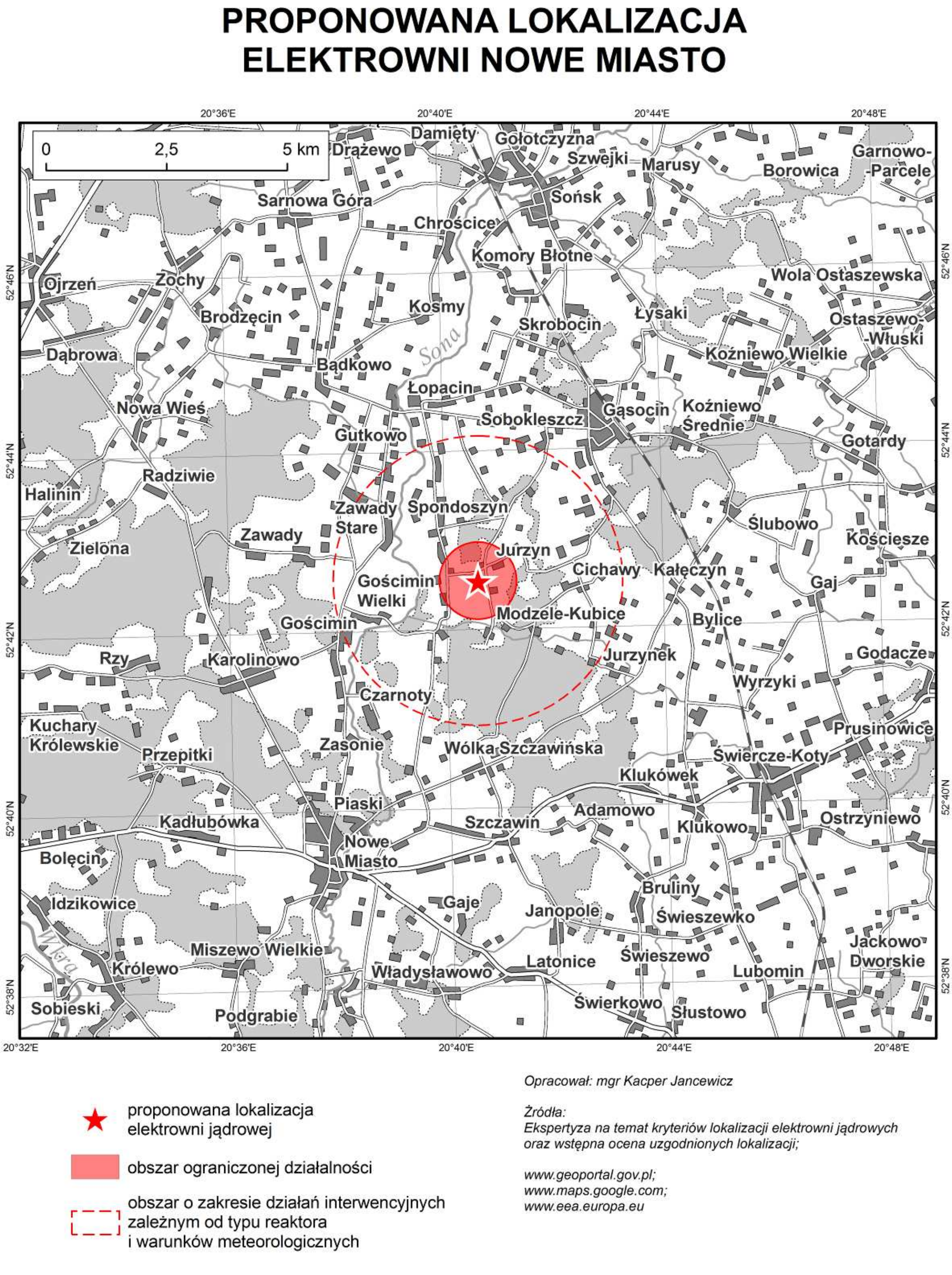

Fig. 6.3.16. Proposed site of Nowe Miasto NPP

[PROPOSED SITE OF NOWE MIASTO POWER PLANT
Proposed power plant site

Limited use area
Area of interventions depending on reactor type and weather conditions
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

Geological structure and hydrogeology

In the substrate of the area where NPP is to be located, mainly boulder clay occurs with boulder structures in the areas of end moraines, and sands and gravels on the deeper level. Occurrence of young and active fault zones in the area was not documented. Mesozoic roof and Tertiary strata lay on the substrate. A seismic shock recorded in modern times occurred more than 30 km away, and maximum soil vibration acceleration is less than 0.04 g.

In the area there is tertiary porous tank "Subniecka Warszawska (central part)" (GZWP 215 a), the average depth of groundwater intakes here is 180 m. Depth to the main utility groundwater level varies between 5 and 15 m, on the boundary there is a quaternary porous tank "Działdowo" . The average depth of groundwater intakes here is from 100 m. The levels of aquifers show **low sensitivity to contamination**. Groundwater runoff occurs in the direction of W. Good insulation from the ground surface with thick layer of aluminium sediments with low infiltration and movement of pollutants **should not cause** contamination of groundwater in case of contamination from the surface.

Infrastructure

The location is in the network area, currently characterized by **a deficit of electricity production** amounting to 300 ≤ dP < 500 MW. The existing transmission grid is loaded at less than 60%, which **gives the possibility to use existing transmission capacity** to evacuate power from the NPP. However, to enable the network connection to NPP, expansion of > 250 km long transmission lines will be necessary. There may be a possibility of network expansion near urban areas. In addition, it is necessary to build the LV/LV/110 station. A detailed description of the impact of network expansion has been described in Chapter 8.3.7.

Site assessment made by PSE

Unfavourable site primarily due to lack of network infrastructure in this region of the country, and the TSO development plan does not provide for construction of 400 kV network in the area.

To lead out 1600 MW from a nuclear power plant, the following are needed:

- construction of 400 kV station
- construction of two 400 kV lines.

GPZ 110/15 kV station is located near the site.

The distance between the NPP site and existing urban infrastructure is as follows: main roads - up to 5 km, municipal roads - up to 5 km, railway lines - up to 10 km, water transport routes - above 15 km, airports - more than 60 km, other urban infrastructure - up to 5 km. So developed communication network near the plant will allow for a diverse supply of goods during construction (building materials) and during operation of the plant (spare parts, uranium) supplied from other regions of the country or outside Poland.

Fauna and Flora

Fauna

The area is not distinguished by the richness of fauna. No nature conservation forms, significant from the faunistic point of view, can be observed in the area. This implies lack of precise information on fauna. The closest bird refuges of Natura 2000 network (Dolina Dolnej Narwi and Dolina Środkowej Wisły) are 30 km away from the planned site. Also the "Atlas of Polish nesting birds distribution" does not provide too much information about the avifauna of the area - the majority of Polish nesting species in the square was not found. The Birds Directive Annex I states that only ortolan *Emberiza hortulana* and white stork *Ciconia ciconia* breed here. It's hard to assess to what extent this is the effect of low values of ornithofauna or poor reconnaissance, however at the current faunistic level it can be safely assumed that this area does not provide above-average wealth of fauna.

It can be assumed that transmission networks expansion associated with the construction of power plant (the impact of transmission networks will be the subject of separate study - see chapter 8.3.7.2.2) will entail an impact on even remote areas of Natura 2000, but the location of the power plant 30 km away from existing areas will result in the highest density of transmission networks (and thus the accumulation of negative impacts, such as death in the collision, the barrier effect, etc.) outside the protected area and beyond the valleys of large rivers (which are a natural bird migration corridor), and thus the potential impact on individual areas will be less than the site located inside or near an SPA or on large rivers. This site seems to **collide the least with fauna protection** and the protection areas, **and furthermore it does not interfere with the ecological corridors. Infrastructure associated with the construction and operation of a NPP will be the least environmentally burdensome of the analyzed locations.**

In conclusion - Nowe Miasto site, due to the impact of the investment on fauna and Natura 2000 areas is the most favourable among analyzed sites.

Plants

The vegetation is scarce, consisting mainly of common species.

Flora

Based on available published data the following list of species was established:

a) in closer proximity (approximately a few km):

- *Carex praecox*
- *Myosrus minimus*

b) further (several km):

- *Dactylorhiza majalis*
- *Diantus superbus*
- *Pulsatilla pratensis*

Near the proposed site positions of plant species from Annex 2 of the Habitats Directive were not observed.

In the area of the proposed site and in the area of the above surface forms of nature conservation occurrence of ca. 5 species of rare and endangered plants under strict protection is possible.

Plants

Due to lack of surface nature conservation forms in the area, there are no documented data on habitats. However, occurrence of certain common habitats from Annex 1 is possible.

The site is the poorest in every respect - habitat flora, nature conservation - among all the analyzed sites, therefore **potential negative impacts will also be the lowest.**

Lack of protected areas

6.3.4 Reserve sites

6.3.4.1 Site – Choczewo

Basic environmental conditions

Choczewo NPP site was reported by Marshal of Pomorskie. It is located in the municipality of Choczewo, Wejherowski district, Pomorskie Province. The exact location of the power plant is shown in **Błąd! Nie można odnaleźć źródła odwołania.**. The municipality where the power plant is to be located has low population density (32 residents/km^2 at average population density in Poland 122 residents/km^2) due to which impacts of power plant construction and operation **will affect a small number of people**.

In the limited use area (the area within 800 meters from the plant) there are currently no residential or other buildings intended for human residence. Therefore, **there is no need for relocations** due to power plant construction.

Preliminary analyses show that due to location in the vicinity of the sea coast and **sufficient water resources** open cycle cooling system can be used in the power plant. The environmental impact of each cooling system solution has been discussed in detail in chapter 8.3.3.

To the east of the proposed site there is Nadmorski Park Krajobrazowy [Seaside Landscape Park]. Depending on the plant's architectural form, **it may decrease landscape values** of this area.

The surroundings of Choczewo NPP have a very favourable wind energy zone, due to which **there will be no accumulation of potential pollutions** emitted from the power plant and other facilities in vicinity.

There are no archaeological sites in the construction area and its vicinity, **thus eliminating hazards to cultural heritage** during ground works or construction delays due to halting works for the period of work of archaeologists.

In the vicinity of the planned investment **occurrence of natural resources and other useful minerals** was not stated, therefore a threat of difficult access and exploitation of deposits does not exist (see: chapter 8.3.6.2).

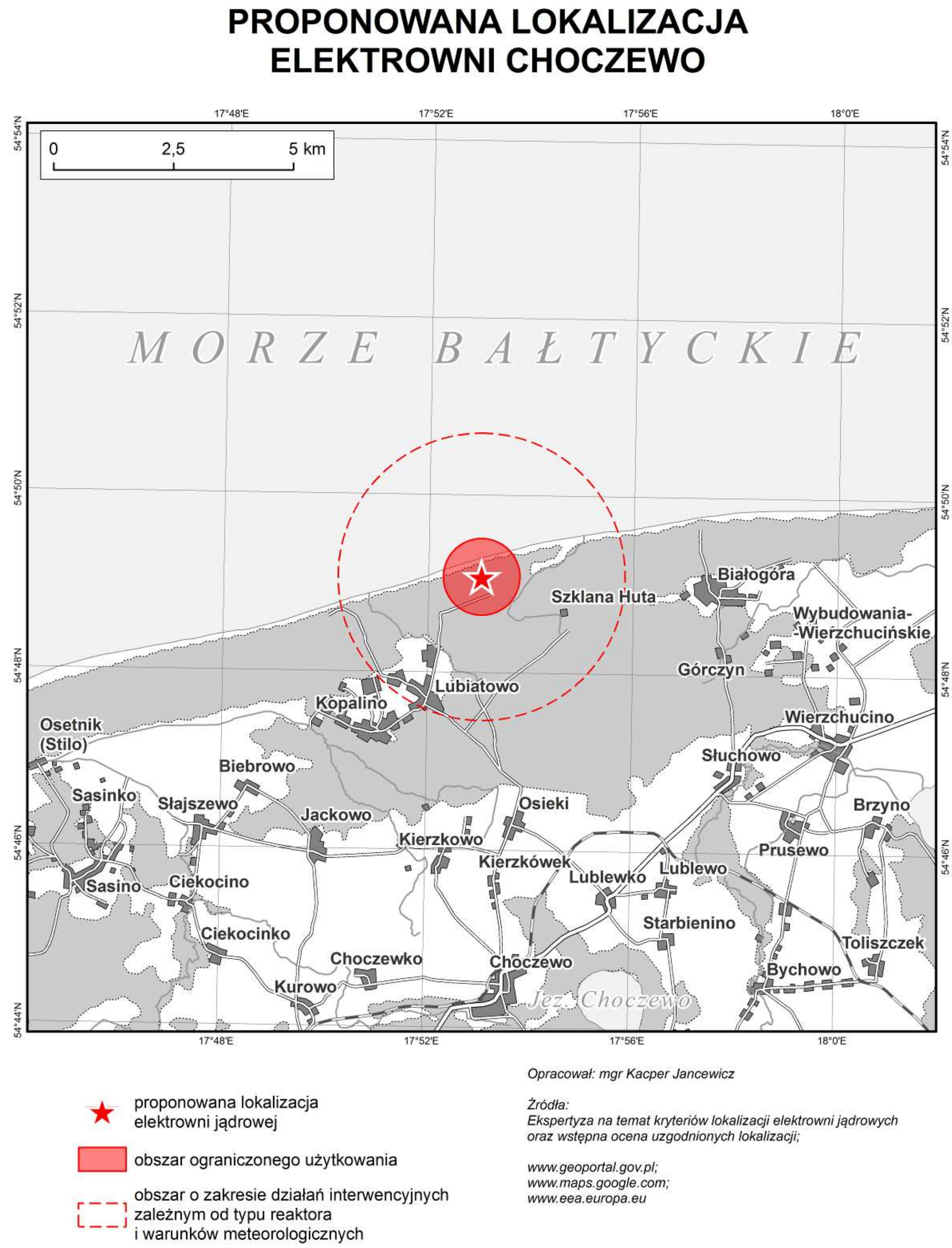

Fig. 6.3.17. Proposed site of Choczewo NPP

[PROPOSED SITE OF CHOCZEWO POWER PLANT
Proposed power plant site

Limited use area
Area of interventions depending on reactor type and weather conditions
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

Geological structure and hydrogeology

Near the surface of the area where the NPP is to be located, there are Aeolian sands and deeper - boulder clays. In the vicinity (ca. 10 km) the substrate contains a series of Triassic outcrops within the chalk, whose tectonic structure is not specified. Neotectonic reactivation of this structure cannot be excluded. Mesozoic roof and Tertiary strata lay on the substrate. In the distance exceeding 20 km a weak seismic shock was recorded, and maximum soil vibration acceleration is less than 0.02 g.

In this area, main groundwater reservoir does not occur. Depth to the main utility groundwater level varies between 5 and 15 m The levels of aquifers show medium sensitivity to contamination. Groundwater runoff occurs in the N direction. In some cases, **there is a threat** of groundwater contamination.

Infrastructure

The location is in the network area, currently characterized by **a deficit of electricity production** amounting to 300 ≤ dP < 500 MW. The existing transmission grid is loaded at less than 60%, which **gives the possibility to use existing transmission capacity** to evacuate power from the NPP. However, to enable the network connection to NPP, expansion of 100 to 250 km long transmission lines will be necessary. There is a possibility of interference of the expansion with two Natura 2000 sites and its course near urban areas. In addition, it is necessary to build the LV/LV/110 station. A detailed description of the impact of network expansion has been described in Chapter 8.3.7.

During emergency shutdown of the unit with capacity 1600 MW, there may occur a threat to stable operation of NPS and stable cooperation of NPS with systems in neighbouring countries.

Construction of NPP in this location will improve the conditions for cross-border trade.

Site assessment made by PSE

From the viewpoint of the power balance in the NPS **location is advantageous**, which was emphasized with other nuclear power plant sites in the northern part of the country.

It should be noted, however, that in this case, difficulties should be expected with evacuation of full power (3200 MW) from the nuclear power plant into the NPS. In PRSP prepared by the TSO connection of the nuclear power plant to Żarnowiec node was considered. Results of analysis showed that in case of 1600 MW capacity, construction of an additional 2-track 400 kV line linking SE Żarnowiec with new station in the region of Gdansk is necessary. Expansion, however, was not sufficient for 3,200 MW and it is difficult to imagine the construction of other 400 kV lines from the node into the NPS. It is therefore proposed to consider this location for nuclear power plant with a capacity of not more than 1600 MW.

110 kV power supply line runs near the site, large distances between main supply points. Lack of centralised heat supply, lack of gas supply network.

The distance between the NPP site and existing urban infrastructure is as follows: main roads - 5-15 km, municipal roads - up to 5 km, railway lines - up to 10 km, water transport routes - up to 5 km, airports - more than 60 km, other urban infrastructure - up to 5 km. So developed communication network near the plant will allow for a diverse supply of goods during construction (building materials) and during operation of the plant (spare parts, uranium) supplied from other regions of the country or outside Poland.

Fauna and Flora

Fauna

The site is planned in the distance of ca. 1 km from the refuge Przybrzeżne Wody Bałtyku [Coastal Baltic Waters]. Small crustaceans dominate the benthic fauna. Large marine mammals are rarely observed - grey seals *Halichoerus grypus*, ringed seals *Phoca hispida* and harbour porpoises *Phocoena phocoena*. The area is a bird sanctuary of European rank.

Key bird species for Natura 2000 Przybrzeżne Wody Bałtyku site:

red-throated loon *Gavia stellata*, black-throated loon *Gavia arctica*, horned grebe *Podiceps auritus*, long-tailed duck *Clangula hyemalis*, common scoter *Melanitta nigra*, velvet scoter *Melanitta fusca*, European herring gull *Larus argentatus*, common murre *Uria aalge* and razorbill *Alca torda*.

This area is a wintering location for 3 bird species from Annex I of the Birds Directive: black-throated loon, red-throated loon and horned grebe. Also populations of long-tailed duck, common scoter, velvet scoter and common murre and periodically European herring gull are significant (depending on intensity of fishing). In the vicinity there is a nesting ground for Eurasian eagle-owl *Bubo bubo* and place of permanent stay for white-tailed eagle *Haliaeetus albicilla* and osprey *Pandion haliaetus*.

Similarly to other sites located on the coast, the site, due to expansion of aerial transmission lines and their impact will be the subject of the separate study - see chapter 8.3.7.2.2 **as it can have significant impact on mortality of migrating birds.**

The location potentially significantly affecting Natura 2000 site Przybrzeżne Wody Bałtyku, but without collisions with ecological corridors. **More detailed analysis of the impact of NPP on Natura 2000 sites will be performed at the stage of preparing the Environmental Impact Report for construction of power plant when selecting a location, though it would be advisable to exclude this location because of the potential environmental effects of its implementation.**

Plants

The site has the only on Polish coast - apart from Słowiński National Park - complex of embankment and parabolic dunes (partially walking) and seaside pine forests of various humidity. The depressions between dunes (deflation troughs) are filled with peat. Often there are wet willow heaths, disappearing communities in Poland with few positions. Large part of the area is covered with forest communities. Apart from pine forests, there are also well-preserved, acidic and fertile alders and swamp birch complexes. The value of the area is increased by bushes with very rare *Myrica gala*, and (scarce in Poland) *Linaria odora*. Populations of vascular and legally protected plant species are exceptionally well represented. Here we have a complex of peat bog and forest communities, creating the natural succession series, unique on the south coast of the Baltic. Also, very rare on national scale plant communities of Atlantic character have been found: *Eleocharitetum multicaulis*, Rhynchosporetum fuscae, Ericetum tetralicis, *Myricetum gale*, occurring in dense patches and on relatively large surfaces, and coastal swamp forest variety with *Erica tetralix* and *Myrica gale*, humid, regionally rare forms of swamp woods, fragments of well-preserved bog birch and birch-oak and beech-oak forests. Vascular plants and cryptogams are unique, including mycoflora with many species of Atlantic range. Several of these species occur here in numerous populations, e.g. *Drosera intermedia, Rhynchospora fusca, Myrica gale, Erica tetralix.* The only one in Pomerania and one of 5 in Poland, position of *Eleocharis multicaulis*. The area of special landscape values.

The proposed location is near the plant refuges IPA:

PL 96 – Białogóra.

PL 106 – Łąki piaśnickie.

Flora

Based on available published data the following list of species was established:

a) in closer proximity (approximately a few km):

- *Baeothryon caespitosum*
- *Betula humilis*
- *Carex buxbaumii*
- *Centaurium litorale*
- *Cnidium dubium*
- *Dactylorhiza fuchsii*
- *Dactylorhiza incarnata*
- *Dactylorhiza maculata*
- *Diantus superbus*
- *Drosera rotundifolia*
- *Dryopteris cristata*
- *Empetrum nigrum*
- *Epipactis palustris*
- *Erica tetralix*
- *Euphrasia nemorea*
- *Galium harcynicum*
- *Gentiana pneumonanthe*
- *Glaux maritima*
- *Goodyera repens*
- *Hieracium echioides*
- *Hippuris vulgaris*
- *Huperzia selago*
- *Iris sibirica*
- *Juncus acutiflorus*
- *Juncus gerardii*
- *Juncus subnodulosus*
- *Lathyrus palustris*
- *Listera cordata*
- *Lycopodiella inundata*
- *Marrubium vulgare*
- *Myrica gale*
- *Najas minor*
- *Nuphar pumila*
- *Ophioglosum vulgatum*
- *Pedicularis palustris*
- *Plantago maritima*

- *Polemonium coeruleum*
- *Potamogeton alpinus*
- *Pyrola media*
- *Radiola linoides*
- *Ranunculus lingua*
- *Rubus chamaemorus*
- *Salsola kali ssp. kali*
- *Scheuchzeria palustris*
- *Stachys arvensis*
- *Triglochin maritimum*
- *Utricularia australis*
- *Utricularia intermedia*
- *Utricularia minor*
- *Viola stagnina*

b) further (several km):

- *Ajuga pyramidalis*
- *Alisma lanceolatum*
- *Bromus secalinus*
- *Campanula latifolia*
- *Carex chordorrhiza*
- *Carex limosa*
- *Carex puilicaris*
- *Cephalanthera longifolia*
- *Corallorhiza trfida*
- *Diphasiastrum tristachyum*
- *Drosera anglica*
- *Drosera intermedia*
- *Epipogium aphyllum*
- *Gentianella baltica*
- *Gymnadenia conopsea*
- *Isoetes lacustris*
- *Koeleria pyramidata*
- *Littorella uniflora*
- *Lobelia dortmanna*
- *Lolium temulentum*
- *Nymphoides peltata*
- *Osmunda regalis*
- *Pulsatilla pratensis*
- *Pyrola media*
- *Rhynchospora fusca*
- *Ruppia maritima*
- *Sparganium angustifolium*
- *Stellaria crassifolia*
- *Zannichellia palustris*

In the area of the proposed site and in the area of the above surface forms of nature conservation, positions (4) are listed of the following species from the Habitats Directive Annex 2:

- 2216 *Linaria odora*
- 1903 *Liparis loeselii*
- 1831 *Luronium natans*
- 1528 *Saxifraga hirculus*

In the area of the proposed site and in the area of the above surface forms of nature conservation occurrence of ca. 84 species of rare and endangered plants under strict protection is possible.

Plants

In the area of the proposed location and protected areas in the vicinity, occurrence of the following habitats from the Habitats Directive Annex 1 is reported:

- 1150 - bays and sea lakes (lagoons)*
- 1210 - nitrophilous strandline vegetation
- 2110 - initial stages of yellow dunes
- 2120 -yellow dunes (*Elymo-Ammophiletum*)
- 2130 - grey dunes*
- 2140 - seaside pine heaths (*Empetrion nigri*)*
- 2170 - dunes with sand willow bushes
- 2180 - mixed forests and forests on coastal dunes
- 2190 - humid depressions between dunes
- 3110 - Lobelia lakes
- 3130 - shores or drained reservoir bottoms with communities with *Littorelletea*, *Isoëto-Nanojuncetea*
- 3150 - oxbow lakes and natural eutrophic reservoirs with the communities with *Nympheion*, *Potamion*
- 3160 - natural dystrophic water reservoirs
- 4010 - humid heaths with Erica tetralix (*Ericion tetralix*)
- 6510 - lowland hay meadows used extensively (*Arrhenatherion elatioris*)
- 7110 - high peat bogs with peat-generating vegetation (live) *
- 7120 - degraded high peat bogs, but able to regenerate naturally and upon stimulation
- 7140 - Transition mires and quaking bogs (mostly with plants from *Scheuchzerio-Caricetea*)
- 7150 - depressions on peat substrates with vegetation from *Rhynchosporion*
- 6410 - Molinia meadows (*Molinion*)

- 9110 - acidic beech (*Luzulo-Fagenion*)
- 9190 - Pomeranian acidic birch-oak forest (*Betulo-Quercetum*)
- 91D0 - bog woodland*
- 91E0 - riparian willow, poplar, alder and ash (*Salicetum albo-fragilis*, *Populetum albae*, *Alnenion glutinoso-incanae*, spring alders)*

* indicates priority habitat

Site with significant diversity of vegetation and numerous forms of nature conservation, **potential negative impact is relatively high**. **More detailed analyses of the impact of NPP on Natura 2000 sites should be performed on the stage of preparing the Environmental Impact Report for construction of the plant when selecting a site.**

Near the site, the following sites protected due to the environment occur:

Special areas of habitat protection (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Protected area: Białogóra, Area code : PLH220003, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive), Area status : area proposed by the Government of Poland.
- Protected area: Mierzeja Sarbska, Area code : PLH220018, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive), Area status : area proposed by the Government of Poland.
- Protected area: Choczewskie Lakes, Area code : PLH220096, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),
- Protected area: Piaśnickie Łąki, Area code : PLH220021, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),

Special areas of birds protection (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Protected area: Przybrzeżne Wody Bałtyku, Area code : PLB990002, Form of protection in terms of Natura 2000: special area of bird protection (Birds Directive),Area status : designated area [by Resolution of Minister of Environment]

Landscape parks (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Nadmorski Park Krajobrazowy

Nature reserves (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Choczewskie Cisy
- Babnica
- Białogóra
- Długosz Królewski in Wierzchucin

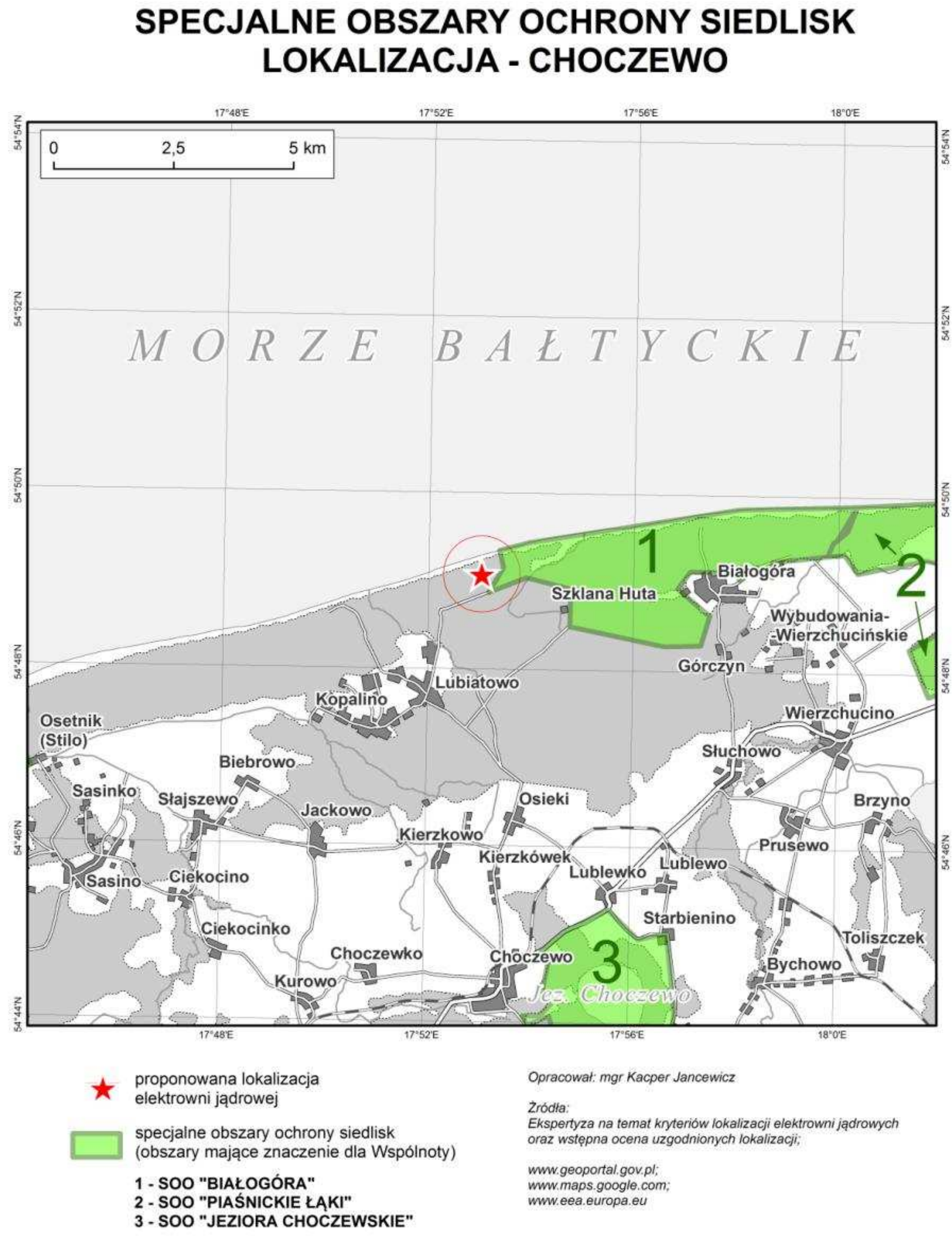

Fig. 6.3.18. Special habitat protection areas in the vicinity of Choczewo site

[SPECIAL HABITAT PROTECTION AREAS - CHOCZEWO SITE
Proposed power plant site

Special habitat protection areas (significant for the Community)
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

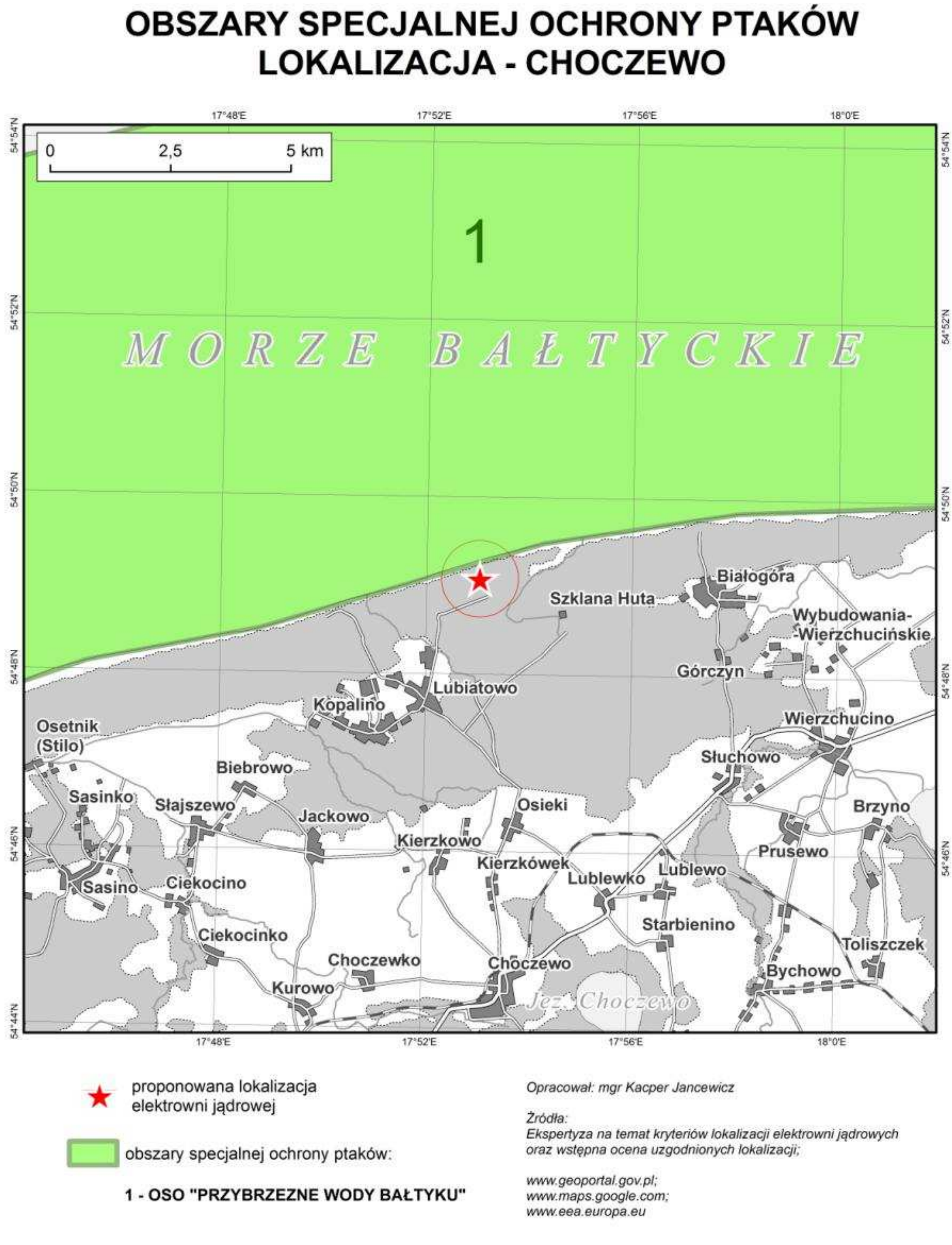

Fig. 6.3.19. Special bird protection areas in the vicinity of Choczewo site

[SPECIAL BIRD PROTECTION AREAS - CHOCZEWO SITE
Proposed power plant site

Special bird protection areas
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
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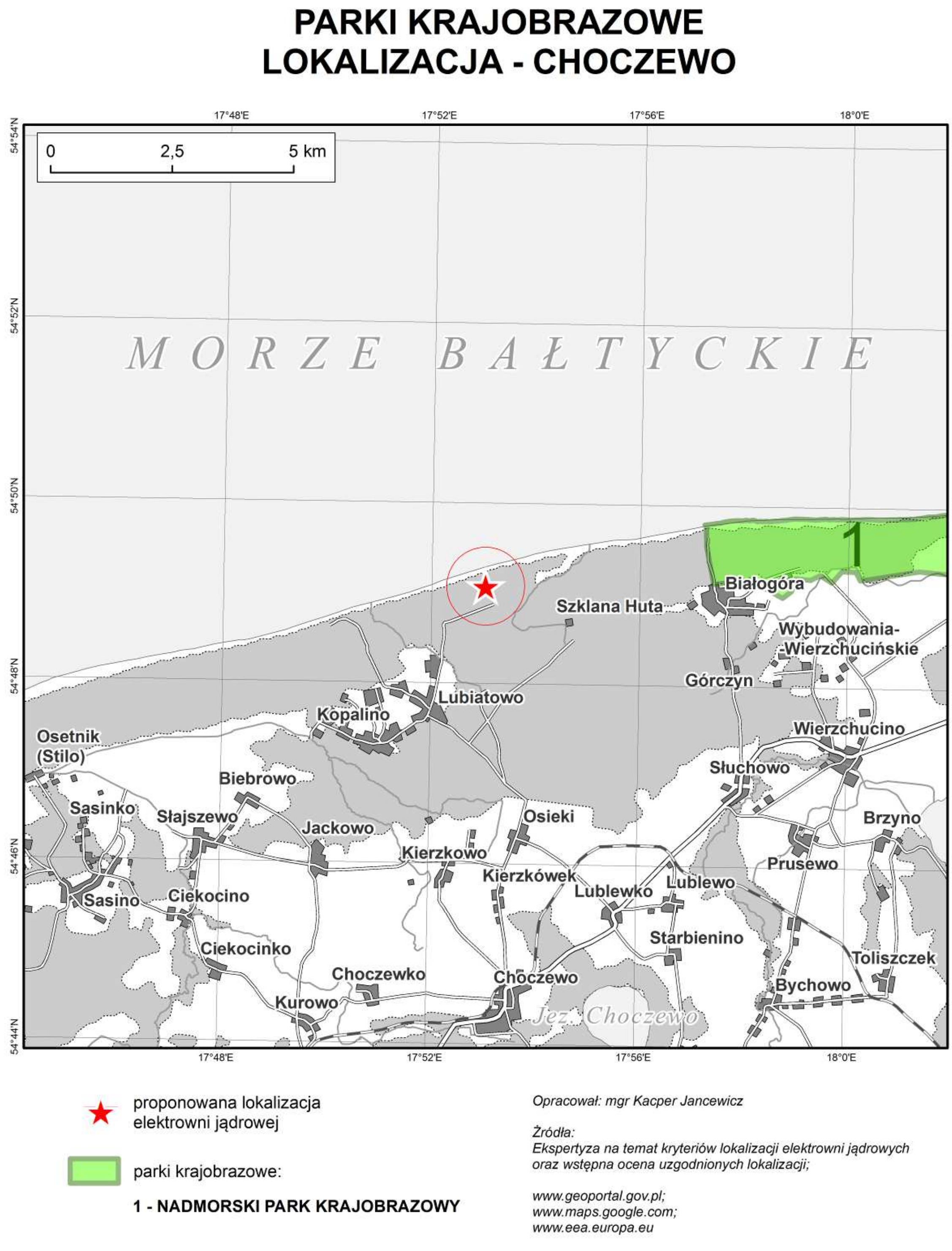

Fig. 6.3.20. Landscape parks in the vicinity of Choczewo site

[LANDSCAPE PARKS – CHOCZEWO SITE
Proposed power plant site

Landscape parks:
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

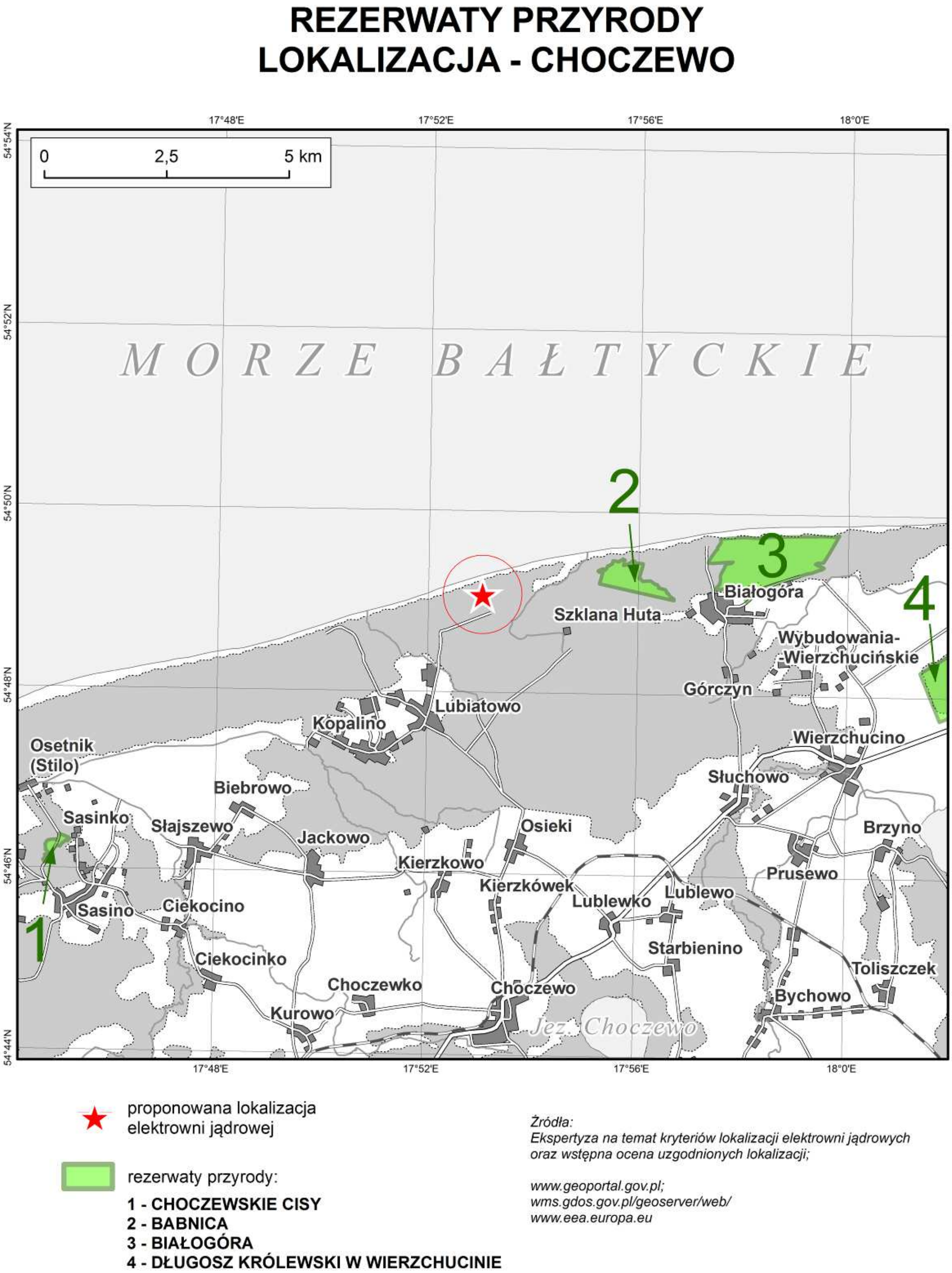

Fig. 6.3.21. Natural reserves in the vicinity of Choczewo site

[NATURAL RESERVES - CHOCZEWO SITE
Proposed power plant site

Natural reserves:
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

6.3.4.2 Lubatowo-Kopalino site

Basic environmental conditions

Lubiatowo-Kopalino NPP site was reported by Marshal of Pomorskie. It is located in the municipality of Choczewo, Wejherowski district, Pomorskie Province. Exact location of the power plant is presented in **Błąd! Nie można odnaleźć źródła odwołania.**. The municipality where the power plant is to be located has low population density (32 residents/km^2 at average population density in Poland 122 residents/km^2) due to which impacts of power plant construction and operation **will affect a small number of people**.

In the limited use area (the area within 800 meters from the plant) there are currently no residential or other buildings intended for human residence. Therefore, **there is no need for relocations** due to power plant construction.

Preliminary analyses show that due to location in the vicinity of the sea coast and **sufficient water resources** open cycle cooling system can be used in the power plant. The environmental impact of each cooling system solution has been discussed in detail in chapter 8.3.3.

The surroundings of Lubiatowo-Kopalino NPP have a very favourable wind energy zone, due to which **there will be no accumulation of potential pollutions** emitted from the power plant and other facilities in vicinity.

In the surrounding area provided for the construction of power plant, there are 13 archaeological sites in Kurowo. Due to possible violation of these sites **ground works should be conducted with extreme caution under the archaeological supervision**. In addition, construction at these sites may be withheld for the duration of work of archaeologists, when during earth works discovery of valuable cultural objects takes place.

In the vicinity of the planned investments **occurrence of natural resources and other useful minerals** was not stated, therefore **a threat of difficult access and exploitation of deposits does not exist** (see: chapter 8.3.6.2).

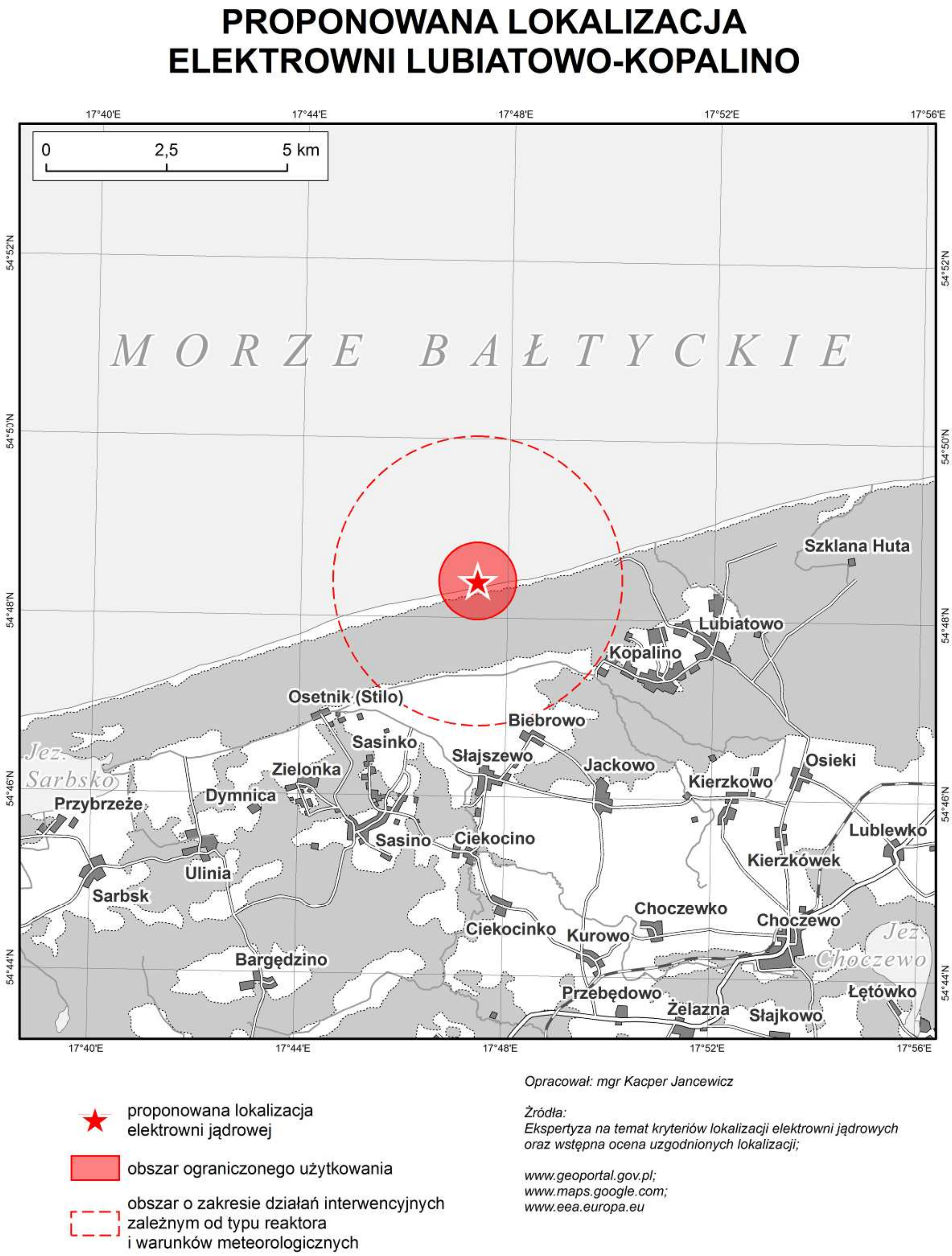

Fig. 6.3.22. Proposed site of Lubiatowo-Kopalino NPP

[PROPOSED SITE OF LUBIATOWO-KOPALINO POWER PLANT
Proposed power plant site

Limited use area
Area of interventions depending on reactor type and weather conditions
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

Geological structure and hydrogeology

In the area of potential NPP site there are boulder clays, and deeper - river and fluvioglacial sands. In the vicinity (ca. 10 km) the substrate contains a series of Triassic outcrops within the chalk, whose tectonic structure is not specified. Neotectonic reactivation of this structure cannot be excluded. Mesozoic roof and Tertiary strata lay on the substrate. In the distance exceeding 20 km a weak seismic shock was recorded, and maximum soil vibration acceleration is less than 0.02 g.

In the area of investment there is quaternary porous tank "Zbiornik Morenowy Salino" (GZWP 108), the average depth of groundwater intakes here is from 10 to 40 m. Depth to the main utility groundwater level varies between 5 and 10 m. The levels of aquifers show very low sensitivity to contamination. Groundwater runoff occurs in the direction of N. Good insulation from the ground surface with thick layer of aluminium sediments with low infiltration and movement of pollutants **should not cause** contamination of groundwater in case of contamination from the surface.

Infrastructure

The location is in the network area, currently characterized by a **small deficit of electricity production** below 100 MW. The existing transmission grid is loaded at more than 60%, which **does not give the possibility to use existing transmission capacity** to evacuate power from the NPP. To enable the network connection to NPP, expansion of > 250 km long transmission lines will be necessary. Potential extension may interfere with the Natura 2000 site. In addition, it is necessary to build the LV/LV/110 station. A detailed description of the impact of network expansion has been described in Chapter 8.3.7.

Site assessment made by PSE

From the viewpoint of the power balance in the NPS **location is advantageous**, which was emphasized with other nuclear power plant sites in the northern part of the country.

It should be noted, however, that in this case, difficulties should be expected with evacuation of full power (3200 MW) from the nuclear power plant into the NPS. In PRSP prepared by the TSO connection of the nuclear power plant to Żarnowiec node was considered. Results of analysis showed that in case of 1600 MW capacity, construction of an additional 2-track 400 kV line linking SE Żarnowiec with new station in the region of Gdansk is necessary. Expansion, however, was not sufficient for 3,200 MW and it is difficult to imagine the construction of other 400 kV lines from the node into the NPS. It is therefore proposed to consider this location for nuclear power plant with a capacity of not more than 1600 MW.

Moreover, for these locations attention should be paid to other factors that may adversely affect the location of nuclear power plant, associated with excess energy production in that area and with overloading of existing transmission networks:

- Construction of wind farms in the north. TSO (Transmission System Operator) has already issued the connection conditions for wind farms connected to SE Żarnowiec for the total power of 346 MW, and currently proceedings are pending concerning construction of further wind farms with a total capacity approximately 1600 MW (including a sea wind farm with capacity 420 or 1560 MW). It should also be noted that TSO issued the connection conditions for wind farms in neighbouring substations with total capacity ca. 1750 MW. Then there are proceedings pending at DSO (Distribution System Operator).

- Construction of a gas power plant with a capacity of 250 MW connected to SE Żarnowiec. At present it is difficult to judge whether the investment is feasible.

110 kV power supply line runs near the site, large distances between main supply points. Lack of centralised heat supply, lack of gas supply network.

The distance between the NPP site and existing urban infrastructure is as follows: main roads - up to 5 km, municipal roads - up to 5 km, railway lines - up to 10 km, water transport routes - from 5 to 15 km, airports - 20- 60 km, other urban infrastructure - up to 5 km. So developed communication network near the plant will allow for a diverse supply of goods during construction (building materials) and during operation of the plant (spare parts, uranium) supplied from other regions of the country or outside Poland.

Fauna and Flora

Fauna

Location on the border of the refuge Przybrzeżne Wody Bałtyku. Small crustaceans dominate the benthic fauna. Large marine mammals are rarely observed - grey seals *Halichoerus grypus*, ringed seals *Phoca hispida* and harbour porpoises *Phocoena phocoena*. The area is a bird sanctuary of European rank.

Key bird species for Natura 2000 Przybrzeżne Wody Bałtyku site:

red-throated loon *Gavia stellata*, black-throated loon *Gavia arctica*, horned grebe *Podiceps auritus*, long-tailed duck *Clangula hyemalis*, common scoter *Melanitta nigra*, velvet scoter *Melanitta fusca*, European herring gull *Larus argentatus*, common murre *Uria aalge* and razorbill *Alca torda*.

This area is a wintering location for 3 bird species from Annex I of the Birds Directive: black-throated loon, red-throated loon and horned grebe. Also populations of long-tailed duck, common scoter, velvet scoter and common murre and periodically European herring gull are significant (depending on intensity of fishing). In the vicinity there is a nesting ground for Eurasian eagle-owl *Bubo bubo* and place of permanent stay for white-tailed eagle *Haliaeetus albicilla* and osprey *Pandion haliaetus*.

Similarly to other sites located on the coast, the site, due to expansion of aerial transmission lines and their impact will be the subject of the separate study - see chapter 8.3.7.2.2 **as it can have significant impact on mortality of migrating birds.**

The location potentially significantly affecting Natura 2000 site Przybrzeżne Wody Bałtyku, but without collisions with ecological corridors. **More detailed analysis of the impact of NPP on Natura 2000 sites will be performed at the stage of preparing the Environmental Impact Report for construction of power plant when selecting a location, though it would be advisable to exclude this location because of the potential environmental effects of its implementation.**

Plants

With the adopted methodology of characteristics of the vegetation - based on the literature, the discussed location is close enough to a location in Choczewo that at this stage it is impossible to differentiate the description analysis of diversity of flora and vegetation for both locations. (See chapter 10.3.4.1)

Site with significant diversity of vegetation and numerous forms of nature conservation, **potential negative impact is relatively high**. **More detailed analyses of the impact of NPP on Natura 2000 sites should be performed on the stage of preparing the Environmental Impact Report for construction of the plant when selecting a site.**

Near the site, the following sites protected due to the environment occur:

Special areas of habitat protection (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Protected area: Białogóra, Area code : PLH220003, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive), Area status : area proposed by the Government of Poland.
- Protected area: Mierzeja Sarbska, Area code : PLH220018, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive), Area status : area proposed by the Government of Poland.
- Protected area: Choczewskie Lakes, Area code : PLH220096, Form of protection in terms of Natura 2000: special area of habitat protection (Habitats Directive),

Special areas of birds protection (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Protected area: Przybrzeżne Wody Bałtyku, Area code : PLB990002, Form of protection in terms of Natura 2000: special area of bird protection (Birds Directive),Area status : designated area [by Resolution of Minister of Environment]

Nature reserves (**Błąd! Nie można odnaleźć źródła odwołania.**):

- Babnica, Borkowskie Wąwozy
- Mierzeje Sarbska
- Choczewskie Cisy

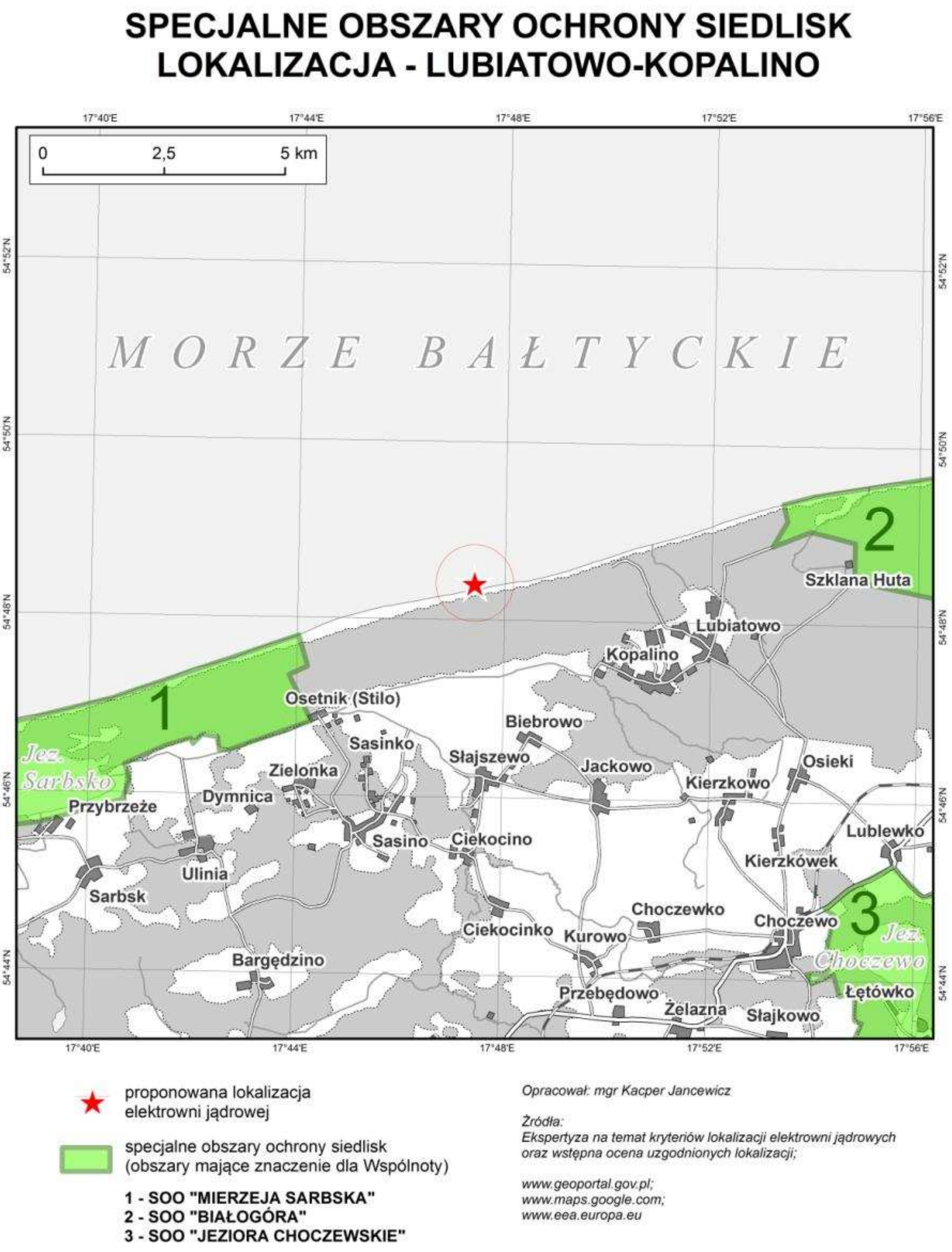

Fig. 6.3.23. Special habitat protection areas in the vicinity of Lubiatowo-Kopalino site

[SPECIAL HABITAT PROTECTION AREAS – LUBIATOWO-KOPALINO SITE
Proposed power plant site

Special habitat protection areas (significant for the Community)
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

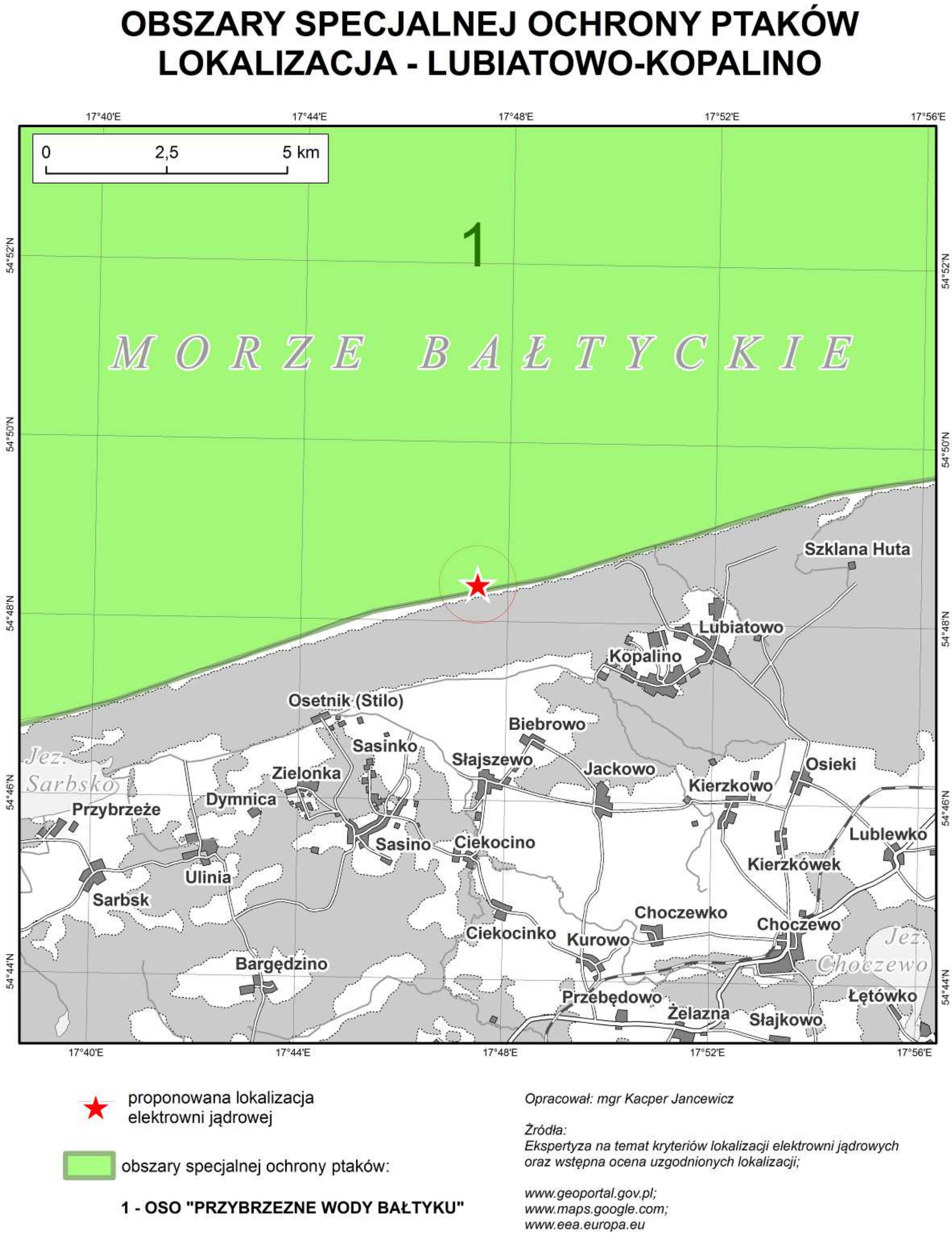

Fig. 6.3.24. Special bird protection areas in the vicinity of Lubiatowo-Kopalino site

[SPECIAL BIRD PROTECTION AREAS – LUBIATOWO-KOPALINO SITE
Proposed power plant site

Special bird protection areas
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

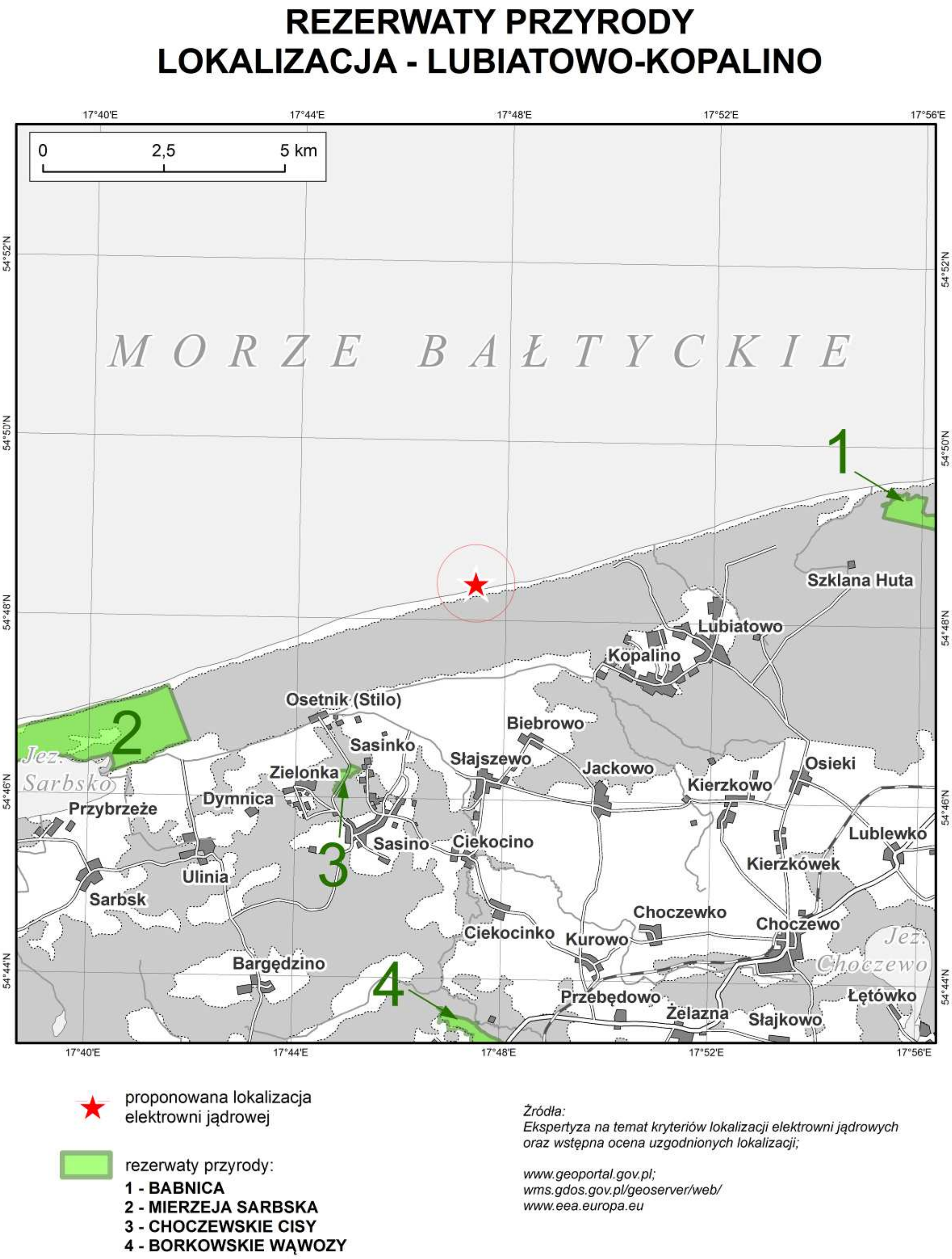

Fig. 6.3.25. Natural reserves in the vicinity of Lubiatowo-Kopalino site

[NATURAL RESERVES – LUBIATOWO-KOPALINO SITE
Proposed power plant site

Natural reserves:
Developed by: mgr Kacper Jancewicz
Sources:
"Expert opinion on criteria of nuclear power plant locations and preliminary assessment of established sites"
www.geoportal.gov.pl;
www.maps.google.com;
www.eea.europa.eu]

6.3.5 Summary and tabulation of major parameters for the recommended and reserve locations

Among the analyzed recommended and reserve locations, the safest in terms of animal biodiversity conservation and implementation of conservation objectives of Natura 2000 sites, is undoubtedly the location in Nowe Miasto. Located 30 km from the nearest refuges, it will have the smallest impact among the analyzed locations on Natura 2000 network (the potential impact of expansion of overhead transmission lines), it does not interfere with the network of ecological corridors, there is also nothing to suggest that there are particularly well attended bird migration routes and there are no data on the wealth of fauna of the area (no data at the current level of faunistic knowledge in Poland certainly demonstrates not outstanding natural values of this area, although they are not necessarily very small). This location looks particularly well against the other five location, four of which lie in the coastal zone, which is on most important Polish migration route of birds, additionally neighbouring the Natura 2000 bird refuges. Warta-Klempicz lies within SPA refuge and in the place of increased migration of birds, and also interferes with the ecological corridor.

It is worth mentioning that due to the fact that the assessment was based on the fragmentary, heterogeneous, literature data, not dedicated to individual locations, when assessing the locations attempts were made at maintaining care in drawing far-reaching conclusions. Hence, locations not far away from the Natura 2000 sites or those placed on the migratory path of birds, gained the status of risky, and they were not given a negative assessment (as was done for locations within Natura 2000 sites). In such situations, there are no clear, compelling premises to exclude a given location from analyzed ones, it can only be regarded as risky (i.e. high probability of significant impact on Natura 2000 sites and/or resources of flora and fauna).

Collective analysis of individual parameters for each of these locations is presented in Table 10.3.1. on the next page.

6.3.6 Other proposals and location variants

Considering the size of the location analysis, this entire section was moved to an Annex constituting an integral part of the Strategic Environmental Assessment Report for the Polish Nuclear Programme.

7 FULL TABLE OF CONTENTS FOR THE FORECAST

8 LIST OF FOOTNOTES

Below, all the footnotes in this document are given. At the same time, this is a synthetic description of data sources and literature used to prepare the report. This manner of presentation is most appropriate due to significant volume of the document.

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[1] Example: "Rządzie, więcej energii" [Government, give us more energy], Gazeta Wyborcza, 2008, URL: http://wyborcza.pl/1,75248,5090397.html (accessed on: 10 December 2010).

[2] IAEA GS-G-2.1 Arrangements for preparedness for emergencies Pub1265_web.pdf
IAEA GS-G-4.1 Format and content of NPP SAR Pub1185_web.pdf
IAEA INSAG 10 Defence in depth Pub1013.pdf
IAEA NS-G-1.13 Radiation protection aspects of NPP design Pub1233_web.pdf
IAEA NS-G-1.2 Safety assessment for NPPs Pub1112_scr.pdf
IAEA NS-G-1.8 Design of Emergency Power Systems Pub1188_web.pdf
IAEA NS-G-3.3 Evaluation of seismic hazards Pub1144_web.pdf
IAEA NS-R-1 Safety of NPPs -design.pdf
IAEA NS-R-3b Site evaluation for NPP Pub1177_web.pdf
IAEA Proc 2003 Safety of transport of radioactive materials Pub1200_web.pdf
IAEA SF-1 Fundamental Safety Principles Pub1273_web.pdf
IAEA Standards status with Internet addresses.pdf
IAEA TS-R-1 Regulations for safe transport Pub1225_web.pdf
IAEA WS-G-3.1 Remediation process Pub1282_web.pdf
IAEA Safety Standards Series: Review and Assessment of Nuclear Facilities by the Regulatory Body Safety Guide No. GS-G-1.2

[3] WENRA List_of_reference_levels_January_2007.pdf
WENRA RHWG Harmonization Report.pdf
WENRA waste and spent fuel storage 2005.pdf
WENRA WGWD Report on Decomm Safety Ref Levels.pdf

[4] "Oceny oddziaływania na środowisko planów i programów. Praktyczny poradnik prawny" [Assessments of environmental impact of plans and programs], Jerzy Jendrośka, Magdalena Bar, Centrum Prawa Ekologicznego, Wrocław 2010.

[5] (European Commission: Integrated Polution Prevention and Control (IPCC). Reference Document on the Application of Best Available Techniques to Industrial Cooling Systems. December 2001. Ministry of Environment. Warsaw, January 2004.

[6] UU Nuclear Regulatory Commission, US NRC Policy Statement on Nuclear Power Plant Safety Goals, Atomic Energy Clearing House, 32(26); (23 June 1986).

[7] Critical population group – the most exposed group, e.g. in the case of the population living in the vicinity of a nuclear power plant it is usually infants or children 2-7 years old who live in the area around the plant.

[8] UNSCEAR Report 2000: Sources and Effects of Ionizing Radiation.

[9] Strupczewski A. Oddziaływanie małych dawek promieniowania na zdrowie człowieka [Impact of small radiation doses on human health], Biuletyn Miesięczny, June 2005, p. 10-25.

[10] Insights into the control of the release of iodine, strontium and other fission products in the containment by severe accident management, NEA/CSNI/R(2000)9.

[11] SPAIN, Convention on Nuclear Safety, Third National Report, September 2004.

[12] FRANCE 3rd French National Report on Implementation of the obligations of the Convention on Nuclear Safety issued for the 2005 Peer Review Meeting, July 2004.

[13] UK-EPR Fundamental Safety Overview Volume 1: Head Document Chapter G: Environmental Impact Sub-Chapter G.3 .

[14] UK AP1000 Safety, Security, and Environmental Report, 11. Radioactive Waste Management

[15] ESBWR Design Control Document/Tier 2 26A6642BJ Rev. 03.

[16] ANSI/ANS, "American National Standard Radioactive Source Term for Normal Operation of Light Water Reactors," ANSI/ANS-18.1-1999.

[17] General Electric Company, "Technical Derivation of BWR 1971 Design Basis Radioactive Material Source Terms," NEDO-10871, March 1973.

[18] ANSI/ANS, "American National Standard Radioactive Source Term for Normal Operation of Light Water Reactors," ANSI/ANS-18.1-1999.

[19] Wielkości emisji są większe niż dopuszczalne wg zaostrzonych przepisów francuskich dla nowych reaktorów, ale stężenia są od 100 do 1000 razy mniejsze niż dopuszczalne stężenia graniczne wg 10CFR20.

[20] US NUCLEAR REGULATORY COMMISSION, US NRC Policy Statement on Nuclear Power Plant Safety Goals, Atomic Energy Clearing House, 32(26); (23 June 1986).

[21] European Utility Requirements for LWR Nuclear power Plants, Volume 1 &2, Rev. C April 2001.

[22] Government Decree (733/2008) on the Safety of Nuclear Power Plants Issued in Helsinki on 27 November 2008, http://www.finlex.fi/fi/laki/kaannokset/2008/en20080733.pdf.

[23] RADIATION AND NUCLEAR SAFETY AUTHORITY (STUK): Statement Issued by the Radiation and Nuclear Safety Authority Concerning the Construction of the Olkiluoto Nuclear Power Plant Unit 3, Annex 1 21.1.2005 Safety Assessment of the Olkiluoto 3 Nuclear Power Plant Unit for the Issuance of Construction License.

[24] This scenario is alternative, equivalent, but formulated differently. At the time of writing of this document (5 December 2010), the decision on the final formulation of this requirement had not been made.

[25] Design Conditions, Design Objectives, and other terms corresponding to the special definitions given in the EUR requirements are spelled with capital letters (the same as in the EUR) so as to highlight their special nature conformant to the EUR definitions.

[26] European Utility Requirements For LWR Nuclear Power Plants 2.1.B. Appendix B: Verification process of the EUR environmental impact targets.

[27] The hazards occurring after accidents are connected with the release of five isotopes of iodine, whereby the radiological hazards caused by each of them is different. For simplicity's sake, the hazards caused by the isotopes are translated into the equivalent for iodine I-131. Hence the term "equivalent I-131 radiological hazard."

[28] UK AP1000 Safety, Security, and Environmental Report, 15. Accident Analyses SSER 15.6-1 Revision 1 15.6 Decrease in Reactor Coolant Inventory.

[29] US NRC RG 1.183 Alternative Radiological Source Terms For Evaluating Design Basis Accidents At Nuclear Power Reactors, July 2000.

[30] NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants", 1998.

[31] UK AP1000 Safety, Security, and Environmental Report, 15. Accident Analyses SSER 15A-1 Revision 1 Appendix 15a, Evaluation Models And Parameters For Analysis Of Radiological Consequences Of Accidents

[32] Subsection 5.5.2, Item (3) of ANSI/ANS-58.14-1993.

[33] 26A6642BP Rev. 03, ESBWR Design Control Document/Tier 2, 15.4.47.

[34] Analysis of compliance of the Standard EPR vs. EUR: the main findings P. Berbey *EUR project manager* Warsaw, April 27 2010.

[35] 45. Fission-Product Source Terms UK AP1000 Probabilistic Risk Assessment.

[36] ESBWR Design Control Document/Tier 2 , 26A6642BP Rev. 03, 15.4-32 Table 15.4-5.

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[39] OECD CSNI, "Consideration of quantitative safety guidelines in member countries", Committee on the Safety of Nuclear Installations, OECD Nuclear Energy Agency, CSNI Report No 177, Paris, (October 1990).

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[41] Gosatomnadzor RF "Criteria for siting the nuclear power station", PNAE-G-03-33-93, Moscow (1996).

[42] NRB-96, "Radiation Safety Norms", Russian Federation Ministry of Health, Moscow, (1996).

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[48] ACRS, Implementation of the Safety Goal Policy, Nuclear Safety, Vol. 33, No. 4, (October- December 1992), 629-631.

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[50] WNA: Decommissioning nuclear facilities (updated October 2010). http://www.world-nuclear.org/info/inf19.html.

[51] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.pdf.

[52] Scientific American.

[53] Decommissioning Maine Yankee, Scientific American.

[54] Maine Yankee Community Advisory Panel on Decommissioning http://www.maineyankee.com/public/cap%20final.pdf.

[55] OECD/NEA Decommissioning of Nuclear Power Plants – Policies, Strategies and Costs (2003).

[56] US NRC Inspection Reports for Maine Yankee from August 1998 through January 2003 (IR 98-04 – 03-03) (www.nrc.gov).

[57] Wald M. Dismantling Nuclear Reactors, Scientific American, March 2003, 33-41.

[58] IAEA Financial aspects of decommissioning, IAEA-TECDOC-1476, November 2005.

[59] UK EPR Fundamental Safety Overview Volume 2: Design And Safety Chapter T: Decommissioning And Dismantling Contents Chapter: T.

[60] Regulatory Guide 1.4,. "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss-of-Coolant Accident for Pressurized Water .Reactors, www.nrc.gov/reading-rm/doc.../reg-guides/power.../01-029.pdf.

[61] Nuclear Regulatory Commission (NRC) Regulatory Guideline 1.145, Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants (NRG-RG-1.145, NRC 1982).

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[63] J. F. Sagendorf, "A Program for Evaluating Atmospheric Dispersion From a Nuclear Power Station,'.NOAA Tech Memo ERL-ARL-42, 1974.

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[65] NRC Regulatory Guide 1.111, Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors (NRC-RG-1.111, NRC 1977).

[66] Fransioli P.: Calculations of Acute and Chronic "Chi/**Q"** Dispersion Estimates for a Surface Release, TDR-MGR-MM-000001, Rev 00, December 17, 1999.

[67] -RODOS RA2 TN03-01, 2003.

[68] Good Practice Guide for Atmospheric Dispersion Modelling.

[69] USNRC, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," Regulatory Guide 1.145, Revision 1, November 1982.

[70] J. Guin et al.: Site Boundary Considerations For New Nuclear – Darlington, http://www.ceaa.gc.ca/050/documents_staticpost/cearref_29525/0105/ai-sb.pdf

[71] UKEPR-0003-110 – Issue 02, pre-construction environmental report chapter 11: radiological impact assessment.
[72] When calculating the daily dose from radiation emitted by a nuclear power plant, the assumed period of 50 years does not cause significant change in the results compared with a 60-year period of operation.
[73] The location factor is the ratio of the dose rate measured indoors to the dose rate measured outdoors.
[74] The $1/r^2$ can also be used. Using 1/r provides a larger safety margin.
[75] ESBWR – UK Preliminary Safety Report Step 2 Sections 1.0 – 2.
[76] Arrêté du 20 novembre 2009 portant homologation de la décision no 2009-DC-0153 de l'Autorité de sûreté nucléaire du 18 août 2009 relative aux niveaux d'intervention en situation d'urgence radiologique, 18 décembre 2009 Journal Officiel De La République Française Texte 38 sur 127.
[77] Fundamental Safety Overview Volume 2: Design And Safety Chapter P: Reference Operating Condition Studies (Pcc), Sub-chapter P.3, p. 11.
[78] AP1000 European Design Control Document, Ch. 2. Site Characteristics, 2009.
[79] AP1000 European Design Control Document EPS-GW-GL-700 15.6-15 Revision 0 Accident Analyses Ch. 15.6.
[80] 10 CFR Part 50.34.
[81] AP1000 European. 15. Accident Analyses Design Control Document, 15.1.5.4.6 Doses.
[82] TEDE is an acronym for Total Effective Dose Equivalent which is normally used in documents prepared in the USA. It is a counterpart of the term "effective dose". According to US regulations, TEDE is a sum of the *committed effective dose equivalent (CEDE*) and the *deep dose equivalent (DDE*). When calculating the two components, one must take into account all the radionuclides, including derivatives from decay of the parent radionuclides, if they make a significant contribution to the dose and the value of the released radioactivity.
[83] ESBWR Design Control Document/Tier 2, 26A6642BP Revision 3 February 2007 Chapter 15 Safety analysis Part 2.
[84] Regulation of the Council of Ministers of 27 April 2004 on the values of the intervention levels for the different types of intervention measures and the criteria for appeal against such measures (Journals of Laws no. 98, item 987).
[85] UK AP1000 Safety, Security, and Environmental Report, 15. Accident Analyses, 15.1.5.4.6 Doses.
[86] LPZ – an area that is defined in US regulations but that does not exist as a separate zone in the regulations of most countries of the European Union. A close counterpart of this area is a 3 km zone around a nuclear power plant where, in the event of a severe accident, such intervention measures as administration of stable iodine may be implemented.
[87] U.S. EPR Final Safety Analysis Report, Tier 2 Revision 1 Ch 15.1, page 2.1-7 http://adamswebsearch2.nrc.gov/idmws/
DocContent.dll?library=PU_ADAMS^pbntad01&LogonID=53e7d43f23702c77d75094c5d2cde4ec&id=092460394.
[88] TEDE is an acronym for Total Effective Dose Equivalent which is normally used in documents prepared in the USA. It is a counterpart of the term "effective dose". According to US regulations, TEDE is a sum of the *committed effective dose equivalent (CEDE*) and the *deep dose equivalent (DDE*). When calculating the two components, one must take into account all the radionuclides, including derivatives from decay of the parent radionuclides, if they make a significant contribution to the dose and the value of the released radioactivity.
[89] Doehnert M. Project of AP1000 power reactor, Intern. Symp. Nuclear Power for Poland, Warsaw 2006.
[90] General Electric Hitachi : The ESBWR Plant General Description **.**
[91] As of 5 December 2010.
[92] UK EPR Fundamental Safety Overview Volume 3: Environmental Impact Chapter D: Potential Environmental And Health Effects Chapter D Section: D.7.3.2.
[93] CM – Carte Marine – seachart, 0 m CM is the water level at the lowest low tide level which, in the case of Flamanville, is equal to 4.92 m.

[94] Sievert is a unit used in radiation protection, equal to a dose absorbed by a human body, taking into account its biological effectiveness. In the nuclear sector, doses a thousand times smaller, i.e. mSv, are of interest.

[95] Państwowa Agencja Atomistyki: Działalność Prezesa Państwowej Agencji Atomistyki oraz ocena stanu bezpieczeństwa jądrowego i ochrony radiologicznej w Polsce w 2009 roku. [National Atomic Energy Agency: Activity of the President of the National Atomic Energy Agency and evaluation of the status of nuclear safety and radiological protection in Poland in 2009], Warsaw, June 2010.

[96] IAEA Sustainability of Nuclear Power, Vienna, 1997.

[97] Hormesis is any physiological effect occurring at small doses that cannot be anticipated by extrapolating the toxical effects caused by large doses. Hormetic effects are usually beneficial. They characterize processes where small doses of agents that are harmful if taken in large doses stimulate the defensive mechanisms of an organism (the Greek word *hormáein* means to set in motion, impel, urge on).

[98] Low level Radiation Health Effects, RSH Compiling the Data, III Edition,March 2002, Chapter 1.3.2 Lower-order Animals.

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[101] UNSCEAR, "Sources and effects of ionizing radiation", Report to the General Assembly, UN, New-York, (1994).

[102] Frigerio, N.A., Stowe, R.S., "Carcinogenic and genetic hazards from background radiation", in: Proc. of a Symp. on Biological Effects of Low-Level Radiation Pertinent to Protection of Man and His Environment , (Chicago 3-7 Nov. 1975), IAEA, Vienna (1976).

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[163] Np.-137; Am-241,242m,243; Cm-243,244,245.

[164] I-129, Tc-99, Sn-126, Cs-135, Zr-93 i Se-79.

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[203] [BAT, Table 3.3], although other reports quote water consumption smaller only by 30%.

[204] NEI: Water Use and Nuclear Power Plants. http://www.nei.org/keyissues/protectingtheenvironment/factsheets/water-use-and-nuclear-power-plants-page4.

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[209] Westinghouse: UK AP1000 Environmental Report. UKP-GW-GL-790. (Sec. 4.2.3.3).

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[213] The given value of irreversible loss is rather high compared to mean annual values for „Warta" power plant - 1.44% Q_w, and estimated in this study - 1.21% Q_w. Perhaps it is the value of maximum loss in summer (this study estimates it at 1.61% Q_w). Water consumption per discharged thermal power index = 0.39 $m^3/s/1000\ MW_t$ is close to the one estimated in this study (0.43 $m^3/s/1000\ MW_t$).

[214] Especially if large conventional thermal power stations are built in the meantime, and such are currently planned on lower Wisła (near Grudziądz and Opaleń).

[215] With 2 units of any type, cooling water demand is lower.

[216] Local water resources seem insufficient without water from the river Warta.

[217] Local water resources seem insufficient without water from Lake Miedwie (also applies to Lisowo and Wiechowo sites).

[218] It was assumed that during normal operation of a power unit 300 persons are on the premises, the number increases to ca. 1000 during fuel reloading and current overhaul downtime, and to 1300 during medium overhaul downtime (every 10 years).

[219] Intake was executed from 8 deep water wells of total capacity 240 m^3/h = 0.067 m^3/s.

[220] Ordinance of Minister of Environment of 24 July 2006 on conditions of introduction of sewage to water or soil and on particularly harmful substances for aquatic environment (Journal of Laws No. 137 of 2006, item 984) - §18.1.

[221] Water law act of 18 July 2001 (Journal of Laws No. 115 of 2001, item 1229, as amended) – art. 39, excerpt 2, point 3.

[222] Ordinance of Council of Ministers of 14 October 2008 on environmental fees (Journal of Laws No. 196 of 2008, item 1217) - §4, point 1-3.

[223] Announcement of Minister of Environment of 4 October 2010 on environmental fee rates for the year 2011 (M. P. No. 74 of 2010, item 945) – Annex No. 2, Table C.

[224] If we disregard outdated analyses performed for the purpose of designing the "old" Żarnowiec power plant: 4 units with WWER-440/W-213 reactors, each with gross capacity 465 MWe, open-cycle cooling system.

[225] UK EPR. Pre-Construction Environmental Report. Chapter 12: Non-radiological Impact Assessment.

[226] UK AP1000 Environment Report. UKP-GW-GL-790, Revision 3.

[227] UNIPEDE / EURELECTRIC: BAT for Cooling Systems. Working Group "Environmental Protection". January 1999.

[228] For instance: In North Sea and English Channel in order to eliminate sea clams, chlorination is performed 7 months a year with concentration from 0.5 to 1.0 mg/l. residual oxidizer concentration on the system outlet is 0.1-0.2 mg/l.

[229] Semi-constant or pulsatory dosing with low concentration is used in Canada against zebra mussels and in France and the Netherlands to reduce number of sea clams in power plants.

[230] Total residual oxidizers (TRO).

[231] Vanderheyden, M.D., Schuyler, G.D.: Evaluation and quantification of the impact of cooling tower emissions on indoor air quality. ASHRAE Transactions of Annual Meeting, Vol. 100, Part 2 (pp. 612-620).

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[236] Response of junior secretary in Ministry of Environment - pp. Prime Minister - to a query no. 11997 on Polish obligations in terms of emission of sulphur dioxide and nitrogen oxides

[237] Fuel and Power Demand Forecast by 2030

[238] Polish Power Industry Policy by 2030

[239] Development Plan in terms of covering current and future power demand for the years 2010-2025. Extract. Konstancin – Jeziorna, March 2010. Polskie Sieci Elektroenergetyczne S.A.

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[241] Kalesnik S., 1979, Podstawy geografii fizycznej {Basics of physical geography], PWN, Warsaw

[242] Journal of Laws of 30 April 2004 No. 92 item 880

[243] Natural and landscape complexes are fragments of natural and cultural landscape under protection due to their visual or aesthetic values.

[244] Sources of photographs: http://ziemianarozdrozu.pl ; http://www.kleszczow.pl ; http://www.freefoto.com ; http://www.oregonlive.com ; http://www.greenpeace.org.uk ; http://www.theenergycollective.com

[245] Attitude of local communities in European countries towards locations of nuclear power plants in their neighbourhood, Senate Office, Warsaw 2009

[246] Ranking of the richest municipalities in the country published in the weekly local government newspaper "Wspólnota"

[247] What specific advantages will municipality and poviat (and to a lesser extent, province) residents obtain from a nuclear power plant?, www.atom.edu.pl

[248] www.kleszczow.pl

[249] www.mg.gov.pl

[250] Thywissen K., 2006. Components of Risk. A Comparative Glossary. SOURCE, Publication Series of UNU-EHS (United Nations University – Institute for Environment and Human Security) 2

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[254] Definition according to Act on protection of agricultural and forest land of 3 February 1995 (Journal of Laws 1995 No. 16, item 78 as amended). As a rule it is assumed that inviolable flow, depending on a river, is 0.5 - 1.5 SNQ, i.e. medium among lowest annual water flows in a river in perennium

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[256] Zarządzanie obszarami Natura 2000. Postanowienia art. 6 dyrektywy “siedliskowej” 92/43/EWG, Polish version of the study Managing Natura 2000 sites. The provisions of Article 6 of the 'Habitats' Directive 92/43/EEC,s. 43, available at http://ec.europa.eu/environment/nature/natura2000/management/docs/art6/provision_of_art6_pl.pdf in the version WWF Polska 2007 [15.07.2008].

[257] The only attempt at definitional approach to public interest is contained in the Act on Spatial Planning and Development (Journal of Laws of 2004 No. 80, item 717, as amended), which in art. 2 p. 4 contains the statutory definition of public interest, according to which it should be construed as "generalized target of goals and measures, taking into account the objectified needs of the general public or local communities, associated with land development". Without going into details, on the example of this definition one may indicate a fundamental problem of determining the content of the concept of "public interest", namely the definition of the indeterminate concept by other vague concepts (objectified needs), and the contradiction of various public interests of different social groups, and individual interests, whose sum is not yet public interest.

[258] Overview of interpretations of the notion of public interests see W. Jakimowicz, Wykładnia w prawie administracyjnym [Interpretation in administrative law], Zakamycze, Kraków 2006, p. 84 et seq., A. S. Duda, Interes prawny w polskim prawie administracyjnym [Legal interest in Polish administrative law], C.H. Beck, Warszawa 2008, p. 19 et seq. and R. Sowiński, Interes publiczny – dobro wspólne [Public interest - the common good]. Universal values as categories shaping the notion of administration, [in:] The right to good administration. Materials from the Congress of Departments of Law and Administrative Procedure, Warszawa-Dębe 23-25 September 2002, Wyd. WNT, Warsaw 2003.

[259] Regional Administrative Court Judgement of 4 August 2005. III SA/Wa 646/05. LEX no. 19088.

[260] K 23/98, OTK 1999, No. 2, item 25.

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[266] G. Kaliszuk, Bezpieczeństwo Energetyczne Polski [Polish Energy Security], „Stosunki międzynarodowe”, 03.01.2010, http://www.stosunki.pl/?q=content/bezpiecze%C5%84stwo-energetyczne-polski [14.12.2010].

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[270] Compare: Management of Natura 2000 areas. Guidelines from 2007 on art. 6. 4 of Habitats Directive, concerning the concepts: alternative solutions, imperative requirements of overriding public interest, compensatory measures, overall coherence, the Commission's opinion - this is a revised version of Chapter 5 of the guidelines for Managing Natura 2000 sites. The provisions of Article 6 of the 'Habitats' Directive 92/43/EEC of 2000, available at

http://ec.europa.eu/environment/nature/natura2000/management/docs/art6/guidance_art6_4_pl.pdf, in the version WWF Polska [15.07.2008].

[271] The method of defining the concept of health and public safety in ECJ case law discussed [in:] Stosowanie prawa Unii Europejskiej przez sądy [Application of European Union law by the courts], A. Wróbel (ed.), Zakamycze, Kraków 2005, p. 248 et seq. The domestic law assumes that public safety and health protection issues will include projects involving flood protection and military infrastructure, and the activities of primary effect on the environment - such as building sewage treatment plants. Compare A. Kawicki, E. Forkiewicz, A. Jendrasiak, Procedura wydawania decyzji o środowiskowych uwarunkowaniach. Komentarz ze wzorami dokumentów [The procedure for issuing a decision on the environmental conditions. Commentary with document templates] volume 2, Municypium SA, Warsaw 2007, p. 153.

[272] Case C 57/89 European Commission v Federal Republic of Germany, judgment of 28 February 1991, elaborated by: . Urban, Opinie Komisji Europejskiej sprawie planów i przedsięwzięć negatywnie oddziałujących na obszary Natura 2000 [European Commission reviews of the plans and projects adversely affecting Natura 2000 areas], „Problemy Ocen Środowiskowych" 2006, no. 1 and idem, Negatywne oddziaływanie planów i przedsięwzięć na sieć Natura 2000 a nadrzędny interes publiczny [The negative impact of plans and projects on Natura 2000 network and overriding public interest]. Analysis of the concept of "imperative reasons arising from overriding public interest", [in:] Wspólnotowe prawo ochrony środowiska i jego implementacja w Polsce trzy lata po akcesji [Community environmental law and its implementation in Poland three years after accession], J. Jendrośka, M. Bar (ed.), CPE, Wrocław 2008, p. 149 et seq. And by Otawski, Wdrażanie sieci Natura 2000 w Polsce – aspekty prawne [Implementation of the Natura 2000 network in Poland - legal aspects], [in:] Problemy prawa rolnego i ochrony środowiska [Problems of agricultural law and environmental protection], Wyd. Forum Naukowe, Poznań 2004, p. 173.

[273] Management of Natura 2000 areas. Guidelines from 2007.

[274] S. Urban, Opinie Komisji Europejskiej [Opinions of the European Commission], p. 29.

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[276] Assessment of plans and projects significantly affecting Natura 2000 sites. Methodological guidance on the provisions of Art. 6 (3) and (4) of the Habitats Directive 92/43/EEC, European Commission, DG Environment, November 2001, WWF Poland Polish version 2005, p. 15 and the decision in case C 355/90 European Commission v Spain, judgment of 2 August 1993, ECR 1993 I-04221, and case C 44/95 Regina versus Secretary of State for the Environment, judgment of 11 July 1996 ECR 1996 I-03 805.

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[278] IV SA/Wa 2319/06, LEX no. 307447.

[279] Polish Power Industry Policy by 2030

[280] Krajowy Ośrodek Badań i Dokumentacji Zabytków [National Centre for Research and Documentation of Monuments]

[281] "Party of origin" means a Party or Parties to this Convention under whose jurisdiction a planned activity is to take place;

[282] "environmental impact assessment" means a national procedure for evaluating the likely impact of the planned activities on the environment;

[283] competent authority" means the authority or public authority designated by a Party as responsible for the execution of the tasks defined in this Convention and/or the authority or authorities entrusted by the Board with making decisions concerning the planned activities;

[284] A summary of the EIA programme was translated into the language of each notified Party; this summary was intended for use by the public http://www.unece.org/env/eia/pubs/factsheet5.html

[285] Example: „Rządzie, więcej energii, Gazeta Wyborcza, 2008, URL: http://wyborcza.pl/1,75248,5090397.html (access date: 2010-12-10)

[286] http://stop-odkrywce.pl

[287] http://www.trzcianka.info/elektrownia-atomowa-klempicz (access date 2010-12-09)

[288] Only in industrial areas

[289] NIMBY syndrome occurs

[290] 69% respondents from Temelin area support the development nuclear power plant in their area. 90% of the population of Dukowany, where the nuclear power plant is located - Moravia - support continued operation.

[291] Most operating nuclear power plants are located in tourist zones, potentially, often with optimal conditions for the development of agriculture

[292] All national and local polls showed widespread support for nuclear power plants, as electricity producers

[293] The investor may not receive permission for such construction

[294] The planned Visaginas nuclear power plant will be located near the nuclear power plant in Igalina. Some respondents (4.5%) asked about the impact of new nuclear power plant on tourism said that it will be positive, the opposite view was held by a smaller proportion (2.5%) of respondents

[295] None of the nuclear power plants was built in areas of higher than average touristic or natural attractiveness. Rather, they were built in industrial or agricultural areas. There currently is a ban on construction of nuclear plants.

[296] Lubmin is a small port near the island of Rügen and Usedom. These are coastal, tourist areas. The nuclear power plant located there - the largest in the former East Germany - was closed in 1990

[297] The reply: "It is difficult to imagine today the construction of new nuclear power plants. Any attempt to argue for their construction would be received by the public as a provocation. The public debate now focuses on the possible extension of the reactors' operation time. In German public opinion, nuclear power stations are not associated with the image of a modern infrastructure. Modern forms of energy are - according to widespread belief among Germans - renewable energy, possibly efficient gas turbines, and most of all thinking about energy efficiency and smart energy consumption. On the other hand nuclear energy is seen as the energy of the past, which today can only act as transitional,
supporting the change to renewable energy - and nothing more. All political parties represented in the Bundestag, are in agreement in this respect"

[298] The two power stations, Jaslovskie Bohunice and Mochovce, were built in the 70s outside the areas of touristic significance

[299] Currently, there is a ban on construction

[300] In Sweden the issue of building safe nuclear power plants was from the old days (1968) put at the first place,e therefore power plants could be located near population centers and it can be assumed that previously such a location in tourist areas was possible

[301] No polls on the location of nuclear power plants.

[302] A license was issued for a location in Akkuyu, in a naturally attractive area of Mediterranean bay

[303] Nuclear power plants were located far from population centers, in uninhabited areas. Only near the new built plants, settlements were constructed for newly arrived employees. In 2007 the government decided that new nuclear power plants will be built on the site of the old, closed plants.

[304] http://www.tvn24.pl/-1,1581562,0,1,mama-gosiewska-przeciwko-energii-atomowej,wiadomosc.html (access date: 2010-12-09)

[305] http://www.atom.edu.pl/images/stories/atomowe/bezpieczenstwo/czarnobyl/zarzad_ptfm_oryginal_oswiadczenia_o_jaskowskim.pdf (access date 2010-12-11)

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328 Gaia Theory– theory proclaiming that the Earth functions as one giant organism, adapted to the changes in order to maintain suitable conditions for life. Theory suggests that life on Earth will continue regardless of the actions of humans.

329 Friends of the Earth International (FoEI) – international environmental organization, having its headquarters in Amsterdam, bringing together more than 70 countries, approximately 1.5 million members and supporters

who carry out campaigns on the most important contemporary environmental and social problems, while working for the local and global sustainable development.

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