Ministry of Energy and Coal Industry of Ukraine

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UPDATED INFORMATION

KHMELNYTSKYI NPP

CONSTRUCTION OF NPP UNITS NO. 3 AND NO. 4

2017

Content

INTRODUCTION

World experience shows that the existence and efficient operation of power engineering and its further development is impossible without the support of the public.

The public participation in the process of making environmentally relevant decisions, discussion of planned activities with all interested community groups at the decision-making stage can prevent conflicts, mitigate the adverse effects of decisions that are made, and avoid excessive financial costs.

Reliability, economical efficiency and environmental safety of electricity production at nuclear power plants are recognized throughout the world.

In addition to the relatively low cost of electricity, the advantages of nuclear power in comparison with traditional sources are less impact on the environment, stability of electricity production, the possibility of creating the fuel reserve for many years to come, and the availability of considerable reserves of natural resources (uranium, zirconium, etc.) in Ukraine.

The foregoing and a number of other factors have predetermined the strategic orientation of Ukraine for the further use of nuclear energy as one of the priority directions of power engineering development to cover its energy needs.

In accordance with the main objective, the strategic planning of nuclear-power complex is to ensure the economically efficient and competitive functioning of the nuclear-power complex in general and its individual facilities, as well as further prospective development in the following determining conditions:

- Unconditional fulfillment of all norms and requirements for the safety of the nuclear-power complex facilities and limiting their impact on the population and the environment;
- ensuring energy security of Ukraine;
- ensuring the efficient use of previously implemented capital investments in the development of the nuclear-power complex;
- ensuring the continuous operation of the nuclear-power complex;
- reduction of carbon-containing gas emissions.

To achieve these objectives, the main tasks and ways of their solution are defined. The key directions of this activity are the extension of the operating life of the existing nuclear power plants and the perspective timely construction of new facilities in addition and instead of those that are being decommissioned.

Based on the capabilities of existing sites, the construction of the first two units of the planned for the construction of new nuclear power units is envisaged at the site of the existing Khmelnytskyi nuclear power plant, namely, power units No. 3 and 4.

The first stage of the activity for the building of the power units was the development of the feasibility study for the construction of power units No. 3 and 4, which is part of the documents required for the approving of the law of Ukraine for location, design and construction in accordance with Ukrainian legislation.

1. Grounds for revision of the Feasibility Study

Feasibility study for the construction of the power units No. 3 and 4 of Khmelnytskyi NPP was developed by the General Designer of KhNPP – Kyiv Research and Design Institute ENERGOPROJECT, PJSC within the framework of the agreement with State Enterprise National Nuclear Energy Generating Company ENERGOATOM, the comprehensive state expertise was carried out and it was approved by the Order No.498-p of the Cabinet of Ministers of Ukraine dated 04.07.2012.

Further, the materials of the feasibility study were corrected in connection with:

- the need to replace the supplier of the VVER-1000 reactor facility (RF) for VVER-1000 manufactured by SKODA JS A.S.;
- the need to implement the provisions of regulations and regulatory documents amended or put into effect after approval of the Feasibility Study.

Technical solutions that are not related to these changes remain relevant to the approved Feasibility Study for all the facilities and structures of the complex of KhNPP units No. 3 and 4.

Activities in the sphere of the nuclear energy use in Ukraine are governed by the Law of Ukraine "Use of Nuclear Energy and Radiation Safety" and "Nuclear Safety Convention" as well as the established relevant legal and regulatory acts.

The need to carry out activities to correct the Feasibility Study for the construction of KhNPP power units No. 3 and 4, including the EIA, is determined by the following documents:

- Construction of Khmelnytskyi NPP Units No. 3, 4, Conceptual Solution No.КР.46.001-14, registered on 20.10.2014;
- Technical requirements for VVER-1000 type reactor facility for Khmelnytskyi NPP Units No. 3, 4, TT.46.003-15, approved by SNRIU;
- Design Engineering Assignment for Construction of Khmelnytskyi NPP Units No. 3, 4; Feasibility Study; Revision No. 431603 dated January 28, 2016.

The scope and representation of all parts of the Feasibility Study is prepared based on the state building standards of Ukraine.

2 Justification for selection of the area and the site for NPP unit location

2.1 The area and the site for NPP unit location

The construction and commissioning of the power units No. 3 and 4 at the site of KhNPP is defined as a priority task and will be implemented in 2 stages of construction:

- the first stage - construction of the power unit No. 3;
- the second stage - construction of the power unit No. 4.

The construction of the power units No. 3 and No. 4 is planned at the existing site of the Khmelnytskyi NPP which was selected and approved for 4,000 MW nuclear power plant; the site selection and drawing up of the act of the site selection were carried out in accordance with the requirements of the current regulatory documents at the construction stage of the power unit No. 1.

Geographical location of the NPP site is shown in Fig. 1.

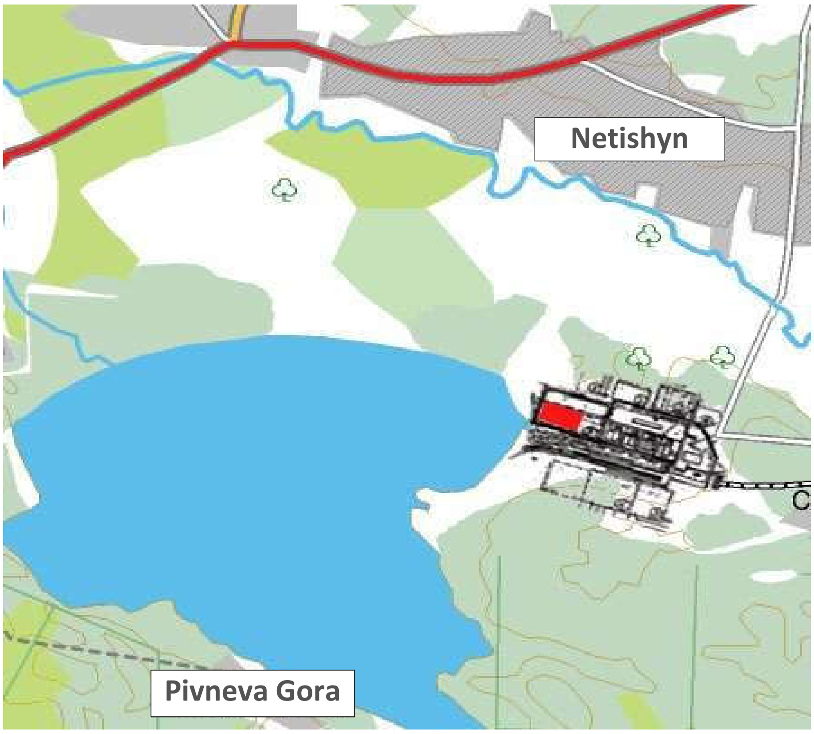


Fig. 1– **Geographical location of KhNPP site**

The site of the Khmelnytskyi nuclear power plant is located in the west of the Slavutskyi District of the Khmelnytskyi Region of Ukraine, 13 km west of the district center of Slavuta, 100 km north of the regional center of Khmelnytskyi, near the town of Netishyn (NPP settlement).

With regard to geo-structure, the region is located within the western slope of the Ukrainian crystalline core-area in the connection with the Volyn-Podolsk Plate.

The hydrographic network is represented by rivers belonging to the Pripyat river basin. The main waterway of the region is the Goryn River and its numerous tributaries.

2.2 Justification for selection of the area and the site for NPP unit location

The feasibility study examined factors related to the site and the mutual influence of the NPP and the site, as well as the adjacent territory, in case of the NPP operation, including factors related to external natural phenomena or events caused by human activities that are important from the point of view of ensuring safety.

Territorial location and population density of Netishyn, the satellite city of the NPP, meets the requirements of Ukrainian and international standards.

According to the results of the calculation of the water resources balance of Goryn River flow within March-April 95 % of the flow probability for the future year of 2020 with the operation of four KhNPP power units will be sufficient for water makeup of the pool.

According to the permit for special water use, the withdrawal of water from the Goryn River is planned to be carried out during the high water period (March-April), while the sanitary consumption after the water intake should be kept at the rate of 6 m^3/s, which is taken into account in the water chemistry balance (VCB).

According to the requirements of the regulatory documentation (RD) of Ukraine, the site is considered suitable for locating the nuclear power plant if it is proved that it is possible to ensure the safe operation of NPP in all modes, including emergency situations and accidents taking into account the factors inherent for this site, including:

- State of soils and groundwater;
- Natural phenomena and events;
- External events related to human activities;
- Existing and future environmental and demographic characteristics of the NPP location region;
- Storage and transportation conditions of fresh and spent nuclear fuel as well as radioactive waste;
- The possibility of implementing the protective measures in the event of severe accidents.

When developing technical solutions, including at subsequent stages, all these factors are taken into account. At the same time, the issues of storage and transportation of fresh and spent fuel for new power units are considered similar to the current NPP. The current plans for the implementation of the protective measures are also being used.

Analysis for the characteristics of the site for KhNPP units No. 3 and No. 4 shows the following.

According to social and environmental conditions, the site meets the requirements set forth in the regulatory documents.

Data characterizing the feasibility of using the KhNPP site for completion of power units No. 3 and No. 4:

- Average population density of the control area (CA) is 74 person/km^2 (less than 100 person/km^2);
- There are no cities with a population of 100,000 people within a radius of 30.00 km;
- The population of Netishyn town is 34.75 thousand people, which is less than 50 thousand people;
- There are no reserves of state significance in the control area (CA);
- The distance to the Horyn River is 1.90 km, which is more than the permissible distance equal to 1 km;
- The sanitary protection zone (SPZ) does not include the residential buildings, public buildings, children's and medical and sanitary institutions, objects of domestic and drinking water supply, industrial and auxiliary structures that are not related to KhNPP;
- The territory is developed and landscaped;
- When using land and reservoirs located around the nuclear power plant, compulsory radiological control is performed.

According to natural conditions, the site meets the requirements set forth in the regulatory documents, namely:

- According to seismic characteristics, the operating base earthquake (OBE) = 5 points, the safe shutdown event (SSE) = 6 points. In accordance with recommendations of the IAEA, the level of seismicity for the KhNPP site is assumed at the ground level PGA = 0.1g;
- According to ground conditions – there are no karst processes, subsiding, highly compressible soils;

• Taking into account the planning marks of the industrial site (206.00 m), the maximum horizons of floods of melt and rainwater of the Goryn River do not pose a threat to NPP facilities;

• The depth of the groundwater is from 3.00 to 4.00 m (it is required at least 3.00 m);

• Repeatability of low winds up to 2 m/s for a year is 26 %, of mists is 26 % (it is required less than 40%.

Analysis of compliance with the requirements of regulatory documents, possible impacts, testifies to the following:

• Fires that can occur outside and within the nuclear power plant site will not have an impact on objects important for safety, located in the area of power units;

• The external potential sources considered are not dangerous, since the shock wave levels for emergency situations accompanied by an explosion are next lower order than the design values accepted for the project for the reactor compartment (RC) project and the standby diesel engine power plant (SDPP).

Therefore, the site is suitable for locating the nuclear power plants from the position of the possible influence of external technogenic factors on its safety.

3 Main technical solutions

As a result of negotiations with potential suppliers of reactor equipment, the decision was taken to use the VVER-1000 reactor facility manufactured by Skoda JS a.s., which complies with all established regulatory documents of Ukraine and the requirements of the International Atomic Energy Agency (IAEA). As a reference reactor facility is considered the reactor of VVER-1000 type, implemented at the Temelin NPP. At the same time, in the project of the KhNPP power units No. 3 and 4 including the applied reactor facility, all measures to improve safety and reliability should be implemented in accordance with the "Integrated (consolidated) program to improve the safety level of NPP power units" The National Nuclear Generating Company Energoatom approved the turbine unit on the basis of the project K-1000-60/1500-2M produced by Turboatom JSC.

The construction of the power units No. 3 and 4 is envisaged using the existing building structures of the reactor compartment, the SDPP and other facilities directly connected with the reactor compartment, which are in the unfinished construction stage. At the same time, all repair and restoration works on construction structures are performed, which are determined by the results of the survey and evaluation of their technical condition.

Types of surveys:

• Reconnaissance survey is carried out before the beginning of the main survey work in order to clarify the nomenclature and the scope of the forthcoming works;

• Examination of as-built documentation - organization of collection of as-built documentation, forms for its presentation and completeness;

• Visual inspection - development of survey programs, assessment of the conformity of building structures and their elements to the project, identifying defects in structures and elements, estimating the size of the structures sections to be repaired, identifying structures and areas subject to instrumental examination;

- Instrument examination - development of programs for the examination of methods for testing and evaluation of results, determination of geometric dimensions, material characteristics, positions of structures and elements, sampling, sample testing.

Based on the results of the survey, after the completion of the repair and restoration works, the required parameters for durability will be achieved, which will ensure reliable operation of the power units throughout the service life of the plant.

3.1 Layout solutions of NPP units

The basis of the Khmelnytskyi NPP project is the principle of modular layout. In each power unit, in addition to normal operation systems, all systems providing radiation and nuclear safety of the power unit are provided, as well as emergency shutdown, cooling down, and removal of residual heat, irrespective of the operation mode of the remaining power units. Common systems necessary to ensure the operation of power units in normal operation modes are allocated to separate NPP facilities.

The project will also provide additional systems and means for control of beyond-design-basis accidents (BDBA), including severe accidents.

The power unit with VVER-1000 reactor (VVER-1000 Ŝkoda JS a.s) operates according to two-circuit scheme: the primary circuit (radioactive) is the water circuit, which directly takes heat from the core of the reactor; the secondary circuit (non-radioactive) is steam-water, receiving heat from the primary circuit, generating steam and using it in the turbo-generator.

The VVER-1000 project, Ŝkoda JS a.s. provides for the implementation of a number of fundamental technical solutions related to:

- The introduction of additional systems and equipment for the BDBA control, such as:

Hydrogen control and removal systems;

Systems of forced (filtered) release of pressure from under the containment;

Systems for external cooling of the reactor vessel during severe accidents;

- The introduction of in-depth diagnostics of process equipment, hardware and software and digital safety control systems;
- Increasing the technical level of the systems by increasing the volume of automation, optimizing control and management algorithms, improving the structure, clarifying and supplementing the functions.

3.2 Reactor compartment

The layout of the reactor compartment is based on the unified approach to the creation of an autonomous monoblock with the VVER-1000 reactor facility. When completing the construction of the power units No. 3 and 4 (VVER-1000 reactor facility made by Ŝkoda JS a.s) it is planned to maintain a unified approach for the layout of the reactor compartment.

The reactor compartment consists of the foundation part, the containment and auxiliary building with concrete dome. The sealed cylindrical containment with an internal diameter of 45.0 m, starting at El. 13.200, is centrally symmetric in the construction with dimensions of 66.0 × 66.0 m. The elevation of the sealed envelope is 66.500. The metal ventilation pipe of the reactor compartment rests on the roof covering of the building. The elevation of the top of the pipe is 100.000.

The main equipment of the primary circuit of the power unit is located in the sealed part (in the containment): the reactor, steam generators, main circulation pumps, vessels of emergency core cooling system (ACCS) and others. In the unsealed part there are block technological systems, which by the nature of technological processes should be located in the contaminated control area.

In relation to the basic project, the reactor room design additionally will include the following equipment:

- Tanks of the external cooling system of the reactor vessel during heavy accidents;
- Venturi scrubber with aerosol filter of the forced (filtered) release of pressure from under the containment.

Tanks of the external cooling system of the reactor vessel (ECSRV) are planned to be placed at El. 36.600 of the reactor compartment and on the roof of the superstructure at El. 45.600 the reactor compartment (nine tanks with additional supply of coolant with total volume of 648 m^3).

The basic layout solutions of the reactor compartment are similar to those existing at the power units No. 1, 2 of KhNPP. The section of the main building is shown in Fig. 2.

The reactor facility VVER-1000 made by Ŝkoda JS a.s. includes:

- VVER-1000 nuclear power reactor made by Ŝkoda JS a.s. of housing type with pressurized water;
- main circulation circuit;
- pressure compensation system;
- the passive part of the emergency core cooling system;
- reactor control and protection system (CPS).

The main circulation circuit includes:

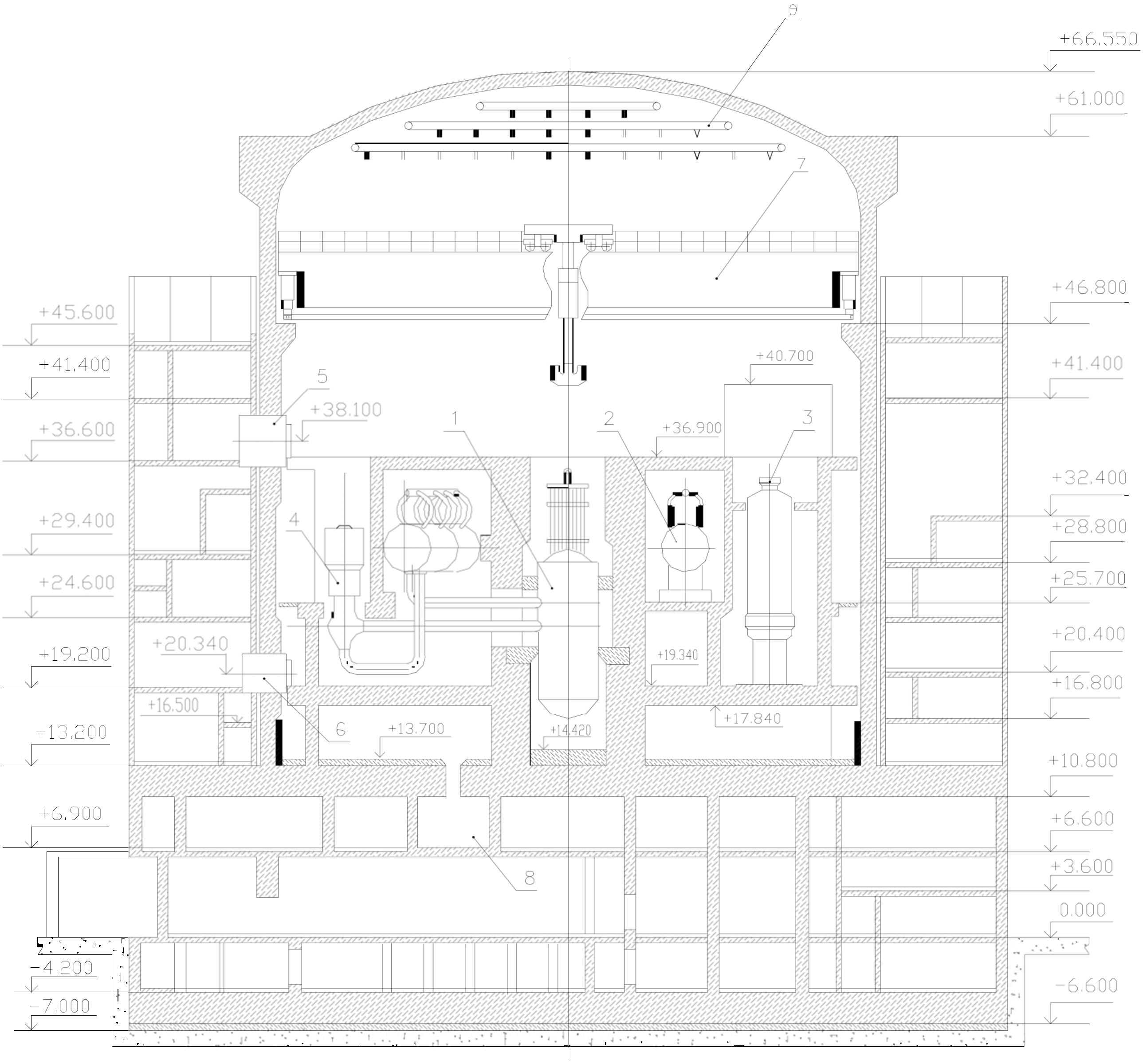
- four circulation loops, each of which includes:
    - steam generator of PGV-1000M type;
    - the main circulating pump unit GTsN-195M;
    - the main circulating piping with nominal diameter of 850 mm (DN 850), connecting the equipment of loops with the reactor.

The pressure compensation system includes:

- Pressure compensator;
- Pressurizer relief tank;
- Pipelines connecting the pressure compensator and the pressurizer relief tank to each other and to the primary circuit;
- Valves.

The passive part of the emergency core cooling system includes:

- Four hydraulic accumulators of ECCS;
- Connecting pipelines and valves.



1 - Reactor
2 – Steam generator
3 – Pressure compensator
4 – GTsN
5 – Main lock
6 – Emergency lock
7 – Polar crane
8 – Sump tank
9 – Sprinkler system

Fig. 2 – **Section of the main building of the power unit**

3.3 The main process equipment and primary circuit systems

3.3.1 Main circulation circuit

The water-cooled power reactor of VVER-1000 type made by Ŝkoda JS a.s. (Fig. 3) on thermal neutrons is a cylindrical vessel consisting of the shell and the removable top unit with a cover. In the shell there are internal devices and the reactor core consisting of fuel assemblies. Brief description of the reactor is:

• Nominal thermal capacity of the reactor facility is 3012 MW (the nominal thermal capacity of the reactor core is 3000 MW);

• Steam capacity in the rated mode - 1470×4 t/h;

• Pressure of the generated steam at the rated load at the steam header outlet of the steam generator (SG) is not less than 6.27 ± 0.01 MPa;

• Steam humidity at the steam header outlet of the steam generator (SG) is no more than 0.2 %;

• Temperature of generated steam at rated load - 278.5 °C;

• Possibility of increasing the power to 104 % (in this case, the conditions and increasing the power to 107% N_r should be determined).

Below are the main data on the reactor shell:

• Total length is 10897 mm;
• Outer diameter (along the flange of the main connector) is 4570 mm;
• Outer diameter of the cylindrical part is 4535 mm;
• Outer diameter (including nozzles) is 5260 mm;
• Thickness of the wall of the cylindrical part (without welding) is 192.5 mm;
• Thickness of surfacing - 7-9 mm;
• Weight is 322,015 kg;
• Service life is 60 years.

The main circulating pump unit GTsN-195 is designed to create circulation of the coolant in the primary circuit and is the vertical centrifugal single-stage pump with the shaft seal assembly, impeller, auxiliary impeller, axial supply of the pumped coolant and side-mounted induction electric motor with flywheel.

The main circulation pipelines are part of the main circulation circuit (MCC) along with the steam generator, the reactor and the GTsN, and connect the MCC equipment to each other in a closed loop.

The main circulation pipeline (MCP) is designed to circulate the primary circuit coolant through the reactor through four loops along the loop: reactor - steam generator – GTsN - reactor. The MCP consists of four loops.

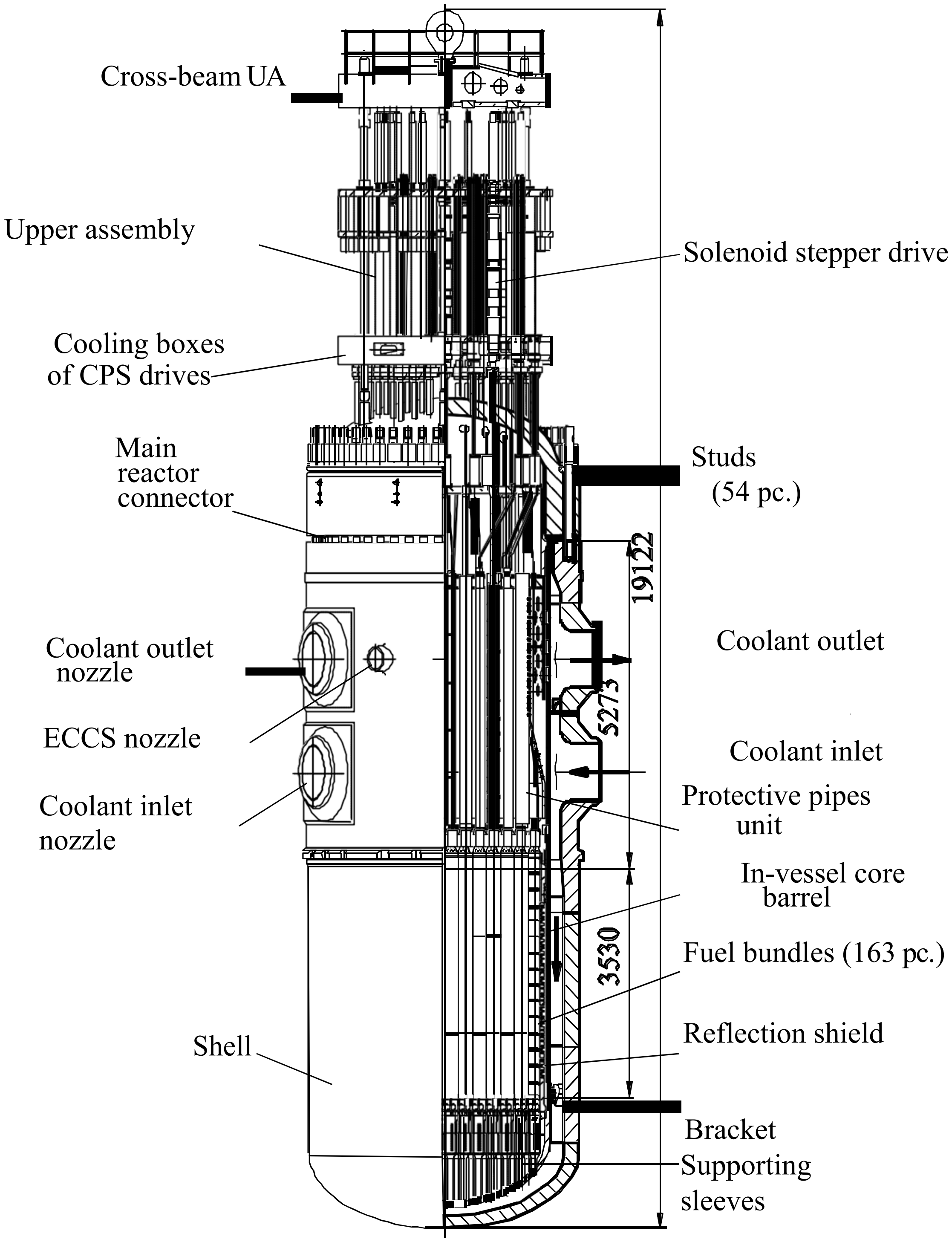


Fig. 3 – **Reactor**

The pressure compensation system in the primary circuit includes the steam pressure compensator with a set of electric heaters, the pressurizer relief tank for the condensation of steam coming from the pressure compensator through safety valves, connecting pipelines, the injection line to the pressure compensator (PC) with the valves. The system is designed to create and maintain pressure in the primary circuit in stationary modes, to limit pressure deviations, in transient and emergency modes, and to reduce the pressure in the cooling mode.

Steam generator of PGV-1000M type is a single-case recuperative heat exchanger of horizontal type with submerged tube bundle and is designed for producing dry saturated steam. The case of the steam generator and the header are made of alloyed structural steel.

3.3.2 Normal operation systems important to safety

The systems of normal operation, important for safety, consist of the following systems:

- Purge and make-up of the primary circuit, including boron control;
- Drainage and air ducts;
- Controlled leakage of the coolant of the primary circuit;
- Cooling of the pool of holding and the reloading of spent nuclear fuel;
- Nitrogen and gas blow-offs system;
- Intermediate circuit system;
- Steam generator blow-down system;
- Special water treatment.

3.3.3 Safety systems

Safety systems consist of the following systems:

- protection of the primary circuit against overpressure;
- emergency gas removal;
- Passive part of emergency core cooling system;
- emergency cooling of high pressure core;
- emergency cooling of low-pressure core;
- protection of the secondary circuit against overpressure, including steam valve blocks on steam lines;
- supply emergency feed water to the steam generators.

3.3.4 Auxiliary systems in relation to V-320

3.3.4.1 External cooling system of the reactor vessel

The system is designed to minimize the consequences of severe accidents, to prevent the melt of the core from flowing out of the reactor shell and, as a result, damage to the last protective barrier, the envelope and the spread of radioactive substances into the environment. The functioning of the system makes it possible to prevent damage to the reactor vessel under the influence of high-temperature alloy of the core, and also to substantially reduce the volume of hydrogen that is formed by the interaction of corium with concrete in the out-of-the-shell stage of a severe accident.

The criteria for CSRV performance of the functions are the following conditions:

- ensuring the removal of residual energy releases from the outer wall and the bottom of the reactor vessel;
- maintaining the temperature of the reactor vessel (RV) below the temperature at which strength characteristics are provided;
- ensuring the pressure reduction in the RV to values at which the integrity of the vessel is ensured.

The strategy of retaining the core melt in the reactor vessel was accepted and implemented in modern NPP projects (AP-1000). For the VVER-1000 power unit (Ŝkoda JS a.s.), the calculation and experimental justification for this capability and design developments for the equipment have been carried out, which makes it possible to consider the possibility of implementing the external cooling system of the reactor vessel for power units No. 3 and 4 of KhNPP.

The following reliability requirements must be fulfilled for CSRV:

- Service life of CSRV equipment:

  In standby mode - 60 years;

  In the cooling mode of the RV for keeping the corium, it is determined in the design;

  Availability factor, no less than – 0.995;

  Coefficient of technical use, no less than – 0.95.

The design of CSRV should provide:

- sustainable heat transfer from the reactor vessel to the cooling water;
- holding the bottom of the reactor vessel with the melt and excluding its separation during plastic deformation;
- preventing the melt from leaving the boundaries of the RV;
- sub-criticality of the melt in the RV;
- The possibility of supplying water to the concrete shaft and withdrawing steam from the concrete shaft;
- minimum removal of radioactive substances into the space of the sealed envelope;
- minimum hydrogen outlet;
- maximum permissible stresses are not exceeded in the structures located in the under-reactor compartment of the concrete shaft for various static and mechanical loads;
- the ability to perform its functions without the control of the operational staff at the initial stage of the ZPA.
- the ability to provide transportation and installation, conduct inspections during operation. There must be design elements and places for grasping by lifting equipment used in the process of transportation and installation.

Shafts for the revision of vessel internals (VIs) and protective tube block (PTB) are used as the basic stock of the coolant. The total volume of the shafts is approximately 328 m^3. The shafts will be interconnected by means of passageway with a diameter of 900 mm (Fig. 4).

The additional coolant stock is in containers at El. 36.600 and 45.600 of RC.

For long-term heat removal from the reactor facility, it is proposed to use unlimited supply of water from the channel of the circulating water supply system.

Schematic diagram of the initial filling of the reactor shaft is shown in Fig. 4.

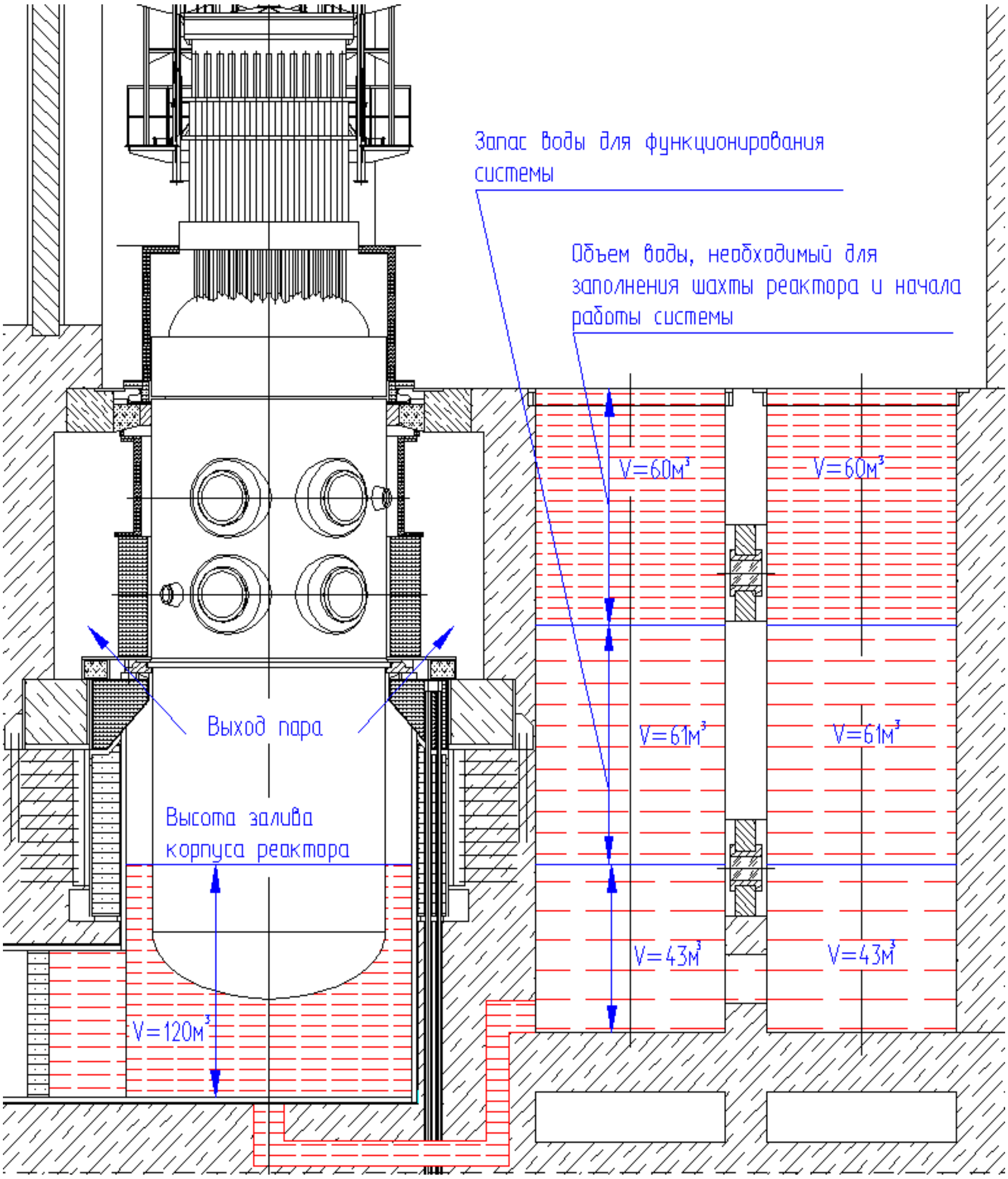


Fig. 4 – **Schematic diagram of the initial filling of the reactor shaft from the shaft of thermal control protective tubes inspection (TCPT) and internals**

To exclude the operation of the CSRV system in case of design accidents and in the BDBA without serious damage to the core, special valves must be provided to exclude the flow of coolant under the bottom of the reactor vessel, the opening of which occurs from the block control panel after the generation of signals, according to which the operator identifies the transition of the accident to a heavy stage.

After the system is started by the operator, the boron solution from the VKU and BZT reactor shaft is transported by gravity through the air channels under the bottom of the reactor vessel. A schematic diagram of the initial filling of the reactor shaft is shown in Fig. 4.

System operation modes

CSRV in case of normal operation and abnormal operation of the reactor facility is in the conditions of cold standby and in a state of complete technical readiness.

In case of the design basis accident (DBA), CSRV is in the conditions of cold standby and in a state of complete technical readiness. After the elimination of the design basis accident at the power level of absorbed dose of up to 100 mSv/h, the revision of the CSRV is performed and if necessary maintenance is carried out.

During the period of BDBA development at the in-vessel stage, the CSRV is transferred to the hot standby condition, which requires a single action for the valves ensuring the filling of the concrete shaft from the emergency water tanks with water.

In severe accidents with core meltdown, the system performs functions to protect the reactor vessel against damage and reduce radioactive emissions.

3.3.4.2 Hydrogen monitoring and removal system

The hydrogen monitoring and removal system is designed to detect and reduce the concentration of hydrogen gas released during accidents to values below the explosive limit.

The Emergency Hydrogen Removal System (EHRS) is a set of autocatalytic hydrogen recombiners located at various elevations of the pressurized volume.

Westinghouse Electric Germany GmbH has estimated that 53 NIS PAR modules are needed to perform their functions for ensuring hydrogen safety in the sealed containment (SC) in case of beyond-design basis and "severe" accidents.

3.3.4.3 The system of forced (filtered) pressure venting from the sealed containment

The system is designed to protect the containment of the nuclear power unit and to reduce radioactive releases into the environment, excluding damage to the containment with increasing the internal pressure in the event of a severe accident with the melting of fuel.

Systems for forced pressure venting from the containment (Filtered Containment Venting Systems - FCVS) are designed to prevent damage to the power unit containment with reactors such as PWR, BWR and VVER as a result of the increase in pressure in the containment beyond the design limit (in severe accidents). The retention efficiency of FCVS for aerosols: > 99.99 % and for elemental iodine> 99.5 %.

FCVS is a modular system that allows placing the system elements based on the dimensions of the room chosen for the system.

The system simultaneously performs the function of gas cleaning and provides the process for smooth controlled change in pressure.

The Filtered Containment Venting System (FCVS) comprises the Venturi scrubber and the aerosol filter, which ensure the purification of the vapor-air mixture of radioactive aerosols and iodine. The system is connected, on the one hand, to the containment through the pipeline and the shut-off valve and, on the other hand, to the vent pipe of the NPP unit through the line with the throttling device installed in it.

3.3.4.4 Stationary and mobile means and sources of power supply, the coolant reserve and supply for BDBA modes (including the severe accident modes)

In case of the complete de-energization of the nuclear power plant and the loss of the ultimate heat sink, additional mobile pumping units with a diesel drive are provided for:

- filling the spray cooling pond (OPI of SCP);
- makeup of steam generators (OPI of sG);
- makeup of the cooling pond (OPI of CP).

The mobile diesel generator set (MDGS) with a voltage of 6 kV is designed for backup power supply of safety system (SS) equipment in the event of complete de-energization of the nuclear power plant and failure in the operation of the SDPP, interconnection, and power supply to consumers of safety systems from autonomous diesel-generator station.

The mobile diesel generator set (MDGS) should provide power supply to consumers with 6 and 0.4 kV at the same time due to the design of the generator or the addition MDGS delivery of additional equipment. The diesel engine must be equipped with an electronic system of automatic speed control (ASCS).

3.3.5 The main architectural and civil engineering and layout solutions of the reactor compartment

The planning structure of the reactor compartment is based on the zoning of different productions, depending on the level of their danger for maintenance personnel and the environment. All RC rooms are divided into the contaminated control area and normally occupied area.

In the reactor compartment there are two fire compartments:

- the first is located inside the containment;
- the second - in the auxiliary building of the reactor compartment.

The boundary between these fire zones is the sealed protective reinforced concrete shell, having the fire resistance rating of at least E150 and serving as a reliable barrier against fire, which can occur in a ring-shaped auxiliary building.

Inside the fire compartment of the reactor compartment there are rooms with equipment that is important for safety. They are considered as independent fire-prevention sections (box of steam generators, control panels, cable rooms of safety systems).

Internal RC premises, bounded by a sealed containment, are not accessible for personnel with the operating reactor.

The boundary of the sealed containment is the constructions of the protective envelope as well as the constructions of walls and ceilings, enclosing this zone, which are passive elements of accident localization system.

Structurally, the RC building consists of three premises, having constructive and layout features, namely:

- The foundation part located below the El. 13.200 m;
- Sealed volume inside the protective cylindrical containment with a diameter 45.00 m to the El. 66.450 m;
- Auxiliary buildings around the containment to El. 45.600 m, with the size in plan of 66.00 × 66.00 m in the axes of the structure.

The sealed containment has two entrances / exits to the auxiliary buildings via sealed airlocks:

- the main one is at El. of the hardware room of 36.600 m;
- the emergency one is at El. of 19.340 m.

Emergency exits and entry to transport gateways are used only during the repair work; they are permanently closed and are designed for the impact of a shock wave.

All exits from the reactor compartment to the outside are equipped with protective sealed doors.

All concrete and metal structures of the reactor compartment, depending on designation of rooms, temperature and humidity conditions, the degree of their radioactive contamination, are covered with special protective coatings, materials and compositions that are stable under conditions of constant exposure to active ionizing radiation, high temperatures, vibration, periodic exposure to deactivating solution.

The reactor compartment of the power unit No. 3 (construction stage I) and the power unit No. 4 (stage II) will be constructed using existing building structures, taking into account the implementation of repair and restoration works based on the results of the survey and assessment of the technical condition. At the same time, the main previously approved design solutions are retained which are refined and finalized taking into account the installation of new equipment (reactor, steam generator, additional safety systems, etc.).

At the same time, the feasibility study included the preliminary calculation taking into account additional loads and influences, which confirms the possibility of using the existing building structures for the completion of the power units.

3.4 Hydraulic engineering solutions

3.4.1 Assessment for the cooling capacity of the reservoir in case of four NPP units operation with a total capacity of 4,000 MW

In connection with the increase in the capacity of Khmelnytskyi nuclear power plant up to 4,000 MW, verification of the water supply of the cooling water pool (CP) under the existing conditions has been carried out. Temperatures of cooling water in the pool with the operation of one, two, three and four power units of 1000 MW each are determined for the weather conditions of the hot decade of the average year, and they are 25.7 °C; 28.7 °C; 32.4 °C and 34.9 C respectively at efficiency factors of the pool as 0.56; 0.66; 0.69 and 0.71.

Based on the results of the temperatures obtained at different heat loads of the pool, it is evident that at the admissible boundary temperature of the cooled water of 33.0 °C, the cooling pool will provide the NPP capacity of 3,240 MW. To provide the NPP capacity of 4,000 MW, the additional cooling of the circulating water is required.

Based on the results of the performed thermal calculations of the cooling pool according to the heat balance, taking into account the degree of influence of the measures considered on the hydrothermal regime of the cooling pool (CP) and ensuring the stable operation of the NPP in the most unfavorable weather conditions in the summer period, as well as the cost parameters for construction of the additional structures, the 1,300 m long protection embankment is recommended for construction.

Construction of 1,300 m long protection embankment makes it possible to improve the cooling efficiency for circulating water in the pool and to guarantee the necessary temperature conditions for the operation of the four power units even in the most unfavorable "hot" hydro-meteorological conditions with a margin of 2-3 °C and the possibility of generating the additional power from the calculation of the power variation at the generator terminals.

The construction of such embankment also makes practically possible to avoid significant dependence of the temperature regime in the pool on the most unfavorable wind conditions in western winds at speeds of 3-6 m/s.

3.4.2 Analysis of the water availability for NPP after the construction of NPP units No. 3, 4

To cool the main and auxiliary equipment of the nuclear power plant, the project provides for the use of off-channel-location storage reservoir created by constructing a water-retaining dam in the valley of the Hnylyi Rig River. The reservoir was designed and constructed as a technological reservoir for nuclear power plant and was calculated based on the permissible cooling temperature of water (no more than 33 °C), for removing heat from nuclear power plant equipment with 4000 MW power (4 power units), taking into account the repair schedule of the main equipment.

Since the construction of power units No. 3 and No. 4 will be carried out in two stages (the first stage - the power unit No. 3, the second stage - the power unit No. 4), the analysis of the entire hydro-economic situation will be performed separately for the first and second stages of the power unit construction, taking into account the water-budget input and water-resources output.

3.5 Standby diesel engine power plant

SDPP, as the emergency power supply system, is the safety system designed to supply electricity to all consumers of the second group of reliability of nuclear power plants.

The project provides for three autonomous channels of the safety system in the technological part and, accordingly, three autonomous channels of the emergency power supply system. Each channel includes electro-technical equipment, a diesel generator (DG), auxiliary systems that support the operation of the DG, the equipment of instrumentation and automation.

The operation of the diesel-generator station is functionally related to the operation of the technical water system of responsible consumers, heating and ventilation systems. At the same time, the technical water consumption is at least 600 m^3/h.

SDPP consists of three completely isolated channels located in separate cells of the buildings of the SDPP.

The first cell for the power unit No. 3 is located in the middle of the building consisting of three cells and located between the power units No. 3 and 2, in the axes 4-6. The second and third cells are at the edges of the building, which consists of three cells located behind the third power unit, in axes 1-3, 7-9, respectively.

The first cell for power unit No. 4 is in the middle of the building consisting of three cells and located between power units No. 3 and 4. The second and third cells are located at the edges of the building located behind the fourth power unit.

3.6 Common standby diesel engine power plant (CSDPP)

CSDPP is an autonomous emergency source of power supply for the responsible mechanisms of NPP power units, which depends on the maintenance of the equipment of power units in the efficient state in case of total loss of alternating current.

CSDPP can also be used to supply power to particularly responsible consumers of nuclear power plants, which rapid restoration of the NPP's operation depends upon its full blackout.

The objective of the CSDPP is to provide power to critical equipment groups.

CSDPP consists of two cells located in the same building. Each cell is equipped with one diesel generator with 5,600 kW power, and of 6.3 kV voltage. One cell of CSDPP provides power supply for a single switchgear (6.0 kV) common for two units. The cells are equipped with autonomous fuel systems, oil, cooling water, starting air, control, protection, alarm, etc. There is no integration of systems of different cells. According to their architectural-building and technological solutions, the cells are similar.

4 Safety assurance

The overall objective is provided by safety management at all stages of the life cycle of nuclear power plants, in all operational states.

4.1 General provisions of the concept for assurance of nuclear and radiation safety

Activities for the design, construction and operation of nuclear power plants should be carried out in accordance with the laws of Ukraine and other legislative acts that regulate relations in the use of nuclear energy and radioactive waste management.

For any activity at nuclear power plants (design, construction, operation, etc.), the basic requirements stipulated by the relevant norms and rules of nuclear and radiation safety in force in Ukraine must be applied.

When developing the Feasibility Study of KhNPP power units No. 3 and 4, the requirements of the following documents were taken into account:

- Laws of Ukraine;
- International agreements ratified in Ukraine;
- Decrees of the President and Decrees of the Supreme Council and the Cabinet of Ministers of Ukraine;
- regulatory documents of Ukraine on nuclear and radiation safety;

Recommendations of the International Commission on Radiation Protection and IAEA are used in those parts that do not contradict the requirements of the above-mentioned documents and are aimed at reducing the radiation impact on personnel, the public and the environment.

Concept for ensuring nuclear and radiation safety of power units with VVER-1000 reactor facilities made by Ŝkoda JS a.s., is based on:

- requirements of the current safety rules and standards in the field of nuclear energy in relation to the specifics of the power units being developed;
- modern philosophy and security principles worked out by the world nuclear community and stated in the safety standards of the International Atomic Energy Agency, publications of the International Nuclear Safety Advisory Group;
- the set of technical solutions tested and verified by operation, taking into account the work for their improvement, including the design of power units with various modifications of reactor facilities with VVER reactors;
- the use of verified and certified calculation methods, codes and programs, proven safety analysis methodology;
- organizational and technical measures to prevent and limit the consequences of beyond design basis accidents;
- experience in the development of new generation of enhanced safety equipment;
- ensuring low sensitivity to m and erroneous personnel decisions;
- ensuring low risks of significant releases of radioactive substances during accidents;
- ensuring the possibility of performing the safety functions without external power supply and control through the "man-machine" interface;
- ensuring that there is no need to evacuate the population living near the nuclear power plant in case of any accidents.

4.2 Assurance of nuclear and radiation safety

Radiation safety is provided by the following engineering, organizational means and activities:

- high reliability of equipment, including improved taking into account the operational experience of NPPs with VVER rectors when introducing alternative solutions tested by the operation of nuclear power plants of various types with the prevention of failures;
- low frequency of initial events that disrupt normal operation;
- maximum decrease in the probability of "severe" damage to the core, including the case when the reactor is shutdown, to the value of at least 10^{-5} per a reactor per year (it is necessary to ensure that the probability of such an event does not exceed $5 \cdot 10^{-6}$ per reactor in a year);
- maximum reduction in the probability of emergence of the limiting accidental release (the emission, if exceeded, measures should be taken to evacuate the population beyond the selected zone) to a value of at least 10^{-6} per a reactor per year (it is necessary to ensure that the probability of such an event does not exceed 10^{-7} per a reactor per year by accidents, during which design characteristics of protective barriers are provided;
- protection against common cause failures and personnel errors;
- negligible probability of occurrences of such events as:
- secondary criticality of the melt;
- "severe" accident with a bypass of the containment;
- "severe" accident at high pressure in the reactor installation;
- "severe" accident with failure of the containment after the emergency process has been reduced to "low pressure scenarios".

Nuclear safety is the compliance with norms, rules, standards and conditions for the use of nuclear materials. This property of the reactor facility and the nuclear power plant as a whole with the required probability to prevent the occurrence of a nuclear accident associated with fuel rod damage exceeding the established limits of safe operation caused by nuclear physical processes due to:

- violation of monitoring and control of fission chain reaction in the core;
- the formation of a critical mass during the transshipment, transportation and storage of fuel elements.

The nuclear safety of the reactor installation is ensured by the system of technological and organizational means due to:

- use of the internal self-protection properties of the reactor installation;
- use of the concept of defense in depth;
- use of safety systems designed using the principle of single failure, diversity, redundancy and physical separation;
- use of proven engineering practice;
- compliance with norms, rules and standards of nuclear and radiation safety, as well as compliance with the requirements set forth in the NPP project;
- respecting and improving the safety culture;
- use of the quality management system at all stages of the life cycle of the nuclear power plant;
- providing the appropriate staff qualifications;
- accounting for operational experience;
- availability of necessary operational documentation.

5 Environmental Impact Assessment (EIA)

5.1 Environmental components and types of impacts analyzed in EIA

The performed environmental impact assessment showed that the main types of impact of the power units No. 3 and 4 of the KhNPP on environmental components are the following:

- Radiation;
- Thermal;
- Chemical.

Effects of noise, vibration and electromagnetic fields are limited to the NPP site and do not exceed permissible values.

The geological environment of the industrial site and the NPP site is characterized by sufficient stability. Its negative impact on the functioning of existing plant facilities and on facilities of power units No. 3 and 4 is not expected.

KhNPP impact on the geological environment (including groundwater level) is almost completely realized during the construction and commissioning of facilities included in the complex of power units No. 1, 2 and was limited to the boundaries of the industrial site and the KhNPP. Most of these facilities are included in the complex of power units No. 3, 4 (cooling water pool, supply and discharge channels, block pumping stations, housing construction in Netishyn, etc.). For the period of operation of the power units No. 3 and 4 the technogenic changes in the state of the geological environment under the influence of the KhNPP facilities is not predicted.

It is also not predicted that the power unit will have negative effect on the objects of the technogenic environment located within the CA.

The components of the environment to which the above effects apply include the air environment, the aquatic environment (surface and groundwater), soils, flora and fauna, and the social and man-made environment.

5.2 Air environment impact assessment

5.2.1 Radiation effect

The radiological situation in the NPP location area is currently mainly determined by radionuclides of natural origin. The short-lived technogenic isotopes in the CA of SS KhNPP were not identified. The area ^{137}Cs contamination is at a level close to global pollution levels (about 3 kBq/m^2).

When calculating the predicted estimates of the contamination of the territory adjacent to the nuclear power plant with gas-aerosol emissions for normal operation of all power units, it was assumed that there is one source of continuous emissions of 100 m in height and total capacity equal to the emissions from the vent pipes of the reactor compartments of the four power units and special buildings.

These emissions include 89 radionuclides with different periods of half-life and emission capacities and, accordingly, different contributions to dose loading. As a result of the calculations, predictions were made for the contamination densities of the near zone of NPP ^{3}H, ^{137}Cs and ^{90}Sr and volumetric concentrations of ^{41}Ar, ^{85}Kr and ^{133}Xe in the near-surface atmosphere near the nuclear power plant with continuous normal operation of four power units (Table 1).

Table 1 – **Total release of radionuclides during KhNPP normal operation**

Radionuclide	**Half-life period**	**Emission power, Bq/day**
^{41}Ar	1.82 h	3.85E+10
^{137}Cs	30.20 years	4.97E+05
^{85}Kr	10.72 years	3.15E+09
^{133}Xe	5.23 days	1.21E+13
^{3}H	12.33 years	2.85E+10
^{90}Sr	29.2 years	1.34E+01

Executed estimates have shown that the main contribution to the dose of gas-aerosol emissions during the operation of the plant will produce radioactive noble gases (RNG) due to irradiation from the cloud (Table 2).

Table 2 – **Estimated RBG concentrations in the ground layer of atmospheric air of CA of SS KhNPP**

Description	Values of RBG concentrations in the ground layer of atmospheric air, Bq/m^3		
	^{41}Ar	^{85}Kr	^{133}Xe
The maximum annual average concentrations received in the east direction at a distance of about one kilometer from nuclear power plant	$n \cdot 10^{-2}$	$n \cdot 10^{-3}$	2.0

The calculated RBG concentrations indicated that, under normal operation conditions (NOC) of the power units the level is several orders of lower than permissible and thus, with a margin, ensure that the effective dose limit of 40 μSv/year for population of category B is not exceeded.

Thus, the effect of gaseous radioactive emissions on the environment is permissible.

5.2.2 Chemical effect

After the start-up of power units No. 3, 4, there will be no new technological processes at the SS KhNPP, accompanied by the release of any harmful substances into the atmosphere, which are different from the existing ones, that is, the qualitative characteristics of the emissions existing during the operation of the two power units will not change.

The estimated expert estimates of surface concentrations of non-radioactive pollutants (air pollutants) in the atmosphere showed that after the commissioning of power units No. 3, 4 as a whole, the quantitative and qualitative characteristics of non-radioactive emissions will not change significantly and their parameters can be considered to remain at the same level. Thus, it can be argued that the surface concentrations of pollutants caused by the releases of the KhNPP OP for all ingredients, as well as for the summation groups, will not exceed the maximum permissible values for settlements. Within the SPZ, they will be from 0.2 to 0.6 maximum permissible concentrations (MPC), and in the zone of the nearest settlements from 0.02 to 0.12 MPC. Outside the SPZ, the values of the maximum surface concentrations by summation groups and by any ingredient will not exceed 0.05 MPC.

5.2.3 Heat and humidity effect

Three circulating cooling systems of the equipment are operated at the NPP.

With the increase in the flow of heated water entering the cooling water pool from 50 m^3/s with the operation of one power unit to 200 m^3/s with the operation of four power units and the existing technology of water cooling, the loss of water for additional evaporation from the surface of the water will amount to 53.1 million m^3/year, from the CP is 0.876 million m^3/year. In addition, out of the CP, the drop losses will be 3.92 million m^3/year.

The increase in thermal discharge in the CP will create slightly different conditions for water exchange in the upper layer of the reservoir and heat exchange in the adjacent atmospheric air layer.

The impact of cooling systems will primarily affect the microclimate of airspace above the water area of the reservoir and spread to a small area adjacent to it.

When the third and then the fourth power units are put into operation, the effect of cooling systems on the microclimate will affect the increase in additional evaporation and, consequently, the humidity of the air. The air temperature should not increase in proportion to the heat discharges, since heat will be expended for additional evaporation, the formation of "steam fog". You can expect an increase in the number of days with fog and ice-covered phenomena. The air temperature in case of operation of four power units will change in admissible limits in comparison with that which is fixed when operating of two power units. The CP zone of influence will not exceed 1.0 km from the watershed line.

Considering the permissible impact of cooling systems on climatic parameters, there is no need in the special measures to limit these impacts during the operation of four power units.

5.2.4 Impact and assessment of the influence of physical factors

5.2.4.1 Noise effects

To assess the impact of noise on the environment, the following assumptions are made:

- the assessment is made concerning the impact of additional noise sources that appear with the commissioning of power units No. 3 and 4;
- due to the absence on the industrial site, outside the production buildings and structures, of the permanent workplaces for the maintenance personnel, the impact of noise is assessed only within these buildings and structures;
- due to the absence within the SPZ of any residential or administrative-household premises with permanent residence of people who are not NPP personnel (population), the established noise pressure limits for the workplace of the service personnel who are there permanently or periodically are taken to assess the impact of noise.

Depending on the type of intended service and the characteristics of the production premises, to reduce the level of sound pressure, heat and sound insulation is performed, soundproofing cabins are installed, and headphones are provided.

5.2.4.2 Possible effects of ultrasound

Ultrasonic effects from operating thermal mechanical equipment during the operation of power units No. 3 and 4 of KhNPP are not expected.

During repair with ultrasonic quality control of welded butt joints, one-time short-term local ultrasonic action is possible.

5.2.4.3 Vibration effect

Vibration effects can occur within the workplace and do not affect the environment.

5.2.4.4 Assessment of the effects of electromagnetic and ionizing radiation

To protect personnel against the effect of electric field, there are stationary protection means on open switchgear (OSG):

- hoods installed above the workplaces at the terminal boxes;
- drives, modular and switchgear cabinets;
- vertical screens between switches of neighboring cells;
- additional screens of switches.

The overhead transmission lines outgoing from NPP OSG for 330 and 750 kV are made with taking into account the requirements of sanitary norms, the impact of emissions and discharges of radioactive substances of KhNPP, for the whole period of operation, on the radiation situation in the area of NPP location was not detected against the background of global fallouts, as evidenced by the results of environmental samples control.

The absolute value of the dose rate on the territory of the control points, throughout the whole operation time, does not depend on their location relative to the NPP, and is due to the natural background and deposition of radionuclides of global origin. The dynamics of the radiation background on the territory of the CA is caused by loss of technogenic radionuclides as a result of the Chernobyl accident, global fallouts and fluctuations in the radiation background.

Since power units No. 3, 4 are identical to those existing ones, it can be concluded that putting them into operation will not lead to excessive changes in the radiation situation, both on the territory of the NPP and in the CA.

Estimates confirm the conclusion.

5.3 Assessment of impacts on surface and underground waters

5.3.1 Assessment of impacts on surface waters

5.3.1.1 Consumption of water resources

Technical water supply

When calculating the VEB of KhNPP power units No.3, 4, the amount of water lost for additional evaporation was 53.1 million m^3/year, taking into account the use factor of the installed capacity of 0.82.

Accordingly, the scarcity of water resources (the need for fresh water for CP from the Goryn River) in range 4 when four power units are operating is from 3.23 to 41.92 million m^3/year (ranging from watery year of 1% of water availability to low water year of 95% of water supply). Replenishment of water resources deficit is possible due to the activation of the useful volume of the NPP reservoir with its subsequent replenishment by the Hnylyi Rig River and Goryn River (during the non-vegetation period). The Goryn River, without violating the established untouchable sanitary consumption (6 m^3/s), taking into account the need for fresh water for spray cooling ponds (SCP), chemical water purification (HWP) and watering, is able to meet the above need.

5.3.1.2 Radiation effect

Observations of the radiation condition of water in water bodies in the vicinity of the SS KhNPP location showed that the degree of pollution of water bodies according to ^{137}Cs and ^{90}Sr meets the requirements of the standard PC_B^{ingest}.

5.3.1.3 Chemical effect

Potential source of water pollution in the CA of SS KhNPP is the cooling water pool (CP).

Water from the CP can enter the surrounding aquatic environment during purging, as well as during the specified by the project "forced" water overflows through the automatic flood spillway of the CP, when the normal banked-up horizon (NBH) is exceeded during the spring and storm floods.

The performed evaluations show that with timely carrying out of controlled purges of the CP during the flood period, in compliance with the regulatory requirements, the chemical effect on surface waters can be reduced to an environmentally acceptable minimum, which excludes the possibility of violating the requirements of sanitary standards for hydro-chemical indicators.

5.3.1.4 Heat effect

The increase in thermal discharge in the CP will create slightly different conditions for water exchange in the upper layer of the pool and heat exchange with the adjacent layer of atmospheric air. The zone of influence of CP on the microclimate will not exceed 1.0 km. These changes in the microclimate are assessed as insignificant and environmentally acceptable.

Model hydrothermal calculations of CP showed that the water temperature in it exceeds the natural water temperature in the river of Horyn in the conditions of four units operation by 13.84 °C. The calculated average monthly temperature of cooled water for meteorological factors in April is 22.04 °C (the month of spring high water is the most probable month of purging discharges) at the natural water temperature in the river of Goryn as 8.2 °C.

Taking into account that during the spring floods the water discharge in the Vilia River ranges from 10 to 100 m^3/s, and the purge discharge rate is regulated in large limits (from 0 to 10 m^3/s and more), the possibility of observing the prescribed temperature conditions in the calculation range by diluting the purging water is obvious and easily controlled by appropriate measurements of the water temperature.

5.3.2 Assessment of impacts on underground waters

In the process of operation of the power units No. 1, 2, as a result of the infiltration of industrial waters, changes occurred in some regime-forming groundwater. As a result, in some areas, the increasing temperature and mineralization of groundwater is recorded, which is fairly stable over time, but this process is local and does not extend beyond the industrial site. Commissioning of the power units No. 3 and 4 may be affected by local increases in the temperature of groundwater, their mineralization or a slight increase in the level in a limited area. At the intakes of household and drinking water supply this will not affect.

The radiative state of groundwater, including the Netishyn water intake, is satisfactory, that is below the limiting level regulated by regulatory documents. Based on the results of the simulation performed by the Scientific and Engineering Center for Radiohydrogeological Ecology Research Programs of the National Academy of Sciences of Ukraine (SEC RFR of the National Academy of Sciences of Ukraine), the water-bearing complex used for water intake is protected against surface chemical and radionuclide pollution, that is it refers to environmentally sustainable sources of domestic and drinking water supply.

5.4 Assessment of impacts on soils

5.4.1 Radiation effect

The radiological situation in the NPP location area is currently mainly determined by radionuclides of natural origin. The short-lived technogenic isotopes in the CA of SS KhNPP were not identified. The ^{137}Cs contamination of the area is at a level close to global pollution levels (about 3 kBq/m^2).

The relief of the surface of the NPP near zone and the presence of orographic barriers were taken into account in modeling the dispersion of gas-aerosol emissions.

5.4.2 Chemical effect

According to the results of the conducted studies, the content of copper, zinc, cadmium in soils, the territory adjacent to the nuclear power plant, is at the background level. Perhaps there is a little extra lead contamination of the soil of agricultural lands adjacent to the roads, which will not lead to exceeding the MPC in agricultural products.

Degradation processes of soils associated with the construction of the SS KhNPP are widespread only in the area of the industrial site. Their presence in the CA is practically unrelated to the work of the NPP.

In general, an analysis of the physical-chemical properties of the soils of the region showed that, despite the considerable variegation of the soil cover, most soils have a significant buffer resistance to man-made loads. The landscapes of the near zone of the NPP are a reliable barrier preventing the expansion of the zone of primary pollution by means of migration.

5.5 Assessment of impacts on vegetation and wildlife

The operation of the two additional power units as a whole will not affect the structure and dynamics of the plant communities, nor will it entail changes in the populations of rare and red-listed plant species. However, in the case of additional construction or other work related to changing the hydraulic regime, violation of the integrity of the vegetation or soil cover, additional research and environmental expertise of this area is necessary.

According to the data of the environmental protection departments of Khmelnytskyi and Rivne Regions, 47 objects of the nature reserve fund of various degree of the reserve are located in the CA of KhNPP, the area of which is more than 3000 hectares. This is a little more than 1 % of the territory of the zone, which is four times lower than the national average factor.

The radiation situation in the CA of KhNPP area is currently determined mainly by radionuclides of natural origin. As bioindicators of radioactive contamination, it is advisable to use fungi, pine, blueberries, mosses and lichens (for each of the tiers) for which there is a sufficient database and the corresponding dependencies are established.

In general, the radiation effect of more than two decades of activity of the SS KhNPP did not affect the state of the plant world in the CA.

It was determined that commissioning and operation in the normal mode of the power units No. 3 and 4 will not have a negative impact on wildlife in the CA of KhNPP. Negative effect on forage reserve, shelters, nesting places and ways of migration of animals are not expected.

5.6 Assessment of impacts on the social environment

5.6.1 Assessment of impacts on public health

5.6.1.1 General

The process of forming the public health is influenced by a whole range of natural, climatic, socio-economic, medical-biological, technogenic and other factors.

One of the most important indicators of the health of the population is the incidence, a continuous analysis of which allows planning and optimizing the current and future activities of local governments, as well as sanitary and epidemiological surveillance.

The conducted researches did not reveal any negative changes in the health status of the population of CA due to the influence of nuclear power plant emissions and, therefore, the risk of increasing morbidity for the local population does not exceed the national average factor.

5.6.1.2 Radiation effect

Dose loads on the population living in the CA of the SS KhNPP are mainly formed due to natural radionuclides (NRN) contained in soil and underlying rocks.

The average weighted total effective dose of irradiation of the population of Ukraine, due to natural sources, is 3.5 mSv/yr^{-1} the main part of which is formed by irradiation from radon.

The maximum contribution to the expected effective dose (from nuclear power plants) at all distances is made by the radioactive noble gases ^{133}Xe, ^{135}Xe upon irradiation from the cloud. The other ways of influencing the dose formation make a significantly smaller contribution (Fig. 5).

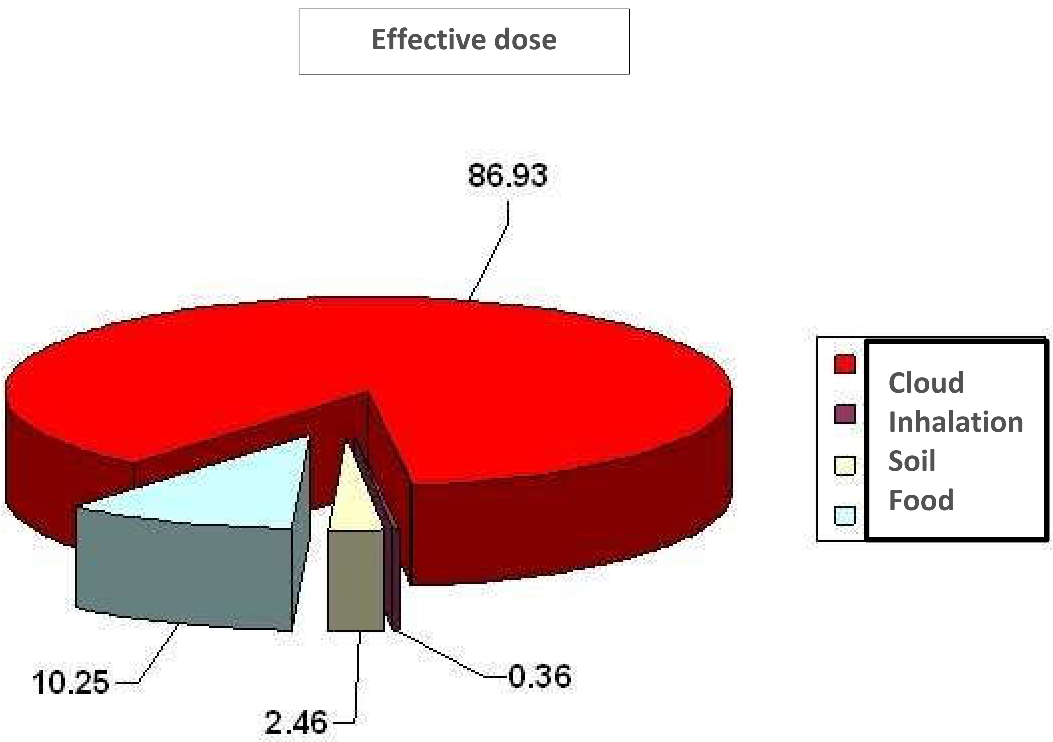
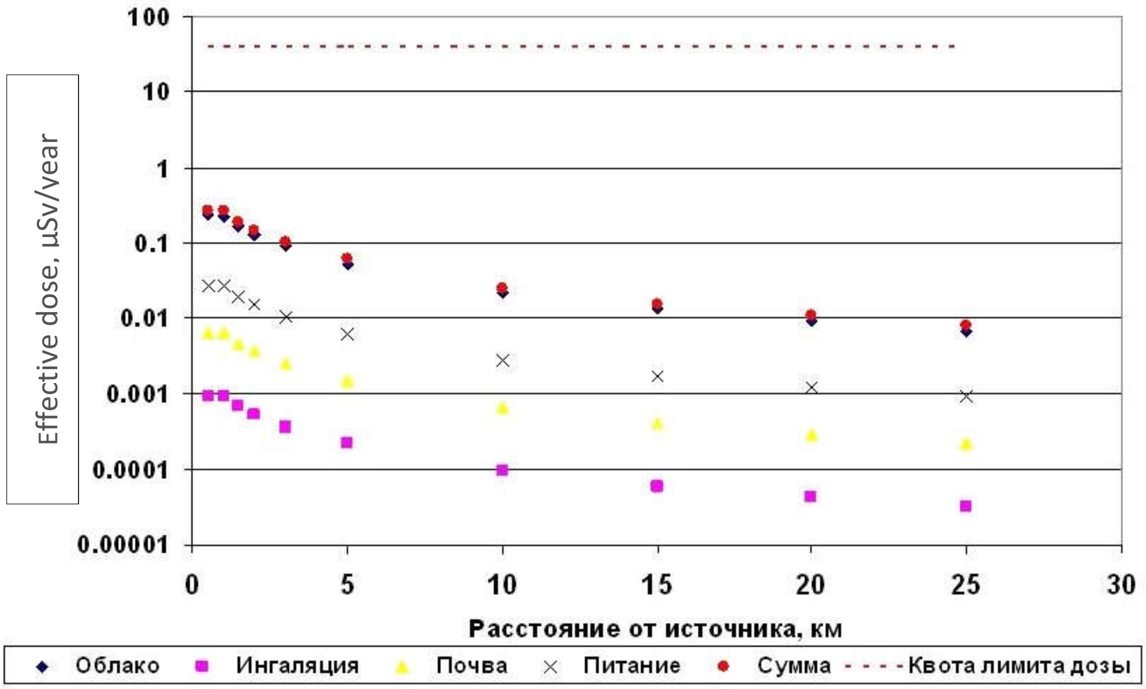


Fig. 5 **– Structure of the formation (in percent) of the expected effective annual dose for the population (reference group "adult", rural population) for the thirtieth year of SS KhNPP operation with four power units according to the exposure pathways (Distance of 3 km)**

The maximum calculated effective individual dose of 0.34 µSv/year was obtained at a distance of 1 km east of the NPP. At a distance of 25 km, the total effective dose decreases to one hundredth of µSv.

The main contribution to the formation of dose loads on the human body will be made by natural radionuclides: ^{40}K, ^{238}U, ^{232}Th and the products of their decay (in the range from 1 to 3 mSv/year). A few hours from the natural background radiation, a person receives approximately the same dose as from the releases of the SS KhNPP for the year.

The population living near nuclear power plants can receive radiation dose due to gas-aerosol emissions of nuclear power plants, which does not exceed 4 % of the maximum dose, i.e. <40 µSv/year. In the case of the SS KhNPP for the population, the estimated dose loads outside the SPZ will be two orders of magnitude below the established limits (Fig. 6).



Distance from the source, km
Cloud / Inhalation / Soil / Food / Total ….Allowable limiting dose

Fig. 6 – **Dependence of the expected effective annual dose for the population (reference group "adult", rural population) for the thirtieth year of SS KhNPP operation with four power units from a distance**

5.6.1.3 Transboundary transfer of radioactive materials

As far as the distance from the source of emissions, the contamination of the territory with radionuclides decreases rapidly, and so does the dose load for the population (fig. 6). Even if the NPP will be located directly on the border, then in this case the quota of the dose limit for the population of neighboring countries will not be exceeded (for most European countries it is higher than for Ukraine and is 200 µSv/year).

Radioactive contamination due to gas-aerosol emissions at long distances outside the CA of KhNPP cannot exceed that of the CA border for a number of physical reasons.

Thus, it can be argued that the radiation impact of normal operation of the KhNPP on contiguous countries will be significantly lower than the established dose quotas, and accordingly the limit of an individual effective annual dose of 1 mSv.

5.6.1.4 General conclusions for the dose loads

A conservative estimate (the forty-fifth year of NPP operation, the maximum conversion factors) showed that on the SPZ boundary the effective annual dose, taking into account all exposure routes for the critical population group, was 0.6 μSv. The maximum calculated, effective, individual dose of 2.8 μSv/year is obtained at a distance of 0.5 km east of the NPP.

At a distance of 25 km, the total, effective dose is reduced to one hundredth of μSv, which indicates that there are no additional negative effects on the health of the population.

5.7 Assessment of impacts on man-made environment

The structures and systems of the existing part of the SS KhNPP are designed and constructed taking into account the possible effects of extreme natural phenomena. Similar design decisions were made in the feasibility study of the power units No. 3 and 4.

The location of the NPP site excludes the possibility of external man-made influences from other objects of economic activity (fire, blast wave, flooding, salvo emission of harmful gases), which can lead to a violation of the normal operation of nuclear power plants and, consequently, additional sources of plant impact on the man-made environment will not be formed.

Assessment of the radiation impact of nuclear power plants on the environment, including man-made is carried out with the help of technical means of radiation monitoring that control both the sources of radionuclides entering the environment (liquid discharges, gas and aerosol emissions) and the radiation situation on the industrial site of the nuclear power plant and the adjacent territory.

As predicted estimates have shown, the additional contribution to pollution by long-lived radionuclides of man-made environment due to gas-aerosol emissions is tens of thousands of times lower than the existing pollution, which in turn is much lower than the established permissible levels. Consequently, when two new power units are put into operation, special agro-technical measures with a change in the structure of land use of agriculture, the re-profiling of the agro-industrial complex and changes in technological processing of products are inexpedient.

5.8 Environment Impact Assessment in a Transboundary Context

To assess the radiological significance of transboundary transfer at normal operation of NPP, the results of calculating the dispersion of gas-aerosol emissions for the CA of the KhNPP are used. These calculations were carried out taking into account the actual meteorological data in the area of NPP location with a certain margin of conservatism. As far as the distance from the source of emissions, the contamination of the territory with radionuclides decreases rapidly, which means that the dose load on the population also decreases. In addition, even in the SPZ, dose loads do not exceed the dose limit for the population. This means that even if the NPP is located directly on the border, then in this case the quota of the dose limit for the population of neighboring countries will not be exceeded (for most European countries it is higher than for Ukraine and is 200 μSv/year).

The radiation effect of normal operation of the KhNPP on adjacent countries will be significantly lower than the established dose quotas, and accordingly the limit of an individual effective annual dose of 1 mSv.

Informing the neighboring states about the possible transboundary impact took place from 2010 to 2013.

The report of SE Atomproektinzhiniring dated December 25, 2013, Measures to inform neighboring countries about possible impact in the transboundary context was made public by posting on the Company's official website (SE NNGC Energoatom http://www.energoatom.kiev.ua/ru/actvts/stroitelstvo/buildon/public/) as The Espoo Convention requires this.

5.9 Environmental impact assessment in case of emergency

5.9.1 Assessment of non-radiation effects

At the start-up of the power units No. 3, 4, as in modern conditions during the operation of power units No. 1, 2, the only potential source of chemical impact on the environment may be CP, which receives purified domestic sewage from the territory of nuclear power plants that do not have radioactive impurities, treated domestic sewage from the city of Netishyn, treated industrial waste water from the enterprises of Neteshyn (going to the general network of domestic sewerage), treated industrial waste water from the territory of nuclear power plants, storm sewage from the site of the nuclear power plant.

Analysis of possible emergency situations associated with chemical releases and discharges, all technological processes and equipment of nuclear power plants, showed that the provided technological solutions exclude the possibility of environmental contamination by harmful chemicals.

In all operating modes of the nuclear power plant, discharges of chemicals and radioactive waste into the environment are excluded.

Flood spillway

Spillway (1st class of capitalization) is designed to pass flood waters. The spillway of automatic action is designed to pass a flash flood at the forced water level in the reservoir up to 70 cm above the NBH while the maximum transformed water flow is 110.0 m^3/s.

Considering the exceptional low repeatability, as well as an exceptionally large influx of fresh water into the CP, while significantly improving the water quality in the CP, the flood spillway does not affect the MPC of pollutants of Goryn River and does not entail an emergency situation associated with chemical discharges.

Purge water

In the case of technological necessity, it is possible to purge the reservoir with the discharge of water through the bottom outlet.

Sanitary supervision authorities monitor the quality of water at the point of discharge of purge water, the quality of water in the river of Goryn prior to the release of purge water and the quality of water in the section of the river of Goryn at a distance of 500 m downstream from the place of release. In case of exceeding the maximum permissible concentration limit for pollutants in the last section, the bottom outlet is blocked and the purge stops.

Thus, the emergency situation associated with chemical blowouts during purging of CP is excluded.

5.9.2 Assessment of radiation effects

For the analysis of radiation effects in accidents, MDBA and BDBA were considered.

As the MDBA (the most severe design accident), a scenario with a break in the main circulation pipeline was adopted.

As the BDBA, a scenario with a guillotine rupture of the GCL DN 2 × 850 mm was adopted, a failure active ACCS and a workable sprinkler system.

The probability of the considered BDBA is $4.29 \cdot 10^{-7}$ per reactor per year, which is included in the allowable range of allowance for BDBA at the value of the "drop-out" criterion of 10^{-8}

The release into the environment, both in the MDBA and in the BDBA, is determined by the leakiness of the containment of the power unit and the time of the existence of increased pressure in it. The emission into the atmosphere includes radioactive noble gases (RNG), radioisotopes of iodine, aerosols ^{137}Cs, ^{90}Sr and other radionuclides.

Impacts on soil and agricultural products

Radioactive contamination of the territory with MDBA and BDBA will not lead to a change in the physicochemical or hydrophysical properties of the soil.

The analysis showed that for the CA of SS KhNPP, a critical source of radionuclides entering agricultural production with likely accidents will be meadows and pastures located in the flood plain of the Goryn River. Consequently, the critical path of migration of radionuclides, both in the early phase of the accident and in the subsequent phases, will be a chain of pastures-animals-livestock production-man.

Conducted assessments of pollution of agricultural products under MDBA and BDBA showed that as a result of air pollution in the early stages of accidents, it is possible to exceed the permissible levels of radionuclide content. At distances up to 30 km from the source of the release, the radioactive contamination of agricultural products may exceed the established lower standards of justification for intervention and actions to limit the consumption of locally produced agricultural products.

Influence on flora and fauna

According to the results of calculations in emergency situations, short-lived radionuclides can be considered as the main dose-forming radionuclides for biocenoses.

For MDBA, a conservative estimate of the maximum absorbed dose in the first year after discharge (at a distance of 2.7 km along the emission track axis, under the worst weather conditions) for plants and agricultural animals is about 20 and 4 mGy/yr (external irradiation), respectively. The obtained estimates of absorbed dose levels showed that changes in the plant and animal communities at the species level are extremely unlikely. Accordingly, biocenosis changes under the influence of radiation factors will not occur.

With BDBA, a conservative estimate of the maximum absorbed dose for the first year after the release (at a distance of 4 km along the emission track axis under worst-case conditions) on plants is about 1 Gy/year, which for the most radiosensitive conifers exceeds the threshold of the currently established lower detection limit for weak radiation effects. At the same time, the border of medium and high severity of radiation effects, as well as the dose limit of even acute radiation, leading to 100% death in different taxonomic groups, outside the SPZ will not be achieved.

Conservative evaluation of the maximum external absorbed dose, with the same conditions on agricultural animals is about 0.04 Gy/year, which does not exceed the threshold of the currently established lower detection limit for weak radiation effects on mammals.

The obtained estimates of the absorbed dose levels allow us to state that changes in the plant and animal communities at the species level are unlikely, although in a limited area along the track axis radiobiological effects can be observed in coniferous trees with BDBA. Accordingly, structural changes in biocenoses under the influence of radiation factors outside the SPZ will not occur.

Within the SPZ, in a limited area, there is a possibility of exceeding the dose of acute radiation to representatives of the most radiosensitive organisms (conifers, mammals (rodents)) at which small effects of ionizing radiation (chromosome damage, reproductive function and physiology) are possible. The dose of acute irradiation (5 days) per pine tree at a distance of 1 km from the source of irradiation (cloud axis, conservative estimate) may be 1 Gy.

Impact on the population

Individual effective doses for the population as a result of MDBA were estimated. Conducted conservative estimates of dose loads on the population, taking into account all pathways of exposure, in addition to the receipt of radionuclides with food, showed that in MDBA (in accordance with the norms, no urgent or urgent countermeasures (including iodine prophylaxis) are required. Reach the threshold of the occurrence of deterministic effects Individual risks of stochastic effects for the population are at a negligible level.

Radioactive contamination of agricultural products as a result of MDBA may exceed the criteria established in the norms for taking decisions on the seizure, replacement and restriction of the use of such products at distances up to 30 km. That is, there is a possibility of long-term countermeasures.

The greatest likelihood of the need to take a decision to seize, replace and restrict the consumption of locally produced agricultural products outside the SPZ in the immediate vicinity of its borders is possible for leafy vegetables and milk. Outside the SPZ, it is possible to impose a ban on consumption of leafy vegetables and milk for a period of 1 to 3 months. And for leafy vegetables this ban can be introduced up to the ZN border, and for milk - up to 15 km from KhNPP. The introduction of these countermeasures is mainly related to the contamination of the territory with iodine isotopes and short-lived radionuclides.

There is also a possibility of imposing a ban on the consumption of grain products and meat grown in the immediate vicinity of the SPZ (up to 6 km). According to the conservative estimates received, the duration of the ban on the consumption of grain products and meat grown in this territory may reach two years.

Individual effective doses to the population were estimated as a result of BDBA. Based on the maximum effective dose estimates, it is necessary to introduce a restriction on the stay of the population in the open air at a distance of up to 4 km from the source of the release. The indicated countermeasure is determined by the preventable dose on the whole body. The calculated dose to the thyroid gland does not exceed the lower limit of justification for iodine prophylaxis. Nevertheless, iodine radioisotopes generally form more than 80% of the effective dose of the acute period of the accident, and the total effective dose at the border of the SPZ is mainly formed due to inhalation. Proceeding from the foregoing, it seems reasonable to use iodine prophylaxis for the population living in CA at the earliest stage of the accident.

Individual risks of occurrence of stochastic effects for the population, in case of not conducting countermeasures (limiting the stay of the population in the open air), exceed the border of individual risk at distances up to 4 km from the emission source. In the case of this countermeasure, individual risks of occurrence of stochastic effects do not exceed the border of individual risk for the population.

As a result of aerial contamination of agricultural crops and pasture vegetation, radioactive contamination of agricultural products with BDBA may exceed the criteria for the decision to seize, replace and limit the use of such products at distances of up to 30 km. That is, there is a possibility of long-term countermeasures.

With BDBA, along the track axis, outside the SPZ, an excess of permissible ^{137}Cs in milk, cattle meat, food grains and leafy vegetables more than 25 km from KhNPP, cabbage up to 20 km, fruit up to 10 km from KhNPP. With BDBA on the track axis, the content of ^{90}Sr may exceed normative in food grains and leafy vegetables at a distance of up to 30 km from KhNPP, in milk up to 10 km, and at small distances up to 4-6 km in meat, vegetables and fruits. According to the conservative estimates received, the duration of the ban on the consumption of grain products and meat grown in this territory may reach two years. In milk, the content of ^{131}I before and after the boundaries of the CA (up to 40 km from the KhNPP) gives grounds for imposing restrictions on its consumption with BDBA. However, at the border of the SPZ, such restrictions can persist for a long time (up to 2 months after the accident for milk for baby food).

These restrictions on the consumption of locally produced food are obtained from the lower bounds of standard justification. When using unconditionally justified levels of intervention (for taking decisions on the seizure, replacement and restriction of the consumption of radioactively contaminated food products), the parameters of restrictions (prohibition time, land area, etc.) will be much smaller.

Thus, as a countermeasure in case of accidents, it may be necessary to restrict the use of local agricultural products in a certain territory.

5.9.3 Assessment of the consequences of accidents on the territory of neighboring countries

Taking into account that the SS KhNPP is located about 160 km from the border with Belarus and about 190 km from the border with Poland, a mesoscale Lagrangian-Euler diffusion model of impurity transfer in the atmosphere (LEDI) was chosen to solve the problem of transboundary transfer of radioactive release of the SS KhNPP.

Based on the results of the assessment of the consequences of transboundary transport, for the considered accidents - MDBA and BDBA, it is possible to conclude the following:

- calculations performed with the help of the mesoscale model of atmospheric transport of LEDI showed that for no one considered accident the limit of the individual annual effective dose on the members of the reference group in the neighboring states will not be exceeded;
- The age group of children is critical (1 to 2 years). A critical meteorological scenario is scenario BDBA, in which deposition occurs during vegetation of plants. For this meteorological scenario, the main way of dose formation (for all the accidents considered) is the food chain. It generates about 99% of the dose;
- The main dose-forming radionuclide in the considered accidents for all meteorological scenarios is ^{131}I.

5.9.4 Ecological risk assessment

The concept of risk (probability of manifestation of the effect) is introduced to compare the significance of the impact of various factors, for example, radiation and non-radiation on human health. The concept of multifactor risk of NPP impact on the population and the environment is used to optimize the use of protective measures during construction, normal operation and accidents at the NPP.

Environmental risk is the likelihood of adverse changes in the natural environment, or the long-term adverse effects of these changes arising from adverse environmental impacts.

The construction and operation of the power units No. 3, 4 is planned on the existing and originally designed for this industrial site of the SS KhNPP. The landscape of the site is industrial and is characterized positively for the placement of power generation units and buildings associated with the operation of power generation units.

The State Hygienic Norms regulate practical activities in conditions of normal operation. To do this, the dose limits of exposure to personnel and the population, the levels of admissible income and maintenance are introduced. The effective dose limit for population exposure in Ukraine is 1 mSv/year. At the same time, the population living near the nuclear power plant can receive a dose of radiation dose due to gas-aerosol emissions of nuclear power plants along all routes of exposure, not exceeding 4% of the maximum dose, i.e. <40 µSv/year.

In the State Hygienic Norms, the reference value of risk is:

- for staff .... 2×10^{-4} /year;
- for the population .... 5×10^{-5} /year.

Radiation risks during the normal operation of KhNPP

The maximum values of the predicted effective average annual individual dose for the 45th year of normal operation of the NPP in case of four power units were obtained at a distance of 0.5 km east of the NPP and amounted to 2.8 µSv/year, which is a thousand times lower than the doses from natural background in the world and average values for Khmelnytskyi and Rivne regions (2.2 and 3.1 mSv/year, respectively). With an increase in the distance from the KhNPP to 25 km, the total effective dose due to plant emissions decreases to one hundredth of mSv. In the case of SS KhNPP, the estimated dose loads for the population outside the SPZ will be two orders of magnitude below the established quotas for gas-aerosol emissions of nuclear power plants.

Radiation risks in case of accidents

The release into the environment during accidents is determined by the leakiness of the containment of the power unit and the time of the existence of increased pressure in it. The composition of the release into the atmosphere includes RNG, radioisotopes of iodine, aerosols ^{137}Cs and ^{90}Sr and other radionuclides.

Estimated estimates of individual risk for the population, as well as for calculating dose loads, were made using the PC COSYMA v.2.1 application software package. This package of programs was developed in the European Union and recommended by the IAEA for such assessments.

Radiation risks in case of MDBA

The conducted calculations showed that at the SPZ border along the track axis individual risks for the population from technogenic irradiation as a result of gas-aerosol emission of nuclear power plants during MDBA, both during protective measures (countermeasures) and without them (less than $2.0\cdot10^{-6}$ and $3.8\cdot10^{-6}$, respectively) are even below the acceptable level of the individual risk in $5\cdot10^{-5}$ year^{-1}.

Radiation risks in case of BDBA

The calculations showed that outside the SPZ boundary along the track axis, individual risks for the population from technogenic exposure due to gas-aerosol release of nuclear power plants in the event of protective measures (countermeasures) will be below $1.3 \cdot 10^{-5}$ and will not exceed the acceptable level of the individual risk in $5 \cdot 10^{-5}$ year^{-1} according to the norms. In the absence of protective measures at the BDBA at the boundary of the SPZ along the track axis several hundred meters away from the worst conditions (contamination during the harvest period under the worst weather conditions), in a very limited area, there may be an excess of the mortality risk for the population at the level of $5 \cdot 10^{-5}$ year^{-1}. The introduction of restrictions on the consumption of food from this site can reduce the dose burden on the population.

.**Measures to reduce the environmental risk of power units operation**

The noise produced by machinery and equipment during the operation of the power units No. 3,and No. 4 of KhNPP can be efficiently reduced when choosing equipment and materials for building construction. Sources of noise can also be insulated with a coating or equipped with sound dampers, if necessary. Noise resulting from vibration can be reduced by installing vibrating equipment on the shock absorbers.

There is the SPZ around the KhNPP, where residents do not live permanently, and where economic activity is limited. Radiological impact on public health, as shown above, within the SPZ is minimal and does not exceed the limits prescribed by the requirements of the radiation safety standards of Ukraine. Outside the SPZ, the impact can be considered insignificant. Nevertheless, minimization of the radiation impact on the environment, personnel and population is provided by the following measures:

- Control over radioactive sources, providing multi-stage proliferation barriers and sealing radioactive substances to prevent their entry into the environment;
- monitoring and minimization of radioactive emissions and discharges;
- Radiological monitoring of environmental objects within the KhNPP.

6 CONCLUSIONS

The effects of emergency non-radiation emissions and discharges in the environment are excluded.

Assessment of the radiation impact in SSE and BDBA:

- Radioactive contamination of the territory will not lead to the change in the physical-chemical, and water-physical properties of the soil;
- Changes in the plant and animal communities at the species level are unlikely, (although in the limited area along the axis of the track the radiobiological effects can be observed in coniferous trees in case of BDBA); structural changes in biocenosies under the influence of radiation factors outside the BDBA will not occur;
- The considered accidents (SSE, BDBA) do not represent the radiation hazard for the population of Ukraine, because according to all criteria of the regulatory documents of Ukraine, Russia, Great Britain, the European Community outside the sanitary protection zone SPZ, there is no need for evacuation, shelter, iodine preventive care, permanent relocation, but necessary restrictions for food consumption can be used. The risks of the occurrence of deterministic effects are zero. The risks of individual stochastic effects (the occurrence of severe hereditary effects and fatal cancer) in case of SSE are below the acceptable level of 10 to 5; in case of BDBA while non-conducting countermeasures, they exceed the acceptable individual risk range at distances up to 4 km from the source of emission; in the case of countermeasures fulfillment, the individual risks of stochastic effects do not exceed the acceptable individual risk for the population;
- no one limit of the individual annual effective dose per member of the reference group in neighboring states will be exceeded for any considered accident.