10 RISK ANALYSIS AND ASSESSMENT

10.1 INTRODUCTION TO RISK ASSESSMENT

Potential emergency situations (risks) resulting from the proposed economic activity, which could lead to environmental impact are addressed in this chapter.

Risk assessment for environmental impact assessment (EIA) differs from risk assessment which is performed later in the Safety Analysis Report (SAR) of a NPP. Usually during the environmental impact assessment process a Technical Design of the NPP is not available yet, therefore for EIA it is important to identify potential emergency situations which are general for different types of power plants and to define emergency situations which have bounding impact on the environment. The risk assessment as presented in an EIA Report shall be considered as preliminary and does not substitute necessity for more sophisticated and detailed risk analysis which has to be based on actual design solutions. At later stages, when reactor type will be selected and Technical Design of this selected type of NPP will be available, a detailed risk analysis, resulting consequences and preventive/mitigation measures will be described in a Safety Analysis Report.

Emergency situations, which could lead to releases and cause radiological exposure of personnel and/or general public, are of primary concern for environmental impact assessment. For this proposed economical activity most of the potential emergency situations can cause radiological and non-radiological or only non-radiological consequences (i.e. emergency shutdown of reactor). Accidents with non-radiological consequences as a rule lead to considerably lower impacts. Most of the non-radiological chemical materials at the power plant are used in auxiliary processes. Design of storage tanks for chemicals and implemented procedures assure the safety usage and storage of chemicals both for the environment and for the personnel. The risk of harmful amounts of chemicals or oils being discharged into the water, atmosphere or soil is minor, therefore in the further analysis consequences of radiological accidents are considered.

The Lithuanian legal document “Regulations on Preparation of Environment Impact Assessment Program and Report” (*State Journal 2006, No. 6-225*) defines that the emergency situations of a proposed economic activity and their potential risks should be assessed according to normative document “Recommendations for Assessment of Potential Accident Risk of Proposed Economic Activity” (*Information Publications, 2002, No. 61-297*).

“Regulations on Prevention of Industrial Accidents, their Elimination and Investigation” (*State Journal, 2004, No. 130-4649*) provide requirements for how industrial accidents shall be assessed. Clause 3.1 of this document states that these regulations are not applicable to facilities which can cause radiological impact. Since radiological impact is of primary concern for EIA the industrial accidents and their investigation will be considered in the Technical Design phase.

Risk assessment performed in this EIA Report contains the following steps:

- Identification of the initiating events, design basis accidents (DBA), severe accidents;
- Screening and selection of accidents which have bounding impact to environment;
- Definition of source terms and releases into environment in case of accidents;
- Dispersion modelling of accidental releases and public exposure assessment;

- Description of protective actions of public in case of radiological or nuclear accident.

Selection of initiating events, DBA and severe accidents is based on the IAEA safety guides and reports:

- External Human Induced Events in Site Evaluation for Nuclear Power Plants *(IAEA Safety Guide No. NS-G-3.1)*;
- Meteorological Events in Site Evaluation for Nuclear Power Plants *(IAEA Safety Guide No. NS-G-3.4)*;
- Accident Analysis for Nuclear Power Plants *(IAEA Safety Reports Series No. 23)*.

Analysis of accidents, classification of consequences and selection of bounding cases is provided in Section 10.2 and is based on "Recommendations for Assessment of Potential Accident Risk of Proposed Economic Activity" (*Information Publications, 2002, No. 61-297*).

Definition of source terms and releases into environment in case of accidents is based on Design Control Documentation (DCD) of different type of reactors. DCD are freely available on the website of the US Nuclear Regulation Commission (www.nrc.gov). DCD contains information which radionuclides are released during normal operation and in case of accidents into environment from different type of reactors.

For dispersion modelling of accidental releases from the NNPP an Air Quality and Emergency Modelling System SILAM (http://silam.fmi.fi) has been used. Accidental releases, dispersion modelling and possible consequences are provided in Section 10.3.

Assessment of consequences in case of accident, protective actions of public in case of radiological or nuclear accident is based on Lithuanian Hygiene Standard HN 87:2002. "Radiation Protection in Nuclear Objects" (*State Journal, 2003, No. 15-624; 2008, No. 35-1251*) and Lithuanian Hygiene Standard HN 99:2000 "Protective Actions of Pubic in Case of Radiological or Nuclear Accident" (*State Journal, 2000, No. 57-1691*).

10.2 NNPP RISK ASSESSMENT

10.2.1 Operational states and accidental conditions at NPP

The entire set of limits and conditions for which an NPP is designed and for which damage to the fuel and release of radioactive material are kept within authorized limits, form the design basis of an NPP. Within the design basis, a number of unintended events are considered, including human errors and equipment failures, whose consequences or potential consequences are not negligible in terms of safety. According to the probability of its occurrence and potential consequences, an event may be classified as an anticipated operational occurrence (also called a transient), design basis accident, beyond design basis accident or severe accident.

Normal operation is NPP operation within specified operational limits and conditions. This includes start-up, power operation, shutting down, shutdown, maintenance, testing and refuelling. Assessment of possible radiological impacts on the environment during normal operation of the NNPP is presented in Chapter 7.

Anticipated operational occurrence (AOO) is an operational process deviating from normal operation which is expected to occur at least once during the operating lifetime of an NPP but which, in view of appropriate design provisions, does not cause any significant damage to items important to safety or lead to accident conditions. AOO is not classified as accident; it is a part of NPP operational state which consists of Normal operation and AOO. Examples of anticipated operational occurrences are loss of normal electrical power and faults such as a turbine trip, malfunction of individual items of a normally running plant, failure to function of individual items of control equipment, and loss of power to the main coolant pump. NPPs are design to withstand such AOO, radioactive releases into the environment rarely exceed the limits that are assigned to normal operation. The dose constraint of annual population exposure during normal operation of NPP and taking into account AOO shall not exceed 0.2 mSv/year.

Design basis accident (DBA) is an accident condition against which a facility is designed according to established design criteria, and for which the damage to the fuel and the release of radioactive material are kept within authorized limits. In case of DBA the safety systems and containment of NPP limit the amount of radioactive materials released into the environment to such a level that restrictions on land and food products are not necessary and according to HN 87:2002 (*State Journal, 2003, No. 15-624; 2008, No. 35-1251*) maximal radiation dose for the population in the case of DBA shall not exceed 10 mSv. Examples of typical DBAs are loss of reactivity control, fuel handling accidents, loss of coolant accident (LOCA), etc.

An accident occurring outside the NPP design basis is called a Beyond Design Basis Accident (BDBA). Such an accident may or may not involve degradation of the reactor core (leading to significant core damage). Examples of BDBAs are total loss of power, total loss of feedwater, LOCA combined with complete loss of an emergency core cooling system, etc.

An accident condition involving significant core degradation is called a Severe Accident (SA). The frequency of SA is less than one in 1 000 000 years of reactor operation (*IAEA Safety Reports Series No. 23*). In case of SA a large proportion of the fuel in the reactor is damaged, and a large amount of this radioactive material is released into containment which prevents a large release to the environment. The limit of release after a severe accident must not cause acute health effects to the population in the vicinity of the NPP, nor should it cause long term restrictions on the use of extensive areas of land or water. There are no regulations for releases in case of SA in Lithuanian legislation. Therefore the limit for the release of radioactive materials arising from a severe accident (100 TBq release of Cs-137) defined in Finnish legislation (*Council State decision 395/91*) is used for environmental impact estimation. According to the Council State decision (*395/91*) accidents leading to large releases of radioactive materials shall be very unlikely. The numerical design objective for this very unlikely release is specified in Finnish Radiation and Nuclear Safety Authority (STUK) Guide YVL 2.8, where it is stated that the mean value of the probability of a release exceeding the target value 100 TBq of Cs-137 must be smaller than $5 \cdot 10^{-7}$ per year. In the design stage of a NPP it is verified that the possibility of a severe accident is less often than once during the 1 000 000 years of reactor operation.

Many of the engineered provisions for radiation protection of the public in normal operation also contribute to the radiation protection in accident conditions. The special measures provided for public protection during accident situations refer to:

- ensuring containment isolation to terminate releases;
- reducing activity releases.

The first requirement for public protection is to ensure that releases are terminated. Containment isolation is provided by diverse means including isolation based on measurements of Reactor Building airborne activity.

The second requirement is to ensure that where releases take place, these are reduced by appropriate filtration and by ensuring that the volatility of radionuclides (in particular iodine) is reduced.

Table 10.2-1 presents possible subdivision of event occurrences.

Table 10.2-1. Subdivision of event occurrences, derived from (*IAEA Safety Reports Series No. 23*).

Occurrence (1/reactor year)	Characteristics		Terminology	Acceptance criteria
$10^{-2} – 1$ (Expected in the life of the plant)	Expected	AOO	Anticipated transients, transients, frequent faults, incidents of moderate frequency, upset conditions, abnormal conditions	No damage to fuel
$10^{-4} – 10^{-2}$ (Chance greater than 1% over the life of the plant)	Possible	DBA	Infrequent incidents, infrequent faults, limiting faults, emergency conditions	No radiological impact at all or no radiological impact outside the exclusion area
$10^{-6} – 10^{-4}$ (Chance less than 1% over the life of the plant)	Unlikely	BDBA	Faulted conditions	Radiological consequences outside exclusion area within limits
$< 10^{-6}$ (Very unlikely to occur)	Remote	SA	Faulted conditions	Emergency response needed

10.2.2 External events

During the site evaluation process the hazards associated with external events that are to be considered in the design of the NPP are determined. These external events are grouped into external natural events and external human induced events. Natural events that are typically considered in NPP design are as follows:

- Earthquake;
- External flooding;
- Extremes of temperature;
- Extreme winds and whirlwinds;
- Rain, snow, ice formation;
- Drought;
- Lightning;
- Natural fires.

External human induced events that are usually considered are:

- Aircraft crash;
- Hazards from adjacent installations, transport activities (missiles, gas cloud, explosion wave, etc.);
- Electromagnetic interference;
- Sabotage, terrorist attack;
- Subsidence;
- External fire;
- Blockage or damage to cooling water intake structures.

10.2.3 International Nuclear Event Scale (INES)

Description of accidental conditions at a NPP is provided in Section 10.2.1. However, this subdivision does not give understanding about the significance of the accident. For instance both fuel handling accidents and LOCA are design basis accidents, but consequences of these accidents are very different. Therefore, the International Nuclear Events Scale (*IAEA and OECD/NEA, 2001*) was implemented to facilitate rapid communication to the media and the public regarding the safety significance of events at all nuclear installations associated with the civil nuclear industry, including events involving the use of radiation sources and the transport of radioactive materials. By putting events into proper perspective, the INES eases common understanding about incidents and accidents at NPPs (see Table 10.2-2). Events which should be communicated are those which are rated at level 2 or above, and events attracting international public interest.

Events which have nuclear or radiological significance are classified using the INES scale, which is divided into eighth levels. Industrial events which do not involve nuclear or radiological operations are termed ‘out of scale’. An example of an ‘out of scale’ event is a fire, if it did not involve any possible radiological hazard and did not affect the safety levels. Anticipated operational occurrences belong to the INES level 0.

Five levels have been selected regarding off-site impacts, the most serious of which is INES level 7. Such an incident would involve a large fraction of the core inventory of a NPP being released. The least serious, INES level 3, involves a dose to a member of the public equivalent to about one tenth of the annual dose limit. Below INES level 3, only the on-site impact and the impact on defence in depth have to be considered.

Incidents, in which civil defence actions are not required, range from INES level 1 (anomaly) to INES level 3 (serious incident). An accident without significant off-site risk is classed as INES level 4. These levels are defined by the committed dose to the critical group. Consequences of the accidents rated at INES level 5 are limited releases which would be likely to result in partial implementation of countermeasures covered by emergency plans to lessen the likelihood of health effects. INES levels 6-7 are classified as those accidents where civil defence actions are necessary, in order of increasing seriousness. These latter levels are defined in terms of the quantity of activity released, radiologically equivalent to a given number of terabequerels of the radioisotope Iodine-131.

The vast majority of reported events from operating worldwide NPPs are rated below INES level 3.

Table 10.2-2. International Nuclear Events Scale (*IAEA and OECD/NEA, 2001*).

Level / Descriptor	Nature of the events
INES 0 Deviating events	Deviations from normal operating conditions can be classed as INES 0, where operational limits and conditions are not exceeded and are properly managed in accordance with adequate procedures. Examples include: a single random failure in a redundant system discovered during periodic inspections or tests, a planned reactor trip and minor spread of containment within controlled area without wider implications for safety culture.
INES 1 Anomaly	Anomaly beyond the authorised regime, but with significant defence in depth remaining. This may be due to equipment failure, human error or procedural inadequacies and may occur in areas covered by the scale, such as plant operation, transport of radioactive materials, fuel handling and waste storage. Examples include: breached of technical specifications or transport regulations and minor defects in the pipe work beyond the expectations of the surveillance programme.
INES 2 Incident	Includes incidents with significant failure in safety provisions but with sufficient defence in depth remaining to cope with additional failures. Events resulting in a dose to a worker exceeding a statutory annual dose limit and/or an event which leads to the presence of the significant quantities of radioactive in the installations in areas not expected any design and which require corrective action.
INES 3 Serious incident	The external release of radioactivity resulting in a dose to the critical group of the order of tenths of mSv. With such a release, off-site protection measures may be needed. On-site events resulting in sufficient dose to workers to cause acute health effects and/or resulting in sever spread of contamination. Or the further failure of safety systems could lead to accident conditions. On such incident was at the Paks NPP in Hungary in 2003. During an outage, fuel assemblies were purified on the bottom of a deep water basin in separate purification equipment. Due to a design failure of the equipment, its cooling circulation system was disturbed and the fuel assemblies overheated. This cause the release of radioactive noble gases and a small amount of Iodine in to the reactor hall. Off-site release was small; levels of external radiation at the site or near its vicinity did not exceed normal background levels. No person was injured; the radiation dose to personnel was at most 10% of the annual dose limit.
INES 4 Accident without significant off-site risk	External release of radiation resulting in a dose to the critical group of the order of a few mSv. Off-site protective actions unlikely. On-site, significant damage to installations. Accident results in the irradiation of one or more workers resulting in an overexposure where a high probability of death occurs. On such event was a criticality accident that occurred in Japan at the Tokkaimure nuclear fuel factory in 1999. Three workers were over-exposed to radiation, two of which died later due to their exposure. The factory was located in an urban area, which was subsequently evacuated, and residents further away advised to protect themselves. The thin walls of the building and the Uranium container did not protect the environment from radiation. The largest dose to a person outside the staff was 16 mSv.

Level / Descriptor	Nature of the events
INES 5 Accident with off-site risk	External release of radioactive materials (in quantities radiologically equivalent to hundred to thousands of terabecquerels of Iodine-131). Such a release would be likely to result in partial implementation of countermeasures covered by emergency plans to lessen the likelihood of health effects. On-site events result in severe damage to installations. This accident may involve a large fraction of the core, a major criticality accident or a major fire or explosion releasing large quantities of radioactivity within the in installations. The Three Mile Island incident in the US in 1979 was an INES level 5 event. The accident initiated from a leak in the reactor system. The reactor emergency cooling was automatically started, and was then incorrectly interrupted by the operators. This caused the overheating and partial melting of the core. Despite the severe damage to the reactor core, the pressure vessel and containment remained intact, preventing external release. The environmental impacts were small.
INES 6 Serious accident	External release of radioactive materials (in quantities radiologically equivalent to tens of thousands of terabecquerels of Iodine-131). Such a release would be likely to result in full implementation of countermeasures covered by local emergency plans to limit serious health effects. Only one such INES level 6 accident has ever occurred. This was in Soviet Union (presently Russia) in 1957, at the reprocessing plant near the town of Kyshtym. A tank containing high-level liquid waste was exploded, causing the release of radioactive material. Health effects were limited by countermeasures, such as evacuation of the population in the environment.
INES 7 Major accident	External release of large fractions of the radioactive material in a large facility (e.g. the core of a power reactor). This would typically involve mixture of short and long lived radioactive fission products (in quantities radiologically equivalent to more than tens of thousands of terabecquerels of Iodine-131). Such a release would result in the possibility of acute health effects; delayed health effects over a wide area, possibly involving more than one country; long term environmental consequences. Only one INES level 7 event has occurred; the 1986 accident at Chernobyl nuclear power plant in the Soviet Union (in the area of the present Ukraine). A reactor was destroyed in an explosion, followed by a fire in the graphite used as a moderator in the reactor. This caused a large release of radioactive material to the environment. Several workers of the power plant and people taking part in the cleaning died of the injuries from the accident or of the immediate health effects caused by radiation. An exclusion zone area of 30 km was ordered around the reactor and about 135 000 people were evacuated.

A very high number of individual accident scenarios at a NPP can be derived from combinations of event categories, plant operational states, applicable acceptance criteria, etc. Even for Safety Analysis Report the complete analysis of all the resultant scenarios is not practicable. Therefore, only typical accidents (criticality accident, loss of coolant accident, fuel handling accidents, etc.) of NPPs are considered in the environmental impact assessment. Since anticipated operational occurrences have no significant impacts on personnel and no impact on the environment they are not considered in the EIA.

10.2.4 Risk identification and analysis

The results of risk analysis are presented in Table 10.2-3. Table structure and content follow recommendations of normative document “Recommendations for Assessment of Potential Accident Risk of Proposed Economic Activity” (*Information Publications, 2002, No. 61-297*). Requirements for classification of consequences of potential accident (for life, environment and property), accident development speed and probability of accident occurring are explained below. More detailed explanations can be found in "Recommendations for Assessment of Potential Accident Risk of Proposed Economic Activity" (*Information Publications, 2002, No. 61-297*).

Classification of consequences for life and health (L)

ID	Class	Characteristic
1	Unimportant	Temporary slight discomfort
2	Limited	A few injuries, long lasting discomfort
3	Serious	A few serious injuries, serious discomfort
4	Very serious	A few (more than 5) deaths, several or several tens of serious injuries, up to 500 evacuated
5	Catastrophic	Several deaths, hundreds of serious injuries, more than 500 evacuated

Classification of consequences for the environment (E)

ID	Class	Characteristic
1	Unimportant	No contamination, localized effects
2	Limited	Minor contamination, localized effects
3	Serious	Minor contamination, widespread effects
4	Very serious	Heavy contamination, localized effects
5	Catastrophic	Very heavy contamination, widespread effects

Classification of consequences for property (P)

ID	Class	Total cost damage, thousands Lt
1	Unimportant	Less than 100
2	Limited	100 - 200
3	Serious	200 - 1000
4	Very serious	1000 - 5000
5	Catastrophic	More than 5000

Classification of accident development speed (S)

ID	Class	Characteristic
1	Early and clear warning	Localized effects, no damage
2	Medium	Some spreading, small damage
3	No warning	Hidden until the effects are fully developed, immediate effects (explosion)

Classification of accident probability (Pb)

ID	Class	Frequency (rough estimation)
1	Improbable	Less than once every 1000 years
2	Hardly probable	Once every 100 – 1000 years
3	Quite probable	Once every 10 – 100 years
4	Probable	Once every 1 – 10 years
5	Very probable	More than once per year

Prioritization of consequences (Pr)

ID	Characteristic of consequences
A	Unimportant
B	Limited
C	Serious
D	Very serious
E	Catastrophic

L - Life
E - Environment
P - Property
S - Speed
Pb - Probability
Pr - Priority

Table 10.2-3. Risk analysis of potential accidents resulting from proposed economic activity.

Object	**Operation**	**Hazard**	**Risk**	**Threatened object**	**Consequences**	**Seriousness**				**Risk level**		**Preventive measures**	**Remarks**
						L	**E**	**P**	**S**	**Pb**	**Pr**		
NPP	Electricity production; SNF and radwaste storage	Impact on constructions	External natural events (Design basis events)	Property	Loads and impacts on NPP operation due to earthquake, flooding; extremes of temperature; winds and whirlwinds; rain; snow; lightning; etc.	-	-	1	1	**5**	**A**	Load combinations for external natural events are considered in the NPP design and construction, safety systems are design against these external natural loads and impacts	The level of water in Lake Druksiai is regulated by a hydrotechnical construction (see Section 7.1.1). If this regulating construction is destroyed by external events, water level decreases to 139.1 m. The water level decrease process will be rather long. The bottom of the present cooling water inlet channel is at 135 m level. Therefore, cooling of NPP will not be lost completely and immediately.
NPP	Electricity production; SNF and radwaste storage	Impact on constructions	External human induced events (Design basis events)	Property	Loads and impacts on NPP operation explosion wave and missiles; external fire; electromagnetic interference; etc.	-	-	1	1	**2**	**A**	External human induced events are considered in the design of NPP. Appropriate design standards and materials are used.	
			Aircraft crash; terrorist attack (Beyond design basis events)	Operating personnel, population, property	These extreme events can cause damages of NPP construction and releases of radioactivity are possible.	3	2	2	3	**1**	**C**	It is expected that all NNPP will demonstrate a full capability to withstand the effect of aircraft crash and other terrorist threats to the integrity of the	

Object	**Operation**	**Hazard**	**Risk**	**Threatened object**	**Consequences**	**Seriousness**				**Risk level**		**Preventive measures**	**Remarks**
						L	**E**	**P**	**S**	**Pb**	**Pr**		
												structures. Appropriate physical protective measures.	
NPP	Electricity production	Radiation exposure	Loss of reactivity control (DBA)	Operating personnel, population, property	Loss of reactivity control could lead to excessive heat production in the nuclear fuel and to potential damage to the barriers against radioactive releases. High radiation fields from direct neutron and gamma radiation leading to potentially high radiation exposure to personnel; exposure of population due to releases; pause in operation	2	2	1	1	**2**	**B**	The reactivity control systems are designed with appropriate limits on the potential amount and rate of reactivity increase to assure that the effects of reactivity accidents can neither result in damage to the reactor coolant pressure boundary nor sufficiently disturb the core, its support structures, or other reactor pressure vessel internals to impair significantly the capability to cool the core.	
NNP	Fuel Transfer	Radiation exposure	Criticality accident (DBA)	Operating personnel, population, property	High radiation fields from direct neutron and gamma radiation leading to potentially high radiation exposure to personnel; exposure of population due to releases; pause in operation	1	2	1	2	**1**	**B**	Occurrence of accident and consequences are limited by design and operational procedures.	The main hazard is to personnel. A second consequence might be off-site release of short lived radioactive fission products and potentially contamination within the facility. In most cases off-site and on-site impact is limited to INES level 4.
NNP	Fuel Transfer	Radiation exposure	Fuel Handling Accident (DBA)	Operating personnel	Accident can occur as a result of a failure of the fuel assembly lifting mechanism, resulting in dropping a raised fuel assembly onto the	1	1	-	1	**3**	**A**	According to operating procedures in case of such accident ventilation system shall be shut down and the	Events during the handling of fresh fuel typically are rated at INES level 0 if there has been no risk of damaging spent fuel elements

Object	Operation	Hazard	Risk	Threatened object	Consequences	Seriousness				Risk level		Preventive measures	Remarks
						L	E	P	S	Pb	Pr		
					reactor core or into the SNF storage pool. Radiation exposure to personnel; pause in operation							fuel-handling area of the Reactor Building or Fuel Building isolated. Depending on the NPP configuration, containment will also provide a safety layer in most cases.	The radioactive inventory of single irradiated FA is much lower than the inventory of the spent fuel pool or the reactor core. As long as the cooling of the spent FA is assured, this provides an important safety layer since the integrity of the fuel matrix is not affected by overheating. In general there will be very long time-scales associated with fuel overheating. Events which do not affect the cooling of the spent FA element and only result in a minor release or no release typically ate be classified at INES level 0. Level 2 may be appropriate for events in which there is damage to the fuel cladding integrity as a result of substantial heat up of the fuel element.
NPP	SNF storage	Radiation exposure	Failure in SNF storage pool cooling (DBA)	Operating personnel	Decay heat removal from spent FAs can be disturbed and damages to fuel cladding are possible. Releases into storage pool water and in space of SNF storage pools hall	1	1	-	2	**3**	**A**	Because of the large water volume and the relatively low decay heat, there is usually plenty of time available for corrective actions to be taken for events involving degradation of spent fuel pool cooling. Also the leakage from the pool is limited by design.	Minor leakages from SNF pool are typically rated at INES level 0. Operation outside operating limits and conditions or a substantial increase in temperature or decrease of the spent fuel pool coolant level is rated at INES level 1. An indication of INES level 2 is the start of fuel element uncovering.
NPP	Electricity production;	Fire	Internal fire	Property	Ignition of combustible materials. Pause in operation	-	-	1	3	**4**	**A**	Appropriate fire prevention and fire	

Object	Operation	Hazard	Risk	Threatened object	Consequences	Seriousness				Risk level		Preventive measures	Remarks
						L	E	P	S	Pb	Pr		
	SNF and radwaste storage		(DBA)									suppression measures	
NPP	Mainte-nance/ Deconta-mination	Chemical hazard	Chemical accident	Operating personnel	Spread of harmful or potentially harmful chemicals.	1	-	-	2	**3**	**A**	Design, construction and operation of discharge equipment, storage and transport pipelines. Automatic alarms and supervision instructions to ensure that no uncontrolled or undetected leaks may arise.	Most of the chemicals stored at NPP are used in auxiliary processes such as the processing of water. Chemicals are also used for purposes such as the decontamination of primary circuit equipment and pipelines.
NPP	Electricity production	Radiation exposure	Loss-of-Coolant Accident Inside Containment (DBA)	Operating personnel, population, property	Piping break inside containment resulting the loss of coolant from reactor coolant system; the cooling capability for the reactor core is reduced. Significant number of fuel claddings can be damaged. Releases into containment.	2	2	1	1	**2**	**B**	The piping is of high quality, designed to nuclear construction industry codes and standards, and for seismic and environmental conditions. Also design of the containment assures integrity and design limits of releases in case of this accidents	LOCA is not expected to occur during the life of the plant, but postulated as a conservative design basis accident.
NPP	Electricity production	Radiation exposure	Main Steam line or Feedwater line Break Accident Outside Containment (DBA)	Operating personnel, population.	A large steam or feedwater line pipe breaks outside containment. Activity released from the broken line is released directly to the environment. There is no fuel damage as a result of this accident.	1	2	-	2	**2**	**A**	The piping is of high quality, designed to nuclear construction industry codes and standards, and for seismic and environmental conditions.	
NPP	Electricity	Radiation	Core damage	Operating	Large release into	3	4	4	1	**1**	**D**	Multiple safety	Core damage will require the

Object	Operation	Hazard	Risk	Threatened object	Consequences	Seriousness				Risk level		Preventive measures	Remarks
						L	E	P	S	Pb	Pr		
	production	exposure	(BDBA)	personnel, population, property	containment. Containment isolation prevents or mitigates releases.							systems to prevent the core damage. Containment assures that there is no large release into environment.	simultaneous failure of multiple safety systems and several incorrect actions from the operating personnel. Core damage frequency is less than 10^{-4} per year and the large release frequency is less than the 10^{-6} per year
NPP	Electricity production	Radiation exposure	Containment failure (Severe Accident)	Operating personnel, population, property	Large release of fission products into environment.	5	5	5	1	**1**	**E**	Multiple safety systems to prevent the containment failure. A fundamental objective is to prevent, as far as possible, all Severe Accidents which might challenge and lead to early failure of the Primary Containment.	The more likely severe accident sequences do not result in containment failure for 72 hours or more. The low frequency severe accident sequences do not result in containment failure in less than 24 hours.

10.3 ACCIDENT CONSEQUENCES ESTIMATION

10.3.1 Source Term Definition for Accident Releases

Accident releases from the new nuclear power plant (NNPP) have been considered for two cases:

- Design basis accident (DBA)
- Severe accident

Lithuanian legislation does not provide specific guidance or requirements on how impact on the environment shall be evaluated in case of DBAs or Severe Accidents. Therefore, experience of foreign countries has been used and the following documents have been considered:

- Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.183, 2000;
- Accident Source Terms for Light-Water Nuclear Power Plants, NUREG-1465, 1995;
- Decision 395/91 of the Council of State on the general regulations for the safety of nuclear power plants, Finland 1991;
- Accident analysis for nuclear power plants. IAEA Safety Reports Series No. 23, 2002.
- The International Nuclear Event Scale (INES). Jointly prepared by IAEA and OECD/NEA. 2001.

There are different DBAs (criticality accident, fuel handling accident, fire, etc.) at NPPs, however for EIA it is important to identify the typical accident which envelopes consequences of all DBAs. According to RG 1.183, such enveloping design basis accident is loss-of-coolant accident LOCA with intact containment (i.e. containment leakage limited to design basis leakage).

Regulations of Finnish Decision 395/91 have been used for estimation of the source term to represent severe accident releases.

Different technological alternatives (reactor types) are considered as options for the new NPP in Lithuania. The activity of released radionuclides depends on reactor type, therefore based on freely available information comparison of activity released from different reactor types in case of accidents was done. The technological alternatives (reactor types) which are considered as options for new NPP in Lithuania are described in Chapter 5.

Two freely available information sources were used for estimation of accident releases:

- Website of U.S. Nuclear Regulation Commission (ABWR; AP1000; ESBWR; U.S. EPR; US-APWR)
- Website of Health and Safety Executive (HSE) (ACR-1000; UK EPR; ESBWR; AP1000).

Information about some reactors (V-392, V-448, SWR-1000, etc.) is not freely available. However, analysis of freely available information on accident releases from different power reactors has showed that activity of released radionuclides depends on reactor power. Therefore, the impact to environment from the most powerful reactors such as ESBWR, EPR and APWR should be considered as the basis of a bounding estimate of source term and potential consequences.

Also it should be noted, that freely available information for some reactors is very comprehensive (all assumptions, initial data, intermediate results and final results are provided) and for some only initial data and resulting radiological consequences are presented.

The set of isotopes, which have been taken into account for estimation of releases in case of DBA and Severe accident, is based on International Nuclear Event Scale (*IAEA and OECD/NEA, 2001*).

Loss of Coolant Accident (LOCA)

ABWR (*DCD US-ABWR, 2008*), APWR (*DCD US-APWR, 2007*) and ESBWR (*DCD US-ESBWR, 2007*) data was examined as basis for source term, since characteristics (power densities, fuel discharge irradiation, enrichment) for these reactors are provided in detail and this will tend to maximise the build up of short and long lived fission products important in the determination of consequences. Analysis of the activities of released isotopes presented in (*DCD US-ABWR, 2008*), (*DCD US-APWR, 2007*), (*DCD US-ESBWR, 2007*) has led to the conclusion that the releases to the environment from APWR in case of LOCA should be considered as bounding case.

Time dependent releases into environment in case of LOCA at APWR are summarized in Table 10.3-1. As it was mentioned above, the list of isotopes is based on INES manual (*IAEA and OECD/NEA, 2001*). According to RG 1.183 in case of LOCA radioactivity release duration 30 days (720 hours) shall be assumed.

This release in case of LOCA can be rated as INES Level 5 event.

Table 10.3-1. Time Dependent Released Activity into Environment during LOCA (Bq) (*DCD US-APWR, 2007*).

Nuclide	0-8hr	8-24hr	24-96hr	96-720hr	TOTAL
Kr-85 (eq for NG)	3.44E+16	1.71E+16	1.13E+16	2.04E+16	8.32E+16
I-131	5.25E+13	2.08E+13	6.85E+13	2.07E+14	3.49E+14
Cs-134	5.33E+12	5.99E+10	0.00E+00	0.00E+00	5.40E+12
Cs-137	3.03E+12	3.41E+10	3.70E+07	0.00E+00	3.06E+12
Te-132	5.22E+12	6.33E+10	3.70E+06	0.00E+00	5.29E+12
Sr-90	1.45E+11	1.89E+09	0.00E+00	0.00E+00	1.47E+11
Co-60	5.88E+08	7.40E+06	3.74E+04	0.00E+00	5.96E+08
Ru-106	9.88E+10	1.28E+09	0.00E+00	0.00E+00	9.99E+10
Am-241	2.78E+06	3.61E+04	0.00E+00	0.00E+00	2.81E+06
Pu-239	1.48E+07	1.92E+05	0.00E+00	0.00E+00	1.50E+07

Severe Accident

As it was mentioned in Section 10.2.1 there are no regulations for releases in case of severe accident in Lithuanian legislation. Therefore the limit for the release of radioactive materials arising from a severe accident (100 TBq release of Cs-137) defined in Finnish legislation (*Council State decision 395/91*) is used to represent a typical large release scenario to indicate the potential scale of consequences for such events, and inform the extent of emergency planning provisions that might be implemented should construction and operation of a new NPP proceed.

Since the APWR reactor is used for LOCA accident, this type of reactor is also selected for severe accident impact estimation.

Only a limitation for Cs-137 is defined in (*Council State decision 395/91*); however the release of other isotopes must be taken into account also. The source term for release into the environment is estimated based on a 100 TBq release of Cs-137. The releases of other isotopes are scaled according to APWR core inventory at time of the release. Core inventory of APWR is provided in (*DCD US-APWR, 2007*).

According to probabilistic risk assessment and severe accident evaluation of APWR (such assessment has been done by the reactor supplier and is presented in DCD for US-APWR) containment integrity is maintained more than 24 hours after onset of core damage. The time period of 24 hours is a goal for containment performance defined in US NRC regulations and also in European Utility Requirements (*EUR 2001*), which includes a deterministic goal that containment integrity shall be maintained for approximately 24 hours following the onset of core damage and a probabilistic goal that the conditional containment failure probability shall be less than approximately 0.1 for the composite of core damage sequences assessed in the probabilistic risk assessment. Therefore, 24 hours delay before the release into the environment is assumed for source term calculations.

Releases into the environment in case of severe accident are summarized in Table 10.3-2. The source term for the release is normalized for Cs-137 100 TBq release. The activities of other released isotopes are scaled according to core inventory after 24 h and "Accident Source Terms for Light-Water Nuclear Power Plants" (*NUREG-1465, 1995*). The core inventory is used for definition of ratios between the different nuclides. Release fractions into containment for various radionuclides are basically in accordance with (*NUREG-1465, 1995*). An exception is the release fraction for Cs, which is assumed to be 0.50 (0.75 is provided in (*NUREG-1465, 1995*)). Since the release is normalized to 100 TBq Cs-137, a higher release fraction of Cs-137 into containment will underestimate activities of other isotopes. Also different countries assume different release fractions into containment. "A Comparison of World-Wide Uses of Severe Reactor Accident Source Terms" (*SAND94, 1994*) gives an overview on how source term for severe accident is defined in various counties.

A release height of 100 m is assumed. Such height is conservative for the nearby range, as there is no population living in the sanitary protection zone (1-3 km). For the assessment of consequences the maximum should fall within a populated area. Release duration is 6 hours.

This severe accident release can be rated as INES Level 6 event.

Table 10.3-2. Releases into the environment in case of Severe Accident (Bq).

	Core Inventory		Release fraction into containment	Releases into Environment after	Eq. I-131
	0 h	24 h		24 h	
Kr-85m	1.79E+18	4.41E+16	1.00	1.24E+13	0.00E+00
Kr-85	6.40E+16	6.40E+16	1.00	1.79E+13	0.00E+00
Kr-87	3.55E+18	7.49E+12	1.00	2.10E+09	0.00E+00
Kr-88	5.00E+18	1.43E+16	1.00	4.00E+12	0.00E+00
Xe-133	1.11E+19	1.07E+19	1.00	2.99E+15	0.00E+00
Xe-135	3.38E+18	4.23E+18	1.00	1.19E+15	0.00E+00
I-131	5.33E+18	4.97E+18	0.75	1.04E+15	1.04E+15
Te-132	7.59E+18	6.13E+18	0.50	8.59E+14	2.58E+14
Sr-90	5.14E+17	5.14E+17	0.05	7.20E+12	7.20E+13
Cs-134	1.25E+18	1.25E+18	0.50	1.76E+14	3.51E+15
Cs-137	7.14E+17	7.14E+17	0.50	1.00E+14	3.00E+15
Pu-239	2.09E+15	2.09E+15	0.001	5.84E+08	5.84E+12
Co-60	1.61E+16	1.61E+16	0.05	2.25E+11	1.35E+13
Ru-106	2.79E+18	2.78E+18	0.05	3.89E+13	2.73E+14
Am-241	9.77E+14	9.81E+14	0.003	8.24E+08	7.42E+12
					8.18E+15

10.3.2 Dispersion and uptake of radionuclides

10.3.2.1 Methodology

The dispersion simulations for the two accident scenarios were made with Air Quality and Emergency Modelling System SILAM of the Finnish Meteorological Institute (FMI) (http://silam.fmi.fi). The SILAM system is a dual-core Lagrangian-Eulerian modelling framework, which was developed by FMI in co-operation with several other institutes from different countries for solving a wide range of emergency, air quality and regulatory problems. Following the standards of the emergency modelling, SILAM evaluates concentrations and depositions of each released nuclide and its derivatives along the decay chain.

The dispersion model was run with meteorological data obtained from the European Center for Medium Range Weather Forecasts (ECMWF) Operational Data Archives. The data covers two consecutive years 2001 and 2002, which were chosen because meteorologically these years represent typical years in Europe.

The assessment of doses from an accidental radioactive release from the NNPP is based on the results of dispersion simulations and it utilizes empirical coefficients and methodologies for converting the modelled concentrations in air and depositions to doses. The specific formulations and all numerical constants used for the dose assessment computations are defined in a separate report (*FMI 2008*).

Comparison with other methodologies

An approach widely used in past similar assessments of dispersion is based on simulations with simple Gaussian plume model using artificial conditions seen as the "worst-case dispersion scenario". The outcome of the Gaussian simulations is equilibrium concentrations and deposition fluxes considered as the upper-limit estimates of the accident impact. Providing reasonable results in the nearest vicinity of the plant, Gaussian models ignore the real pattern of dispersion – with wind meandering, actual developments of vertical and horizontal mixing along the day etc. They do not indicate the probability of observation of the simulated pattern in reality. The results are obtained without information on how realistic they are and how often such dispersion conditions take place in the specific geographical region.

The approach applied in this current work is based on brute-force multi-scale computations of dispersion using actual meteorological data from weather archives. The 3-D modelling system used in this assessment is built to solve the turbulent dispersion equation taking into account the variability of the meteorological conditions and the inhomogeneity of the turbulent diffusion coefficient in space or time. This approach allows replacing the artificial "worst case" with physically and statistically grounded characteristics. Having the simulations made over a sufficiently long period, the percentiles of concentrations and depositions can be calculated in a straightforward way. This methodology is very expensive computationally but it is also the most universal: it is applicable at any scale and for any type of source.

10.3.2.2 Results of the dispersion modelling and dose estimates

The exposure of the environment and people depends on the specific meteorological conditions during the accident and the geographical location of the receiving point. To cover all realistic meteorological conditions several cases in different meteorological conditions during the years 2001 and 2002 have been simulated. 2-dimensional maps have been created of the exposure levels, which are not exceeded with a certain probability for any realistic meteorological conditions.

The dispersion has been simulated for an area of about 1200 km wide (computation domain), which is extensive enough for the purpose of the assessment. For the loss of coolant accident (LOCA) and severe accident (SA) release scenarios, the simulation of a particular case lasts until the pollutants released during the accident leave the computation domain. An estimate of the time needed is: $t = X_s / 30$, where X_s is the domain size in km, and 30 km/h is a typical wind speed at the top of the boundary layer. Hence, for a domain of about 1200 km in horizontal size the transport time of nuclides outside the area is about 40 hours.

Using the above screening formula, simulation duration for a single case was taken as 32 days for LOCA scenario and 2 days for SA. The model starts computations of a case at the beginning of each day during the whole period selected for the assessment (2 years 2001 and 2002). Due to the short duration of the release for SA, two sets of cases had to be analysed: day-time release and night-time release. Daytime and night-time releases appear under strongly different atmospheric conditions and this is why it is reasonable to assess these two sets of cases independently.

Each of the 3 cases (LOCA, SA-day, SA-night) have been analysed with two spatial resolutions to account for both regional and local effects. A resolution of 20 km is used for long-range transport and a resolution of 2 km for near-range transport.

The assessment was performed on the basis of 98 % of depositions and doses. This means that, in case of an accident, the presented values can be exceeded in some places only with the probability of 2 %. Thus, if 98-th percentile of deposition at some place for the LOCA scenario is equal to 100 Bq/m^2, it means that if a LOCA accident happens, the probability for this place to be affected by concentrations higher than 100 Bq/m^2 is 2 %. Importantly, the information is place-specific, i.e. the assessment results in geographical maps of the percentiles.

The following figures (Figure 10.3-1) illustrate the dependence of the deposition values on distance from the NNPP and on percentile. The X-axis represents the longitude for

East-West cross-section and latitude for North-South cross-section. The Y-axis represents the percentile – the range shown is from 70 % to 100 % (max value), with 100 % at the bottom. Because of the anisotropy of wind directions both latitudinal and longitudinal cross-sections are provided. For example, directly to the east from the NNPP on the meridian of 20^0E, the deposition in case of a LOCA accident is maximum 10 Bq/m^2 with the probability of about 83 %. The results of this study for the deposition of I-131 in case of LOCA accident are the geographical regions corresponding to the 98-th percentiles in these cross-sections. Similarly, the dose values also depend on the distance from the NNPP and the percentile.

As expected, the area with higher concentrations is larger for the higher percentile. This increase is observed (but not necessarily uniformly) over the whole grid: at every point the concentration for 99 % is higher than for 98 %. The cross-section figures show significant and irregular jumps from 99 % to 100 %. The maximum values are the most sensitive among all parameters to model limitations and inaccuracies in the meteorological data – and thus the most uncertain. This is why it is reasonable not to use the maximum percentiles as the basis for the assessment.

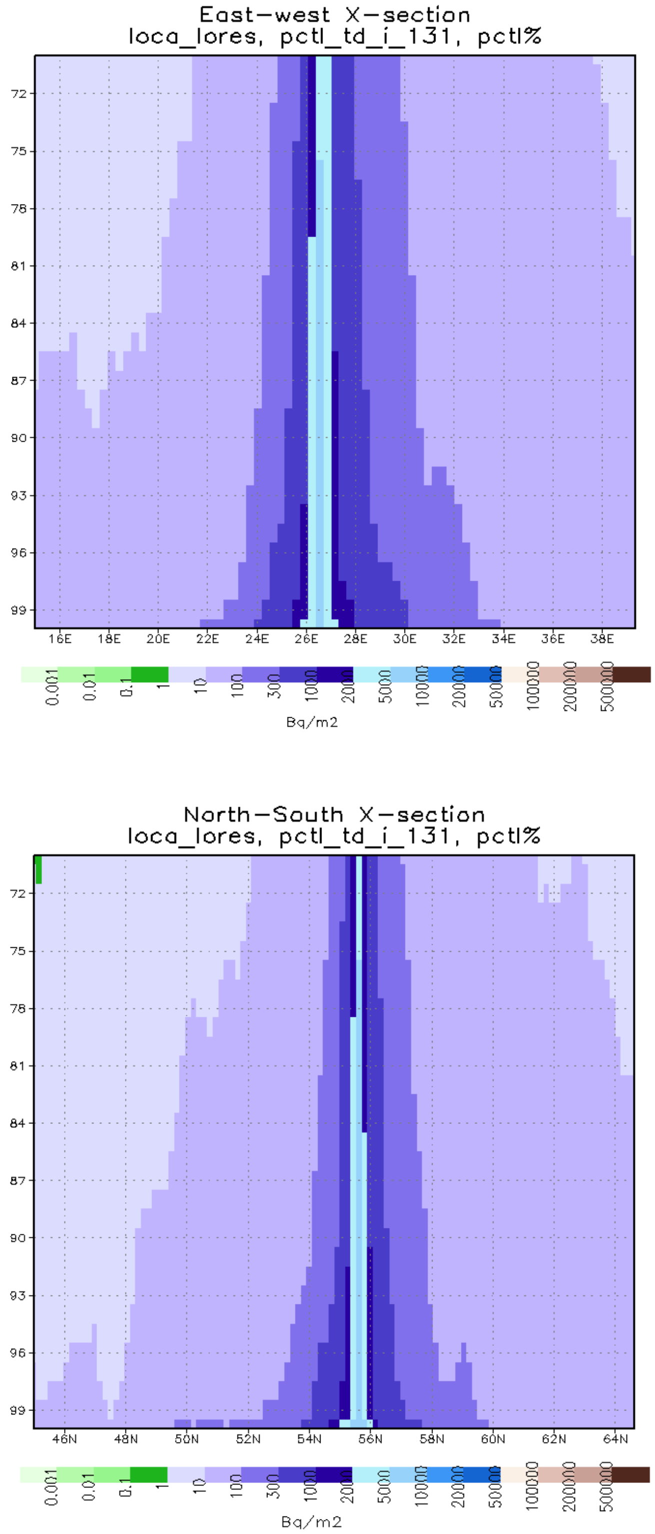

Figure 10.3-1. Loss of coolant accident (LOCA), deposition of Iodine-131 in Bq/m^2 in the large domain with 20 km resolution; upper map: east-west cross-section, lower map: north-south cross section.

The maps presented to describe the results have the scale in latitudinal and longitudinal degrees. The geographical location of the NNPP itself is 26.56^{0}E, 55.6044^{0}N. At this latitude one degree of distance along parallel (west-east cross-section) is equivalent to 62.8 km while one degree distance along meridian (south-north cross-section) is equivalent to 111 km.

Deposition

Cesium-137 (Cs-137) and Iodine-131 (I-131) are essential nuclides when assessing the radioactive deposition and dose after a postulated NPP accident, since they are biologically the most significant of the radionuclides released in an NPP accident. Cs-137 has a radiological half-life of 30 years. Thus once it is released into the environment, it remains present for many years. This is why it is especially important in the assessment of the long-term impacts. Compared to Cs-137, I-131 has a short radiological half-life of 8 days. I-131 can accumulate in the thyroid and harm it as it decays. The risk relates especially to children, but it can be mitigated by taking iodine supplements. In this report the deposition maps are presented for Cs-137 and I-131. The unit of radioactivity used in these maps is Becquerel [Bq].

Doses

Radioactive releases to the atmosphere may contribute to radiation exposure through several pathways either externally or internally. External exposure is due to the direct radiation from a radioactive plume or from radionuclides deposited on the ground. External dose thus includes the dose from cloud shine and the dose from ground shine. Internal exposure is due to inhalation or ingestion of radioactive material. The ingestion dose includes the intake of radioactive substances taking into account the migration of the radioactive nuclides along the food chains finally reaching the human body.

The total effective dose includes both external and internal dose. The short-term effective dose is determined by the dose from cloud and ground shine as well as inhalation dose. Long-term effective dose is mainly due to ground shine and ingestion. The unit of dose is Sievert [Sv]. In this chapter dose maps are presented for total external dose. The calculation period for the doses is 50 years.

LOSS OF COOLANT ACCIDENT

This section contains the 98-percentile maps for the depositions of I-131 and Cs-137 as well as cloud-shine and external doses resulting from the LOCA release scenario. Also the rates for ground-shine dose and external dose are presented to be compared with the criteria for protective actions (section 10.4). In the maps one degree of distance along parallel (west-east cross-section) is equivalent to 62.8 km while one degree distance along meridian (south-north cross-section) is equivalent to 111 km.

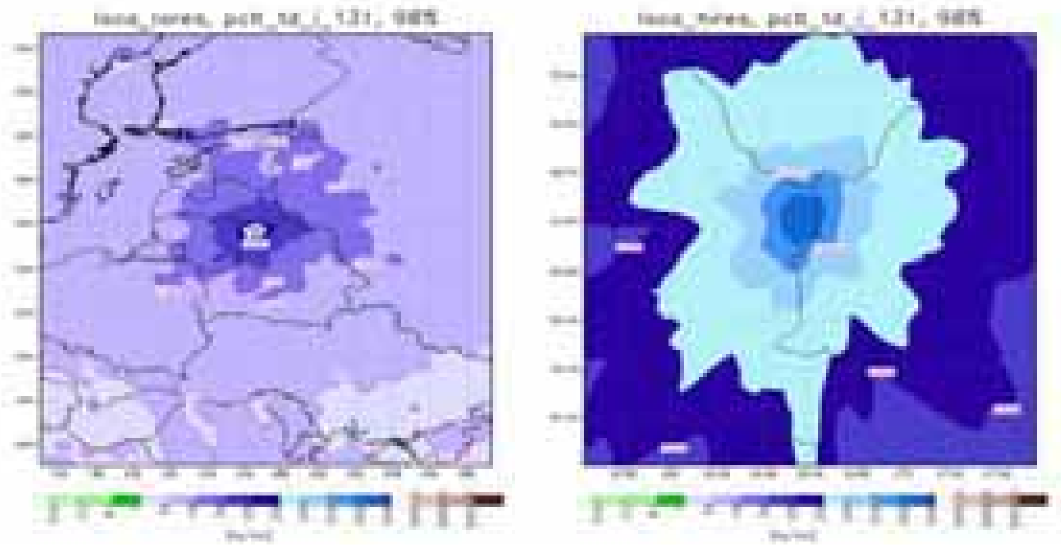

Figure 10.3-2. Loss of coolant accident (LOCA), total deposition of I-131 in Bq/m^2 (left panel: large domain with 20 km resolution; right panel: fine-grid domain, 2 km resolution).

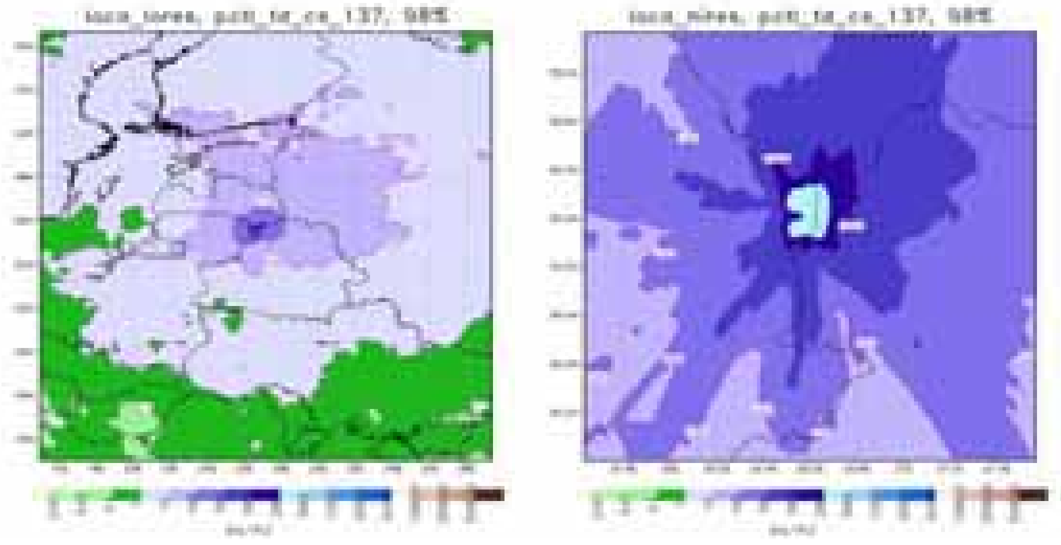

Figure 10.3-3. Loss of coolant accident (LOCA), total deposition of Cs-137 in Bq/m^2 (left panel: large domain with 20 km resolution; right panel: fine-grid domain, 2 km resolution).

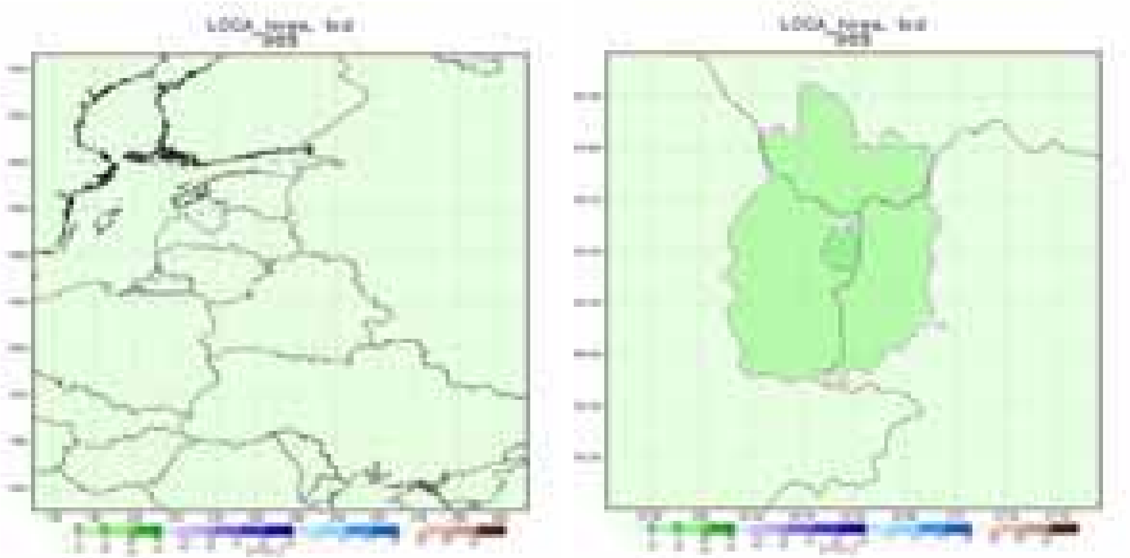

Figure 10.3-4. Loss of coolant accident (LOCA), cloud-shine dose [mSv] (left panel: large domain with 20 km resolution; right panel: fine-grid domain 2 km resolution).

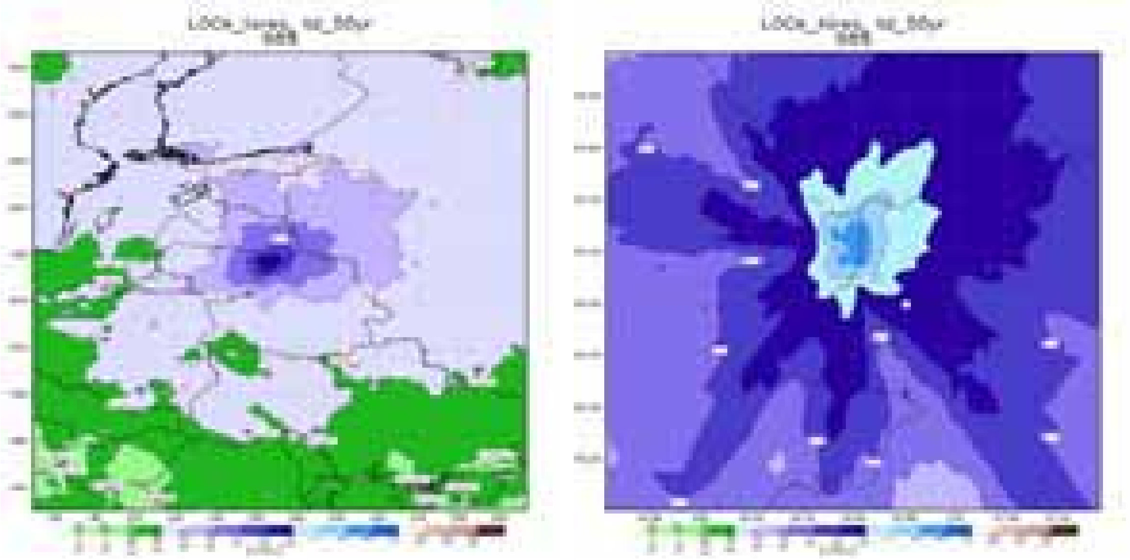

Figure 10.3-5. Loss of coolant accident (LOCA), total external dose over 50 years [mSv] (left panel: large domain with 20 km resolution; right panel: fine-grid domain, 2 km resolution).

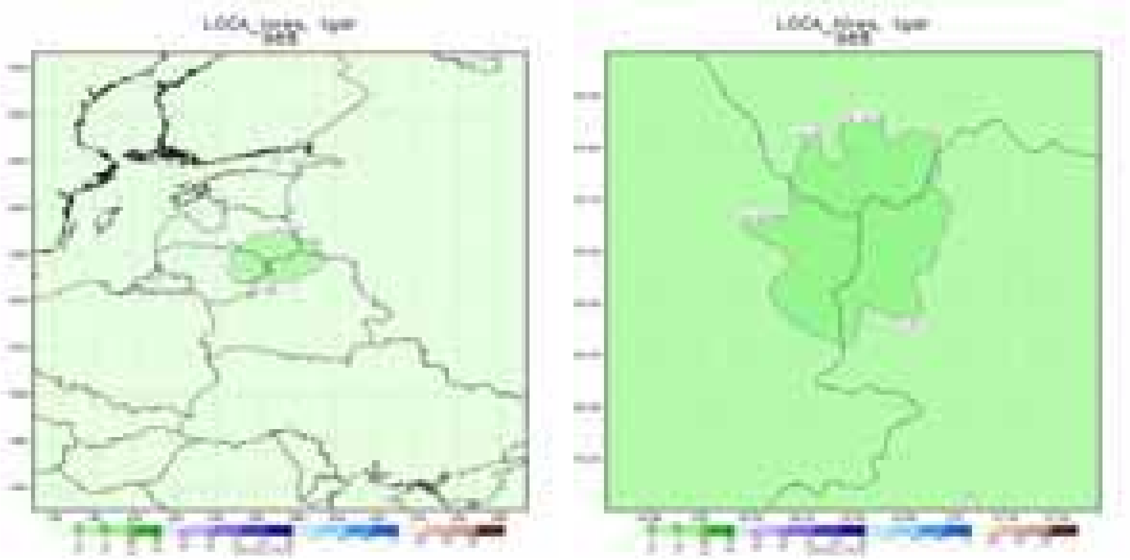

Figure 10.3-6. Loss of coolant accident (LOCA), ground-shine dose rate [mSv/hr] (left panel: large domain with 20 km resolution; right panel: fine-grid domain 2 km resolution).

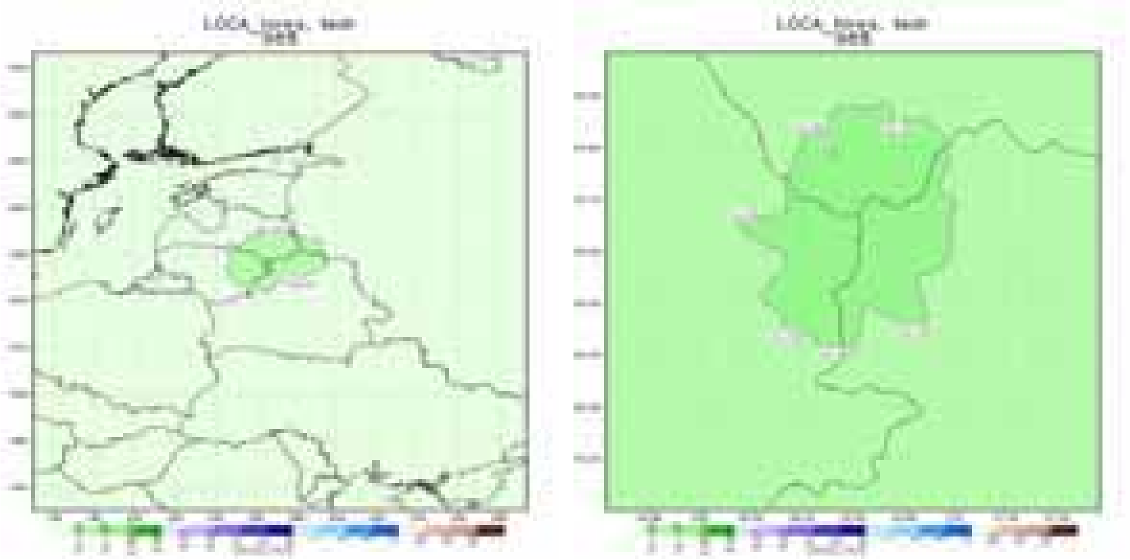

Figure 10.3-7. Loss of coolant accident (LOCA), external dose rate [mSv/hr] (left panel: large domain with 20 km resolution; right panel: fine-grid domain 2 km resolution).

SEVERE ACCIDENT

Severe accident, daytime release

This section contains the 98-percentile maps for the depositions of I-131 and Cs-137 as well as cloud-shine and external doses resulting from the SA, daytime release scenario. Also the rates for ground-shine dose and external dose are presented to be compared with the criteria for protective actions (section 10.4). As before, in the maps one degree of distance along parallel (west-east cross-section) is equivalent to 62.8 km while one degree distance along meridian (south-north cross-section) is equivalent to 111 km.

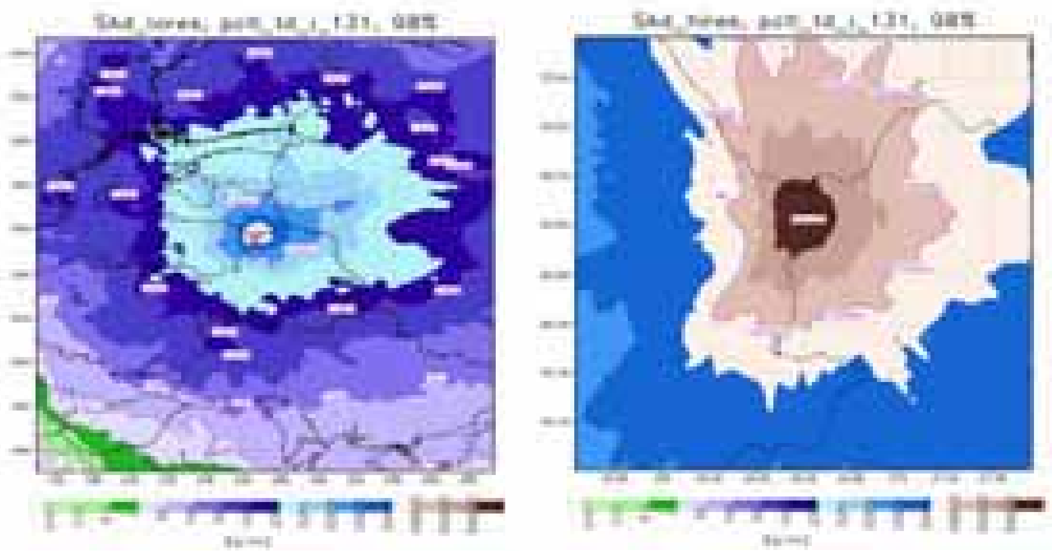

Figure 10.3-8. Severe accident, daytime release (SAd); total deposition of I-131 in Bq/m^2 (left panel: large domain with 20 km resolution; right panel: fine-grid domain, 2 km resolution).

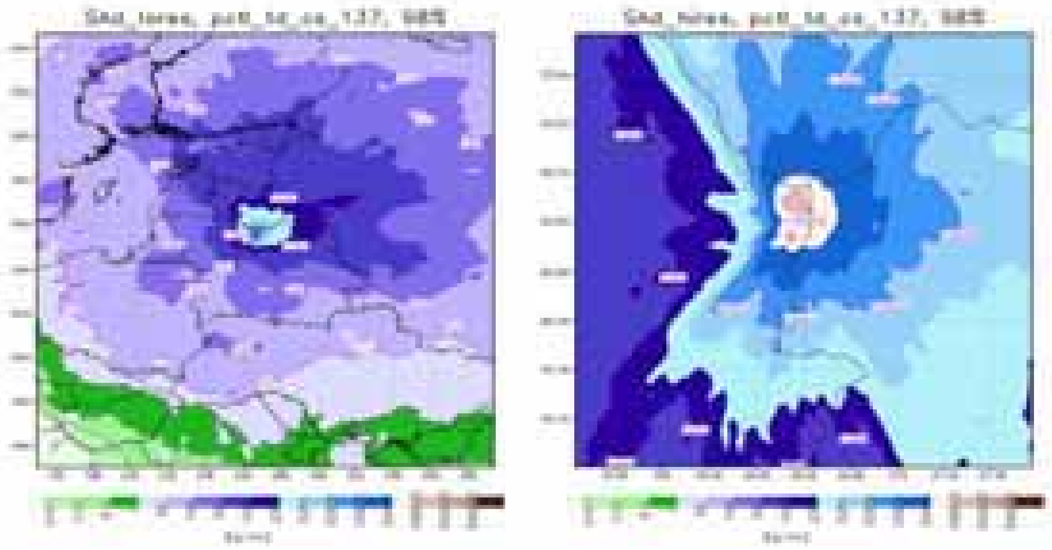

Figure 10.3-9. Severe accident, daytime release (SAd); total deposition of Cs-137 in Bq/m^2 (left panel: large domain with 20 km resolution; right panel: fine-grid domain, 2 km resolution).

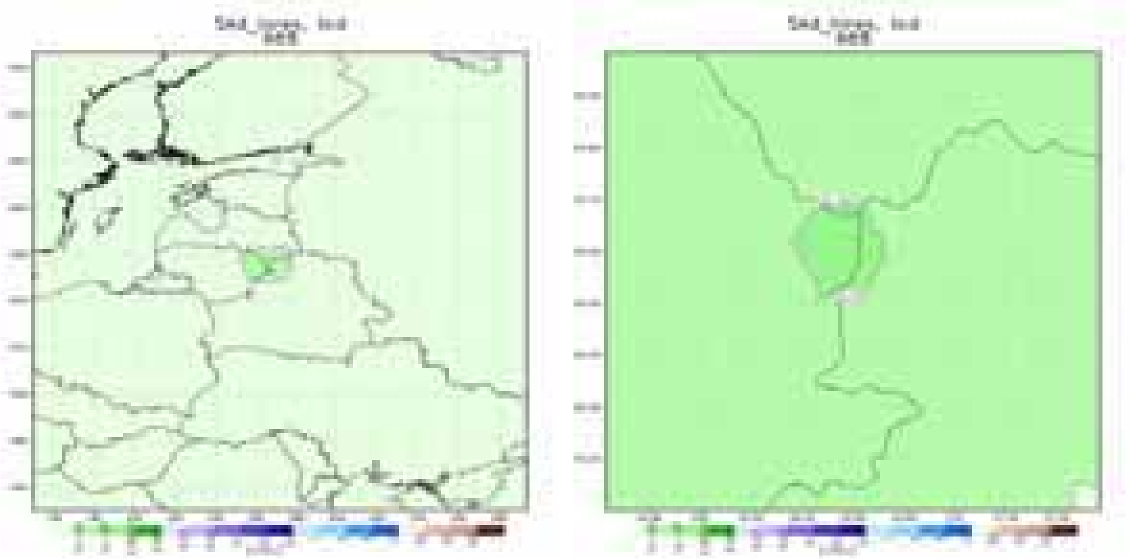

Figure 10.3-10. Severe accident, daytime release (SAd); cloud-shine dose [mSv] (left panel: large domain with 20 km resolution; right panel: fine-grid domain 2 km resolution).

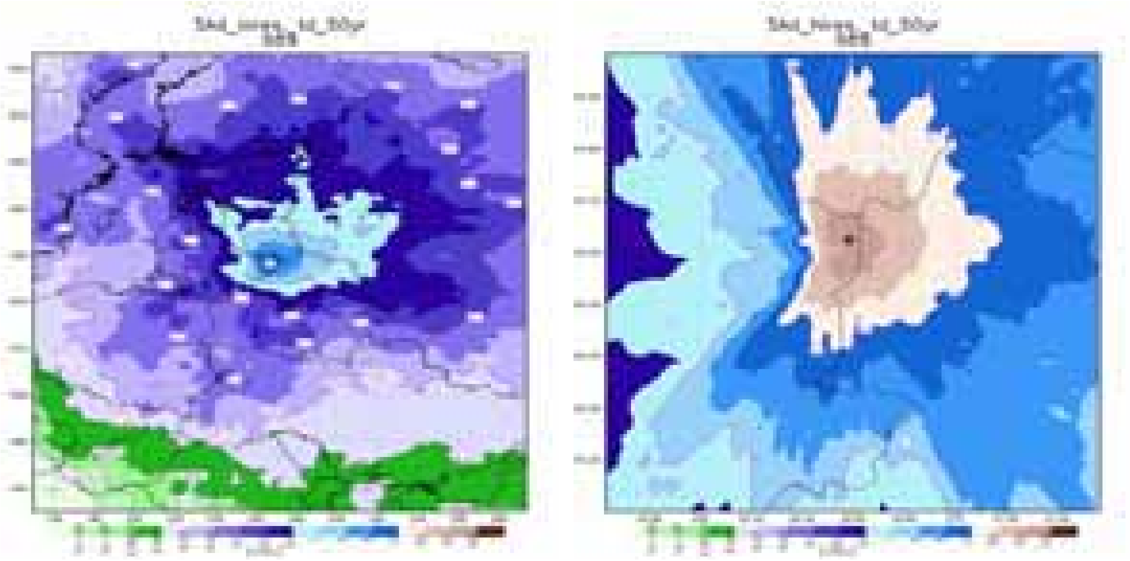

Figure 10.3-11. Severe accident, daytime release (SAd), total external dose over 50 years [mSv] (left panel: large domain with 20 km resolution; right panel: fine-grid domain, 2 km resolution).

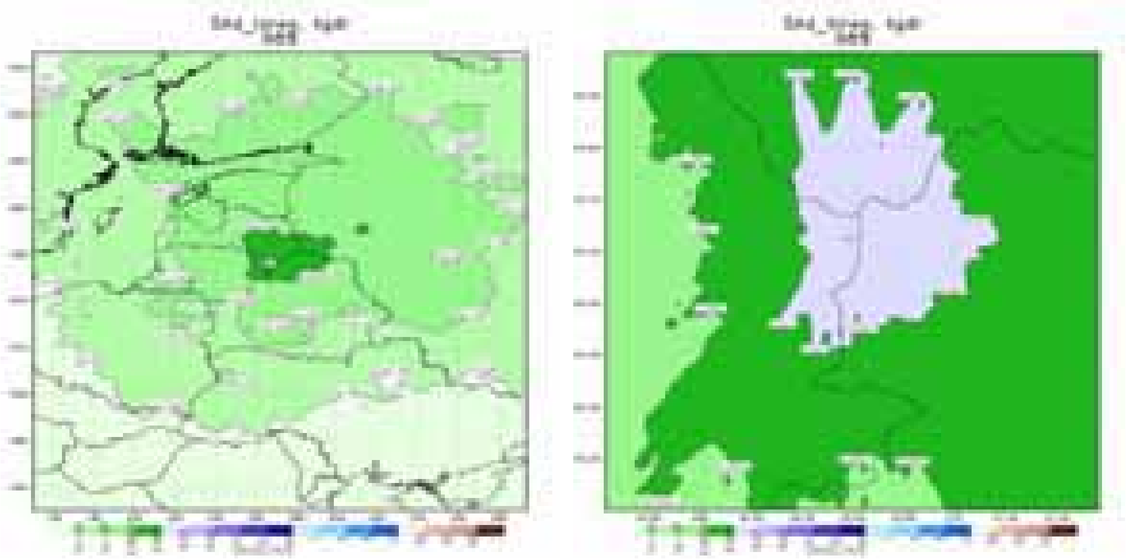

Figure 10.3-12. Severe accident, daytime release (SAd), ground-shine dose rate [mSv/hr] (left panel: large domain with 20 km resolution; right panel: fine-grid domain 2 km resolution).

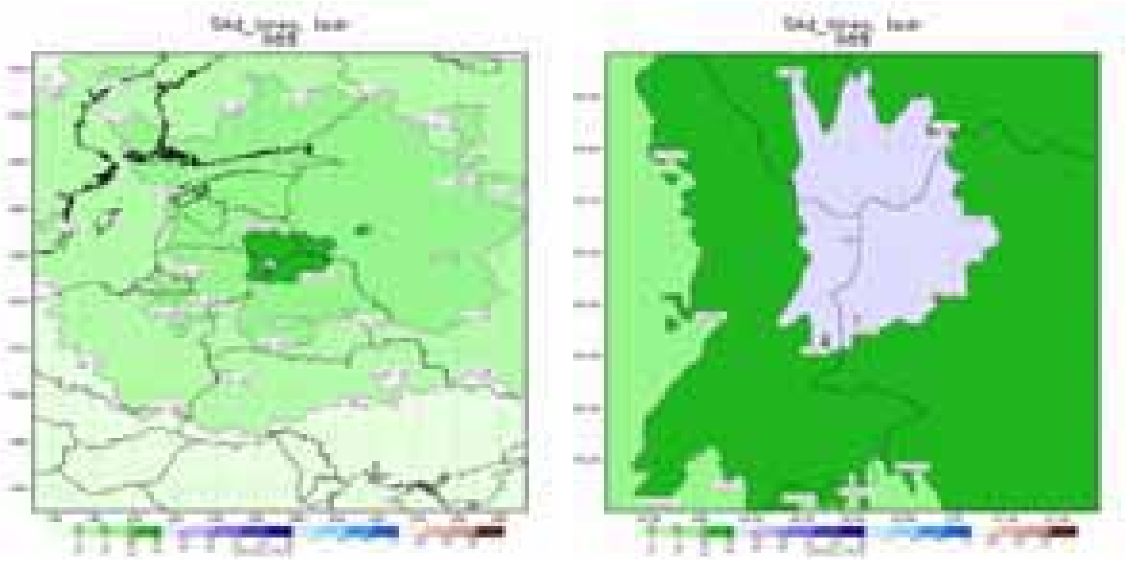

Figure 10.3-13. Severe accident, daytime release (SAd), external dose rate [mSv/hr] (left panel: large domain with 20 km resolution; right panel: fine-grid domain 2 km resolution).

<u>Severe accident, night-time release</u>

This section contains the 98-percentile maps for the depositions of I-131 and Cs-137 as well as cloud-shine and external doses resulting from the SA, night-time release scenario. Also the rates for ground-shine dose and external dose are presented to be compared with the criteria for protective actions (section 10.4). As before, in the maps one degree of distance along parallel (west-east cross-section) is equivalent to 62.8 km while one degree distance along meridian (south-north cross-section) is equivalent to 111 km.

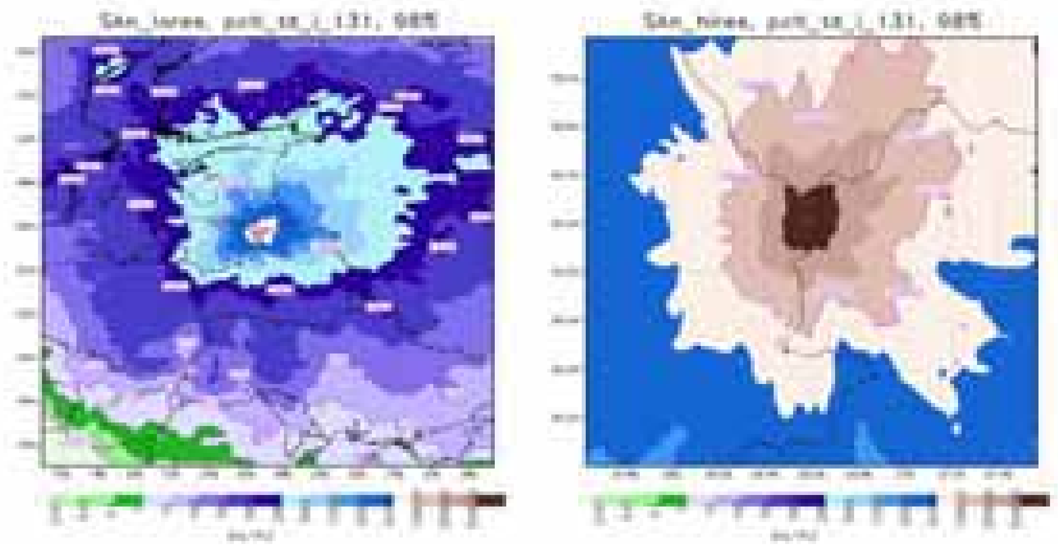

Figure 10.3-14. Severe accident, night-time release (SAn); total deposition of I-131 in Bq/m^2 (left panel: large domain with 20 km resolution; right panel: fine-grid domain, 2 km resolution).

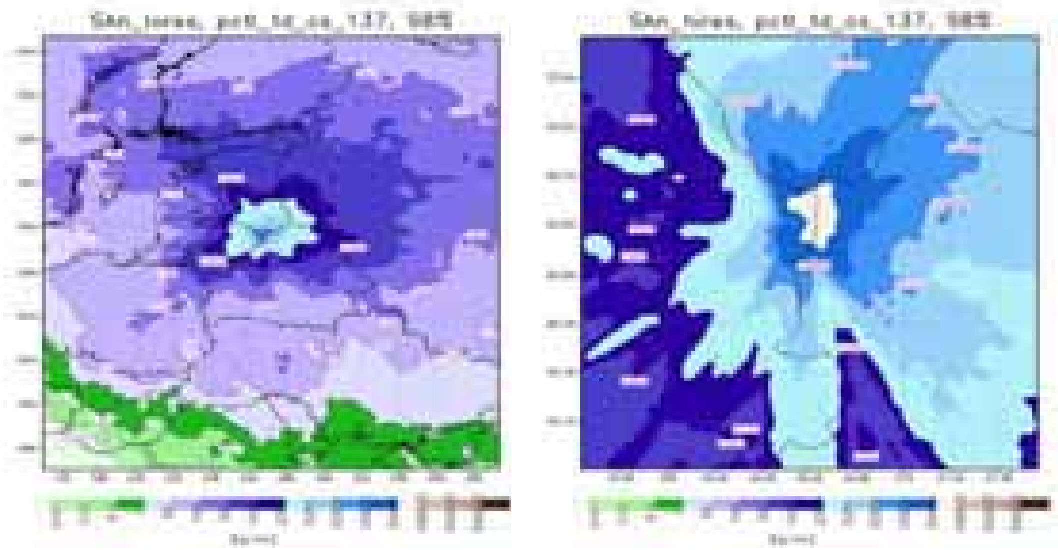

Figure 10.3-15. Severe accident, night-time release (SAn); total deposition of Cs-137 in Bq/m^2 (left panel: large domain with 20 km resolution; right panel: fine-grid domain, 2 km resolution).

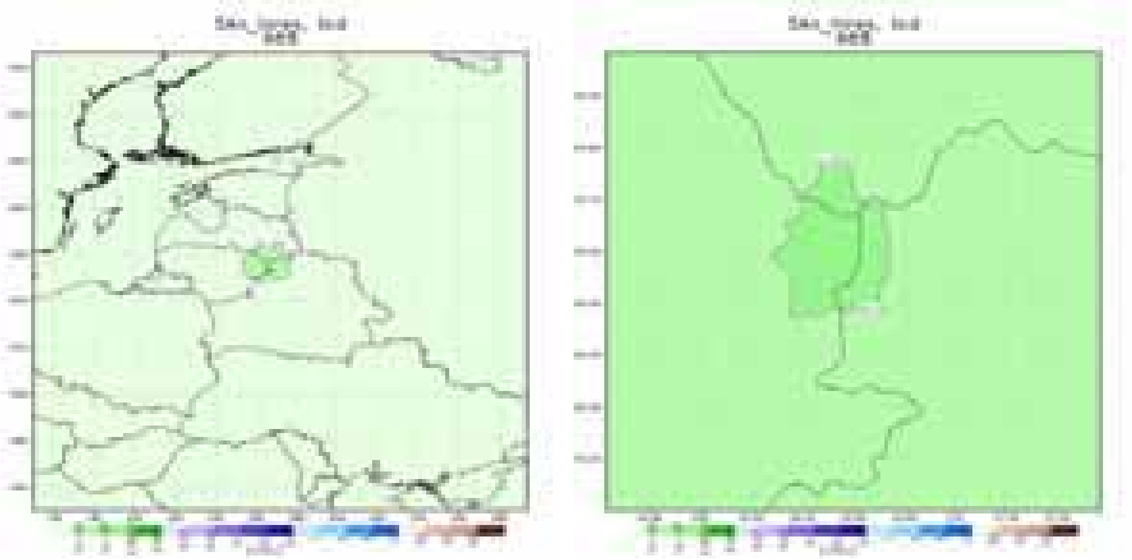

Figure 10.3-16. Severe accident, night-time release; cloud-shine dose [mSv] (left panel: large domain with 20 km resolution; right panel: fine-grid domain 2 km resolution).

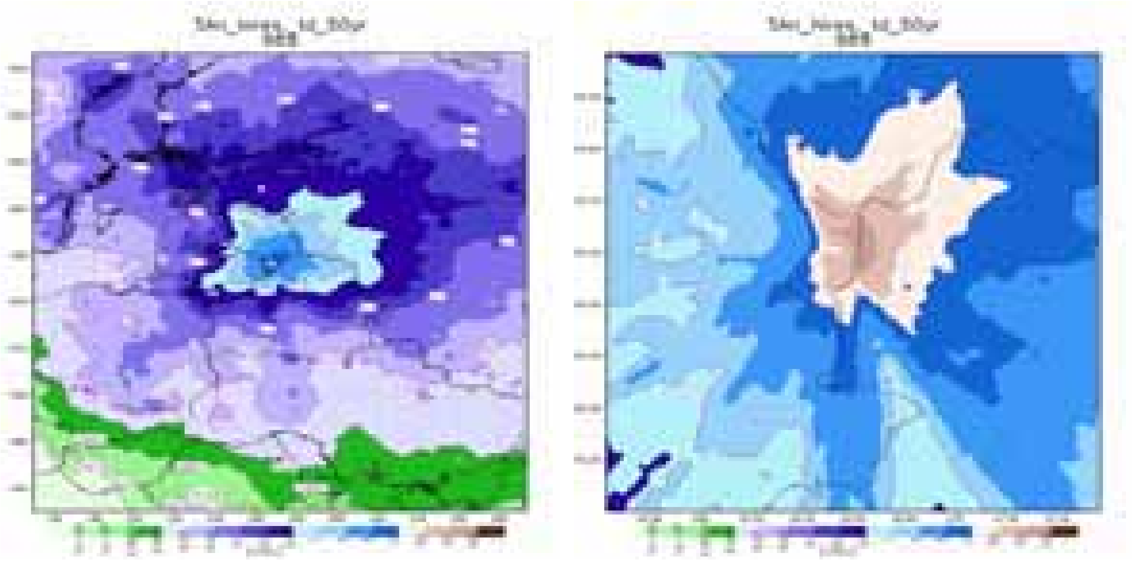

Figure 10.3-17. Severe accident, night-time release (SAn); total external dose over 50 years [mSv] (left panel: large domain with 20 km resolution; right panel: fine-grid domain, 2 km resolution).

From Figure 10.3-14, Figure 10.3-15 and Figure 10.3-17 we can see that compared with the SA daytime release the areas of depositions of I-131 and Cs-137 and total external dose due to the SA night-time release would be slightly smaller.

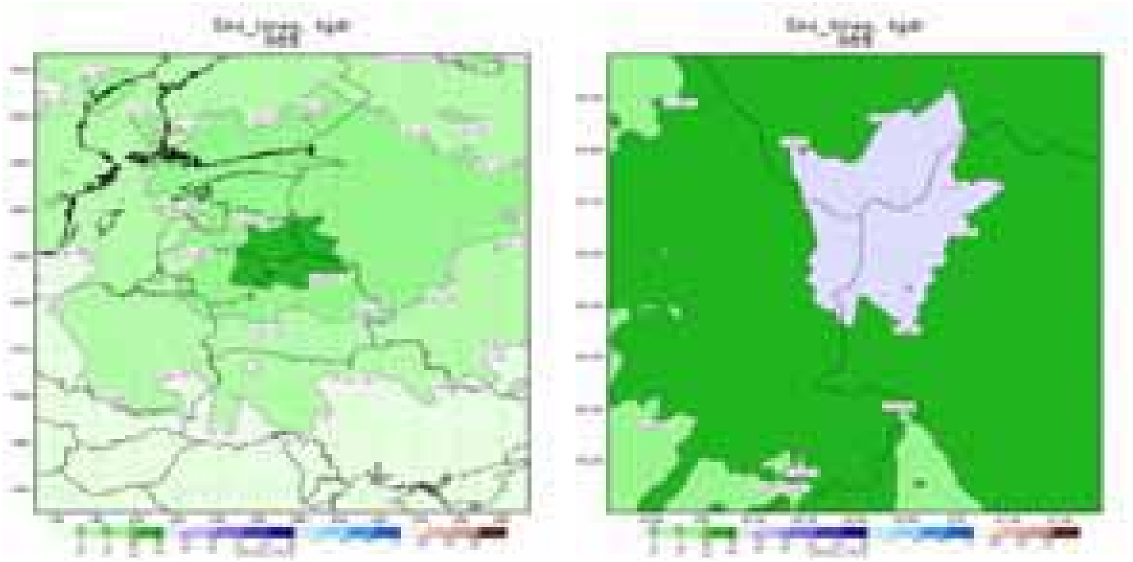

Figure 10.3-18. Severe accident, night-time release (SAn), ground-shine dose rate [mSv/hr] (left panel: large domain with 20 km resolution; right panel: fine-grid domain 2 km resolution).

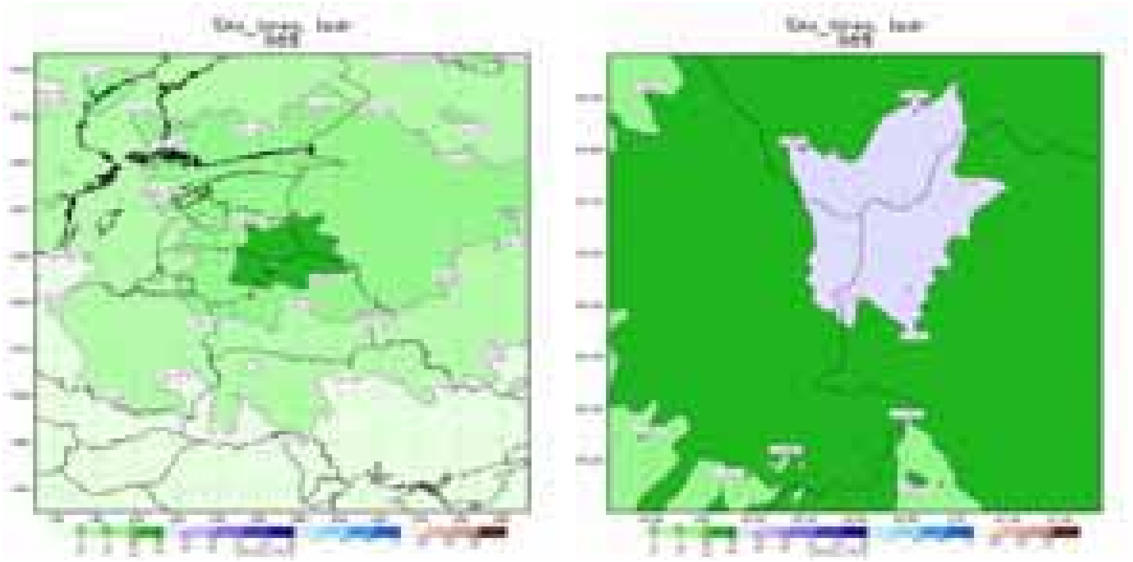

Figure 10.3-19. Severe accident, night-time release (SAn), external dose rate [mSv/hr] (left panel: large domain with 20 km resolution; right panel: fine-grid domain 2 km resolution).

10.4 ASSESSMENT OF ACCIDENT CONSEQUENCES

The accident consequence analyses for the DBA and reference SA illustrated in Section 10.3 provide a basis for accident consequence assessment in the EIA and for the description of the emergency planning. Specifically, estimates of radiation doses can be made at different distances and for individual pathways of exposure. This information can be used to determine protective actions that might need to be undertaken and the spatial scales over which those actions might need to be implemented. In particular, examination of the variability in spatial patterns of doses from realisation to realisation yields information on the extent to which responses would be affected by the meteorological conditions at the time of the accident, and scaling the results to releases of different magnitude yields information on the extent to which responses would be affected by the source-term characteristics of the accident. These issues are not addressed in detail here, as this is a matter for comprehensive safety assessment studies. Rather information is provided related to the assessment of accident consequences and the emergency actions that would be taken in response to a wide range of actions. However, indications are given in Table 10.4-3 of the protective actions that could be needed in the case of DBA and SA.

According to HN 87:2002 (*State Journal, 2003, No. 15-624; 2008, No. 35-1251*), safety of the new designed and constructed nuclear power plant shall assure that during operation or decommissioning the dose for the members of public caused by one design basis accident shall be less than the intervention level applied for protective action – sheltering, i.e. 10 mSv. As it was mentioned before, bounding design basis accident for the NNPP is LOCA. Dispersion modelling and dose estimation for the members of public have showed that total radiation dose even accumulated over 50 years is less than 10 mSv.

Requirements for protective actions of the public in case of a radiological or nuclear accident are provided in HN 99:2000 (*State Journal, 2000, No. 57-1691*). Protective actions are divided into urgent and longer term protective measures.

Urgent protective actions shall be applied in pre-release (time between the start of accident sequence having the potential for off-site consequences and the emission of radioactive material into the atmosphere; the duration may vary from about half an hour to one day or more) and in early (time of release; the release phase may last from a fraction of an hour to several days) phase of emergency. Urgent protective actions are summarized in Table 10.4-1.

Table 10.4-1. Urgent protective actions.

Protective action	Description
Sheltering	Sheltering protects population from external exposure from plume, from inhalation of radioactive aerosols (internal exposure) and from deposits of radionuclides on skin and clothes. The level of avertable dose when the sheltering should be taken is ≥ 10 mSv no longer than 2 days. Regulatory authority may wish to recommend sheltering at lower intervention levels for shorter periods or so as to facilitate further protective actions, e.g. evacuation. Sheltering is recommended in any case when general emergency is classified (before the release of radionuclides into environment), projections indicate that urgent protective actions should be taken and operational intervention levels are as follow: – ambient dose rate in the plume – (0.1 – 1) mSv/h; – ambient dose rate from deposition - ≥ 1 mSv/h;
Iodine prophylaxis	The purpose of iodine prophylaxis is to prevent exceeding of threshold dose for deterministic effects of thyroid gland (acute radiation thyroiditis, chronic lymphocytic thyroiditis and hypothyroidism) and to decrease thyroid doses as much as possible to reduce risk of thyroid cancer and benign thyroid nodules. Iodine prophylaxis is recommended in any case when one of the following Operational Intervention Level is exceeded: – ambient dose rate in the plume ≥ 0.1 mSv/h; – ambient dose rate from deposition ≥ 1 μSv/h; – ground deposition level of I-131 – ≥ 10 kBq/m^2 (restricted consumption of potentially contaminated general food); – ground deposition level of I-131 – ≥ 2 kBq/m^2 (restricted consumption of milk and drinking water); – specific concentration of I-131 of general food ≥ 1 kBq/kg (restricted consumption of potentially contaminated foods); – volumetric concentration of I-131 of milk ad drinking water ≥ 0.1 kBq/kg (restricted consumption of potentially contaminated milk and drinking water).
Evacuation	Evacuation is an urgent protective action that should be pre-planned in advance and implemented before the radioactive release into the environment has occurred. Evacuation of population from contaminated area can also be implemented in early phase of emergency after the release occurs. Evacuation is implemented with respect of these Operational Intervention Levels: – ambient dose rate in the plume ≥ 1 mSv/h; – ambient dose rate from ground deposition ≥ 1 mSv/h. Evacuation is recommended in any case even though one of Operational Intervention Level is exceeded.
Improvised respiratory protection	In early phase of emergency, for population being in the open area at the time of passing of radioactive cloud, improvised respiratory protection is recommended. It decreases the internal exposure from intake of inhaled radioactive aerosols and radioactive iodine. Special respirators are used for respiratory protection. If they are not available, simple materials for protection can be used

Protective action	Description
Restriction of foodstuffs, drinking water and feeding stuffs	Restriction or banning of consumption of contaminated foodstuffs and drinking water are important protective actions in early and late phase of emergency. Considering the projections and scale of general emergency, movement direction of radioactive plume, people are warned against consumption of fresh vegetables, berries, fruits from the open area, unprotected well water, from drinking milk within 100 km radius in grazing time for 2-3 weeks period. In case the value of ambient dose rate from deposition is ≥ 1 μSv/h, consumption of potentially contaminated foodstuffs should be restricted. This operational intervention level shows, that ambient dose rate from deposition during the first days after the accident exceeds natural background and the values of maximum permitted activity concentration of foodstuffs could be exceeded. Due to soil contamination by I-131 2-7 days after general emergency consumption of surface contaminated foods and milk in case the animals were grazing contaminate grass is banned. Due to contamination of soil by I-131 more than ≥ 10 kBq/m^2 consumption of potentially contaminated foods or ≥ 2 kBq/m^2 – milk and drinking water shall be banned. Restrictions are valid while the volumetric or specific concentration measurements of foodstuff, milk, drinking water will be performed. Due to soil contamination by Cs-137 2-7 days after general emergency consumption of foods which potentially could be contaminated is banned. Due to contamination of soil by Cs-137 more than ≥ 2 kBq/m^2 consumption of potentially contaminated foods or Cs-137 ≥ 10 kBq/m^2 – milk and drinking water shall be banned. Restrictions are valid while the volumetric or specific concentration measurements of foodstuff, milk, drinking water will be performed. First 1 – 2 weeks after general emergency consumption of contaminated foods shall be restricted or banned if the value of specific concentration of I-131 exceeds ≥ 1 kBq/kg and volumetric concentration of milk and drinking water exceeds ≥ 0.1 kBq/l. First 1 – 2 weeks after general emergency consumption of contaminated foods shall be restricted or banned if the value of specific concentration of Cs-137 exceeds ≥ 0.2 kBq/kg or volumetric concentration of milk and drinking water exceeds ≥ 0.3 kBq/l.
Decontamination of persons and clothing	Decontamination is complete or partial removal of radionuclides from a human body, clothing, other objects and the surface of the ground. Decontamination of contaminated persons affected by radioactive plume, by radioactive substances on skin and clothing, from ground deposition should be organised in decontamination points. Decontamination points can be a part of intermediate evacuation points or separate mobile decontamination points. Tasks of decontamination point: – take in and register people from contamination territory; – to measure a radioactive contamination of people, clothes and personal belongings; – decontamination of people and control of its effectiveness; – to evaluate whole body, organ, tissue exposures and incorporated radionuclides; – to collect separately contaminated clothes, other things in order to prevent the possible spread of contamination; – first medical aid or medical examination shall be performed if necessary.

The long term protective actions are applied in the late phase (late phase lasts until the time when any protection measures are not necessary; depending on emergency scale it may last several and more years) of emergency. The purpose of long term protective actions is generally to reduce the risk of stochastic health effects (cancer and genetic effects) and to prevent serious deterministic effects of protracted exposures. Long term protective actions are summarized in Table 10.4-2.

Table 10.4-2. Long term protective actions.

Protective action	Description
Temporary relocation	Temporary relocation is organized and concerted measure of relocation of population from affected area for longer but limited time (for several months to a year). The purpose is to protect population from external irradiation from the radioactive material deposited on the ground and surfaces, to prevent internal exposure from inhalation of re-suspended particulate radioactivity. Temporary relocation from contaminated territory shall be initiated, when generic intervention level is 30 mSv per month. Recommendations for temporary relocation are based on ambient dose rate from deposition. When ambient dose rate from deposition exceeds ≥ 0.2 mSv/h and 50% reduction in dose due to partial occupancy is taken into account, population is averted 30 mSv dose in 30 days. If the dose that can be averted by the relocation is less than 10 mSv in the subsequent month relocation is terminated. In the time of temporary relocation of population recovery operations in contaminated area are initiated: decontamination of soil, buildings, roads, etc.
Permanent resettlement	Permanent resettlement should be considered if the lifetime dose is projected to exceed 1 Sv.
Decontamination of environment	In late phase of emergency the following measures are recommended: – To decontaminate the soil by using different depth of ploughing; – To remove a shallow surface layer of the contaminated soil (5 – 10 cm).
Recovery measures in agriculture	The main principle of the recovery actions is application of materials (sapropell, potassium fertilizers, aluminosilicates, farmyard manure, phosphate fertilizers, etc.) that reduce radiocaesium and radiostrontium uptake into plants. Also it is recommended to apply changes in land use, select suitable varieties of a crop that accumulate lower levels of the caesium and strontium radionuclides; to alter animal species, replace sheep or goats with cattle (sheep and goats accumulate caesium in milk and meat 2-5 times more than cows); and other recovery measures.

Based on modelling results (see Section 10.3), protective actions that might be needed in case of LOCA and Severe Accident at new NPP are described in Table 10.4-3. It should be noted that the modelling was performed on the basis of 98% probability of depositions and doses. This means that the results presented in Section 10.3 can be exceeded only with the probability of 2 %. Thus the depositions and doses resulting from an accident can also be less than the presented values. It should also be noted that the modelling results are site specific, as can be seen from the maps included in Section 10.3. Because of the reasons explained, the protective actions do not necessarily extend up to the distance given in Table 10.4-3. It is also likely that the areas where the protective actions are implemented are not uniform around the NNPP, since they depend on how the radioactive plume will disperse. The dispersion of the plume depends on the prevailing weather conditions.

It should be emphasized that the doses accumulated during the accident episode (cloud-shine dose, skin dose, etc) should be clearly distinguished from the dose rates, such as the ground dose rate, total external dose rate, etc. The primary difference between these parameters is that e.g. the cloud dose is collected only during the accident episode itself – i.e. during 2 days or 32 days for SA and LOCA cases, respectively. After the main episode is over the accumulation stops because the contaminated cloud has gone or has been deposited. To the opposite, the doses originating from the deposited radioactivity –

ground-shine dose, ingestion dose, etc – are essentially long-term and by the end of the episode only the rate of their accumulation is established. With this rate (minus radioactive decay and environmental self- and forced cleaning) the accumulation continues for a long period of time.

Table 10.4-3. Protective actions in case of LOCA and Severe Accident at NNPP.

Protective action	Criteria	LOCA	Severe Accident
Sheltering	Ambient dose rate in the plume: (0.1–1) mSv/h. Ambient dose rate from deposition: ≥ 1 mSv/h.	Maximum calculated total dose from the cloud (plume) during the whole LOCA episode (32 days) is 3.1E-05 mSv. Maximum calculated dose rate from deposition is 9.2E-05 mSv/h. Maximum calculated values are in the vicinity of NPP (up to 10 km). Sheltering is not necessary in case of LOCA.	Maximum calculated total dose from the cloud (plume) during the whole SA episode (2 days) is 6.2E-05 mSv. Maximum calculated dose rate from deposition is 0.01 mSv/h. Maximum calculated values are in the vicinity of NPP (up to 10 km). Sheltering is not necessary in case of Severe Accident.
Iodine prophylaxis	Ambient dose rate in the plume: ≥ 0.1 mSv/h; Ambient dose rate from deposition: ≥ 1 μSv/h; I-131 deposition: ≥ 2 kBq/m^2.	Maximum calculated total dose from the cloud (plume) during the whole LOCA episode (32 days) is 3.1E-05 mSv. Maximum calculated dose rate from deposition is 9.2E-02 μSv/h. Maximum calculated (at the distance 10-15 km from NPP) deposition of I-131 is 41.2 kBq/m^2. Based on criteria of I-131 deposition, in case of LOCA iodine prophylaxis will be needed for population living within 10-15 km distance from NPP.	Maximum calculated total dose from the cloud (plume) during the whole SA episode (2 days) is 6.2E-05 mSv. Maximum calculated dose rate from deposition is 10 μSv/h. Maximum calculated deposition of I-131 is 1272.0 kBq/m^2. Based on criteria for I-131 deposition, iodine prophylaxis will be needed for population living within 250-600 km distance from NPP.
Evacuation	Avertable dose ≥ 50 mSv; Ambient dose rate in the plume: ≥ 1 mSv/h; Ambient dose rate from deposition: ≥ 1 mSv/h.	Avertable dose is less than 50 mSv. Maximum calculated total dose from the cloud (plume) during the whole LOCA episode (32 days) is 3.1E-05 mSv. Maximum calculated dose rate from deposition is 9.2E-05 mSv/h. Evacuation is not necessary in case of LOCA.	Avertable dose is less than 50 mSv. Maximum calculated total dose from the cloud (plume) during the whole SA episode (2 days) is 6.2E-05 mSv. Maximum calculated dose rate from deposition is 0.01 mSv/h. Evacuation is not necessary in case of Severe Accident.

Protective action	Criteria	LOCA	Severe Accident
Restriction of foodstuffs, drinking water and feeding stuffs	Ambient dose rate from deposition: ≥ 1 μSv/h; I-131 deposition: ≥ 10 kBq/m^2 (food ban); I-131 deposition: ≥ 2 kBq/m^2 (milk and drinking water ban); Cs-137 deposition: ≥ 2 kBq/m^2 (food ban); Cs-137 deposition: ≥ 10 kBq/m^2 (milk and drinking water ban).	Maximum calculated dose rate from deposition is 9.2E-02 μSv/h. Maximum calculated deposition of I-131 and Cs-137 is 41.2 and 4.3 kBq/m^2 respectively. According to criteria of I-131 deposition food should be banned at the distance of 10-15 km; milk and drinking water should be banned at the distance of 30-35 km. According to criteria of Cs-137 deposition food should be banned at the distance of about 5 km.	Maximum calculated dose rate from deposition is 10 μSv/h. Maximum calculated deposition of I-131 and Cs-137 is 1272.0 and 143.8 kBq/m^2 respectively. According to criteria of I-131 deposition food should be banned at the distance of 100-250 km; milk and drinking water should be banned at the distance of 200-600 km. According to criteria of Cs-137 deposition food should be banned at the distance of 50-100 km; milk and drinking water should be banned at the distance of 20-50 km.
Temporary relocation	30 mSv per month; Ambient dose rate from deposition exceeds ≥ 0.2 mSv/h (2-30 days after emergency)	External dose rate is 1.0E-04 mSv/h. Dose received per month will be 0.074 mSv. Maximum calculated dose rate from deposition is 9.2E-05 mSv/h. Temporary relocation is not necessary in case of LOCA.	External dose rate is 0.018 mSv/h. Dose received per month will be 13.4 mSv. Maximum calculated dose rate from deposition is 0.01 mSv/h. Temporary relocation is not necessary in case of Severe Accident.
Permanent resettle-ment	Lifetime dose: > 1 Sv.	Maximum calculated lifetime dose is 3.44 mSv. Permanent resettlement is not needed in case of LOCA.	Maximum calculated lifetime dose is 117 mSv. Permanent resettlement is not needed in case of Severe Accident.

The main protective actions in case of LOCA and Severe Accident are iodine prophylaxis and restriction on the use of foodstuffs, milk and drinking water. In case of LOCA the territory where these protective actions might be needed is much smaller (up to 35 km from NPP) in comparison with Severe Accident (up to 600 km). It should be noted that the highest distances for protective actions is caused due to deposition of I-131. However the iodine prophylaxis and restrictions on the use of foodstuffs, milk and drinking water are temporary, since the radiological half-life of I-131 is 8 days and activity of I-131 deposition reduces rapidly. Activity of Cs-137 deposition is lower than I-131, however Cs-137 has radiological half-life of 30 years, therefore based on criteria defined for Cs-137 distances for restriction on the use of foodstuffs, milk and drinking water will be lower (up to 5 km in case of LOCA and up to 100 km in case of SA), but restriction will be long-lasting.

10.5 EMERGENCY PREPAREDNESS AND RESPONSE

Emergency response arrangements at nuclear power stations means adequate provision is made for responding to an emergency situation. To mitigate the consequence of an accident to the public, the power plant and rescue service authorities maintain emergency preparedness. This is aimed at civil defence actions in a radiation hazard situation. Nuclear energy legislation sets requirements for civil defence, rescue and emergency response actions.

Emergency preparedness encompasses a wide range of emergency response arrangements for different incidents and accidents. The power station will have its own emergency organisation formed from the power plant's personnel. They will be trained for duties defined in advance by the emergency plan, as informed by the safety analysis for the power plant. The objectives of this taskforce include the organisation and implementation of rescue and other urgent activities, as part of coping with the consequences of an accident, providing support for the development and implementation of measures to enhance plant safety in emergencies, and providing emergency training to emergency response authorities and forces. Engineered equipment includes a sheltered on-site emergency centre, computerised radiation monitoring system and local notification system.

The organisation should have the appropriate rooms, channels of communication and equipment to deal with any type of incident or accident. Equipment provided includes the appropriate radiation measuring devices to allow monitoring of the site and within the exclusion zone (presently 3 km in radius for the Ignalina NPP; to be confirmed for a new plant once a design is selected).

A simplified diagram of the current emergency notification and communication system for the Ignalina NPP is represented in Figure 10.5-1. A similar system is likely to be implemented for the new NPP.

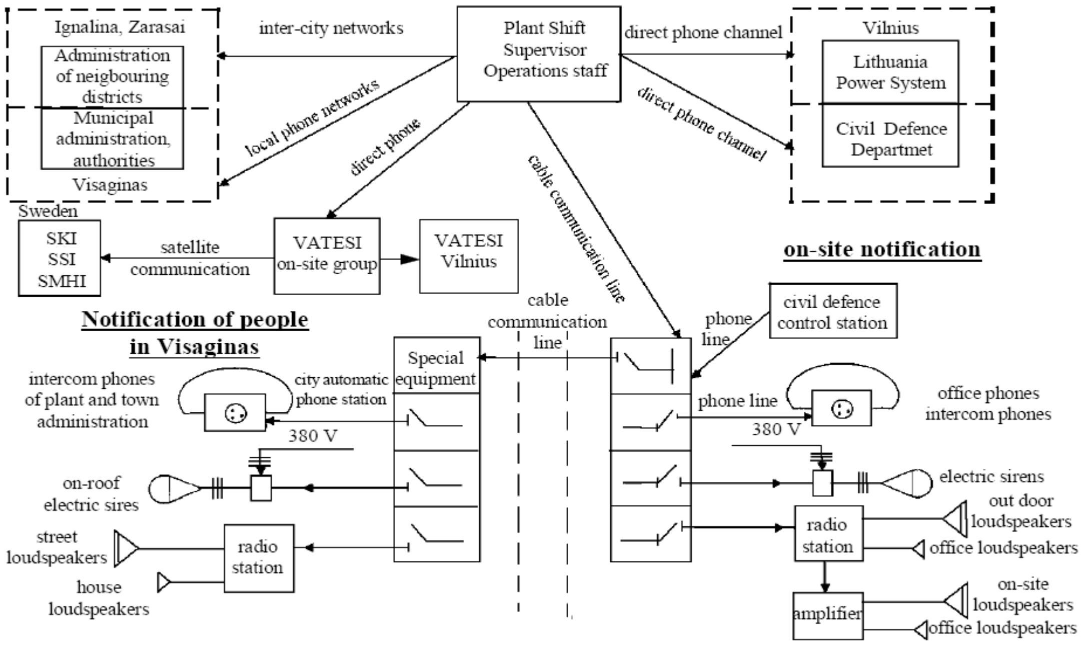

Figure 10.5-1 Block diagram of the Ignalina NPP notification system for personnel and population ***(Handbook about the Ignalina Nuclear Power Plant, for the emergency preparedness organizations around the Baltic sea. Kaunas, Lithuanian Energy Institute. 1997.*****)**

It is the role of the emergency organisations to make necessary announcements and alarms and take actions for managing situations in the event of an emergency. The present emergency notification system at Ignalina includes (*INPP Handbook, 1997*):

- Notification of plant personnel.

- Notification of Visaginas residents and administration authorities of the nearby regions.
- Direct phone connection with the Department of Civil Defence in Vilnius and Dispatcher of the Lithuania Power System.
- INMARSAT satellite communications system, installed in VATESI office in the plant administrative building, for notification of Swedish authorities: Radiation Protection Institute, Swedish Nuclear Power Inspectorate and Swedish Meteorological Institute.

Personnel notification systems include (*INPP Handbook, 1997*):

- One-way loudspeaker communications network, consisting of loud speakers installed in reactor buildings and around the site.
- Wire transmission network consisting of radio centre and office radio receivers.
- Conference hall cabinet where telephones of the plant administration of linked.
- Emergency warning sirens installed inside the power plant units and on site.

The emergency response plan would be implemented during an emergency or recognition that a serious problem may be evolving at the plant. The measures needed in an accident and the civil defence actions will be described in the emergency plan. The plan is designed for the protection of personnel as well as confinement and mitigation in the case of a radiation accident at the nuclear power plant. This basic document provides instructions for the organisation of engineering, medical, evacuation and other actions which may be required. This plan is valid for all on-site personnel, the fire protection staff, the security guards and the attached persons.

The emergency situations are classified into three types according to severity and controllability: emergency standby, site emergency and general emergency. Each has their own actions, according to the nature and scope of the situation.

During emergency standby, the safety level of the power plant is intact but the operators may consider or recognise the potential for the situation to deteriorate and therefore take pre-emptive, precautionary local actions. The preparedness is raised by the manning of the emergency operator centre. The situation is also reported to VATESI and the local rescue authority.

During a site emergency, safety has deteriorated or is in imminent danger of deteriorating, such that a radiation threat is considered a possibility. The emergency organisation is alerted in full, should the event escalate to a general emergency (core damage, release of radioactive material, or excessive radiation hazard). VATESI is alerted and the local rescue authority informed.

During a general emergency, there is a realistic or actual risk of radioactive releases which require civil defence actions. The emergency organisation is alerted in full, and is ready to immediately implement protective actions. VATESI and the local rescue authority are alerted immediately.

The Ignalina nuclear power plant, and site of the new power plant, is situated 6 km from the town of Visaginas, which has a population of about 32 600. The emergency plan currently in force enables notification of an accident to the residents through remote control communication. This includes loudspeaker communication network and alarm warning sirens. The emergency plan does not provide a shelter. It does however provide for action to be taken including: communication to the population of the town advising them to stay indoors and to close all windows and doors, the administration of Iodine tablets, evacuation to an area out of the path of radioactivity being blown by the wind and the control of food and water supplies.

During the first stages of an accident, it is important to be protected against the radiation from the release plume and avoid radiation dose by inhalation. Evacuation is the most efficient form of protection, but in most accidents the radiation dose is reduced adequately enough by the protection of a building (i.e. sheltering).

Taking Iodine tablets can protect the thyroid against radioactive Iodine. This ensures the thyroid is filled with stable Iodine, and as a result little radioactive Iodine is absorbed into the body.

The radiation dose caused directly by the fallout and dust can be decreased significantly by temporarily transferring the population away from the contaminated area, followed, if required or possible, by local cleaning (decontamination) of the ground and buildings. A restriction on movement may be implemented to control access to contaminated area, except during necessary emergency actions. If required, and if possible, evacuation is implemented before the radioactive plume reaches the area. Taking into account wind direction a number of evacuation routes are prepared. Inhabitants would be evacuated by public or personnel transport, to intermediate evacuation points controlled by the municipal emergency situation commissions. These points are set up to control departure from and arrival to contaminated territory, fulfil radiometric control of people, animals and transporting means, ensure necessary medical aid, perform sanitary treatment of people and decontamination of engineering.

The use of Iodine pills, evacuation of the population and restrictions on movement can efficiently decrease the largest radiation dose caused by the accident. Such restrictions are only required in the immediate vicinity of the nuclear power plant, and only cover a small area. Further away from the contaminated area, the dose will be so small that no long-term restrictions on movement will be expected.

Protecting domestic and production animals can reduce the radiation dose to foodstuffs, by moving animals indoors and protecting their feed. In fallout situations, instructions will be given for producing as clean feed as possible and reserving clean water. The control of food and water supplies is essential, after a large accidental release of radioactivity into the environment. Some foodstuffs may be restricted. The maximum permitted levels of radioactive contamination in foodstuffs are given in Lithuanian Hygiene Standard HN 99:2000.

Large-scale civil defences are only required during a severe accident, during an INES level six accident or greater. Civil defence structures of neighbouring countries, such as Latvia, Belarus and the Kaliningrad region of Russia, would be informed about an accident by the department of Civil Defence using inter-state means of communication, and civil defence structures of Latvia and Belarus also via the local warning zone of the nuclear power plant (serving a 30 km radius for Ignalina, to be confirmed for a new nuclear plant, but may be reduced with agreement of the appropriate Regulatory authorities)

Should an off-site release of radioactivity occur, the Ministry of Environment shall first of all present information regarding the nuclear accident to VATESI. VATESI then provides information regarding the accident to the IAEA and neighbouring countries, including; time, exact place and nature of accident, possible or determined causes of the accident, general characteristics of environmental release and the quality, composition and height of the radioactive release. In case of a nuclear accident the Department of Civil Defence will provide information to the municipal civil defence subdivisions about the accident via an automatic management and notification system.

The Visaginas population including plant personnel would be evacuated by the decision of the Government in accordance with the plan of the Department of Civil Defence. The new power plant unit will not bring any changes to the existing civil defence actions of the area.

The Department of Civil Defence organises radiation monitoring. A permanent radiation level monitoring system is currently employed at the Ignalina site and its vicinity. Variations of radiation levels in Lithuania, caused by the transfer of radioactive substances from other countries or released into the atmosphere by an accident at the Ignalina site can be monitored and tracked.

11 DIFFICULTIES AND UNCERTAINTIES OF THE ENVIRONMENTAL IMPACT ASSESSMENT

The potential uncertainty factors or practical difficulties encountered during the EIA work have been identified as comprehensively as possible during the assessment work, and their implications on the reliability of the impact assessment results have been taken into consideration. Identified uncertainties and difficulties and their implications are mainly described in the relevant sections of Chapters 7 and 10.

The available environmental data and the assessment of impacts always involve generalisations and assumptions. At this stage of the NNPP project for instance the technical data is still preliminary and incomplete, thus causing the need for above mentioned generalisations and assumptions.

The limited amount of data regarding the Belarus region has caused difficulties in parts of the assessment work. Only information on performed radiological monitoring was received from Belarus despite official requests through the Lithuanian Ministry of Environment for other information as well.

Some difficulties were encountered when trying to compile sufficiently reliable up to date data on Lake Druksiai hydrology and the hydrology of River Prorva and other rivers in Belarus. For instance actual data of the present outflow from the lake does not exist. Extrapolations from available measurement data had to be made in order to acquire sufficient hydrological data. Lack of sufficient data may cause uncertainties and inaccuracy in the assessment work. Therefore the represented assessment of water balance should be considered preliminary.

There are no regulations for releases in case of a severe nuclear accident in Lithuanian legislation. Therefore the limit for the release of radioactive materials arising from a severe accident (100 TBq release of Cs-137) defined in Finnish legislation had to be used for environmental impact estimation.