EUROPEAN “STRESS TESTS”
FOR NUCLEAR POWER PLANTS

National Report of Bulgaria

Nuclear Regulatory Agency

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INTRODUCTION

Following the nuclear accident at the “Fukushima” nuclear power plant on 11 March 2011, the Bulgarian Government placed on its agenda the need of urgent actions to reassess the Kozloduy nuclear power plant preparedness to respond in emergencies.

On 24 March 2011 the Nuclear Regulatory Agency (NRA) made the Government initiative more specific and presented to Kozloduy NPP its requirements on review and verification of the technical status of the structures, systems and components (SSCs); operating environment and operability of SSCs involved in severe accident management; as well as the actuality and applicability of corresponding procedures and instructions. Presented, to that moment, requirements had as objective the implementation of preliminary and short term actions for plant safety reassessment till the adoption of common requirements to all nuclear power plants - later known as “stress tests”. Kozloduy NPP fulfilled the specified requirements and on 10 June 2011 submitted to NRA a report on the results of the respective reviews.

On 31 May 2011, the NRA required the conduct of an in-depth reassessment of Kozloduy NPP safety in the light of Fukushima accident (stress-tests) [1], which should be in conformity with the methodology adopted by the ENSREG and the EC.

According to [1] and [2], the “stress tests” should summarize plant response and the effectiveness of preventive measures in extreme situations by identifying any potential weaknesses and cliff-edge effects. This is necessary to assess the robustness of the defence-in-depth approach applied, the adequacy of existing accident management measures, as well as to identify potential technical and organizational (procedures, human resources, organization of emergency response or use of external resources) improvements to enhance Kozloduy NPP safety. In this respect, stress tests objectives could be summarized as:

- Defining measures provided by the plant design and plant compliance with the design requirements with regard to external hazards;
- Defining plant capabilities to respond to beyond design basis events, namely assessing plant robustness and identifying potential weaknesses;
- Defining measures to improve the existing level of robustness of SSCs in order to improve the overall plant robustness against extreme natural phenomena.

The present report has been prepared on the basis of the Final Kozloduy NPP Report on Reassessment of Plant Safety [3]. All nuclear facilities located on the Kozloduy NPP site are covered, in which nuclear fuel is used or stored.

The NRA has done a careful review and verification of licensee report and made some small changes, mostly editorial in nature. Regulatory requirements in the basic fields, subject of this report, have also been included. Furthermore, the NRA has proposed safety improvement measures additional to those proposed by the licensee.

The first part of the report provides the main data for the site and the on-site nuclear facilities with special emphasis being made on their characteristics. The design bases of the nuclear facilities, reassessment of safety margins and cliff edge effects are provided in parts 2 to 6. Each of the parts 2 to 6 also summarizes the proposed measures to improve plant robustness to extreme natural phenomena. Plant data and reassessment provided in report are as of 30 June 2011.

1. GENERAL DATA FOR KOZLODUY NPP

1.1 KOZLODUY NPP SITE GENERAL DESCRIPTION

1.1.1 Location

Kozloduy Nuclear Power Plant has been constructed in the north-west of Bulgaria, on the right bank of the River Danube. It is located 5 km to the east of the town of Kozloduy and 200 to the north of Sofia, the capital of Bulgaria.

The site is located in the northern part of the first not flooded terrace of the river Danube and has average height of +35.00 m. The whole site area is about 2.2 km^2, and with the circulation and service water supply channels it reaches 4.5 km^2. The 30 km zone around the site has no military or large industrial facilities. The area consists predominantly of flat landscapes with no protected and sensitive areas in the immediate vicinity of the plant. The climate is moderate continental with cold winters and hot summers, with one of the lowest annual rainfall in the country (section 2 from [4][5]).

1.1.2 Nuclear facilities

In Kozloduy NPP site 6 units have been built with total electric power of 3760 MW, with pressure water reactors, spent fuel storage facility (SFS) and spent fuel dry storage facility (DSFS).

Under the Decision of the Council of Ministers of 20.12.2008 units 1 and 2 were declared facilities for radioactive waste (RAW) management, which are subject of decommissioning, and which were given to State Enterprise "Radioactive Waste" .There is no nuclear fuel remaining at the site of Units 1 and 2, and that is why they have not been covered by the present report.

Units 3 and 4 are taken out of commercial operation since 31.12.2006. The fuel of both units is removed from the core and is stored on the lower shelf in the fuel storage pools (FSP) near the reactor. The primary and secondary circuits are filled with conservation solutions to inhibit corrosion processes. Availability for core refuelling is maintained in case of an accident with not compensated leakage from FSP.

Units 5 and 6 are in operation, unit 5 going through its 18th fuel campaign and unit 6 – 17th fuel campaign. Both units operate mainly in base mode of rated power operation according to the terms of the license for operation.

The Spent Fuel Storage Facility (SFS) is in operation since, while a Dry Spent Fuel Storage Facility (DSFS) is being commissioned.

Kozloduy NPP is the Licensee of the facilities subject to this report.

1.1.3 General Plant Facilities and Structures

Outdoor switchyard

Kozloduy NPP is connected to the electric energy system (EES) of Bulgaria via three own distribution systems (OSY) under voltage 400 kV, 220 kV and 110 kV. Between them connections are made through autotransformers. 400 kV system is designed by logic “double section bus system”, 220 kV system – “double bus system”, 110 kV system – “double bus with transfer busbar”.

Transmission lines outgoing from the plant are as follows:

- Eight transit transmission lines 400 kV, of which 2 are between the lines to the EES system in Romania and 6 lines to substations within the country;
- five transmission lines 220 kV, from which 3 transit lines to substations in the country and 2 radial lines to bank pump station (BPS);

- four transmission lines 110 kV, from which 2 transit lines to substations in the country and 2 radial lines to substations in the country.

The total number of the transmission lines to which Kozloduy NPP is connected is 17, among which 13 are transit and 4 are radial. The OSY is shown on Figure 1 including all lead-outs and connections.

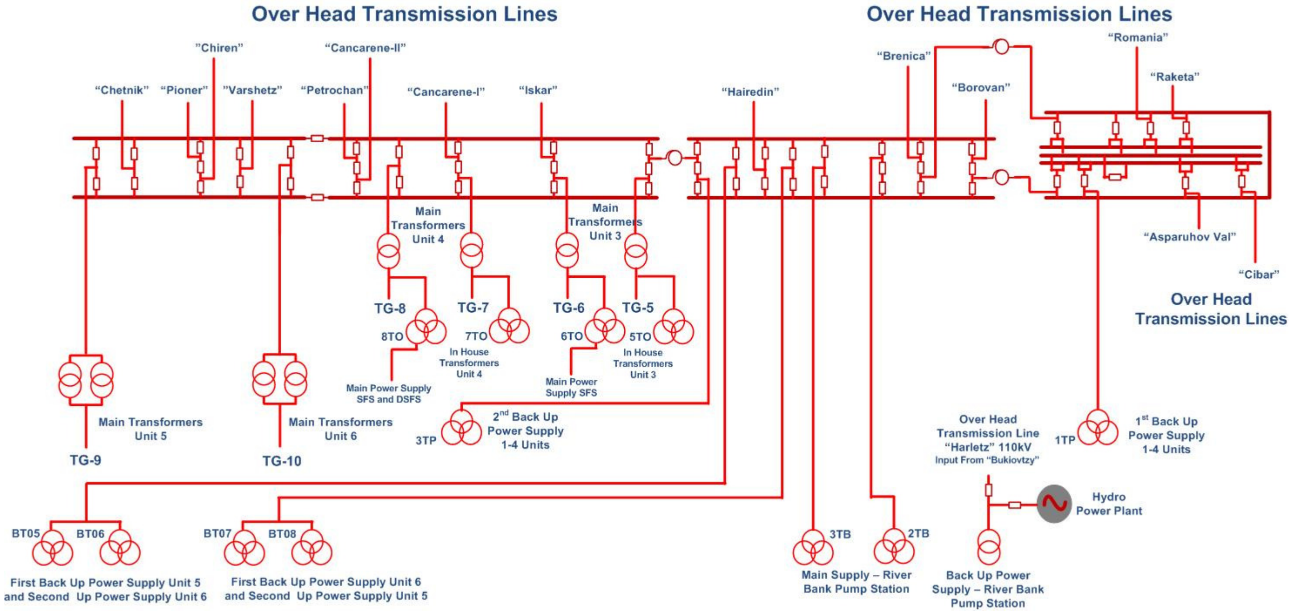

Figure 1. OSY diagram

The figure 2 shows a more detailed electrical diagram of OSY-400kV, connected to the power supply of units 5-6. The triple redundancy of stationary power supply could be seen on the diagram. The connection point of mobile diesel generators is indicated as well.

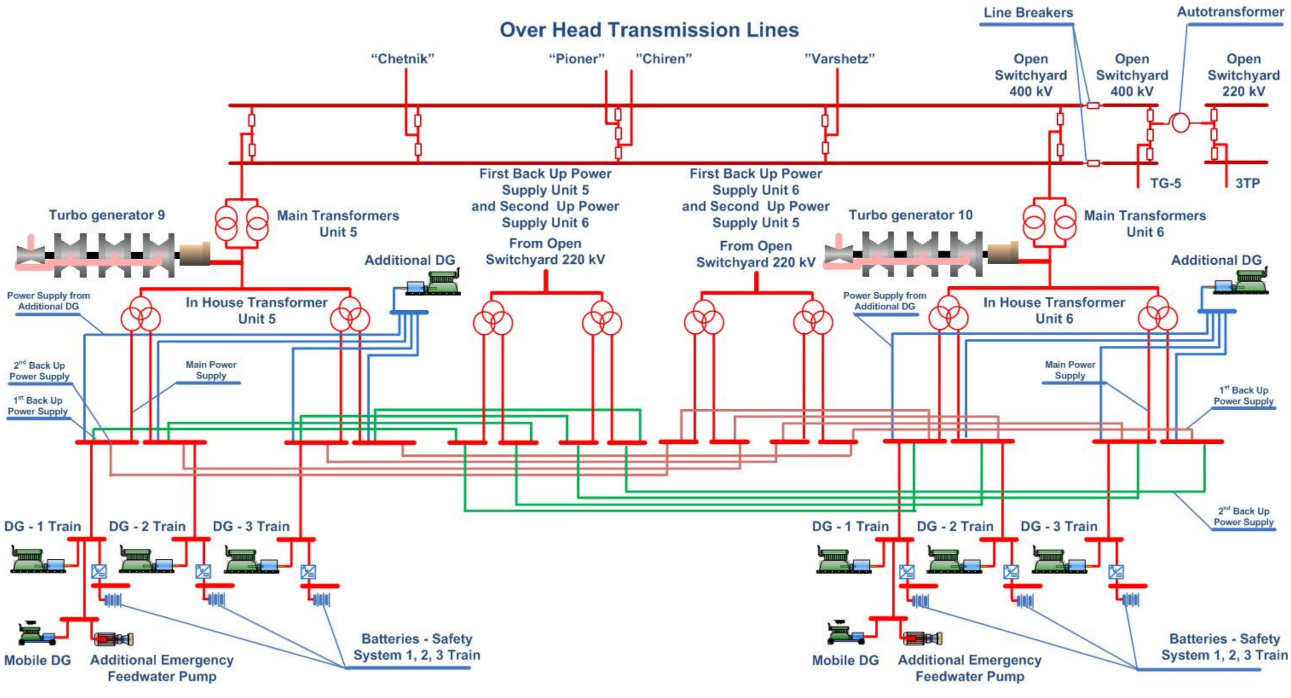

Figure 2. OSY 400 kV, Units 5 and 6

In the electric energy system "Plan for EES recovery following a severe accident" is in force. According to this plan at collapse of the EES, voltage is to be supplied to Kozloduy NPP by 4 possible corridors. The corridors are powered from sources with possible zero start – HPP and neighbouring EES. In Kozloduy NPP procedures for personnel actions are approved for starting the option under the plan for distribution of the resulting voltage and power supply to units and BPS auxiliaries.

Electric power supply loads in Kozloduy NPP are divided into 3 categories, according to their consumed electricity and the extent of reliability of power supply:

- Category I loads - AC and DC power loads, not allowing under safety conditions power outages for more than one semi-period – 20 ms in all modes, including mode of total loss of alternate current voltage from the working and backup auxiliary transformers (blackout mode);
- Category II loads - AC and DC power loads, which have increased requirements to the reliability of electricity supply, and allowing for power outages for a time determined by the nuclear safety conditions up to 1 min (time for start-up of DG and automatic start-up of loads with triggered load system);
- Category III loads – AC power loads, which do not have higher requirements on the reliability of power supply than the requirements for presence of automatic switch to backup equipment.

Bank pump stations and the channels

In august 1974 bank pump station (BPS) - 1, cold and hot water channels and circulation pump station (CPS) - 1 were commissioned, together with plant service water systems. Later on bank pump stations -2 and 3 with general supply channel and circulation pump stations - 2, 3 and 4(for Units 3 and 4; 5; 6 accordingly) with the required pipelines, closed low pressure channels, spray ponds and other facilities were constructed. The structures in BPS-2 and BPS-3 are the modified variant of the structures in BPS-1, with the motors of the pump sets set at a higher elevation for failure free operation at potential construction of water power system Nikopol – Turno Magurele. The bank pump stations 1, 2 and 3 are located on flat terrain (at km 687 of Danube River), at a lower terrace, to the site of Kozloduy NPP and circulation pump stations (CPS) are constructed in the area of Kozloduy NPP. The site has been selected so that to avoid to the maximum extent possible sediment deposition and river level fluctuation.

The water of Danube River falls into the supply channel that takes it to the specially formed chambers (advance chambers) located before BPS 1,2 and 3. The advance chambers ensure smooth transition to the suction holes of thirty four water bank pumps. The number of water pumps in operation depends on the moment of the plant power and Danube River level.

Pumped water from the pump units, within the cast facilities, which are in the outlet chambers of pressure pipelines. Each chamber has a metal enclosure – structures used for drying of certain sections. By means of this structure it is possible to supply water from the hot channel to the advance chambers to avoid freezing of water in them in winter.

In the pressure pipelines water is supplied to the so called cold channel, by which it gravitationally reaches circulation pump stations ensuring service water supply to the nuclear facilities. The cold channel has length of 7023 m and depth of 5. 60 m, with trapezoidal cross section of bottom width 20 m. The last section of the cold channel with length of 950 m is located on Kozloduy NPP site and is entirely built in a trench and separated by seismically qualified overflow barrier intended to prevent from lowering of the level in this area.

Having fulfilled its purpose, service water returns to the river by so called hot channel. It has a length of 6930 m, trapezoidal cross-section with bottom width 12 m, at the beginning and 15 m in the rest. The conductivity of the hot channel is 180 m^3/s and depends on the elevation of the spillway after the low pressure channels and water level in Danube River.

Emergency pump station is located immediately before BPS- 2 and 3. It is fitted with three emergency pump units, which in case of need supply water to the emergency inventory of "cold" channel and, thus, ensure emergency service water supply. Loss of water from emergency inventory is prevented both from barrier in the beginning of the hot channel and from hot water recirculation facility before the CPS-1.

If needed, alternative service water supply can be implemented from lake "Shishmanov shaft" from which water, gravitationally, passes by an open channel and by water intake from it by a pipeline falls into the emergency inventory of "cold" channel.

Off-site power supply to BPS is performed by switchyard 220 kV, with transmission lines "Atom" and "Neutron" and line "Harlets" 110 kV. The voltage is transformed from 220 kV or 110 kV to 6 kV and is supplied to the pump sets of the BPS.

At loss of power supply by the three transmission lines, through uninterruptible power supply system essential components related with the nuclear and fire safety systems, as well with the auxiliary systems are powered.

In the BPS diesel generator station is equipped, consisting of two diesel generators constant available and having active power 1600 kW each. The diesel generators supply power to the emergency pump station which provides the emergency service water inventory in the cold channel. The water supplied can be used by all circulating pump stations [4][6][5].

In the BPS two batteries are installed. They ensure continuous power supply to the following loads:

- DC power supply to control, protection and alarm systems;
- Process measurements and instrumentation;
- Operational voltage for 6kV and 0.4кV circuit breakers;
- Operational voltage for DG automation logics;
- Emergency lighting.

1.2 MAIN DATA FOR UNITS 3 AND 4

1.2.1 Key Features of Units 3 and 4

Units 3 and 4 of Kozloduy NPP are water-water pressurized reactor, type VVER-440, upgraded design 230, with two circuits – primary (radioactive) and secondary (conventional) [13][14]. The thermal power of the reactors is 1375 MW, primary circuit pressure is 12,3 MPa and the secondary - 4,4 MPa.

The first criticality date is December 4, 1980 for Unit 3 and April 25, 1982 for Unit 4. Additional information for the units is provided in the table below:

Table 1.2-1: Historical date for Units 3 and 4.

Characteristics	Unit 3	Unit 4
Start of construction	October 1973	October 1973
First criticality	4 December 1980	25 April 1982
Reaching 100% power	27.01.1981	17.06.1982
Fuel campaigns operated	22	21
Final shutdown for decommissioning	31 December 2006	31 December 2006

Fuel Storage Pond (FSP)

FSP is for spent and irradiated nuclear fuel. The pool is made of concrete structure lined with stainless steel, separated from the partition of two compartments – area containing the racks and the universal slot for intermediate location of fresh or spent nuclear fuel container. The spent fuel remains in the FSP for at least three years to reduce decay heat to the permissible limits allowing for their transportation.

1.2.2 Systems Ensuring or Supporting the Fundamental Safety Functions

1.2.2.1 Reactivity control

The geometry of the assemblies storage racks available in the FSP (assemblies pitch) ensures sub-criticality of the fuel assembles of at least 5% even in case of filling the FSP with non-borated water solutions in all temperature conditions of the solution.

1.2.2.2 Heat removal from the fuel storage pools to the ultimate heat sink

The main logic for heat removal from the fuel assemblies is by water in storage pools the heat from which is transferred by heat-exchangers for cooling of the service water essential components, and hence to the ultimate heat sink, the Danube.

The cooling system includes two pumps for cooling of the pool through two heat exchangers. These facilities form two independent channels for water cooling – shown on figure 3. Each of them has the capacity to perform the function to 100%. The pumps for cooling the pool are designed to implement the solution circulation through heat exchangers for cooling. The heat exchangers are cooled by water from the service water of safety systems, the pumps are provided with uninterruptible power supply from the diesel generators.

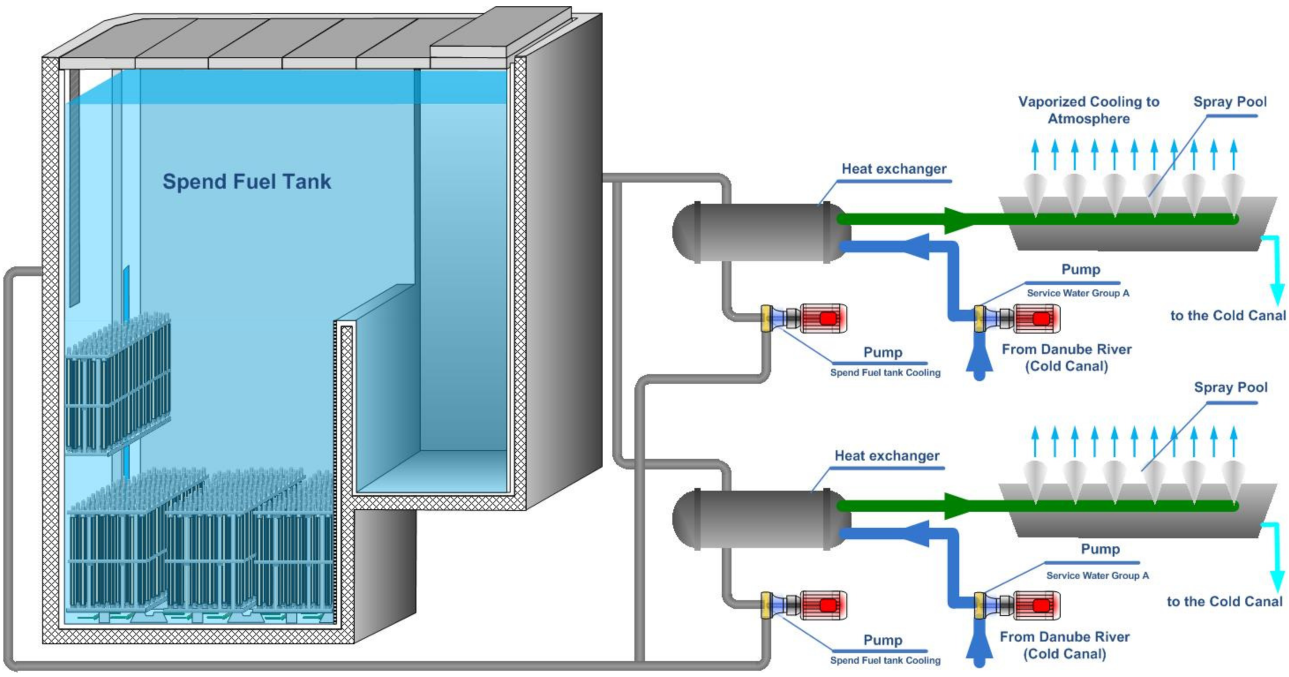

Figure 3. FSP of units 3 and 4

Heat removal logics are available during all the time, while there is fuel in the FSP. According to the technical specifications, there are strict time limits for unavailability of one heat exchanger or one pump in the heat removal logics [15][16]. With the cooldown system inoperable, cooling is provided by other methods (filling and drainage) or non-design cooldown logics (following procedures developed) to maintain temperature in the FSP (figure 4). At loss of power, power is supply to at least one cooldown pump and one pool filling pump. At loss of the cooling channels of the given unit or significant loss of coolant from FSP of either unit there is possibility to use logics for water supply for the FSP and for cooling from the adjacent unit.

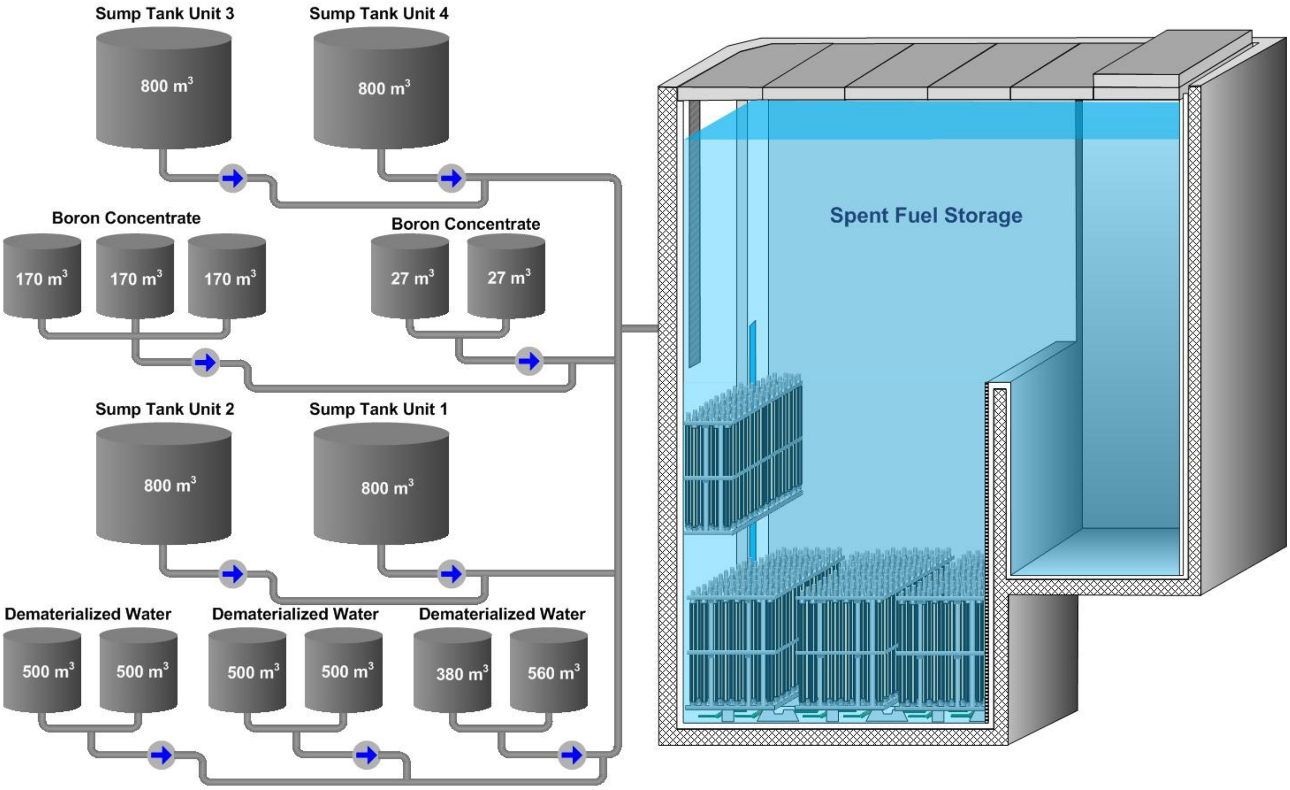

Figure 4: Alternative supply sources for FSP 3 and 4

In emergency cases and following specially developed procedures the fuel from FSP can be returned to the reactor installation to ensure its cooling. In this case for long-term cooling, planned cooldown system is used in water-water and recirculation mode. Following this logic one or two SGs are filled with water which is cooled in the process condensers and are filled into the deaerators from where with the cooldown pumps return again to the SGs involved in the cooldown. Essential components service water cools the process condenser, so that in this logic the ultimate heat sink is Danube River. The diagram is shown on Figure 5.

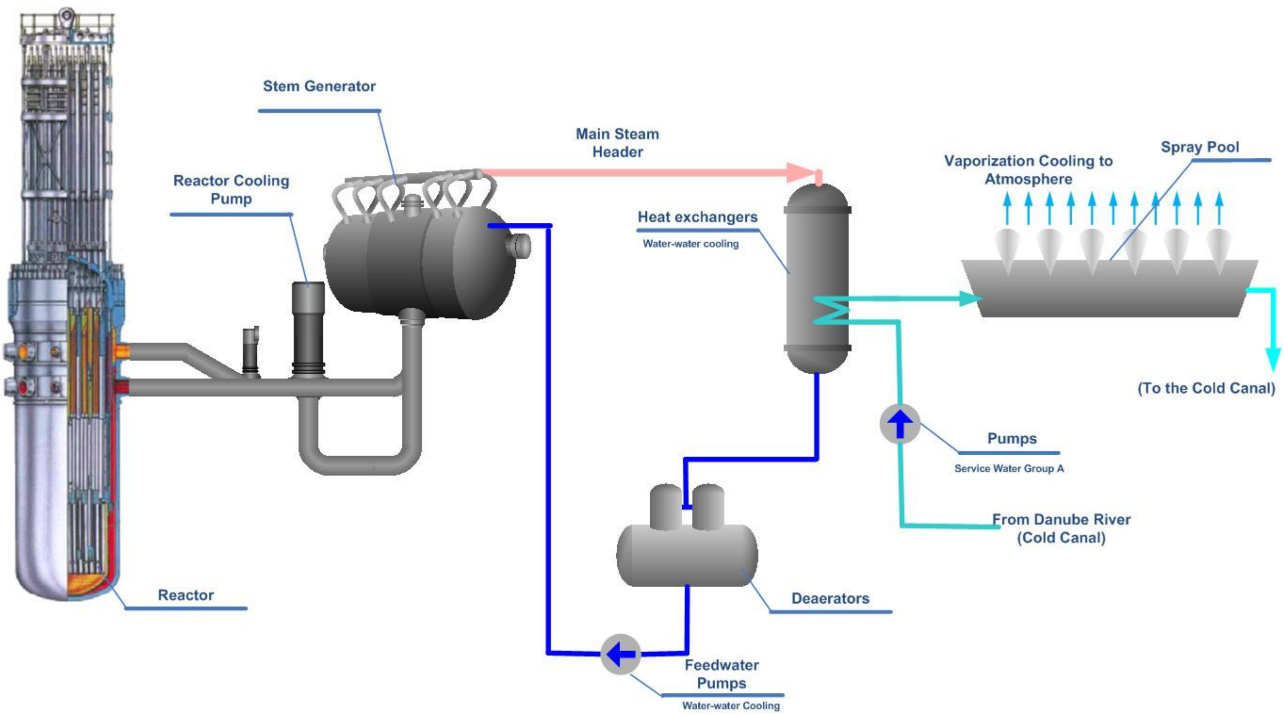

Figure 5: Ultimate heat sink

Electric loads associated with ensuring safety of the fuel in the FSP are designed for power supply from normal and backup power supply systems from the unit electric power distribution systems. Electric power of the cooling pumps is of II category. At loss of offsite power supply, diesel generators provide emergency power supply to them.

Additionally, for the cooling pumps an independent power supply is ensured from independent diesel generator of additional system for steam generator emergency makeup (ASSGEM) as well as from mobile DG.

At a complete inability for cooling by essential components service water cooling can be ensured from fire protection station-2 by the line of additional system for steam generators makeup which is a completely autonomous system, operation for 7 days in full autonomy mode is guaranteed.

1.2.2.3 Auxiliary AC power supply

Auxiliary electric power distribution

Connection between Units 3 and 4 with the EES is ensured with startup transformer, connected to OSY 220 kV through overhead lines.

Power is supplied to Units 3 and 4 auxiliaries from the complex switchgear (CSG) 6 kV and 0,4 kV and power assemblies 0,4 kV. The equipment of the systems is located in special premises protected against internal (fires, floods) and external events with numerous improvements in the design aimed at improving their sustainability.

Backup power supply

Units 3 and 4 auxiliaries are supplied from EES, from OSY 220 kV through backup transformer. Where needed, the units auxiliaries can be powered from OSY 400 kV through their own unit transformers and auxiliary transformers.

Emergency power supply

At loss of main and backup power supply, the loads are supplied with emergency power supply depending on the significance category they belong to. The first category loads are connected to sections that preserve uninterruptible power supply through inventors from the batteries of respective safety trains. The second category loads are connected to the so-called diesel sections. In case of station blackout (loss of external power supply), the diesel generators ensure the emergency power supply. Fuel and lubricants reserves ensure the operations of all diesel generators for not less than 4 days.

The equipment related to providing emergency power supply is located in special premises. They are protected against internal (fires, floods) and external events both by design solutions for physical separation, premises design, etc. and by numerous improvements to the design aimed at enhancing their resistance against internal and external hazards. Each emergency diesel-generator is located in a separate compartment of diesel-generator station. The compartments where individual diesel-generators are located are separated by fire reinforced concrete walls. The doors between the compartments are fire protected and sealed.

At loss of emergency power supply to the unit, it is possible to supply power from the neighbouring unit, for this purpose technical and organizational measures are provided. Inventories of combustible-lubrication materials ensure operation of all DGs for at least 4 days, and during this period delivery of additional inventory can be organized.

Alternative power supply sources

<u>Additional stationary diesel-generators</u>

Additional power supply sources are 4 independent diesel-generators as part of additional system for steam generator emergency makeup. The system is seismically qualified and can provide long-term cooling (up to 7 days) of the fuel in the reactor or in the FSP.

Potential connections and logics with neighbouring units

Backup power supply sections of units 3 and 4 are interconnected, so that it is possible to supply power from the adjacent unit for backup and emergency backup power supply.

Mobile power supply sources

Another, alternative power supply source is a mobile diesel generator located on site with capability to supply power to the safety related equipment associated with maintenance of the reactor and the FSP in a safe condition. The mobile diesel-generator has a nominal power of 1100 kW and can be connected to one pre-selected uninterruptible power supply 6kV section.

Preparedness to use alternative power supply sources

In Kozloduy NPP are developed specific operating procedures, personnel have been trained, and periodic exercises are conducted for the use of alternative sources of electrical power. The mobile DG is in a state of readiness. Mobile diesel-generator platform with the equipment installed on it is stored in a specially built hall.

1.2.2.4 DC power supply

Each channel of the safety systems has batteries that are independent source of direct current for uninterruptible power for I category loads. Their capacity is 1751 Ah.

Original design of Units 3 and 4 provides three-channel structure of the AC and DC emergency power supply, with channel capacity 3x100% and complete separation between the channels. Each channel consists of diesel-generator, diesel-generator battery, 6 and 0.4 kV AC uninterruptible power units with transformers between them, rectifier, inventers, battery and DC power board. Each channel is physically separated and independent, as additional measures for protection against external and internal hazards have been provided.

There is mutual redundancy and recharging between the batteries of the diesel-generators and safety systems. Additional links have been created to allow redundancy and recharging of the batteries from all uninterruptible power supply sections - I category or from uninterruptible power supply sections - II category. The unit batteries from uninterruptible power supply sections - I category and batteries in diesel-generator station-2 have the same capacity that allows for mutual redundancy in an emergency situation.

1.3 MAIN DATA ON UNITS 5 AND 6

1.3.1 Main data of Units 5 and 6

Each unit has installed power of 1000 MWe and includes the reactor installation with VVER-1000/B-320 reactor, the turbine-generator installation with K-1000/60-1500-2 turbine and TBB-1000-4У3 electrical generator.

VVER-1000/V-320 is a heterogeneous thermal neutrons water-water energy reactor, of the vessel type. Demineralised water with diluted boric acid in it is used as the coolant and the moderator in the primary circuit, with concentration of the boric acid changing during operation. The reactor core includes 163 fuel assemblies, each consisting of 312 fuel elements. The primary pressure is 15. 7 MPa, reactor inlet water temperature is 288°C. Low enrichment uranium dioxide is used as a fuel with enrichment of 4.4 % ^{235}U concentration. The primary coolant is heated at passing through the core. After that it is delivered to the steam generators where heat is transferred to the secondary circuit.

Some of the main characteristics of Units 5 and 6 are provided in table 1.3-1:

Table 1.3-1: Main data of Units 5 and 6.

CHARACTERISTICS	VALUE
Reactor thermal power	3000 MW
Unit electric power	1000 MW
Unit efficiency factor (gross)	34,17 %
Primary circuit pressure	15.7 MPa
Secondary circuit pressure (MSH)	6.27 MPa

Table 1.3-2: Historical data for Units 5 and 6.

DESCRIPTION	UNIT 5	UNIT 6
Commencement of constriction	09.07.1980	01.04.1982
Physical start-up – the first criticality	05.11.1987	29.05.1991
Reaching 100% power	21.06.1988	13.08.1992
Acceptance to operation	23.12.1988	30.12.1993

Fuel Storage Pond

The fuel storage pool (FSP) serves for storage of spent fuel (until the residual heat reaches permissible level). The capacity of the FSP is 612 FAs and it ensures storage of the spent FAs for at least three years (section 9 of [4][5]). It is provided with tight fuel storage and consists of 4 parts – three sections designed directly for storage of spent fuel assemblies and universal slot for fresh and spent fuel handling. The universal slot is used for both transport container for spent fuel and containers with fresh fuel and with hermetic casks. The transport containers loading zone is separated from the spent fuel assemblies storage zone, so that in case of dropping a container, fuel elements are not damaged or the boron solution level over the assemblies is not reduced.

The fencing structures of FSP are designed to retain cooling boron solution (that may contain radioactive products) as well as to mitigate ionizing irradiation. They present reinforced concrete walls with double metal hermetic lining with potential leak control drainages.

1.3.2 Systems Ensuring or Supporting the Fundamental Safety Functions

In the design of safety related systems and equipment design solutions are used, based on the passive principle of operation. Safe failure principle and inherent self protection properties (self-control, thermal inertia, reactivity feedback and natural coolant circulation) and other natural processes are underlain in the design.

Specific technical solutions applied in the design of safety systems are multi-channel structure (redundancy), physical separation and diversity. The combination of these solutions ensures resistance of safety systems to common cause failures, i.e. total loss of the ability of safety systems to perform their function.

1.3.2.1 Reactivity control

Reactivity control both during reactor operation and in shutdown mode is performed by two principally independent ways of action:

- Moving the control rods by the core height;
- Changing the concentration of dissolved boric acid in the primary coolant.

In normal operation the core criticality in hot shutdown mode with the reactor pressurized, cooling from hot to cold state, maintenance outage are ensured by injecting control rods in the core and the primary circuit blowdown and makeup system.

Following the reactor shutdown by changing the concentration of boron solution change in the reactivity due to xenon decay and coolant cooling to the cold state is compensated and also the necessary sub-criticality during refuelling, which is not less than 2% (with reactor control and protection system control rods fully extracted) is provided.

In emergency situations with loss of offsite power supply and/or isolation of containment system the core criticality is ensured by inserting the control rods, emergency boron injection system - high and medium pressure, and the emergency core cooling.

At large loss of coolant accident core criticality is ensured by passive part of emergency core cooling system , emergency boron injection system - high and medium pressure, and the low pressure emergency cooldown system.

<u>Reactivity rapid control systems</u>

Reactor control and protection system has the following key functions:

- reactor emergency protection;
- rapid reduction of reactor power at tripping of the unit main equipment;
- unloading and limitation of reactor power at tripping the unit main equipment;
- operational control of unit power.

The system control rods are designed so that at normal operation they are maintained in extreme upper or intermediate position from electromagnets. In case of actuation of emergency protection or at loss of the system power supply due to any reason, the electromagnets release the control rods, which enter the core due to gravitation, i.e. passive actuation of protection takes place.

Effectiveness of the emergency protection is selected based on the need to compensate for abrupt changes in reactivity associated with bringing the reactor to sub-critical condition of any power level, and considering the reduction in efficiency due to postulated sticking in the extreme upper position of most effective control rod and use of the rest for operational control and balancing the energy release field providing sub-criticality of not less than the minimum allowable (required) value equal to 0.01 Δκ/κ, i.e. 1% (section 4 of [4][5]).

The design provides for movement of control rods at a constant speed of 2 cm/s and dropping them at the emergency protection signals within max. 4 s.

<u>Reactivity smooth control systems</u>

The reactivity smooth control systems include all systems that influence on the reactivity by changing the boric acid in the primary circuit. They combine the functions of both normal operation systems and safety systems.

Normal operation systems used for reactivity control

<u>Makeup and Blowdown System.</u>

One of the key functions of the system is to perform operational control of primary circuit boron concentration and thus precise reactor power control. The system can be used both at normal operation and in other, accidents modes where the containment system is not isolated. At loss of off-site power, for the system to be used operation of the additional diesel-generator and at least one of the safety system channels is required. Through the primary circuit makeup-blowdown system boric acid removal from primary circuit is performed during reactor transfer to critical state, at power increase, at compensation of intoxication and other processes associated with smooth introduction of positive reactivity. Through the system boron injection is also performed in load reduction or reactor attenuation mode, at reactor intoxication compensation and other modes associated with smooth introduction of negative reactivity.

Boron concentrate system - supply boric acid solution with concentration of 40 g/kg, to the suction side of makeup pumps in primary circuit boric acid concentration increase mode.

Reactor building boron containing water system - collect coolant removed from the primary circuit; storage and supply to the primary circuit of coolant with boric acid standby concentration.

Safety systems used for reactivity control

High pressure emergency boron injection system.

The system is designed for emergency injection of emergency boric acid solution to the primary circuit with concentration of 40 g/kg in case of loss of off-site power or in case of failure to supply boric acid solution through the primary circuit makeup and blowdown system and need for shut down of reactor at primary circuit high pressure (9-18 MPa).

Intermediate pressure emergency boron injection system.

The system is designed for emergency injection of emergency boric acid solution to the primary circuit with concentration of 40 g/kg in case of loss of off-site power or in case of failure to supply boric acid solution through the primary circuit makeup and blowdown system and need for shut down of reactor at primary circuit intermediate pressure (below 11 MPa).

Systems ensuring core criticality with the reactor depressurized

With the reactor depressurized and presence of fuel in the core before and after refuelling criticality of the core is provided by the control rods and the boric acid solution with concentration ≥ 16 g/kg circulating in the primary circuit and emergency and normal cooldown system. Material balance of the coolant can be maintained by boron solution from primary circuit emergency makeup tank (EMT).

During refuelling the material balance of the entire system consisting of fuel storage pool, reactor, primary circuit and emergency and normal cooldown system is maintained with boric acid solution with concentration ≥16 g/kg through FSP water filter purification system or reactor building boron containing water system.

The fuel sub-criticality during all stages of refuelling outage is ensured by taking measures to prevent from penetration of clean condensate to the reactor circuit and FSP and to carry out automatic and manual physical and chemical monitoring of the coolant content.

Systems ensuring fuel storage pool sub-criticality

The spent fuel sub-criticality for at least 5% in FSP is ensured through: ensuring reliable distance between the cells for storage during the entire period of operation of the FSP; use of homogenous absorber on the water of FSP with boric acid solution with concentration 16 g/kg; use of effective fixed heterogeneous absorbers that do not lose their properties in the process of operation. The cells for assemblies are designed from borated stainless steel. The absorbing capacity (at burn-up of ^{10}B and wall depth reduction due to the corrosion) of the racks cells is preserved during the entire service life.

Maintaining the water level and water chemistry of the FSP is ensured by FSP water purification system. At fuel storage mode the water level is maintained at height +28.8 m with total volume of 585 m^3. In refuelling mode FSP is connected to the refuelling shaft and the water level is maintained at the height of +36.2 m which requires additional water inventory (about 1400 m^3) ensured by FSP water purification system.

1.3.2.2 Reactor Heat Removal to the Ultimate Heat Sink

The heat removal logics can be divided mainly into two types:

- Heat removal to the ultimate heat sink – River Danube;

- Heat removal to the ultimate heat sink – the atmosphere.

Main ultimate heat sink from the reactors is provided by water of Danube River. At loss of the main ultimate heat sink systems are provided to remove heat to the alternative ultimate heat sink which is the atmosphere.

Heat transfer to the ultimate heat sink is ensured by the Circulating Water System where heat is transferred by the turbine condenser (incoming steam is cooled down) to the circulating water, which itself returns to the Danube River (Figure 6). This process is used both during unit operation and with the turbine tripped at primary circuit temperature approximately to 120°C. In case of loss of main ultimate heat sink – River Danube – ultimate heat sink – the atmosphere – can be used. This can be done through heat removal from the steam generators to the atmosphere by means of steam dump through the BRU-A. In this case the steam generators can be supplied from feedwater system or emergency makeup water system.

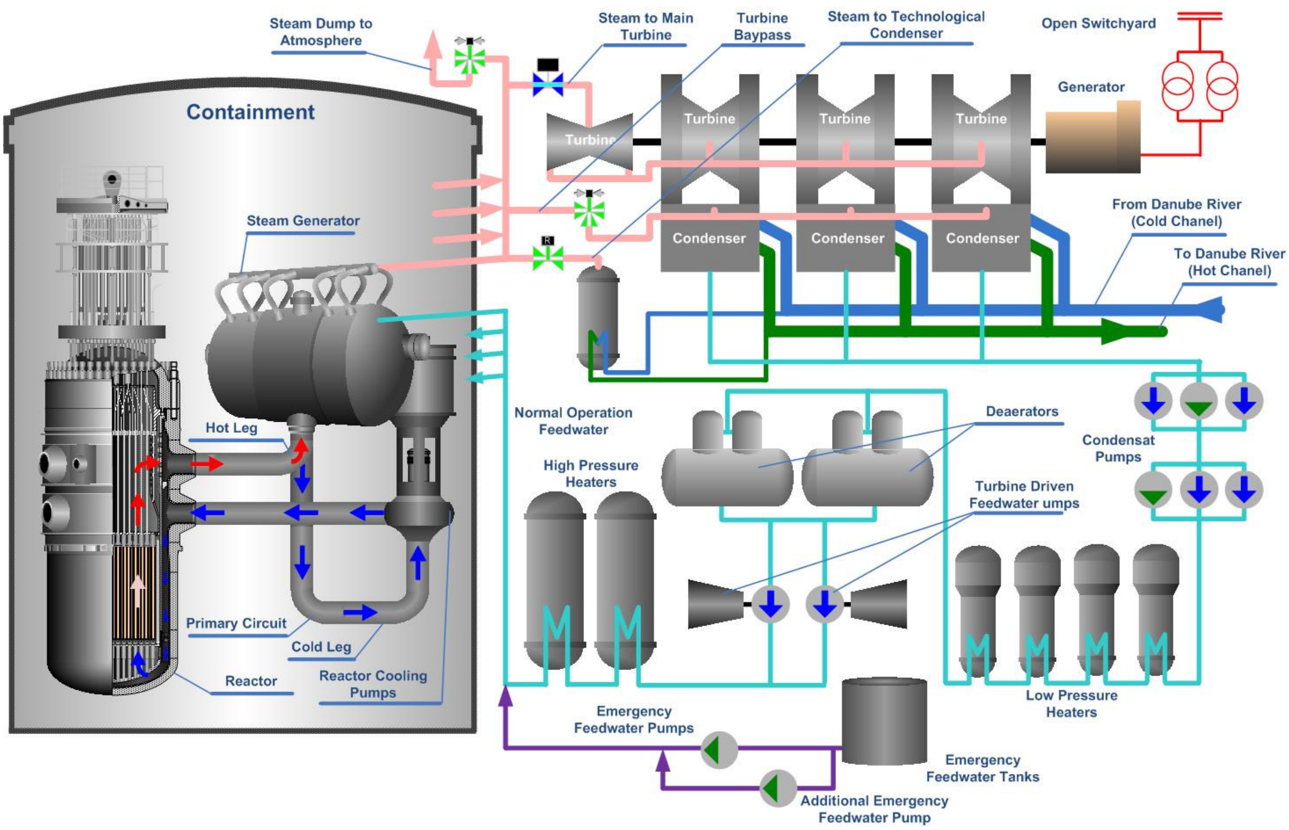

Figure 6: Heat removal to the ultimate heat sink , Unit 5 and 6

At primary circuit temperature decrease below 120°C, the only way of cooldown remains the so-called water-water cooldown which in turn uses the atmosphere as the ultimate heat sink. Reactor heat removal is done through emergency and normal core cooling system to essential components service water supply system which circulates by closed circuit and transfers heat from the reactor to the atmosphere through spray ponds (Figure 7)

Heat removal systems

Systems for heat removal to the main ultimate heat sink.

<u>Circulation water system.</u>

The system serves for cooling water supply to the turbine condensers supplying it from cold channel (water from River Danube) and removal of heated water after the condenser to the hot channel.

BRU-K.

The system is designed for heat removal from the SG directly to the condenser in start-up, shutdown or transient modes with abrupt load decrease, when the turbine load is lower than the reactor power, i.e. at steam cooldown of the primary circuit and temperature over 120°C.

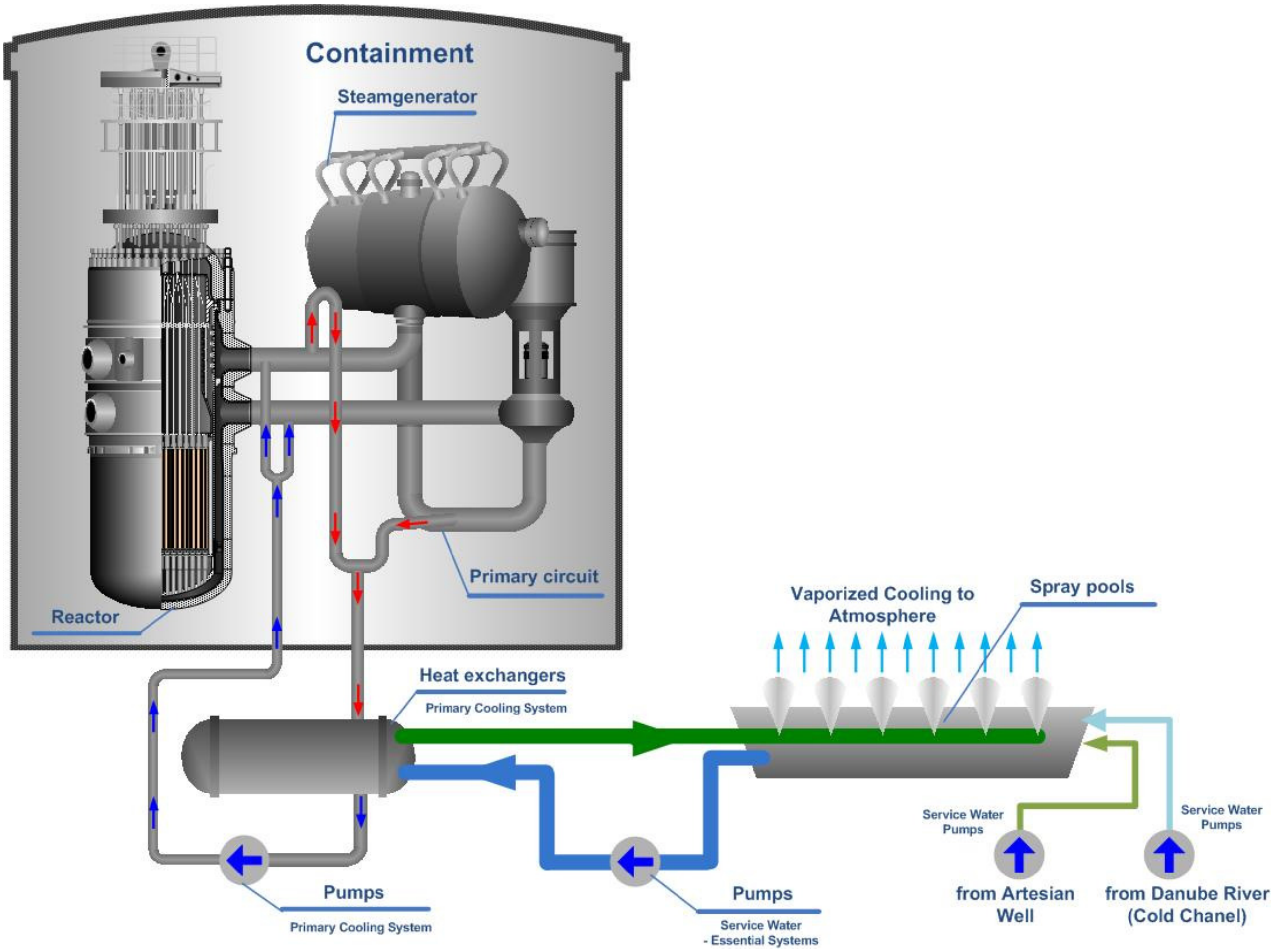

Figure 7. Water-water cooling

SG makeup water system.

The makeup water system is designed for supply of makeup water to the steam generators in all modes of normal operations, transients and anticipated operational occurrences, in which systems are available in the turbine hall. (section 6 from [4][5])

The makeup water from the two generators is supplied through two groups of pumps:

- Two, powered from the turbine pumps, intended for operation at reactor operation at power over 6-7%;
- Two auxiliary electric pumps intended for operation in transient modes at power below 6-7%.

SG emergency makeup water system.

The steam generator emergency makeup water system is a protective safety system which is designed for supply of makeup water to the steam generators at loss of off-site power of the unit or at failure of normal makeup water supply to the steam generators. The system consists of three independent trains.

SG alternative makeup water system.

SG alternative makeup water system is a system for beyond design basis accidents management and is designed to ensure supply of makeup water to the steam generators at total loss of AC power supply sources in order to ensure reliable removal of decay heat from the core during at least 24 h. (section 12 from [4][5]) The power supply of the pump and the I&C is from mobile diesel-generator.

The suction pipeline of the pump is connected through a T-joint to the suction pipeline of the pump of the first channel of steam generator emergency makeup water system. The pump connection is provided through one manual valve. The pressure pipeline is connected to the pressure header of the pump of the first channel of steam generator emergency makeup water system.

Systems for heat removal to the alternative ultimate heat sink

Essential components service water system.

The system serves for water supply to the safety system components. It includes spray ponds that remove heat to the atmosphere, pumps and pipelines to the heat-exchangers. The system is a supporting safety system and consists of 3 independent trains. Each train provides for 100% the functioning of the system.

Low pressure emergency and normal cooldown system.

The low pressure emergency and normal core cooldown system combine the functions of a protective safety system and a normal operation system. (section 12 from [4][5]) The system is designed for:

- reactor core emergency cooldown and continued core heat removal in accidents conditions associated with primary circuit leakage, including main circulation line break that ensures supply to the primary circuit of boric acid with concentration over 16 g/kg with flow rate 250-300 m^3/h at primary circuit pressure ≤ 2.16 MPa and 700-750 m^3/h at primary circuit atmospheric pressure.
- primary circuit normal cooldown during reactor shutdown and core decay heat removal at maintenance and refuelling;

The system is a protective safety system and consists of three independent trains with each train providing for 100% of the system functions.

BRU-A system.

The system of fast acting devices for the steam dump to the atmosphere is designed to release steam from the main steam lines to the atmosphere. The heat is removed from the SGs directly to the atmosphere at steam cooldown of the primary circuit. BRU-A system is used when BRU-K system is not operable. The use requires replenishment of large amount of water in the SG makeup system. SG makeup at BRU-A operation is through makeup water systems listed in the preceding paragraph.

Intermediate level emergency boron supply system.

This is a protective safety system designed for emergency primary circuit supply with boric acid solution with initial concentration of 40 g/kg and flow-rate over 130 m^3/h, at accident conditions with high pressure (≤ 110 kgf/ m^2) maintained in the primary circuit as well as for replenishment of leakages in modes with the primary circuit depressurized.

Using the system as well as all other systems supplying boron solution to the primary circuit heat removal from the primary circuit can be performed by "feed-and-bleed" procedure.

Emergency core cooling system – passive part.

Passive part of ECCS is a protective safety system (section 12 from [4][5]) designed for flooding of the core at large loss of coolant accident when the primary circuit pressure drops below 5.9 MPa .

The boron acid concentration in the hydro accumulators is 16 g/kg and ensures sub-criticality in the reactor core. The system is designed so that the boron acid solution volume in three hydro accumulators (out of four installed) to be sufficient at occurrence of double-ended break of the main circulation line, for core cooldown before start-up of primary circuit normal and emergency cooldown pumps.

Availability of heat removal logics and measures to extend the systems operability

The equipment and pipelines of all active safety systems are physically separated and protected against external events. Service water supply system channels are spatially separated. Electric power supply sources and inventories of working media and cooling water ensure autonomy of safety systems for not less than 72 hours.

Heat removal systems AC and DC power supply

Electric power supply to the active components for each channel of the safety systems is ensured for uninterruptible power supply I and II category. The equipment that cannot be de-energized for time over 20 ms is powered from I category power supply, i.e. from the batteries. For Units 5 and 6 it is proved that one battery of safety system train can bear full load for over 10 hours.

The capacity of the fuel storage tank of each emergency diesel-generator is 100 m^3 and allows for 72 hours operation at full load.

Electric power supply for normal operation systems is category III which at loss of offsite power supply can be powered by the backup diesel generator manually following a special procedure. Steam generators alternative makeup system is powered from mobile diesel generator, [18][19].

Alternative cooling logics and equipment

Besides steam generators alternative makeup system on Units 5 and 6 there are other means for alternative core cooling logics at beyond design basis accidents. There is a capability for service water supply from the advance chambers of CPS-3, 4 to the first channel of the essential components service water supply system with diesel pumps for spray ponds fuelling.

In addition, procedures have been developed and personnel trained to perform primary circuit "feed and bleed" procedure.

1.3.2.3 Heat removal from the fuel storage ponds to the ultimate heat sink

In all design modes except for the isolation of containment system FSP fuel is cooled by the cooling system of the FSP whose heat exchangers are cooled by essential components service water supply system.

FSP cooling system has three channels, each of which includes a pump, heat exchanger, piping and valves (Figure 8). The pumps, heat exchangers and the equipment of each channel of the FSP cooling system are located in a separate rooms. Electric power supply to the active components for each train of the system for FSP cooling is ensured from respective train of the system for I and II categories uninterruptible power supply.

Channels are connected together by links of suction and pressure lines, which enable switching from one channel to another in case of failure of one of the channels. On the pressure and suction lines per three localizing fast acting valves are placed, one of which is located in the containment. Each heat exchanger of the system is cooled by the respective channel of essential components service water supply system. Each system channel is capable of providing residual heat removal from the pool in all unit operational states.

In fuel storage mode sufficient time is available in case of failure of one channel to ensure reliable removal of residual heat from the fuel. Start-up of backup channel is done by the operator remotely from the MCR.

In emergency modes with containment isolation removal of the residual heat from the fuel stored can be provided in two ways: by pool water evaporation and by supply of water to the pool by spray system.

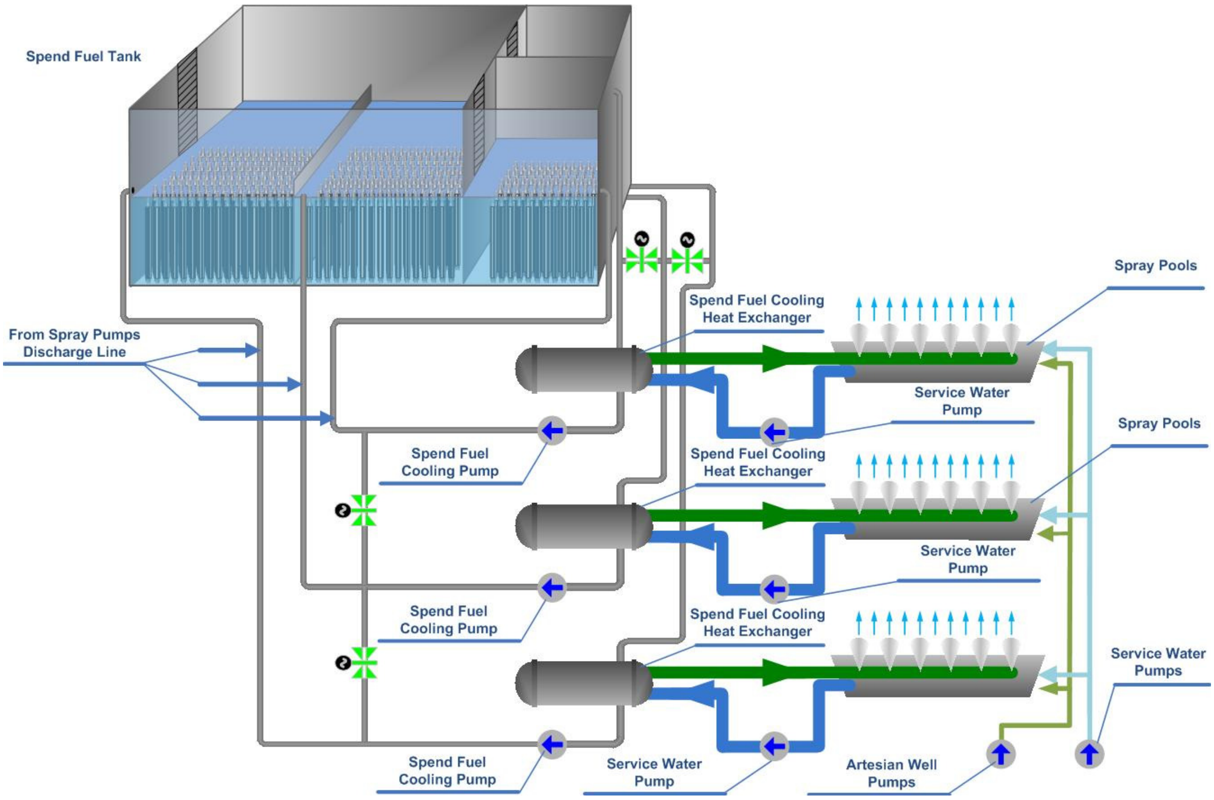

Figure 8. FSP for Units 5 and 6

In emergency modes with containment isolation isolating valves of the head and suction pipelines of FSP cooling system close and the system does not operate. The head pipelines of the system are connected with the spray system head pipelines, while the valves located on these lines are always closed. At containment pressure increase (when the isolation valves are closed) locking of opening of these valves is automatically removed and cooling of the FSP is provided through water supply by the spray pumps head and the water overflow to the EMT. It is possible to come to evaporation of the water in the pool. In this case, to prevent from unacceptable reduction of fuel compartment level and uncovering of the fuel, emergency makeup from spray system is also used.

1.3.2.4 Heat removal from containment area to the ultimate heat sink

Cooling of the premises and equipment in containment system at unit normal operation, at transients and at loss of offsite power supply is mainly from the following recirculation ventilation systems:

- System for cooling the containment premises without central hall, consisting of three channels having two units each;
- The system for cooling of the upper part of the steam generator compartments and central hall consisting of three channels having one unit each;
- System for cooling of space between concrete cavity and dry protection of the reactor, consisting of three channels having one unit each.

Each channel of this systems is ensured from respective channel of uninterruptible power supply system and essential components service water supply system.(section 9 of [4][5])

At accidents associated with containment system pressure increase heat is removed by spray system and then to the channels of essential components service water supply system. The spray system is designed to localize accidents through condensation of the evaporated part of the coolant released to the containment.

The system also performs the following functions:

- Cooling and reduction of pressure in the containment to atmospheric level through cold borated water injection to the containment system;
- Emergency make-up of the FSP in case the FSP cooling system fails.

Alternative cooling logics and equipment

In the framework of units 5 and 6 modernization programme pressure reduction filter system has been installed.

Pressure reduction filter system mitigates consequences of a severe accident preventing from overpressure in the containment system and consists of:

- Venturi type scrubber
- Tear-off membrane for pressure 0.5 MPa, i.e. near the design pressure in the containment system;
- Containment system isolating valves, which are normally closed.

1.3.2.5 Auxiliary AC power supply

Main cable routes and sections

Off-site power supply of Units 5 and 6 of Kozloduy NPP is through switchyard 400kV (working) and 220 kV switchyard (backup).

Connections of 400 kV (to unit transformer) and 220 kV (for startup transformers of Unit 5) are implemented by overhead lines connecting the transformer of Units 5 and 6 sites with OSY. Backup transformers of unit 6 are supplied from 220kV switchyard via cable 220 kV, traced in the underground cable channel. The cable channel is provided with fire alarm system (section 8 from [4][5])

Connections of 6 kV and 0.4 kV cables are made by cables located in protected areas, corridors, shafts and ducts, with automatic fire fighting and fire doors. All cables are coated with flame retardant coating. Cable connections from DGS to the safety systems sections are laid in autonomous cable ducts and premises.

Backup power supply cable connections between the units and part of general plant facilities are placed on overpasses in special protective metal trays.

Auxiliaries of Units 5 and 6 during normal operation are powered by 24 kV bus after the generator circuit breaker, auxiliary transformer with split coils 24/6/6 kV, power 63/31. 5/31. 5 MW, which supply power to normal operation sections. For normal operation of the unit simultaneous operation of both auxiliary transformers is required.

Backup power supply

Using automatic switch to backup equipment at failure to auxiliary transformer power supply power is supplied from backup power supply transformers group to Unit 5 or Unit 6 from OSY 220 kV depending on the selected priority of the automatic switch to backup equipment. One set (two per unit) of backup transformers can provide backup for both units.

Each unit has individual set of start-up transformers located on the site of the unit, physically separated from one another. Transformers are protected from neighbouring transformers of the transformer site with fire barrier. Restrictions in the availability of backup power supply sources and Availability of backup power is associated with the presence of voltage in OSY 220kV. At loss of voltage on all three systems 400\220\110 kV voltage can be obtained by the following corridors:

- Romania – substation "Tsantsareni";
- Substation "Sofia-West" in the directions from "Chaira" or Serbia, substation “Nish”.

Emergency power supply

Emergency power supply sources are DGs with power 6.3 MW each and batteries in respective safety systems.

Operating source of uninterruptible power of the systems is sections 6 kV category III, normally powered from auxiliary generator or from EES. In case of blackout or in the case of accident situation the start-up signal is issued independently for each diesel generator. The start-up of diesel generators to II category Section is during time up to 15 sec., which is more than the actuation time of automatic switch to backup equipment of unit sections 6 kV. The diesel-generators are constantly in hot standby mode and are ready for triggered loading and load intake.

The diesel-generators are located in separate buildings, separated from each other. The buildings are divided into three groups, separated geographically from each other. Cable floors, channels and routes of individual diesel generator stations are autonomous and independent from one another. Each diesel generator station has autonomous inventory of fuel, oil and start-up air. Cooling water needed for the operation of diesel generator stations is from essential components service water supply system, which is also a part of the safety systems.

Diesel-generators are designed to operate for 72 hours in autonomous mode, which is determined by the available diesel fuel. Fuel can be added in the external fuel tank\100m^3\through pipelines by overpass or by vehicles. Transportation of fuel by overpass requires presence of voltage of pumps in oil sector. Start-up air in the balloons of each diesel generator station is sufficient for 6 starts. Availability of cooling water is a provision for operation of diesel generator stations, which is determined by the presence of water in the spray ponds. The spray ponds may be supplemented with water from the diesel pumps in Circulation pump station or artesian water from shaft pumps stations, powered by electricity from bank pump station. .

Alternative power supply sources

Additional stationary diesel-generator stations

At loss of offsite power supply units 5 and 6 have general plant diesel generator stations, from which according to the procedure (time to 30 min) normal operation sections and part of the equipment for normal operation, which is needed to ease the cooling down of the reactor installation.

Additional DG unit has nominal power of 5.2 MW. The capacity of the fuel storage tank is 100 m^3 and it allows for 72 hours operation at full load.

Potential connections and logics with neighbouring units

There are connections for backup power supply between units 5 and 6:

- Backup power 6 kV – 2nd backup power;
- Backup power, 0,4kV section part.

Between Units 5 and 6 on one hand, and units 1 to 4 on the other hand there are no direct electrical connections. All electrical connections are in the switchyard.

Mobile power supply sources

To ensure emergency power supply of the safety systems loads in total and durative loss of auxiliary voltage mobile diesel-generator (MDG) is provided. The mobile DG is capable to perform the functions of backup diesel-generator, where necessary, to ensure supply of electric power to the loads of one safety system channel.

The mobile diesel-generator is for outdoor installation, set on the platform together with the fuel tank, control panel and the power cable wound on a drum, if its use is required it is transported with the carrier. The diesel nominal power is 1227 kW. The nominal power of the generator is 1100 kW with voltage 6000 V, 50Hz. The mobile diesel-generator start-up is done manually through the battery. Maximum fuel flow rate is 320 litres per hour. The fuel tank has a capacity of three tons, which is sufficient for operation of the unit at full load for about 9 hours. 6kV power cable for connection of generator to the respective section (with length ≈140m) is located on the platform of the facility.

There is a program for emergency power supply of pumps intended for steam generators alternative makeup in station blackout mode. Under this program operating personnel has been trained. Time to fulfil the program is about 50 min.

1.3.2.6 Batteries

The batteries are designed to ensure power supply to category I AC and DC power loads (through inverter) in case of failure of the respective rectifier. The batteries operate under constant charging ensured by two rectifiers. The batteries are integral part of uninterruptible power supply systems which provide uninterruptible power supply to the I category loads of the safety systems. The units are provided with I category uninterruptible power supply as follows:

- Batteries on safety systems trains – 3 in total;
- Battery for normal operation equipment (general unit battery);
- Battery of computer information system;
- 3 nickel-cadmium rechargeable batteries with a nominal capacity of 270A\h in 10-hour discharge for start-up of emergency diesel generators;
- Additional computerized systems are provided with own UPS.

Batteries of the safety systems of the two units, with the exception of the second system of unit 5, are assembled with 106 cells, sequentially connected. The capacity of one battery is 1133A/h for 10-hour value.

The battery of the second system of Unit 5 is equipped with 106 battery elements, sequentially connected. Battery capacity is 1200/h at 10 hour discharge to 1,8V of element at 20°C. [20].

All safety system batteries of both units are mounted on seismically qualified metal racks.

When performing real tests on the battery of the second train of the safety system for unit 5 all possible loads are actuated in station blackout mode, the battery supplies power to these loads for 10 hours and 18 minutes, until voltage reaches 191V. The battery should automatically trip at 180 V and at continuous extrapolation it is estimated that the battery can last up to 11 hours and 32 minutes.

In normal operation the batteries are in recharging mode and the battery itself and the loads are powered from 2^{nd} or 3^{rd} category through rectifier.

The loads DC power supply is through direct current boards. From the buses of the safety systems direct current board respective devices for relay protections, control and signalling, devices for safety systems automation, automation and signalling for fire alarm and fire fighting, emergency lighting, etc. are powered [21]. From direct current board of the respective diesel generator start-up systems, DG control and auxiliary equipment, emergency lighting and fire alarm are powered.

The loads AC power supply is through inventers. The loads powered this way include I&C, safety related valves, etc.

The batteries of the safety systems are located at the elevation of 13,20 in the reactor building building, in the rooms of respective system. Geographically they are separated from each other.

The batteries to the respective DG are located in the respective diesel cell, independently on one another. These batteries meet all requirements of I category equipment, i.e. physical separation, independence, lack of connection between different trains, seismic reinforcement, limited access, etc. They all are located at elevation over 0,00.

Maintaining and extension of battery operability can be provided in two ways:

- power supply to the rectifiers of the respective battery from side source;
- in blackout mode when the batteries are not powered, battery load reduction by excluding duplicating loads or limiting the loads.

1.4 MAIN DATA FOR SFS

1.4.1 Main data of spent fuel storage facility

The storage facility is an independent building of the NPP site containing a pool with four sections for storage and respective handling equipment required for spent nuclear fuel (SNF) handling. [22].

The initial design of SFS provides for its use for temporary storage of SNF from VVER-440 reactors before its transfer to Russia. Before completion of construction of the facility design has been prepared for additional equipment of SFS for intake and temporary storage of SNF from VVER-1000 reactors. Construction of SFS on Kozloduy NPP site has been completed in late 1990 and before obtaining Authorization for operation in 2001 it was operated with temporary permit. The storage facility is wet type, which implies SNF storage in baskets in a pool under water.

SFS building is a reinforced concrete structure, partly solid and partly prefabricated, and supporting structures are metal.

The design capacity of the SFS is as follows:

- maximum number of baskets - 168;
- maximum total capacity of the energy output shall not exceed 1064 kW;
- maximum energy output capacity in one compartment shall not exceed 555 kW.

Handling equipment and facilities consist of:

- Bridge crane 160/32/8t;
- Bridge crane 16 t;
- Refuelling machines RM SFS-440/1000;
- Facilities and equipment for transportation and storage of SNF of VVER-440 and VVER-1000 reactors.
- Facilities and equipment for handling operations with container “CONSTOR 440/84”.

1.4.2 Systems Ensuring or Supporting the Fundamental Safety Functions

1.4.2.1 Reactivity control

The location of the assemblies in the casing, distance between the assemblies (assemblies pitch) ensure sub-criticality of the media of at least 5% in normal and accident conditions of operation.

1.4.2.2 Heat Removal from the pools in SFS to the Ultimate Heat Sink

The main ultimate heat sink from SFS is Danube River.

Connection with the ultimate heat sink from residual heat source - FSP spent fuel - is by means of cooling water in heat-exchangers, provided from the II or III system for reliable service water supply of units 3 and 4.

According to the design the FSP cooldown system refers to normal operation systems. To increase its reliability, the system has been designed to fulfil part of the requirements placed to the safety related systems.

The FSP heat removal system is two-channel. To ensure the system normal operation it is required to maintain operable at least 2 (out of 3) heat exchangers and 1 (out of 2) pumps.

The pump sets on the FSP cooling system are category 1 loads and their power supply is ensured from two-transformer substation, which is in turn powered at blackout from backup diesel generator.

Alternative ultimate heat sink is the atmosphere at closed cooling system, through the spray pools by means of essential components service water supply system of Unit 4. Connection is provided fro emergency cooling water supply from Danube River through fire protection pump station -2.

1.4.2.3 AC power supply

Power supply distribution

For SFS equipment power supply a substation with two dry transformers have been constructed. The power is supplied to the substation by two independent cable lines from 6 kV sections on units 3 and 4.

The main elements forming the SFS electric power supply logic are as follows:

- two transformers 6/0,4 kV ;630 kVA: They are located in one room of SFS.
- two 0,4 kV sections (I and II): Each of the sections is connected with one of the transformers.
- 9 assemblies 0,4 kV: four of the assemblies are connected with the operating power supply from SFS I section (operating) and from SFS II section (backup). The other 4 are connected with power supply from SFS section I (operating) and SFS II section (backup) and are located in a separate room and one separate assembly with power supply from SFS I section (operating) and from EDGP (backup-uninterruptible), which is located in a separate room.

The auxiliary electric equipment is located in separate rooms of SFS, which are seismically and fire resistant. To decrease the fire hazard, the greater part of the cables is with cover made of inflammable material. Besides, treatment of cable sheaves with fire protection composition is provided.

The power and control cables routs of the two independent channels of SFS electric power supply are specially separated – they go through separate rooms, or where impossible, by different walls of the room.

In case of failure to power supply to one of the auxiliary switchgear sections due to external cause (failure to transformer or in 6 kV chain) automatically switches off the automatic circuit breaker and entire load on auxiliary transformer substations set is connect to the single transformer.

Emergency power supply

At loss of power supply switchgear 0.4 kV of SFS due to an external cause autonomous backup diesel generator is provided, 250 kVA, 0.4 kV, which is located on the SFS site and through special circuit breaker supplies power to the I section of switchgear 0.4 kV of SFS, and through section circuit breaker – to the II section.

The diesel-generator is located in a separate building and is physically separated from other power supply sources. It refers to the first seismic category. The autonomous SFS diesel generator is provided with fuel and oil inventory for continuous nominal load operation for 72 hours [24]. The emergency inventory of fuel is stored in the oil stocks of Units 5 and 6 site.

Alternative power supply sources

At loss of SFS switchgear 0.4 kV and failure to supply power from own diesel generator one of the sections is also supplied with emergency power supply from diesel-generator station 2. From the section first category loads are powered.

At loss of all SFS power supply sources procedure for electric power supply to the required 0,4 kV loads of the SFS systems from the mobile diesel-generator is applied [26].

The mobile diesel-generator is provided with fuel and oil inventory for continuous nominal load operation for about 10 hours [27]. The emergency inventory of the fuel is stored in the oil stocks of Units 5 and 6 site.

In Kozloduy NPP special procedure is developed specifying electric power supply from mobile diesel generator [27]. Movement of the platform with mobile diesel generator from the hall to SFS is carried out by a carrier and is organized by the manager of support service according to Kozloduy NPP Emergency Plan [25].

1.4.2.4 DC power supply

In order to provide for short-term disturbances in the power supply for the time before power supply from backup diesel-generator UPS devices are installed [28].

The loads powered from the UPS devices are as follows: radiation monitoring system, interlocks and protections system, control room workstation, electric equipment in refuelling machine cabin. The UPSs location is commensurate with their purpose and meet the fire protection requirements. The design does not provide for alternative option for UPSs batteries recharging.

1.5 MAIN DATA FOR DSFS

1.5.1 Main data of spent dry spent fuel storage

The storage facility is dry type and is based on the technology with use of containers with air cooling through natural convection.

DSFS is an independent structure, consisting of one-floor hall. The main support frames consist of reinforced concrete floor slabs and columns, fire protection steel farms and stiffening reinforced concrete protective walls. The DSFS design provides for storage of 2800 assemblies with SNF from VVER-440 in containers CONSTOR® 440/84 (total of 96 containers).

DSFS is divided into two main areas: intake area and storage room. The storage room serves for storing of CONSTOR® containers and is surrounded by shielding walls. The neighbouring intake area is separated from the storage room with shielding wall with sliding shielded doors, allowing for the containers to be placed inside and outside the storage room.

Containers CONSTOR® 440/84 are used for storage of spent fuel assemblies from VVER-440. Each container CONSTOR® 440/84 has capacity for storage of 84 assemblies with spent fuel from VVER-440. The technology for elaboration of CONSTOR containers is based on the use of steel to ensure hermetic closing of the containers, heavy concrete for additional shielding and system for closing through welding. All safety functions, namely, radiation shielding; radioactive decay heat removal; hermetic closing and maintaining criticality, are fulfilled due to the design of the container itself.

1.5.2 Systems Ensuring or Supporting the Fundamental Safety Functions

1.5.2.1 Heat removal from DSFS to the ultimate heat sink

The main ultimate heat sink from the DSFS is the atmosphere by means of natural ventilation system. The system capability to maintain the required temperatures in the containers for the entire ambient temperature design range is substantiated in Interim Safety Analysis Report [30] for the DSFS.

1.5.2.2 Auxiliary AC power supply

According to the DSFS design the essential loads classified as category 1 are: the emergency lighting, fire alarm system and fire protection systems. Those are powered from: backup power supply from Kozloduy NPP; backup power supply from diesel generator and additional separate uninterruptible power supply. The crane is classified as category 2 and at interruption of normal power supply it will automatically switch to backup power supply from diesel generator. The electric power supply required for general activities in the DSFS are from category 3.

Operational power of DSFS is supplied from 2 independent power supply outputs of switchgear 6 kV from Units 3 and 4 through a step-down transformer to the main switchboard.

The backup power supply is provided by a diesel generator that can be available for max. 24 hours. The diesel generator is installed in a separate building, close to the DSFS building. The generator is with automatic start-up and is provided with cabinet, ensuring automatic start-up of the backup generator.

Emergency power supply is ensured from UPS for the 1st category equipment, such as data recorders, core monitoring and alarm devices, etc. to ensure safe evacuation of the building after loss of normal power supply. These systems are mounted in place and have discharge time from 10 minutes, which is sufficient to start the backup power supply.

1.6 SCOPE AND MAIN RESULTS OF PSA

Scope and main results of PSA of Units 3 and 4

For units 3 and 4 full-scale PSA has been performed. Later and multiple updates of probabilistic studies were carried out and repeatedly extended in scope, structure and methodology, so that to reflect both the current state of the plant, after numerous upgrades, and the development of the analyses methods. The summarized results of PSA Level 1 for FSP fuel damage frequency that most precisely reflect the actual state of the units are provided in Table 1.7-1 below.

Table 1.6-1 Summary results of the fuel damage frequency in SFP

Initiating event category	FSP fuel damage frequency [per year]
Internal initiating events	2,0E-05
Seismic impact	1,9E-06
Fire impact	2,3E-06
Total FSP fuel damage frequency	**2,4E-05**

The main contributors to the risk of damage to the fuel in the FSP, related to the internal initiating events are the initiators "Leakage from FSP",(48% of total risk) and "Loss of off-site power" and "Loss of non-service water", with 22%.

On the basis of PSA Risk Monitor was developed, which is used in the daily operation of units 3 and 4 of Kozloduy NPP. Furthermore, other PSA applications were developed, such as probabilistic assessment of operational events.

It should be noted that the above estimates of the current state of the units are too conservative, given the constantly decreasing heat in the assemblies and additional technical and organizational measures for the prevention and mitigation of potential emergency situations. These measures were developed after bringing the unit in state "SNF storage in FSP" and are not considered in the PSA [31][32].

Scope and main results of Units 5 and 6 PSA

The first probabilistic safety assessment for VVER-1000 reactors ever was performed for units 5 and 6 of Kozloduy NPP. Since multiple tests have been extended in the scope, methodology and structure. The aim was to reflect both the current state of the plant, after numerous upgrades, and the development of analyses methods. The results of PSA Level 1 in the table below represent the state at the time:

Table 1.6-1: Level 1 PSA results.

	Internal IEs	Internal fires	Internal floodings	Seismic impact	Total
Core damage frequency with unit power operation, /year.	9,32E-06	3,11E-06	1,98E-07	3,34E-06	1,6E-05
Core damage frequency at low power operation, /year	5,22E-06	1,98E-07	2,94E-08	3,66E-09	5,45E-06
FSP fuel damage frequency/year	1,50E-06	1,21E-07	1,67E-09	1,66E-08	1,64E-06
Total, events/ reactor years.	**1,60E-05**	**3,43E-06**	**2,29E-07**	**3,36E-06**	**2,30E-05**

Probabilistic Safety Assessment Level 2 is being updated and available results are not updated. Scope of the analysis is the same as in level 1 PSA. Model of PSA level-2 for units 5 and 6 reflects the actual status of the units by 2001, i.e. no measures of the modernization program have been considered. Within modernization frames additional facilities are built that will have a huge impact as to prevent containment failure and on the disposal of radioactive fission products into the environment. The results for 5 and 6 units of Kozloduy NPP received in 2001 and updated by the time indicate frequency value of large early releases (LERF) of **5. 37E-06 1/year**.

On the basis of PSA Risk Monitor was developed, which is used in everyday operation of Kozloduy NPP. Furthermore, other PSA applications are also developed or are under development - risk-informed testing, risk-informed maintenance, risk-informed Technical Specifications [33].

Scope and main results of SFS PSA

Full scope probabilistic safety assessment for SFS has not been completed. There is safety analyses for a whole range of potential initiating events performed using potential hazard and operability analysis method (HAZOP) [34].

2. EARTHQUAKE

REGULATORY REQUIREMENTS

Legal requirements towards external hazards are specified by the Regulation on ensuring the Safety of Nuclear Power Plants [43], CMD № 172/19.07.2004. The Regulation includes the following GENERAL REQUIREMENTS:

Art. 9. *The design limits shall at least include:*

4. criteria on protection of the containment, including temperatures, pressure and leak rates, considering the necessary margins ensuring its integrity and leak tightness in case of extreme external events, severe accidents and combinations of initiating events.

Art. 12. *(3) The design shall consider initiating events resulting from possible human errors and probable combinations of internal and external events and hazards, based on realistic assumptions.*

Art. 13. *The NPP design shall take account of the following external events and site specific hazards:*

1. extreme weather conditions;

2. earthquakes;

3. external flooding;

4. aircraft crashes;

5. hazards arising from nearby transportation and industrial activities;

6. sabotage;

7. electromagnetic interference.

***Art. 19**. (1) Deterministic safety analysis shall include:*

2. identification of the postulated initiating events characteristics, including those specific for the selected site;

***Art. 21.** (2) The probabilistic safety analyses shall include:*

1. all modes of operation, all postulated initiating events, including internal fire and flooding, severe weather conditions and seismic events;

***Art. 23.** (1) A comprehensive analysis of the risk from fires shall be carried out to substantiate the adequacy of fire protection arrangements. Personnel performing the analyses shall have experience both in technological system analysis and fire protection.*

(2) The analysis under para. 1 shall postulate a single fire in an area with combustible materials, consideration of an additional failure (independent of the fire) and their consequences, such as internal explosion or internal flooding. The analysis shall identify the fire spread in each area, the impact on the SSCs located in this area and in any other area, which may be affected by the failures or the environmental conditions as a result of the fire. The consequences of failures or improper operation of the fire detection and extinguishing systems during normal operation shall be analysed as well.

SPECIFIC REQUIREMETS of the Regulation related to earthquakes are the following:

***Art. 29.** Engineering surveys and investigations of natural processes, phenomena and factors having potential impact on NPP safety shall be conducted for the region and the site for situating a NPP:*

1. the following tectonic characteristics shall be defined:

a) location of faults, of potential earthquake foci zones and of geodynamic zones with respect to the NPP site, indicating the orientation and boundaries of potentially dangerous fault zones;

b) amplitudes, speed and gradients of the latest and contemporary movements of the earth crust, parameters of potential dislocations;

c) characteristics of capable fault areas (geometric schemes, dislocation amplitudes and directions along the faults, data of the latest activity known);

2. within the NPP site boundaries, the following shall be identified:

a) characteristics of the input ground motion in earthquakes of intensity of design basis earthquakes (of seismic level 1) with frequency of 10-2 events per year and safe shutdown earthquake (of seismic level 2) with frequency of 10-4 events per year at the zero level of the site;

b) the hazard of landslide displacements of the slopes considering the ground layers conditions and seismic motions with an intensity up to safe shutdown earthquake inclusive and accounting also for the impact of ground-waters, tectonic characteristics, contemporary geodynamic processes;

d) the availability of specific earth layers (biogenic, collapsing, swelling, salted, alluvial, human induced), their thickness and physical-mechanical properties (deformation modules, strength characteristics, etc) and their impact on the non-uniform subsidence beneath the NPP structures, the reactor buildings inclination during earthquakes with an intensity up to safe shutdown earthquake inclusive;

e) the zones of water saturated disconnected earth layers yielding to self-liquefaction when exposed to seismic impacts with an intensity up to safe shutdown earthquake inclusive;

The facilities subject to stress tests of Kozloduy NPP were designed and constructed within the period from 1973 to 1992. During this period of time both the seismicity itself (earthquakes with focal in Vrancha in 1977, 1986 and 1990) and the normative documents for its definition have changed. Kozloduy NPP has responded consistently to all those changes by performing the required additional surveys. New seismic characteristics of the site have been identified and safety related facilities ensured for them.

2.1 INITIAL SEISMIC DESIGN BASES OF KOZLODUY NPP

2.1.1 Initial seismic design bases of units 3 and 4

According to the design of 1973 of Kozloduy NPP units 1 and 2 the seismic activity of the region has been assessed for as VI degree of MSK-64 scale, due to which in the design special measures have not been taken for improvement of the seismic resistance of the structures. Following the earthquake of 4.03.1977 with epicentre in the region of Vrancha mountain the site seismic re-evaluation has been performed and operational base earthquake (OBE) level was accepted as the VI degree with peak ground acceleration (PGA) of 0.05g and design basis earthquake (DBE) – the VII degree with PGA of 0.1g.

In the design of units 3 and 4 of Kozloduy NPP the following maximum seismic impacts on the site have been adopted:

- OBE - VI degree by MSK-64 scale
- DBE - VII degree by MSK-64 scale;
- Floor response spectra – the spectrum of accelerogram of the Vrancha earthquake dated 4.03.1977, recorded in Bukuresht and brought to PGA of 0.1 g.

2.1.2 Initial seismic design bases of units 5 and 6

The design of Units 5 and 6 has been developed with the following seismic characteristics:

- The design basis earthquake (DBE OBE) = VI degree by MSK-64 scale with peak ground acceleration (PGA) of 0.05g with recurrence period of 100 years and
- Safe shutdown earthquake (DBE DBE) = VII degree by MSK-64 scale with peak ground acceleration (PGA) of 0.1g with recurrence period of 10000 years.

2.1.3 Initial seismic design bases of SFS

SFS has been designed during the period from 1982 to 1984 with the following seismic characteristics: DBE = VII degree by MSK-64 scale with peak ground acceleration (PGA) of 0.1g with recurrence period of 10 000 years.

2.1.4 Initial seismic design bases of DSFS

DSFS has been designed and constructed after 1992 and its design incorporated actual seismic characteristics of the site defined in 1992:

- OBE Seismic Level-1 with peak ground acceleration (PGA) of 0.10 g with recurrence period of 100 years
- DBE Seismic Level-2 (DBE) with peak ground acceleration (PGA) of 0.20 g with recurrence period of 10000 years.

2.2 CURRENT SEISMIC DESIGN BASES – RLE OF KOZLODUY NPP

Current seismic characteristics of Kozloduy NPP site were defined during the period from 1990 to 1992 and are valid for all facilities in the site.

2.2.1 Reassessment of seismic design bases

For Kozloduy NPP during the period from 1990 to 1992 under a joint project with the IAEA - BUL 9/012 "Site and Seismic Safety of Kozloduy and Belene NPPs" new seismic characteristics of the site were defined and the influences of local earthquakes and other specific parameters were additionally analyzed. Using probabilistic and deterministic methods the seismic levels have been defined for the recurrence period respectively 100 and 10000 years based on the tectonic, geological, geomorphologic, seismic and geophysical data. Thus, the following has been identified for Kozloduy NPP site:

- For level with recurrence period of 100 years peak ground acceleration (PGA) is 0.10g and
- For level with recurrence period of 10000 years peak ground acceleration (PGA) is 0.20g.
- Design floor response spectra and respective 3D accelerograms with duration of 61s.

Following the IAEA recommendation additionally impact of a local earthquake has been studied. Floor response spectra from the local earthquakes and respective 3D accelerograms (with duration of 20 s) have been defined.

The seismic characteristics – seismic levels, design floor response spectra and respective 3d accelerograms were reviewed and confirmed by IAEA experts during the period from 1992 to 2008.

Also, the so called Review Level Earthquake (RLE) has been defined. This is the level for which all 1st seismic category SSCs are reviewed for the plants already designed (which is the case of Kozloduy NPP).

2.2.2 Methodology for reassessment of seismic design bases

For reassessment of the seismic characteristics of Kozloduy NPP site project IAEA BUL implemented during the period from 1990 to 1994 guidance of the applicable IAEA documents [37][38] have been applied.

Both standard levels of peak ground acceleration with recurrence periods respectively 100 (Seismic Level-1) and 10000 years (Seismic Level-2) are defined based on tectonic, geological, geomorphologic, seismic and geophysical data using probabilistic and deterministic methods. The RLE is defined according to the rules of defining of Seismic Level-2.

The methodology of probabilistic analysis of seismic hazard is based on standardized mathematical model of Cornel and software of McGuire 1976 and Toro and McGuire 1988.

The seismic-tectonic characteristics of the regional and local area of Kozloduy NPP are defined based on comprehensive geological, geophysical, geodesic, geomorphologic, seismic, seismologic and other studies and the results provided are within scope and scales required in [37].

The following conclusions are made based on the summary of the results:

- there are no large fault structures with high energy potential in the area investigated (there are no data of presence of a capable fault).
- Kozloduy NPP site is located in the relatively most stable part of the Moesian platform. This conclusion is confirmed also by cumulative database of the local seismologic network around the site existing already for 14 years.

The used earthquake catalogue covers period from 375 to 1990. The catalogue data are unified and standardized in accordance with the existing requirements. The intensity of the earthquake is assessed by MSK-64 scale. The catalogue contains 812 independent seismic events.

Most part of the observed seismic events are associated with well-known eight seismogen areas: Sofian, Marishka, Gornooryakhovska, Kresnenska, Negotinska-Krayna and Kampuling-Vrancha (shallow and medium depth) and local. For this areas space, time and energy characteristics have been studied in detail.

Through analysis of registered accelerograms for medium soil conditions for each of them attenuation principles have been defined. Also, magnitude-frequency dependencies for specific zones are obtained.

Seismic input uncertainties are studied and reported through the so called logical tree (logic diagram). 24 seismic hazard curves have been obtained.

Design seismic level characteristics are also defined – design floor response spectra and respective 3D accelerogram regarding the site geological conditions. The peak ground accelerations, defined using deterministic method, are significantly lower than those defined from seismic hazard (1.35 – 1.7 times). The local earthquakes effects M=4.5 under the site at the depth of 5 km and M=5.0 at 5.0 km distance and 5.0 km depth on the structures and equipment have been studied separately.

2.3 ASSESSMENT OF CONSISTENCY OF SEISMIC DESIGN BASES REASSESSMENT OF KOZLODUY NPP SITE

All aspects and stages of the reassessment of the seismic characteristics are discussed during multiple missions involving IAEA experts and lead specialists in the industry in Bulgaria, Macedonia and Romania, as well as representatives of NRA and Kozloduy NPP. The assessments provided in the final reports of the IAEA missions are conducted during the period from 1992 to 2002 can be accepted as sufficient to certify consistency of the seismic design basis. Indirectly, such seismic input is validated and adopted in the evaluation of follow-up actions with international participation which were considered and approved by international experts of the missions organized.

2.3.1 Compliance with applicable documents and standards

The site seismic characteristics reassessment has been performed mainly based on IAEA Safety Standard [37]. After implementation of the comparative analysis based on the state-of-the-art standard [39] and the one actual during [37] it has been identified that the seismic characteristics reassessed in 1992 with additional studies in 1995 meet the requirements of both applicable document [39] and regulation [40] enforced in 2004 as follows:

- the site shall not be located directly on an capable fault;
- the condition of peak ground acceleration less than 0.4g on the free surface at earthquake (PGA) with recurrence period of 10000 years shall be met.

2.3.2 Conclusion for consistency of the current design bases

Kozloduy NPP site seismic characteristics reassessed in 1992 with additional studies performed in 1995 for local earthquakes and probabilistic definition of seismic impact on the entire seismic PSA [31] meet the requirements of current normative framework. The requirements of [40] are performed as follows:

- in the study of the area of Kozloduy NPP site there are no major fault structures with high energy potential (no evidence of capable fault);
- Kozloduy NPP site is defined for a level of PGA with recurrence period of 10000 years and PGA 0.2g.

2.4 PROVISIONS MADE FOR PROTECTION AT RLE OF UNITS 3 AND 4

The analysis performed [41] is based on the documents applicable at the moment. The review and assessment mainly used SAR ([13] and [14]) and PSA [31] and available technical reports for analyses and expertises, qualified documents, technical passports of equipment. They used available lists of equipment required for the unit safe shutdown SSEL (Safe Shutdown Equipment List). Account has been taken of the results of international review missions for the safety and seismic security of the plant.

2.4.1 Systems, structures and components (SSCs) required to maintain FSP 3 and 4 in safe condition

The actual state and operability of the equipment have been identified based on the performed review of seismic qualification of the elements (components) and the method for performance of seismic qualification of the SSCs referring to seismic category 1 [41].

Following implementation of Short-term and Comprehensive Modernization Programme for Units 3 and 4 all safety related design and operation deficiencies have been removed and the facilities meet current safety standards and best international practice [41].

2.4.1.1 Buildings

The seismic categorization of individual elements of the main buildings has been completed considering a number of factors (section 7.4.11, [13][14]), as well as the results of implementation of modernizations and improvements of the original design V230. In 2001 reinforcement of the reactor buildings was implemented, that significantly increased the stability of the structure.

Seismic qualification of major civil structures of units 3 and 4 has been confirmed as follows:

- Seismic category 1 (seismic impact RLE):
  - Main building-3,4 (Reactor building, Near reactor FSP and fresh fuel compartment, Longitudinal electric stand, MCR building, Ventilation centre)
  - Additional system for SG emergency makeup 3 and 4
  - Circulation pump station 2
  - Diesel-generator station 2, Diesel-generators of bank pump station
  - Spray pools
  - Fire protection system 2
  - Emergency pump station of bank pump station and cooling water supply channels
- Seismic category 2 (seismic impact OBE)
  - Turbine hall – Units 3 and 4

2.4.1.2 SSEL systems and components

The original deign classification of the systems of units 3 and 4 has been completed in accordance with [45] and [46].

Later the systems and components have been classified in accordance with current normative documents. The procedure for qualification is verified according to the international requirements and the systems and equipment have been re-qualified as follows:

- Safety classification is performed according to [44] as the main document, and also functions from [47] [48] were used.
- Seismic classification is performed based on the IAEA guideline [38] considering [49].

The qualification is performed for components included in the safe shutdown equipment list and used for SNF safe storage in the in the FSP. Seismic qualification and operability of the following equipment ensuring spent nuclear fuel safe storage in the FSP has been confirmed.

<u>Seismic category 1:</u>

- Reactor (core, reactor internals), reactor vessel and lid;
- Fuel storage pool;
- Primary circuit main circulation lines and Reactor coolant pumps;
- Steam generators;
- Pressurizer primary circuit pressure maintaining system;
- Thermal-physical and neutron-physical parameters – neutron flux monitoring equipment;
- FSP cooldown system;
- Makeup water system;

- Main steam lines system (main steam header);
- Emergency makeup water system;
- FSP flooding system;
- Core flooding system;
- Steam generator compartment pressure reduction system - Spray system;
- Uninterruptible power supply system, category 1 and 2;
- Automatic seismic protection system ;
- Triggered load system (for the diesel generators loading);
- Containment system;
- Containment pressure reduction system;
- Essential components service water supply system;
- Fire alarm and protection system;
- Additional system for SG emergency makeup Units 3 and 4.
- Refuelling handling equipment – refuelling machine and 250 t crane in the containment central hall.

Seismic category 2:

- Spent nuclear fuel storage system water purification system;
- Fresh fuel compartment.

2.4.2 Key operational measures to maintain FSP 3 and 4 in safe state after the earthquake

According to the updated version of SAR, [13][14] measures for Units 3 and 4 are provided and implemented to ensure the required protection against seismic and fire impacts.

Additionally to ensure the safe and secure storage of fuel in FSP seismic qualification of the systems ensuring its functioning (FSP civil structure; FSP racks [50]; FSP flooding system; FSP cooldown system; FSP overflow line to emergency makeup tank (EMT); universal slot line the EMT; universal slot drain line to EMT (AB); FSP emergency flooding system) [51], [52] was performed. The updated analysis of postulated initiating events for the units in state "E" according to the regulation for spent fuel control [53] shows adherence to the criteria at different water density, as well as FSP cooldown and flooding system redundancy [51].

The FSP civil structure performs the design functions, having the required robustness and carrying capacity at different combinations of load, including emergency temperature and seismic impacts for DBE. Also, FSP rack robustness at different modes has been proved [54].

Instructions have been developed, as appendices to [55][56], specifying personnel actions and performance of improvement measures only by specific programmes (agreed with the NRA) at achieving safety limits for FSP fuel storage in state E.

Following the events in Fukushima, according to [57] in the Power Generation 1 a group of technical and organizational measures was developed aimed at a comprehensive review and assessment of the current status of the safety related equipment [43]. Special emphasis is focused on the cases with beyond design basis accidents and adverse external and internal impacts at spent nuclear fuel storage in the FSP in state "E".

The following measures have been developed and implemented:

- producing list of beyond design basis accidents scenarios for Units 3 and 4;

- programme for Units 3 and 4 operating personnel training in the beyond design basis accidents scenarios.

2.4.3 Evaluation of indirect effects of the earthquake

2.4.3.1 Evaluation of potential failures of non seismically qualified SSCs that may compromise heat removal to the ultimate heat sink through mechanical interaction or through internal flooding

The analyses of condition of ventilation reinforced concrete chimney of the auxiliary building 2 demonstrate proper robustness [60], but if scenarios with earthquake events with a level over RLE are reviewed and analysed then falling of a part of the chimney is possible. According to the analysis performed [41] it is evaluated that at falling of one third part of the length of the ventilation chimney (50 m from its top), the debris will not affect the additional system for SG emergency makeup (ASSGEM) of unit 4 and CPS-2, but will fall on the AB (its south-east part) and radioactive contamination can hinder personnel access to some areas (e.g. ASSGEM building).

2.4.3.2 Potential loss of off-site power due to destruction of the main site infrastructure

At loss of off-site power backup power is supplied to the FSP cooldown pumps from ASSGEM sections. Thus FSP condom pumps power supply is ensured both from the system diesel-generator and emergency diesel-generators of ASSGEM.

If conservative scenario is considered where events occur due to an earthquake causing simultaneous occurrence of an accident in the nuclear installation of Power Generation 2 and nuclear installation in Power Generation 1 and the need of using Mobile Diesel Generators (MDG) in two places, it becomes clear that availability of at least two MDGs is required.

2.4.3.3 Loss of ultimate heat sink

Essential components service water supply system ensures cooling water supply to the heat exchangers for FSP cooldown and the backup supply is ensured by fire pump station 2, by means of two headers, notched into the service water head pipelines.

According to the safety analysis of FSP [52] it is possible to connect additional alternative systems for the pool flooding and cooldown that can replenish for sufficiently large flow-rate maintaining the level in the FSP for the time of elimination of the leakage or for the time for the fuel movement into the reactor.

An underwater protective barrier (overflow) is constructed before the section – “end curve 8” for restriction of overflow of the Danube water outside the advance chamber of CPS 2 back to the cold channel. The scenario to cope with the consequences of loss of ultimate heat sink includes Additional system for SG emergency cooldown.

If there is loss of BPS, for SG, with the standard systems components maintained (primary and secondary circuits) water inventories enclosed in the advance chambers of CPS-2 and between it and the advance chamber of CPS-1 and underwater barrier at end curve 8 are used.

An emergency pump station directly before BPS-2 and 3 was built. The emergency pump station ensures independent water supply from the advance chamber of BPS-2 and 3 to cold channel after end curve 8.

If due to some reason the spray pool function fails, for nuclear installation cooling ASSGEM-3,4 systems are used whose inventory tanks have backup power supply besides fire water and artesian wells water in the site.

2.5 PROVISIONS MADE FOR PROTECTION AT RLE OF UNITS 5 AND 6

The actual state and the operability of the equipment have been identified based on the review of the elements (components) seismic qualification and the method for performance of the seismic qualification of SSCs of seismic category 1 [41].

2.5.1 Systems, structures and components (SSCs), required for bringing and maintaining of units 5 and 6 in safe shutdown mode

Based on the SSEL existing in the plant SSCs required for nuclear facility shutdown and maintaining in safe condition that need to remain operable during and after earthquake have been identified.

The analyses performed [41] are focused mainly on the reactor installation at power operation and specifically on the limits for ensuring integrity of the second protective barrier – fuel elements cladding. The stress tests for FSP cover respective structures at operations with SNF (the most adverse operational states allowable by the technical specifications), again considering the fuel elements cladding integrity.

The elements seismic qualification has been reviewed having established the current status and operability of the equipment.

All buildings and facilities related to the unit nuclear safety have been analyzed in the framework of Modernization Programme of Units 5 and 6, according to the new requirements for seismic stability.

2.5.1.1 Buildings

Seismic stability of all safety related buildings and structures has been reviewed in the framework of modernization programme of Units 5 and 6 for site specific impact.

Seismic qualification of the main civil structures of Units 5 and 6, Seismic category 1, has been performed as follows:

- Reactor building;
- FSP-5,6;
- Diesel-generator stations including underground tanks;
- Auxiliary building. Liquid radioactive waste storage;
- Spray pools;
- The walls of the advance chambers of CPS -3,4. (The seismic category of the advance chamber of CPS is given in relation with the safety of units 3 and 4 existing at the time.)
- Cooling water channels in the Power Generation 2 area. (The seismic qualification is performed for the advance chambers and bridge fences at A=922.00 and at A=1108.00.)
- Cable channels between DGS and reactor building.

2.5.1.2 SSEL systems and components

In the framework of Modernization Programme of Units 5 and 6 [64] safety related equipment qualification was performed. The verification of the qualification procedure for compliance with international requirements, item 3.2.1.1 [4][5] was performed as well as equipment qualification status was verified and the following was developed [68]:

- SSSL (Safe Shutdown Systems List);
- SSEL (Safe Shutdown Equipment List);
- HECL – Harsh Environment Component List.

At a later stage after completion of analysis of the current state of Units 5 and 6 equipment qualification as part of activities under contract of Kozloduy NPP and VNIAES – Moscow these lists were reconsidered and updated. The final list of equipment that has not been qualified was developed [69]. Currently seismic qualification of Units 5 and 6 remaining equipment not qualified for seismic impacts is underway by replacement or by a combination of expertise (including analogy) and analytical methods.

The process of seismic qualification in the plant continues systematically, including supply of new equipment, maintenance and modernizations. The qualified equipment list SSEL (Safety Shutdown Equipment List) is maintained updated [65].

2.5.1.2.1 Safety systems

The design classification of the systems of Units 5 and 6 is performed according to [45] (similar to [46]). In the framework of Modernization Programme of Units 5 and 6 (and in accordance with IAEA regulations) classification of the systems and components in terms of safety, seismicity and quality was performed according to current normative documents, item 3.2.1.1 [4][5].

The safety classification is performed according to [47] as the main document, using the functions from [48] for confirmation, item 3.2.1.1 [4][5]. The seismic classification has been performed based on the guidance of [38] with account of [49]. The safety systems classification is provided in table 3.2-1 [4][5].

Seismic qualification and operability of the following systems was confirmed:

- High pressure emergency boron injection system;
- Medium pressure emergency boron injection system;
- Emergency and normal core cooldown system;
- Passive emergency core cooldown system;
- Primary circuit overpressure protection;
- Secondary circuit overpressure protection;
- Primary circuit emergency gas removal system;
- SG emergency makeup water supply system;
- Containment;
- Spray system;
- Pressure reduction filtering system;
- Hydrogen concentration control and reduction system;
- Essential components service water supply system;
- Supporting ventilation systems;

2.5.1.2.2 Reactor

The systems and components classification is performed in the framework of modernization of Units 5 and 6 of Kozloduy NPP. The reactor and the internals has been originally designed considering seismic impact of 9 points by MSK-64 scale (PGA= 0,4g), item 3.13.4 [4][5], item 6.3.3 [64]. According to item 6.3.3 [64] these requirements are specified in the Terms of Reference (ToR) and confirmed. Item 4.7 [4][5] summarizes the actions performed for the reactor modernization with regard to the Modernization Programme of Units 5 and 6. The equipment seismic qualification has been reviewed in the framework of the modernization programme [4][5] and [64].

2.5.1.2.3 Reactor building major equipment

The major equipment in the reactor building has been designed considering the seismic impact loads from 9 points by MSK 1964 (PGA= 0,4g) [4] and [5]. Item 5.5 [4][5] summarizes the actions completed for modernization of the primary circuit and related systems with regard to the modernization programme of Units 5 and 6.

Under the modernization programme analysis of the behaviour and calculation of the seismic resistance of the major equipment and the safety systems equipment was performed and proposals developed for required reinforcements, item 6.3.3 [64], item 3.13.4 [4][5].

The seismic qualification of the pipelines, equipment and fixing elements of the primary circuit has been reviewed in a number of measures under the modernization programme with the results are summarized considering the new seismic requirements for the site. Qualification of the following primary circuit equipment was confirmed:

- Main circulation lines;
- Steam generators
- Reactor coolant pumps

2.5.1.2.4 Emergency power supply system equipment

Robustness against loss of power supply is ensured by the following design features:

- ensuring 2 (for the second category) or 3 (for the first category) different power supply sources to any safety system: from auxiliary transformers, from diesel-generators and from batteries;
- each of the units is provided with four diesel-generators (3 originally designed and 1 installed under Modernization programme), located in different rooms;
- availability of devices with passive action (gravitational operation of the emergency protection, hydraulic accumulators, safety valves), allowing vital safety systems for performing their functions at station blackout.

All the new equipment is qualified as safety systems equipment with safety class 3 according to [47] and in combination with IAEA definition for safety functions, respectively, equipment class 1E according to IEEE, corresponding to respective seismic qualification for seismic category 1 – item 8.3.2.2.16 [4][5].

All new components of uninterruptible power supply system category 2 is seismically qualified and refer to safety class 3, seismic category 1 (item 8.3.2.3.9 [4][5]).

2.5.1.2.5 Fuel storage, reloading and transportation system

The selected systems below are seismically qualified and given seismic category 1:

- Fresh fuel storage system
- Core refuelling system
- Spent fuel near reactor storage system

2.5.1.2.6 Auxiliary systems operating with water medium

The selected systems below are seismically qualified and given seismic category 1:

- Makeup and blowdown system
- Primary circuit controlled drains system

2.5.1.2.7 Main steam lines system from SG to main steam isolation valve

According to item 5.5 [4][5] of the modernization programme analysis of possible locations for main steam and feedwater lines breaks as well as of the effects of the breaks was performed. After that limiting supports and protective devices against the effects of line breaks were designed and installed.

2.5.1.2.8 Emergency reactor protection system

The ERPS set consists of two independent sets physically separated in different rooms that cannot fail simultaneously due to a common cause.

Specific components of the sets are seismically qualified as category 1 and 2 depending on the functions performed (item 7.2.4.1.1 [4][5]).

2.5.1.2.9 MCR, ECR boards

The metal structures on the boards and panels of MCR and ECR are seismically qualified as category 1. The monitoring and control instrumentation is seismically qualified.

2.5.1.2.10 I&C equipment

Safety systems I&C systems are operable in all modes of unit operation, including loss of auxiliary power supply (item 7.3.1.1 [4][5]). The systems are seismically qualified as Seismic category 1.

2.5.1.2.11 Neutron flux monitoring equipment (NFME)

The hardware of neutron flux monitoring equipment, as well as equipment for reactor emergency protection bear seismic impacts with intensity corresponding to safe shutdown equipment (DBE) up to 8 points by MSK-64 scale at the elevation + 24,6 m, + 13,2 m, minus 4,2 m – I category; equipment of automatic power controller and power limiting controller is qualified for II category according to item 7.2.4.5.1 [4][5]. According to item 7.2.4.5.2 [4][5] the NFME set corresponds to [70].

2.5.2 The main operational measures to bring and maintain units 5 and 6 in safe shutdown state after an earthquake

As the results of the performed review [41] the following main operational and emergency measures were established to prevent from the core or SNF damage after an earthquake:

- seismic monitoring and control system. At the same time personnel action plan during and after an earthquake was developed, [71].
- emergency plan. There is system for relation and interaction of emergency plan of Kozloduy NPP [25] with the national emergency services and inclusion of the emergency actions at the plant in the National Emergency Plan [72].
- personnel action plan during and after an earthquake has been foreseen and implemented [73].
- emergency Instruction detailing the actions at an earthquake has been developed and implemented [74].
- event emergency procedure for personnel actions during an earthquake has been developed and implemented [75].
- mobile equipment. A diesel-generator is provided. Mobile diesel pumps for emergency water pumping are featured, item 6 [76].
- Unit 5 and 6 equipment surveillance programme has been developed and is being observed, [78].
- trials and functional tests of the equipment are performed. The actions for assessment of the technical condition of the SSCs are planned in such a way, that their performance is preventive, before occurrence of their damage, in order to reduce failure probability.
- protocols of SSCs periodic inspections are produced. The results of SSCs inspection according to programme [79] from 30.06.2011 are provided in the completion certificate [76].
- automatic actions – emergency tripping system at an earthquake [77], item 7.2.4.2.3 [4][5].
- automatic plant information systems is established and integrated with similar national system conducting continuous radiation monitoring within 3 km zone.
- other scheduled measures to prevent, recover from and restriction of accident consequences.

Following the accident in Fukushima a detailed programme was developed for review and assessment of Kozloduy NPP Co. preparedness for management and reduction of the consequences of beyond design basis accidents, external and internal impacts [81]. The results of the current work under the programme are summarized in the preliminary report [82].

According to item 2.4.2 [82] the number of portable submersible pumps in Power Generation 2 should be optimized, considering more adequate response at internal; floodings. Efficient and additional measures were proposed considering enhancement of protection at external and internal impacts (Appendix No. 1, [82]), item 2.4.2 [82].

Measures have been taken for development and updating of the emergency procedures for OSY personnel actions at earthquake, flooding, fire and explosion in departments, where needed, item 2.8.2 [82].

According to the information of item 2.9.2 [82] the emergency crew capability to perform the emergency plan and its procedures was tested realistically in an exercise for accident with earthquake and flooding. The persons responsible from the emergency activities management group according to the emergency procedure are familiarized with the procedure and properly follow it.

2.5.3 Assessment of indirect effects of the earthquake

2.5.3.1 Assessment of potential failures of SSCs not seismically qualified that can compromise heat removal to the ultimate heat sink by mechanical impact or by internal flooding

Measures are provided to ensure that at destruction of elements with lower seismic class will not damage the SSCs required for nuclear installation shutdown and maintaining in safe shutdown mode.

In this review general plant systems not seismically classified but important for coping with secondary post-earthquake effects are identified and analyzed. Measures taken to preserve their functionality during and after the earthquake are discussed.

Within the framework of Modernization Programme [66] and [67] the following measures to prevent from seismically induced interactions have been analyzed and implemented:

- implementation of a project to ensure free seismically induced movement of the cable channels;
- implementation of a project for turbine hall reinforcement;
- implementation of a project to reinforce structural elements of turbine hall over the cable channels;
- coupled lines limiters have been mounted to prevent from damage to the safety systems neighbouring equipment.

2.5.3.2 Potential loss of off-site power due to destruction of the main site infrastructure

After analyzing potential scenarios the following accident states that may be caused by a seismic impact lower than RLE and at RLE were defined [41].

<u>Total loss of AC power supply sources</u>

In 2006 a strategy was developed and implementation of activities started for alternative makeup of the steam generators from alternative systems at total loss AC power supply sources. The base for it is article 32, item 2, article 33, and article 74 of [40].

The project was completed and in 2009 functional tests of SG alternative makeup system were conducted. The system is capable to provide makeup for the steam generators at initiating events with total loss of electric power supply of categories I and II as well as at unavailability of SG emergency makeup pumps (TX10-30D01). The system operates regardless of the standard systems of the unit using only part of the piping of one train of SG emergency makeup system.

Loss of OSY

As the OSY is not qualified as Seismic category 1 there is potential for its failure also at a seismic impact lower than RLE. Moreover, that the national electric grid is seismically warranted by industrial standards for impacts lower than RLE and OBE. Thus, even at earthquakes lower than RLE there is potential for permanent loss of external power supply due to damage and destruction in the national power generation and power supply grid.

The logics of the generator voltage of Units 5 and 6 of Kozloduy NPP are built by logic “generator – transformer ". The connection between unit and its parallel operation with the remaining units of the plant is provided at 400kV side of unit transformers. To improve the reliability generator circuit breakers are installed and transformers are connected between the circuit breaker and unit transformers.

Thus auxiliary loads of the units can be powered from transformers with tripped generators. The connections between the elements of the main electric logic of the unit and deviations of transformers are made using phased capsulated bus wires 24kV. In transformers there is no switching equipment which increases the reliability.

To increase the reliability and reduce potential of total loss of power supply to OSY 400 kV, the system is designed as double section busbar system.

To increase the reliability of Units 5 and 6 with power of 1000 MW is principle of its connection to 400 kV side by logic “two circuit breakers for connection” has been adopted.

Loss of safety systems power supply

3 batteries are provided per one for the three trains of the safety systems. The batteries operate in continuous charging mode with their charging provided from rectifiers constituting a UPSS compound. According to [4][5] the batteries are charged for at least 2 hours (to 3 hours for new batteries) at maximum load (for AC voltage – in inventors). Based on the tests performed it was identified that the batteries last over 10 hours at real load [80].

Loss of category II emergency power supply sources

The required inventories of fuel and oil for continuous operation of emergency sources of category II power supply are provided as follows, [42]:

- DGS-5,6 from safety systems: general operational fuel inventory ensures continuous operation of each DG for at least 3 days;
- DDG-5,6: 70 hours’ operation ensured;
- Diesel pumps in CPS-3,4: 24 hours’ operation of all pumps (8) simultaneously;
- DG “Emergency preparedness”: 8 hours’ continuous operation of DG at nominal load without charging.

2.5.3.3 Loss of ultimate heat sink

Essential components service water supply system design does not provide for specific measures to maintain cooling water supply.

In the essential components service water supply system principles of redundancy, physical separation and independence of the trains is adopted.

For units 5 and 6 six spray pools are built. The system trains operate by a closed circuit with water cooling in the spray pools. Each spray pool is designed to remove all the heat generated in an accident mode of the unit and to ensure service water temperature for essential components cooling within the range from +4°C to +33°C. in selection of the sizes of the spray pools, level change from 1.5 m ensures group A service water supply system operation without filling of the pool with wind speed up to 2 m/s for 30 hours.

Normal and emergency makeup of the spray pools is provided. The makeup is provided from normal electric pumps and in case of loss of external power supply from diesel pumps. The pumps are located in CPS 3 and 4. The emergency makeup of the spray pools is provided from 6 shaft pump station (ShPS) in the Valley of Danube River.

On the other hand, at loss of group A service water supply system reactor fuel cooling can be ensured by use of alternative system for SG makeup, and FSP fuel cooling can be ensured by FSP flooding system.

The Shaft Pump Stations 1÷6 are powered from BPS by cable-overhead lines 6kV with process name ShPS-A and ShPS-B. ShPS-A is powered from the V 6kV section of BPS. ShPS-B is powered from the IX 6kV section "Uninterruptible power supply". Procedure for temporary power supply of ShPS-A outlet to ShPS of diesel-generator of BPS.

2.5.3.4 Other indirect impacts caused by fires or explosions

2.5.3.4.1 Internal flooding due to seismic causes – at the site or in the buildings

In this review existing analyses of hazards from internal flooding as well as seismic qualification status of the site and buildings pipelines has been assessed.

Measures are provided to prevent from adverse effects on the plant safety from internal flooding resulting from rupture of non-seismically qualified pipelines in the site of the buildings.

2.5.3.4.2 Analyses of consequences of internal flooding in reactor building outside the containment turbine hall

Under the modernization programme analyses of consequences of internal flooding were performed, [83]. Individual analyses of flooding of rooms for all respective fluid systems located in the reactor building outside the containment, Appendices 5 to 24 [83], for turbine hall, Appendices 25 [83] were developed. Appendix 26 [83] specified the differences for unit 5 as the study is performed based on unit 6. For each room conclusions are provided depending on the influence of the flooding on the safety system equipment and on the civil structures.

2.5.3.4.3 Measures to cope with fires

According to item 3.3.14 of [4][5] the fire extinguishing system is built in accordance with the following requirements:

- To reduce fire risk;
- To ensure physical separation of the systems required for the plant safety.

The fire safety system of units 5 and 6 consists of the following subsystems, item 7.6.1 [4][5]:

- External fire ring - Units 5, 6;
- Reactor building and DGS fire alarm and fire extinguishing systems;
- Containment fire alarm and automatic fire extinguishing system;
- Gas fire fighting system in the electric equipment rooms;
- Turbine hall and electric building fire alarm and fire extinguishing systems;
- Auxiliary building-3 fire alarm and fire extinguishing systems.

2.5.3.4.4 Measures for protection against explosions

According to the analysis [84] in the report assessment of the safety impact and proposals are made for organizational measures to prevent from and to reduce the consequences of explosion on petrol station owned by Kozloduy NPP located in the area of Garage No. 2: the total amount of petrol in the petrol station shall not exceed three tons.

In pursuance of this recommendation analysis and assessment of the impact from potential explosion of petrol occurred in the plant owned petrol station on the neighbouring facilities and structures in the area of Kozloduy NPP have been developed, [85]. The results of the study [85] demonstrate that at potential explosion of petrol the NFs and safety systems components will not be affected.

2.6 PROVISIONS MADE FOR PROTECTION AT RLE OF SFS

2.6.1 Systems, structures and components (SSCs) required for maintaining SFS in safe state

According to the recommendations the stress tests are performed based on the available and approved by Kozloduy NPP instructions, procedures, technical specifications, SAR, technical decisions and their substantiations, results of studies and reviews.

Analysis [41] was performed covering all operational states taking into account the most unfavourable conditions (boundary conditions of operation) according to [23].

To cope with different accident scenarios SSCs (elements) are summarized according to lists mentioned in item 2.1.1.4. of [82]:

- Emergency DG of SFS;
- Mobile DG;
- Interlocking of the refuelling machine in SFS by industrial seismic protection system (III and IV unit);
- Level gauges in the rooms at emergency flooding of elevation -7.20m;
- Fire alarm system in SFS;
- Fire tubes drying from elevation 0.00m to the roof of building in SFS;
- Compartments for SNF storage (civil structure, pipelines and valves for leak control);
- SFS building;
- Bridge crane 160/32/8t (incl. load carrying structures for container handling);
- Crane 16 t (incl. load carrying structures for SNF handling)
- SFS DG building.

This review was conducted based on documents: SAR of SFS [22], technical specifications of SFS [23] and SAR of Unit 3 [13] as well as below mentioned the most conservative safety classes [47] and seismic categories [70].

- SFS building – Seismic category 1
- Systems and structures for transfer of the fuel and bridge crane 16t - Seismic category 1
- SFS DG building - Seismic category 1;
- SFS emergency DG - Seismic category 1
- System for collection and return of the leakage - Seismic category 1/ 2 according to table П6.1., Appendix 6, Part 3 of [22].
- Pipelines and valves for leak control in the compartments for spent fuel storage - Seismic category 1/ 2 according to Appendix 6 of [22].

The SFS civil structure is designed during the period from 1982 to 1984 in accordance with assignment of the Russian side as its general designer and in compliance with the normative documents applicable at the time of the designing

Following the reassessment of the seismic characteristics of the site design for the civil structure reinforcement considering the new seismic levels has been developed and implemented:

After implementation of the seismic reinforcement on the main support structure it bears all combinations of seismic impact DBE and operational loads.

The further combination includes continuous, effective and temporary loads plus temperature impact for anticipated operational occurrences or dynamic power at shell falling into the pool.

2.6.2 The main operational measures to maintain the SFS in safe state after earthquake

During the period from 1994 to 2000 a series of projects and technical solutions are developed and implemented aimed at improving the safety of SFS related with seismic qualification and seismic strengthening of buildings, equipment and components as follows:

- SFS building securing for RLE
- study of the civil structure and for extreme loads of snow and wind defined for Kozloduy NPP region:
- construction of new systems and equipment in SFS
- qualification of electric equipment and I&C in SFS
- the technical solutions relating to the seismic qualification of electric equipment and I&C have also been implemented as follows:

Due to actuation of the sensors (alarms) for the level in the room at emergency flooding of elevation -7.20m in the lists of SSCs (management and reduction of consequences of beyond design basis accidents in SFS, internal and external events) their seismic qualification status shall be confirmed due to lack of a referent qualification document.

The following safety related systems equipment, valves and pipelines are qualified:

- compartment cooldown system;
- spent fuel storage pool.

During the period from 1994 to 1998 the following projects related with equipment seismic qualification (mechanical-process, handling equipment) have been implemented:

- Seismic strengthening of the SFS civil structure. Recovery of process and electrical installations.
- Seismic strengthening of railways of cranes with lifting capacity Q=160/32/8t and Q=16t in SFS
- seismic qualification and seismic strengthening of mechanical-process equipment of SFS performing safety functions,

During the period from 2001 to 2004 a programme and detailed design was developed for seismic qualification of the equipment in SFS and a part of equipment was replaced where needed.

In 2005 technical solution for SFS equipment, pipelines and valves reinforcement and replacement was implemented [101].

2.6.3 Assessment of indirect effects of the earthquake

2.6.3.1 Assessment of potential failures to SSCs, not seismically qualified that may compromise heat removal to the ultimate heat sink, by mechanical interaction or by internal flooding

SFS Building is located on Kozloduy NPP site, to the south of Auxiliary Building 2. On 36 m of the north-east corner of SFS ventilation pipe (chimney) of AB-2 is located.

The ventilation - 2 has the required seismic safety and at RLE damage to SSCs (SFS building, emergency DG building) or hindered access to them is not anticipated.

2.6.3.2 Potential loss of off-site power due to destruction of the main site infrastructure

At analysis of accident with DBE loss of off-site power supply shall be considered first of all. SSCs (emergency DG of SFS and mobile DG of NPP) are provided to ensure power supply to the SFS loads from autonomous sources of category I and II power supply.

To ensure reliable functioning of the systems in conditions of loss of off-site power according to [42] the required inventories of fuel and oil for SFS are maintained:

2.6.3.3 Other indirect impacts caused by fires or explosions

Active and passive measures have been taken to ensure SFS fire safety to the extent possible (section 12.6.3 [22]).

- passive measures – the main civil structures are built of reinforced concrete, the roof is filled with 6m fire strips (zones) of non-combustible materials.
- active measures – they include external (ground for the plant) fire ring, internal fire fighting installation with fire taps in the rooms and dry tube for water extinguishing of cover.

Fulfilment of the requirements of fire safety ensure the safety of SFS in case of fire occurrence.

The following possible explosions are discussed:

- explosion of the receiver site of Kozloduy NPP – 1 and 2;
- explosion of the receiver site of Kozloduy NPP – 3.

Thus, the possible events defined do not jeopardize safety of SFS operation.

2.7 MEASURES FOR PROTECTION OF DSFS SEISMIC DESIGN BASES

2.7.1 Systems, structures and components (SSCs) required for DSFS maintaining in safe state

The analyses are performed based on the NRA approved technical design for construction of DSFS [35]. As input the latest Interim safety analysis report [36] was used.

Regardless of the fact that the quantity of radioactive material in the DSFS is large at the end of storage period, in the containers safe leak-tight confinement of this material is always ensured in pursuance of defence-in-depth principle. The radioactive decay heat is removed in a passive way.

All safety functions during the storage are maintained in a passive way as there is no need in active safety systems.

All SSCs of DSFS are classified considering their safety functions in accordance with the referent documents:

The main SSCs required maintaining operability during and after earthquake are:

- building;
- crane 145 t;
- containers;

The analyzed accident scenarios during and after earthquake are as follows:

- mechanical impact from earthquake;
- container blocked with debris;
- fire impact;
- station blackout.

In accordance with [102] the classification of the structure with relation to the external events is done by the following logic:

- Class 1: high adverse impact;
- Class 2: moderate adverse impact;
- Class 3: low adverse impact;
- Class 4: conventional adverse impact;

DSFS refers to Design class 3 (SV 3). It is additionally substantiated in Section 10.6.1 [36] while the maximum annual effective dose for an person of the population of the boundary radiation protection zone is <5mSv after postulated design basis or beyond design basis accident.

DSFS building Seismic category – Design class 3 (SV 3) in accordance with [102].

It can bear design basis and safe shutdown earthquake, without catastrophic collapse.

Crane 145 t - Seismic category – Design class 3 (SV 3) in accordance with [102].

The crane is designed for DBE and DBE without destruction of the structures or falling of load. Improper operation of the crane, electric and measuring components do not lead to hazardous condition.

Containers CONSTOR® 440/84 - Design class 3 (SV 3) in accordance with [102].

They are designed not to reverse after design basis earthquake.

Shielding doors and operational signalling of the doors. Seismic category – Design class 3 (SV 3) in accordance with [102].

In design DSFS requirements of [53] article 5 (1, 2 and 3) are met and defence-in-depth principles are applied.

2.7.1.1 Seismic design basis for DSFS building

DSFS is classified as Design class 3 (SV 3) in accordance with [102] .

With regard to the earthquake two design earthquakes are defined, including:

- design basis earthquake (DBE) from 1 E-02 /year (acceleration 0,1 g);
- safe shutdown earthquake (DBE) from 1 E-04 /year (acceleration 0,2 g).

Design criteria at am earthquake are as follows:

- robustness against collapse allowing inelastic behaviour during an earthquake 0,2 g and elastic behaviour at 0,1 g;
- ensuring bridge crane for the same design class as the structure;
- ensuring stability of the containers against inversion.

Analyses have been performed considering all normal and specific loads and combinations of loads in accordance with the applicable European standards and [102].

2.7.1.2 Seismic design basis for crane 145 t in DSFS building

Similarly to the building, the crane was also evaluated for the following adverse combinations of load conditions:

- OBE (SL1 from 0,1 g) with operating crane 145 t
- DBE (SL2 from 0,2 g) with standby crane 145 t.

Both the building and the crane are designed for OBE and DBE without destruction of the structures or load falling.

2.7.1.3 Seismic design basis for other process equipment

Clamping devices (hook and sleepers) and contact devices are evaluated only for design basis earthquake (SL1 from 0,1 g) with the operating crane in the storage area, including load from own weight, fixed loads and impulse loads.

The protective door is estimated for DBE (SL1 from 0,1 g) at any position of the door, and for DBE (SL2 from 0,2 g) at the closed position of the door.

2.7.1.4 Seismic design basis for containers CONSTOR® 440/84

Stability of the containers against inversion at seismic loads for design basis earthquake (SL1 from 0,1 g) and for safe shutdown earthquake (SL2 from 0,2 g) was confirmed.

2.7.2 The main operational measures to maintain DSFS in safe condition after earthquake

DSFS has fire alarm system ensuring local warning and the warning in the continuously functioning centre with personnel notifying the site fire fighting service. There is proper access of the fire vehicles to DSFS and corridor between DSFS and SFS. The main operational measures will be updated and described in the Final Safety Analysis Report. This will be a part of the documentation required for issuance of licence of DSFS.

2.7.3 Assessment of indirect effects of the earthquake

The existing facilities of Kozloduy NPP site that may impact on the DSFS after a seismic event are SFS and AB-2 chimney.

As a result of the analyses performed, various strengthening had been done at the SFSF building (additional steel joints, frames and supports, as well as the construction of new monolith concrete walls). These analyses has been performed using the latest data on seismic acceleration and spectres.

AB-2 stack has been analyzed against the new site seismic characteristics. It is important to note that even in stack damage scenario, the stack will not impact the DSFS, because of its distance from the building.

It is concluded that the DSFS site will not have adverse impact from other facilities on Kozloduy NPP site at an earthquake.

2.7.3.1 Assessment of potential failures to SSCs not seismically qualified that may compromise safety and robustness of the containers through mechanical interaction or through internal flooding

This scenario considers the consequences at container blocking with debris that could result from extreme external initiating events, such as an earthquake, explosion of gas or aircraft crash.

For the degree of piling with debris of 100% results of calculations with conservative assumptions show that the maximum temperature of the cladding may be only exceeded accordingly after more than 2 or 3 days.

Considering the structure of the roof a realistic degree of burial with 50% confidence should be anticipated. This increases the time available for countermeasures to more than 7 days. Even for this worst case scenario of an accident with loss of heat removal there is sufficient time available to take adequate countermeasures, i.e. to remove the debris and restore natural ventilation.

2.7.3.2 Potential loss of off-site power due to destruction of the main site infrastructure

The scenario for total loss of power supply is not relevant with regard to DSFS safety. Due to availability of passive system for decay heat removal the safe mode of the storage facility operation does not depend on the power supply.

2.7.3.3 Other indirect impacts caused by fires, explosions, flooding

The earthquake as an initiating design basis event may cause a fire, which indicate thermal effects on the containers.

To avoid negative effects on safety resulting from fire the following provisions are made:

- primary fire protection is provided by the design though minimizing potential sources of ignition and fire loads.
- in case of fire occurrence the DSFS building is provided with fire detection system.
- design fire protection of the containers. The containers are designed to withstand severe boundary accident event of a fire at a constant temperature of 600 ° C with a duration of 1 hour while maintaining the temperature of the fuel cladding below 330° C.

In the design of containers and DSFS building scenario of an explosion of the site or an explosion of a vehicle near DSFS is not considered. The internal explosion can be excluded since there are no explosive materials within the facility.

The building of the DSFS storage hall is designed to withstand the pressure wave from the explosion of a gas cloud. However, it can not be excluded that construction debris from the roof (thin metal plates) could fall into the storage hall. The emergency procedures and instructions shall specify the way and the process tools required for removal of the debris.

2.8 POTENTIAL DESTRUCTIONS OUTSIDE THE SITE LEADING TO PREVENTION OR BLOCKING OF PERSONNEL OR EQUIPMENT ACCESS TO THE SITE

To take into account possible adverse effects of seismically induced damage to the national infrastructure around the plant on its ability to maintain their safety functions after the seismic event it is necessary to conduct studies that show when and how seismic failures and the damage can be anticipated in it. Possible adverse effects on the plant are mainly limited to:

- loss of off-site power,
- destruction of roads and bridges
- extensive destruction in the nearest settlements leading to impossibility to complete the operational staff of the plant
- potential accidents in the gas transport network with following gassing, etc.

It is necessary to further analyze the behaviour of the infrastructure around the plant in the seismic and evaluate its impact on the its safety.

2.9 COMPLIANCE WITH CURRENT LICENSING BASE

2.9.1 General provisions

Kozloduy NPP has established and maintains an effective system of management of activities to ensure compliance with the licensing conditions of nuclear installations through effective organizational structure with clearly defined goals, functions and objectives ensuring human and financial resources. Processes and activities are described in the Handbook for Quality Management at Kozloduy NPP [88] and Rules for the arrangement and performance [89].

Guideline "Safety and Quality" organizes the entire process of obtaining necessary licenses and permits for nuclear facilities, according to the requirements of the safe use of nuclear energy and its regulations acts [90]:

- Register terms of licenses, permits and prescriptions of the NRA and other specialized review authorities controlling their implementation and report them to the relevant review authority.
- Organizes and conducts internal peer review to comply with the license terms and conditions and the conditions of permits, regulations, norms, rules and instructions issued by the regulators, documents and analyzes the results of the review, where needed, develops corrective and preventive measures.

Activities for the implementation of the licensing conditions shall be performed by the structural units responsible for the operation of the respective nuclear facilities.

2.9.2 Project management. Incorporation of changes

Rules for project management have been approved and the terms and conditions for incorporation of changes have been specified to ensure that these changes are in accordance with the approved design bases.

Changes in a project are made in order to increase reliability and efficiency of operation, maintenance and control of the facilities; to incorporate the new requirements of the normative framework or regulatory body, to reduce the risk, consider the operating experience, generally increase the safety of the plant operation.

Any change is implemented with a technical decision. For a change related to the safety of the nuclear facilities a written request for authorization from the NRA shall be submitted.

2.9.3 General process for ensuring SSCs required for maintaining the units in safe shutdown state after earthquake

Under the licensing documents and in accordance with licensing requirements and conditions, Kozloduy NPP as the operating organization has developed a system of technical and organizational measures to maintain proper condition of safety related SSCs through diagnostics, performing preventive measures, maintenance, repair, testing, inspections and operational control, replacing the structures and components with service life expired. A system for documenting the results of the activities performed and the operational control has been established.

For qualification of all safety related SSCs of nuclear facilities a continuous process has been created involving archiving (passports factory instructions), documentation (plans, programs, instructions) and maintaining data (functional tests, availability acts, monitoring) to ensure ability of the equipment to perform its functions during its entire lifetime. This process is started with the design of the nuclear facilities and will continue until the end of their lifetime taking into account the aging of SSCs, modifications, repair, service history, failures of components, replacement of components and distortions in the normal operating conditions.

At Units 5 and 6 "The list of SSCs classified according to safety, seismicity and quality" [89] has been approved.

Maintenance and repairs in the Kozloduy NPP are performed by highly qualified and trained personnel. The purpose of maintenance and repair is to ensure that SSCs are able to perform their design functions and maintain the design features in accordance with the technical specifications of nuclear facilities.

Activities for maintenance and repair include:

- planning of maintenance and repair;
- carrying out planned maintenance and repair;
- emergency repairs and removal of defects;
- quality control in maintenance and repair.

Scheduled maintenance and repair are performed to maintain and restore the equipment and its components. These activities are consistent with the requirements of manufacturers, regulators and normative-technical documents, have a certain periodicity and specified scope and cover the following types of maintenance and repair: general overhaul, intermediate repair, routine repair, and planned preventive maintenance.

The frequency and the scope of scheduled maintenance and repair are determined according to their importance to safety, technical specifications and operating instructions containing the operating limits of reliability of equipment and systems, results of current monitoring and periodic functional tests, periodic analyses of the failures occurred and trends of important process parameters and indicators for safe operation.

Quality control during maintenance and repairs is performed by highly qualified, authorized personnel to the extent specified in the documents to carry out an activity.

All activities are performed according to approved plans, programs and procedures.

For the facilities under regulatory control periodic technical reviews shall be conducted to make sure that they are operable and their safe operation is possible.

Design, engineering, technology, installation, operational and maintenance documentation of the facilities under regulatory control is developed in compliance with the requirements of the NRA for performance of the respective work in accordance with the NPP design.

Control for meeting the requirements of normative documents for TH is carried out by the inspectors of departmental technical inspection in sector "Internal Departmental Technical Inspection" of Safety Management.

Surveillance Program for Units 1 to 4 Equipment [92] and Surveillance Program for Units 5 and 6 Equipment [93] have been introduced. They take into account requirements of the Safety Analysis Report for the facilities, technical specifications, results of the safety systems reliability analyses. The programs are aimed at maintaining the availability of equipment and validation of the limits and conditions during operation.

Maintenance and repair activities, non-destructive testing of metal, modernization and reconstruction, certification and testing of equipment, including their qualification are included in the "Program of units 3 and 4 lifetime management" [94] and "Program of units 5 and 6 lifetime management" [95]. The selection of SSCs subject to monitoring and evaluation of the remaining lifetime is made to considering their classification and qualification, and their importance for performance of safety functions. The list of safety related systems and components subject to repair and maintenance of units 5 and 6 has been approved [96].

To implement these programs specialized units and structures have been established. For each activity written procedures are developed in accordance with quality assurance system. The activities are carried out by qualified personnel.

Safe operation of hydraulic facilities and all activities for the control of their condition as well as civil structures is ensured by a separate structure - Workshop "Hydraulic facilities and civil structures" for effective lifetime management. Seismic monitoring of the facilities and KNPP site and cadastral services within the company has been conducted.

Lifetime management includes passport provision, review of the status and development of engineering and construction facilities through dedicated observations and measurements, programs for comprehensive and 72-hour tests of newly constructed facilities and equipment, testing after repair and reconstruction, development and/or ensuring measures for corrective effects on the facilities, control of changes.

For seismic monitoring of SSCs in the KNPP there is a system of ten accelerographs of three different types. The system ensures seismic monitoring of equipment and structures, recording and archiving of data. The layout of the accelerographs was approved by the IAEA. Schedules are developed for monthly, biannual and annual inspection. For each activity, written procedures are developed in accordance with the quality assurance system. For each review acts are produced. The activities are carried out by qualified personnel. Acts are archived file to the appropriate device.

Geodetic deformation monitoring of hydraulic technical facilities, civil structures and process equipment, implementation and control of cadastral activities in the areas owned by the KNPP are performed.

For control of the hydraulic technical facilities constructed for service technical water supply (BPS, CPS 1-4, cold channel, hot channel, backup hot channel shaft pump stations 1-6) "Operating

Instruction" [128] and "Action Plan for emergency operating conditions of the existing hydraulic technical facilities for service water supply KNPP" [124] are developed.

2.9.4 Programmes and procedures ensuring supplies, stocks, inventories and mobile equipment

Activities for planning and maintaining preparedness to respond to emergency conditions, assessment of the initiating events, accident classification, notification, accident management and protection of personnel, population and environment are specified in the internal emergency plan of the plant.

Activation of emergency structures of KNPP

Emergency situations are classified according to the Regulation for emergency planning and emergency preparedness for nuclear and radiological emergency [97], in terms of possible consequences and associated activities that must be met.

Class "general emergency" is an emergency involving actual or possible release of radioactive substances and radiation exposure of the personnel and population requiring immediate protective measures for the population.

Class "field emergency" is an emergency involving a significant reduction in the protection of the personnel and persons in the area for precautionary measures.

Class "local emergency" is an accident involving a significant reduction in the level of protection of the personnel without risk to the population.

Class "alarm" - events have occurred resulting in the safety level unknown or significantly reduced, including natural disasters (flooding, hurricanes, snow drifts).

Alarm is declared when a natural disaster (flooding, hurricane, snow storm) causing destruction of civil structures on the site related to violation of the operational process.

The emergency plans of Kozloduy NPP provide for availability of mobile equipment and supplies located on the site and fit for use.

Emergency fuel inventories

Necessary, inviolable and emergency inventories of diesel fuel and oil to ensure continuous operation of the emergency sources of power supply of the Kozloduy NPP site, requirements to control, procedures and responsibilities for maintenance and repair are specified in the "Instruction for provision of the necessary fuel and oil inventories for continuous operation of the emergency source of power supply in the KNPP" [42].

Persons are assigned to conduct an independent internal review for the maintenance of the fuel and oil inventories, ensure supplies, control maintenance, planning and replenishment of the inventories, and perform periodic internal inspection. The requirements are specified for incoming and periodic monitoring of the chemical composition of the fuel.

Action plan for emergency operating conditions of existing hydraulic technical facilities for service water supply at KNPP [124].

Emergency operating conditions of hydraulic technical facilities are considered to be those in which the operation mode for one or more technical facilities goes beyond the design boundary calculated loads and there is evidence of violation of their design suitability and safety.

Within the action plan for emergency conditions [124] an organization has been established ensuring continual availability for performance of urgent measures to mitigate the consequences in accident conditions and conditions for operation of hydraulic technical facilities in KNPP. The plan is to be introduced in case of natural disasters - earthquakes, flooding from Danube River, heavy rains and storms causing erosion of air slopes, landslides, excavating and levelling, etc.

The required constant reserve of technical resources, tools and materials to cope with and mitigate the consequences, manner of notification in case of events, including relevant external organizations are specified.

Three emergency storage facilities have been established and maintained. In emergency warehouses construction materials and tools, devices, materials and aids required for prompt localization of potential damage and violations are stored. Open warehouses are fenced and marked appropriately and access for the equipment is ensured.

The Emergency Plan of Auto-transport Department

The emergency plan of the Auto-transport department [130] is part of the internal emergency plan of Kozloduy NPP. The measures are planned for transport providing emergency and restoration works in an emergency: ensuring 24-hour emergency shifts; maintaining operability of designated Action Plan Emergency vehicles, transport of the duty persons according to the emergency plan from the gathering location, evacuation of the personnel not involved in the emergency activities.

Conduct of emergency and restoration works in the accident involves the transport of materials and spare parts and provision of specialized material handling equipment - 9 trucks (dump trucks, flatbed machines), an engineering equipment - 8 machines (Fadroma, bulldozers) and 15 special vehicles (cranes, tractors and tanks). Freight transport and specialized material handling equipment is owned by the Kozloduy NPP and includes 32 vehicles located at the site of Units 5 and 6.

The emergency plan of Auto-transport department includes snow clearing and sanding the road surface of the NPP during the winter period.

The activity of the Auto-transport department during an emergency is coordinated by the Shift Supervisor of the nuclear power unit till the establishment of emergency structures, and after its establishment it is coordinated by Head of Support Services of the Management Team.

Emergency inventories according to the technical specifications

According to technical specifications of the nuclear facilities the necessary emergency inventories of boric acid, reagents, agents for chemical and radio chemical laboratories, boric solutions and demineralised water in tank compartment SK2, SK3 and shop for chemical water treatment is maintained to bring them in safe condition.

The emergency plan of Kozloduy NPP [25] provides for measures relating to the management of nuclear facilities during and after the earthquake, with a focus on anticipation and prevention in the sequence of action. At KNPP site the necessary infrastructure to respond to seismic events has been designed and built.

2.9.5 General process to ensure the availability and preparedness of external mobile equipment and supplies provided in the emergency plans after the earthquake (natural disasters)

External forces and resources to be involved to support KNPP are specified in the National Emergency Plan for carrying out rescue and emergency repair work in case of disasters, emergencies and accidents [72]. State authorities maintain a reserve of funds for decontamination, food, clothing and fuel for the needs of application of the external emergency plan.

A system has been established for liaison with the national emergency services and the inclusion of emergency operations in the National Emergency Plan [72].

Providing fire and emergency rescue activities on the site of Kozloduy NPP and the area of preventive measures is ensured with forces and resources of the Regional Service for fire safety and protection of the population - KNPP and the Regional Service for fire safety and protection of the population - Kozloduy. According to the National Emergency Plan the General Directorate for Fire Safety and Protection of Population of the Ministry of Internal Affairs established a reserve of forces and means for introducing them as necessary in the area of emergency and precautionary measures.

When introducing the National Emergency Plan the National Headquarters for control and coordination under the Council of Ministers chaired by Prime Minister of Bulgaria or Minister of Internal Affairs and the Supreme Council to the National Emergency Plan for protection against disaster and emergency convene. Under the National Headquarters for control and coordination Expert Council is formed with member experts from various ministries and departments, which defines and coordinates the actions for the supply of necessary raw materials and equipment.

At a distance of 80 km from the plant site the training base of Bulgaria and the training centre for lifeguards at General Directorate for fire safety and protection of the population is located. The centre is certified by NATO and the European Commission and has heavy engineering equipment, mobile laboratories, and crews for response for 24 hour duty service.

2.9.6 Potential deviations from the licensing base, actions and measures for their elimination

Kozloduy NPP meets the requirements, standards and rules on nuclear safety, radiation protection and physical protection when carrying out activities under the license.

No non-conformities with the licensing base for any of the nuclear installation were identified and the recommendations made result from conservative analyses with combination of the most adverse operational states and with the analysis of cliff edge effects.

2.10 ASSESSMENT OF SAFETY MARGINS AGAINST EARTHQUAKE

The margins reassessment should define the boundary capacity of the nuclear facility, i.e. to determine the values of the accelerations at which refusals of the SSCs will compromise the performance of safety functions and damage to the fuel will be inevitable.

2.10.1 Description of methods for margins assessment

The equipment which is important for safety and is involved in accident sequences was analyzed for seismic resistance defined as parameters of functions describing the conventional probability of its failure (fragility curves).

For the purposes of the safety margins reassessment review of the parameters of the functions of conventional probability for the destruction of individual SSCs obtained in [31] and [33] is conducted.

The curves of the conventional probability of failure of components (element of building structure, equipment or a separate element of the facility) is defined by its probability of failure at different values of the reference parameter of the seismic response. The purpose of the seismic vulnerability analysis is to determine the value of the peak ground acceleration where seismically induced efforts in the component under consideration located at a given point of the civil structure will exceed its capacity.

Assessment of this acceleration value is done using the data for the design stage and reassessment of the seismic analysis, taking into account the dynamic response of the components, the actual spatial dimensions of structures and properties of materials.

The analysis consists in the consistent review of all ranges of seismic effects, for each range safety related SSCs that fail being presented. Changes in the behaviour of nuclear facilities (the change in the accident sequences progress) and the change in safety functions performance shall be defined.

Consistent review of each range is used to determine the ability of nuclear facilities to withstand impacts of various degrees of severity. This systematic approach allows to achieve the main purpose of the reassessment of safety, namely to define the limiting values of the accelerations that the unit can withstand without a serious damage to the fuel and release of radioactive substances into the environment.

2.10.2 Evaluation of safety margins against earthquake for units 3 and 4

According to the result provided in [38] it follows that Units 3 and 4 margin is 0,16g or 80% of RLE (PGA=0,2g), i.e. the units can bear without fuel damage earthquake 1,8 times greater than the DBE reassessed and valid as for 30.06.2011.

2.10.2.1 Assessment of the seismic impact leading to severe fuel damage

Based on analysis [41] it can be concluded that the fuel damage cannot be prevented at PGA over 0,36g, i.e. at acceleration for which liquefaction of sands under fire protection station-2 and CPS-2 is anticipated.

Till this level of impact the unit performs reliable cooling of fuel in the FSP (or reactor). The upper part of the range $0,26<PGA\leq0,36$ partial depressurization of the fuel assemblies is possible due to falling of heavy object on the FSP.

2.10.2.2 Scenario with beyond design basis earthquake followed by beyond design basis flooding

According to the analysis [41][60] the only realistic scenario is destruction of water supply system "Iron Gate" 1 and 2 resulting from the earthquake. In this case, however, the effect of water level will be realized at a later phase of the accident process development (about 20 hours after the earthquake).

At loss of off-site power and failure to the DGs due to the earthquake, power supply to the loads connected to the uninterruptible power supply sections fails.

As stated in [41] for recovery of FSP heat removal, actions of the operating personnel are required for recovery of power supply to the FSP cooling pumps. According to the design, switchgear 0,4kV can be supply from the ASSGEM sections, i.e. from EDG of ASSGEM. Another possibility for recovery of FSP cooling pumps power supply is through MDG.

In all cases, for recovery of power supply of FSP cooling pumps access to switchgear 0,4kV is required. Therefore, if anticipated destructions of civil structures lead to restriction of this access, respective actions shall be taken to recover the access. Due to low energy release of the fuel and significant inventory of coolant in the FSP, it can be anticipated that there is significant time available to allow for adequately arranging and effectively implementing all the required measures for recovery of access to switchgear 0,4 kV. For more detail for the time available see item 5.3.1.2 of the report.

In the early phase of accident process, ASSGEM can be used for performance of any one of its functions. After the water level reaches Kozloduy NPP site, ASSGEM can be used only as an alternative source of supplying pool cooling pumps due to flooding of the basement of ASSGEM. The power supply from ASSGEM is guarantees for 72 hours as each EDG has at least 72 hours of fuel inventory [42].

As the ultimate heat sink from the heat exchanger for FSP cooling, at simultaneous loss of off-site power and emergency power supply from the diesel-generators in DGS-2, only the cooling water supplied from the diesel pumps to the fire pump station 2 will remain.

Obviously, the FSP decay heat removal function can be ensured at selection of a scenario for combination of the external events.

At this scenario the only significant consequence is associated with the seismic impact itself, i.e. with possible falling of covering elements in the FSP. As stated in [41], at mechanical damage of the fuel, release of fission products from the gas gap of the fuel elements can be anticipated. This activity will be released into the environment, as the Central hall does not have the status of a confined compartment.

It can be concluded that the degree of redundancy of FSP fuel cooling function was reduced to a greater extent than at independent effect of each external event included in the scenarios.

In the event that before the earthquake and flooding, the fuel is placed in the reactor according to the conditions of [43], [62] and [63], then due to the loss of the normal cooldown system and loss of ASSGEM pumps, heat removal can be provided only by fire trucks and SG flow rate can be ensured by opening of SG SVs.

Regardless of low energy release of the fuel, the effectiveness of application of such cooling logic should be analytically reviewed.

At the assessment of applicability of the cooling logic with fire trucks the following complicating circumstances shall be considered:

- the fire trucks owned by the Kozloduy NPP are situated opposite the entrance to units 5 and 6. This means that their access to points of connection will not be hampered by the water level. Building structures and facilities of the fire service are designed according to the national seismic standards. This means that they are guaranteed for seismic impacts with Кс=0.10, assuming non-linear deformities and partial damages. This means that at an earthquake within the range of 0,26 < PGA ≤ 0,36g, the buildings under fire will be severely damaged or destroyed, thus, hindering release of the vehicle from the garages. Therefore, there is a serious potential that the fire truck available in the fire service can be used to provide the SG heat removal function.
- it is possible to use fire trucks delivered from other locations not affected by the scenario only after 24 hours. This possibility shall be addressed in the emergency plan and seriously reassessed considering that at seismic impact of the studied range multiple seismically induced fires are likely to occur in the area in civil structures, and the fire services in the near regions are also likely to be seriously affected.

2.10.2.3 Measures to enhance robustness of Units 3 and 4

As SNF storage in the FSP of Units 3 and 4 is anticipated to be completed in 2012, there is no need in taking specific measures to enhance robustness of these NIs.

2.10.3 Evaluation of safety margins against earthquake for units 5 and 6

The margin of Units 5 and 6 according to [41] is 0,13 g or 65% as compared to RLE (PGA=0,2g, i.e. the units can bear without fuel damage earthquake by 1,65 times greater than RLE re-evaluated and valid as per 30.06.2011.

2.10.3.1 Assessment of the seismic impact leading to severe fuel damage

Based on the analysis performed in [41] it can be concluded that fuel damage cannot be prevented at PGA over 0.33-0.35 g, i.e. at the acceleration for which liquefaction of sands under the spray pools is anticipated.

2.10.3.2 Assessment of the seismic impact causing loss of Units 5 and 6 containment structure integrity

Reactor buildings of Units 5 and 6 are provided with tight protective shells protecting the reactor and primary circuit equipment against extreme external events and serving as the last barrier against spread of radioactive substances in the atmosphere.

Loss of containment integrity can occur at compromising of the protective shell, compromising of the locks or some of the penetrations.

The main results of conducting the analysis regarding the dynamic non-linear behaviour and seismic capacity of the protective containment structure of Units 5 and 6 can be systemized as follows:

- limited damages and cracking in the concrete without loss of confinement – at impacts with PGA=0,75g.;
- loss of confinement due to plastic deformities in the steel lining – impacts with PGA=1,7g.;

- destruction of the structure due to break of support beams and shear of reinforced concrete section – at impact with PGA=1,9g.

The most probable mechanism for loss confinement of the protective shell of units 5 and 6 is by means of shearing the shell in the connection between the expanded section at the base and standard section of the cylindrical part. Conservatively estimated value of the seismic acceleration of the free field is aмax = 1.9g (9,5xMP3).

2.10.3.3 Scenario with beyond design earthquake followed by beyond design flooding

The only realistic scenarios for combination of beyond design basis earthquake with flooding regards water supply system “Iron Gate” 1 and 2 resulting from the seismic impact in the natural water in Danube River with confidence p = 1% [60]. In these cases, however, the generated MWL i.e. water level is not relevant for development of accident process and the behaviour of the units are defined completely by the effects caused by the seismic impact, see [41].

For the purposes of reassessment of safety margins for Units 5 and 6 of Kozloduy NPP postulated combination of beyond design basis earthquake and beyond design basis flooding is considered with the earthquake range $0,2 < PGA \leq 0,32$ g and water level over +33,20 m.

According to the assumptions made at selection of the scenarios for combination of beyond design basis earthquake and beyond design basis flooding loss of emergency feedwater pumps is taken. It should be noted that this loss is defined completely by the effects of the water level and will occur at later stages of the accident development process.

As noted in all scenarios combination of beyond design basis earthquake with flooding leads to loss of ShPS due to flooding. With their loss there is also loss of emergency makeup to the spray pools of Units 5 and 6, i.e. the time to ensure ultimate heat sink shall be limited.

According to the results of [41], at an earthquake within the range of seismic impacts $0,2 < PGA \leq 0,32$g connection to the power supply network fails, i.e. the units go to the mode with loss of off-site power.

2.10.3.3.1 Description of accident sequences

2.10.3.3.1.1 Reactor. Cooldown process

As stated in [41], at this level of seismic impact loss of off-site power of NFs located in Kozloduy NPP site is anticipated.

As the result of the earthquake the reactor emergency protection will be actuated. Actuation of the emergency protection will take place at signal from industrial seismic protection system, in parallel signal for "Tripping of 3 out of 4 operating reactor coolant pump with reactor operation over 5%Nnom power" or "Reduction of frequency of 3 out of 4 sections powering reactor coolant pump, under 46 Hz" will be actuated.

It should be noted that as consequences from destruction of the turbine hall rupture of the pipeline connected to the SG can be anticipated, i.e. the unit will go into an accident situation with isolable break in the secondary circuit. Termination of the leak in the secondary circuit (that ensures termination of non-controlled cooldown of the primary circuit and prevention of potential for PTS process) required closing of all MSIVs. The seismic impacts of this range do not affect functionality of main steam isolation valve and the valves of its binding, due to which it can be accepted that SG isolation will be fully successful. Due to loss of I&C equipment may require the operating personnel to duplicate the action of the automation from MCR.

The loss of make-up and blowdown system (caused by the loss of auxiliary sections) predetermines termination of sealing water supply to the reactor coolant pump seals. As fro this range of the seismic impacts there is no loss of intermediate circuit system, then the primary circuit integrity does not fail.

Therefore, to cope with the accident process performance of the safety functions of the remaining available equipment is required.

For the overall performance of the function to ensure sub-criticality it is required that at least one the following systems: high pressure emergency boron injection system or medium pressure emergency core cooling system remain operable. The analysis in [41], demonstrates:

- medium pressure emergency core cooling system remains operable after the earthquake. For Unit 5, however, only two trains of the system are available due to failure of the first train of the essential components service water supply system;
- high pressure emergency boron injection system remains operable after the earthquake.

It follows from the above stated that performance of the function for both units can be ensured as due to remaining high level of redundancy.

Primary circuit heat removal function will be affected both by the earthquake and by the flooding as:

- Seismically induced failure of the SG makeup water system due to destruction of the turbine hall, some reduction of resources for performance of the functions before the emergency feedwater systems and SG alternative makeup system.
- Emergency feedwater pumps fail as the result of flooding of rooms with water supplied from adjacent rooms. This failure, however is anticipated at the accident progress much later phase in time.
- The steam generators alternative makeup system will not be affected by the earthquake and the water level, but movement of MDG may be hindered. The system can be used to for makeup of only one of the two units as the power supply source MDG is the only one at the site.

The SG alternative makeup system to ensure primary circuit heat removal only during time a little over 24 hours [87]. This time is fully sufficient for cooldown of one unit to cold state. In spite of this, it should be taken into account that the use of SG alternative makeup system depends on capability of MDG to move to the point of connection.

For other units (to which MDG is not connected) the heat removal function to the secondary circuit can be used after reaching of the water level to Kozloduy NPP site. In this case, to prevent from heating of the reactor installation and to recover the reactor core cooling, the operating personnel shall use instructions for effective recovery from SBEOPs package (see instructions ВФЗ-2.1 and ВФЗ-3.1.), [98] and [99].

In the most general case, the actions are limited to cooldown of the reactor installation to 150°C and lowering the primary circuit pressure to parameters at which it is possible to connect emergency normal cooldown, [98] and [99], i.e. to performance of feed-and-bleed procedure.

Obviously, when discussing scenario of combination of beyond design basis earthquake with beyond design basis flooding of major importance is the time for the water level reaching to Kozloduy NPP site and the time for flooding elevation - 4,20, i.e. the time from the earthquake to achieving the emergency feedwater pumps failure.

According to the analyse [86] it can be demonstrated that about 20 hours are available from the destruction of water supply systems “Iron Gate” 1 and 2 to the reaching of the water level to the kilometre of Kozloduy NPP site. Obviously, it can be anticipated that the loss of emergency feedwater pumps will be occur at the end of the reactor cooldown or after its completion (depending on the cooldown speed, selected by the operating personnel). Therefore, based on the analyses [31] it can be accepted that the water inventories in the SGs are sufficient for successful completion of cooldown and performance of actions in ВФЗ-2.1 and ВФЗ-3.1, [98] and [99].

Ensuring stable over time cooling of the reactor core for a period of 72 hours without external supply can be achieved when the unit is cooled to cold state and core cooling is provided through emergency and normal cooldown system and the heat from the emergency core cooling system heat-exchanger is removed from the essential components service water supply system to the ultimate heat sink – water in spray pools.

The water in the spray pools and operational inventories of diesel fuel of the site are sufficient to ensure safe condition of the reactor in cold state for 7 days without additional supplies.

The core cooling function by primary circuit will be affected by the combination of the external events, as follows:

- unit 5: performance of the function for the line of scheduled and maintenance cooldown will be limited to two trains of Unit 5 emergency and scheduled cooldown system. Due to flooding of ShPS, the inventories in the spray ponds ensure 60 hours' performance of the function at stage by stage switching of the available trains;
- unit 6: The function will be used according to the design bases, i.e. all the system trains will be available as they will not be affected by the earthquake. Due to the flooding of ShPS, inventories in the spray ponds guarantee 90 hours' performance of the function at stage by stage switching of the available trains.

Obviously, for Unit 5 of Kozloduy NPP appropriate solutions shall be found for filling of spray ponds and/or using inventories from water of the first train of the safety systems.

2.10.3.3.1.2 Reactor. Cold state

In this condition the heat is removed from the fuel by operation of emergency and normal cooldown system by the line for scheduled or maintenance cooldown. The ultimate heat sink is the spray pools.

When considering the scenario with combination of beyond design basis earthquake with beyond design basis flooding, the functionality of either operating systems (emergency and normal cooldown system or essential components service water supply system) does not depend on the water level, i.e. performance of the safety functions is fully determined by the earthquake impact.

Therefore, for this condition scenario with combination of beyond design basis earthquake with beyond design basis flooding is not considered as the earthquake effect has been defined under [41].

2.10.3.3.1.3 FSP

FSP fuel heat removal is provided by joint operation of the FSP cooldown system or essential components service water supply system.

When considering scenario with combination of beyond design basis earthquake with beyond design basis flooding, the functionality of either operating systems (FSP cooldown or essential components service water supply system) does not depend on the water level, i.e. here also performance of the safety functions is fully determined by the earthquake impact.

Therefore, for this condition scenario with combination of beyond design basis earthquake with beyond design basis flooding is not considered as the effect of the external events has been defined under [41].

2.10.3.4 Measures to enhance robustness of Units 5 and 6

After the completed analyses for units 5 and 6 of Kozloduy NPP it is recommended to perform study of capabilities for alternative residual heat removal after failure of essential components service water supply system. In this proposal consideration is given to possible use of ASSGEM system which is available in Kozloduy NPP site.

2.10.4 Evaluation of safety margins against earthquake for SFS

The SFS margin is at least 0,16g or 80% considering RLE (PGA=0.2 g), i.e. SFS can bear without fuel damage at an earthquake by 1,8 times greater than the RLE re-evaluated and valid as per 30.06.2011.

2.10.4.1 Assessment of the seismic impact leading to severe fuel damage.

Based on the analysis performed in [41] it can be concluded that with the restrictions placed in [42] SFS can perform the functions for safe storage of the spent fuel up to seismic impact in the range of 0.36 – 0.39 g, after which collapse of the main support structure occurs and the capability of the building for natural ventilation of the pool cooling fails. Extension of the time for safe storage of the fuel in this situation depends on the possibility for cleaning the construction debris and recovery, if possible, the natural ventilation.

2.10.4.2 Evaluation of the seismic with loss of SFS integrity

According to the approach applied in analysis [41] seismic accelerations at which it is accepted that the structure integrity fails and it cannot ensure natural air circulation required for the fuel damage were defined. The following values are obtained:

- destructive acceleration for columns by row D (190/50 cm) – 0.39 g;
- destructive acceleration for columns by row (60/50 cm) – 0.44 g.

Therefore, in the below part of the considered range of seismic acceleration destruction of the main support columns of SFS and falling of roof and the cranes over the pools cover can be anticipated. This may potentially lead to damage to the shells storing the fuel and to damage of the reinforced concrete structure of the pools coupled with significant leaks in the damaged sections.

2.10.4.3 Scenario with beyond design basis earthquake followed by the beyond design basis flooding

According to the results of [86], there are no SSCs that will be affected by the MWL. Therefore, for this nuclear installation scenario with combination of beyond design basis earthquake and beyond design basis flooding as the effect of external events is defined in the framework of [41].

2.10.4.4 Measures to enhance robustness of SFS

With regard to SFS measures to increase robustness are not proposed as its margin is fully dependent on the capacity of the civil structure.

2.10.5 Evaluation of safety margins against earthquake for DSFS

According to analysis performed [41], it follows that the relative units of DSFS margin are 0,11g or 55% of the design DBE that for the nuclear installation is 0,2g, i.e. DSFS can withstand without damage to the fuel an earthquake 1,55 greater than the design DBE.

2.10.5.1 Assessment of the seismic impact leading to severe fuel damage

Based on engineering evaluation given in [41] it can be summarized that DSFS can perform its functions for spent fuel safe storage to seismic accelerations of about 0,31 g, then collapse of the main support structure can be anticipated. Extension of safe storage of the fuel in this situation depends on the possibility of cleaning of the constriction debris and restoring, if possible, the natural ventilation.

2.10.5.2 Scenario with beyond design basis earthquake followed by beyond design basis flooding

According to the results of [86], no SSCs will be affected by MWL. Therefore, for this nuclear installation scenario with combination of beyond design basis earthquake with beyond design basis flooding is not considered as the effect of the external events has been defined under [41].

2.10.5.3 Measures to enhance DSFS robustness

With regard to DSFS measures to increase robustness are not proposed as its margin is fully dependent on the capacity of the civil structure.

2.11 CONCLUSION FOR EVALUATION OF THE INFLUENCE OF SEISMIC IMPACTS ON THE SITE OF KOZLODUY NPP

According to the review of the seismic characteristics of Kozloduy NPP site re-evaluated in 1992 (Project BUL 9/012 "Site and Seismic Safety of Kozloduy and Belene NPPs") and additional studies of 1995 (Studies for local earthquakes and probabilistic determination of seismic effects for seismic PSA) it can be concluded that the re-evaluated seismic bases at the site comply with current regulations.

The safety related equipment involved in the emergency scenarios, defined as parameters of functions describing its conventional probability of failure (fragility curves) is analyzed for seismic resistance. Limits of seismic accelerations that any nuclear facility can withstand without severe damage to the fuel and disposal of radioactive substances into the environment are defined.

It follows from the above findings that the analysis of beyond design basis seismic impact is sufficiently conservative and gives confidence that in seismic terms the SSCs of Kozloduy NPP are able to ensure the safety of the plant for real maximum seismic impacts probable for the site.

The presented below measures for improvement of plant robustness relate only to Kozloduy NPP units 5 & 6. In respect to SFSF and DSFS no robustness improvement measures have been proposed, as their margin is completely defined by the capacity of the building structure. As it is expected that storage of SF in SFP 3 & 4 will end by mid 2012, no specific measures to improve robustness have been proposed for those facilities.

- Provision of a mobile diesel generator for each unit;
- Research and investigation of the possibilities for alternatives for residual heat removal in case of loss of Essential Service Water System. This proposal relates to the possible use of ASGFWS (Additional SGs Emergency Feed Water System), which system is already available on the Kozloduy NPP site;
- Securing the availability of at least one tank of the SGs Emergency Feedwater System in shutdown mode in order to provide for the use of the SG as alternative for the residual heat removal;

As a result of the review of licensee (Kozloduy NPP) reassessment of safety margins of on-site facilities in case of an earthquake, the NRA considers that weaknesses and strengths have been correctly identified and that proposed measures for improvements of plant robustness in earthquakes are acceptable.

3. EXTERNAL FLOODING

REGULATORY REQUIREMENTS

SPECIFIC REQUIREMENTS of the Regulation on Ensuring the Safety of NPPs related to external flooding are the following:

Art. 29. *Engineering surveys and investigations of natural processes, phenomena and factors having potential impact on NPP safety shall be conducted for the region and the site for situating a NPP:*

2. within the NPP site boundaries, the following shall be identified:

f) the impact on NPP safety of the groundwater level uplift and flooding the site as a result of spreading of underground water uplift coming from dams, filtration of irrigated lands, water flows, precipitation, snow melting;

g) tornado intensity, the peak tangential values of the periphery speed and the speed of the tornado progressive motion; the pressure drop between the tornado periphery and the centre;

3. for a NPP site shall be defined the maximum water level and the duration of possible flooding due to rainfall, intensive snow melting, high water level in water basins, river blocking by ice, avalanche and slide; for the NPP site shall be evaluated the characteristics of possible maximum run off floods from watercourses with a frequency of 10-4 events per year combined with a high tides and waves caused by winds;

4. for a NPP site situated at a sea, lake or dam coast, the probability of occurrence and the maximum height of tsunami or seiches waves shall be evaluated considering the seismic tectonic conditions, the shore configuration, landslides and collapse in the water;

Art. 30. *(5) Characteristics of the impact on the NPP and respective probabilities shall be determined for events induced by:*

3. floods, including those resulting from failures of dams located upstream of the NPP site, or due to rainfall, avalanches and snow melting;

8. water level fluctuations in the NPP water supply source.

According to [131] that all nuclear power plants located on sites where flooding is possible shall withstand the design MWL. The most appropriate design solution is the elevation of the plant and the safety related components above the MWL.

3.1 DESIGN BASIS

3.1.1 Flooding against which the plant is designed

The sources of potential external flooding are maximum possible natural water levels of Danube River, destruction of the walls of water supply system “Iron Gate”, accident on “Shishmanov Val”, slope waters from location “Marishkin Dol”, waters from tributary valley “Marichin Valog” and durative heavy rains in the plant site.

3.1.2 Current reassessments of MWL

3.1.2.1 Characteristics of the MWL reassessed

In determining the maximum possible water level of Danube River both natural extreme water levels and water levels at the rupture of the two water supply systems "Iron Gate" 1 and 2 are considered. Separately, the impact of intense local rainfall, water retention due to ice drift and the formation of waves when water enters the valley is also considered.

Below options of potential flooding of the plant site, caused by potential rupture of the dam of lake "Shishmanov shaft", the slope water from "Marishkin Dol" or water from tributary valley “Marichini Valog” are also considered.

3.1.2.1.1 Definition of MWL due to increase of Danube River level

The design of the plant and three new studies relating to the determination and revaluation of the maximum water level (MWL), which can be reached at the plant site are discussed. For level 0,00 at the plant site elevation 35.00 of Baltic altitude system was adopted.

Initially, the maximum water levels of Danube River have been set in detailed design (Volume "Hydrology", 1972, and Volume "НОПТУ", May ,1975) at Kozloduy NPP water intake facilities at 687 km of:

Potential to reach	1%	0,1%	0,01%
Water level	29,93 m	30,87 m	31,73 m

The Updated Safety Analysis Report [4] confirmed maximum water levels in natural modes:

Potential to reach	1%	0,1%	0,01%
Water level	30,58 m	31,47 m	32,23 m

In a study of Energoproekt for “Reassessment of maximum flooding” Part I, December 1991, and Part II, March 1993, maximum water levels in case of postulated destruction of the water supply system "Iron Gate" 1 and 2 are set out. Considering overflow and destruction of dikes and accumulation of the high wave from flooded plains the maximum level is 31,43 m, with 0,80 m lower than the design 32,23 m.

In 2010 a survey was conducted in conjunction with the design of Belene NPP to determine the hydrologic and hydraulic characteristics of the Danube River [103]. According to the survey the maximum water level in the Kozloduy NPP in the course of catastrophic wave caused by the destruction of this water supply system "Iron Gate" is 32,53 m. This MWL is reached 28 hours and 20 minutes after the anticipated destruction of the water supply system "Iron Gates 1" and will last approximately 2 hours.

In all postulated cases involving extreme increase in the level of the Danube River the elevation of MWL at flooding is lower than elevation 0.00 of the site, which confirms the definition of the plant site “NON-FLOODING”.

3.1.2.1.2 Definition of MWL due to rupture of the dam of lake "Shishmanov Val"

The flooding of the plant site due to rupture of the dam of "Shishmanov shaft” has been studied. As a result of this study in the destruction of the wall with present water quantity of 2 885 600m^3 it can be calculated that the water level will not exceed elevation 25.50 and will not jeopardise the plant safety. In the theoretical assumption that the volume of the impoundment is limited to the maximum extent possible (8,1.106 m^3), actually effective volume is 6 990 000 m^3 (dead volume - 1 110 000m^3). In case of release of this quantity of water from the dam it is anticipated that the main damage from flooding will be caused rather to the town of Kozloduy. The flooding of the plain northwest of Kozloduy NPP assessed under an expert review will not exceed elevation of 29.00, i.e. this water level is not a direct danger to the plant with the elevation 35.00. The only possible variant is to disable shaft pumps stations in a short time.

3.1.2.1.3 Definition of MWL from tributary valley “Marichin Valog”

Another potential source of flooding of the plant site is the tributary valley “Marichin Valog”. It is preceded with a small tributary of the Danube River with non-constant water swelling. In the late 70-s, near the spray pools an erosive gully with a depth of 5m passed, which was subsequently corrected and filled. This action has eliminated the possibility of flooding of the plant site from this source.

3.1.2.1.4 Definition of MWL from slope water from location “Marishkin Dol”

To ensure smooth passing of high water quantities from the slope waters around "Marishkin Dol", the slope waters to the west of Kozloduy NPP site and water from irrigation channel M-1 (sized to have a throughput of 3,20m^3/s) at overflow or leakage of its siphons, a drainage channel was built to the west of the plant site with section 9.00m2. The construction of this channel ensured elimination of ravine generation and flooding hazard at Kozloduy NPP site from the aforementioned sources.

3.1.2.2 Methodology used for assessment of design basis flooding

As methodology for definition of the MWL the methodology of the study provided in report [103] is adopted. The report discusses tracing of the movement and the overlaying of catastrophic waves caused by destruction of dams in lower Danube. The most important is the first scenario considered, assuming sequential destruction of the existing water supply system “Iron Gates” 1 and 2. In this scenario, catastrophic wave is overlaid on the basic quantity Q_0 = 10 000 m^3/s. This destruction logic aims to obtain the maximum possible parameters of the wave resulting from overlaying of two waves. The resulting maximum water level in the Kozloduy NPP is 32,53 m. It would be reached 28 hours and 20 minutes after the assumed destruction of water supply system "Iron Gates 1" and will last approximately 2 hours. It is 30 cm higher than the design MWL under natural conditions, but is 2,47 m below the site elevation 0.00.

3.1.2.2.1 Influence of heavy rainfalls

The rain downstream Danube River over the Kozloduy NPP is involved in the statistical determination of natural MWL and should not be added to it again. Otherwise, however, there is a question in the calculations for the flow of catastrophic wave caused by destruction of water supply system "Iron Gates 1". The rain from the plane around Kozloduy NPP and the river bank can be involved in raising the water level around the site.

Precipitations with probability p = 0.01% and catastrophic wave from destruction on the walls of the "Iron Gates" are independent events and the likelihood of simultaneous occurrence is negligibly low and should not be overlapped. Assuming also precipitation probability 0.01%, the probability to occur simultaneously is 0.01 x 0.01 = 0.0001%. This probability is unacceptably small for nuclear power plants. Therefore, it is more realistic to assume an additional increase in water level due to rainfall with greater probability, e.g. approximately p = 1%. In this sense, at the expert level an additional increase of MWL by approximately 10 cm at the expense of rain could be accepted.

3.1.2.2.2 Water retention due to ice drift

In the section of river Danube located on the Bulgarian territory for more than 70 years there were only 5 seizures at a flow-rate of 4870 m^3/s to 11 910 m^3/s. The fact that the last one was in 1963 shows that after the construction of water supply system "Iron Gate" likelihood of the river freezing has decreased significantly.

The phenomena of catastrophic wave due to an accident at the "Iron Gate" 1 and 2 and ice phenomena are unlikely and should not be combined, moreover that at catastrophic high waters with quantity over 20 000 m^3/s ice jam is not possible. It is possible at low to medium water (about 25,00), such as in winter. For these reasons, raising the water level and flooding of Kozloduy NPP of water retention due to ice drift is not applicable.

3.1.2.2.3 Waving

Simultaneously with high waves and rainfall strong waving is compatible. It will be due to uneven terrain, high irregularities of speeds and strong winds. Assuming at an expert level the wave height 0,60 m the excess can be estimated at 0,30 m (half the height of the waving).

3.1.3 Conclusion with regard to consistency of the protection against external flooding

It follows from the foregoing that during the operation of Kozloduy NPP a number of studies were performed to reassess the maximum water level. The results do not differ significantly. Between the design value of this account, was significantly Between the design value of the natural water level at 0,01% confidence of 32,23 and the last survey of 2010 at flow of catastrophic wave the difference is 30cm. The precondition for a sudden complete destruction of the wall of water supply system "Iron Gate 1" is increased as potential destruction of the wall can not be complete and sudden. It will be gradual and will start from one part of the composite wall. The wave of destruction will occur gradually and will be with a smaller peak.

Recent studies conducted in 2010 for the destruction of water supply system Iron Gates 1 and 2 at baseline water quantity 10 000 m^3/s and destruction of Nikopol - Turnu Magurele system (if built) show water level 34,51 m. Even under these conditions Kozloduy NPP is not flooded.

Finally, the following conclusions can be drawn:

- the Kozloduy NPP design MWL reflects all influencing factors, and this is confirmed by tests performed later;
- at overlapping of low probability events the following limiting values of MWL could be defined - 32,53 + 0,1 + 0,30 = 32,93 m

MWL for Kozloduy NPP site is defined at 32,93m at current condition of hydro-technical structures by Danube River. The scenario involving occurrence of this water level is sudden and sequential break of water supply systems “Iron gates” 1 and 2 with overlapping of the two waves and water quantity 10000 m3/s. Additional supplements are taken for local rainfall and waving.

The following analyses of the plant safety are performed for MWL = 32,93m.

The natural water levels in the detailed design of Kozloduy NPP are obtained empirically with the observation data in their basis has confidence greater than 1%. At the next stage levels and flows with confidence 0.5%, 0.1% and 0.01% were obtained by extrapolation. The study of the maximum water levels at these low probabilities is accompanied by overflow of protection dikes. Overflow of the dikes is likely to start higher along Danube River, in Timok, Vidin, Orsoya and Tsibar. The same will be with the Romanian dikes, as well as according to the studies from 2010 [103]. Dependencies of water levels in the likelihood, where the level exceeds the elevation of the dike (32,00 m for Kozloduy NPP) will differ from the water levels with larger probabilities and lower levels, namely due to overflow of protection dikes which radically alter the area flooded. For the natural waters in Danube River with probabilities 10-5 to 10-7 water levels anticipated are as follows:

Potential to reach	10^{-5}	10^{-6}	10^{-7}
Water level	32,40 m	32,60 m	32,70 m

Based on the water levels in natural state of Danube River defined this way the combination of two events - natural extreme water levels at small probabilities (10-5 to 10-7) and rupture of water supply system "Iron Gate" 1 and 2 can also be assessed. It should be noted that combining the two scenarios will lead to an event with a very low probability of occurrence. The water levels anticipated are as follows:

Potential to reach	10^{-5}	10^{-6}	10^{-7}
Water level	32,98 m	33,26 m	33,42 m

These results also confirm the accepted assumption that Kozloduy NPP is **"NON FLOODING".**

3.2 ENSURING THE PLANT PROTECTION AGAINST MWL

3.2.1 SSCs required for bringing and maintaining of the units in safe shutdown state most threatened at MWL

3.2.1.1 Units 3 and 4s of Kozloduy NPP

3.2.1.1.1 Major SSCs

The list of SSCs of safety systems and safety related systems includes equipment failure to which may lead to failure to perform the following fundamental safety functions:

- Residual heat removal from the spent fuel pool during and after an accident;
- Limiting radioactive releases into the environment.

According to the current license for operation of Units 3 and 4 in state "E" spent nuclear fuel is stored in the near reactor pool. In accident states related to non-replenishable leakage from the spent fuel pool, according to the applicable documents [55][56], the fuel can be moved to reactor to ensure its reliable cooling with available systems in the secondary circuit. At definition of systems critical for ensuring safety this requires considering both possible locations for spent fuel storage.

3.2.1.1.2 Protective measures to maintain cooling water supply

The spent fuel pool cooling system is a two-train system with: pool cooling pumps, heat exchangers, service water and electric power supply. At MWL loss of spent fuel pool cooling system is not anticipated.

Essential component service water system is the main source of cooling water. The pool cooling heat exchangers are always connected for service water. The nominal temperature of the water in the pool is maintained by starting and tripping of the pool cooldown pumps. Cooling water removal at all cooling logics will be by normal drain headers.

For redundancy of spent fuel cooling in the spent fuel pool to the pressure collectors for essential components service water two independent headers are mounted for additional cooling water from fire protection system-2.

At inoperable cooldown system, the cooldown is provided by other methods (filling and draining) or by maintaining FSP temperature below 65 ^{0}C through non-design cooling logics (following procedures developed).

3.2.1.1.3 Protective measures to maintain emergency power supply

At MWL loss of emergency power supply sources located in Diesel-generator station – 2 is not anticipated.

It should be noted that backup power supply of the pumps for the pools cooling is provided from ASSGEM sections. Thus, at loss of off-site power pumps power supply is ensured both from system diesel-generators and from emergency diesel-generators of ASSGEM.

In accordance with 4.2.1.1. of [42], the operational (inviolable) fuel inventory in Diesel-generator station – 2 is totally 136,2 m3 (22,7 m3 per one diesel-generator) which according to item 4.2.1.2 of [42] ensures continuous operation of each of the diesel-generators for at least 7 days.

In accordance with item 4.2.1.5 of [42], the operational oil inventory is 2,7 m3, stored in oil tank of each cell in Diesel-generator station - 2 or total of 16,2 m3. This oil inventory according to item 4.2.1.6. of [42] ensures operation of the 6 diesel-generators in Diesel-generator station - 2 for at least 10 days. Considering also the non-operational inventory additional operation of all Diesel-generators for at least 7 days can be provided for fuel, in accordance with item 4.2.1.4 and 20 days for oil in accordance with item 4.2.1.7 of [42].

3.2.1.2 Units 5 and 6s of Kozloduy NPP

3.2.1.2.1 Major SSCs

The list of SSCs of safety systems and safety related systems includes equipment failure to which may lead to deterioration of or failure to perform the following functions:

- Reactor safe shutdown and maintaining in safe critical condition during and after accident;
- Core decay heat removal after reactor shutdown during and after accident;
- FSP decay heat removal during and after accident;
- Limiting radioactive releases into the environment.

Based on Level 1 PSA results [33] major SSCs for individual systems have been defined.

3.2.1.2.2 Protective measures to maintain cooling water supply

The design of conventional components service water supply system does not provide for specific measures for maintaining of cooling water supply besides those provided for performance of the system function. The cooling water is provided from pumps taking water from the advance chamber of cold channel. The system is not a part of the safety system and belongs to normal operation systems.

The essential components service water supply system is a part of the safety system. The design incorporates all principles of building safety system: redundancy, physical separation and independence of the trains. The system trains operate by a closed circuit with cooling of water in spray pools. Each train includes per two spray pools. Each of them is designed to remove the entire quantity of heat generated in unit accident mode and to ensure essential components service water inlet temperature within the range of +4°C +33°C.

With this dimensions of the spray pool, the level change by 1.5 m ensures operation of essential component service water without pools filling at wind speed up to 2 m/s for 30 hours. Spray pools operating and emergency makeup with water is ensured.

The operating makeup is ensured from 4 electric pumps for service water supply and in case of loss of off-site power from 4 diesel pumps. These are located in Circulation pump station 3 and 4, while each station has per 2 electric and 2 diesel pumps.

The emergency makeup of the spray pools is provided from 6 artesian wells in Danube River lowland.

At loss of all options for spray pools makeup with water the reactor fuel cooling can be ensured by using alternative system for the steam generators makeup, and the spent fuel pools fuel – by the system for their filling.

3.2.1.2.3 Protective measures for maintaining of emergency power supply

The AC emergency power supply sources for Units 5 and 6 are emergency diesel-generators, additional diesel-generators and mobile diesel-generator.

As the additional diesel-generators are located above elevation 0,00 at the site and the normal operation sections powered from them are located at elevation 3.60, they are not potentially threatened due to MWL.

Units 5 and 6 safety systems equipment power supply is provided from emergency diesel-generators (3 per each unit). The sections powered from them are located at elevation 20,40, they are not potentially threatened due to MWL.

Potential threat from flooding exists for cable channels between DGS and reactor building located at elevation 31 m.

The plant diesel-generators equipment layout suggests that at potential flooding of the rooms in diesel-generator stations the main auxiliary facilities will be affected, such as transferring fuel pumps of the diesel-generators. In this situation the diesel-generator can operate till the fuel depletion in gravitation tank (for about 7 hours at full power), and during this time options to fill this inventory with tank trucks shall be found. Obviously, the water entering the diesel generator station premises does not involve direct and immediate failure of emergency diesel generators.

In accordance with [42], the fuel and oil inventories for continuous mode of operation of the emergency power supply sources of the II category ensure:

- Emergency diesel-generators: in accordance with 4.3.1.1. of [42], the operational (inviolable) fuel inventory in diesel-generator stations-5,6 is totally 672 m3 (112 m3 per each diesel-generator), that according to item 4.3.1.2 of [42] ensure continuous operation of each of the diesel-generators for 3 days;
- Additional diesel-generator: 70 hours' operation ensured;
- Diesel pumps in circulation pump station - 3,4: 24 hours' operation of all pumps (8 per 2 fire and two for service water supply) simultaneously;
- Diesel-generator "Emergency preparedness": 8 hours' continuous operation at nominal load without charging.

In the oil stocks at the site of Units 5 and 6 emergency inventory (in two tanks with capacity per 2000 m3) ensuring additional operation of all simultaneously during 7 days is stored. The oil inventories (operational and backup) are sufficient for the diesel-generators operation during 20 days, according to item 4.3.1.5 of [42].

The mobile diesel-generator is designed to ensure power supply of alternative pumps for steam generators makeup water pumps. The mobile diesel-generator can power only one out of two pumps (that of unit 5 of unit 6). The fuel tank has capacity of 3,5 m3. The maximum flow-rate of the fuel is about 320 l/h. With this flow-rate the inventory in the tank located on the platform is sufficient for about 11 hours' continuous operation.

DC power supply systems of safety systems (I, II and III trains) are located at elevation 20,40 and are not affected by MWL. According to the data from technical tests, the batteries last over 10 hours with real load without degradation.

3.2.1.3 SFS

3.2.1.3.1 Major SSCs

In definition of critical SSCs documents [23],[104], and from [106] belowto [110] inclusively were considered.

The system for filling, makeup, transfusion and emptying of the fuel storage pools is determined as critical SSCs due to the requirements of item 5.5.2 of [23]. The ventilation systems are determined as critical SSCs due to the requirements of item 5.8.1 of [23] and [110]. The power supply system is determined as significant SSCs due to the requirements for the ventilation systems as well as due to item 5.9.2 of [23].

3.2.1.3.2 Protective measures for maintaining cooling water supply

According to the defined SSCs the spent fuel compartments cooling system is not of interest for safety margins reassessment as according to [23], it may remain inoperable for up to four days, besides item 6.5.1.2 [22] stated that normally fuel storage pool cooling system operation is required for one week per month.

3.2.1.3.3 Protective measures for maintaining emergency power supply

For power supply or category 1 and 2 equipment a complete two-transformer substation with dry transformers with capacity of 630 kVA and two-section switchgear with redundancy between the sections is provided. The substation power supply is by two independent cable lines from 6 kV sections of units 3 and 4.

3.2.1.4 DSFS

3.2.1.4.1 Major SSCs

In accordance with [30], the following SSCs are required to preserve their functions during and after potential flooding of the site:

- Facility and site rain water removal system – to remove excessive surface water from DSFS and DSFS site.
- Containers CONSTOR® 440/84 for VVER 440 fuel storage.

In accordance with [30], spent fuel storage hall is almost a continuous shielding structure preventing from significant water access. All vulnerable positions of this structure, such as shielding doors and emergency exits, can be quickly sealed.

Containers CONSTOR® 440/84 are hermetically sealed. The containers are designed with thick walls (480 and 500 mm) so that to ensure lack of neutron interaction between the fuel in the container and surrounding containers. Therefore, flooding of the containers cannot affect criticality of the fuel containers. The containers provide a double airtight barrier against water access into the radioactive material inside and outside surfaces of the containers are free from contamination (within the permissible limits) so that flooding does not cause liquid discharges of radioactive material into the environment.

3.2.1.4.2 Protective measures for maintaining ultimate heat sink

The containers in DSFS are cooled by natural air convection at atmospheric pressure. This predetermines impossibility for occurrence of loss of containers cooling.

3.2.1.4.3 Protective measures for maintaining emergency power supply

Application of passive principle for DSFS containers cooling predetermines the independence of performance of safety functions on the power supply sources.

3.2.2 The main design provisions for prevention of flooding impact on the plant

3.2.2.1 Site selection

Kozloduy NPP site is located in the second Danube terrace. Elevation of the terrain to the river bank is about 26,0 ÷ 26,5 m, in the valley - about 25,0 ÷ 26,0 m, and the terrace of the site - an absolute elevation of +35.0 m. On the North the plant site borders the Danubian Plain. On the south of the site, the slope of the watershed plateau is relatively high (100 ÷ 110 m), on the west it is about 90 m, while on the east it is lower and decreases to 30 m above sea level. The whole valley is the embankment dike with elevations 31.80 ÷ 33,00.

3.2.2.2 Lowland drain system

Due to the persistently high level of groundwater over a large area in the lowlands near Kozloduy NPP drainage systems are constructed which include also waters descending the northern slopes of gullies plateaus. Drain systems include 3 types of channels: drainage, collection and main.

Water from the main channels is transferred to the pumping station in dikes in Danube River. For Kozloduy NPP site, these drain systems are particularly important as domestic wastewater and rainwater is discharged into the main collecting channels of the systems.

Main drain channel passes through the cold channel and ends up with a protective dike with advance chamber and drain pump station. This pump station operates all year round and especially during the rising of water levels in Danube river above the elevation of 23.00 m. It maintains low water level below ground at the depth of 2 ÷ 3 m due to agro-technical considerations, for the growth of crops and plants, and thus provides draining of all filtration waters from the channels.

3.2.2.3 Site sewage system

Kozloduy NPP sewage system is designed to collect domestic and rain waters from Kozloduy NPP and take the waters to drain channel No. 1 of Kozloduy drainage system. Part of the industrial wastewater of Kozloduy NPP is also discharged into this network.

Rain water sewage for the entire area is discharged directly into drain channel No. 1 and therefore the access of water into it to elevation 32.93 is not hindered.

Domestic sewage water from the site of units 1 to 4 is discharged without purification in Drain channel No. 1 through a channel of trapezoidal cross-section. For industrial waste waters local treatment facilities are built. The domestic sewage waters from the site of units 5 and 6 are cleaned, and then discharged into Drain channel No. 1 through pipeline ∅300.

In domestic sewage of Power Generation 2 the water through the second treatment plant before discharge into drain channel No. 1. The presence of the treatment plant, however, does not solve the problem of penetration of water in domestic sewage system.

3.2.3 Main operational measures for protection against external flooding

3.2.3.1 Control and monitoring of Danube river water level

3.2.3.1.1 Visual inspection

For Danube River water level monitoring and control level measuring rack is mounted in the advance chamber of bank pump station, km 687. The rack shows the absolute elevation of Danube river water level by Baltic height system.

3.2.3.1.2 Water level monitoring automated system

Announcement of flooding of River Danube and accident on hydro-technical facilities at Kozloduy NPP can be indicated by the indications of automated system for the following hydraulic state in dual channel "AQUA". The system performs automated monitoring of water levels and water quantities in the dual channel, water levels in Danube River and water temperature in hot channel, end of hot channel and beginning of cold channel.

3.2.3.1.3 Interaction with the Agency for exploration and maintaining of Danube River

Another source for Danube River level monitoring are the daily reports received electronically from the Agency for exploration and maintenance of the Danube River in the town of Ruse.

3.2.3.1.4 Underground waters monitoring

Kozloduy NPP site region underground water level monitoring is performed the so-called piezometers specially built for tube wells. All piezometers are benchmarked and related with Kozloduy NPP coordinate system.

Through monthly monitoring of the location of piezometric line indirect monitoring of condition of the lining and the joints of dual channel, spray pools, underground water lines is also performed.

3.2.3.2 Emergency procedures

The actions at flooding or accidents caused by flooding are specified in the following documents of Kozloduy NPP:

- Emergency plan of Kozloduy NPP, [25];
- Emergency action plan for accident situations by the existing XTC for Kozloduy NPP service water supply, [124];
- Instruction for operation, monitoring and control of XTC buildings for Kozloduy NPP service water supply, [128];
- Instruction for starting of annunciations process by Kozloduy NPP alarm system, [129];
- Action plan of “Auto-transport” department at emergency situation in Kozloduy NPP, [130];
- Plan for medical support at accident in Kozloduy NPP;
- External emergency plant of Kozloduy NPP [72].

3.2.4 Potential impact from outside the plant, including prevention or blocking of personnel and equipment access to the site

3.2.4.1 Potential impacts on the adjacent facilities in the lowland at MWL

The lowland is divided from the hydro-technical channels of Kozloduy NPP into three zones. The most western zone is limited to the east from hot channel-2, to the south from Kozloduy NPP and to the west reaches and enters the town of Kozloduy. The medium zone is limited from hot channel-2, Kozloduy NPP and the dual channel. The eastern zone is limited from the dual channel and the bed of Ogosta River. Below the flooding of the lowland situated between Kozloduy NPP site and Danube River is considered separately for the three different zones in order to demonstrate indirect impact of such flooding that may influence on the plant operation.

3.2.4.1.1 Potential impacts at flooding of the lowland at break of the dike in the area between hot channel-2 and BPS

At break of the national dike first shaft pump stations located in the immediate vicinity of the national dike will be flooded and hindered as sources of supplemental water for spray pools of Units 5 and 6. Access to the bank pump station by land is most likely to be lost. This will happen during the first hours following the break of the state dike because the drain channels and roads to the bank pump station are at lower elevation and will be quickly flooded. At flooding of the lowland and filling to elevation 32.00 meters also destruction of part of the columns of power lines on the way of the tidal wave can be anticipated.

The emergency pipelines of the emergency pump station of bank pump station to the emergency capacity are steel and placed in the pit, but when crossing the drain channels are open and bridging them. These open areas are vulnerable and can be damaged by tidal wave.

In the valley formed by the hot channel-2, cold channel-1 and the Danube embankment all the sewage from the site of Units 1 to 4 and from the reactor building, diesel generator stations and the Turbine Hall of the site of Units 5 and 6 are drained. The rest of the sewage of the site of Units 5 and 6 will also retain water because water will pass over the siphons of low pressure channels and under hot channel-2 in outfalls for sewage and rain water. This can create conditions of water return by sewage collectors for domestic and rain water sewers, passing by spray pools and filling to the elevation of plain flooding. It is possible for sewage pits the site to be filled with water to el. 32,93 m. The availability of treatment plant for domestic waters for the site of Units 5 and 6 does not prevent the entry of water in domestic sewage system as it is possible that water passes through shaft 537, which serves as an overflow at excess capacity of the treatment plant.

In the town of Kozloduy the vicinity of the mill and a part of Lom highway will be flooded. The access from the town of Kozloduy to the site will be possible in the ring highway and pass point Kharlets. To the west the water will reach the town part to the north of hotel "Istar", will flood the buildings of ECR, the treatment plant, settlements.

3.2.4.1.2 Potential impacts at flooding of the lowland at break of the dike in the area between the town of Kozloduy and hot channel-2

At flooding of the valley of this area the end result will be almost the same as described in item 3.2.4.1.1. The difference will be that only part of the columns will take the initial impact of the tidal wave as the others are protected by hot channel-2.

3.2.4.1.3 Potential impacts at flooding of the valley at break of the dike in the zone between BPS and Ogosta River

In flooding of the valley from this area power lines Harlets, Neutron and Danube will be affected the most. In the area there are no other facilities related to the operation of Kozloduy NPP besides the open stores. Under certain conditions the formation of the initial tidal wave the dike of warm-channel-1 may be eroded and destroyed. Ingress of water to the area of the valley between the dual channel and hot channel-2 can only occur in reinforced concrete pipes passing under dual channel.

3.2.4.2 Loss of off-site power

Flooding of the valley and filling to elevation 32.93 can be accompanied by the destruction of part of the columns of power lines connecting Kozloduy NPP and bank pump station with electric energy system of the Republic of Bulgaria (EES) in the path of tidal wave .

Since these columns are constructed with a height commensurate with the level of the terrain, the distance between power lines and water surface in some areas will be 5 - 5.5 m lower than it was before the flooding between the same power lines and the ground. This significant reduction in the distance may lead to short circuits resulted in, respectively, failure of operation also of those power lines whose columns are not destroyed by tidal waves. With all this, even if the very site of the outdoor switchyard (OSY) is not affected by the flooding it is possible that the plant will be temporarily left without off-site power due to the loss of part of the connections with the EES of the Republic of Bulgaria.

At common cause de-energizing of bank pump station, through diesel-generators located in the diesel-generator stations emergency power supply for the emergency pumps supplying water to the advance chamber (emergency volume) of the circulation pump stations and one bank pump can be provided.

3.2.4.3 Loss of cooling water

According to [86], the valley flooding will not lead to loss of cooling water.

At overflow or rupture of the dike and flooding to elevation 32.93, hot channel-2 will be filled with water to the elevation of the river as regardless whether operating or not, its facilities for discharge into the river are not equipped with closed facilities. The same refers to hot channel-1.

According to the design of Units 3 and 4 of Kozloduy NPP loss of bank pump station does not affect the functioning of essential components service water pumps, as the service water drain from heat exchangers can be supplied to the hot channel or to spray pools. Water from the spray pools in the spillways returns back into the cold channel, and hence in the advance chamber of circulation pump stations. The purpose of the advance chamber is to provide an adequate supply of water at blackout of Units 1 to 4. At such accident according to the design in Circulation pump station-1 advance chamber after "curve8" water inventory of 21380 m^3 will remain, and in advance chamber of Circulation pump station-2 it will be 15000 m^3.

Flooding of valley and its filling to elevation 32.93 will lead to loss of function of the bank pump station in the valley, at which loss of emergency makeup of spray pools of Units 5 and 6 will occur. Normal makeup (from Circulation pump station 3 and 4) of spray pools will be retained. The advance chamber of Circulation Pump Station 3 and 4 ensures the necessary water supplies.

3.2.4.4 Possibility of intervention of support and external services to support the plant operation

From what was said above, it follows that the postulated flooding of the area around the plant with MWL has no impact on road infrastructure within its area, as well as of the road access to it. In this situation one can rely on full support from the outside, including access of machines, supply of equipment and materials on the site. There is neither restrictions in personnel access, nor time delayed in access of these personnel to the plant.

For performance of fire fighting and rescue activities in the area of Kozloduy NPP continuous day and night shifts with personnel and equipment from Regional Authority for Fire Safety and Personnel Protection -Kozloduy NPP is provided. Regional Fire Service is located immediately on Kozloduy NPP site. For fire fighting, participation in mitigation of disasters, accidents headquarters for management of fire fighting and rescue activities is formed. In case of occurrence of fire or loss of makeup water for automatic fire fighting system the necessary personnel and equipment can be immediately provided from the fire service to ensure normal operation of the plant.

3.3 PLANT COMPLIANCE WITH THE CURRENT LICENSING CONDITIONS

The overall process for ensuring the SSCs required for safe maintaining of the units in shutdown, ensuring the availability and preparedness of external equipment and supplies provided in emergency plans after the flood does not differ from the one those described in paragraph 2.10 of this report.

3.4 EVALUATION OF SAFETY MARGINS AGAINST EXTERNAL FLOODINGS

3.4.1 Definition of safety margins against external flooding

3.4.1.1 Description of the approach

Based on the inspections carried out in the plant area the assumption that flooding of Kozloduy NPP separate facilities is possible due to weaknesses in the sewerage network was confirmed – it is possible that water returns in sewer collectors for domestic and rainwater sewers and fills the spaces to the elevation of the plain flooding. Thus, in all buildings where the lowest elevation of rainwater or domestic sewer is below 32.93 water penetration from outside becomes possible. Physical flooding of the given room depends on the presence of drains, manholes or damages below elevation 32,93 m.

The assessment of the plant margins at external flooding is based on individual margins of all buildings and facilities directly related to the safety of the plant. The margin of a building is determined by the lowest location where flooding of a room in the building can theoretically occur as compared to the assumed MWL of flooding of the plant. The nuclear facilities margins are determined on the basis of SSCs required to bring the nuclear facilities in a safe condition.

For the purposes of safety margins re-evaluation cases where critical equipment is located below the elevation of MWL - 32,93 m for a building or facility are considered. If the equipment is located above this elevation it is assumed that any flooding of this area will not negatively affect the normal operation of equipment.

Based on the evaluated margins for each building and facility results for the following are defined:

- flooded equipment (not functioning);
- equipment critically close to flooding (functioning);
- not flooded equipment (functioning).

The flooded equipment is considered to be the equipment for which it was found that the location of flooding (i.e., the penetration of water) in the building/premises and equipment is below the elevation of MWL (32,93 m). With the rooms where flooding location is above this elevation the equipment is not considered to be flooded, even if it is located below MWL elevation.

Equipment critically close to flooding is considered to be that for which it is found that the flooding location is up to 50 cm above the MWL elevation and the equipment is below that elevation. This scenario includes the rooms with water entry level between 32,93 and 33,43m. The selection of the water level height 50 cm higher than the MWL is related to low probabilities of occurrence of high water in Danube River in combination of catastrophic wave – anticipated in item 3.1.3. The difference between the MWL (32,93) adopted in this study and the water level at $\mathbf{p = 10^{-7}}$ and catastrophic wave (33,42) is 49cm. For convenience in future studies value of 50cm can be adopted.

As a result of evaluating the design basis of the plant it can be concluded that at occurrence of external flooding with overflow or destruction of the protective dike of Danube River the facilities located in the valley between hot channel-2 and dual channel will be affected directly, and those of the site - indirectly through the sewage system.

At the tidal wave incursion of the valley an expert assessment showed that it would move at a speed exceeding 5 m/s. It should be noted that since the break in the cold dike to the flooding of the valley with water the process will have the nature of attenuation to full equalization of water levels.

Below in the sequence of flooding directly (in the valley) the flooded facilities are presented, and indirectly the flooded (on-site) buildings affecting the safety of the plant are provided only for those areas where there is danger of flooding.

3.4.1.2 Facilities of Kozloduy NPP site directly affected by MWL

<u>3.4.1.2.1 Shaft pump stations</u>

At overflow and break of the state dike the shaft pump stations will be flooded first. They are located next to the heel of the dike and the approximate height is 25 - 26m. With their failure loss of the emergency makeup to the spray pools of Units 5 and 6 also occurs.

<u>3.4.1.2.2 Power lines</u>

As presented in item 3.2.4.2 the flooding of the lowland and its filling to elevation 32.93 will probably be accompanied by the destruction of part of the columns of power lines connecting the Kozloduy NPP with the EES, on the way of the tidal wave. Therefore, for the purpose of safety margins reassessment it can be conservatively assumed that a part of the power lines situated in the valley between hot channel-2 and dual channel fail at penetration of water from Danube River.

<u>3.4.1.2.3 BPS and channels</u>

Elevation 0,00 of the bank pump station site corresponds to the absolute elevation 33,00. It is considered not flooded at MWL – 32,93. At elevation 32,93, however, the pumps by their factory characteristics do not function.

At berms crown elevation 33.00 of hot and cold channels and level of water in them 32.93, in practice there will be a total water mirror. Although the dikes are not resized to this level, at commissioning they were tested overflow over an average dike, which has an average elevation of 32.80. Under these conditions, the hot channel will be with the elevation of the Danube River and will be connected to the cold channel through spillway of the average dike between the bridge "Valya" and bridge "Heavy loads" - at elevation 32.80.

Another potential problem is that if the dry slope of the channel remains under cold water, there is a potential of slope sliding if this condition is prolonged.

3.4.1.3 Buildings and facilities of Kozloduy NPP site the flooding of which occurs in sewage system

The description of the sewage network is provided in [86]. Water penetration into the buildings of Kozloduy NPP site at external flooding can occur both by rainwater and domestic sewage. Examination of wells confirmed the expressed thesis that despite the availability of treatment plant for domestic sewage at the site of Units 5 and 6 water return to in shaft 542 to elevation 32,93 m is possible.

All cable channels and process tunnels drained into rainwater sewage and those whose bottom is lower than 32.93 will be flooded. Corresponding penetrations at entry in the buildings, if they are not tight, should be considered as a source of flooding.

3.4.1.3.1 Units 3 and 4 of Kozloduy NPP

Description of safety related SSCs of units 3 and 4 are provided in [86]. The sewage system for production wastewater (returning back) of Units 3 and 4, before discharge into drain channel-1 passes through the local treatment facilities the level of which is significantly higher than the elevation of flooding, and the pipes are placed in watertight protective channels. Accordingly, there is no risk of flooding safety related SSCs through them. The domestic and rain waters are discharged directly into drain channel-1 without treatment and the possibility of reaching the water to the buildings is precisely through them.

For the purposes of safety margins reassessment a review was performed on two buildings of additional system for steam generator emergency makeup. The review is aimed at determining the risk of flooding in sewage network. Level 0,00 of additional system for steam generator emergency makeup is established as 35.60. During the review it was confirmed that two buildings of additional system for steam generator emergency makeup have siphon at elevation -4,50 = 31,10 m which is discharged into shaft 1591 of Unit 3 and shaft 1766 of unit 4.

The availability of these siphons determined the ability of returning of rainwater sewage and as a result, two buildings of additional system for steam generator emergency makeup can be flooded if the water elevation exceeds 31.10. The difference between the critical height of the flooding and MWL is -1,83 m, i.e. these buildings are likely to be flooded first through rainwater sewage. Obviously, the buildings of additional system for steam generator emergency makeup have margin of external flooding at MWL.

In accordance with [86], only the pumps of additional system for steam generator emergency makeup will be affected by flooding of the building because they are located at elevation -3.00 m, which determines that it will be flooded with water level above 32.50 m. The loss of these pumps (1 ÷ 4 CEFWS PUMPS) is relevant only if spent fuel is in the reactor as they are part of an alternative logic of the primary circuit cooling through the secondary circuit at loss of the design cooling system. ASSGEM pump system (1 ÷ 4 CEFWS PUMPS) is not related to cooling of spent nuclear fuel when it is in the FSP.

Emergency diesel generators of additional system for steam generator emergency makeup remain available with their section for power supply of different systems, including pumps for spent fuel storage pool cooldown.

Obviously, it follows from the flooding of building additional system for steam generator emergency makeup that there will be loss of the only alternative for cooling of the spent fuel by water-water cooling of the reactor by the steam generators for cases where the fuel is placed in the reactor under conditions of [43], [62], [63] (use of emergency cooling logic at failure of the standard logic - using normal cooldown with ultimate heat sink for essential components service water supply).

Since MWL does not affect the operation of standard logics for safety functions assurance, it can be assumed that the effect of flooding of the building of additional system for steam generator emergency makeup is expressed only in reduction of the number of systems capable of performing the same safety function.

3.4.1.3.2 Units 5 and 6 of Kozloduy NPP

3.4.1.3.2.1 Rooms with drain pumps near the first and second staircase at reactor building clean zone of units 5 and 6

In the reactor building of Units 5 and 6 premises of drain pumps to the first and second staircase at elevation of -4,20 m are examined as it was found that rainwater and domestic sewage is released from the building of the reactor department by these premises to the respective shafts outside the reactor building.

Domestic and rainwater sewage enters vertically into the room and exits through the general penetration. The pipes are steel, and their connections are welded. The lowest elevation of the sewer pipe is 33.20, which is 0,27 m higher than the designated MWL. At reaching such a height of water due to external flooding influx of water into reactor building through the sewage network is not expected.

Engineering evaluation of leakage at rupture of pipes of domestic sewage in the room to the first staircase (made of cast iron pipes and sealing of connections between pieces of lead fibres) and the room to the second staircase (made of PVC pipes) has been performed. Based on the results of the calculations the level of flooding from 0,32 m for premises of elevation -4,20 m is defined. From the value obtained from water level at elevation -4,20 m at flooding from water retention of domestic sewage it can be seen that:

- There is a margin of 38 cm to flooding of windings of the electric motors of the pumps for the steam generators emergency makeup (the latter are located on the concrete base with height from floor of 70 cm according to data from [33]);
- There is a margin of 8 cm to flooding of emergency control room. The room has a threshold with height of 40 cm and does not have drain opening to the drain system. The flooding of the room starts after increase of the water level above 40 cm.

It should be noted that for recovery of normal operational conditions after MWL an operable drain system will be required.

3.4.1.3.2.2 Cable channels between the reactor building of units 5 and 6 and the emergency diesel-generator stations

The cable channels connecting the diesel generator stations and reactor building of units 5 and 6 are composed of trough elements with trapezoidal cross-section. The routes for all cable channels are placed at elevation 31.00. Connections between the elements constituting the cable channels are not watertight and in the presence of water above elevation 31.00, in the area around them smooth entry of water inside the cable channels is expected. The compromising of the cables, at flooding of the cable channels will depend on the state of their insulation.

Penetrations connecting cable channel to the reactor building and diesel generator stations are repaired under the modernization programme and are seismic-resistant and waterproof. Influx of water through these penetrations is nor expected.

3.4.1.4 Summary of safety margins at external flooding

Based of the performed walkdowns, review of the available documentation and engineering evaluation it was assumed that one possible scenario of flooding of the buildings and facilities of the site is through the sewage system of the plant. Walkdowns are performed for precise localization of the lowest sewage exits in the buildings where equipment is located – directly related to the safety of the plant. Although these places have no openings (drains, sinks, etc..) direct flooding of the premises is possible due to lack of sewer connections (especially when they are PVC or cast iron pipes with lead sealing) and through plugs and manholes.

The study identified no buildings or facilities the flooding of which will directly influence the plant safety functions.

The facilities failure to which will lead to the greatest effect on the nuclear facilities in Kozloduy NPP are electric wires located in the valley between hot channel-2 and dual channel. The loss of their functions can lead to loss of off-site power supply for the plant.

The most important weak points found in this study of flooding of the plant with MWL= 32,93 m, can be divided as follows:

- Shutdown of the Power Generation and passing to the diesel-generators electric power supply source – due to possible failure of a part of the power lines connecting plant to the EES;
- Termination of water supply or cold channel due to loss of bank pump station and lack of access to it by land;
- loss of emergency power supply of the Spray pools of units 5 and 6 due to failure of the shaft pump stations;
- flooding of a part of a part of the town infrastructure and access from the town of Kozloduy to the plant by the ring road which does not affect access to the plant;
- flooding of a part of underground communications under elevation 32,93 m – drainage into the rainwater sewage and leakage in the channels where they are located;
- loss of redundant system (alternative) for spent fuel cooling by the steam generators when the fuel is in the reactor – failure of the pumps of additional system for steam generator emergency makeup;

The sequence of flooding of the facilities leading to selected consequences is provided in Table 3.4-1.

Additional weak point complicating the situation is that at overflow of the protective dike without its destruction the water flooding the plain between Kozloduy NPP and Danube River will remain accumulated in a closed space between hot channel-2, dual channel and protective dike. Thus, although the anticipated disastrous wave will continue for several hours, the water retained in this space may remain for indefinitely long time up to complete and natural drainage.

Table 3.4-1: Condition of different buildings and facilities at flooding with MWL presented in the sequence of flooding.

Building and structure	Condition	Consequences at flooding	Margin
Shaft pump stations	flooded	- loss of alternative makeup of Spray pools of units 5 and 6	---
Power lines	flooded	- potential loss of off-site power of the plant	---
Pumps of additional system for steam generator emergency makeup	flooded	- alternative for cooling of spent fuel by steam generators with the fuel in the reactor	---
Cable channels between reactor building of units 5 and 6 and Diesel-generator station	flooded	Without consequences due to control of cable insulation	---
Mud-oil trap	flooded	Without consequences	---
Bank pump station	critically	- cold channel water supply	0,08m

Building and structure	Condition	Consequences at flooding	Margin
	close to flooding	termination	
Reactor building – elevation -4,20, units 5 and 6 rooms of drain pumps to the I and II staircase	critically close to flooding	Without consequences, nut with limited and/or hindered access to the rooms	0,27m
Reactor building Units 5 and 6 – emergency control room	critically close to flooding	Without consequences	0,35m*
Emergency diesel-generator stations– units 5 and 6	not flooded	Without consequences	0,57m
Turbine hall - unit 5	not flooded	Without consequences	0.57m
Units 5 and 6 steam generators emergency makeup water supply pumps electric motors	not flooded	Without consequences	0,65m*
FPS-2	not flooded	Without consequences	0.67m
Turbine hall - unit 6	not flooded	Without consequences	1.07m
Turbine hall - unit 3 and 4	not flooded	Without consequences	1,57m
SFS	not flooded	Without consequences	1,87m
OSY	not flooded	Without consequences	> 2m
Reactor building – unit 3 and 4	not flooded	Without consequences	> 2m
Boron compartment – unit 3 and 4	not flooded	Without consequences	> 2m
DGS at units 3 and 4	not flooded	Without consequences	> 2m
Transverse electric shelf – unit 3 and 4	not flooded	Without consequences	> 2m
CPS 1 and 2	not flooded	Without consequences	> 2m
CPS 3 and 4	not flooded	Without consequences	> 2m
Spray pools – unit 3 and 4	not flooded	Without consequences	> 2m
Spray pools – unit 5 and 6	not flooded	Without consequences	> 2m

Note * The margin is defined as *reactor building margin – elevation -4,20 for units 5 and 6 (0,27m) is added and the margin and the anticipated water level in the rooms– 0,08m foe room 5,6AE052 and 0,38m – for room 5,6A038/1,2,3.*

3.4.2 Potential measures to increase plant robustness against external flooding

Following identification of plant weaknesses, possible measures to enhance and ensure plant robustness against external flooding with MWL = 32,93 m are proposed, more important of which are:

- Development of measures for prevention of water intake in the plant drainage network in case of valley flooding;
- Development of an emergency procedure for personnel actions in case of wall ruptures of water-power dams „Jelezni Vrata 1” and “Jelezni Vrata 2”.

In addition to the proposed measures, the NRA considers necessary that possibilities should be reviewed and analyzed for implementation of the following additional measures:

- Modernization of the Draining and Canalization System in accordance with the planned design for reconstruction of the system from the Modernization program of Kozloduy NPP units 5 & 6.
- Investigation of possibilities for protection of the equipment of BPS 2 and 3 in case of external flooding with MWL = 32,93 m.

3.5 CONCLUSION FOR THE INFLUENCE OF EXTERNAL FLOODING ON KOZLODUY NPP SITE

The conducted analysis confirmed that the requirements of "Regulations for ensuring the safety of nuclear power plants" are met. The MWL and its duration are defined, the possibility of river blocking due to ice is assessed, the ability of combination of MWL with other hazards is studied. Analysis of the results confirms no flooding ability of Kozloduy NPP site which will satisfy the IAEA requirements, referred to in the beginning of the section.

As a result of the review of licensee (Kozloduy NPP) reassessment of safety margins of on-site facilities in case of external flooding, the NRA considers that weaknesses and strengths have been correctly identified and that proposed measures for improvements of plant robustness in earthquakes are acceptable. At the same time NRA considers as necessary to propose the additional measures listed in point 3.4.2.

4. EXTREME METEOROLOGICAL IMPACTS

REGULATORY REQUIREMENTS

Specific requirements from the Regulation on ensuring the safety of NPPs, related to extreme meteorological impacts are as follows:

Art. 29. *Engineering surveys and investigations of natural processes, phenomena and factors having potential impact on NPP safety shall be conducted for the region and the site for situating a NPP:*

2. within the NPP site boundaries, the following shall be identified:

g) tornado intensity, the peak tangential values of the periphery speed and the speed of the tornado progressive motion; the pressure drop between the tornado periphery and the centre;

5. for a NPP site, the impact on safety of other processes, phenomena and factors of natural origin shall be determined (hurricane, extreme rainfalls, air and water temperatures, icings, thunderstorms, dust-storms and sand-storms, erosion of river and water basins banks).

4.1 ACTUAL ASSESSMENT OF METEOROLOGICAL PHENOMENA USED AS DESIGN BASIS FOR THE SITE CONSTRUCTION

To assess the climate characteristics of the region around Kozloduy NPP in the design basis data from the meteo-stations in Lom, Oryahovo Buzovets and data for the period from 1916 to 1977 were used. For this assessment data for 1969-2010 from the meteorological monitoring system for Kozloduy NPP site are used.

The estimates of meteorological phenomena in the vicinity of Kozloduy NPP for the past 11 years confirm the trends in climate change described in the fourth report of the Intergovernmental Panel on Climate Change (IPCC).

4.1.1 Extreme winds and sand spouts (tornado)

Dominating for Kozloduy NPP are the west winds, followed in frequency by east and north-west winds.

At probability P=1% (once per 100 years) the maximum velocity of wind in Kozloduy NPP and Oryahovo are respectively 37-42 m/s. Dominating are west winds with wind frequency 34.9-35.5 % at winds 4.2-5.6 m/s.

At probability P = 0.01% (probability once per 10000 years) the calculated wind velocity is 45 m/s, which is accepted as extreme, at application of the estimated impacts on the civil structures and facilities ensuring nuclear and radiation safety.

According to the analysis of National Institute of Meteorology and Hydrology of BAS performed in 2009 the characteristics of 16 sand-spouts observed during the period from 1986 to 2009 and evaluated for the zone with the radius of 178 km around Kozloduy NPP are: maximum velocity - 332 km/h (92,2 m/s); wind speed - 263 km/h (73,1 m/s); motion speed - 69 km/h (19,2 m/s); radius corresponding to the maximum wind speed air flow 45.7 m; probability of sand spout occurrence with the above characteristics in the area of 12 500 km2 around Kozloduy NPP is 6.3×10^{-7} for 1 year and with speed over 332 km/h – 1.26×10^{-8} for 1 year.

The probability of wind spout over the given section of area 100 000 km^2 during one year is estimated at $5{,}05x10^{-6}$.

The maximum wind speed 92,2 m/s will lead to pressure on the structures of 5,2 5,2 kN/m^2.

4.1.2 Humidity and freezing

The average annual humidity is 78%. With specific combination of temperature, humidity and wind speed, the probability of icing and freezing increases. The most likely combinations temperature-wind-humidity necessary to determine the combined ice and wind loading on the facilities are: a temperature between 0ºC to -4ºC, wind speed between 0 and 3 to 5 m/s and relative humidity along Danube River between 95 and 100%.

With data from meteorological monitoring system in the last four years a combination of such conditions was not observed in the region of Kozloduy, which is mainly due to lower levels of humidity. The risk of icing conditions on the basis of the last 11 years has averaged 2% annually. This means that freezing is relatively rare.

4.1.3 Extreme precipitations

The annual rainfall in the region is about 518-558 mm and is one of the lowest in the country, due to rainfall "shadow" of the Southern Carpathians in the ocean incursions from the west. It is unevenly distributed throughout the year. In autumn rainfall is about 130 mm, which represents 23-25% of the annual amount. In winter rainfall is about 110-120 mm (20-23%), in the spring - 135-150 mm (24-29%), and in summer 145-150 mm (26-29%) [4][5].

In some years a number of days with precipitation can reach 4-5 days. Heavy rains with high intensity are of short duration. Maximum 24 hours for Kozloduy are 86 ÷ 87 mm [4][5].

4.1.4 Lightning

ZEUS lightning recording system has been in operation for several years and the data it receives for the field with coordinates 0 – 32^0 E and 31 – 46^0 N which includes the territory of Bulgaria shows that the number of recorded lightning over land is more significant from April to September as compared to the other months of the year. For Kozloduy territory within a radius of about 50 km for the summer months June, July and August of 2005 and 2006 around 3000-4000 lightning were recorded. Considering that the average three-month period in the world is over 5000, it can be estimated that the number of lightning in the area of Kozloduy NPP is below average statistical values [137].

4.1.5 Extreme snowfalls

Snow in the region is volatile and with relatively shallow depth due to the fact that stable snow cover is typical of regions with average January temperatures below -3 º C. There is no characteristic period of the calendar year in which snow cover is regularly formed [136].

The average annual snow cover height does not exceed 20 cm. Of the greatest recurrence of 24-30% is the height of 11-20 cm. Considered in decades, in winter months snow cover height for not more than 3-4 days is about 5 cm. This allows for excluding the possibility for the water reserves in the snow cover in the region of Kozloduy to be involved in possible flooding even during sudden warming [136].

Height of snow cover of 70-80 cm has a low recurrence - only 3% (1 to 2 days, based on the past data for 1977). This value is considered extreme.

4.1.6 Ice phenomena

Continued detention of negative temperatures in the Bulgarian section of Danube River for several days may lead to the onset of freezing of the river. After impoundment of water supply system "Iron Gate" likelihood of ice occurrence in Oryahovo station decreased from 79% to 62%.

For the period from 1963 to now there has been no complete freezing in the section of the river.

4.1.7 Extreme temperatures

The average annual temperature for the region is from 11.3 to 12.0 ^{0}C [135].

The monthly outdoor air temperature for July is t_{VII} = 24,5 ^{0}C. Absolute maximum temperatures range from 38.4 to 43.3 ^{0}C. According to the Kozloduy meteorological monitoring system data for the period of 2000-2011 the absolute maximum temperature for Kozloduy NPP site is Tmax = 43,3 ° C, measured on July 24, 2007 at 17:00. as extreme temperature 43.3 ^{0}C is defined.

Average January temperature is t_I = -0,9 ^{0}C. The absolute minimum temperatures in the region range from -20.0 to -26.6 ^{0}C. According to the meteorological monitoring system data for the period of 2000-2011 absolute minimum temperature is Tmin = -24,4 ^{0}C, measured on 8 February 2005 at 5:00. As extremely low temperature -26.6 ºC is accepted.

4.1.8 Low standing of Danube River

Daily measurements of Danube River water levels are performed by hydro-meteorological station in the town of Oryahovo and BPS of the Kozloduy NPP.

Statistical analysis of data on Danube River level in the area of Kozloduy NPP indicates that a 99% probability of the river level is above elevation 20.50 meters.

For the whole period of operation of the plant minimum water level of Danube River reached elevation of up to 21,20 m.

4.1.9 Potential combinations of extreme meteorological impacts affecting the site

With regard to the normal operation of Kozloduy NPP there are the following possible combinations of meteorological impacts:

- Combination of temperature-wind-humidity within the limit of temperature between 0ºC and -4ºC, wind speed between 0 and 5 m/s and relative humidity between 95 and 100%, at which preconditions for freezing are established.
- Combination of high temperatures, extremely low precipitations and low standing of Danube River – Potential for reaching the extremely low water level of elevation 20.50 is below 1%; this has not happened for the entire period of the plant operation.

4.1.10 Evaluation of frequency of occurrence of extreme weather conditions postulated in the design basis

Table 4.1-1: Frequency of occurrence of extreme meteorological conditions.

Extreme meteorological conditions	Parameter value	Occurrence frequency
Extreme winds	Wind with speed 45 m/s	1×10^{-4} per 1 year
	27 m/s	0,1 per 1 year
	20 m/s	Once per year
Sand spout	Wind with maximum velocity 332 km/h, wind speed - 263 km/h, motion speed - 69 km/h, radius - 45,7 m, for area 12 500 km^2	$6{,}3\times10^{-7}$ per 1 year
	with speed over 332 km/h	$1{,}26\times10^{-8}$ per 1 year
	Wind with max. speed 332 km/h, wind speed - 263 km/h, motion speed - 69 km/h, radius - 45,7 m for area of 100 000 km^2	$5{,}05\text{x}10^{-6}$ per 1 year

Extreme meteorological conditions	Parameter value	Occurrence frequency
	With speed over 332 km/h	$1x10^{-7}$ per 1 year
Snowfalls	11-20 cm	24-30%
	70-80 cm	3%
High temperatures	+43.3°C Absolute maximum air temperature	2,5%
Low temperatures	-26,6°C Absolute minimum air temperature	2,5%
Extreme precipitations	518-558 mm	Annual precipitation, one of the lowest in the country
	Occurrence of ice on Danube River – ice in Oryahovo	62% from 100 years
	Freezing of Danube River – ice in Oryahovo	No data for freezing since 1963
Lightning	Statistics data for 2005 and 2006: 3000-4000 Lightning for June, July and August, in noon and afternoon hours.	
Low standing on Danube River	Probability of water level elevation 20.50m	99%

4.2 ACTUAL STANDARD REQUIREMENTS FOR LOADS FROM EXTREME EXTERNAL EVENTS

The requirements for loads from external events are provided below as follows [138]:

Wind load:

Table 4.2-1: Wind load.

	Standard wind value w_m [kN/m^2]	Load factor γ_f	Computational value [kN/m^2]
Current norms	0,48	1,4	0,67
Extreme value	1,24	1	1,24

Snow load:

Table 4.2-2: Snow load.

	Standard snow value s_t [kN/m^2]	Load factor γ_f	Computational value [kN/m^2]
Current norms	1,2	1,4	1,68
Extreme value	1.6	1	1.6

For purposes of this assessment extreme value of snow load at snow cover 80 cm (3% recurrence for past periods, as of 1977) and volumetric weight of sleet precipitation 2,0 kN/m^3 (by Eurocode 1), which is St = 1.6 kN/m^2 is conservatively assumed.

Impacts from high temperatures

Maximum temperature during the warm half year t_{ew}=34^{0}C as required by regulations.

Absolute highest outdoor air temperature recorded at the site is 43,3^{0}C and it is considered extreme.

Impacts from low temperatures

Maximum temperature during the cold half year t_{ew}=-20^{0}C as required by regulations.

Absolute lowest outdoor air temperature recorded at the site is – $26,6^0$C and it is considered extreme.

4.3 DESIGN BASIS

The following climate characteristics underlay the design bases of the nuclear facilities of Kozloduy NPP site:

- Average annual temperature +11,6°C
- T_{av} for July +24,3°C
- T_{av} for January -1,5°C
- T_{max} absolute +43,0°C
- T_{min} absolute -29,0°C
- Average annual relative air humidity - 70%
- Average annual precipitations – 520 mm
- Snow cover – not durative, maximum up to 30-40 days, typically do not exceed 15-20 cm
- Maximum recorded snow cover 80 cm with 3% recurrence
- Dominating wind direction – West and North West
- Average annual wind speed 1-4 m/s
- Days with wind speed over 11,0 m/s – 69
- Days with wind speed over 16,0 m/s – 4-5 days
- Extreme wind speed - 45 m/s

The facilities at the site are designed before the 80-ies of the 20th century according to the regulations and standards applicable at the time. Changes in regulations and standards lead to a change in design requirements and implementation of large-scale programs for modernization and safety improvement of all nuclear facilities on the site, including with respect to seismic effects. Activities associated with retraining and ensuring seismic stability of the equipment of safety systems and civil structures with regard to increased seismic impact were completed in full-scale.

Buildings in which safety related systems and components are located are I seismic category and are not directly affected by extreme weather phenomena.

4.3.1 Review of meteorological conditions used as design basis for SSCs ensuring safety of Units 3 and 4 and structures margins assessment

4.3.1.1 Extreme winds

Main building, Turbine Hall, CPS 2 and DGS 2

In the period 1997-2000 seismic strengthening of the main building, Turbine Hall, Circulation Pump Station 2 and Diesel Generator Station 2 was implemented in accordance with the requirements of "Load and effects on buildings and equipment" 1989.

Standard wind load in the current design basis of the buildings meet the requirements of [138] on the standard value of the wind - 0,48 kN/m^2 and calculated value - 0.67 kN/m^2.

Performed seismic strengthening measures lead to increased reliability of the buildings for bearing loads from wind. The seismic reinforcements are valid for the determination of the required capacity of the building to bear horizontal loads (from seismic impacts and wind). Due to the nature of the reinforced concrete structure the seismic force exceeds the load from the extreme wind by many times, therefore the buildings have the capacity to bear also extreme wind loads.

ASSGEM 3, ASSGEM 4 and fire pump station-2

Additional system for steam generator emergency makeup (ASSGEM-3) of unit 3 and ASSGEM-4 of unit 4, and Fire Pump Station 2 were designed and put into service before 1997 as a system of seismic category I and are designed for seismic effects of DBE level.

The wind load calculated in the design basis (1.40 kN/m^2) of the three buildings is greater than the extreme value (1.24 kN/m^2) of these standards. The available margin is within 2.6%, taking into account the significance factor according to the current standards and elastic work of the structures.

Reinforced concrete ventilation pipes 1 and 2

In 1999 a constructive investigation of "Energoproekt" LLC of the three reinforced concrete pipes at the site was performed identifying that the facilities are designed for the effects of wind with calculated load from 1,26 kN/m^2 exceeding the extreme values of 1.24 kN/m^2 of these norms.

The facilities have the required carrying capacity to bear the normative and extreme wind load as the design value of the wind is 88% higher as compared against the normative value and 1.6% against the extreme value the wind.

Spray pools 3, 4 unit

Design basis of the three spray pools comply with their first class in seismic resistance and the calculated maximum wind speed of 45 m/s (load - 1.24 kN/m^2) at probability P = 0.01% (once per 10 000 years), which meets the requirements of the regulations and specified extreme wind speeds.

Losses of water treatment during extreme winds do not affect the performance of the system safety function (ultimate heat sink) as the system is open and has a continuous makeup from the advance chamber before CPS-2.

4.3.1.2 Snowfalls

Units 3 and 4 – Reactor building

The design basis for the calculated extreme snow loads (2.52 kN/m^2) exceeds the standard calculated value of these standards (1.68 kN/m^2).

Facilities have the necessary carrying capacity to withstand standard and extreme snow loads as the design calculated value of snow load is higher than 50% as compared against the normative value and 57% as compared against the extreme values of snow load.

ASSGEM 3 and 4, FPS 2, CPS 2 AND DGS 2

The design snow load in the design basis (1.40 kN/m^2) is less than the defined extreme (1.6 kN/m^2) and standard (1.68 kN/m^2) value. In relatively heavy structures such as reinforced concrete, with a high ratio of permanent loads to the snow loads, the impact of the increase of snow is minimal. The physical condition of structural elements and the influence of a constant load are rather leading to determining the bearing capacity of the elements and determination of sections, in which boundary deformation and loss of bearing capacity occurs. The roofs of the above structures have sufficient bearing capacity to accommodate the load of snow according to the new standards.

Reinforced concrete ventilation pipe

Due to its constructive features it is not affected by snowfalls and freezing.

Spray pools

The snowfalls do not apply pressure on their structure.

4.3.1.3 Extreme temperatures

High temperatures, to the maximum measured for the area of Kozloduy NPP does not bear mechanical loads on structures and buildings at Units 3 and 4.

In the given design basis extreme values of temperatures do not lead to failure to the plant safety functions.

In the operational history of the plant there are no events and accident initiated by extremely low or extremely high temperatures.

FSP 3, 4

Due to the closing and autonomous nature of the spent fuel storage system and auxiliary systems, these are not affected by the external factors „Extreme temperatures".

Spray pools

Design flow of sources of supplemental water is sufficient to compensate for evaporation losses at extremely high temperatures.

The technological temperature mode of the spray pools provides for non-freezing of the water even at extreme temperatures.

4.3.1.4 Freezing

For technological provision of the required temperature mode and protection of CPS 1-4 pumps against freezing recirculation of hot water is set before CPS 1.

4.3.2 Review of meteorological conditions used as design basis for SSCs ensuring safety of Units 5 and 6 and structures margins assessment

4.3.2.1 Extreme winds

Main building–Reactor building, Turbine hall with electric technical devices

The normative wind load in the design basis (0.55 kN/m^2) of Main building and Turbine hall with electric technical device exceeding the normative requirements of [138] and the accepted load factor $\gamma_f = 2.5$ ensures calculated wind load 1,38kN/m^2, exceeding the extreme value (1,24 kN/ m^2).

The wind load for which these structures are sized are 11% higher than the extreme wind load and 106% than the normative wind load.

The design of the civil structure of the reactor building of unit 5 and unit 6 takes into account the external effects of air shock wave with pressure fronts 0,3 kgf/cm^2 (30 kN/m^2) for 1s time [4][5]. As the wind spout with maximum wind speed of 92,2 m/s will lead to pressure on the structures of 5,2 kN/m^2 it can be assumed that the building of the reactor building has a reserve of bearing capacity against wind spout load.

Furthermore, the construction of the containment shell is designed to withstand impact from an air craft falling with speed 750 km/h and weighing 10 t, which ensures a supply of bearing capacity for flying objects at wind spouts.

Reinforced concrete ventilation pipe

In 1999 a constructive investigation of "Energoproekt" LLC of the three reinforced concrete pipes at the site was performed identifying that the facilities are designed for the effects of wind with calculated load from 1,26 kN/m^2 exceeding the extreme values of 1.24 kN/m^2 of these norms.

The facilities have the required carrying capacity to bear the normative and extreme wind load as the design value of the wind is 88% higher as compared against the normative value and 1.6% against the extreme value the wind.

Steel ventilation pipe

The design basis of the calculated wind load for the reinforced concrete ventilation pipes (1,38 kN/m^2) exceed the value of these against the current standards (0,67 kN/m^2) as well as extreme calculated values (1,24 kN/m^2).

The facilities have the required bearing capacity to withstand normative and extreme wind load as the design calculated value of wind load is 105% higher against the normative value and 11.3% against the extreme value of the wind load.

The buildings of diesel generator stations are designed to withstand the pressure on the front from the explosive shock wave equal to 0,3 kg/cm^2 = 30 kN/m^2 with up to 1 sec. duration [4][5], This provides them with reserve for load bearing capacity against wind spout.

CPS 3 AND 4, DGS -1,2 3 cells

The calculated wind load in the design basis (0,66 kN/m^2) is close to the value required by current standards (0,67 kN/m^2) but is about twice as low as the extreme values (1,24 kN/m^2).

Surface civil structures (prefabricated concrete elements) of CPS 3 and 4 were not strengthened during the modernization program. It can be conservatively assumed that damages will occur in their structures at extreme wind. In this case, if the spray pool makeup pumps are damaged, it is running emergency makeup of the pools of 6. ShPS in the Valley of Danube River, i.e. the safety functions are not violated.

Given that the structure of the buildings DGS is reinforced concrete ("heavy"), it can be assumed that at calculation and sizing of the combinations for seismic impact.. Therefore, the structure can accommodate the calculated effort under extreme wind pressure, which are close and lower than those at a seismic impact.

Spray pools Units 5, 6

The design basis of spray pools are consistent with their 1 category seismic resistance and the estimated maximum wind speed at probability p = 0.01% (once per 10,000 years) of 45 m/s.), which meets the requirements set for normative and extreme wind speeds.

Supplementary water for spray pools, which comes from pumps CPS-3 and CPS-4 and as a reserve - diesel pumps and ShPS, compensates for losses from spraying at weak and moderate winds. There is a process option at extremely strong winds to eliminate losses from blowing, the water supplied for cooling is released directly to the bottom of the spray pools without spraying in nozzles, as its cooling is by convection.

4.3.2.2 Snowfalls

Main building – Reactor building Units 5 and 6

The calculated value of snow load (2,52 kN /m^2) is 50% higher than the applicable standards (1,68 kN/m2) and 57% higher that the extreme value of snow load (1.6 kN/m^2). The structure has reliable stiffness and can withstand extreme snowfall.

Reinforced concrete ventilation pipe

Due to the structure of the ventilation pipes they are not threatened by damage from snow loads.

CPS 3 AND CPS 4, DGS-1,2 and 3 cells

The calculated value of snow load in the design basis of the buildings (0,98 kN/м^2) is lower than the current standards (1,68 kN/м^2) and extreme value (1.6 kN/м^2). At relatively heavy structures, such as reinforced concrete, with high ratio of permanent loads to the snow loads the impact of the snow load increase is minimal. The physical condition of structural elements and the influence of a constant load is rather leading to determining the bearing capacity of the elements and determination of sections, in which boundary deformation and loss of bearing capacity occurs.

The roofs of DGS-1,2 and 3 cells have sufficient bearing capacity to accommodate the load of snow according to the new standards.

Surface civil structures (prefabricated concrete elements) of CPS 3 and 4 were not strengthened during the modernization program. Given that extreme snow loads can be present for a short period of time (recurrence 3% for 1-2 days), it can be assumed that the extreme snow loads will lead to the limit bearing capacity of the building. But even assuming conservatively that damage will occur in their structures at extreme snow loads the safety functions are not violated. In this case, if spray pools makeup pumps are damaged, then emergency makeup of the pools from 6 ShPS in the Valley of Danube River.

Spray pools

Snowfalls do not apply load on the spray pools structure.

4.3.2.3 Extreme temperatures

High temperatures, to the maximum measured for the area of Kozloduy NPP do not bear mechanical loads on structures and buildings at Units 5 and 6.

In the given design basis extreme values of temperatures do not lead to failure to the plant safety functions.

In the operational history of the plant there are no events and accident initiated by extremely low or extremely high temperatures.

Spray pools

Design flow of sources of supplemental water is sufficient to compensate for evaporation losses at extremely high temperatures.

The technological temperature mode of the spray pools provides for non-freezing of the water even at extreme temperatures.

Freezing

To protect the bars before the pumps in BPS against freezing and icing recirculation facility is built – hot water battery. It ensures supply of hot water to the advance chamber of BPS 1 , 2 and 3.

Probability of ice drifting occurrence has been assessed in the BPS design. To protect the advance chamber before BPS 2 and 3 against floating missiles bridge-barrier reinforced concrete facility with immovable bars.

For technological provision of the required temperature mode and protection of bars of pumps CPS 1-4 against freezing hot water recirculation unit is constructed before CPS 1.

4.3.3 SFS

4.3.3.1 Extreme winds

With the implementation of two projects for seismic strengthening of the civil structure of the spent fuel storage [139], and Detailed Design for increasing resistance of steel columns and roof farms under extreme wind and snow load [140] the necessary margins for extreme wind load were achieved, while the design basis for calculated wind loads (1,74 kN/m^2), exceeds 27.6% extreme computational cost (1,364 kN/m^2).

The facility has adequate bearing capacity to withstand specific standard and extreme loads.

4.3.3.2 Snowfalls

The calculated snow loads value (1.4 KN/m^2) is lower than the current norms (1.68 KN/m^2) and extreme values of snow loads (1.6 KN/m^2). The limiting values of snow loads can be determined with additional structural calculations and reviews in sections of the most loaded construction elements.

Given that extreme snow loads can be reached for a short period of time (occurrence 3% for 1-2 days), it can be assumed that the extreme snow loads will not lead to exceeding the limiting bearing capacity of the building.

4.3.3.3 Extreme temperatures

High temperatures, to the maximum measured for the area of Kozloduy NPP do not bear mechanical loads on the structures of SFS.

In the given design basis extreme values of temperatures do not lead to failure to the SFS safety functions.

In the operational history of the plant there are no events and accident initiated by extremely low or extremely high temperatures.

4.3.4 DSFS

4.3.4.1 Extreme winds

The wind load value 1,40kN/m^2 is taken in the design. It is 13% higher than the extreme calculated value for wind load from 1,24 kN/ m^2.

Wind loads for structures are designed larger than the extreme values and these structures have the necessary bearing capacity to withstand the normative and extreme wind loads.

4.3.4.2 Snowfalls

The calculated snow loads value (2,52 kN/m^2) is 50% higher than the current norms (1.68 KN/m^2) and 57% higher than the extreme values of snow loads (1.6 KN/m^2).

The structures have the necessary bearing capacity to withstand specific normative and extreme snow loads.

4.3.4.3 Extreme temperatures

High temperatures, to the maximum measured for the area of Kozloduy NPP do not bear mechanical loads on the structures of DSFS.

In the given design basis extreme values of temperatures do not lead to failure to the DSFS safety functions.

In the operational history of the plant there are no events and accident initiated by extremely low or extremely high temperatures.

4.3.5 Outdoor Switchyard

4.3.5.1 Extreme winds

The structure if OSY building is provided for bearing capacity, robustness and deformability according to the requirements of the applicable normative documents.

4.3.5.2 Extreme snowfalls

The calculated value of snow load (2,52 kN/m^2) is by 50% greater than the normative value (1.68 kN/m^2) and 57% greater than the extreme values of snow loads (1.6 kN/m^2).

The structure has reliable stiffness and may withstand normative and extreme snow loads.

4.3.5.3 Extreme temperatures

Extreme temperatures are within the design basis of OSY SSCs.

High temperatures do not apply mechanical loads for the structures and buildings.

4.3.5.4 Freezing

The freezing in the region of Kozloduy is a relatively seldom phenomena.

The current operational experience since 1971 shows that for OSY there is no case of rupture of power lines for off-site power supply or failure to off-site power supply due to freezing. Considering the large number of connections in various directions of Kozloduy NPP, breaking of all lines simultaneously is unlikely.

4.4 CONCLUSION FOR IMPACT OF THE EXTREME METEOROLOGICAL EXTERNAL EVENTS ON THE BUILDINGS AND FACILITIES OF KOZLODUY NPP SITE

Facilities at the site, except ASSGEM, FPS 2 and DSFS, were designed before early 80s of the 20th century, according to the regulations and standards applicable at the time. Changes in regulations and standards have led to a change in design requirements and implementation of large-scale programs for modernization and safety improvement of all nuclear facilities on the site.

Safety related systems and components are contained in the buildings of I seismic category.

<u>Assessment of the impacts on the extreme external events on structures:</u>

The considered structures have the necessary bearing capacity to withstand the high loads from external events due to change in the regulations and set extreme values with the following exceptions:

- The surface parts of CPS 3 and 4 were not strengthened during the modernization program and the design calculation loads are lower than those in current normative documentation and the defined extreme values. Based on this it can be assumed that their surface structures are vulnerable to extreme external events and their non-support structural elements could occur damaged at an extreme wind. In this case, if the spray pool makeup pumps fail, the pools emergency makeup is provided from 6 ShPS in the valley of Danube River, i.e. the safety functions are not threatened.
- In the elements of the roof structures of CPS 3 and 4 and SFS damage could occur during prolonged detention of snow cover with around the extreme thickness (80 cm). Although the retention of maximum snow cover is within 1-2 days continuous monitoring of the thickness of the snow is organized and measures are taken for their roof structures cleaning.

With regard to the wind spout as it could have a small radius more concentrated impact on individual structures and systems can be expected rather than a significant impact on the site as a whole.

It can be assumed that if individual buildings fall into the "eye" of the wind spouts the roofing structures, and particularly the lighter ones, may be damaged but not enough to jeopardize the operation of the equipment located therein.

Assessments of structures margins are based on the use of the most conservative approaches. In fact, these margins are expected to be larger.

<u>Security of the plant against the effects of extreme external influences:</u>

Loss of pools spray water: The impact of extreme temperatures and winds on evaporation of spray pools water is compensated by developed organizational and technological measures.

In a wind spout, the most dangerous in terms of safety is when it appears above the spray pools. The low probability of occurrence of the event at the site has been already mentioned. It is still less if we consider the probability of occurrence of a wind spout in a small area of the whole site, such as the pools. If this option occurs, "emptying" of the basin can be expected which threatens the performance of "Loss of the ultimate heat sink" function. Given the expected radius of wind spout it is likely to affect only one spray pool, which means that the function as a whole is not compromised. Highly conservative case - loss of the three pools is a hazard considered in detail in Part 5 of the report "Loss of power supply and loss of ultimate heat sink".

Freezing of spray pools nozzles: process feature spray pools does not allow for freezing of the nozzles in operation.

Rupture of the lines: it can also be expected that if tornado strikes switchyard or certain lines, this will result for the plant in a partial or complete loss of off-site power. Total loss of power as the worst consequence of the wind spout is discussed in detail in Part 5 of the report "Loss of power supply and loss of ultimate heat sink".

Freezing of OSY: The current operational experience (from 1971 to present) shows that on the switchyard there was no case of rupture of power line for off-site power supply or failure to off-site power supply due to freezing. Considering the large number of connections in different directions of Kozloduy breaking of all lines simultaneously is unlikely. Due to the fact that freezing is a rare phenomenon and has not occurred in recent years the necessary data to determine its basic characteristics are not available.

Freezing and icing of water before BPS: The design of BPS and dual channel provides for structures for protection against freezing and icing of water before BPS. To protect the advance chamber before BPS 2 and 3 against floating missiles bridge-barrier reinforced concrete structure with immovable bars is constructed.

Freezing of the bars of CPS 1-4 pumps: For the process provision of the required temperature mode and protection of CPS 1-4 pumps bars against freezing hot water recirculation is set before CPS 1.

Lightning: The existing lightning installations of the site facilities provide lightning protection zone with protection probability over 99.5%.

Low level of Danube River: The plant has developed procedure for actions at emergency low level of River Danube.

The analysis of the technical condition of structures considering typical effects of external events on the site (extreme winds, tornado, snow and ice, extreme temperatures, extreme rainfall) and the organizational and technical measures for the management and control designed to supply power to site loads and cooling of nuclear fuel shows that the safety related systems are in accordance with the design requirements and the available instructions and procedures are applicable to the action of staff in emergency situations.

As a result of the licensee (Kozloduy NPP) reassessment of margins of on-site facilities in respect to extreme meteorological impact, NRA considers that weaknesses and strengths have been properly identified as well as margins of structures and facilities.

5. LOSS OF POWER SUPPLY AND LOSS OF ULTIMATE HEAT SINK

In this section results are summarized of the analyses of the response and robustness of the nuclear installations at the Kozloduy NPP in case of loss of the power supply and loss of ultimate heat sink.

The legal requirements to the design and safety assessment of nuclear reactors are established with the Regulation on ensuring the safety of nuclear power plants [40]. According to this Regulation the safety shall be assessed using deterministic and probabilistic approaches in order to confirm the design basis and the defence-in-depth.

The Regulation also requires that the plant design and operation shall be periodically reviewed in the light of the operational experience and new safety significant information for the identification of deviations from the current requirements and the internationally recognized operational experience. In implementation of this requirement the last periodic safety review of the Kozloduy units 5 and 6 has been performed against the requirements of the new Regulations for implementation of the Nuclear Act and has been concluded in 2009. Based on the results of the periodic safety review the licensee has developed a Program for improvement of the nuclear safety and radiation protection, the long-term measures of which has been still under implementation.

More detailed guidance on performing safety assessment and reassessment are included in the Regulatory Guide on deterministic safety assessment and the Regulatory Guide on probabilistic safety analysis.

In accordance with the Regulation [40] and the guides the selection of the postulated initiating events for safety analysis shall be performed by the use of deterministic and probabilistic methods and the selected events shall be grouped into four categories of plant states depending on their estimated frequency of occurrence. The site-specific external hazards that shall be accounted for in the design are defined in art. 13 of the Regulation, while art. 14 regulates that the performance of the plant in beyond design basis accidents shall be assessed in addition to the design basis (design extension). The beyond design basis accidents without severe core degradation that shall be analyzed (if not prevented by the inherent safety features and design principles) are specified in the Regulation and the Regulatory Guide on deterministic safety assessment, as follows:

- total loss of on-site and off-site power (station blackout);
- anticipated transients without scram;
- multiple SG tube rupture (for pressurised water reactors);
- total loss of feed water;
- total loss of the component cooling water;
- loss of coolant accident together with complete loss of an emergency core cooling system (high or low pressure);
- loss of main heat sink;
- uncontrolled decrease of the concentration of the neutron absorber in the coolant (for pressurised water reactors);
- uncontrolled level drop during mid-loop operation during refueling or shut down for maintenance (for pressurised water reactors);
- loss of required safety systems in the long term after a postulated initiating event;
- loss of core cooling in residual heat removal mode;
- total loss of spent fuel pool cooling.

The Regulation [40] sets also requirements to the design of the systems important to safety, including to the supporting safety systems and the systems providing the ultimate heat sink, as summarized below:

Art. 86 requires that the plant design shall have provisions for supporting safety systems fulfilling auxiliary services on supply of safety systems with fluids and energy, and maintaining their operational conditions over a justified period of time in all operational states and design basis accidents. Further art. 87 regulates that these systems shall be designed with adequate component reliability and redundancy to ensure the necessary effectiveness on the assumption of a single failure, independent of the initial state. The functional reliability of supporting systems shall be sufficient enough to meet the required reliability criteria of the respective safety system. A provision for testing the functional capability of the supporting systems and for failure indication shall be made in the design. According to art. 88 the fulfillment of the supporting function shall have a priority over the systems' own protections if this would not aggravate the consequences for safety. The design shall also specify the non-isolable own protections of the components of the supporting safety systems.

In accordance with art. 60 the plant design shall provide for reliable systems to remove to an ultimate heat sink the residual heat from the core and from SSCs important to safety, in all operational states and design basis accidents. All systems that contribute to the heat transfer (by conveying heat, by providing power or by supplying fluids to the heat transport systems) shall be designed according to their contribution to the heat-transfer function. The systems' reliability shall be achieved by the use of proven components, redundancy, diversity, physical separation and isolation. Furthermore art. 61 requires that the natural phenomena and human induced events, specific to the plant site, shall be taken into account in the design of the systems and in the possible choice of diversity in the ultimate heat sinks. Adequate consideration shall be given to the residual heat removal from the reactor core and cooling of the localization system components in case of a severe accident.

The legal requirements to the plant design and safety assessment are fully harmonized with the WENRA Reference levels for existing reactors.

The design of the structures and systems that ensure the ultimate heat sink and the power supply functions are described in details in chapter 1 of the report. The presentation of the stress test results in this chapter is focused mainly on the design solutions aimed at preventing events with loss heat sink and power supply as well as on the plant behaviour in case of subsequent degradation of the following safety functions, as specified in art. 33 [43]:

- Removal of decay heat from the reactor core at specific operational conditions and accidents with maintaining reactor coolant circuit boundaries;
- Removal of heat from safety systems to ultimate heat sink;
- Provision of the required safety systems support functions;
- Removal of decay heat from spent fuel, storage outside the reactor core, but within the boundaries of the power unit.

Assessment is provided for the time period available to the operator to execute measures to prevent severe accident at various scenarios.

The following nuclear facilities are subject to the analysis:

- Nuclear reactors of units 5 and 6;
- Fuel pool of units 5 and 6;
- Fuel pool of the shut down units 3 and 4;
- Storage for spent nuclear fuel.

The analysis does not cover facility for spent fuel dry storage, as heat removal in it is provided on the passive principle, and as an ultimate heat sink ambient air is used.

As a result of the assessment of the Kozloduy plant in case of loss of power and heat sink conclusions are made on the robustness of the provisions, the strong safety features are defined, the areas that need further improvement are identified and subsequent safety improvement measures are specified.

5.1 NUCLEAR REACTORS – UNITS 5 AND 6

5.1.1 Loss of power supply

5.1.1.1 Loss of off-site power supply

Operational power supply to units 5 and 6 is provided through the auxiliaries transformers, energized by the generator voltage. Standby power supply is provided from OSY-220 kV. The second standby power to the units is provided from the standby power supply busbars of the other power unit (unit 5 is powered from unit 6 and vice versa).

Off-site power supply to the bank pumping stations is provided from OSY-220 kV, and the redundancy is provided from Bukyovtsy substation of 110 kV.

<u>5.1.1.1.1 Design schemes at loss of off-site power supply, sources, capacity and operability for the emergency power supply</u>

Loss of the off-site power is defined as interruption to all the connections with the NPP with EES. In case of loss of off-site power supply safety-related consumers are powered from independent emergency power supply sources located at area of units 5 and 6.

- Emergency DGs

Each of the units 5 and 6 has three automated diesel-generators, per one for each of the safety system trains. According to section 3 and section 8 of [4] and [5], the diesel generators are class 3 by OPB-88/97 and IAEA definition for safety functions, respectively, class E1 by IEEE, and comply with respective seismic category 1. They are located at the site level. Consumers which are supplied from emergency DGs are safety systems, FSP (SFP) cooling pumps and fire-protection pumps.

- Accumulator batteries

Power to the first category consumers during all operational modes, including complete loss of power supply mode, is provided from the accumulator batteries. Accumulator batteries energize the I&C in the reactor compartment, primary steam-gas mixture emergency removal system, BRU-A and emergency lighting.

Reliable power supply system for the bank pumping station is intended to supply power to consumers related to nuclear and fire safety (emergency service water pumps, shaft pumping stations, fire-annunciation installation and fire extinguishing in BPS and their supporting systems). Diesel-generator station in the BPS is equipped with two diesel-generator sets.

There are two accumulator batteries installed in the BPS which serve to guarantee uninterrupted power supply to the most important consumers ensuring accident-free operation of facilities in the BPS.

<u>5.1.1.1.2 Independency of emergency power supply and measures to prolong operational time period</u>

- Emergency DGs – At operation of two emergency DGs (one per the unit) total capacity of fuel and oil of the emergency DGs is sufficient for more than 38 days.
- Accumulator battery – No need to undertake measures to prolong operational time period of the accumulator batteries, as far as the battery of one safety system train has a discharge capacity of more than 10 hours under full load. See description in par. 1.3.2.6.1. „Accumulator batteries“.
- DG of the BPS – Total reserve of fuel and oil at the BPS site ensure uninterrupted operation of both DGs during 56 hours and 45 minutes.

5.1.1.2 Loss of off-site power supply and loss of emergency diesel-generators

<u>5.1.1.2.1 Design schemes of permanently installed sources of additional emergency power supply to the site, capacity and availability for putting into operation</u>

Each of the two units has one additional independent diesel-generator with nominal power of 5.2 MW. According to the design these DGs are intended to ensure voltage to normal power supply busbars, through which – in case of loss of secondary circuit normal make-up – heated water is supplied to the SG from the deaerators, instead of cool water from the reservoirs of the secondary circuit emergency make-up system. In this way thermal stresses in the SG tubing are prevented. These DGs can be used also for removal of reactor decay heat as well as in case of failure of the three emergency DGs. Additional DGs are in hot standby mode.

Additional DG is located in the container of platform of 1m above the site and according to [4] and [5] refers to class 4 by OPB-88/97 and respective seismic category 2.

Total fuel and oil reserve of additional DGs ensure uninterrupted operation of each of them for more than 4 days.

<u>5.1.1.2.2 Capacity of the batteries, operational time period and capabilities to recharge the batteries</u>

No possibility is envisioned to recharge the accumulator batteries of the safety system from additional or mobile DG. Their charging is provided from emergency DG of the related safety train of the SS. Common-plant accumulator battery and that of the computer-based informational system can be charged from additional diesel generator. Full description of the accumulator battery functions is provided in par. 1.3.2.6.1. „Accumulator batteries“.

<u>5.1.1.2.3 Time to reaching severe accident in the specified conditions. Threshold values in plant behavior</u>

The following conditions of the units were assessed:

- Power operations;

- Cold condition (N=18 MW, 20 hours after shutdown), pressurized primary circuit and drained SG;
- Cold condition (N=18 MW, 20 hours after shutdown), pressurized primary circuit and non-drained SG;
- Cold condition (N=16.2 MW, 28 hours after shutdown), depressurized primary circuit;
- Outage cooldown of the primary circuit (N=12 MW, 72 hours after shutdown and N=6 MW, about 18 days after shutdown).

Operator actions aimed at prolongation of the time period before fuel damage occurs are specified for each of the modes considered in the analyses.

Table 5.1-1: Assessment of time period to fuel damage at loss of normal and standby power supply and failure to emergency DGs.

	Option	Time to fuel damage (h:min)
1	Power operations (Considered: actuation of MDG and use of water reserve in the tanks of SG emergency make-up system)	115:45 (4.8 days)
2	Shut down reactor, planned cooldown at pressurized primary circuit and drained SG (Considered: drainage of ECCS three hydro accumulators)	16:44
3	Shut down reactor, planned cooldown at pressurized primary circuit and non-drained SG (Considered: drainage of ECCS three hydro accumulators, make-up of SG from high pressure deaerator, chemically demineralised water system tanks and SG emergency make-up system tanks)	More than 3 days and 19 hours
4	Shut down reactor, planned cooldown at depressurized primary circuit (Considered: drainage of ECCS three hydro accumulators)	19:45
5	Shut down reactor, outage cooldown (Considered: drainage of ECCS three hydro accumulators)	
	3 days after shutdown	25:51
	18 days after shutdown	50:12

The first threshold is discharge of the accumulator batteries (about 10 hours after complete loss of AC sources). As a result the shift personnel losses information on unit parameters. Before that the valves required for accident management shall be positioned (safety valves of the pressurize, BRU-A, steam/gas mixture emergency removal line, etc.).

However, discharge of the accumulator batteries does not terminate the started processes of heat removal (motor-driven valves will maintain their position).

The second threshold is water exhaust in chemically demineralised water tanks (at pump make-up of SG auxiliary make-up system) and in the tanks of SG emergency make-up system (at make-up using SG EMS).

At power operations exhaust of the three SG emergency make-up system tanks, of the high pressure deaerator water reserve and chemically demineralised water tank is expected after more than 3 days.

The third threshold is exhaust of fuel oil reserve for additional and mobile DG. Fuel oil reserve for additional DG is sufficient for more than 4 days, and for MDG – for 60 hours. Oil reserves for both DGs are sufficient for this period of time. If emergency DGs are inoperable, oil and fuel intended for these can be used on the operating DGs, with which their operation is ensured for more than 30 days.

5.1.1.3 Loss of off-site power supply, emergency diesel-generator and additional diesel-generator

<u>5.1.1.3.1 Capacity of the batteries, operational time period and capabilities to recharge them in this situation</u>

See par. 5.1.1.2.2.

<u>5.1.1.3.2 Actions envisioned to provide mobile on-site or mobile off-site power supply sources</u>

There is a mobile diesel-generator (MDG) located in area of units 1 and 2 of the Kozloduy NPP which is mounted of the platform jointly with the fuel tank, control board and the power cable wound on the coil. Transportation to the platform is provided by a truck. The mobile DG is used to energize the pump of SG alternative make-up system (SG EMS) through own busbar. MDG may be connected to energize SG EMS on one of the two units, though its power is sufficient to energize the pumps of both units.

Total reserve of fuel and oil of the MDG ensures its uninterrupted operation at nominal power during 21 hours and 40 minutes [21]. To energize only the pump of SG alternative make-up system, this reserve is sufficient for 60 hours.

<u>5.1.1.3.3 Competence of the shift personnel and time period required to connect mobile power supply sources. Time period required for experts to perform these activities</u>

There is an operator training centre established at the Kozloduy NPP. This system specifies the scope and duration of training for different job positions. Off-schedule trainings are envisioned in relation with changes to the regulatory requirements, modification to and introduction of new systems, procedures and instructions, etc. Planning, conducting and analyses of the delivered training results are regulated.

Training is held on the full-scale simulator and emergency response exercises. All the SBEOPs are simulated at the full-scale simulator. Emergency response exercises include the shift personnel and various groups and teams according to Internal emergency response plan of the NPP.

Actions of the operators in case of loss of power supply are specified in „Instruction on elimination of anticipated operational occurrences and accidents in the RI" [21] and in SBEOP for actions at blackout mode of the unit.

Actions related to actuation and loading of additional DGs are specified in procedures on restoration of power supply to category III consumers of units 5 and 6 from the common-plant diesel-generator [141],[142].

Procedure has been developed on transportation and actuation of the MDG to the busbars to the rooms of SG EMS pumps. The established success criteria is the time from conditioning of the alarm on complete loss of power supply till the pump actuation less than 2 hours. Meeting the criteria is confirmed in the observation sheet of the emergency response exercise.

<u>5.1.1.3.4 Time period required providing alternate current power supply and restoration of core cooling before fuel damage occurs. Threshold values in plant behavior</u>

The following conditions were assessed:

- Power operations;
- Cold condition, pressurized primary circuit and drained SG;
- Cold condition, pressurized primary circuit and non-drained SG;

- Cold condition, depressurized primary circuit;
- Outage cooldown of the primary circuit.

Operator actions aimed at prolongation of the time period before fuel damage occurs are specified for each of the modes considered in the analyses.

Table 5.1-2: Assessment of time period to fuel damage at loss of normal and standby power supply, failure to all emergency DGs, failure to additional DG.

	Option	Time to fuel damage (h:min)
1	Power operations (Considered: passive make-up of SG; actuation of SG EMS, energized from MDG. Time depends upon the configuration of the passive make-up of SG.)	45:00÷49:00
2	Shut down reactor, planned cooldown at pressurized primary circuit and drained SG (Considered: actuation of SG EMS, energized from MDG; drainage of the ECCS three hydro accumulators.)	66:44
3	Shut down reactor, planned cooldown at pressurized primary circuit and non-drained SG (Considered: actuation of SG EMS, energized from MDG; drainage of ECCS three hydro accumulators.)	69:44
4	Shut down reactor, planned cooldown at depressurized primary circuit (Considered: drainage of ECCS three hydro accumulators.)	7:28
5	Shut down reactor, outage cooldown (Considered: drainage of ECCS three hydro accumulators.)	
	3 days after shutdown	9:15
	18 days after shutdown	16:53

Threshold effect on the progress of the process is provided by discharge of the accumulator batteries (after about 10 hours). After that the operator does not dispose information on unit parameters and shall perform accident management actions blindly.

If an event occurs at power operations or in cold condition with pressurized primary circuit, threshold effect is provided by exhaust of water reserve in the tanks of SG emergency make-up system. In the first case this effect is expected to come after about 28 hours, and in the second case – after 50 hours.

In case of depressurized reactor the threshold is start of core heating up which occurs relatively early – after less than 2 hours. During this period the operator shall prepare and start drainage of the hydro accumulators (preferable first to the cold part of the reactor). Drainage of the three hydro accumulators delays start of core heat-up for 4 hours.

5.1.1.4 Loss of off-site power supply, emergency diesel-generators, additional diesel-generator and mobile diesel-generator

5.1.1.4.1 Capacity of the batteries, operational time period and capabilities to recharge them in this situation

See par. 5.1.1.2.2.

5.1.1.4.2 Actions envisioned to provide mobile on-site or mobile off-site power supply sources

See par.5.1.1.2.2.

5.1.1.4.3 Time period required providing alternate current power supply and restoration of core cooling before fuel damage occurs. Threshold values in plant behavior

Assessments were performed for conditions of the units, described in section of Ch.15 [4][5]. Operator actions aimed at prolongation of the time period before fuel damage occurs are specified for each of the modes considered in the analyses.

Table 5.1-3: Assessment of time period to fuel damage at loss of normal and standby power supply, failure of all emergency DGs, failure of additional DG, failure of mobile DG.

	Option	Time to fuel damage (h:min)
1	Power operations (Considered: passive make-up of SG from the high pressure deaerator)	16:15
2	Shut down reactor, planned cooldown at pressurized primary circuit and drained SG (Considered: drainage of ECCS three hydro accumulators.)	16:44
3	Shut down reactor, planned cooldown at pressurized primary circuit and non-drained SG (Considered: drainage of ECCS three hydro accumulators.)	19:44
4	Shut down reactor, planned cooldown at depressurized primary circuit (Considered: drainage of ECCS three hydro accumulators.)	7:28
5	Shut down reactor, outage cooldown (Considered: drainage of ECCS three hydro accumulators.)	
	3 days after shutdown	9:15
	18 days after shutdown	16:53

Threshold effect on the progress of the process is provided by discharge of the accumulator batteries (after about 10 hours). After that the operator does not dispose information on unit parameters and shall perform accident management actions blindly.

If an event occurs at power operations or in cold condition with the pressurized primary circuit and non-drained SG, threshold effect is drainage of the SG. In order to prevent rapid increase of fuel temperature it is required within 6 to 8 (up to 9 in cold condition) hours to ensure water supply to the SG.

In case of depressurized reactor, threshold is start of core heating up, which occurs relatively early – after less than 2 hours. During this period the operator shall prepare and start drainage of the hydro accumulators (preferable first to the cold part of the reactor). Drainage of three hydro accumulators delays start of core heat-up for additional 4 hours.

5.1.2 Measures to improve robustness at loss of power supply

2 new mobile DGs will be delivered, and the existing one will remain standby for the remaining structures at the NPP area;

Power supply is provided for charging of the one accumulator batteries of the safety systems from mobile DG;

5.1.3 Loss of ultimate heat sink

5.1.3.1 Design bases to remove heat to main ultimate sink at different operational conditions

Decay heat sources of power units 5 and 6 are as follows:

- Core decay heat;
- Fuel pool decay heat.

The main ultimate heat sink for the nuclear installations at the Kozloduy NPP is Danube River. Connection to the ultimate heat sink is provided via direct scheme from the service water supply system through a pair of channels. Water from Danube River is delivered to the cold channel by pumps, located at bank pump stations.

Redundancy to connection to the Danube River is provided by Emergency pump station, which ensure independent water supply in emergency reserve of the cold channel through two independent pressure steel water lines.

Water for cooling of turbine condensers and for cooling of consumers in nuclear facilities is delivered by circulation pumping stations with intake chambers and pumps, pressure steel pipelines and filtering premises with filtering units. Facilities for removal of heated water are the removal steel pipelines, siphon spillways shafts, low pressure removal channels, outlet shaft with the intake chamber and overflow, inlet and inspection shafts. For the needs of Kozloduy NPP totally 4 circulation pumping stations (CPS) were constructed: one per two shutdown pairs of units 1-2 and 3-4 (VVER-440) and one per each of two nuclear power units 5 and 6 (VVER-1000).

CPS 3 and CPS 4 service the operating units, correspondingly unit 5 and unit 6. Two pumping station are identical. Each pump station has the following:

- Motor-driven pumps for cooling of turbine condensers with water intake at elevation of 29 m;
- Motor-driven pumps for service water supply to normal operation system consumers in the turbine hall, reactor compartment, auxiliary building and chemically demineralised water system with water intake at elevation of 28 m;
- Motor-driven pumps for water supply to the spray pools with water intake at elevation of 28 m;
- Diesel-pumps for water supply to the spray pools with water intake at elevation of 26.3 m, virtually from the bottom of the cold channel;
- Fire-protection pumps with water intake at elevation of 26.3 m, virtually from the bottom of the cold channel.

Series of the design measures have been implemented to prevent loss of connection to the Danube River – measures to prevent loss of the pumping stations, tools to prevent blocking of the main cooling water inlet, alternative ways of water supply, etc.

Redundancy for removal of spent service water from NPP site (units 5 and 6) to the Danube River is provided with the second warm channel.

For water supply to the spray pools of units 5 and 6, independent water supply is provided from the terrace of the Danube river, 6 shaft wells and 6 shaft pumping stations. Water amount which can be delivered from the shaft pumping stations to the spray pools is sufficient to replenish for losses from the six spray pools due to steaming and entrainment at quiet weather (wind speed of 2 m/s). Water from the shaft pumping station is delivered to the spray pools via separate steel pipeline.

Cooling of the consumers of units 5 and 6 is provided from:

- System for service water supply, intended for cooling of consumers of normal operation systems – ultimate heat sink is Danube river.

- System for service water supply, intended to remove heat from equipment of the safety systems during all operational modes and emergency conditions. Each of the three trains of the system operate via the self-contained circuit, and this water cooling is provided in the spray pools. Ultimate heat sink is ambient air.

During power operations of the nuclear power units the main ways to remove heat to the ultimate sink are as follows:

- Through circulation water system – from the turbine condensers to the warm channel and via it – to the Danube river;
- Through system for service water supply to consumers of normal operation systems – to the warm channel and via it – to the Danube river;
- Through system for service water supply to consumers of the safety systems – to the spray pools and then – to ambient air.

After the reactor is shut down, fuel decay heat in the core is removed in two stages:

(1) through the secondary circuit, in steam water mode from the hot state to state at which it is possible to transfer to cooldown via emergency and planned cooldown system.

(2) through the primary circuit via emergency and planned cooldown system on cooling circuit. Cooling of the safety system consumers is provided through the system for service water supply to safety system consumers to the atmosphere. Subcriticality is maintained by insertion of the control rods and by primary boric solution injection systems.

At complete unavailability of the secondary circuit systems, reaching of the primary circuit parameters at which it is possible to transfer to operation of the cooling circuit, „feed-and-bleed" procedure may be applied.

During cold condition, the main way to remove heat to the ultimate heat sink is through service water supply system of safety system consumers via the spray pools to the atmosphere.

5.1.3.2 Loss of main ultimate heat sink

<u>5.1.3.2.1 Schemes and procedures on heat removal to alternative heat sinks</u>

At loss of access to the Danube river due to simultaneous loss of BPS and/or low-pressure channels and emergency pump station and its pipelines to the emergency volume, in these cases heat release from the core of each of the nuclear reactors 5 and 6 is provided via self-contained circuit through the service water supply system to the safety systems consumers through the spray pools to the atmosphere.

Each spray pool is designed to remove entire heat released from the unit during emergency mode, and to maintain inlet service water temperature for safety system consumers cooling within the range of $+4^{o}C$ to $+33^{o}C$.

<u>5.1.3.2.2 Time limitations for use of alternative heat sink and capabilities to increase the time available</u>

At initial water level in the given spray pool, correspondent to maximum, and at wind speed less than 2 m/s, the pool can operate without filling during 30 hours. At this water level in it reduces on 1.5 m. Loss due to steaming and water entrainment is $170 \div 175\ m^3/h$.

In order to fill one spray pool to minimum permissible level 2526 m^3 of water is required, and to maximum level – 7650 m^3.

Water supply to the spray pools may be provided from:

- Motor-driven pumps of service water system for cooling of normal operation system consumers, 2 per unit, each with flowrate of $1440 m^3/h$. The pumps can operate at level of the cold channel above elevation 28 m.

- Diesel-pumps of service water system for cooling of normal operation system consumers, 2 per unit, each with flowrate of 290 ÷ 500 m^3/h. The pumps pump out virtually from the bottom of the cold channel and may use entire emergency reserve – 52264 m^3 in the intake chamber of CPS-3 and 21762 m^3 in the intake chamber of CPS-4.
- The pumps in shaft pumping stations, each with flowrate of 180 m^3/h. The pumps are of two groups with diverse power supply. One pump of each group may operate in each shaft pump station. Total flowrate to the spray pools is 1080 m^3/h. In case of overflow or breaking of the state dike the shaft pump stations will be flooded and their use for water supply to the spray ponds will not be possible.

Evaluation of time to exhaust of emergency volume is done considering the following conditions:

- One channel of service water system for cooling of nuclear-service consumers is sufficient to remove decay heat from the reactor and FSP (SFP);
- One pair of spray pools ensures cooling of per one safety system train of two units 5 and 6.

Assuming that at the start of water supply to the ponds, they are empty (water was drained completely) in order to fill the pair of the ponds to minimum level at which they are operable, 2x2526 = 5052 m^3 of water is required. Time required for that is:

- 53 min with motor-driven pumps of service water system;
- 2 h 35 min with diesel pumps of service water system.

To replenish for loss due to steaming and water entrainment in one pair of spray pools (340 – 350 m^3/h), operation of one of the motor-driven pumps or one of the diesel pumps is sufficient.

Considering emergency water reserve for CPS-3 and CPS-4 (totally 74026 m^3) and volume, required to fill both spray pools to permissible minimum (provided that they were completely drained), loss due to steaming and water entrainment from all the spray pools may be replenished for during 197 hours (8.2 days).

5.1.3.3 Loss of ultimate heat sink and loss of alternative heat sink

<u>5.1.3.3.1 Off-site actions envisioned to prevent fuel damage</u>

Required off-site actions are related with refilling of double spray pools and they shall be taken up to 8 days after the initiating event. At this stage such actions are not envisioned in the emergency response plan.

<u>5.1.3.3.2 Time required to recover one of the lost heat sinks or to initiate off-site actions on restoration of core cooling before fuel damage at different operational conditions</u>

In the following table results are summarized for robustness assessment for units 5 and 6 at loss of main ultimate heat sink and alternative heat sink. The following conditions of the units were assessed:

- Power operations (for initiating event 1 and initiating event 2);
- Cold condition (N=18 MW, 20 hours after shutdown), pressurized primary circuit and drained SG (for initiating event 3);
- Cold condition (N=18 MW, 20 hours after shutdown), pressurized primary circuit and non-drained SG (for initiating event 4);
- Cold condition (N=16.2 MW, 28 hours after shutdown), depressurized primary circuit (for initiating event 5).
- Outage cooldown of the primary circuit (N=12 MW, 72 hours after shutdown and N=6 MW, 18 days after shutdown) (for initiating event 6).

Table 5.1-4: Assessment of time period to fuel damage at initiating events with loss of ultimate heat sink.

Initiating event	Option	Time to fuel damage
–	Loss of bank and shaft pumping station	
1	Loss of vacuum in the turbine condenser	Reduced to initiating event 3, initiating event 4 or initiating event 5
2	Complete loss of make-up water to the SG	Reduced to initiating event 3, initiating event 4 or initiating event 5
3	Loss of primary circuit cooling due to failure of emergency and planned cooldown system at pressurized primary circuit and drained SG (Considered: make-up of SG with SG EMS and with one of auxiliary make-up pumps from chemically demineralised water system tanks)	> 295 h (12.3 days)
4	Loss of primary circuit cooling due to failure of emergency and planned cooldown system at pressurized primary circuit and non-drained SG (Considered: make-up of SG with SG EMS and with one of auxiliary make-up pumps from chemically demineralised water system tanks)	> 298 h (12.4 days)
5	Loss of primary circuit cooling due to failure of emergency and planned cooldown system at depressurized primary circuit (Considered: drainage of ECCS three hydro accumulators)	> 204 h (8.5 days)
6	Loss of primary circuit cooling due to failure of emergency and planned cooldown system during the mode of outage cooldown of the primary circuit (Considered: drainage of ECCS three hydro accumulators)	> 206÷209 h (8.6 days)
–	Rupture of the connections between the spray pools and nuclear power units 5 and 6	
1	Loss of vacuum in the turbine condenser (Considered: make-up of SG with SG EMS and with one of auxiliary make-up pumps from chemically demineralised water system tanks)	> 99 h 30 min (4.2 days)
2	Complete loss of make-up water to the SG (Considered: make-up of SG with SG EMS)	27÷31 h
3	Loss of primary circuit cooling due to failure of emergency and planned cooldown system at pressurized primary circuit and drained SG (Considered: make-up of SG with SG EMS and with one of auxiliary make-up pumps from chemically demineralised water system tanks)	97:50 h (> 4 days)
4	Loss of primary circuit cooling due to failure of emergency and planned cooldown system at pressurized primary circuit and non-drained SG (Considered: make-up of SG with SG EMS and with one of	100:50 h (> 4.2 days)

Initiating event	Option	Time to fuel damage
	auxiliary make-up pumps from chemically demineralised water system tanks)	
5	Loss of primary circuit cooling due to failure of emergency and planned cooldown system at depressurized primary circuit (Considered: drainage of ECCS three hydro accumulators and use of reserve in the boron control system tank)	19:45 h
6	Loss of primary circuit cooling due to failure of emergency and planned cooldown system during the mode of outage cooldown of the primary circuit (Considered: drainage of ECCS three hydro accumulators and use of reserve in the boron control system tank)	
	3 days after shutdown	25:51 h
	18 days after shutdown	50:12

5.1.3.4 Loss of ultimate heat sink, in combination with station blackout (i.e. loss of off-site and emergency power supply to the site)

Simultaneous loss of power supply and ultimate heat sink is considered as:

- Loss of off-site power supply and all the stationary AC sources at the NPP site (emergency and additional DGs);
- Loss of main ultimate heat sink, defined as loss of Danube river water intake structures.

As a result of postulated off-site initiating event it is assumed that loss of operability occurs to:

- Open switchyards of Kozloduy NPP;
- Emergency DGs;
- Additional DGs;
- Bank pumping stations and their structures, including DG;
- Shaft pumping station.

For accident management the following can be used

- Mobile DG and their powered facilities;
- Emergency water volume in the cold channel;
- Pumps with own diesel motor, including fire-protection ones;
- Category I loads of the power supply to discharging of the SS accumulator batteries;
- Manually-operated valves;
- Other equipment which is not affected by the initiating event.

<u>5.1.3.4.1 Time of independence of the site before fuel damage occurs due to loss of primary circuit water</u>

Below is described response of the power units 5 and 6 at different operational conditions.

Table 5.1-5: Assessment of time period to fuel damage at initiating events with loss of power supply and ultimate heat sink.

No.	Initial condition of the unit	Assessment result
1.	Power operations	Event is reduced to scenario of loss of normal and standby power supply, failure to all emergency DGs and additional DG. Time to core damage: 45 – 49 hours
2.	Shut down reactor, planned cooldown at pressurized primary circuit and drained SG	Event is reduced to scenario of loss of normal and standby power supply, failure to all emergency DGs and additional DG. Time to core damage: 66 hours 44 min
3.	Shut down reactor, planned cooldown at pressurized primary circuit and non-drained SG	Event is reduced to scenario of loss of normal and standby power supply, failure to all emergency DGs and additional DG. Time to core damage: 69 hours 44 min
4.	Shut down reactor, planned cooldown at depressurized primary circuit	Event is reduced to scenario of loss of normal and standby power supply and failure to all emergency DGs and additional DG. Time to core damage: 7 hours 28 min
5.	Shut down reactor, outage cooldown	Event is reduced to scenario of loss of normal and standby power supply and failure to all emergency DGs and additional DG. Time to core damage: - 3 days after shutdown: 9 hours 15 min - 18 days after shutdown: 16 hours 53 min

5.1.3.4.2 Off-site actions envisioned to prevent fuel damage

Emergency response plan envisions usage of the mobile DG.

5.1.4 Measures to improve robustness to loss of ultimate heat sink

Assessment is performed on condition, efficiency and availability of emergency water supply system from Shishamnov val;

5.2 FSP (SFP) OF UNITS 5 AND 6

5.2.1 Loss of power supply

5.2.1.1 Loss of off-site power supply

5.2.1.1.1 Design schemes at loss of off-site power supply, sources, capacity and availability for operation of emergency power supply

Spent Fuel Pools (SFP) are located in the containments and serve to store and maintain the spent fuel (to reduction of decay heat to the permissible level) during not less than three years.

By 30.06.2011 in SFP 5 355 fuel assemblies and in SFP 6 365 fuel assemblies are stored.

SFP cooling systems are the part of units 5 and 6 systems. Correspondingly normal and standby power supply of SFP cooldown system of units 5 and 6 is similar to normal and standby power supply to the reactor installations. These systems are classified safety related normal operation systems. These are three-train systems (redundancy 3 x 100%) and are powered from the emergency DGs.

5.2.1.1.2 Independence of the emergency power supply sources and measures to prolong operational time

With two emergency DGs in operation (one per unit) total reserve of fuel and oil of the emergency DGs is sufficient for more than 38 days.

5.2.1.2 Loss of off-site power supply and loss of emergency DG

The following Table provides the times for heating and evaporation of water to the level of the heated part of the assemblies in case of loss of off-site and emergency power. Two options for different fuel quantities have been considered. The first one for the current amount of spent fuel by 30.06.2011 and the second with all fuel removed from the core in the SFP after the reactor is taken out for a refuelling outage. The initial level in the SFP in each case is considered the one adequate for normal operation +28.80 m.

If the additional DG is available, durations specified in the table prolong at least to 19 hours due to usage of water reserves in the boron system tanks.

Table 5.2-1: Time to occurrence of the main events in SFP in case of complete loss of alternate current power supply.

Parameter	FSP 5	FSP 6
Spent fuel only		
Time for heating from 50ºC to 100ºC [h:min]	22:52	39:53
Time from 50ºC to start uncoverage of the fuel assembly [h:min]	136:21 (more than 5 days)	237:47 (more than 9 days)
Spent fuel and unloaded core		
Time for heating from 70ºC to 100ºC [h:min]	1:52	1:48
Time from 70ºC to start uncoverage of the fuel assembly [h:min]	17:28	16:51

5.2.2 Measures to improve robustness at loss of power supply

These systems for power supply of the SFP are the same which ensure power supply to units 5 and 6, with exception of the additional DG and mobile DG. If the proposal related to units 5 and 6 is implemented, reliability of the power supply to the SFP cooldown system will enhance.

5.2.3 Loss of ultimate heat sink

At failure to all the trains of SFP cooling system, as well as at isolation of the containment, decay heat removal from the stored fuel is provided through pool water steaming. To prevent impermissible level reduction in fuel compartments and uncoverage of the fuel emergency scheme is used for filling through one of the containment spray system pumps with water from ECCS tank-sump. The pump motor is cooled by service water system for cooling of the safety system consumers.

Response of the equipment at loss of ultimate heat sink is the same, as at loss of power supply, but heat removal stops significantly later – after exhaust of emergency water volume from the cold channel and termination of spray pools make-up. Thus durations, analyzed for the case of complete loss of alternate current power supply, specified above, prolong on 197 hours (8.2 days).

A possibility exists to supply service water by diesel-pumps from the inlet chamber of CPS-3 (CPS-4) to the first train of service water system for cooling of safety system consumers. Scheme is proposed, according to which cooling can be ensured for the motors of the pumps of the first train of the emergency core cooling system. Thus, due to water reserve in the tank-sump, steaming from

SFP may be replenished for 32 h 15 min at the most severe conditions (the fuel is relocated from the reactor to the SFP).

If boric solution reserve is used in the tanks of boron system, time period during which loss due to steaming can be compensated for, prolongs on at least 19 hours. In this case operation of the pumps, used for filling, is independent from operation of service water system.

5.2.4 Measures to improve robustness to loss of ultimate heat sink

The main mean to improve robustness of SFP-5 and SFP-6 is to ensure make-up of the spray pools (proposal introduced above in par. 5.1.4.

5.3 SFP OF UNITS 3 AND 4

5.3.1 Loss of power supply

5.3.1.1 Loss of off-site power supply

5.3.1.1.1 Design schemes at loss of off-site power supply, sources, capacity and availability for operation of emergency power supply

Main and standby power supply

After shutdown of units 3 and 4 at the end of 2006, their consumers are powered from the start-up auxiliary transformer which is energized from OSY 220 kV. Standby power supply is provided to units 3 and 4 from OSY 110 kV through units 1 and 2 (shut down, without fuel in the SFP) and through the connections between busbars of standby power supply between units 1 ÷ 4. As standby power supply, power supply from OSY 400 kV may also be used.

Emergency alternate current power supply

- Emergency DGs of units 3 and 4

In condition „E" of units 3 and 4 their consumers, which require reliable power supply for category II, receive power supply from 6 diesel-generator sets (three per unit, redundancy 3x100%).

- Emergency DGs of additional system for emergency make-up of SG (ASSGEM)

At loss of off-site power supply and impossibility to supply power from emergency DGs, power supply to the pumps for SFP cooling is provided from emergency DGs of the additional system for SG emergency make-up (two per unit).

5.3.1.1.2 Independence of emergency power supply sources and measures to prolong operational time

- Emergency DGs of units 3 and 4

Fuel and oil reserves for emergency DGs ensure their uninterrupted operation for more than 4 days.

- Emergency DGs of additional system for SG emergency make-up (ASSGEM)

Fuel and oil reserves for emergency DGs of ASSGEM ensure their uninterrupted operation during 5 days.

5.3.1.2 Loss of off-site power supply and loss of emergency diesel-generators

Assessments done for changes of temperature and water steaming in the SFP due to complete loss of all power supply sources indicate that time to start of fuel assembly uncoverage at power of decay heat up as of 01.08.2011 are correspondingly:

- For SFP-3: 6.8 days [143];
- For SFP-4: 9.2 days [143].

5.3.2 Measures to improve robustness at loss of power supply

Power supply to the systems for fuel cooling in SFP-3 and SFP-4 is provided from diverse physically separated sources (emergency diesel generators – three per unit, emergency diesel-generators of ASSGEM, mobile DG). At low value of the decay heat from the fuel stored in the pools, available time reserve before the fuel uncoverage is started is about one week for SFP-3 and more than 9 days for SFP-4 at assumption of complete loss of cooling. Consequently no additional measures are required to enhance robustness of SFP-3 and SFP-4.

5.3.3 Loss of ultimate heat sink

5.3.3.1 Design bases to remove heat to main ultimate heat sink

Decay heat removal from spent fuel in SFP-3,4 is provided from SFP cooling systems. Through the heat exchangers of these systems, heat is transferred to service water system for cooling of safety system consumers. After cooling, due to steaming in the spray pools, water is delivered back to the cold channel.

5.3.3.2 Loss of main ultimate heat sink

Alternative way to remove heat from SFP is usage of – as the ultimate heat sink – cooling water from the inlet chamber before CPS, as supplied by the diesel-pumps, located in FPS-2, to the heat exchangers for SFP cooling.

If it is impossible to remove heat via normal scheme, this may be provided due to steaming from water surface. To replenish for loss due to steaming, two possibilities are envisioned: with SFP filling pump – from the tank-sump (EMT) or other tanks and with diesel-pumps of FPS-2 from the cold channel.

There are many alternative ways to remove heat from SFP (described in emergency procedures), which are ensured with independent power supply (electric or with diesel motor) and with diverse water sources. Due to that at loss of main ultimate heat sink, loss of safety function „Heat removal from the spent fuel stored in the reactor building but outside to the reactor" is not expected.

5.3.3.3 Loss of ultimate heat sink and loss of alternative heat sink

Times to occurrence of main events at complete loss of all the possibilities for cooling and filling of SFP-3,4 before uncoverage of fuel assemblies stored in the pools are the same, as at complete loss of AC sources.

5.3.3.4 Loss of ultimate heat sink, in combination with station blackout (i.e. loss of off-site and emergency power supply at the site)

Times to occurrence of the main events are the same, as at complete loss of AC sources.

5.3.4 Measures to improve robustness to loss of ultimate heat sink

In relation with SFP-3 and SFP-4 no measures are required to enhance robustness to loss of ultimate heat sink.

5.4 SPENT FUEL STORAGE FACILITY (SFSF)

5.4.1 Loss of power supply

5.4.1.1 Loss of off-site power supply

5.4.1.1.1 Design schemes at loss of off-site power supply, sources, capacity and availability for operation of emergency power supply

Standby power supply is provided from the DG of the SFSF and from UPS device. The standby DG energizes on priority the systems for radiation monitoring, pool filling and make-up system and leakage return system, ventilation systems. Later other consumers may be powered.

SFSF may be energized also from the mobile DG.

5.4.1.1.2 Independence of emergency power supply sources and measures to prolong operational time

Total fuel reserve ensures operation of DG of the SFSF during 72 hours (3 days).

5.4.1.2 Loss of off-site power supply and loss of emergency power

Analysis of the postulated initiating events due to loss of power supply to SFSF shows, that uncoverage is not reached for the spent fuel, located in storage pool, in the containers or storage tubes.

Assessments done for water heating and steaming in the most loaded compartment of the pool show, that start of assembly uncoverage is after more than 29 days.

5.4.1.3 Loss of off-site power supply, emergency power supply and additional alternate current power supply

5.4.2 Measures to improve robustness to loss of power supply

It is reasonable to analyze the possibility of installation of independent water cooling system to the SFSF compartments, with independent power supply.

5.4.3 Loss of ultimate heat sink

Connection of SFSF with ultimate heat sink of the Danube River is provided by service water supply system. SFSF is provided with service water via two independent lines of these systems of units 3 and 4.

At complete loss of the main and alternative heat sinks, due to low value of decay heat release, heat may be removed to ambient air due to steaming. Effect of absence of possibility to replenish for losses is the same as at loss of the power supply. Times to occurrence of main events, assessed for the case of complete loss of alternate current power supply, should be increased with the time of reduction of emergency water reserve in the intake chamber of CPS-2 below elevation of water intake from the pumps of service water system for cooling of safety system consumers of units 3 and 4.

In addition, analysis was conducted for beyond design basis accident with complete loss of water in the SFP due to beyond design basis earthquake, at which ground stability is affected and significant cracks open in the reinforced concrete of the SFP.

Drainage of fuel storage compartments at existing condition of SFSF and simultaneous failure to all systems and unavailability of natural ventilation will bring to significant increase in temperature of fuel elements (to 600°C) and of the civil structure (up to 340°C), which is not permissible from the point of view of safety margins for safe SF storage but will not result in fuel melting [110].

Analysis of events with complete loss of power supply cover also events with complete loss of cooling of the SFP (loss of ultimate heat sink).

5.4.4 Measures to improve robustness of SFSF to loss of ultimate heat sink

In relation with SFSF, no measures are proposed to enhance robustness to loss of ultimate heat sink.

5.5 CONCLUSION

A reassessment of the safety margins of the nuclear installations at the Kozloduy site is performed for the events with consequent loss of safety functions that would lead to a severe accident. The scope includes the nuclear reactors and the spent fuel pools of units 5 and 6, the spent fuel pools of units 3 and 4 and the spent fuel storage facility. The reassessment is based on safety analysis performed with deterministic approach.

The results of the analysis of postulated initiating events with loss of power and loss of ultimate heat sink show in general strong robustness of the provisions and adequate time period for implementation of additional recovery actions. Specifically, the results imply that:

- Due to the low value of residual heat loss of electrical power and/or ultimate heat sink in SFP does not lead to severe damage to the fuel, including total loss of water in the storage pool;

- The low value of residual heat in SFP-3 and SFP-4 provides sufficient time for recovery of failed safety functions (6.8 days for FSP-3 and 9.2 days for FSP-4);
- Most vulnerable are Units 5 and 6 and their spent fuel pools.

During power operations and in cold state but with pressurized primary circuit the reactors are the most robust against loss of power and ultimate heat sink because:

- The residual heat from the core can be removed to the secondary circuit. The ultimate heat sink is air (steam discharge from safety or relief valves of SG) ;
- Multiple sources of water can be used for the steam generators make-up depending on the source of power;
- All available sources of power supply can be used.

At failure to all power sources (main, backup, emergency DGs, additional DGs, and mobile DG) before the start of core damage the operator has not less than 16 hours.

The worst case of loss of the ultimate heat sink is disconnecting the power units from the spray pools. In this case under the above conditions, the shortest time to the core damage is over 28 hours.

Reactors are most vulnerable in cold depressurized primary circuit because:

- The ultimate heat sink is atmospheric air, the connection to it is ensured only through the spray pools;
- There are no systems powered from mobile DG to provide heat removal from the primary circuit or to fill it.

The minimum time to fuel damage is up to 7 hours and 30 minutes at failure of both- the emergency and the additional DGs.

At loss of the ultimate heat sink, except in the event of disconnection of the units from the spray pools, time to core damage is extended with the time for the depletion of water in the emergency inventory of the cold channel (197 hours or 8.2 days). Minimum time in cold state and with reactor depressurized amounts to 19 hours and 45 minutes.

The heat from the SFP of Units 5 and 6 is removed to the spray pools only. No systems powered from additional or mobile DG ensuring heat removal or filling of the pools. The loss of off-site power supply and the emergency DGs is equivalent to disconnection of the units from the spray pools. Minimum time reserves at the beginning of fuel uncovering are:

- Over 5 days in storage of spent fuel only;
- Less than 17 hours when moving all the fuel from the reactor to the SFP.

The critical element for the robustness of Units 5 and 6 and their pools are spray pools and their connections with the diesel generator stations, as:

- Spray pools are the only ultimate heat sink of the core with the cold and depressurized primary circuit and fuel in the SFP;
- Through them heat is removed from the emergency diesel generators and from the safety systems pump motors.

Therefore, the priority measures to improve the robustness of the units to extreme external events are:

- Technical solutions to prevent loss of water from spray pools;
- Ensuring alternative means of supplementing spray pools from independent sources;
- Technical solutions to enhance the reliability of tunnels and pipelines connecting the DGS with the spray pools.

Essential factor for the accidents management resulting from extreme external influences, including serious accidents is the availability of safety systems battery. Therefore, an important measure is to provide capabilities for the batteries recharging also from additional and the emergency DGs.

Specific suggestions for improving the robustness of Kozloduy NPP to loss of power and ultimate heat sink are as follows:

- To assess the status, effectiveness and availability of emergency systems for water supply from dam "Shishmanov Val";
- To deliver 2 new mobile DGs and the current one to remain in reserve for other facilities within the NPP area;
- To supply power to charge one of the batteries of safety systems from mobile DG;
- To analyze the possibility of installation of independent water-cooling system to the SFSF compartments, with independent power supply.

As a result of the performed regulatory review of the licensee stress-test report related to the loss of safety functions, it is concluded that the strong and the week plant features are correctly identified and that the proposed measures for further improvement of the robustness of the loss of power supply and of the ultimate heat sink are acceptable. In addition to the proposed measures, the Nuclear Regulatory Agency deems necessary to be considered and analyzed options for implementation of the following design provisions:

- Ensuring of power supply of the systems that implement primary decay heat removal or make-up functions in shutdown state with open primary circuit by a mobile DG;
- Ensuring of possibility for primary make-up in shutdown states with unavailable emergency DGs, e.g. by implementation of power supply by the batteries of the valve motors at the hydroaccumulators connecting pipes;
- Ensuring of power supply by the additional DG or mobile DG of systems that implement heat removal or make-up functions of the spent fuel pools of units 5 and 6.

6. SEVERE ACCIDENT MANAGEMENT

Requirements of the **Regulation on ensuring the safety of nuclear power plants** related to the management of severe accidents are presented in:

Section I "Design basis" of Chapter Two "Design basis and safety assessment", where according to:

"Art. 9. The design limits shall at least include:

4. criteria on protection of the containment, including temperatures, pressure and leak rates, considering the necessary margins ensuring its integrity and leak tightness in case of extreme external events, severe accidents and combinations of initiating events.

Art. 10. (3) For severe accidents, the limit of cesium-137 release in the atmosphere is 30 TBq that does not impose long-term restrictions for soil and water use in the monitored area. Combined release of other radionuclides different from cesium isotopes shall not in a long-term perspective, starting three months after the accident, provoke a greater hazard than the one identified for cesium release within the indicated limit.

(4) The frequency of a large radioactive release into the environment that requires undertaking of immediate protective measures for the population shall not exceed 1.10^{-6} events per NPP per year.

Art.14. (3) If the analysis of severe accident consequences does not confirm the implementation of the criteria under Art. 10, para. 3 and 4, the design shall consider additional technical measures for severe accident management aimed at mitigation of the consequences."

In Section I "General requirements to NPP" of Chapter Four "Safety Requirements for design of NPP and plant systems", where according to:

"Art. 32. (2) For all operational states and accident conditions the NPP unit shall be capable of performing the following fundamental safety functions:

1. control of the reactivity:

2. removal of the heat from the reactor core:

3. confinement of radioactive substances within the established boundaries.

Art. 33. Safety systems and SSCs important to safety shall perform the following safety functions:

13. to limit the radiation exposure to the personnel and public in and following design basis accidents and selected severe accidents that release radioactive material from sources outside of the reactor containment;

Art. 39. For management of severe accidents, plant design shall provide for the use of:

1. instrumentation, qualified for severe accident conditions, to provide the main control room with information allowing timely evaluation of plant status:

2. technical means for containment isolation, overpressure protection, management of combustible gases temperature and concentration:

3. technical means for prevention of high-pressure core melt scenarios and containment melt through.

Art. 45. The frequency of core damage in a severe accident, determined on the basis of probabilistic safety analysis, shall be sufficiently lower than 10^{-5} events per NPP per year.

Art. 46. The characteristics of nuclear fuel of reactor structures and of reactor coolant system components (including the coolant clean up system) shall exclude re-criticality in severe accidents, considering the operation of the other systems.

Art. 61. (1) Natural phenomena and human induced events, specific to the NPP site, shall be taken into account in the design of the systems and in the possible choice of diversity in the ultimate heat sinks.

(2) Adequate consideration shall be given to the residual heat removal from the reactor core and cooling of the localization system components in case of a severe accident.

Art. 74. Design shall include the possibilities for heat removal from the core during severe accidents.

Art. 76. (2) In establishment of confinement functions, provisions shall include a leaktight structure-systems and means for control of containment parameters, for containment structure isolation, and for reducing the concentration of fission products, hydrogen and other substances that could be released in the containment atmosphere during and after design basis and severe accidents.

Art. 77. (2) Design shall include means for containment structure surveillance in all operational states and design basis accidents. Design shall make provisions for maintaining the integrity of the containment structure in the event of a severe accident with account taken of the effects of any predicted combustion of flammable gases.

Art. 78. (2) Design shall ensure possibilities to control containment radioactive leakages in case of a severe accident.

Art. 80. (3) Design shall include the arrangements to maintain the functionality of isolation devices during a severe accident.

Art. 81. (2) Design shall include the arrangements to ensure capability of isolation devices to maintain their functionality in the event of a severe accident.

Art. 82. Containment design shall include measures and technical means to ensure sufficiently low pressure difference between the separate internal compartments not to challenge the integrity of pressure bearing structure or of other systems with confinement functions, taking into account the pressure and the possible effects resulting from design basis and severe accidents.

Art. 83. (2) Design shall include the arrangements to ensure the capability of heat (generated as a result of a severe accident) removal from the containment.

Art. 84. (3) Design shall include the arrangements to ensure control of concentrations of radioactive fission products, hydrogen and other substances that may be generated or released in the event of a severe accident."

In Section IV "Operation" of Chapter Five "Construction, commissioning and operation of NPP", where according to:

"Art. 124. (1) Operators actions for diagnosis of plant state, for re-establishment or compensation for lost safety functions, and for prevention and mitigation the consequences of a core damage, shall be specified in severe accidents management guidelines and symptom-based emergency operating instructions (AB EOI).

(2) The set of AB EOI shall include:

1. diagnosis procedures:

2. procedures for optimal recovery in case of transients and design basis accidents:

3. procedures for monitoring the plant state and for restoration of safety functions, such as subcriticality. core cooling, heat removal, coolant inventory, integrity of the reactor coolant pressure boundary and containment integrity;

4. procedures for transition to severe accident management.

(3) For development of AB EOI their format, structure and contents shall be specified in a way that:

1. gives precise, clear and sufficient guidance to the personnel to perform the prescribed actions, including when a transition to other procedures, instructions and guidelines is needed;

2. it is easy to distinguish them from the normal operation procedures and easy to use them;

3. they include directions for monitoring of specified technological parameters (symptoms), for following the automated system response, main operator actions for immediate implementation and the anticipated result of them, and alternative operator actions in case of failure of the main ones:

4. the supplementary background information that aids the operators to follow the procedures is clearly separated.

(4) The data used for development of the documents under Para. 1 shall be specific to the corresponding nuclear plant (unit). The effectiveness of the operator actions shall be analytically validated using verified computer codes and plant specific calculation models. The results of the analysis shall be documented and used as a technical basis of the instructions.

(5) Accident procedures shall be verified and validated by an independent team of experts according to established internal rules (programs) in the form, in which they are used. The practical capability for implementation of operators actions shall be validated using simulator tools.

(6) The up-to-date status of the procedures for accidents shall be periodically verified."

Requirements of the **Regulation on emergency planning and emergency preparedness in case of nuclear and radiological emergency**, having regard to the management of severe accidents are:

In Chapter One "General Provisions", where according to:

"Art. 1 (1) This regulation shall establish:

1. The conditions and order for development of emergency plans;

2. The persons who implement the emergency plans and their obligations;

3. The actions and measures for mitigation (localisation) and liquidation of the consequences of a nuclear or radiation accident, hereinafter referred to as "accident";

4. The methods for informing the general public;

5. The order of maintaining and testing of the emergency preparedness.

(2) This regulation shall establish also the order of interaction between the licensee and relevant permit holder in accordance with the Act of Safe Use of Nuclear Energy (ASUNE) and the central and local executive bodies during implementation the measure laid down in art.1 (1) 3.

Art.2 (1) The actions and measures for mitigation and liquidation of the consequences of an accident shall be planned, determined and implemented on the basis of the assessment of the radiation risk evaluation and type of facility, category of the radioactive source, site or practice creating risk, as well as the accident classification.".

In Section I "General provisions" of Chapter Two "Emergency planning", where according to:

"Art. 6. (1) Emergency planning is an activity of establishing into emergency plan of a system of measures for mitigating and liquidation of the consequences of an accident and for creation and maintaining of emergency preparedness.

(2) Emergency planning shall be based on the analysis of potential scenarios for arising and development of accidents and assessment of risk of the radiation consequences from these accidents for the personnel, population and environment.

(3) The goals of implementation of the measures defined in the emergency plan are to mitigate and reduce the accident consequences to human health, quality of life, property and environment, as well as is the basis for the resumption of normal social and economical conditions of life after liquidation of the consequences of the accident."

In Section II "On-site Emergency Plan" and Section III «Off-site Emergency Plans", which regulates the development of on-site and off-site emergency plans and identify the responsible parties.

In Chapter Three "emergency response", which regulates the procedures for emergency response interventions, intervention criteria and informing the population.

In Chapter IV "Maintaining emergency preparedness", which according to:

"Art.43. To maintain the emergency preparedness, the licensee or relevant permit holder and executives bodies shall ensure that the members of the emergency response teams:

1. Possess the necessary qualification, experience and skills to implement the emergency plans;

2. Have passed over training for implementation of the emergency plans, relevant procedures and operational instructions and for proceeding with the foreseen technical means;

3. Periodically passed over different types of training for maintaining and enhancing their qualification, experience and skill."

6.1 ORGANISATION AND ARRANGEMENTS OF THE LICENSEE TO MANAGE ACCIDENTS

6.1.1 Organisation of the licensee to manage the accident

By initiating Emergency Plan of Kozloduy NPP [25] (EP), emergency response organization is put into force (Appendix 4.1.1-1 of [25]) including in it elements of the organizational structure at normal operation.

The responsible post holder for entire management of activities according to EP is Emergency Response Officer. Before Emergency response teams are established the Shift Supervisor (Duty officer) of the NPP (CD NPP) performs responsibilities and duties for emergency response of Emergency Response Officer activities, as follows:

- CD NPP (Power Generation 1) - in case of accident at Units 1 to 4 and common-plant facilities (open switchyard-OSY, bank pump station-BPS, spent fuel storage-SFS);
- CD NPP (Power Generation 2) - for units 5-6 and Specialized Division "RAW-Kozloduy/Radioactive waste-Kozloduy".

Initiating of the emergency organization is provided in three levels depending upon Emergency conditions:

- level "I" - at accident class "ALERT";
- level "II" - at accident class "SITE ACCIDENT";
- level "III" - at accident classes "LOCAL ACCIDENT" or "GENERAL ACCIDENT".

This emergency organization is based on preliminary organized and continuously maintained emergency duty of the usual staff in Kozloduy NPP, as regulated in a separate instruction which ensures obstacle-free establishment of the correspondent emergency structures depending upon location of the accident facility.

Functional dependence between accident class, content of emergency response structure and location is shown in Appendix 4.1.1-2 [112].

After their configuration at alerting the EP personnel, the Emergency teams receive status of "emergency response personnel". Status of "emergency response personnel" is assigned also to personnel of additionally ensured emergency teams (maintenance, other personnel in Kozloduy NPP, as well as to personnel of off-site emergency response organizations) for performing of emergency response activities.

Specific responsibilities of the job positions of the Emergency plan for performing these responsibilities are regulated in separate instructions and procedures. This documentation is disseminated and stored at the work places assigned to the personnel of Emergency teams after initiating of EP.

Actions of services, performing actions on the EP, are regulated in separate plans, reconciled and approved according to the order established.

At establishment of Emergency structures the executive director in Kozloduy NPPor his deputy may carry functions of manager of the Emergency activities, and the related record is introduced to Emergency Response Officer activities' register and signed.

Management team (MT) is subordinate to Emergency Response Officer activities and is alerted at all emergency conditions. Before arrival and establishment, its functions are performed by the operating shift personnel under management of the correspondent CD NPP.

Depending upon emergency condition, members of MT and emergency personnel (operating on duty) are positioned on:

- their workplaces:
  - main control rooms (MCR);
  - control room of the open switchyard (CR OSY);
  - command room of bank pump station (CR BPS), or in
- accident management centre (AMC).

Detailed information about the duties of positions in the emergency plan and procedures for their implementation is given in the following documents: [25], [72], [113] to [124] and [130].

6.1.1.1 Staffing and shift management in normal operation

Operative management at operations of installations in Kozloduy NPPis provided by operational shifts for 24 hours per day, 7 days per week. It is distributed to 5 shifts which are ensured and 2 standby shifts.

The top operative shift manager is Shift Supervisor of the Nuclear Power Plant (CD NPP), correspondingly CD NPP (Power Generation 1) – for units 1 to 4 and CD NPP (Power Generation 2) – for units 5 and 6. He is responsible for maintaining technical specification requirements at operation of the installations, as well as for organization and conduct of immediate actions in case of accident, natural phenomena and disasters and for the first aid.

According to Instruction on operative interfaces [111] in Kozloduy NPP during the accident operative manager of the shift personnel of the given division performs functions of operative manager on accident liquidation for personnel of the related division.

Personnel in Kozloduy NPPis trained and instructed to report to the related operations manager of the division on each event which can bring to reduction of safety level at operation of the plant installations. This is the precondition for timely assessment, definition of emergency condition and taking of the correspondent measures.

6.1.1.2 Plans for strengthening the site organisation for accident management

In case of physical isolation caused by external hazard, e.g. flooding will be mobilized additional staff (operators and maintenance).

It is necessary to revise the emergency plan to take into account of possible effects caused by physical isolation caused by external hazards.

6.1.1.3 Measures taken to enable optimum intervention by personnel

The structure and responsibilities of the Management team are shown in Appendix 4.1.2.1-1 of [25] and Figure 6.1-1 demonstrates the organization of emergency response.

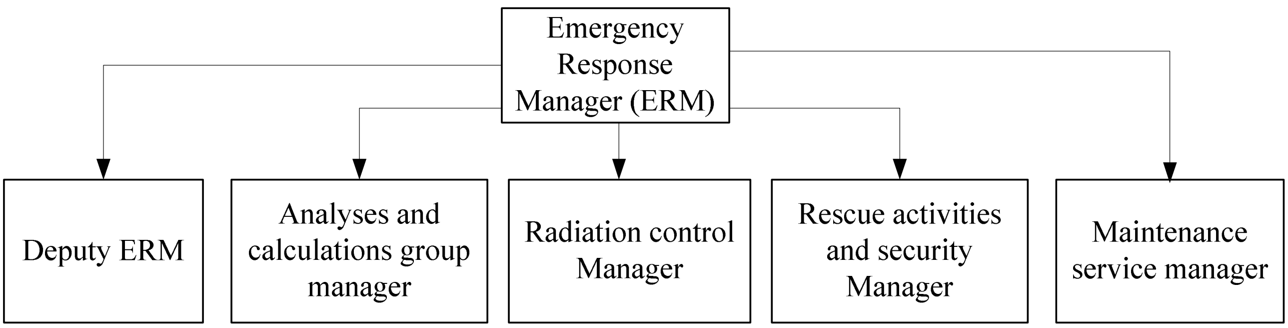

Figure 6.1-1: Structure of the Organization of Emergency Response in KNPP

The MT performs the following main tasks:

- arranges for receipt of information on the conditions of affected facilities and the operating units;
- manages activities on assessment of accident;
- prepares decisions for:
  - taking of measures on protection of the personnel and on accident management;
  - establishment of additional reserve teams - if required;
  - shut down or maintaining in operation of non-affected units;

- supply of required materials, raw materials and spare parts for performing of urgent repair-and-recovery activities;
- requesting support from the National Headquarters on Control and Coordination (NHCC) and from Ministry of Economy, Energy and Tourism;
- starting of recovery activities;
- stoppage of activities according to Emergency Plan and restoration of functional capabilities of failed facilities.

• prepares and forwards messages to higher-level authorities and local municipal authorities, according to the flowchart provided in Appendix 6.9-1 [126] of [25].

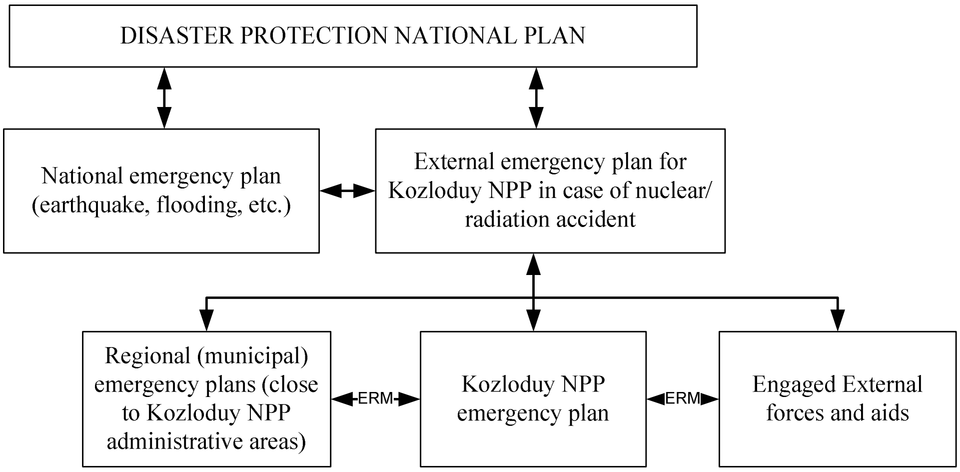

Figure 6.1-2: Chart for interaction with the state control authorities, local authorities in case of an accident at the KNPP

6.1.1.4 Use of off-site technical support for accident management

After initiating of the EP, Emergency Response Officer activities periodically informs on accident progress and measures taken to localize it and to mitigate the consequences:

- to emergency centre of Nuclear Regulatory Agency;
- to on-duty officer in General Directorate of Fire Safety and Public Protection - Ministry of Interior (GD FSPP);
- person on duty in Ministry of Economy, Energy and Tourism;
- persons on duty in Municipality Kozloduy and Municipality Mizia;
- on-duty persons in Operative communication and information centres (OCIC) in Vratsa and Montana.

Off-site forces and means involved in providing support to Kozloduy NPP, are defined in National emergency plan for conducting of rescue and urgent emergency-recovery activities at occurrence of disasters, accidents and disasters.

At “local accident” or “general accident” Emergency Response Officer coordinates joint emergency measures with GD FSPP and its teams, involved in providing support to Kozloduy NPP. Under management of the Emergency Response Officer, joint actions are provided between involved forces and on-site teams and teams at the site territory and at the PAZ (precautionary action zone).

Maintaining of non-affected facilities in a safe condition and mitigation of consequences at the affected facilities is executed by emergency personnel in Kozloduy NPP in accordance with existing procedures and directives, received from NRA and MEET.

If required, the technical decisions are developed and reconciled on repair-and-recovery activities.

For performing the tasks by the forces involved, Emergency Response Officer via Manager of support services alerts the technical managers in the situation through provision of the following data:

- information on radiation situation and accident progress;
- schemes of movement routes and facilities where tasks will be performed;
- dispatching of divisions to preliminary defined sites in vicinity of accident location and instructing in the situation;
- support by radiation monitoring specialists;
- data exchange for maintaining uninterrupted communications and control.

Emergency Response Officer maintains uninterrupted interfacing and receives information from Evacuation Committee of Municipality Kozloduy for evacuation of plant personnel and their families in accordance with envisioned in National emergency plan deadlines and settlements.

Entire activity on organization of interfaces for conducting of localizing, rescue, protection and liquidation measures at beyond design basis, severe accident in Kozloduy NPP is provided by the Chairman of NHCC who coordinates and manages activities of involved forces and means, and the line management of divisions is delivered the technical managers.

Organization of interfaces and management of involved forces and means for conducting of localizing, rescue, protection and liquidation measures at the site of Kozloduy NPP is provided by the Emergency Response Officer activities.

General interface scheme at executing of joint tasks is shown in Appendix 6.9-1 of [25].

Summary time schedule for conducting of Emergency measures is provided in Appendix 6.11-1 of [25].

Table 6.1-1: General time schedule for emergency measures implementation

№	Emergency measure	Implementation deadline	Performer	Supervisor
1	Initial assessment of the initiating event (Accident classification) *(T_0 is accepted to be the time of event occurrence)*	Tclass.= T_0 + ≤ 15 min	Unit supervisor, operational personal	Shift supervisor (GR1 – ERM)
2	Emergency personal level I, II and III notification	Tclass. + ≤ 15 min	Telephone operator on duty	Shift supervisor (GR1 – ERM)
3	Notification of municipal authorities after accident classification. Notification NRA, National service of civil protection, Ministry of industry and energy, and Permanent Committee for civil protection against adversities, accidents and disasters Full-scale activation of the Emergency plan	Ткласс + ≤ 15 min T_0+ ≤ 1 h T_0+ ≤ 2 h	GR1 (ERM) GR1 (ERM) GR1 (ERM)	
4	Accident management activities: • immediate actions on limitation of accident progression; • analysis and periodical assessment of emergency status; • in case of significant development of accident progression;	 T_0 + ≤ 15 min once per hour Immediately	 Unit supervisor and GR2 GR3 GR3	 Shift supervisor (GR1) GR1(ERM)

№	Emergency measure	Implementation deadline	Performer	Supervisor
	• Strategies and procedures selection.			GR1(ERM)
5	Measures for protection of personal, emergency personal and civil protection:			
	• protective sheltering;	Immediately	GR5, GR6	GR1 (ERM)
	• iodine protective treatment;	Under certain criteria	GR4	GR1 (ERM)
	• Respiratory protection;	If necessary	GR4	GR1 (ERM)
	• Recommendations for immediate civil protective measures based on accident classification;	T_{class}+ <u>≤ 15 min</u>	GR3	GR1 (ERM)
	• Evacuation.	If feasible	GR5, GR6	GR1 (ERM)
6	Rescue measures implementation	If necessary	GR5	GR1 (ERM)
7	Personal registration and record keeping	Permanently	GR5	GR1 (ERM)
8	Measures for radioactive contamination control	Permanently	GR4	GR1 (ERM)
9	Decision for implementation of immediate protective measures on the site	T_0+ <u>≤ 30 min</u>	(GR1 - ERM)	
10	Completion of protective measures on the site	T_0+ <u>≤ 2 h</u>	(GR1-ERM)	
11	Monitoring implementation on:			
	• the site and protective zones;	T_0+ <u>≤ 1 h</u>		GR4
	• places of implementation of immediate rescue measures and other activities	T_0+ <u>≤ 1 h</u>		GR4
	• radiation survey of evacuation routes	T_0+ <u>≤ 2 h</u>		GR4
	• Routes for introducing of forces and aids	T_0+ <u>≤ 4 h</u>		GR4
12	Organization and interaction with national and regional authorities	After T_0+ <u>≤ 2h</u> <u>Permanently</u>	GR6	

6.1.1.5 Procedures, training and exercises

Actions of the personnel at design and beyond design basis accidents are defined in instructions for actions of the personnel in case of accident. Envisioned in instructions actions of the personnel result in bringing of the nuclear installations into safe condition.

Actions of the personnel on diagnostics of condition of Units 5 and 6, on restoration of or replenishment for failed safety functions and on prevention or localization of consequences of core damage are defined in symptom-based emergency instructions (SBEOP). SBEOP were developed on the bases of protection of fundamental safety functions with approach similar to the Westinghouse one, as step-by-step procedures with description of main and alternative operator actions in two-column format. SBEOP are controlled and maintained adequate to existing power capacity through strict on-site rules on verification and validation which envision multiple checks before these are introduced into operation. Analytic validation is conducted on an original technique provided by Department of Energy (DOE USA). The validation covers all design modes and wide range of accidents, included in and required by [1].

For Units 5 and 6, 3 sets are envisioned of SBEOP as follows:

- SBEOP for power operations;
- SBEOP for shut down reactor with pressurized primary circuit;
- SBEOP for shut down reactor with depressurized primary circuit.

SBEOP structure contains:

- procedures on diagnostics of condition;
- procedures on optimal recovery;

- procedures on recovery of CSFs (critical safety functions);
- procedures of ADP type (Accidents with destruction of protection).

Actions on SBEOP are alerted after actuation of the emergency protection and/or involvement of the safety systems. The structure and scope of SBEOP cover all design accidents and wide range of beyond design basis accidents.

Set of SBEOP on power operations is introduced into operation and distributed to operator workplaces.

SBEOP for shut down reactor with pressurized primary circuit has passed processes of verification and validation. Up to present operator training is conducted for work with instructions of this type, and after this they will be introduced into operation.

SBEOPs set for shut down reactor with depressurized primary circuit – will be subject to internal procedures of verification and validation at the NPP.

To these sets there are developed instructions for actions for response to emergency conditions in FSP in modes "shutting down for maintenance" and "REFUELLING".

For conducting of training full-scale simulator of units 5 and 6 (FSS 1000) is used which is maintained in accordance with reference unit 6, according to requirements of the regulatory authority and standards set in ANSI/ANS-3.5-1998.

Two types of training is delivered to the operators of the MCR - refreshment and introductory for licensing.

Introductory training for licensing of SRO, NUDE, CD NPP and RPh has various durations according to: „Regulation on conditions and procedure for enhancing of professional qualification and procedure on issuing licenses for specialized training and certificates for authorization for use of nuclear energy".

Refreshment training of the operators of the MCR is held according to preliminary approved schedule twice annually with duration of 5 training days. Training scenarios are developed on the basis of analysis of events which occurred at various NPPs, considering probability of such failures at units 5 and 6. Training is held by the licensed instructors. During the training on FSS 1000, the teams are trained to work on SBEOP to bring the reactor installation into steady-state and safe condition.

For severe accident management at Units 5 and 6 guidelines were developed for severe accidents (SAMG), which follow the format of SBEOP. Certain criteria are defined for transition from SBEOP to SAMG. SAMG will undergo internal procedures of verification and validation in NPP, followed by training of operators to work with them, then at the end of 2012 will be implemented.

SAMGs for Units 5 and 6 were developed on the basis of system analysis of the processes and phenomena during severe accidents [145]. The purpose of system analysis is to define the basis for knowledge of processes and phenomena, occurring at progress of severe accidents, all the technical means (equipment and systems), which allow for reaching of the set purposes in the course of severe accident management (SAM).

Strategies defined for severe accident management are the following:

- Pressure reduction in the primary circuit;
- Pressure reduction in the secondary circuit;
- Water injection to the primary circuit;
- Water injection to the secondary circuit;
- Pressure reduction in the containment.

SAMG includes three step-by-step procedures at the MCR:

- SAMG-00 Loss of 6 kV sources of electric power supply;
- SAMG-01 Initial actions at severe accident;
- SAMG-02 Long-term actions at severe accident.

and procedures on AMC in the format of the flowchart:

- SAMG-01 ‚Accident management at availability of sources of electric power supply";
- SAMG-02, Accident management at complete loss of sources of electric power supply".

Lecture course was developed and classroom training held for the managing personnel of the MCR on severe accident management guidelines [146].

In accordance with License for operation of Units 3 and 4, EMERGENCY INSTRUCTIONS were developed and introduced for regulating activities of the shift personnel to overcome the emergency conditions of fuel storage pool (FSP) during long-term storage of spent nuclear fuel (SNF) [55][56].

In accordance with License for operation of SFS EMERGENCY INSTRUCTION is developed and introduced for regulating activities of the personnel of SFS department to overcome the emergency conditions of SFS [104].

Mobile devices performance is regulated in a special procedure on connecting, starting-up and loading of the mobile diesel generator.[105], which is attached to the Kozloduy NPP Emergency plan [25]. This procedure is explained in details in paragraph 6.1.2.1.

For training on Emergency Planning the following is developed:

- program for training on Emergency Planning;
- courses for training in three levels:
  - the first level - for personnel, not included in groups and teams and of off-site organizations;
  - the second level - for emergency personnel – detailed studying of EP;
  - the third level - for emergency personnel, on the workplaces of positions of the EP with learning of Emergency procedures, instructions, methods, etc.

Training delivery is documented according to adopted in Kozloduy NPP system for personnel qualification.

Types of training, exercises, related participants and periodicity are shown in the following table.

Table 6.1-2: Types of training, exercises and participants

Seq. No.	Type of exercise	Participants	Frequency
1.	General emergency exercises	Emergency structures and remaining personnel	Once annually
2.	Separated emergency exercises	Separate working groups and teams of Emergency structures	Not less than twice annually
3.	Functional tests of tools for notification and information	Services for maintenance and servicing	Once per month

Training, emergency exercises and general emergency training is held according to approved by the Executive Director schedule and to preliminary developed and approved program.

Developed scenarios for Emergency exercises are used for conducting of such exercises with the Emergency teams.

The purpose of exercises for actions in case of an accident is to verify and maintain preparedness of the personnel to adequate actions in case of an accident in Kozloduy NPP.

During general emergency training the following is checked:

- operative preparedness of emergency personnel to correct and precise actions at accident;
- preparedness of MT and emergency personnel of the groups and teams to execute actual plan at accident situation;
- rapid and precise actions, organization, coordination and interfaces of Emergency teams;
- functioning of the systems for interfacing, notification and management during accident;
- preparedness and possibility for timely evacuation of the personnel;
- condition and operability of emergency technical means;
- interfaces and coordination with the off-site organizations and departments;
- functionality and applicability of developed personnel and public protection plan at possible accident at the NPP;
- preparedness and capabilities of the NPP personnel for prompt orientation and actions at accident situation;
- specific knowledge and skills of the personnel, their practical capabilities for actions at complicated accident situation.

During separate emergency drills the following is checked:

- operational preparedness of separate crews;
- notification;
- collection of the emergency team at the workplace according to Emergency Plan;
- review of the feasibility of various emergency plans.

6.1.2 Possibility to use existing equipment

6.1.2.1 Provisions to use mobile devices (availability of such devices, time to bring them on site and put them in operation)

Mobile diesel-generator (MDG) is one of measures on design modernization intended to improve safety and has the purpose of redundancy of diesel-generators (DG) and providing for emergency power supply to "reliable power supply" busbars at common-cause failures in Kozloduy NPP.

Procedure has been developed on transportation and actuation of MDG to the busbars in premises of the pumps of steam generators emergency make-up system (SG EMS). The established success criteria are the time from conditioning of alarm on complete loss of power supply to the pump actuation less than 2 hours. Performance criterion is confirmed by observation list of emergency training, provided that it does not take into account the destruction of infrastructure, which may occur as a result of external influences.

Total reserve of fuel and oil of MDG ensures its uninterrupted operation at nominal power during 21 hours and 40 minutes. To provide power supply only to the pump of the system for alternative make-up of the SG, the reserve is sufficient for 60 hours.

Figure 6.1-3: Kozloduy NPP. Mobile diesel generator.

6.1.2.2 Provisions for and management of supplies (fuel for diesel generators, water, etc.)

From the maintained reserves of fuel and oil in accordance with normative requirements, emergency instructions and technical specification in Kozloduy NPP it is calculated that:

- For units 5 and 6

Emergency DGs - at operation of two emergency DGs (one per unit) total reserve of fuel and oil of emergency DGs is sufficient for more than 38 days.

Accumulator batteries (AB) – see par.5.1.1.2.2.

Total reserve of fuel and oil of additional DGs ensures uninterrupted operation of each of them for more than 4 days.

- For units 3 and 4

Emergency DGs of units 3 and 4 - fuel and oil reserves for emergency DGs ensure their uninterrupted operation for more than 4 days.

Emergency DGs of additional system for SG emergency make-up (ASSGEM) - fuel and oil reserves for emergency DGs of ASSGEM ensure their uninterrupted operation during 5 days.

- For SFS - Fuel and oil reserves for emergency DG of SFS ensure its uninterrupted operation during 72 hours (3 days).
- For DSFS – Nuclear safety of DSFS does not depend upon availability of the power supply and availability of water.

Total inventory of boric acid solutions for primary circuit makeup:

- For units 3 and 4 is 1000 m^3;
- For units 5 and 6 is 1795 m^3

Total inventory of water for makeup with demineralised water:

- For units 3 and 4 is 3400 m^3;

- For units 5 and 6 is 1350 m^3
- For SFS is 500 m^3 in AB-2

6.1.2.3 Management of radioactive releases, provisions to limit them

The localizing systems have been executed in the design of the unit which ensure meeting the set criteria for localization of releases of the radioactive substances to the environment.

To execute the localizing functions, systems and means for controlling containment environmental parameters are installed in the containment, for isolating the containment and for reduction of concentration of radioactive substances of fission, hydrogen, other substances which may release to the containment environment during and after design and severe accidents. For performing of these safety functions the following systems have been installed:

- Containment system (CS);
- Spray system;
- Filtering pressure reduction system;
- Hydrogen recombination system.

Within modernization program the following measures were executed (section 12 of [4][5]), related to CS:

- Improvement of containment testing procedure;
- Qualification of cable penetrations and planning of their replacement;
- Installation of filtering ventilation;
- Development and introduction of severe accident radiation monitoring systems.

6.1.2.4 Communication and information systems (internal and external)

For Kozloduy NPP these are:

1. System for continuous measurement of the most important for safety process parameters

Visualization system of safety-related parameters is intended to support the operators at complicated situations of analysis of the condition of the unit and to monitor efficiency of operator actions, related to restoration of safe condition of the reactor through tabulated, graphical and schematic computer-aid displaying both main process parameters and calculated thermal physical parameters (or criteria), directly characterizing safety of the reactor.

For performing its functions the system continuously measures the most important for safety process parameters and by calculating them, takes information on Critical Safety Functions (CSFs). This information besides of the Main Control Room (MCR) can be also observed in AMC.

2. Systems of process radiation monitoring: These systems of process radiation monitoring are controlled from dosimetry control boards, where information is visualized and archived for:

- dose rate and concentration of radioactive gases and aerosols in non-attended and semi-attended premises and in various process media of the Reactor Building (RB) and Auxiliary Building (AB);
- amounts of gas aerosol and liquid radioactive releases.

This information can be monitored also in AMC.

According to recommendations of EUROATOM 2004 modernization of the system is performed.

3. Automated information System for off-site radiation monitoring: Automated Information System for Off-Site Radiation Monitoring (AIS OSRM "Berthold") includes:

- 2 Basic Stations (BS) and 8 Monitoring Stations (MS), which measure equivalent dose rate (EDR) of gamma-radiation and ground-level radiation of I-131. BS is located at the sites of Power Generation 1 and Power Generation 2 (each one); two of the MSs are located at NPP area, and the remaining – in PAZ (within the radius of 1.8 km of the NPP, at 45º from each other);
- 5 Water Stations (WS), which measure specific volume activity of waste water.

The system is integrated with National automated system for uninterrupted monitoring of radiation gamma background of Ministry on Environment and Water (MEW), by which conditions are ensured for early warning in case of radiation accident. This information can be monitored also in AMC.

4. Automated information system for radiation monitoring of the industrial site:

Automated information system for radiation monitoring of the industrial site (AIS RMIS) provides for information on level of gamma background in fourteen (14) points at the site of Kozloduy NPP. This information can be monitored also in AMC.

5. System for meteorological monitoring:

The system for meteorological monitoring (SMM) ensures representative for the region of Kozloduy NPP meteorological information, required to prepare of forecasts on radioactive transfers and dose rate loads in areas of Emergency Planning.

Automatic System for aero-logical observations (ASAO) allows for definition of speed and direction of main transfer and height of mixing layer for area of Kozloduy NPP.

ASAO System is integrated with the system of meteorological monitoring (SMM). Data from ASAO system is provided by national institutions.

These systems ensure uninterrupted monitoring as well as processing and archiving of data. Their operating stations are located in central radiation monitoring room (CRMR) in Power Generation 2 where conditions are created for work in case of radiation accident. Information from the AIS OSRM and SMM is also displayed in the AMC.

6. Monitoring of environment and the Kozloduy NPP site:

At the site of the Kozloduy NPP and in areas of preventive and urgent protection measures (PAZ and UPMA), field measurements are done by means of:

- three off-road vehicles;
- mobile laboratory.

Laboratory analysis of samples from environmental and from the site of Kozloduy NPP is performed in laboratories of “Radio environmental Monitoring” department. Preliminary processing of the samples, radiochemical isolation are performed there, as well as concentrated and consequent radiometric and spectrometric measurements in accordance with existing methods of analysis. This information can be monitored also in AMC.

7. Information system of the AMC:

Information system of the AMC (IS of AMC) is a set of hardware and software (firmware) means for information support (ensuring information and data exchange) between the management team of the emergency activities and the emergency personnel in the AMC.

IS of AMC receives input data from these systems for monitoring of safety-related parameters, automated radiation monitoring systems of the NPP and meteorological observation system.

Generated input data is used for assessment of the condition of facilities, radioactive releases and dose rates to public, and is required for decision-making and application of protection measures.

8. Warning and communication means:

Kozloduy NPP, in case of initiation of the Emergency Plan, has available the advanced warning system, which is intended to assure qualitative and reliable warning at the NPP site, as well as for settlements within 12 km area.

If required all other process means are used (pager, radio station, office telephone, home telephone, mobile telephone) for information, telephone and radio exchange and loudspeakers, with which it is possible to notify the personnel, managing authorities and public.

6.1.3 Evaluation of factors that may impede accident management and respective contingencies

6.1.3.1 Extensive destruction of infrastructure or flooding around the installation that hinders access to the site

On the basis of assessments done in relation with „Earthquakes" within the range of seismic impacts 0,26 < PGA ≤ 0,36g which is significantly beyond design 0,2 g, significant failures and damages are expected to seismically non-qualified structures and structures at the site. At the site, at this level of seismic impacts it is probable that all administrative buildings designed according to general industrial regulations (Administrative Building, Engineering Laboratory Building, medical centre) will be severely damaged and not available, and it is probable that seismically non-qualified process trestles will fail. There is a probability of failure to the bridges above the cold channel, and in this case direct connection between Power Generation 1 and Power Generation 2 may fail.

Such damages shall be expected also to buildings and infrastructure in vicinity of the site. Due to beyond design basis seismic impacts it is highly probable that the hospital and fire protection building in the town won't function normally. These secondary effects from the combined impact of the earthquake and sequential flooding shall be considered at planning of Emergency actions and at diversification of evacuation routes, delivery of required fuel and materials to the plant, at assessment of access of the shift personnel.

At seismic acceleration within the range of 0,26 < PGA ≤ 0,36g surely the upper part of ventilation stack of the auxiliary building AB-2 will be destructed. At its destruction, the top one third of the chimney (about 50 m) may affect partially the neighbouring site infrastructure (roads) that will cause difficulties in accessing SFS via these roads for the emergency teams or heavy machinery.

In the considered range of seismic acceleration, the SFS maintains capability to perform its functions of safe storage of the spent fuel.

Possible adverse effects of seismically induced damage to the national infrastructure around the plant on its ability to maintain their safety functions after the seismic event are detailed in item 2.9 of this report.

Analyses of „Off-site flooding" show that even volley discharge of entire volume of "Shishmanov val" dam cannot increase water level in the valley in vicinity of the plant more than elevation +29.00, therefore there is no hazard of flooding at the site and direct impact on safety functions. At assessment of response capabilities, it is required to consider possible flooding of the part of Kozloduy town and correspondingly possible difficulties in accessing the plant.

All scenarios of combination of the beyond design basis earthquake with flooding lead to loss of ShPS due to flooding. With their loss emergency make-up of the spray pools of Units 5 and 6 is also lost, i.e. time for ensuring of ultimate heat sink will be limited.

More important weaknesses were found at studying of flooding of the plant with MWL = 32,93 m, and may be divided as follows:

- termination to electric production and transfer of electric power supply sources to DGS – due to possible loss of the part of electric lines, connecting Kozloduy NPP with the power grid;

- termination to water supply in cold channel - loss of BPS and unavailability of access to the BPS overland;
- loss of emergency make-up of the spray pools of unit 5 and 6– loss of shaft pump station (ShPS);
- flooding of the part of town infrastructure and access from Kozloduy town to the plant via bypass road.
- flooding of the part of underground communications below elevation 32,93 m – drainage of the rainwater sewerage and leaks in its channels.

Potential external impacts due to flooding including failure to personnel access, equipment and material delivery to the site are discussed in item 3.2.4. of this report.

6.1.3.2 Loss of communication facilities/systems

At complete loss of power supply to the plant, margin for restoration of the power supply to communication structures/systems is as follows:

- Availability of these systems from the UPS up to 8 hours;
- Availability of these systems from DG-1 and DG-2 in AMC, more than 4 days.

6.1.3.3 Impairment of work performance due to high local dose rates, radioactive contamination and destruction of some facilities on site

Depending upon the type of emergency condition in Kozloduy NPP measures are conducted, specified in Appendix 6.5-1 of [25].

Table 0-3: Emergency conditions and relevant measures

Emergency condition	Measures
ALARM	1. Activation of the emergency personnel – Level I 2. Notification of NRA, Ministry of Energy, etc. 3. Conducting NPP site monitoring. 4. Ensuring radiation protection of the involved emergency personnel and their dose load control. 5. Providing technical support. 6. Depending on the conditions, increasing the ALARM status to FIELD EMERGENCY or cancellation.
ON-SITE EMERGENCY	1. Activation of the emergency personnel – Level II. 2. Notification of NRA, Ministry of Energy, etc. 3. Conducting 3 km zone monitoring. 4. Ensuring radiation protection of the involved emergency personnel and their dose load control. 5. Providing technical support. 6. Increasing the condition to LOCAL EMERGENCY or reducing the classification.
LOCAL EMERGENCY	1. Activation of all emergency personnel – Level III. 2. Notification of NRA, Ministry of Energy, etc. 3. Conducting monitoring in PAZ and 12 km zone (PAZ sub zone). 4. Ensuring radiation protection of the involved emergency personnel and their dose load control. 5. Providing technical support. 6. Increasing the condition to GENERAL EMERGENCY or reducing the classification.

Emergency condition	Measures
GENERAL EMERGENCY	1. Activation of all emergency personnel – Level III. 2. Notification of NRA, Ministry of Energy, local authorities (Kozloduy and Mizia). 3. Conducting monitoring in PAZ and 12 km zone (PAZ sub zone). 4. Ensuring radiation protection of the involved emergency personnel and their dose load control. 5. Providing technical support 6. Based on the assessment periodically /or in case of status changing/ recommendations to the off-site authorities for taking protective measures.

Specified measures are defined on the basis of additional information from radiation monitoring and in accordance with involvement criteria at the early stage of accident, according to Appendix 6.5-2 of [25].

Application of specific protection measures is directed by Emergency Response Officer activities, both at warning and through following messages.

For members of emergency teams and for individuals involved in the intervention every reasonable effort shall be made to maintain the annual effective doses below 100 mSv.

When a member of the emergency personnel receives an effective annual doses of 100 mSv, he/she is replaced by personnel of the emergency teams Emergency Plan (Command 1).

In emergencies, when implementation of lifesaving activities are required the limit of 100 mSv may be exceeded. For example, actions to prevent core damage. In case of emergency activities involving very high risk, they are performed by volunteers from the emergency personnel of the emergency teams. Furthermore, the head of the enterprise is obliged to submit to the Minister of Health and the Chairman of the NRA the statement accompanied by a list of staff who performs the operations, their written consent, time and place of operations, the opinion of the health or other medical establishment and any other information about the circumstances and the measures taken.

For the work of emergency personnel of the MCR/ECR and AMC the design solutions provide habitability in the event of a radiological or nuclear accident. These solutions ensure protection against ionizing radiation, isolation from the environment, air purification from radioactive purification higher than the external atmospheric pressure, air-conditioning, etc. to ensure long-term safe stay of the personnel.

6.1.3.4 Impact on the accessibility and habitability of the MCR and the ECR, measures to be taken to avoid or manage this situation

<u>Units 3 and 4</u>

Control and management of the technological processes is provided by two main control rooms (one per each unit). In the technical design separated layout is adopted of the main control rooms which ensure:

- high fire safety of the rooms;
- higher reliability in control of each unit;
- possibility of better cable layout.

Furthermore, design provides for two Emergency Control Rooms (ECR), one per each unit, from which the units can be shut down in case of accident situation at the main control rooms.

Control of all the main and auxiliary mechanisms and components of the unit is carried out at the MCR.

At the MCR control is performed for operating auxiliaries transformers 15,75/6,3 kV, switchgears 6 kV with standby power supply to 6 kV busbars, unit operating and standby transformers 6/0,4 kV, elements of the grid for reliable power supply to the units.

At the MCR the following communications are provided:

- two-way loud speaking communication of duty operator and the shift of the operating personnel;
- command loudspeaker and alarm in the main production premises and in area of the power plant.

At the MCRs of the units conditioning systems are mounted for maintaining required conditions for uninterrupted work of the operators. This is combined with maintaining and setting at the MCR of the so called “working” are for the MCR operators.

For ensuring habitability in case of accident with potential radiological consequences the emergency system is installed which maintains overpressure at the MCR and includes filter for particles and aerosols (iodine).

In case of fire which may affect environment at the MCR, isolation valves are installed in air ducts of the existing ventilation system at the MCR which close automatically. This prevents smoke from spreading at the MCR.

For the ECR, own climate system is provided to ensure operation of located equipment, sensitive to high temperature conditions.

Ensuring the required ventilation and conditioning systems is thoroughly considered also at designing of the new systems related to safety – ASSGEM and fire protection pump station (FPS-2), and the problem was settled at construction of the corresponding new buildings during 1997 to 1999.

<u>Units 5 and 6</u>

Management of the reactor installation, control of conditions of the reactor, management and control of the process systems during normal operation modes and at emergency conditions are provided at the MCR (main control room).

At the MCR, controls are located for the process safety systems, normal operation safety-related systems and normal operation systems.

MCR is located in separate premise, in the reactor building outside the containment in the “clean” area and is assigned the first category on the seismic stability. Location of the MCR is on an elevation lower than the reactor. Design accidents related to loss of coolant do not affect the MCR. As a result of analyses of beyond design seismic impacts the civil structure of the MCR and adjacent premises maintains its integrity. At analyses of beyond design combined impacts of the earthquake and off-site flooding, the MCR also maintains its functionality. At analyses of beyond design impacts of off-site flooding, the MCR is not affected. At severe accident, the MCR may become inhabitable, if the melt penetrates through the foundation of the containment [145]**.**

ECR (Standby control room) is intended, in case of failure to the MCR, for reliable transfer of the unit in subcritical cold condition and for maintaining the unit in that condition for unlimited time, for actuation of the safety systems and for receiving information on condition of the reactor.

ECR is located at elevation of -4.20 in reactor building. The premise of the standby control room is assigned category I of the seismic stability. Design accidents related to loss of coolant do not affect the MCR. As a result of analyses of the beyond design seismic impacts the civil structure of the ECR and adjacent premises maintains its integrity. At analyses of beyond design combined impacts of earthquake and off-site flooding it is possible - the ECR to be flooded. At analyses of the beyond design impacts of off-site flooding it is possible that the adjacent premises of the ECR are flooded what will hinder access to the premise.

SFS - accessibility and habitability

At complete drainage of FSP compartments dose rate is expected to reach the values requiring appropriate level of intervention.

DSFS - accessibility and habitability

At studies performed within the analysis of the earthquake it is defined that for the container blocked with debris which might result from extreme off-site initiating events, such as the earthquake, maximum temperature of the container will increase.

For 100% blocking with debris results of calculations at conservative assumptions show that maximum temperature of the shell may be exceeded correspondingly only after more than 2 days.

Considering the structure of the roof cover, it is required to expect realistic level of buried surely below 50%. This will increase available time for counter measures to more than 7 days. Even for this the worst case of accident scenario with loss of heat removal there is sufficient time available for taking adequate countermeasures, i.e. to remove debris and to restore the natural ventilation.

6.1.3.5 Impact on the different premises used by the crisis teams or for which access would be necessary for management of the accident

At assessments done for the earthquake, flooding and combination of beyond design basis earthquake with flooding, no difficulties were defined for access to the MCR.

Functioning of the AMC at seismic impacts has some main problems - Even at moderate seismic impacts (below DBE of the plant), when in principle accident should not occur, functionality of the AMC depends upon secondary seismic effects – destruction of above-ground structures and hindering of access of the personnel to the AMC. This is considered in design and has accident-independent underground access to AMC premises.

6.1.3.6 Feasibility and effectiveness of accident management measures under the conditions of external hazards (earthquakes, floods)

Units 3 and 4

In accordance with results of assessment of the margins at the earthquake, fuel damage cannot be prevented at PGA above 0,36g, i.e. at acceleration of input impact, for which sand liquefaction is expected under FPS-2 and circulation pump station (CPS-2). Therefore at assessment the earthquake is considered within the range of 0,26 < PGA ≤ 0,36 which defines the spectrum of beyond design earthquake, at which seismic-induced failures to the SSCs do not result in fuel damage.

Also level of the earthquake was assessed which leads to loss of integrity of the containment, and for the integrity of the containment of units 3 and 4 the following conclusion is derived:

The most probable mechanism for loss of leak-tightness of the containment premises system of units 3 and 4 is through destruction of the wall on axis 19 to elevation +10.10m. Seismic acceleration value, at which loss of function of the containment premises system is expected, is Am = 1.25 g. This value is more than 6 times higher than the RLE and is virtually impossible considering actual seismic-tectonic situation at the Kozloduy NPP site and neighbouring area.

Compared to the original design bases, which define DBE of 0,1g for the nuclear installation, the margin makes 0,26g or 260%, i.e. the units may withstand without fuel damage the earthquake 3,6 times stronger than DBE of the initial design.

In accordance with results of assessment of the margins at flooding, it is defined that among all the buildings, in which equipment is located related to performing of safety functions for Units 3 and 4 of the Kozloduy NPP, only building of ASSGEM is exposed to hazard of flooding at maximum water level (MWL). Elevation 0.00 of ASSGEM is set to 35.60 m. Analysis shows that at level of Danube River above 31.10 m flooding is possible of ASSGEM building basement (due to availability of the siphons at elevation of -4.50 = 31,10m). Pumps of ASSGEM system are located at elevation of -3.00 m which determines that they will be affected at MWL more than +32,50 m.

The only scenario is damage of water supply dams „Zhelezni vrata" 1 and 2 as a result of the earthquake. However in this case the effect of MWL will be executed at sufficiently later phase of accident progress process (about 20 hours after the earthquake).

In accordance with results of assessment of the margins at extreme meteorological conditions it is defined that due to closed and self-contained nature of the spent fuel storage system, FSP 3 and 4 and their auxiliary systems there is a high safety level in relation to external factor „Extreme winds and tornados".

Units 5 and 6

The design of Units 5 and 6 of Kozloduy NPP is robust to impacts of the off-site hazards. The reactor and the main structures of the primary circuit are located in the reinforced concrete containment, intended to localize radioactive products after accident in its own space which is qualified for seismic impacts of 0,2 g [4][5].The main systems and components of the safety systems and these safety-related systems also are located in buildings qualified for seismic impacts 0,2g [4][5]. Analyses of beyond design seismic impacts show that to seismic impacts 0.36 g system with which accident management are provided, are available. At analyses of beyond design combined impacts of the earthquake and off-site flooding it is shown that safety functions are performed of units 5 and 6 with survived equipment. At analyses of beyond design impacts of the off-site flooding it is shown that systems and equipment required for performing safety functions, are not affected.

Personnel of Units 5 and 6 takes measures in accordance with Emergency procedures of the units to shut down the reactor and maintain it in safe condition. In parallel with the emergency procedures of Units 5 and 6, on-site and off-site emergency response plan will be initiated according to Appendix 3.2 of [25].

SFS

In accordance with assessment performed for the earthquake it is defined that SFS may perform its functions for safe storage of the spent fuel at seismic acceleration within the range of 0.12 – 0.39g. Prolongation of time for safe storage of fuel in this situation depends upon the possibility of removal of construction debris and upon restoration, if it is possible, of the natural ventilation.

DSFS

DSFS will perform its functions of safe storage of the spent fuel at seismic acceleration of about 0.31 g. Prolongation of time for safe storage of fuel in this situation depends upon the possibility of removal of construction debris and upon restoration, if it is possible of the natural ventilation. This is seen from the analysis performed for the earthquake.

6.1.3.7 Unavailability of power supply

Units 3 and 4

In accordance with results of assessment of margins to loss of electric power and loss of ultimate heat sink, it is defined that power supply to these systems for cooling of the fuel in FSP-3 and FSP-4 is provided from various physically separated sources (emergency diesel generators – three per unit, emergency diesel-generators of ASSGEM, mobile DG). At low value of decay heat of the fuel stored in the pools, the available time margin before the assemblies uncoverage starts is about one week for FSP-3 and more than 9 days for FSP-4 at assumption of complete loss of cooling.

Units 5 and 6

Impacts of unavailability of the power supply to Units 5 and 6 of the Kozloduy NPP were analyzed within assessment of loss of power supply and loss of ultimate heat sink. All the options were assessed of sequential loss of sources of electric power supply. Virtually availability of equipment is reduced for accident management, but the design has available sufficient standby power supply sources, actuation of which leads to restoration of the equipment required for accident management. Recovery operator actions are described in the Emergency procedures.

SFS

Analysis of the postulated initiating events due to loss of power supply to SFS shows that uncoverage of the spent fuel stored in the storage pool, is not reached.

DSFS

Scenario of complete loss of power supply is not relevant to safety of DSFS. Due to availability of the passive system to remove heat of the radioactive decay, safety operational mode of the storage structure is not dependent upon power supply. This is seen from the analysis performed for loss of power supply and loss of ultimate heat sink.

6.1.3.8 Potential failure of instrumentation

Units 3 and 4

Within short-term modernization program of the units analysis was done for definition of environmental parameters for equipment qualification at emergency conditions. As the first step of the qualification the sensors of emergency protection chains were replaced with qualified sensors of Emergency protection chains. For some of the sensors related to safety, new location was selected, and they were moved to area which does not require qualification on extreme environmental conditions.

As a result, at present all the measurement channels, related to reactor protection are qualified for correspondent seismic and environmental conditions. For conditioning of process parameter signals, precise digital equipment is used. Uninterruptable Power Supply units (UPS) additionally isolate power supply to these channels, by which independence is assured for the power supply to the channels.

In addition to that the qualification program is executed for the remaining equipment related to safety, including test of samples of equipment for ageing, seismic and environmental conditions at loss-of-coolant accident. On the basis of results of the qualification program the remaining safety-related sensors were also replaced.

To support Operator actions additional set of the computerized systems was implemented, such as:

- Computerized system for supporting the operator and recording the process parameters at normal operations and in case of accident;
- Safety-related parameters display system based on own qualified transducers (SPDS);
- New digital systems for fire detection and fire alarm allowing the operator for timely localization of fire;
- Multiple additional alarms from the local boards, outside the MCR.
- Failure to stationery systems for monitoring of radiation background, temperature and water level in the FSP is possible to be replenished for with portable measurement means.

Units 5 and 6

Failure to measurement instrumentation is analyzed at assessment of the earthquake, and potential failure of measurement instrumentation does not lead to loss of information due to triple redundancy of the measurement channels.

The unit has available Post accident monitoring parameters system (PAMS) which is entirely seismically qualified, including the measurement channels, and these also have triple redundancy.

SFS

Failure to stationary systems for monitoring of radiation background, temperature and water level in the compartments, is possible to be replenished for with portable measurement means.

DSFS

Failure to stationary systems for monitoring of radiation background and temperatures in container storage hall, is possible to be replenished for with portable measurement means.

6.1.3.9 Potential effects from the other neighbouring installations at site

Units 3 and 4

The design assumes impacts from the neighbouring unit due to location of Fuel storage pools (FSP) of Units 3 and 4 in common premise of the Central Hall in the reactor building.

The design envisions also common plant control and monitoring rooms (of both units):

- dose rate control post;
- control room of the reactor building, special water purification and process ventilation (RB CR);

In case of accident at Units 5 and 6 and SFS, the personnel of Units 3 and 4 acts in accordance with NPP Emergency Response Plan.

Units 5 and 6

In case of accident at Units 3 and 4 and SFS, the personnel of Units 5 and 6 acts in accordance with NPP Emergency Response Plan.

SFS

In accordance with assessment performed for the earthquake it is defined that Ventilation stack - 2 possesses the required seismic safety, and at earthquake level of the RLE damage is not expected to SFS building or emergency DG building as well as difficulties to access them.

In case of accident of Units 3 and 4, Units 5 and 6, the personnel of SFS acts in accordance with NPP Emergency Response Plan.

DSFS

In case of accident of Units 3 and 4, Units 5 and 6 and wet SFS, the personnel of SFS acts in accordance with NPP Emergency Response Plan.

6.1.4 Measures which can be envisaged to enhance accident management capabilities

Units 3 and 4

Measures to enhance robustness of Units 3 and 4s of Kozloduy NPP resulted from the analysis of combination of beyond design basis earthquake and flooding:

In relation with performing of safety functions, flooding of the pumps of CEFWS (1÷4 CEFWS pumps) leads only to reduction of quantity of the systems performing the same safety functions, and this is only if the spent nuclear fuel is located in the reactor, as 1÷4 CEFWS pumps are not relevant to cooling of the FSP.

Therefore, as a result of the analysis the following recommendation may be introduced:

- Studying of possibility to prevent the flooding of buildings of the CEFWS.
- Implementation of periodic visual inspections to guarantee the leak tightness of the penetrations of rainwater and domestic sewerage;
- Implementation of periodic inspections to guarantee the leak tightness of the penetrations of pipelines, cable traces, etc.;

Measures to improve robustness at loss of power supply

Power supply to these systems for cooling of the fuel in FSP-3 and FSP-4 is provided from various physically separated sources (emergency diesel generators – three per unit, emergency diesel-generators of CEFWS, mobile DG). At low value of decay heat of the fuel stored in the pools available time margin before the assemblies uncoverage starts is about one week for FSP-3 and more than 9 days for FSP-4 at assumption of complete loss of cooling. Consequently no additional measures are required to enhance robustness of FSP-3 and FSP-4.

Measures to improve robustness to loss of ultimate heat sink

At low value of decay heat of the fuel stored in the pools available time margin before the assemblies uncoverage starts is about one week for FSP-3 and more than 9 days for FSP-4 at assumption of complete loss of cooling.

Units 5 and 6

The set of SBEOP for shut down reactor with the pressurized primary circuit has passed processes of verification and validation. Up to present operator training is conducted for work with instructions of this type, and after this they will be introduced into operation.

The set of SBEOP for shut down reactor with the depressurized primary circuit will be subject to internal procedures of verification and validation at the NPP.

For severe accident management at Units 5 and 6 guidelines were developed for severe accidents which follow the format of SBEOP. It is planned to subject these procedures to processes of verification and validation and to introduce them to work in the end of 2012.

SFS

Additional measures to improve robustness of SFS at loss of power supply are described in item 5.4.2.

DSFS

Measures envisioned in On-site and Off-site Emergency plan are sufficient.

6.2 MAINTAINING THE CONTAINMENT INTEGRITY OF UNIT 5 AND 6 AFTER OCCURRENCE OF SIGNIFICANT FUEL DAMAGE (UP TO CORE MELTDOWN) IN THE REACTOR CORE

6.2.1 Elimination of fuel damage / meltdown in high pressure

6.2.1.1 Design provisions

Strategy was developed for pressure reduction in the reactor vessel [145] within the severe accident management guidelines. The main technical means for pressure reduction at accident progress before severe phase is the safety valves of the primary circuit and the system for emergency gas removal from the primary circuit. As additional possibility to reduce pressure in the reactor vessel, valves can be used on lines of sealing water drainage [147] of the main circulation pumps. For ensuring feasible possibility for use of the system for emergency gas removal from the primary circuit in conditions of severe progress of the accident, modification was performed on the power supply to system valves, and redundancy provided for power supply of the correspondent valves from the accumulator batteries.

6.2.1.2 Operational provisions

At occurrence of emergency conditions the operators of Units 5 and 6 initiate performing SBEOP. This should happen several hours before the accident reaches severe phase with fuel damage. In SBEOP strategies are envisioned for accident management – restoration of the CSF-Heat removal and CSF- Core cooling, Restoration of electric power supply. Successful executing of actions envisioned in these strategies at the end will prevent fuel damage, as well as will decrease pressure in the reactor vessel.

6.2.2 Management of hydrogen risks inside the containment

6.2.2.1 Design provisions, including consideration of adequacy in view of hydrogen production rate and amount

Units 5 and 6 are provided with Hydrogen reduction system in the containment which consists of 8 passive autocatalytic recombiners (PAR), located within the containment structure and intended to burn hydrogen generated during the accident. The system is designed with capacity to handle hydrogen generated at design-basis accident with maximum leak of the primary circuit. Additional analyses of the NPP show that the hydrogen reduction system is able to reduce hydrogen generated during in-vessel phase of severe accident to admissible levels, therefore explosive concentrations won't be reached [147].

At the out-of-vessel phase of severe accident, the operation of the system is not efficient due to lack of oxygen in gas environment of the containment, as required for the process of fixation of hydrogen in the PAR. Though during out-of-vessel phase of severe accident within the containment significant amounts of hydrogen are generated, these do not impose direct hazard of explosion, since there is no oxygen.

6.2.2.2 Operational provisions

In developed SAMG and EP procedures are envisaged actions for monitoring, assessment and predicting of hydrogen concentration within of containment premises. Actions are described for control of Spray systems depending upon concentration of hydrogen.

6.2.3 Prevention of overpressure of the containment

6.2.3.1 Design provisions, including means to restrict radioactive releases if prevention of overpressure requires steam / gas relief from containment

The design of Units 5 and 6 envisions the Spray systems for heat removal from the containment and for fixing iodine in steam-air mixture at loss-of-coolant accidents. As a result of operation of these systems pressure reduction is reached in the containment to safe values. Spray systems are qualified as safety systems. They actuate automatically at pressure within the containment increases above safe operation limits.

To control pressure in conditions of severe accident at units 5 and 6 additional filtering systems are installed for pressure reduction, operating on passive principle. At pressure increase in the containment to design level rupture to membrane occurs which is connected to the pipeline, linked to a vessel filled in with filtration solution. Gas environment from the containment passes through the filtering solution and is released through the throttling system to ventilation stacks of units 5 and 6.

6.2.3.2 Operational and organisational provisions

During normal operations pressurization is maintained in the containment. Means for protection against overpressurization are maintained ready.

At emergency conditions active protection means actuate automatically depending upon actuation setpoints and are controlled in accordance with directives of Emergency instructions.

6.2.4 Prevention of re-criticality

6.2.4.1 Design provisions

In VVER reactors, at unaffected geometry of the core, water-uranium relation is close to optimal in relation with the reactivity. This means that at occurrence of significant changes to core geometry, the reactivity of the core reduces. Due to this reason repeated criticality in the core during severe accident is of low probability [148].

6.2.4.2 Operational provisions

All systems used for the reactor make-up in conditions of severe accident use borated water and don't bear risk of repeated subcriticality [148].

6.2.5 Prevention of basement melt through

6.2.5.1 Potential design arrangements for retention of the corium in the pressure vessel

Possibility was analyzed for external-to-vessel cooling of the reactor. It is defined that in some options of severe accident progress damage to vessel cannot be avoided.

The SAMG envision actions for restoration of coolant supply to the reactor. If during in-vessel phase of severe accident the operators manage to deliver sufficient coolant to the core, there is a chance to cool down fragments and melting product from the reactor core and to localize this in the reactor vessel.

As a mean to supply coolant to the primary circuit, available trains of the safety systems (SS) can be used – Emergency core cooling system - high pressure (ECCS–HP), low pressure (ECCS-LP), make-up and blowdown system trains (system TK).

6.2.5.2 Potential arrangements to cool the corium inside the containment after reactor pressure vessel rupture

Cooling of the corium in the core in out-of-vessel phase is possible through restoration of boric acid solution supply to the primary circuit, and such actions are envisioned in the SAMG. For this purpose, some of recovered safety systems (SS) can be used – Emergency core cooling system - high pressure (ECCS–HP), low pressure (ECCS-LP), make-up and blowdown system trains (system TK).

6.2.5.3 Cliff edge effects related to time delay between reactor shutdown and core meltdown

Table 6.2-1: Time margin between shutdown of the reactor and core melting

Sequence	Core damage (hours)	Comments:
Station blackout, without operator actions, batteries 2h	5.5	Pxз~4.2 bar abs at damage to the containment (lack of ventilation due to pressure). Conditions for manual ventilation per SAMG met at ~45000 sec (12.5 hours) (hydrogen).
blackout, pressure decrease in the primary circuit at 650 C (1 valve) (3.2 hours)	11.5	Pxз~5 bar abs at >111 hours (lack of ventilation due to pressure).
LLOCA + station blackout	4.5	Pxз~3.25 bar at >44 hours. Extrapolation: 5 bar at ~140 hours (lack of ventilation due to pressure).

6.2.6 Need for and supply of electrical AC and DC power and compressed air to equipment used for protecting containment integrity

6.2.6.1 Design provisions

Active equipment which ensures containment integrity and requires restoration of power supply, is the components of the Spray systems: pumps and valves. These are supplied with power from the electric busbars and assemblies of units 5 and 6 – category II.

6.2.6.2 Operational provisions

In the procedures and operational documentation available at the MCR and ECR, there are descriptions of sources of power supply to each component of the unit. Steps are clearly set for operations performing during operation and maintenance.

6.2.7 I&C, needed for protecting containment integrity

Units 5 and 6 have informational systems to support the operators in emergency conditions, such as the SPDS – for control of the CSFs, PAMS.

Within [145] designing of the PAMS systematic analyses were performed for the available measurement channels. The suitable ones were selected which are required for accident management.

The required measurement channels are installed with extended measurement range, and these are designed to withstand severe accidents conditions and included in the scope of the PAMS.

Controls for the main systems for accident management are located both at the MCR and at the ECR and are available to the operators. Emergency procedures describe specific actions and specify required control instrumentation.

Units 5 and 6 do not have available system for direct monitoring of water steaming and oxygen within the containment, but it is envisioned to install such system.

Hydrogen concentration measurement channels have lower measurement range of the expected hydrogen concentration in the containment at out-of-vessel phase of severe accident.

6.2.8 Measures which can be envisaged to enhance capability to maintain containment integrity after occurrence of severe fuel damage

In the process of implementing is a project to close the ionizing chamber channels located within the walls of the reactor vessel shaft, where bypassing of the containment is supposed at severe accident.

The licensee will examine the possibility for installation of additional hydrogen recombiners in the containment structure volume.

6.3 ACCIDENT MANAGEMENT MEASURES TO RESTRICT THE RADIOACTIVE RELEASES

6.3.1 Radioactive releases after loss of containment integrity of unit 5 and 6

6.3.1.1 Design provisions

The containment of VVER-1000/V320 type reactor, in which the reactor and the primary circuit are located, consists of a cylinder with a dome at the top. The structure is constructed of pre-stressed concrete with thin steel lining on the internal surface. The containment volume is large.

Characteristics related to safety of the unit, are analyzed in relation with severe accident risks, including direct heating of the containment in probable scenarios of high pressure melting ejection (HPME), hydrogen explosion, interaction between fuel/coolant (FCI) and steam explosion outside the reactor vessel, possibility of cooling outside the reactor vessel and bypassing of the containment. Probabilistic/deterministic assessment shows that (i) direct heating of the containment does not impose significant threat to the containment of VVER-1000/V320 and that (ii) the containment integrity is subject to significant hazard of melting from the penetrations of the main slab at scenario with possibility of cooling outside the reactor vessel.

The MCR and ECR of VVER-1000 are located at the lower level in the reactor building, i.e. under the structure of the containment. Main slab of the containment which might be affected by the corium in scenario with melting outside of the reactor vessel, is elevated, and below there is a set of premises that which are outside the containment and in which safety related pumps and equipment are located, and after which these premises may become inaccessible, including the MCR.

Melting penetration through the main slab of the containment is not the immediate hazard of the first day (days) after such hypothetical accident, due to structural characteristics of the shaft (wall thickness of the base is 3.194 m, thickness of the main slab of the shaft is 3.6 m).

There is more probable scenario, at which melt outside the reactor vessel can bypass the main slab as well as leak through the penetrations of ionizing chamber channels in the main slab in premises under it, but at present a project is being implemented at Units 5 and 6 to eliminate this option [149].

The localizing systems were executed in the design of the unit which ensure meeting the set criteria for localization of releases of the radioactive substances to the environment.

To execute the localizing functions, systems and means for controlling containment environmental parameters are installed in the containment, for isolating the containment and for reduction of concentration of radioactive fission products, hydrogen, other substances which may release to the containment environment during and after design and severe accidents. For performing of these safety functions the following systems were installed:

- Containment system (CS);
- Spray system;
- Filtering pressure reduction system;
- Hydrogen recombination system.

Within modernization program the following measures were executed (section 12 of [4][5]), related to CS:

- Improvement of containment testing procedure;
- Qualification of cable penetrations and planning of their replacement;
- Installation of filtering ventilation;
- Development and introduction of severe accident radiation monitoring systems.

6.3.1.2 Operational provisions

Organizational and technical means in case of radioactive releases after loss of containment integrity of Units 5 and 6 are described in the Emergency Response Plan of the Kozloduy NPP. This includes operations of the shift personnel of the MCR on SBEOP and SAMG in parallel with coordination actions on external-to-plant National emergency plan (National emergency plan) [72].

Off-site forces and means, involved in providing support to Kozloduy NPPare defined in National emergency plan for conducting of rescue and urgent emergency-recovery activities at occurrence of disasters, accidents and disasters.

6.3.2 Accident management after uncovering of the top of fuel in the fuel pool

6.3.2.1 Hydrogen management

Units 3 and 4

Measures for hydrogen control at long-term storage of SNF in the FSP (for more than 4 years after removing the fuel from the reactor and its low energy release rate), are not envisioned in the design.

Units 5 and 6

FSP of Units 5 and 6 is located within the containment. Hydrogen which may generate in case of possible damage, will spread within the containment and will be recombined by the PAR

SFS

According to the assessment performed for complete loss of off-site power supply and loss of emergency power supply, hydrogen accumulation is possible due to switching off of the ventilation systems, but minimum air flow rate of 17,5 m^3/h is sufficient to ensure that concentration of hydrogen above the surface of the pools does not exceed 0,4 % volumetric [22].

6.3.2.2 Providing adequate shielding against radiation

Units 3 and 4

Executing of protection measures, envisioned in the emergency response plan, see par.6.1.3.1.4. of [25], ensure adequate protection against radiation.

Analyses of the earthquake, flooding, combination of beyond design flooding and the earthquake, loss of power supply and loss of ultimate heat sink, do not show loss of the SSCs, including ventilation systems.

Units 5 and 6

Radioactive substances which would be release in case of an accident in the FSP, will be maintained within the containment.

SFS

Executing of protection measures, envisioned in the emergency response plan, see par.6.1.3.1.4. of [25], ensures adequate protection against radiation.

6.3.2.3 Restricting releases after severe damage of spent fuel in the fuel storage pools

Units 3 and 4

Analyses of the stress-test on separate positions show that hypothetically only partial, mechanical failures are possible and not significant damage of fuel in the FSP.

FSP is located in the central hall, outside the SG box compartment and consequently, in case of hypothetic fuel damage in the FSP comparatively hostile consequences may be reached in relation with radioactive releases. Contact of the central hall (at destruction) with the environment is the cause for the most part of releases of the radioactive substances during the accident occurring with containment bypassing. This defeats the purpose of strategies for maintaining of under-pressure in the SGBC.

Units 5 and 6

Radioactive substances which would be released in case of an accident in FSP will be maintained within the containment, when the unit is in condition of the isolated containment.

In the emergency instruction treating the IEs (initiating events) in the FSP, actions are envisioned for evacuation of the personnel in the containment and isolation of the containment, if accident occurs in condition of the unit with not isolated containment.

SFS

At emptying of fuel storage compartment, releases of aerosols and radioactive noble gases may not be localized, as in order to prevent damage of the fuel elements conditions are necessary for efficient natural air circulation through the compartment [22], [110].

6.3.2.4 Instrumentation needed to monitor the spent fuel state and to manage the accident

Units 3 and 4

Units 3 and 4 have available the following systems:

- Monitoring system for radiation background above FSP.
- Monitoring system for temperature and water level in FSP.
- Leakage monitoring system.
- Accident does not impact I&C.

Units 5 and 6

I&C, required for monitoring of condition of fuel in FSP, are located at the MCR. At level reduction in the pools up to the controlled margin sound and light alarm actuates.

SFS

SFS has available the following systems:

- Monitoring system for radiation background above fuel storage compartments and SFS building.
- Monitoring system for temperature and water level in compartments.
- Leakage monitoring system.

6.3.2.5 Availability and habitability of the control room

Units 3 and 4

Accessibility and habitability of the MCR are not limited at these accidents.

Units 5 and 6

Accessibility and habitability of the MCR are not limited at accident in FSP.

SFS

At complete drainage of the FSP compartments, control room in the SFS is not accessible [22].

6.3.3 Accident management of radioactive releases from dry spent fuel storage

Beyond design basis accidents such as earthquake and flooding do not result in release of the radioactive materials or to reduction of protective shielding provided by the containers in the DSFS [30].

6.3.4 Measures which can be envisaged to enhance capability to restrict radioactive releases

Units 3 and 4

Analyses of the stress-test show large safety margins for units 3 and 4.

Units 5 and 6

Installation of additional hydrogen recombiners within the containment.

Installation of the measuring channels for monitoring and assessment of concentration of water steaming and oxygen within the containment.

Implementation of the project to close the ionizing chamber channels located within the walls of the reactor vessel shaft, where bypassing of the containment is supposed at severe accident.

SFS

In relation with SFS, no measures are proposed to enhance robustness.

DSFS

Beyond design basis accidents such as earthquake and flooding do not result in release of the radioactive materials to the environment [30].

6.4 CONCLUSION

The information on the management of severe accidents in KNPP shows that the following objectives are met:

- constant emergency preparedness of the personnel;
- activities for accident management, recovery of control over structure, facility or activity, including a combination of accidents and other emergencies, such as explosion, fire, flooding, earthquake and limiting the consequences thereof is in place;
- the necessary measures to protect personnel, public and environment, aimed at preventing serious deterministic effects and reduce the risk of stochastic effects to as low as reasonably achievable are in place.

Adopted procedures and instructions specify responsibility, effective communication with national and local authorities and to provide technical assistance outside KNPP.

The analysis of existing technical and operational means to protect the integrity of the containment shell, and those to limit radioactive releases outside the containment zone allows for concluding that they are effective. In addition, the following improvements could be planned:

- installation of additional hydrogen recombiners in the containment structure;
- installation of measuring channels for monitoring and evaluating the concentration of water vapour and oxygen in the containment structure.

Finally, the organization’s emergency planning capability to operate plant in emergency conditions, and current operational and technical measures confirm the preparedness of NPP "Kozloduy" for severe accident management [150].

Regardless of the above conclusion and in order to improve the sustainability of the units in the course of severe accidents and the monitoring of parameters in the reactor vessel, in the process of implementing are corrective measures identified in the project associated with the development of Unit 5 and 6 SAMG, and confirmed during the periodical safety review of the units in 2008:

- installation of a wide-range temperature sensor for monitoring the temperature of the reactor vessel, in order to ensure the information necessary for action in the SAMG;
- Implementation of the project to close the ionizing chamber channels located within the walls of the reactor vessel shaft, where bypassing of the containment is supposed at severe accident..

As a result of the periodic safety review, which was held in 2008 following measures to improve nuclear safety were identified by the licensee, which are in progress:

- implementation of severe accident management guidelines, according to the developed program;
- implementation of the symptom-oriented emergency instructions for reactor shutdown condition with closed and open primary circuit;
- updating, verification and enforcement of guidelines for management of severe accidents, taking into account the improvements.

BNRA confirms the necessity of implementing the proposed by the licensee corrective measures and in respect of the possible combination of earthquake and flood events, with subsequent loss of power and ultimate heat sink, BNRA consideres appropriate that the following corrective actions should be additionally implemented:

- updating the on-site and off-site emergency plans taking into account the following aspects:
  - difficult access to the secondary control room of units 5 and 6;

- possible drying of the SFS basin compartments, with subsequent increase of the dose rate to the levels of intervention;
- providing alternative ways for evacuation, transport of fuels and materials needed by the plant, and access of operational staff.

- construction of a new AMC, which to be located outside the Kozloduy NPP site;
- study of the options for localizing of the core melt in case of severe accident.

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[116] ДОД.АГ.ИН.204 - operating instruction for forecast analyses group .

[117] ДОД.АГ.ИН.200 – Instruction for assessment of consequences from accident of reactor, based on the unit emergency conditions .

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LIST OF ABBREVIATIONS

AB	Auxiliary building
AIS OSRM	Automated Information System for Off-Site Radiation Monitoring
AMC	Accident Management Centre
AMS	Accident management system
ASSGEM	Additional system for steam generator emergency makeup
BPS	Bank Pumping Station
BRU-A	Fast active steam dump to the atmosphere
BRU-K	Fast active steam dump to the condenser
CMD	Council of Ministers Decree
CPS	Circulation pump station
DBE	Design Basis Earthquake
DG	Diesel generator
DGS	Diesel generator station
DSFS	Dry spent fuel storage facility
ECCS	Emergency core cooling system
ECR	Emergency control room
EES	Electric energy system
EES - NG	National Grid (power transmission system)
EMT	Emergency makeup tank
FAs	Fuel assemblies
FSP - SFP	Spent Fuel Pool (near reactor)
I&C	Instrumentation and control
IAEA	International Atomic Energy Agency
MCR	Main control room
MDG	Mobile Diesel Generator
MEET	Ministry of Economy, Energy and Tourism
MEW	Ministry on Environment and Water
MS	Monitoring Stations
MWL	Maximum water level
NPP	Nuclear power plant
NPP SS	Nuclear power plant shift supervisor
NRA	Nuclear Regulatory Agency
OSY	Outdoor (open) switchyard
PAMS	Post-accident management system

PGA	Peak ground acceleration
PSA	Probabilistic safety assessment
RAW	Radioactive Waste
RB	Reactor Building
RLE	Review level earthquake
SAMG	Severe accident management guidelines
SAR	Safety analysis report
SBEOPs	Symptom based emergency operating procedures
SFS	Spent fuel storage facility
SG	Steam generator
SG EMS	Steam generators emergency makeup system
ShPS	Shaft pump station
SK	S AB
SNF	Spent nuclear fuel
SSCs	Structures, systems and components
SSE	Safe shutdown earthquake
SSEL	Safe Shutdown Equipment List
SV	Safety valves
UPS	Uninterruptible power supply
VVER	Water-Water Energy Reactor