**“Stress Tests”**

**Bushehr NPP**

**Islamic Republic of Iran**

**Evaluation of Safety and Safety Margins of BNPP-1**

**In the Light of the Accident of the**

**NPP Fukushima**

**NPPs Safety Development and Improvement Co.**

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**ABBREVIATIONS**

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# General

Correct understanding of the following text requires familiarity with the contents of Chapter 1 (section 1-2) which describes the technological systems designed to fulfill the main and auxiliary safety functions within the Bushehr NPP.

## Loss of electrical power

The generic requirements for the electrical power supply in nuclear power plants (NPPs) in Iran are comprised in the Iran Nuclear Safety Standards. According to these safety standards, one source of supplying the safety-related trains is the unit turbo-generator of a NPP (‘load rejection to house-load operation’, automatic systems have to be available). Also two off-site (grid) connections have to exist for electrical power supply from which the electrical power for all trains of the emergency power system can be provided (main grid connection and stand by grid connection). If possible, these two connections should be functionally separated from each other and decoupled with regard to their protective circuits, and they should also be linked either to separate off-site power grid switchyards or to different voltage levels.

At Bushehr Nuclear Power Plant - Unit 1 (BNPP-1), electrical power are supplied by following group of sources:

**The operating (working) source of power** for auxiliary consumption of unit are three transformers connected to the two branch of the power output from the 1000 MWe turbo-generator.

The auxiliary transformers supply each 4 sections for 10 kV self consumption of the unit (4×10 kV busbars of sections BA, BB, BC & BD), from which the main drives for the 1st and the 2nd circuits are supplied as well as the sections for the 10 kV emergency supply, which drives the safety systems. Downstream, there are the 660 V and 400 V power systems. By means of generator switches, these branches transformers can be supplied from two sources:

- 1000 MWe turbo-generator (at power operation of the unit)

- Two 400 kV overhead lines (from Choghadak-I substation)

During normal operation, supply to the station power transformers takes place through the generator of the plant.

**The reserve (stand-by) source of power** for unit are two auxiliary stand-by transformers which one of them is connected to autotransformer and supplied from 400 kV substation i.e. Choghadak-II and the other one supplied from the 230 kV bushehr (thermal) power plant using one 230 kV overhead line and have been envisaged as stand-by power supply sources from external power system.

The Bushehr (themal) power plant has three grid connections and can be supplied from three directions:

- from BNPP-1: 2 lines 230 kV

- from Busheher-2 substation: 1 line 230 kV

- from Choghadak-I substation: 1 line 230 kV

Reserve transformers are connected via reserve connections to 10 kV unit switchgears of normal power supply. Reserve sources are used under normal and abnormal operation, as well as in emergency situations when the operating sources are partially or fully disabled. The reserve sources in unit are able to replace with each other and also with working transformers.

**The Emergency sources of power** were designed for situations when both the operating (working) and reserve (stand-by) sources fail. The emergency sources of power supply (Emergency DG and accumulator batteries) are safety sources intended for unit. The plant has a 4-train emergency power system. All of these emergency power supply sources are functionally separated and are located in the emergency diesel generator buildings with the voltage levels 10 kV, 660 V and 400 V, as well as 220-V and 24-V battery-buffered DC power and 380 V battery-buffered AC power.

### Loss of off-site power (LOOP)

#### Design provisions taking into account this situation: ordinary back-up AC power sources provided, capacity and preparedness to take them in operation

External power supply system 400 kV is determined with the priority power supply source for power auxiliary loads (both for normal operation and emergency power supply) and executed via 400 kV switchgear and auxiliary power working transformers 10BT01, 10BT02, 10BT03. Transformers 10BT01, 10BT02, 10BT03 are switched to the tap between generator 10QA01 and 10QA02 circuit breakers and step-up transformers 10АТ01 and 10АТ02.

In the normal operation mode the auxiliary power supply system is constantly connected with the 400 kV off-site grid and with the unit generator via the unit step-up transformers.

When the reactor is not producing electricity and the main lines (i.e. 400 kV overhead lines) is out of service, the electrical panels are supplied via two auxiliary-lines called the reserved sources. In this case the reactor is supplied directly by the electricity transmission system via the reserved transformers (10,20BS01).

The loss of the off-site power supply (LOOP) (e.g. during network disintegration accompanied by the loss of 400 kV and 230 kV sub-stations) does not cause the automatic transfer to emergency supply sources during the power operation of the unit.

After the plant disconnection from 400 kV and 230 kV grids due to external reasons, TG is not stopped and generator is not disconnected from the home consumption grid, the unit controllers regulate the unit to home consumption operation. In the case of a loss of off-site power, Bushehr NPP has the ability of load rejection to house-load operation. In this regime (i.e. loss of the connection with external power network of 400 kV and 230 kV), for a short period of time for 30-40 minutes, the auxiliary power supply system can be energized from the generator. According to technical specifications for turbine, maximum allowed duration of unit house-load operation comprises 45 minutes. The long-term operation of TG for self-consumption wasn’t tested in practice. If regulation to home consumption fails, unit electric supply is recovered from the back-up power supply.

To have sufficient on-site electrical power sources, BNPP-1 reactor has redundant conventional backup sources capable of supplying the electrical panels vital for correct operation of the safety equipment. The conventional backup sources for reactor consist of two emergency diesel generator sets.

Emergency power supply system performs the prescribed function in all operation modes, including loss of operating and standby power supply sources (loss of power).

During loss of power on normal operation auxiliary power supply buses, the design provides for (independent from the off-site power supply system) the functioning of the emergency power supply system, due to disconnection of sectional links and connection of the diesel-generators to the emergency power supply system sections, isolated from the normal operation system.

There are four independent channels in the safety system. Each channel of the emergency power supply system provides power supply to the process components and control safety system of the appropriate channel. Power supply of safety system loads is fed from emergency diesel-generators, connected to the 10 kV switchgears and from storage batteries. The main auxiliary loads are also fed from diesel-generators of reliable power supply.

During an accident in the power system with a loss of voltage on 400 kV and 230 kV buses and provided that the main generator is tripped (turbine stop valves closed), loss of off-site power occurs. In the situation of loss of the main and auxiliary lines and failure of house load operation:

- The reactor loads are energized by the on-site sources, i.e. the backup diesel generator sets [these generator sets start automatically in the event of simultaneous loss of the main and auxiliary systems or a significant voltage drop on the backed-up electrical panels;

- The control rods drop under gravity, which terminates the nuclear fission reaction and controls the reactivity;

- The reactor core continues to emit heat (called residual power), which must be removed from the core to prevent its temperature from rising and ultimately damage it;

- The residual heat removal from the spent fuel pool will be carried out by the emergency essential service water system. The pumps for spent fuel pool and essential service water, electrically supplied by the emergency power system

A loss of the auxiliary power supply (total loss of power) initiates the following automatic actions in the emergency power supply system:

- The CBs of the working inputs at 10 kV auxiliary sections of normal operation are disconnected by undervoltage protection;

- By “loss-of-power” signal, the diesel generator of the emergency power supply system (EPSS) starts;

- EPSS are automatically disconnected from the normal operation bus-bars (by opening sectionalizing circuit breakers);

- DGs are connected to relevant EPSS bus-bars;

- EPSS loads (the key safety drives) are gradually activated in accordance with the program for gradual loading and are fed from DGs;

- The restoration of charging accumulator batteries is after the connection of DGs to the EPSS 10 kV substation (i.e. maximally within 15 seconds).

The reliable power supply system of Normal Operation is fed from its own DG.

#### Autonomy of the on-site power sources and provisions taken to prolong the service time of on-site AC power supply

The emergency power system is arranged in four trains (4×100 %) which are built physically separated and functionally independent and each channel is equipped with two diesel-generators (2×3100=6200 kW) as emergency power supply sources of the emergency power supply system. The steady load on each EPSS train is less than the nominal DG output (5.4 MW). Diesel-generators are connected in parallel and connected with the emergency power supply section via one circuit breaker. Diesel-generators in each channel of emergency power supply system are selected in such a way, as to provide power requirements, without overloading, of one safety channel and supporting system during operation in the independent mode. The emergency power system is protected against site-specific design basis earthquake and flooding.

This system is subdivided into:

- An interruptible grid (an AC power supply (10 kV, 660 V, 380/220 V)) **[Emergency sources for the AC supply]**

- An uninterruptible grid (a DC power supply (220 V, ±24 V) and a battery safety AC power supply (380/220 V)) **[Emergency sources for the DC supply]**.

The electrical supply of the emergency power system is normally provided by the station supply system. In case of a challenge (loss of the electrical station supply) the four emergency diesel generators have to take over automatically (activated by the reactor protection system) the electrical supply of the safety-related trains. A manual activation of these diesel generators is also possible.

Two diesel-generators of each emergency power supply channel will be started automatically by compressed air and will be connected when the nominal voltage is reached. The time from the standby mode to the readiness to take the load is not more than 15 s. If one out of two diesel-generators fails, diesel-generator plant is not connected to the appropriate emergency power supply section or is disconnected if it has been connected to the section.

Fuel store at the NPP fuel and oil (F&O) storage provide the operation of all safety system diesel generators at rated power during no less than 5 days.

Service tanks of EDG are located in DG set building ZK1/ZK2. Intermediate tanks with a capacity of 100 m3 (each) are located in the intermediate storage facilities ZS2 and ZS3 (Intermediate Diesel Oil Storehouse for ZK1/ZK2). Besides, fuel storage for 5 days is located in the building ZS21 (Oil Storage Tank).

Regarding the autonomy of the on-site electrical power supplies, the fuel and oil capacity of the four emergency diesel generators are sufficient for at least 48 hours without manual measures and fuel autonomy is guaranteed for 2 days. The compressed air reserves required to start each generator set allows at least six consecutive start-ups without cylinder replenishment with process air are ensured. The cooling of these diesels power engines is normally provided by the essential service water system VE (via a closed cooling water circuit VJ). With following manual measures, the operating time can be increased to about one week or longer:

- Switch-off of unnecessary loads;

- Intermittent operation of the emergency diesel generators;

- Switch-off of unnecessary emergency diesel generators and so on.

List of loads, fuel supply system and the specification of safety channels of emergency power supply system have been given in previous sections (Chapter 1).

#### Consideration of extreme meteorological events (storms, dust, fog and sultry, heavy rainfall, etc.) impact on loss of electrical power

The equipment of main transformers (10AT01,02 systems), coupling transformers (10AS01,02 systems) and stand-by transformers (10,20BS01), installed in ZH.0 and ZH.8 buildings respectively. These buildings have the earthquake resistant Category II b as per PN AE G-5-006-87 and safety class 4 as per PN AE G-01-011-97 (OPB 88/97). The ZH.0 and ZH.8 buildings seismic strengthen for DBE is 0.10g for Horizontal acceleration and 0.07g for vertical acceleration.

The equipment of 400 kV GIS system installed in the ZJ.0 Building and Accommodation of 400kV indoor switchyard ventilation center installed in the ZJ.7 Building have the earthquake resistant Category II b as per PN AE G-5-006-87 and safety class 4 as per PN AE G-01-011-97 (OPB 88/97). The ZJ.0 and ZJ.7 buildings seismic strengthing for DBE is 0.10g for Horizontal acceleration and 0.07g for vertical acceleration.

Impact of Extreme wind loads, Loads resulted from hurricane, tornado, Loads resulted from extreme floods and tsunami and Plane crash are not considered for non of these buildings.

### Loss of off-site power and loss of the ordinary back-up AC power source

#### Design provisions taking into account this situation: permanently installed diverse back-up AC power sources and/ or means to timely provide other diverse AC power sources, capacity and preparedness to take them in operation, robustness of the provisions in connection with seismic events and flooding

#### Battery redundancy, diversity, capacity, duration and possibilities to re-charge batteries

#### Actions foreseen to arrange exceptional AC power supply from transportable or dedicated off-site source

#### Competence of shift staff to make necessary electrical connections and time needed for those actions; time needed by experts to make the necessary connections

#### Time available to provide AC power and to restore core and spent fuel pool cooling before fuel damage: consideration of various time delays from reactor shutdown and loss of normal reactor core cooling condition (e.g. start of water loss from the primary circuit)

#### Consideration of extreme meteorological events (storms, dust, fog and sultry, heavy rainfall, etc.) impact on loss of electrical power

### Loss of off-site power and loss of the ordinary back-up AC power sources, and loss of permanently installed diverse back-up AC power sources (station blackout – SBO)

#### Battery redundancy, diversity, capacity, duration and possibilities to re-charge batteries

#### Actions foreseen to arrange exceptional AC power supply from transportable or dedicated off-site source

#### Competence of shift staff to make necessary electrical connections and time needed for those actions; time needed by experts to make the necessary connections

#### Time available to provide AC power and to restore core and spent fuel pool cooling before fuel damage: consideration of various time delays from reactor shutdown and loss of normal reactor core cooling condition (e.g., start of water loss from the primary circuit)

The most limiting factor in case of an SBO (transfer of heat from the primary circuit, transfer of heat from the spent fuel pool, loss of cooling in the I&C rooms, discharge period of the accumulator batteries, breach of RCP seals, depletion of available water resources, persistent LOCA via stuck open PORV, loss of natural circulation due to low water level in closed RCS) is the time until the fuel in the core is damaged. Another aspect limiting the time a unit can stay in SBO mode, is the discharge time of batteries. Until the batteries are discharged, the power supply for key valves, I&C for communicating the values of key parameters, control circuits, emergency lighting etc. is preserved. Table … shows the approximate time till occurrence of cliff edge effects.

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| transfer of heat from the primary circuit | 3.1 hr | For sealed RCS, calculation by KORSAR shows that FA cladding temperature exceeds 1200 С about 3.1 hr from the accident onset (for fuel rod of average power), assuming no personnel actions. |
| transfer of heat from the spent fuel pools | 24 hr | Uncovery of FAs in SFP does not take place earlier than 24 hr from loss of SFP cooling. Maximum residual heat release from FAs (19.48 MW) |
| loss of cooling in the I&C rooms | - | - |
| discharge period of the accumulator batteries | 2 hr | Discharge period of batteries may be extended to … by load stripping |
| breach of RCP seals | 24 hr | In the course of the tests a possibility of GTsNA-1391 standby was determined within 24 h in hot circuit Тsuc=(290±5) °С, Рsuc=(15,3±0,49) MPa at Тenv=75°С without operation of auxiliary systems (water of intermediate circuit, sealing water). |
| depletion of available water resources | 4.8 hr | This is the minimum available time till emptying of emergency feed-water tanks. |
| persistent LOCA via stuck open PORV | 3.7 hr | The analysis is not available, LB LOCA without ECCS considered as the bounding case. |
| loss of natural circulation due to low water level in closed RCS | 2.22 hr | The available time until level of coolant in RCS drops below reactor hot nozzle. |

In case of an SBO, the ultimate heat sink for the transfer of heat from systems supplied by accumulator batteries is unavailable, which poses a threat to the I&C overseeing the safety systems. In case cooling of these systems is not recovered, the proper functioning of the I&C could be compromised even if a long-term power supply is provided.

When unit is run at power or in a hot state, an SBO would lead to a loss of power for the SG and thus a decrease in the amount of water available for secondary parts of the SG. The pressure in the SG is regulated by releasing steam into the atmosphere. This would lead to gradual uncovering of the tubes of the heat exchanger in the SG and thus to a reduction in the effective heat exchange surface for transferring heat from the primary circuit. This situation would lead to a loss of the secondary heat transfer system. From the moment the SG are unable to transfer all the residual heat produced in the core, the temperature of the coolant in the primary side would increase. Due to thermal expansion of the coolant, this would lead to an increased level volume of the pressurizer and consequently, to increased pressure in the RCS.

Until the power supply is recovered after an SBO, the water supply in the SG guarantees the transfer of heat from the core via the SG into the atmosphere for several hours. The limiting condition in case of an SBO is the time until the fuel in the core would overheat. In the worst case scenario, the temperature could reach 450 oC (for WWER type reactors) at the outlet from the core within few hours after an SBO. The same time period (approximately 2 hr) would also be available to recover the power supply in case the heat transfer function is lost in the shut down unit and the level of coolant in the core dropped, while it is still possible to let water gradually pour into the core by gravity effect. If heat cannot be transferred from the SFP, the stored fuel would not start overheating for tens of hours after the SBO.

From the analyses of SBO scenarios, including the failure of heat transfer from the primary circuit using the SG, it follows that without carrying out the alternative activities described in the EOPs, there is very short time reserve for restoring the heat transfer from the primary side. The temperature of 450 °C at the outlet from the core, which is the limiting value in terms of fuel damage, would, in the worst-case scenario, be reached after 3.1 hours after the SBO.

To ensure the transfer of heat, it is necessary to restore power supply for at least one safety connection within this time period. This would prevent uncovering and possible damage to fuel in the early stages of an accident.

As a consequence of a power supply loss, the cooling of spent nuclear fuel would be interrupted and the water in the SFSP would warm up. The trend of temperature increase in the SFSP after cooling stops depends on the initial conditions (time since the spent fuel was removed from the reactor, amount of fuel in the SFSP, etc.). Even under maximum temperature load on the SFSP, loss of the cooling function in the SFSP will not lead immediately to damage to the stored spent fuel; it would take at least tens of hours (typically 24 hours).

#### Consideration of extreme meteorological events (storms, dust, fog and sultry, heavy rainfall, etc.) impact on loss of electrical power

### Conclusion on the adequacy of protection against loss of electrical power

### Measures envisaged preventing cliff-edge effects and increasing robustness of the NPP in case of loss of electrical power (hardware, procedures, and organizational provisions)

## Loss of the decay heat removal capability/ ultimate heat sink

The Ultimate Heat Sink (UHS) in the Bushehr nuclear power plant is the sea water of Persian Gulf. To remove residual heat release from the reactor core, heat removal from fuel pool and also for cooling of safety system mechanisms, Nuclear Component Cooling System TF was designed, which is cooled by Service Cooling Water System VE.

***The system TF*** is designed to remove heat from reactor building consumers and reactor auxiliary building to Service Cooling Water System VE in all modes of Unit operation, including the emergency ones.

In modes of anticipated operational occurrences and at design-basis accidents, the system has to remove heat from the consumers engaged in Unit cooldown, up to temperature in primary circuit ≤ 70 ℃.

In normal operation modes (the Unit operates at power, heat-up, scheduled and maintenance cool-down and so on), the system removes heat from normal operation system consumers.

In design-basis accidents modes, the system supplies TF cooling water to:

* Heat exchanger of emergency and planned cooldown of the primary circuit and spent fuel pool;
* Pump of emergency and planned cooldown of the primary circuit and spent fuel pool;
* Emergency boron injection pump;
* Spent fuel pool cool-down pump,
* Closed cooling water pumps (TF Pumps).

***The System VE*** is a part of common heat residual system from reactor plant and performs functions of heat removal from Nuclear Component Cooling System TF and Secured Closed Cooling Water System VJ to the Persian Gulf in all modes of Unit operation including the emergency ones.

The Service Cooling Water System VE for Nuclear Component Cooling System TF of Secured Closed Cooling Water System VJ is a supporting safety system combining functions of normal operation when the Unit operates at power.

The aquatic area of Bushehr NPP is a source of service water supply. The system of service water supply operates by direct flow principal. The sea water enters the plant cooling system by ZM.0 channel and is supplied by direct flow to pumphouses ZM2,4,5, common for all groups of service water pumps.

By the pumps of main cooling water (system VC), and also essential consumers (system VE) and conventional consumers (system VF) the sea water is supplied to the consumers of corresponding systems in the pressure water pipelines.

The used heated water from NPP drops again to the Persian Gulf through the discharge channel. The heated water through the open discharge channel ZN33 and underwater discharge channel ZN35 is removed at a distance 1250 m from the shore and it is discharged to the gulf there through the Cooling Water Jet Discharge Structure ZN4. Such separation of water intake and water discharge places enables to prevent action of discharged water temperature to the temperature of taken-in water.

### Design provisions to prevent the loss of the primary ultimate heat sink

The TF and VE systems are designed according to the following requirements:

* System has to perform its functions in any emergency situation, including situations under conditions of main and standby power supply of normal operation loss at nuclear power plant (plant de-energizing);
* System has the four-channel structure, in other words it complied with the process system structure (emergency boron injection, emergency cooling and so on) of the primary circuit;
* It operates within the whole required period of time (time when the fuel is in reactor or in spent fuel pool);
* Systems TF, VE are responsible for water temperature supplied for cooling of all consumers of reactor building with temperature not more than 33оС in all modes of operation except for the mode of auxiliaries loss (main and stand-by power supply of normal operation loss at nuclear power plant). In case of main and standby power supply of normal operation loss at nuclear power, the precooling is stopped and, depending on temperature in Persian Gulf, the temperature of cooling water VE may be up to 38оС, and it means that the cooling temperature of reactor building consumers shall exceed 33оС.

#### Design provisions to prevent the loss of the primary ultimate heat sink, such as alternative inlets for sea water or systems to protect main water inlet from blocking

All elements of TF, VE systems refer to the first seismic stability category. The power supply of TF, VE system equipment is executed from the reliable power supply circuit of the second category. Systems TF, VE function in all modes of normal operation including start-up and shutdown of the Unit and also in all emergency modes. Combination of normal operation functions and supporting safety systems functions by these systems does not reduce NPP safety level, as independently on mode, the system operates with the same process sequence and using the same mechanisms and equipment, and the media flows do not change directions.

Failures in others systems have no affect the system functions performance, as the single system failure principle is implemented in the design. Any failure in any one of TF, VE systems channels do not lead to loss of functionality of this system both in emergency situation and in normal operation modes.

When one of TF, VE system channel is damaged that caused its deactivation, withdrawal of this faulty system for repair is carried out in accordance with the regulation on safety system channels withdrawal for repair.

Space separation of channel walls and floors allows withstanding fire at least 1.5 hour, and availability of automated firefighting system enables to preserve the system operability, if fire is developed in one of channels.

All equipment and pipelines belong to seismic stability category I and designed for SSE that enable the system to perform its functions at SSE and also at aircraft crash. Structures with installed system equipment are operable at seismic activity with SSE magnitude and also at aircraft crash. The system is capable to perform its functions at all acts of nature accepted for this project.

In every channel of Service Cooling Water System VE, the continuous mechanical treatment of all heat-exchangers from the sea water side (VL system) is designed in order to prevent impurifications and deposits on the surfaces of heat-exchangers. To avoid mussels accumulation in heat-exchanger, the filtering plants against mussels are installed in every channel of VE system before every heat-exchanger (VB system). The Heat Exchanger Cleaning Equipment systems VL and Mussel Filter Equipment VB operate only in a mode of normal operation. During emergencies, operation of these systems is not required as during preliminary operation of VE system by experiments the setpoints for filtering equipment actuation were set that to provide a three day time allowance until the next cleaning (three days – time for power supply recovery after onset of accident with de-energizing).

To prevent accumulation of seaweeds and mussels in equipment, sodium hypochlorite (NaOCl) manufactured in Chlorine Dosing Equipment Building ZM.9is added to sea water upstream of the fine cleaning meshes. The continuous dosage of active chloride is 2000 ppm (pro mille). Besides, every hour a new dosage equal to 10 g/m3is ejected within 15 minutes.

The system is capable to perform its functions at all natural impacts accepted for this design. The structures where this system equipment is arranged are capable to operate during seismic activities of SSE magnitude and after aircraft crash.

#### Robustness of the provisions in connection with seismic and flooding

The TF and VE systems are capable to perform their functions at all acts of nature accepted for BNPP-1.

All elements of TF and VE systems such as equipment and pipelines are belong to seismic stability category I and designed for SSE that enable the system to perform its functions at SSE and also at aircraft crash. The TF and VE systems are capable to perform their functions at all acts of nature accepted for BNPP-1.

The system TF arranged in the reactor auxiliary building (building ZC) and the reactor compartment (buildings ZA, ZB.0). According to the Bushehr NPP final safety assessment report (FSAR) all of these three buildings are water resistant and have watertight external door.

The system VE arranged in the pump house buildings (buildings ZM2,4,5). The elevation for the service water pump-house location is governed by maximum and minimum water levels in the Gulf and the pump-house is deepened because of necessity to retain operability of system VE pumps at extreme minimum water level in the Persian Gulf equal to minus 3.900 m. The entrance to Main Cooling Water Pump house ZМ2,4,5 is made from elevation +13.500 m and To exclude flooding of the pump rooms through the entrances, they are equipped with hermetically sealed doors, and the sealed doors are fabricated and installed on the stringent requirements such as:

* Doors against flooding shall preserve their properties through the whole time of operation at normal operation conditions;
* Locks of the doors against flooding shall be designed considering the hydrostatic pressure. Locking devices are to be opened without keys considering evacuation of personnel in case of fire;
* The criteria that specifies requirements for allowed water leaks through the doors is non-exceeding of the limit for safe operation of building rooms and systems and equipment important for safety located in them in case of emergencies (flooding of basement, overpressure);
* The allowed leaks through doors during flooding and accidents shall not exceed 0.2 m3 per day;
* External and internal surfaces of doors against flooding shall be covered by anticorrosive coating according to operating conditions of adjoining rooms.

### Loss of the primary ultimate heat sink (e.g. loss of access to cooling water from the sea)

In Bushehr nuclear power plant, the primary ultimate heat sink (Persian Gulf water) can be lost for one of the following reasons:

* Water intake blockage due to an external object;
* Presence of fossil fuels in the sea water;
* Inefficiency of heat exchangers due to sedimentation or rusting of the heat transfer surfaces;
* Flooding at the inlet part of the pumps due to internal causes.
* Flooding at the inlet part of the pumps due to external causes.
* Loss of power supply to the pumps.

The mentioned reasons have a different chance of occurrence and their importance is different in term of safety of power plant.

#### Availability of an alternate heat sink, design provisions to prevent its loss

Alternative heat sink in the Bushehr NPP is the atmosphere. After loss of primary ultimate heat sink, pressure and subsequently the temperature increases in the primary circuit. The generated heat in the primary circuit can be transferred to the alternative ultimate heat sink via Bru-A valves by following sequence:

After loss of primary ultimate heat sink at first the heat generated in the fuel rods will be transferred to the primary coolant, and then in the steam generators the primary heat will be transferred to the water of secondary circuit. After that pressure of secondary circuit will be raised and then by opening the steam dump valve to the atmosphere (BRU-A) the heat is injected into the atmosphere in the form of saturated steam and this will be repeated again and again until the water in the secondary side of steam generator runs out.

The SG water can be supplied by emergency feedwater system (RS System) arranged in the ZX building. RS system is a safety related system and the pipelines, valves and equipment of the system, including the pipelines which connect this system with other systems up to the first shut-off valve (this valve is also included) – refer to safety class 2 as per PNAE G-01-011-97 (ОPB-88/97), seismic category I as per PNAE G-5-006-87, group B as per PNAE G-7-008-89. Part of the system, including valves, demineralized water tanks filling pipes, refers to safety class 4 as per PNAE G-01-011-97 seismic category II as per PNAE G-5-006-87.

Equipment of the system completely conforms to the requirements of OPB, and for its functions the equipment are designed as protective equipment. Emergency feedwater system (RS) performs the following functions:

* Demineralized water supply to the steam generators under abnormal operating conditions and during emergencies and failures of the main feedwater system, including external impacts, in order to ensure cooling of reactor and removal of residual heat from the reactor core.

The design of emergency feedwater system (RS) of BNPP-1 meets the following criteria and requirements specified by the general designer and related to the reactor plant:

* Creation of required supply of demineralized water to steam generator for cooling of the reactor plant through BRU-A to a temperature of 150 °С in the primary coolant system;
* Provision of demineralized water supply to the steam generators at a flow rate of not less than: 150 m3/hr at SG pressure of Р=6,3 MPa (64 kgf/cm2); 125 m3/hr at a pressure of Р=6,9 MPa (70 kgf/cm2); and 80 m3/hr at SG pressure of Р=8,4 MPa (86 kgf/cm2);
* The time delay for supplying water from each emergency feedwater pump RS12,22,32,42D001 to the corresponding SG is not more than 120 seconds;
* Emergency feedwater system (RS) has a four-channel design, which means that the design of system RS conforms to the design of other safety systems;
* The system can be tested (on a channel-by-channel basis) during the Unit operation at power without losing its functions. lose

The RS system has 4 tanks and each tank has 360 m3 useful volumes, which can be used for steam generator feed and bleed process to stabilize the primary circuit and subsequently the reactor parameters.

#### Possible time constraints for availability of alternate heat sink and possibilities to increase the available time

The only time constraint for availability of alternate heat sink is the discharge time of water in the steam generator secondary side and reservoir’s water in the RS tanks, and as long as the water of SG secondary side is supplied by the emergency feedwater system (RS System), the alternative ultimate heat sink will be available.

The water amounts in RS tanks considering personnel actions as per 51.BU.1 0.00.AB.WI.ATEX.003 is enough for reactor plant changeover to cold condition. In addition, the RS system tanks can be filled up by the UD system.

Of course this is only true until the power of unit for supplying the BRU-A power is available, and in the time of loss of power, the BRU-A can work with the battery only for 2 hours.

### Loss of the primary ultimate heat sink and the alternate heat sink

Loss of the primary ultimate heat sink can occur only in case of loss of all the essential cooling systems (TF, VE and TH systems). Complete loss of operability of all of these three systems can be considered as an envelope case of loss of primary ultimate heat sink. Alternative heat sink in the Bushehr nuclear power plant unit-1 is the atmosphere and loss of alternative heat sink can occur if the Emergency feedwater system (RS system) is lost.

At the time of the primary ultimate heat sink and the alternate heat sink, the mobile technology is considered for reactor and SFP heat removal. To remove the residual heat from reactor, demiwater can be injected into primary circuit in an alternative manner by using mobile pumps (pressure on delivery of the pump 1.6 MPa, flow 150 m3/h).

The reactor residual heat can be removed also from secondary side. In this case demiwater can be added directly into SG in an alternative manner by using mobile diesel pump.

For spent fuel storage pool, a mobile pump is suggested to supply the make-up water with flowrate 40 m3/h.

Within the completion of the project, connection points are prepared which enable the mobile devices to be connected to the primary circuit for injecting water into primary circuit and adding demiwater to the SG emergency feedwater system (RS system).

#### Time available to recover one of the lost heat sinks or to initiate external actions and to restore core and spent fuel pool cooling before fuel damage: consideration of various examples of time delay from reactor shutdown to loss of normal reactor core and spent fuel pool cooling condition (e.g. start of water loss from the primary circuit)

The time available for connecting the mobile pump to the connection point prepared in the primary circuit is less than two hour.

### Conclusion on the adequacy of protection against loss of ultimate heat sink

### Measures envisaged preventing cliff-edge effects and increasing robustness of the NPP in case of loss of ultimate heat sink (hardware, procedures, and organisational provisions)

## Loss of the primary ultimate heat sink, combined with station black out

### Time of autonomy of the site before loss of normal cooling condition of the reactor core and spent fuel pool makes fuel damage unavoidable (e.g., start of water loss from the primary circuit)

### External actions foreseen to prevent fuel degradation (equipment on-site and off-site, time necessary, availability of competent human resources, identification of any cliff-edge effects and when they occur)

### Measures envisaged preventing cliff-edge effects and increasing robustness of the NPP in case of loss of primary ultimate heat sink, combined with station black out (hardware, procedures, organizational provisions)