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SUMMARY OF EU STRESS TEST FOR LOVIISA NUCLEAR POWER PLANT

1 LOVIISA NUCLEAR POWER PLANT

Loviisa town is located approximately 90 km eastwards from Helsinki at the coast of Gulf of Finland. Loviisa Nuclear Power Plant (Loviisa NPP) is located approximately 10 km southeast from Loviisa town center at the island of Hästholmen. The site consists of two VVER-440 pressurized water reactors, two shared spent fuel storages, low and intermediate level waste storages, liquid waste solidification plant and all necessary facilities for support functions (offices, workshops, fire station etc.). The first criticality was reached in 1977 at Loviisa 1 and 1980 at Loviisa 2.

Loviisa NPP was extensively modified already in the design phase in comparison with the reference plant. The process systems were mainly designed in Soviet Union and large modifications included for example the containment system (leak tight ice-condenser containment with Westinghouse ice condenser), automation systems (Siemens) and safety systems. Significant modifications have been made throughout the plant lifetime as well. For example new systems have been constructed (e.g. auxiliary emergency feedwater system, severe accident management systems (SAM)) and many existing systems have been modified. Renewal of automation is currently under way.

2 SAFETY FUNCTIONS

2.1 Safety functions for reactor

Loviisa NPP is equipped with similar safety systems as typical pressurized water reactors. Most important safety functions are reactivity control, residual heat removal and containment of radioactive substances.

Residual heat can be transferred in various ways to sea by normal systems or safety systems. During power operation heat is transferred through the main condensers and during shutdown through the secondary side heat exchangers into the sea. In accident situations heat can be transferred in sump recirculation mode from containment sump through intermediate cooling circuit into sea, or steam from steam generators can be blown into the atmosphere. Water can be pumped into the steam generators either by electrical pumps or diesel driven pumps. Safety systems are backed up by emergency diesel generators or they have a direct diesel drive.

A specific feature of Loviisa NPP is the containment that is equipped with ice condensers. In most accident situations the ice condensers restrain pressure increase as long as there is significant amount of ice left. The containments have also been equipped with internal and external spray systems designed to remove heat from the containment into the sea. The internal spray system uses intermediate cooling circuit and is backed up by emergency diesel generators. The external spray system has dedicated sea water cooling circuit and is also equipped with fire water connection for external water supply. The external spray is backed up by severe accident management (SAM) diesel generators.

In the stress test, the availability of safety systems is evaluated in predefined accident situations. In this connection also the support systems are considered, such as electrical systems and ventilation. Detailed system dependences are analyzed in a probabilistic risk assessment (PRA).

2.2 Safety functions for fuel storages

At Loviisa there are two separate spent fuel storages containing several pools each. The spent fuel storages are connected to Loviisa Unit 2 systems. In addition both of the containments include a spent fuel storage pool for refueling and storing fuel recently removed from the reactor. In all of these storages subcriticality is maintained even with unborated water.

Residual heat is transferred into the sea by intermediate cooling circuit and from there finally into the sea. This chain is backed up by emergency diesels. In case cooling would not be available the water would eventually boil and heat would be removed in this way. Vaporized water can be compensated by adding water with several available systems.

3 POWER SUPPLY

Loviisa NPP has several power sources available. The power plant is connected to external grid by 400 kV and 110 kV connections. In incident or accident situations the safety systems can be powered by eight emergency diesels. These diesels provide power to safety systems and their support functions. One diesel per plant unit is sufficient to ensure safety functions. The emergency diesels can be replaced by external connection to on-site diesel generator plant or to nearby Ahvenkoski hydro power plant. Four emergency diesels are arranged to provide power to Unit 1 and the other four to Unit 2. The emergency diesels can be also cross-connected between the plant units. The emergency diesels can be started and supplied by their own batteries.

Loviisa NPP has also two dedicated severe accident management (SAM) diesels, common for both plant units. The purpose of the diesels is to provide power to systems that are needed to manage a severe accident situation. The SAM diesels can be started and supplied by their own batteries.

There is a separate diesel generator plant at the site. This diesel generator can be connected to replace plant emergency diesel generator at both units simultaneously.

To provide power for the plants' I&C, protection and control of electrical systems important to safety there are DC systems installed. The DC systems and batteries can be powered by all above mentioned power sources, with the exception that SAM diesels only power the most important DC systems.

There are auxiliary emergency feed water system and fire water system that do not need electricity from plant systems. Instead the pumps and the diesel engines in these systems are arranged at same shaft. Start-up power is provided by dedicated batteries.

The emergency preparedness centre is equipped with its own independent diesel generator.

4 EARTHQUAKES

At the time of construction of the Loviisa NPP, earthquake was not a design basis load. The new structures, equipment and systems critical to safety constructed after 2001 are designed to withstand the design basis earthquake (DBE).

Seismic evaluations have been done afterwards within the level 1 PRA. The evaluations show, that seismic events do not pose a major threat to plant safety due to low seismicity and low equipment failure probabilities.

5 FLOODING

Seismic activity at the Loviisa NPP site and surroundings is very low and the sea is shallow. Therefore tsunamis caused by seismic events can be excluded. There are also no dams that could cause a significant tsunami.

At Loviisa site the high sea level is caused by weather phenomena. If all the identified factors would be at their estimated maximum level simultaneously, the sea level would be at 2.13 m. The impacting factors include total volume of water in the Baltic Sea (83 cm), rise in the mean sea level as a result of strong wind (60 cm), specific phase of a standing wave (20 cm), low air pressure (40 cm) and tide (10 cm). The highest experienced sea level was 1.77 m in January 2005 and no problems were encountered. Seawater is expected to rise to its peak level at a rate of 10 cm/h.

If the sea level rises 1.3 m above the average level, inspections to lower plant compartments are increased. When the level exceeds 1.75 m, preparations for shutdown are initiated and at 1.95 m the plant is shut down. The plant is more vulnerable to external flooding when either of the units is in cold or refuelling outage and the main sea water systems are open for maintenance. If high water level is forecast during outage, the open manholes of sea water system can be sealed in advance. The outage risk will be decreased by the ongoing replacement of the concrete bulkhead beams with higher steel sluice gates equipped with seals.

The critical sea level is 2.1 m during outage (will increase to 2.45 m after gate modifications) and 3.0 m during power operation. The sea levels are significantly higher during winter than during summer. Plant annual outages are scheduled at the summer time.

During power operation, large volumes of sea water could get into the plant if the sea water would get on the yard area at level above 3.0 m. This is possible if sea water rises more than 2.5 m and if the surge from certain direction carries water into the yard area, or if the sea water level rises above 3.0 m. Water will flow through open doors and other hatches into the plant. The auxiliary emergency feedwater system could be used to remove residual heat for some time at least up to 3.0 m water level. Fortum estimates the risk caused by floods to be very small.

Atmospherically generated meteotsunami caused by travelling thunder front is the most probable type of the tsunamis in the Gulf of Finland. The wave height is estimated to be relatively low at the site and such an event is most likely to occur during summer when the water level is low. The phenomenon is being further studied, but the frequency of it is estimated to be included in the very low probability of the flood risk.

6 EXTREME WEATHER CONDITIONS

The Loviisa PRA covers extreme weather phenomena related to air and seawater temperature, seawater level, strong winds and storms, snow storms and freezing conditions, heavy rainfall and snowing, lightning, algae and frazil ice. Also the various combinations of simultaneous extreme weather conditions have been investigated.

The design bases for external air are -28 °C and +25 °C. Extremely low temperatures are not deemed to jeopardise the availability of the plant's systems due to the big thermal loads during normal operation. The actual high temperature tolerances for flow-through and free convection cooled devices are +40 °C. Safety related ventilation systems are sea water cooled.

The design basis for seawater temperature is +23 °C, but loss of instrumentation room ventilation would require the temperature to rise above +35 °C. The risk related to high seawater temperature is low because high temperature leads to administrative power reductions before the temperature rises to the point that could cause losses of control equipment. Also the frequencies of extremely high temperatures are low.

The risks related to high sea level are explained in conjunction with flooding. A low sea level could prevent cooling water intake from discharge side if main intake is blocked by oil, algae or frazil ice.

The design basis for high winds for non-bearing structures is 36 m/s. Load-bearing plant structures, like steel and reinforced concrete structures can withstand considerably higher wind speeds. A wind speed exceeding 28 m/s could detach sheet metal and debris. A wind speed exceeding 39 m/s is assumed to result in a loss off offsite power lasting 15 h on average. The turbine hall can withstand a tornado of 46 m/s and unidirectional winds up to 66 m/s. The ventilation stack can withstand winds up to 53 m/s.

The design basis for heavy rainfall is 72 mm/h and the roofs are designed to withstand a 180 mm layer of water. A possible flooding of rainwater into the turbine hall does not threaten safety-significant equipment.

There is a small frequency of exceeding the design bases presented above and this has been taken into account in PRA. The core damage frequency due to extreme weather event is currently $6.6 \cdot 10^{-6}$ /a, which is roughly 14% of the total risk of the plant. The most significant risk is related to heavy algae concentration combined with strong wind exceeding 39 m/s. The modification (cooling towers) under preparation would further decrease the risk.

Recent improvements in the robustness of the plant against weather phenomena include the recovery possibility of a main transformer during cold and refuelling outage in 3 hours after demand. A backup diesel generator that can feed both units was installed in autumn 2011. It can be used to generate onsite electricity for the plant if the offsite power connection is lost.

7 LOSS OF ULTIMATE HEAT SINK AND LOSS OF ELECTRICAL POWER

7.1 Reactor

As part of extensive PRA studies Loviisa NPP has identified possible threats for ultimate heat sink. These studies have shown that there is a possibility (though probability is low) that algae, oil, fragile ice and some other phenomena could block sea water intake. Blocking of sea water intake does not cause any immediate threats for the reactors, since water volumes in the secondary side of the plant are large compared to the thermal power of the unit.

Residual heat can be removed from steam generators by releasing steam with various valves. Coolant inventory of steam generators can be maintained with several systems. Auxiliary emergency feed water system is dedicated to operate without any external power supply or sea water cooling. In the stress test the available water reservoirs at the plant site and the possibilities to use this water are evaluated. The conclusion of this evaluation is that residual heat can be removed through steam generators for about ten days without external help. Depending on the accident situation pumping actions by plant fire brigade might be needed after three days.

In case of a station blackout, primary circuit boration is needed after some time to reduce the primary circuit temperature. This would prevent primary coolant pumps seals leakage caused by high temperature. Experimental study is ongoing to determine the seal properties. Until the results are available, seal leakage has been conservatively assumed after 10 h.

For loss of power the time delay is the same. The difference is that fewer systems are available to maintain the coolant inventory of steam generators. In the stress test a matrix of available systems in different loss of power and loss of heat sink scenarios is presented.

In case of primary circuit is opened for fuel reloading it is not possible to pressurize primary circuit and remove steam through steam generators. The residual heat removal can be ensured also in this case as the same water reservoirs are available as in power operation. Steam created in the containment will cause pressure increase above the design pressure, unless heat is removed from the containment by internal or external spray system. The containment external spray system is powered by independent severe accident management power system and is also equipped with connections for the use of water sources by external pumps. If water can't be brought outside the plant site or sea is not available, the on-site water reservoirs must be utilized. In this case the decay heat removal can be ensured for about two days assuming that the containment isolation has the priority over water use.

Based on the stress test in some case the sufficiency of water is not limiting, but the volume of the diesel tanks. Depending on accident there might be need for refueling the diesel engines from diesel reservoirs available at the plant site. The emergency diesel can run 3 days (2 diesels running) and diesel generator plant 86 h (2 emergency diesels are replaced). One diesel per plant unit can power the systems that are needed to ensure the safety functions. SAM diesels provide power to the external spray systems and are discussed in connection to severe accidents.

7.2 Fuel storages

If the cooling is interrupted for some reason, the water starts to heat up and finally boil. Boiling is very effective mean to transfer heat from the spent fuel and the situation in the pool stays stable as long as boiling is compensated by make-up water. Time delays to fuel uncovery are analysed in the stress test if make-up water could not be delivered. In the containment fuel storage it takes with unloaded core almost 2 days and after fuel loading over 6 days until fuel uncovery. In the spent fuel storages the time delays are longer until fuel uncovery, at least 3 weeks.

Steam created in the containment fuel storage can be dealt with containment external spray in a similar manner as for open reactor pressure vessel. From the other storages steam can be discharged into the environment by ventilation systems or by opening the building door. The steam contains only minor amount of radioactive material and release limits are not exceeded.

8 SEVERE ACCIDENT MANAGEMENT

8.1 Prevention of radioactive releases

Significant plant changes have been done at Loviisa NPP regarding to severe accident management. The aim of these changes has been isolation of the containment building and ensuring that the leaktightness is maintained throughout the accident. If the containment integrity can be ensured the radioactive releases from the plant site are very small. The actions are arranged under so called SAM (severe accident management) safety functions, that are containment isolation, hydrogen management, in-vessel retention of corium through external cooling of the reactor pressure vessel, and in a long term, heat removal from the containment.

Execution of SAM safety functions is separated from normal and safety related electrical and automation systems. There is dedicated SAM electrical system and SAM automation and these systems are qualified for severe accident conditions where necessary. The SAM-automation can be operated from main and SAM control rooms. There are also local control centers for manual actions. The local control centers are located in areas protected against radiation.

Execution of SAM safety functions during external events was evaluated in the stress test. In special severe accident situations, such as initiated by flood or loss of heat sink, after some time external help is needed to transport water and to provide pumps to site. Also in these cases the SAM safety functions can be executed in a short term with good confidence.

Temporary actions and connections might be required to prevent fuel damage in the fuel storages, if there is a severe accident in the reactor. These measures can be done in auxiliary building or in the reactor building outside the containment. In both of these locations the radiation conditions are expected to ensure working conditions.

There is diesel fuel in the day tanks of SAM-diesels for 16.5 h with full power and for 24 h if 1 diesel is running. One SAM-diesel in total is sufficient to ensure SAM safety functions to both units.

8.2 Organisational issues

For emergency situation the emergency preparedness organization will be called to duty. This organization is responsible for the emergency response at the site and communication with the authorities. The organisation is gathered into two places, mainly in the emergency center at the site and partly at company main office 100 km away from the site to provide technical support. In emergency preparedness organization there are experts from all relevant technical fields and the crisis management facilities at site are designed against increased radiation levels of severe accident.

The accident management strategies and organizational issues for accident at both of the reactors and all spent fuel storages simultaneously were evaluated in the stress test. The accident management measures are designed to be executable by the shift during power operation and during shutdown conditions there are additional personnel on-site. No external help is needed in a short term.

Most of the communication means are backed up by emergency diesels. Some communication means can be operated by battery power and can be manually recharged from SAM-diesel or emergency centre diesel backed up network. The accident can be managed with these rechargeable communication means.

9 CONCLUSIONS

At the design stage and during the lifetime of the Loviisa NPP significant provisions against external events have been implemented. Several plant modifications were already ongoing or in the design phase before the Fukushima accident, such as renewal of secondary side relief valves, renewal of automation, new diesel generator plant (installed in autumn 2011), enhancement of lightning protection by grounding network modification, replacement of the concrete bulkheads, and cooling towers for residual heat removal.

In the national evaluation for Ministry of Employment and the Economy as well as in the EU stress test, an evaluation is done how Loviisa NPP can cope with these events. The results show that safety functions can be ensured for significant time before external help is needed.

In the EU stress test also the management of a severe accident was evaluated. Loviisa NPP has implemented significant plant changes for severe accident management. No major deficiencies were found.

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Despite of the good situation of ensuring plant safety in external hazards and managing severe accidents, the preparation of national evaluation for Ministry of Employment and the Economy as well as the EU stress test have given some ideas, how preparation of Loviisa NPP related to these events could be further improved. Improvement ideas cover e.g. following areas:

- Further development of guidelines and procedures

- Ensure heat removal from spent fuel storages in severe accident by applying SAM automation and electricity.

- Enhancement of long-term accident management capabilities by improved operability of communication systems and optimization the amount and usability of water and diesel reservoirs.

- Battery capacity extensions.

- Further flood protections.

These new ideas will be investigated in detail in the future. Possibilities to implement the modifications, positive impact to safety and also adverse effects will be evaluated. Implementation decisions will be made after these evaluations.