ANALYSING AND DECREASING EXTERNAL EVENT RISKS OF LOVIISA NPP

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Studies of the external event risks and how to decrease them have been persistent work for Loviisa NPP starting in the beginning of 1990's. The core damage frequency (CDF) has been reduced by a factor of more than ten in spite of the fact that new initiators, factors and phenomena have been identified and included in the analysis. Improvements decreasing internal event risks have not necessarily decreased the risks of external events whereas improvements to decrease the flood risks due to internal hazards affect considerably also the weather risks. Many improvements have been designed in several phases against same external phenomena because of new knowledge, changed risk profile, changed climate and increased transportation in the surroundings. The first improvements in 1993 were against high sea water and then against coolant intake blockages. In 2011 new information was obtained from high sea water levels indicating that the earlier frequency estimates were not valid anymore because the climate has changed. New analyses led into the year 2014 flood protection. Independent air-cooled cooling towers were under investigation and found to be the most effective way to improve plant safety in the beginning of 2011 by decreasing CDF due to coolant intake blockage risks. The Fukushima accident affected the final design of the cooling towers that were taken into use in 2015.

I. INTRODUCTION

The first PRA for Loviisa 1 VVER type PWR (Model 213, 510 MW) was completed in 1989 at level 1 for internal initiating events at full power. Since then PRA has become an important tool for making safety-related back fittings for the Loviisa plant and the utility has pursued continuous improvements of key plant systems and procedures. PRA has been updated annually, and the core damage frequency (CDF) has been reduced by a factor of more than ten in spite of the fact that new initiators and phenomena have been identified.

The basis of the Loviisa PRA, its practices and guidelines were created for the study of internal initiators at power and for its applications.[1,2] The objectives from the beginning of the study have been estimating the core damage risk, identifying risk important accident sequences, systems, equipment and actions, identifying potential needs for modifications and informing the executive bodies of the company, increasing the knowledge of operating and training staff on the dominating risk factors and how to prevent and mitigate them. Later on, additionally an objective has been to use PRA in all safety related decision making, together with deterministic safety analyses. For this purpose it has been considered to be important to develop a full-scope PRA, covering all potential initiating events and to take all them into account in a living PRA.

Nowadays, the level 1 PRA covers internal and external events including fires, floods, seismic, severe weather and man-made external events for full, low and non-power states. Terrorism is not taken into account in the PRA. The model includes over 600 initiating events and over 7000 frequency estimates for them when all plant operating states are taken into account. In the PSA for low power and shutdown modes the refueling outage was divided into 16 states (phases), largely based on which components or subsystems are under maintenance in each state, and what requirements are set for different safety systems.[3]

The fire risk assessment is based on world-wide statistics on fires (OECD/NEA FIRE database) in different rooms and buildings of nuclear power plants. It was completed in 1997 for power operation[4,5], integrated with other PRA as late as in 2005 and completed for shutdown states in 2011[6]. The cause-fires are rather evenly spread around the plant, with no single dominating room. The study for the Lo2 unit continues still being currently mostly a copy of the Lo1 fire PRA. Mapping the cable routes and the rooms for fire risk evaluation have been the most time consuming tasks. Tens of improvements have been completed during the years.

The internal flood risk assessment was started by first identifying the locations of safety-significant equipment as well as vessels and pipelines that are potential sources of floods. The work focused on rooms and areas where a flood could cause initiating events and also fail safety components that would be needed in case of such an initiating event. Critical and maximum flood levels were assessed as well as the time available, before the critical level is reached, for possible recovery actions. In case of the circulating water (sea water) system leakages the spectrum of initiating events depends on the sea level at the time of the event. The study was completed for power operation in 1994[7] and for shutdown states in 2002. Several plant modifications have been implemented.

The seismic PRA was completed in 1992 for power operation[8] and updated in 2010 and extended to shutdown states as well[9]. Seismic PRA identified large water tanks, such as the feed water tanks and the steam generators, as the most vulnerable components. No plant modifications were considered necessary due to the low core damage risk due to low seismicity. The seismic PRA is currently under extensive updating, including new estimation of the seismic hazard.

The weather PRA and the related risk reduction are the main issues of this paper. At first the PRA utilization and Loviisa risk reduction are presented.

Refueling pool risks have also been studied taking into account both internal and external initiating events.

The scope of level 2 PRA is the same as in the level 1. Only seismic risks of level 2 have not been specifically studied because their contribution has been so small, only 0.4 % of CDF.

Loviisa NPP is located at the southern coast of Finland and it consists of two 510 MWe VVER-440 (PWR) reactors commissioned in 1977 and 1981. The plant protection system, instrumentation and control systems, the ice-condenser containment and many auxiliary systems are largely Western design. The engineered safety features (ESF) were designed especially for this plant according to the safety criteria and guides valid in the early seventies, almost similar to the U.S. ones. Most of the active components in ESF's are 4 x 100 % capacity, supported by four diesel generators per unit. A large heat capacity (e.g. six primary loops with large horizontal steam generators) makes the design internally forgiving for loss-of-heat-sink transients. Both units have lifetime load factors over 80 %, low activity doses and releases, and few forced outages. However, since the plant is a one-of-a-kind design, a hybrid of Eastern and Western technologies, and the design basis did not include all important events, it is not surprising to encounter some rather plant-specific risk contributors.

II. USE OF THE PRA AND RISK REDUCTION

Since 1990 Loviisa PRA has been updated annually and extended to cover all kinds of possible initiating events. It has been used extensively in the nuclear safety related decision making, adding up to over 270 documented applications, currently about 30 applications per year, and many of them have been presented in conferences like PSAM:

- Identification of dominating risk contributors and possible means for reducing risk by plant modifications and improved procedures,
- Supporting new design with risk assessments (cost-benefit analyses taking into account accident costs, risk estimates of alternatives, reliability targets, risk analyses of construction works),
- Economic optimization and prioritization of design options,
- Long term cooling risk analysis for the design of a new auxiliary residual heat removal system,
- Improvement of operator training,
- Support in plant disturbances/events, justification of temporary (and permanent) configurations, extended test intervals and extended outage times,
- Justification and risk informed evaluation of certain rules of Technical Specifications,
- Risk-informed safety classification of systems and components,
- Risk informed in-service inspection of piping,
- Equipment categorisation for the maintenance program,
- Annual refuelling outage risk estimates,
- Availability analysis taking into account rare events that might lead into long outages and
- Risk follow-up.

Figure 1 illustrates annual CDF reduction between 1996 and 2015. Notice that the different risk areas are presented in the figure columns in the same order as in the legend. Plant improvements until 1996 have been presented e.g. in Refs. 1 and 2. Those earlier improvements were mainly designed to reduce the risks coming from internal initiating events. Some of the most important of them were

- Improved air cooling system for instrumentation rooms (CDF due to loss of instrumentation room cooling reduced in 1990 from $1 \cdot 10^{-3}$ /year to $8 \cdot 10^{-6}$/year),
- Improved containment sump strainers,
- Automated isolation of a leaking steam generator (1994), improved N^{16} detection (1995), additional pressurizer spray (1994-6) and additional water tank (CDF due to primary to secondary leakages reduced from $2 \cdot 10^{-4}$/year to $2 \cdot 10^{-6}$/year).

Through 2001 - 2003 the shutdown PSA was updated and extended to cover flood events and severe weather phenomena. That is shown in Fig. 1 as an increase in the annual risk profile. During 2004 - 2005 very small leakages have been taken into account both inside (> 5 kg/s) and outside (> 0.5 kg/s) containment. New symptom based event oriented emergency operating procedures were taken into use in 2006. The development process of these new EOPs improved the knowledge of the behavior of plant. The PSA model has been changed to better reflect these new procedures and the new knowledge. The risk reduction shown in Fig. 1 is partly caused by more detailed analyses and new knowledge.

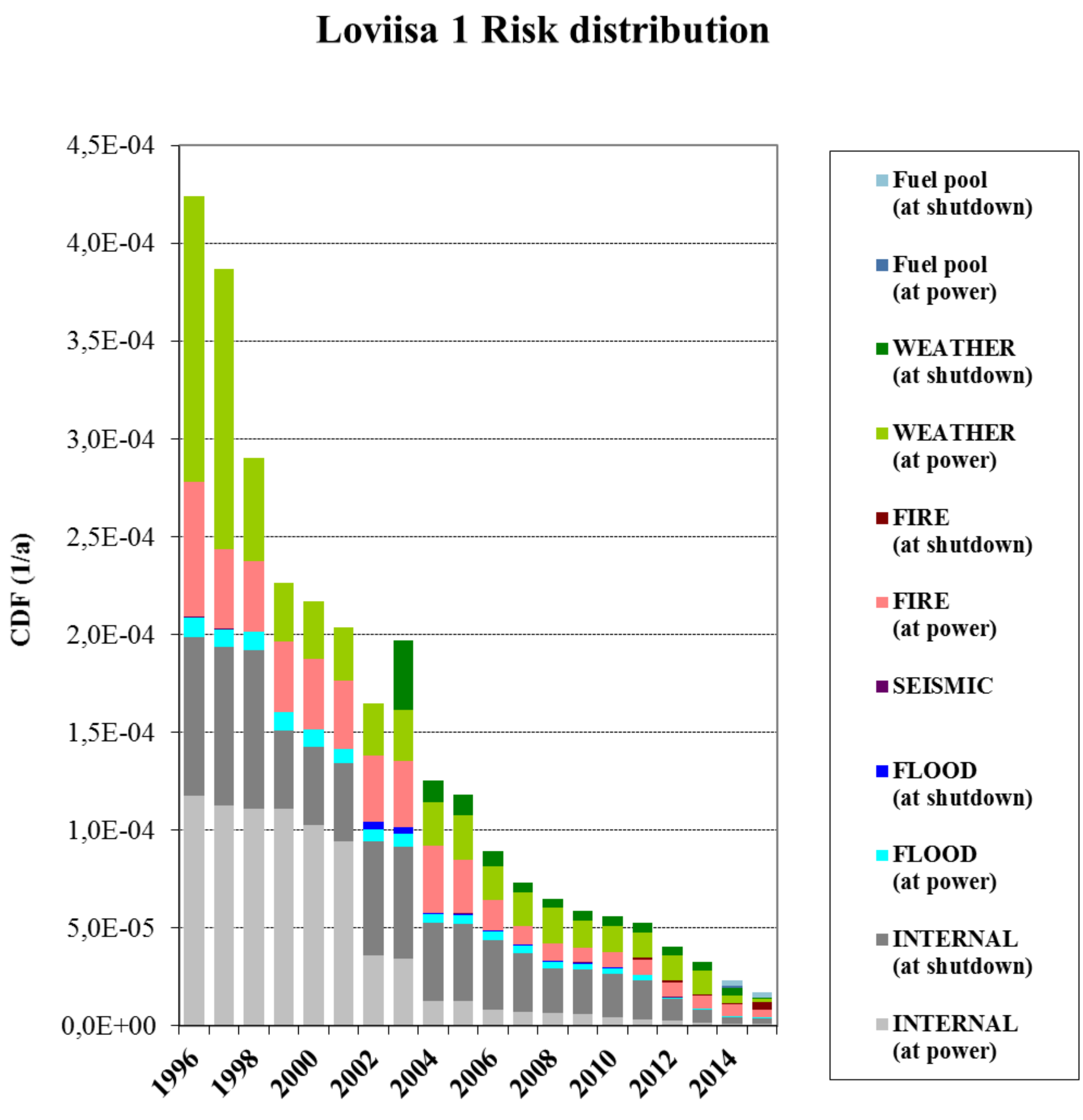

Fig. 1. Loviisa 1 risk reduction (1/a = 1/year).

External events and events during shutdown states have turned out to be important risk contributors needing risk reduction. These risks are not necessarily decreased by the improvements designed to decrease the risks of internal events. For example the improvements related to primary to secondary leakages have no or only minor effect on the external event risks although they reduced CDF significantly.

III. WEATHER RISK ANALYSIS

III.A. Identification and screening

The severe weather risk assessment began with an identification of potentially risky weather-related phenomena including hydrological, oceanographic, meteorological and biological phenomena as well as man-made phenomena. Terrorism is not in the scope of the PRA. Detailed analysis was carried out for phenomena and combinations that passed certain screening criteria. The main principles in the screening analysis were[10]

1. The phenomenon must have strength exceeding the design basis at 50 % confidence with a frequency larger than 10^{-8} per year.
2. The phenomenon that exceeds the design basis must lead to detectable consequences at the plant, site or power grid, so that a reactor trip is made or the plant is run into a safer operating state.
3. The effect of the event is analyzed 24 hours or to a stabilized state.
4. If the identified phenomenon can be foreseen 12 hours beforehand no power operation risk is considered. A potential shutdown risk has to be studied if the cold state is not safe due to this phenomenon.

The screening phase produced relevant thresholds for each phenomenon, exceeding of which causes an initiating event and weakening some relevant safety function. To be defined as an initiating event the phenomenon must not be enveloped by already defined initiators. It was taken into account that the thresholds can be smaller or lower with certain phenomena together with additional failures, like e.g. with high or low temperature and ventilation failures, with excess sea vegetation and strainer failures or with high sea water level and erroneous installation of the bulkhead gates during shutdown. Ultimately many weather-related phenomena and their combinations were analysed in detail, e.g. sea level, extreme water and air temperatures, wind, rain, snow, lightning, sea vegetation, fouling and transportations in the vicinity. Transportations were the only identified man-made phenomena that could pose a risk to the plant.

III.B. Initiating event definitions and frequencies

The distributions of the maximum annual wind speed, sea level, rain/snow events and temperatures were determined based on local or regional meteorological data collected by Loviisa NPP, Finnish Meteorological Institute and Finnish Institute of Marine Research. The frequency and amount of sea-vegetation was based on site experience (”precursor” events). The basic exceedance frequency of a phenomenon was multiplied by a relevant fraction (e.g. wind direction sector, or the fraction of a year for certain conditions, or relative target area for cyclones) to obtain the initiator frequency. The calendar times of shutdown states vary from year to year and this has a notable effect on the frequencies of some phenomena. For example the monthly frequency estimates for a high sea water level were multiplied by the monthly Plant Operating State (POS) occurrence probabilities, in order to get POS-specific frequencies.

Because of correlations between phenomena the probabilities of combinations can be larger than the products of individual probabilities. For example, a high wind from a certain direction can raise the sea level, loosen vegetation and metal sheets (roof or siding), and thereby increase the probabilities of seawater inlet or heat exchanger flow blockages and loss of power events. The probability of frazil ice blocking the cooling (sea-) water intakes is highest during cold weather below freezing point but only with high wind and when the sea surface is not yet covered with ice.

III.C. Decreasing external flooding risks

One of the first important findings in the flood risk analysis of internal hazards was that a possible break in the circulating water system in the turbine building could lead to flooding of the reactor building basement through cable tunnels (at level -0.60 m) and fail primary coolant pump seal cooling pumps and emergency core cooling system equipment. It would take several hours before the water level in the turbine hall would rise up to dangerous levels even from breaks larger than one meter in diameter. Anyway, walls (+1.00 m) have been built to prevent this sequence, reducing the risk (VC3FLOOD) from $3 \cdot 10^{-6}$/year in 1993 to $3 \cdot 10^{-8}$/year in 1994. This improvement is important also for decreasing external flood risks. It showed its importance also in the stress tests after the Fukushima accident.

High sea level could lead to same consequences as above (VC3FLOOD) during annual outage when the circulating water system is under maintenance and isolated from the sea by a temporary dam (+1.00 m). The plant units have a common turbine building and the other unit is normally at power operation. Thus, this is a shutdown risk of the other unit and a power operation risk of the other unit. This dam consisting of concrete beams was mounted in the sea water system outlet channel for each scheduled maintenance and refueling period. Flooding into turbine building was possible during outage through temporary open manholes in main circulating water pipelines, if the dam is not mounted properly (flood risk analysis) or the sea water level exceeds the height of the dam (weather risk analysis). Sea water had once reached the dam top level. A new procedure and one meter higher dam were established, reducing the risk from $3 \cdot 10^{-5}$/year in 1992 to $1 \cdot 10^{-6}$/year in 1993. This level +2.0 m was considered extremely high.

The extreme sea water level estimates in Loviisa PRA were based on observations from about 100 years and extrapolations and the estimation was done by the Finnish Institute of Marine Research in 1990.

Shutdown weather PRA was completed in 2003. During summer time when the refueling outages took place extreme sea water levels are orders of magnitude less probable than during winter time according to the statistics. Monthly extreme sea water level probability estimates were needed and the estimation was ordered from the Finnish Institute of Marine Research. They showed that this external flooding risk is sensitive to the refueling outage schedule. Moving the outages earlier or later increases the risk considerably and there was a tendency that outages get later than during the first 10 or 20 years. Lo2 has outages later than Lo1. That is why the shutdown operation external flooding risk of Lo2 is much higher than that of Lo1. It was not negligible in spite of the “extremely” high dam. During the shutdown risk analysis it was found out that the temporary dam was once mounted one beam too low. Procedures were improved to control the adequate height of the temporary dam.

In January 2005 sea water rose to an exceptionally high level of 1.73 m that seemed to be an outlier in the series of observations. This was thought to be an indication of the climate change. New extreme sea water levels were estimated taking into account this observation in addition to the older ones and potential climate change. A forecast to the next 30 years showed an increasing trend. After this every year a little higher estimates were used in Loviisa PRA.

The concrete beams were getting old and new design was started to replace them with sluice gates. It was possible to design the sluice gates higher than the concrete dams. The first one was installed in 2012 in the other outlet channel of Lo1. The top level of the gate was +2.47 m and it decreased the core damage risk estimate by $2.5 \cdot 10^{-7}$/year. In year 2014 the gate top was raised to the level of +3.00 m. The other three channel modifications were scheduled to years 2014, 2016 and 2018.

In 2011 new information was obtained from high sea water levels indicating that the earlier frequency estimates were not valid anymore because the climate has changed. The Finnish Meteorological Institute (FMI) informed Fortum that due to the long-term changes in climate conditions, over 30 years long data series are not directly suitable for the analysis of the present climate. New estimates were needed and Fortum started negotiations with FMI. Eventually a research project was commissioned by three power companies: Fortum Power and Heat Oy (Loviisa NPP), Vattenfall Forsmarks Kraftgrupp AB (Forsmark NPP) and OKG AB Oskarshamn (Oskarshamn NPP). It was carried out by FMI in 2013 – 2015 and it is clear that the Fukushima accident prompted this re-evaluation of the extreme sea level estimates in the Baltic Sea.

In the study[11] both observed and simulated meteorological data have been used as alternative inputs to a sea level model. The meteorological observations are so-called reanalyzed gridded data sets known as ERA-40 and ERA-Interim. The climate simulation data set used in the study includes a set of 11 different climate modelling realizations, most of them covering 150 years of data. Each climate model has two components: a global and a regional model. The global models are used to provide boundary conditions for the regional models. The sea level model consists of several separate components. The two most important components are a linear regression model that describes the water volume variations in the Baltic Sea, and a dynamic model that describes the intra-basin sea level variations in the Baltic Sea under the assumption that the connection to the North Sea is completely closed. The other components of the model are tides, land uplift, and the global mean sea level rise, including the distribution of meltwater from ice sheets.

Figure 2 shows the exceedance distribution of daily maxima of the sea level observations (red) for the 30-year period 1983-2012, and the daily maxima of the sea level model simulations (cyan) with meteorological observations as input for the same period. Of the 11 climate models the best 6 were selected on the basis of how well they model the meteorological observations. From these 6 models 850 years of sea level data were calculated (blue). The differences between observations and simulations were used to estimate the distribution of the unmodelled component of the sea level model and the regional climate models. When making these estimates the global meteorological observations (not models) were the boundary conditions for the regional climate models. The exceedance distribution of the simulated sea level and the exceedance distribution of the not modelled component were combined in a statistical sense to calculate the estimate of the simulated sea level (black). A conservative estimate for the upper limit (brown dashed line) of the exceedance distribution was obtained by calculating the distribution of the sum of the individual sea level components: intra-basin variation, water balance of the Baltic Sea, tide, and the not modelled component. The lower limit (red dashed line) is based on Generalized Extreme Value (GEV) analysis. The black curve is the best estimate. The sea levels are given in N2000 and N60 height systems.

The new exceedance frequency of 10^{-6} events per year is 3.12 m (N60), which is 18 cm lower than the earlier estimate in 2001 for the year 2030 and 22 cm higher than the earlier estimate in 1991 for the year 1990. The new 3.00 m exceedance frequency is $8.9 \cdot 10^{-6}$ /year whereas the earlier estimate was $4.6 \cdot 10^{-7}$/year. The new exceedance frequency of 10^{-8} events per year is 3.79 m whereas the old one was 3.50 m.

The Fukushima accident stress tests in 2011 showed also the vulnerability of the plant to high sea water. Although the estimated annual probability of exceeding the design value is very small, the consequences of flooding of the basement would be severe, as all cooling systems might be lost. Therefore, to ensure safe operation in the long term, the possibilities for decreasing the risk of seawater flooding had to be examined. Several options were being studied including flood banks to protect the site area and new check valves for rainwater drains to prevent seawater from flowing into the plant. The work turned out to be more challenging than originally estimated.

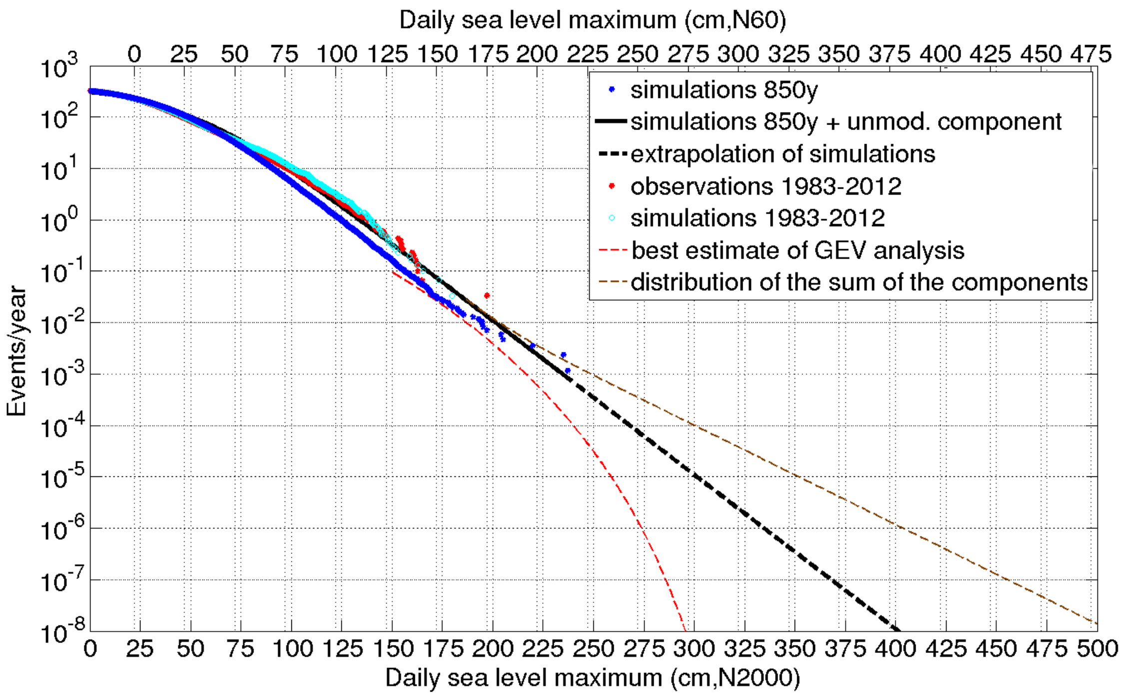

Fig. 2.Exceedance frequency of the daily maximum sea level at Loviisa.

When the first results of the new sea level analyses were obtained in May 2014 a new design was prompted. According to them high sea water dominated the core damage risk, which was not acceptable despite the uncertainties. Based on PRA results it was found out that a protection of the auxiliary emergency feed water building would decrease the core damage risk effectively. This protection was possible to realize reliably and in a short time. It is based on flood gates that are installed when sea water rises over a certain level. The mechanical part of the protection was completed and tried already in the end of year 2014. Procedures were written and final tests performed in the beginning of 2015. The auxiliary emergency feed water building is protected up to +4.20 m. The risk reduction was $5 \cdot 10^{-6}$/year coming from power operation.

III.D. Decreasing the risks of losing the ultimate heat sink

The level 1 PRA was extended starting 1994 to cover severe weather phenomena. Review of the worldwide experience indicated many initiators or precursor events for coolant intake blockages, although they had not led to severe accidents. The blockage risks of the cooling water intakes turned out to be the most important core damage risk contributors for the Loviisa plant, although the plant has no experiences of losing the cooling water due to problems in the intake and although the plant has alternative ways of getting cooling water. One interesting finding was that even if the cooling water intake blockages have caused only minor availability problems for the plant, they could have a large contribution to the core damage risk.[12]

The cooling water for Loviisa NPP is taken from the sea via a 67 m^2 tunnel that is branched into both units. Both tunnels end up in a pond in front of the sea water pumping stations, which are divided into four channels. The length of the tunnel to Loviisa 1 pumping station is 300 m. Every channel is equipped with a cleaning device, a service water pump (0.5 m^3/s) and a main sea water pump (6.4 m^3/s). The service water pumps provide component cooling water (CCW) and the main sea water pumps feed to the main condensers. The cleaning device consists of three coarse bar screens in the main tunnel intake (clear opening 80 mm), a fine bar screen in all four channels (clear opening 16 mm) and a chain basket filter in all four channels (netting density 1 mm^2).

There are four service water pumps of which two operate normally. One pump is enough for safety systems in accident situations and one operating chain basket filter is judged to be enough for service water pumps. Four CCW heat exchangers are normally in operation and one is standby. If a plant unit has problems in getting cooling water it is possible to connect the service water from the other unit to provide cooling water for CCW heat exchangers.

If the main sea water pumps are stopped early enough in case of excessive sea vegetation, the filters will not be completely blocked and the much lower service water flow is ensured. An automatic stopping of the main sea water pumps was installed in order to prevent the blockage of the filters and to ensure their integrity and thus also the operability of the service water. The CDF coming from the blockage and break of the chain basket filters was reduced in 1996 from $8 \cdot 10^{-4}$ to $1 \cdot 10^{-5}$ per year (taking into account those cut sets that are affected by the automatic stopping). Several changes in the operating procedures and in the maintenance procedures were developed to guarantee sea water cooling in different kinds of situations. E. g. warming up the intake water by condenser water to prevent frazil ice blockage decrease the CDF in 1997 by $3 \cdot 10^{-6}$ per year and scheduling the maintenance of the sea water cleaning device to low risk season (January – March) reduced CDF in 1999 from $1.8 \cdot 10^{-5}$ to $1.1 \cdot 10^{-5}$ per year. During the low risk season there is ice deck on the sea and no excessive sea vegetation and therefore negligible blockage risk.

Loss of cooling from the primary coolant pump (PCP) seals was found to be the most important common contributor to the severe weather risk. In 2001 an automatic PCP seal water intake from the make-up system was implemented to ensure PCP seal integrity in case of a loss of normal seal water cooling. This improvement led to a weather risk reduction of $1.2 \cdot 10^{-5}$ /year.

During power operation the plant can be cooled by auxiliary feed water system by blowing steam into the atmosphere. During cold shutdown states the loss of service water due to excessive sea vegetation or other clogging material in the sea is an essential risk contributor because the normal residual heat removal system and the emergency cooling systems are cooled by the same service water system (SWS) and because the other redundancy can be under maintenance. Especially the dependency of the cooling of the plant on SWS during cold plant operating states leads to the problem that all events that jeopardize SWS operation can be important risk contributors. The weather risks were $1.7 \cdot 10^{-5}$/year at full-power, $6.5 \cdot 10^{-6}$/year at stretch-out and $4.2 \cdot 10^{-5}$ for a refueling outage. Thus, the weather risks were two times higher at normal short refueling outages than at power operation. The highest risks came from the cold shutdown states because the reactor cooling was completely dependent on the sea water. Securing the ultimate heat sink during 2002 - 2007 by

- new residual heat removal system,
- circulating water purification filter blockage recovery by new service water return line and
- diesel generator cooling backup by service water system

decreased both internal and external risks. These modifications ensure cooling down to cold shutdown, and they reduced weather and shutdown CDF by $5 \cdot 10^{-5}$ /year. Later on it was shown that the new residual heat removal system decreased considerably fire risks at shutdown. Cooling towers were also considered but not seriously studied.

Risk estimates showed that oil transportations pose a significant core damage risk for Loviisa NPP. Oil transportation had increased in the Gulf of Finland during the last previous years and they were considered to further increase in the coming years enhancing the importance of this risk. Therefore, a more detailed assessment of oil spill impact frequencies was performed by using simulation of accidents taking into account hydro meteorological conditions, oil properties and leakage sizes as well as recent oil spill statistics. These studies showed that oil risk was a high risk contributor during cold shutdown states.[13]

In the beginning of 2011 ideas to improve the nuclear safety of the plant were studied as part of a power uprating project. Risk reduction potentials of over 30 ideas were estimated and cost-benefit analyses were done for the most promising ones taking into account costs due to accidents and production losses. An independent ultimate heat sink was found to be the most effective (because of oil risk at shutdown) and realizable plant improvement. An air-cooled cooling tower solution for removing residual heat was selected to be developed further. Other improvements that were also studied further were emergency core cooling water recirculation through containment sumps during cold shutdown states, modernization of the polar crane in containment, replacement of turbine bypass valves by new valves that do not need high pressure oil reduction station and flood bank around the plant area.

Then the Fukushima Dai-ichi accident happened in March 11, 2011. It speeded up the cooling tower improvement and affected the design so that two cooling towers were designed for both units, the other for residual heat removal and the other for fuel pool cooling. The stress tests did not reveal any new site-related external hazards or vulnerabilities of the plants to external events. No need for immediate action was recognised, but some additional studies of external hazards and feasibility studies for plant modifications to improve robustness against external events were found justified. The following examples of safety improvements and additional analyses of external events were mentioned: enhanced protection against high seawater level and detailed structural analysis of spent fuel pools to demonstrate integrity of the pools in the case of an earthquake with consequential boiling in the pools.

In 2012 emergency operating procedures for cold shutdown, especially concerning emergency recirculation water, decreased CDF by $2 \cdot 10^{-6}$ /year due to LOCA and transients.

Modernization of the pressurizer system at the Loviisa unit 1 was carried out in 2012. The modification had been decided before 2011 and it was done because of restrictions to use the emergency spray of the pressurizer in a pressure higher than 12 bars. At the same time, the valves of the pressurizer spray system were replaced and the spray lines coming from the high pressure emergency core cooling system were moved to the low pressure core cooling system. In addition, the capacity of the relief train of the pressurizer was increased. The modification included also I&C, electrical and piping changes. The same modification was implemented at the Loviisa unit 2 during the 2014 annual maintenance outage.

Construction of a new diesel powered off-site generator plant was carried out in 2011-2012. The power of the plant is 10 MW and it can be used as a peak power plant for electrical grid or as a power supply for the nuclear plants. It is not safety classified, but it can supply power as a last resort to the safety and non-safety classified systems of both units. It's also used as a back-up diesel for the systems used in the loss of ultimate heat sink as an air-cooled diesel which is located on the highest place of the site.

The installation work of the independent air-cooled cooling units started in summer 2014 and was completed in February 2015. They were taken into use after tests in the refuelling outage of 2015. Core damage risk reduction was estimated as 17 % for Lo1 and 15 % for Lo2 ($3.6 \cdot 10^{-6}$ /year), which is amazingly high taking into account the long plant betterment history. The risk reduction came mostly from the oil risk reduction and from cold shutdown.

III.D. Risks after modifications in 2015

The core damage frequencies after the modifications in the refueling outages of 2015 are $1.7 \cdot 10^{-5}$ /year for Lo1 and $2{,}0 \cdot 10^{-5}$ /year for Lo2. The effects including all the improvements during year 2015 are illustrated in Fig. 3 indicating also the effects to the level 2 results. Large Early Release Frequencies (LERF) are approximately half of the corresponding CDF frequencies in the average, but their shares are larger in case of external events because the severe accident management is not effective in them. Weather risks at power operation decreased mainly because of the flood protection of the auxiliary emergency feed water building, partly in 2014 and finally in 2015. Weather risks at shutdown decreased because of the independent air-cooled cooling towers. The presented seismic risk covers both power and shutdown operation.

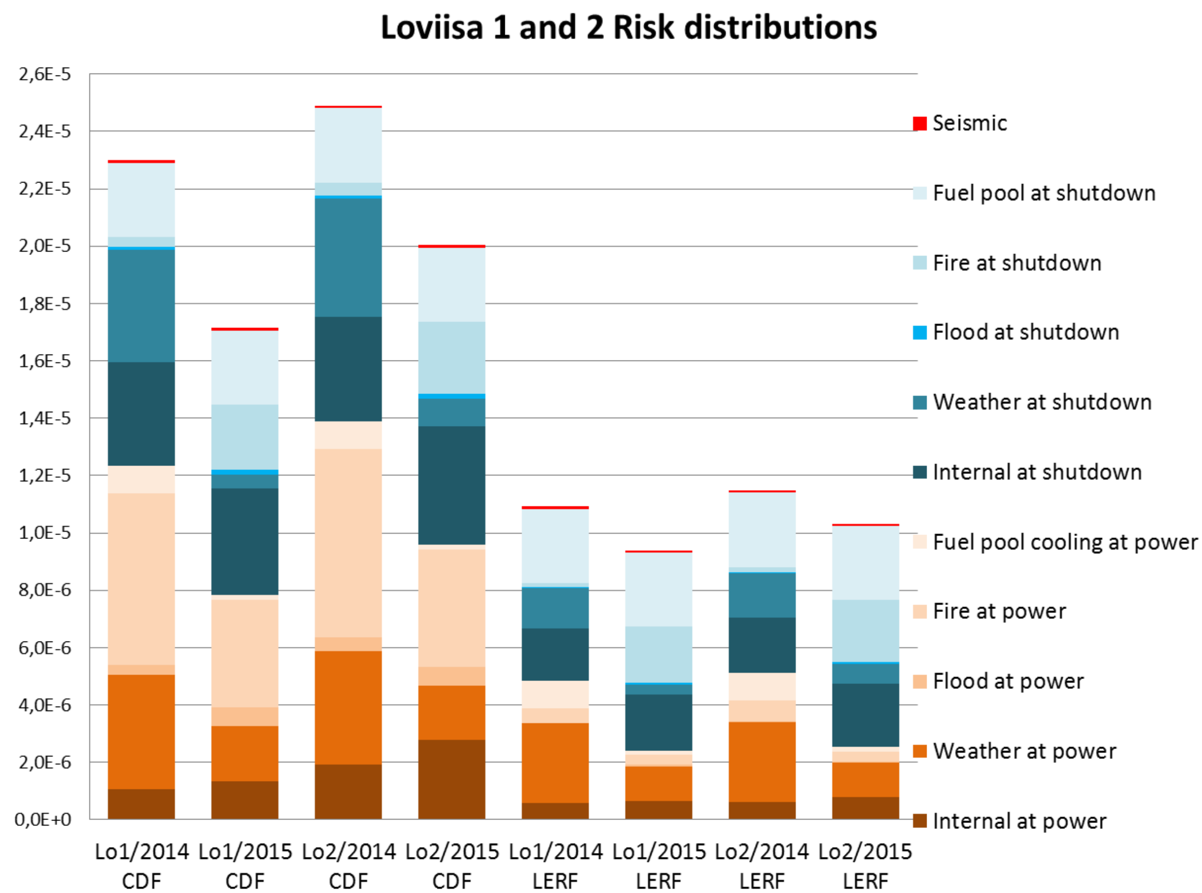

Fig. 3. The effects of the risk reductions per year in 2015.

For continued safe operation, plant improvement projects are still necessary. The largest ongoing investment is the renewal of the plant I&C system. The previously mentioned modernization of the polar crane in containment and replacement of turbine bypass valves are ongoing projects. The first one will decrease shutdown risks and the second one will decrease fire risks.

The core damage risk distributions of both Loviisa units are presented in Fig. 4. One reason that Loviisa 2 has a higher core damage risk is the different instrumentation room ventilation system. The core damage risks come mainly from other initiators than internal initiators at power operation. The normal PRA initiating events at power operation like loss of coolant accidents, transients and loss of off-site power contribute only 8 % in case of Loviisa 1 and 14 % in case of Loviisa 2 to CDF. Heavy load drops are the main contributors in the internal initiators at shutdown and in the fuel pool risks at shutdown. Fires are the most important risk contributors and they are rather evenly spread between different rooms.

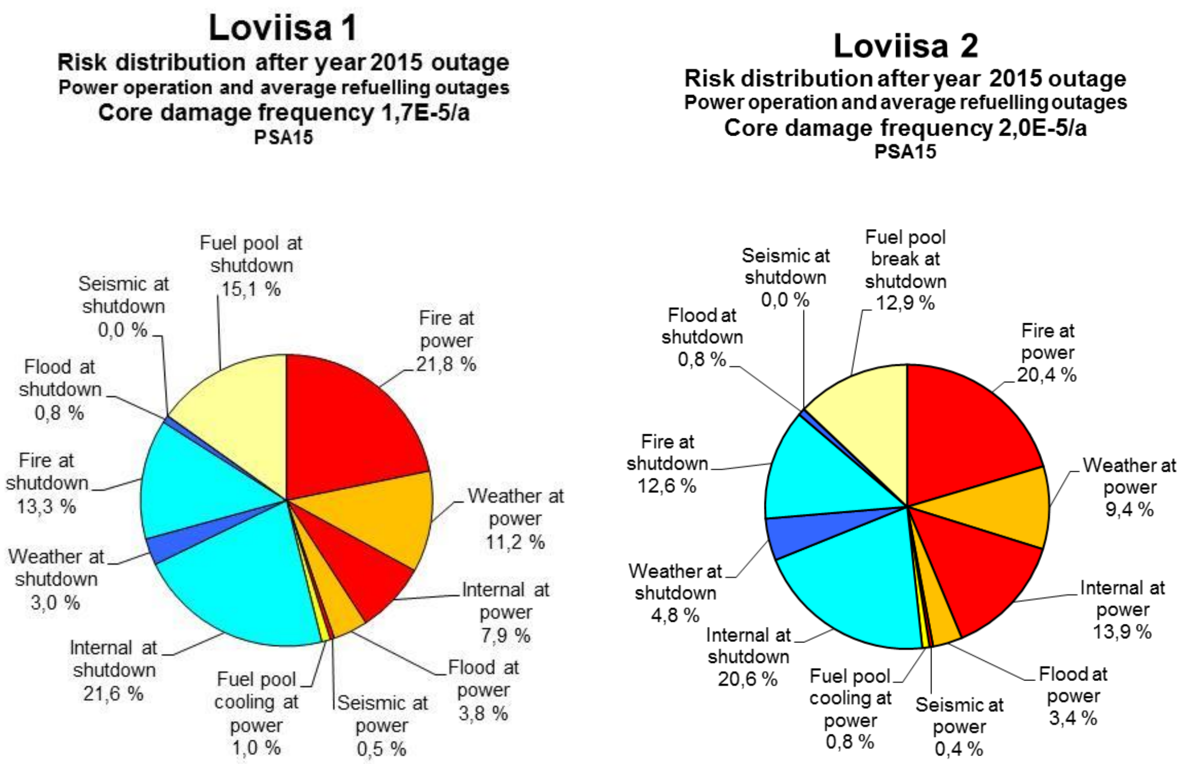

Fig. 4. The core damage risks of Loviisa 1 and Loviisa 2.

IV. CONCLUSIONS

PRA is an important tool in the safety related decision making for Loviisa NPP, especially in supporting the safety improvements, thanks to the PRA approach that provides a consistent and integrated model of nuclear safety that includes different design and engineering areas and human factors as well. By looking at the long history of Loviisa PRA development and safety improvements it has been shown that it is highly important to follow up changes in the environment, climate and knowledge. Many improvements have been designed in several phases against the same external phenomena because of new knowledge, changed risk profile, changed climate and increased transportation in the surroundings. Due to large uncertainties in the frequency estimation of external events some plant modifications have resulted in decreasing at least uncertainties. It is better to get rid of troublesome uncertainties than to live with them. The core damage risks of Loviisa NPP come mainly from other initiators than internal initiators at power operation.

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