Role of PRA in New NPP Projects

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Abstract

In Finland, a plant specific, Level 1 and 2 Probabilistic Risk Analysis (PRA) is required as a prerequisite for issuing the construction license and operating license. The use of PRA in various applications and the main insights are presented. These applications include e.g. PRA support to the design of SSCs, definition of pre-service and in-service inspection programs, evaluation of the safety classification of SSCs, development of procedures, training and in definition of risk informed technical specifications, periodic testing and on-line preventive maintenance programs. In addition, PRA shall be used to assess the adequacy and coverage of the phase and system commissioning programs. Also the potential risks related to commissioning tests during nuclear test phase, shall be assessed with the help of PRA. In OL3 project, risk informed approach has been applied on a large scale for the first time in the design, construction and commissioning of a new NPP unit. Pre-nuclear commissioning tests have started at OL3 site and the plant is foreseen to begin commercial operation in 2013. Decisions have been made to launch new NPP projects. Teollisuuden Voima Oyj (TVO) is planning to build a new unit (OL4) at Olkiluoto site and a new utility, Fennovoima, is planning to build one unit at one of two alternative green field sites in Northern parts of Finland. Insights from PRAs of operating NPPs have been used in the evaluation of possible new sites to ensure that the site specific concerns and environmental conditions are adequately taken into account in the design of SSCs. Although the seismic activity at the Olkiluoto site is low, a comprehensive seismic risk analysis is being conducted. Its results support the review of the deterministic seismic design. For new sites, a probabilistic seismic hazard analysis has been carried out for the determination of the design earthquake. Experiences from OL3 licensing have been utilized in the further development of risk informed requirements in Finland.

Keywords PRA/PSA, Licensing, PRA applications, Risk-Informed

1. Introduction

In Finland, PRA is a formal licensing document. A plant specific, full scope Level 1 and 2 PRA has to be submitted to the regulatory authority (STUK) for approval in the context of construction and operating license application. Regulatory requirements are also set forth for the use of PRA in all phases of the NPP built. Hence, the risk informed approach is to be applied in several areas during the design and construction of NPPs, e.g. supporting the detailed design of systems, structures and components (SSC), definition of pre-service and in-service inspection programs, evaluation of the safety classification of SSCs, development of procedures, training of NPP staff and in definition of risk informed technical specifications, periodic testing (in-service testing) and on-line preventive maintenance programs. In the past, risk insights have led to several modifications of the operating NPPs in Finland, as well as to many design changes to the EPR plant (OL3) under construction. In addition to the internal events PRA, internal and external hazard analyses provided useful insights to ensure that the site specific concerns and environmental conditions are adequately taken into account in the design. Risk informed approach has also been applied to grading of quality assurance requirements of certain organizational activities, as well as for assessing the risk related to different commissioning phases. Experience from risk informed safety management of operating NPPs and from the licensing of OL3 EPR have been utilised in the further development of risk informed regulation in Finland.
2. Risk informed licensing

2.1 NPP licensing process in Finland

The Nuclear Energy Act (990/1987) and Decree (161/1988) define the licensing procedure in detail. Licensing of a new NPP is performed in three stages.

1. Decision in Principle: can it be done?
2. Construction license: how will it be done?
3. Operating license: was it done right?

1. Decision in Principle (DiP)

An environmental impact of the new plant unit has to be investigated prior to the application for the Decision in Principle in compliance with the Law on Environmental Impact Assessment (EIA) Procedure. For OL3 EPR plant the EIA was performed in 1998.

The construction of a nuclear power plant requires a DiP made by the Government. The main criterion in DiP process is to ensure that the construction of a new NPP is in line with the overall good of society. The DiP is then forwarded to Parliament for perusal. Parliament may reverse the DiP as such or may decide that it remains in force. The application may include alternative sites and reactor types to be chosen later.

The Government pays special attention to

- the need for the nuclear facility project with respect to the country's energy supply
- the suitability of the intended site of the nuclear facility and its effects on the environment, and
- the arrangements for the nuclear fuel and waste management.

STUK prepares a preliminary safety assessment of the application. In the safety assessment, STUK aims to ensure that all safety related requirements set forth in government decrees are adequately met.

A positive statement of the municipality of the site planned for the nuclear facility is also a prerequisite for approving the DiP.

2. Construction license

The license to construct a nuclear power plant is granted by the Government. The application and hearing procedures of the license are prescribed in detail in the Nuclear Energy Act and Decree. At this stage, a full scope preliminary Level 1 and 2 PRA has to be sent to STUK for approval, together with other licensing documentation. This so-called “design phase PRA” shall demonstrate the plant's compliance with the probabilistic design objectives for core damage frequency CDF and large release frequency (LRF). In addition the licensee has to indicate by means of the design phase PRA that the foundation of the plant design is fit and the norms used are adequate. This concerns especially events like harsh weather or other exceptional environmental conditions and seismic events, the frequencies and consequences of which may comprise large uncertainties. The design basis for external events has to be defined so that the probabilistic safety target can be fulfilled. The purpose of the design phase PRA is to support the development of a balanced plant design. The aim is also to reveal the interconnections and interactions between the safety, support and surrogate systems as well as common cause failures and potential weak points in the plant design. STUK will review the design phase PRA and assess the acceptability of the design phase PRA prior to giving a statement on the construction license.
PRA will be complemented during construction as the detailed design of the plant unit will be finalized. Design has to be modified unless these objectives are met. If dominant risk factors are identified after issuing a Construction license, all reasonable efforts have to be taken to reduce the risk.

3. Operating license

The Government issues the license for the operation of the nuclear power plant. The application and hearing procedures of the license are presented in detail in the Nuclear Energy Act and Decree. STUK makes a statement on the application for the operating license. A safety assessment will be attached to the statement. At this stage, a full scope updated Level 1 and 2 PRA has to be sent to STUK for approval, together with other licensing documentation. In addition, PRA applications required by regulatory guides have to be submitted to STUK, as well. During construction, PRA shall be updated to comply with the detailed design information of SSCs and more detailed modelling of plant response to various initiating events. The fulfilment of the numerical criteria for CDF and LRF has to be demonstrated as well.

In Finland, the operating license of a nuclear power plant is granted only for a fixed term. Usually the period of validity of the license is twenty years. In considering the duration of the license, special attention is paid to safety precautions and the estimated duration of operations. STUK can interrupt the operation of a nuclear power plant if necessary for ensuring safety. Table 1 summarises the NPP licensing process and the role of PRA.

<table>
<thead>
<tr>
<th>1. Decision in principle (DiP) on the construction of a nuclear power plant</th>
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<tbody>
<tr>
<td>• Political debate on whether using nuclear energy is for the overall good of society</td>
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<td>• Government decision and Parliament ratification/rejection</td>
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<td>• STUK’s preliminary safety assessment (PRA not required at this stage)</td>
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<tr>
<th>2. Application for a construction license, (CDF &lt; 1E-5 /a, LRF &lt; 5E-7 /a)</th>
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<tr>
<td>• Submission of level 1 and 2 design phase PRA to STUK</td>
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<td>• Evaluation of the acceptability of design phase PRA</td>
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<td>– (Upgrade of PRA and/or the plant design)</td>
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<tr>
<th>Construction phase</th>
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<tr>
<td>• Completion of design phase PRA (Applications such as RI-ISI, RI-IST, RI-TS, RI-PM, Training, Procedures, Safety classification of SSC)</td>
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<th>Operation phase</th>
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<tr>
<td>• Utilization of PRA during operation (Plant modifications, RI-ISI, RI-IST, RI-TS, RI-PM, Training, Procedures, Incident and Event Analysis)</td>
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Table 1. PRA and Licensing of NPPs in Finland

2.2 Concept of Risk Informed Regulation and Safety Management

As a necessary complement to the deterministic safety design, a probabilistic risk analysis (PRA) is required to verify the reliability of all vital safety functions. PRA results indicate the balance of the design features from the safety point of view, and the weakest points that possibly need to be strengthened. The guidelines for performing and applying PRA are set forth in the Regulatory Guide YVL 2.8 issued by STUK in 1987 and renewed in 1996 and 2002. The guide is currently being revised and the new revision will be issued in 2012. Regulatory guide YVL 2.8 and the new draft guide YVL A.7 “Probabilistic Risk Analysis for NPPs” specify the following probabilistic design objectives:
− mean value of the core damage frequency (CDF) is less than $1.0 \times 10^{-5}$/year; assessed and verified in full scope Level 1 PRA
− mean value of a large radioactive release frequency (LRF) is less than $5.0 \times 10^{-7}$/year; assessed and verified in full scope Level 2 PRA.

PRA is formally integrated in the regulatory process of NPPs already in the early design phase and it is to run through the construction and operation phases all through the plant service time, as shown in Fig. 1. The life cycle model of PRA forms the concept of risk informed regulation and risk informed safety management. In the life cycle model the risk informed regulatory activities and safety management activities are tightly connected.

A full scope plant specific Level 1 and 2 PRA includes internal initiators, fires, flooding, harsh weather conditions and seismic events for full power operation mode and for low power and shutdown mode. It is essential that the plant staff performs PRA as far as possible in-house in order to become well prepared for using the PRA for decision making purposes. The regulatory guide includes specific prerequisites for the quality of PRA. Accordingly the licensee has to use state-of-the-art PRA methods including human factor analysis, best estimate thermal hydraulic analyses and to perform quantitative uncertainty and sensitivity analyses. In addition the licensee has to draw up and maintain guidelines for ensuring an adequate quality level of evolving PRA model and for using PRA for safety management activities.

In the same living PRA spirit STUK’s personnel conducts thorough reviews in-house. The value of PRA insights in decision making process is greatly diminished if there are shortages in the PRA scope. In Finland, the scope is one of the main attributes that define the quality of PRA. With a thorough in-house regulatory review STUK aims to gain assurance that also other important quality aspects, e.g. transparency, level of detail, state-of-the art methodology, good documentation and QA process, are adequately accounted for. Since the requirements for a plant specific PRA are comprehensive, the quality of PRA is usually adequate for all applications, with only small changes.

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<td>• Program for on-line PM</td>
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<td>• Program for Systems Testing</td>
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<td>• Safety Classification and Graded QA of SSC</td>
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<td>• Compliance with Safety Objectives</td>
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<td>• Maintenance Planning</td>
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<td>• Graded QA</td>
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<td>• Short Term</td>
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<td>• Exemption from Tech Specs</td>
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<td>• Analysis of Safety Margins during Incidents</td>
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<td>PSA Based Event Analysis (incl. risk follow-up of licensee events and precursor studies)</td>
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<td>Strategic SAM Planning (PRA level 2)</td>
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<td>• Evaluation of Significance of Critical Phenomena and Human Factor</td>
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<td>• Evaluation of Mitigation Measures</td>
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Figure 1. Living PRA framework in Finland
The essence of the risk informed regulation and safety management in Finland is that the PRA works as an interactive communication platform between the licensee and STUK. Identical, reviewed PRA model used for resolution of safety issues both by the licensees and STUK. Licensees are committed to provide STUK with a PRA model in electronic form and to regularly maintain and update it.

During the past decade, more requirements have been set forth to extend the use of PRA to various risk informed applications. Many of these PRA applications have been examined through pilot applications initiated by STUK and conducted in full co-operation with the licensees. STUK has also developed a powerful and versatile PRA code (FinPSA) for model development, calculations and review purposes. In the course of risk informing the safety regulation, STUK initiated several research projects, such as methodology development for fire risk analysis (experiments, modelling tools, fire propagation analyses, probabilistic fire simulation), software reliability studies and modelling of severe accidents.

3. **Examples of risk informed design**

3.1 **Use of PRA during the design of OL3 EPR**

Even though the EPR design is based on deterministic rules and standards, PRA has systematically been utilized during the design process to optimize the design with respect to safety and availability. First, the PRA covered only internal initiators at Level 1, but soon it was complemented with a Level 1+ model to assess the containment phenomena and accident mitigation measures. For the OL3 construction license application, PRA was further developed towards a full scope Level 1 and 2 analysis, in order to meet Finnish requirements.

EPR design includes several features strongly contributing to low risk and well balanced design of a nuclear power plant. Examples of such design features include:

- Four redundant, separated safety trains (divisions)
- Diversity in systems design and safety functions
- Physical separation against internal & external hazards
- Station Black-Out (SBO) diesel generators (diverse of EDGs)
- Reactor Coolant Pump (RCP) stand-still seal system, back-up for normal seal system
- Double-wall containment with steel liner
- Severe accidents are taken into account in design (e.g. cooled corium spreading area and dedicated severe accident mitigation systems)

Furthermore, the design of the OL 3 systems is based on the following principles:

- Each system needed to support reliable normal operation has at least two trains (2x100%). Therefore no single failure is expected to initiate a plant wide transient
- For controlling anticipated operational transients, and also many class 1 postulated accidents, functional diversity is required. Both of the respective systems have to fulfill the single failure criterion.
- For controlling postulated accidents, there are four-redundant subsystems with capacity of 50 to 100% (depending on the accident type), and thus at least two subsystems can be lost without loss of safety function.
- The systems designed for severe accident management shall fulfill the single failure criterion.

Probabilistic tools have proven to be very useful in identifying potential design weaknesses, optimizing the design by exploring the safety benefits of various design alternatives taking also into account economy. Examples of risk informed design modifications and identified issues in OL3 are briefly discussed in the next Chapter.
3.2 Examples of Risk Informed Design Modifications in OL3

During the pre-licensing phase, following design changes were made mainly based on STUK’s remarks on EPR conceptual design and discussions between regulatory body, power utility and the vendor:

− Emergency Boron System (EBS) capacity to meet N+2 failure criterion (additional redundancy added, now 3x100% capacity)
− Safety injection System capacity to meet N+2 failure criterion
− Leak tightness of inner containment - a steel liner added
− Containment heat removal system capacity to meet single failure criterion (N+1)
− Primary circuit was provided with pipe whip restraints to limit loads resulting from large breaks (to complement LBB)
− Diversity of safety systems was improved, e.g., emergency feed water and emergency core cooling systems (ECCS): component cooling, power supply, SBO-diesel backup)
− Hard-wired back-up system of digital I&C for the most important functions
− Separation of safety related systems and components was improved
− Arrangements for removal of fuel from the reactor after LOCAs
− Simplification of the phases of molten core handling by removing the need for layer flip (flip of metal and oxide layers when transported from the reactor to the corium spreading area)

In addition, the following remarks were made by STUK:

− Primary to secondary leakage prevention - no release of coolant to the atmosphere (prim. and sec. pressure reduction)
− Design of the recirculation of the safety injection system (containment sump design)
− Highest design burn-up difficult to license
− New physical protection requirements
  − Aircraft crashes: large passenger jet as design basis
  − Chemical and biological weapons and electromagnetic pulses (HEMP) and microwave beams

As a result of the regulatory review of construction license documentation additional changes were required to the original plant design. Some of these modifications and identified issues are briefly discussed below.

Risk informed changes and issues related to internal hazards (fires & floods)

Some issues concerning the concept of physical separation emerged in STUK’s review 2004 for construction license. Main concern was the existence of heavy fire loads, e.g. the lubrication oil system of RCP motors and FRNC-cables planned to be installed without fixed fire extinguishing systems. Fire separation concept by fire compartmentation is not complete in certain areas as in reactor containment, reactor building annulus and in control room areas. According to Reg. guide YVL 4.3, STUK required specific fire analysis for reactor containment, reactor building annulus and MCR where all safety divisions (e.g. power and I&C-cables) are located in the same fire compartment.

Based on the results of fire analyses, fire separation of safety divisions in the reactor building annulus is implemented by vertical and horizontal fire barriers by mineral wool elements, which were not included in the original design.

In reactor containment, one RCP contains more than 1000 liters lubrication oil in total. Burning of big amount of oil is not acceptable and shall be prevented by strict means. Applied defense in depth concept covers additional double casing oils systems to collect oil leaks, drainage on pump room floor, fire detection, CCTV-cameras, water deluge extinguishing system by manual actuation in MCR, RCP protection & monitoring on vibration, bearing temperature etc.
Fire loads in many cable rooms and tunnels are very heavy and the defense in depth concept is required to prevent long term fires which could endanger integrity and function of fire compartments. STUK kicked off FRNC-cable fire safety research with Technical Research Centre (VTT) in 2004. A representative set of power and I&C FRNC-cables, to be installed at OL3, have been tested at VTT: cone calorimeter tests, thermogravimetric analysis (TGA), differential temperature analysis and differential scanning calorimeter (DTA/DSC) have been applied. In addition, fire spreading tests have been made by the new testing device for vertical cable specimen (2 meters in length), which is heated up to different temperatures and then ignited by a burner.

VTT developed a multilayer cable fire model for one FRNC cable type and performed fire simulations (CFD simulation by FDS code) for a typical cable tunnel and cable spreading room including sensitivity studies (boundary conditions for ignition and fire spreading along the cables; also different pilot fires and ventilation conditions were varied). The results pointed out sensitivity on air flow provided by ventilation system which was modeled in a simplified way due to the limitations of the FDS code. The results indicated that long-term fires are not probable, if room ventilation is stopped and room is isolated i.e. fire damper and fire door closed. The smallest initial fire causing fire ignition and spreading on FRNC cables was not estimated exactly but the critical heat release rate was expected to be quite high (even some MWs/several minutes) based on the fire simulations performed so far.

The cable spreading area below the main control room will be equipped with a gas fire extinguishing system (manual start from the MCR). Cables of all four divisions are located in this area. Other heavy fire loads as DGs, DG fuel tanks, oil filled big transformers, TGs lubrication oil spreading areas are protected with water extinguishing systems with automatic actuation.

Major flood sources in safeguards buildings are service water systems, intermediate cooling circuits and fire water systems. Flood spreading between safety divisions is primarily designed to be prevented by water tight barriers below ground level. However, in many areas prevention of flood spreading is provided by flood drainage and flood alarm systems, and in addition by operator measures of stopping pumps and isolating of leaking system. Additionally, the physical protection against floods was improved in essential service water pumping stations.

Risk informed changes and issues related to external hazards

Loss of sea water cooling due to frazil ice or algae is a potential risk at Finnish NPP sites. The original design of OL3 from the beginning covers some specific features to prevent these risks. Water intake for service water system is possible to switch to outlet channel. For prevention of frazil ice formation, dedicated anti-icing system have been designed to pump warm water to inlet channel and to heat coarse bar screens by electricity.

In winter time, a heavy snow storm may block DG air intake(s). This is a potential risk since a simultaneous LOOP due to high wind may occur. Diesel generator air intakes have been modified to prevent snow blockage and in addition alternative air intake is possible from inside the building.

Other design changes and issues identified

- Process Systems
  - Provisions for cooling in case of Loss of Ultimate Heat Sink (72 hours) - feed to EFWS tanks from Demineralized water system and fire water systems
  - Diversification of containment isolation valves
  - Modification of SGTR management to minimize direct releases to environment
- Electrical systems
  - Gas turbine plant to improve reliability of the off-site AC power supply to the site
  - Additional manual start-up and control power supply for SBO diesel generators
- I&C systems
- Diversification of priority and actuator control (PAC) modules
- Diverse safety injection system start-up signal (from SAS)
- To decrease the importance of Safety Chilled Water System (QKA), the room cooling in safeguard buildings was diversified by adding new heat exchangers cooled by CCWS
- Changes to Severe Accident Management
  - Additional primary system depressurization valve to meet single failure criterion
  - Reliability of hydrogen management was improved (arrangements to improve hydrogen distribution)
  - Separate pressure sensors (hot leg and containment) were introduced for design basis accidents (DBA) and severe accidents
  - Additional temperature measurements were introduced in the reactor pit and corium spreading area to follow fulfillment of SAM measures
  - Reliability of electric supply for SAM loads was improved by separating the supply from DBA supplies. In addition, dedicated 12 hour batteries were introduced in division 1 and 4 to supply power in the early phases of the accident (I&C, isolation valves, depressurization)
  - Design of corium spreading area hatch (aluminium)

4. Use of PRA during construction and commissioning

4.1 Risk Informed Pre- and In-Service Inspections (RI-PSI/ISI)

OL3 will be the first new NPP in the world to fully apply risk informed methodology for the development of pre- and in-service inspection programs for both the safety classified and the non-safety classified piping. Methodologies for RI-PSI/ISI applications have been developed for approximately 20 years. So far, these methodologies have only been applied to existing NPPs and the detailed guidance concerning their application to new NPPs is still in progress. This has imposed great challenges for the regulatory body, licensee and the vendor in ensuring the adequate scope and coverage of OL3 inspection programs when combining the traditional approach with risk informed.

It is stated in the regulatory guides YVL 2.8 and YVL 3.5 that the insights of PRA must be used in the development of the pre-service and in-service inspection programs for piping (RI-PSI/ISI). Related to pre-service inspections, the risk informed approach shall be applied to safety class 2 (SC2) piping to at least 7.5% of the total number of SC2 welds/targets. Inspection coverage in safety class 1 is 100%. Risk informed methodology for in-service inspections shall be applied for both the safety classified (SC1-SC3) and non-Safety classified piping (EYT class). Methodological approaches presented in ASME XI, appendix R can be used as a reference in RI-PSI/ISI applications. Combining the consequence evaluation by PRA and the estimation of degradation potential, taking into account the secondary impacts of pipe breaks, the inspections are focused on risk significant piping segments. The limitation of radiation doses (ALARA principle) shall also be taken into account by focusing inspections and optimizing inspection periods.

For OL3 NPP, a preliminary RI-PSI program has been developed by the vendor. After the initial screening, mainly based on the exemptions rules from the ASME Section XI, altogether eleven out of 40 systems containing SC2 piping were analyzed. The risk informed process identified potentially important inspections locations on nine systems. This reduced scope was the basis given to an Expert Panel in charge of the selection of the welds to be included in the RI-PSI program. Wide technical expertise was presented in the expert panel: layout, PRA, system design, degradation mechanism, in-service Inspection, non destructive examination (NDE) and radiation. As a result of the expert panel process, 62 welds were added to the inspection scope. Thus, the preliminary pre-inspection scope is now 223 welds, which corresponds approximately to 12.7% of the total number of SC2 inspectable welds/targets defined with all exemption rules from ASME XI.
The latest update of OL3 RI-PSI program, currently under review by STUK, addresses the level 2 PRA results, high energy line break studies, shutdown analysis, and identification of risk outliers, as required by STUK. The same methodology will be applied to risk informed in-service inspection program.

4.2 Risk Informed Technical Specifications (RI-TS)

Regulatory guide YVL 2.8 states that the requirements and conditions for operation set forth in Tech Specs shall be assessed with the help of PRA. The assessment shall include the optimization of the test intervals and test strategies of components and systems as well as the assessment of the allowed outage times (AOT). PRA has to be used for identifying such situations in which the transition to other operating mode may cause higher risk than that of continuing power operation and fixing the failures. Hence, the PRA has to include the modeling of transition phases, such as planned shutdown. A method for risk informed Tech Specs has been developed for OL3 and a draft application has been submitted to STUK.

4.3 PRA Support for Safety Classification

According to Finnish regulations, the functions important to the safety of the SSC of a nuclear power plant shall be defined and classified according to their safety significance. PRA shall be used to support the Safety classification of SSCs.

In the classification process of OL3 SSCs, some changes were made based on PRA insights. For example, the component cooling water system and essential seawater system classification was upgraded from SC3 to SC2 and reactor coolant pump trip breakers from SC4 to SC2. The safety classification document was reviewed already in conjunction with the application for a construction licence and it will be re-assessed during construction in case of substantial design modifications or changes in the PRA model followed by additional re-assessment in operating license phase. In case PRA results suggest a high safety significance for a system, the changing of safety class can also be avoided by modifying the design, e.g. by adding redundancy or diversity.

PRA assessment shall also be used to demonstrate that the requirements for quality management system concerning the safety classification of each component are in accordance with the risk importance of the component (Graded QA approach).

4.4 Other Risk Informed Applications

Optimization of on-line maintenance

The insights of PRA must be applied in drawing up a program for the on-line preventive maintenance. Accordingly if the licensee wants to perform preventive maintenance work during operation, an acceptable risk impact of on-line preventive maintenance program must be demonstrated. For OL3 NPP, the flexibility in maintenance planning is possible, since most of the systems have four trains, thus fulfilling the single failure criterion and most limiting failure combination, even when one redundant train is under maintenance during power operation.

Staff Training

The results of PRA must be taken into account in the planning of personnel training. The most important accident sequences and significant operator actions in terms of risk have to be trained at least in the period of three year. In the planning of training of maintenance crew, attention needs to be paid to risk significant measures identified in the context of HRA.
Procedures

In order to ensure the coverage of disturbance and emergency operating procedures, PRA must be used to determine those situations for which the procedures shall be drawn up. Accordingly, in case shortcomings in the coverage would appear, the licensee has to write new Emergency Operation Procedures (EOP) to provide guidance for operators to better manage certain accident sequences which the PRA indicated to be of high importance to risk.

Use of PRA in Commissioning

OL3 commissioning is divided into five phases: pre-operational tests in phase A and B, nuclear commissioning tests in phase C and D, and finally a demonstration run in phase E. STUK has required that PRA shall be used to assess the adequacy and coverage of the phase and system commissioning programs of OL3 NPP. Also the potential risks related to commissioning tests during nuclear test phase, shall be assessed with the help of PRA. In case the risk related to a specific test is relatively high, potential measures to reduce the risk should be discussed. Risk reduction measures could include for example following considerations:

- development of specific test procedures and additional precautions, e.g.
  - the test may be replaced by another test
  - the test may be shifted to the non-nuclear commissioning phase B
  - adequate information may be received from other tests
- reducing the test related risk by decreasing the probability of potential disturbances or by strengthening the plant response by e.g. additional testing of redundant/diverse system functions

The licensee will submit risk assessments related to OL3 commissioning tests as a part of phase and system commissioning documentation.

5. Conclusions

For more than 20 years, STUK has actively promoted the use of PRA in risk informed safety management. In Finland, PRA is a licensing document, which shall be included in both the construction license and the operating license applications. PRA shall be plant specific and cover full range of potential initiating events and operating modes and it has to be used to demonstrate the plant's compliance with the probabilistic design objectives for core damage frequency CDF and large release frequency (LRF), and that the foundation of the plant design is fit and the norms used are adequate. In OL3 project, risk informed approach has been applied on a large scale for the first time in the design, construction and commissioning of a new NPP unit.

After the construction license was granted for OL3 NPP, STUK has continued intensive regulatory control of the detailed design process of SSCs and construction of the plant. While the construction work progresses, the role of PRA and risk informed approach in the oversight process increases significantly. Already prior the OL3 NPP Project, requirements had been set forth to extend the use of PRA to various risk informed applications. The objective is to enhance the effective implementation of risk informed safety management at the NPPs and also to increase risk awareness and risk informed regulation at the regulatory body. In OL3, the risk informed approach has been applied in several areas during the design and construction of OL3, e.g. supporting the detailed design of SSCs, ensure adequate provisions against internal and external hazards, definition of pre-service and in-service inspection programs, evaluation of the safety classification of SSCs, development of procedures, training of NPP staff and in definition of risk informed technical specifications, periodic testing (in-service testing), on-line preventive maintenance programs. Further, the experience gained from STUK’s oversight activities with the operating NPPs as well as during the OL3 licensing process have clearly shown that risk informed regulation and safety management contributes largely to strengthening of safety, reducing of licensee’s burden and increasing of public confidence.
Role of PRA in New NPP Projects

A. Julin, J. Sandberg and R. Virolainen
Radiation and Nuclear Safety Authority (STUK),
Helsinki, Finland

Index of presentation

1. Introduction
2. Risk Informed Licensing Requirements
3. Use of PRA in Licensing Process
4. New NPP Projects
5. Concluding remarks
1.1 Introduction

- In Finland, the foundation for the risk informed decision making is set forth in the nuclear safety legislation

- The detailed requirements for conducting the PRA and use of PRA applications are set forth in Regulatory Guides issued by STUK

- PRA has to be applied already in the early design phase and is to run all through the plant service time, covering construction, commissioning and operation phases

1.2 Introduction

- STUK has actively promoted the use of PRA in risk informed safety management for more than 20 years

- Several PRA applications have been required in Regulatory Guides as a condition for construction and operating licenses

- During the past decade, more requirements have been set forth to extend the use of PRA to various risk informed applications
  - Many of these PRA applications have been examined through pilot studies initiated by STUK
  - STUK has also developed a powerful and versatile PRA code (FinPSA) for model development, calculations and review purposes
1.3 Introduction

Deterministic and probabilistic approaches work in parallel and interact

- Results of deterministic assessment provide input for PRA models and data
- PRA provides insights on adequacy and focus on deterministic assessment and criteria
- PRA provides insights on the need to improve the reliability of safety functions and plant systems
  - PRA complements the deterministic approach and determines the appropriate extent of Defence-in-Depth

2. Risk Informed Licensing Requirements (1/4)

- Nuclear Energy Degree level: Applicant has to submit to STUK
  - Design phase PRA while applying for a Construction Licence
  - PRA while applying for an Operating Licence
  - Government Decision level: Nuclear power plant safety and design of its safety systems shall be substantiated by PRA

- Regulatory Guide level: Detailed requirements on PRA and its applications have been set forth in the regulatory guides
2.1 Risk Informed Licencing Requirements (2/4)

- Full scope plant specific PRA (Level 1 and 2)
  - Internal initiators, fires, internal flooding, harsh weather conditions and seismic events
  - Full power and shutdown modes

- Design Phase PRA and PRA for new unit are performed by vendor in close contact with the applicant
  - Several risk informed applications

- Thorough regulatory review
  - STUK personnel performs reviews

- Continuous updating to reflect the actual plant configuration

2.2 Risk Informed Licencing Requirements (3/4)

- PRA is formally integrated in the licensing process of NPP

- Acceptable Design phase PRA is a prerequisite for issuing a Construction Licence

- Acceptable PRA is a prerequisite for issuing an Operating Licence

- Design Phase PRA and PRA have to demonstrate that the plant meets the numerical design objectives
  - Core Damage Frequency < 1E-5/a
  - Large Release Frequency < 5E-7 /a
2.3 Risk Informed Licensing Process

Decision in Principle on the construction of a NPP unit (Political decision)
- A new NPP is in line with the overall good of society
- Applicant of a licence performs an Environmental Impact Assessment (EIA)
- STUK evaluates in a preliminary safety assessment whether the candidate plant designs fulfill Finnish regulations

Application for a Construction Licence, CDF < 1E-5 a, LRF < 5E-7 a
- Submission of Level 1 and 2 Design Phase PRA to STUK and application (Safety classification of SSC, Preliminary RI/BI method, Preliminary PRA for Decommissioning)
- Evaluation of the acceptability of Design Phase PRA (and applications)
  - Design Phase PRA is to demonstrate that the plant design basis is adequate and design requirements are sufficient

Construction Phase
- Complements to Design Phase PRA and working on applications (RHST, RI-SS, RI-PM, EP, Training, EO Procedures, Safety classification of SSC)

Application for an Operating Licence, CDF < 1E-5 a, LRF < 5E-7 a
- Submission of Level 1 and 2 PRA and applications to STUK
- Evaluation of the acceptability, ensure the conclusions made in the design phase PRA
- Set a basis for the risk informed safety management

Operation Phase
- Utilization of PRA during operation and updates (Plant modifications, RHST, RI-SS, RI-Tech Specs, RI-PM, Training, Procedures, Incident and Event Analysis, PRA for Decommissioning)

Requirements for a Construction License Application

Draft Regulatory Guide YVL A.7 (and Regulatory Guide YVL 2.8)

<table>
<thead>
<tr>
<th>#</th>
<th>PRA Submittal</th>
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<tbody>
<tr>
<td></td>
<td>Design Phase PRA Level 1 and 2, documentation and computer model</td>
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<tr>
<td></td>
<td>- full scope - internal events, internal &amp; external hazards</td>
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<tr>
<td></td>
<td>- demonstrate that the plant design basis is adequate and design requirements are sufficient</td>
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<td>- balanced plant design</td>
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<td>- operating experience from similar type of plants</td>
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<td></td>
<td>- if not available, expert judgment, experience and information from corresponding applications or sites</td>
</tr>
<tr>
<td></td>
<td>- quantitative design criteria has to be met</td>
</tr>
<tr>
<td></td>
<td>CDF &lt; 1E-6 a, LRF &lt; 5E-7 a</td>
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<tr>
<td></td>
<td>- upgrade of PRA and/or the plant design</td>
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</table>

PRA assessment of the safety classification of SSCs, incl. methodology description (together with Safety Classification Document) For acceptance
### Draft Regulatory Guide YVL A.7 (and Regulatory Guide YVL 2.8)

<table>
<thead>
<tr>
<th>#</th>
<th>PRA Submittal</th>
<th>To STUK</th>
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<tbody>
<tr>
<td></td>
<td>Preliminary Risk Informed PSI/IS Methodology Description</td>
<td>For information</td>
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<tr>
<td></td>
<td><strong>Preliminary risk assessment for decommissioning phase</strong></td>
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<td></td>
<td>- risk of fuel damage and potential radioactive release</td>
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<td>- shall be considered in the plant design (e.g. fuel cooling system</td>
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<td>dependencies, transportation, handling, storages)</td>
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<td></td>
<td>- systems shared between NPP units</td>
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### Requirements for a Construction Phase (prior to operating license application)

<table>
<thead>
<tr>
<th>#</th>
<th>PRA submittal</th>
<th>To STUK</th>
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<tbody>
<tr>
<td></td>
<td><strong>Update of PRA model and documentation:</strong></td>
<td></td>
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<tr>
<td></td>
<td>a) Updated system analyses, FMEAs, importance measures and fault tree models</td>
<td>For information, incl. in system pre-inspection documentation and</td>
</tr>
<tr>
<td></td>
<td>b) Level 1 and 2 computer model, basis for modifications and update of results</td>
<td>modification plans</td>
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<tr>
<td></td>
<td><strong>PRA assessment of the safety classification of SSCs:</strong></td>
<td>For information</td>
</tr>
<tr>
<td></td>
<td>- if significant changes have been made during construction</td>
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<td></td>
<td><strong>Risk informed Tech Specs (scope and balance):</strong></td>
<td>For information (methodology and application)</td>
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<td></td>
<td>- all operating modes</td>
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<td></td>
<td>- continued operation vs. shutdown risk</td>
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<tr>
<td></td>
<td>**Risk informed ISI, RI-IST, preventive maintenance, training program,</td>
<td>For information as a part of each application (including methodology)</td>
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<td></td>
<td>disturbance and emergency operating procedures**</td>
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### Requirements for a Operating License Application

#### Draft Regulatory Guide YVL A.7

<table>
<thead>
<tr>
<th>#</th>
<th>PRA Submittal</th>
<th>To STUK</th>
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<tbody>
<tr>
<td></td>
<td>Final full scope plant specific PRA Level 1 and 2</td>
<td>For acceptance</td>
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<td>documentation and computer model</td>
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<td></td>
<td>– ensure the conclusions made in the design phase PRA</td>
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<tr>
<td></td>
<td>– set a basis for the risk informed safety management</td>
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<td></td>
<td>– quantitative design criteria has to be met</td>
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<td></td>
<td>CDF ≤ 1E-6a, LRF ≤ 5E-7a</td>
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<td></td>
<td>– upgrade of PRA and/or the plant design</td>
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#### Requirements for a Operating License Application 2/2

<table>
<thead>
<tr>
<th>#</th>
<th>PRA submittal</th>
<th>To STUK</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>PRA assessment of the safety classification of SSCs</td>
<td>For acceptance</td>
</tr>
<tr>
<td></td>
<td>Risk informed Tech Specs (scope and balance)</td>
<td>For acceptance (application)</td>
</tr>
<tr>
<td></td>
<td>– all operating modes</td>
<td></td>
</tr>
<tr>
<td></td>
<td>– continued operation vs. shutdown risk</td>
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<tr>
<td></td>
<td>Risk informed ISI, RI-IST, preventive maintenance, training</td>
<td>For acceptance as a part of each application</td>
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<tr>
<td></td>
<td>program, disturbance and emergency operating procedures</td>
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</tbody>
</table>

503
### Requirements during Operation 1/2

#### Draft Regulatory Guide YVL A.7

<table>
<thead>
<tr>
<th>#</th>
<th>Documentation</th>
<th>Delivery to STUK</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Assessment of the risk impact of a plant modification</td>
<td>For acceptance as a part of pre-inspection documentation</td>
</tr>
<tr>
<td>2</td>
<td>Update of SSC safety classification assessment (of changes)</td>
<td>For acceptance</td>
</tr>
<tr>
<td>3</td>
<td>Risk assessment of annual outages</td>
<td>For information</td>
</tr>
<tr>
<td>4</td>
<td>Risk informed Tech Specs (exemptions and needs for changes)</td>
<td>For acceptance</td>
</tr>
<tr>
<td>5</td>
<td>Risk informed ISL IST, preventive maintenance, training program, improvements of plant life management and quality management programmes</td>
<td>For acceptance as a part of each application.</td>
</tr>
<tr>
<td>6</td>
<td>Risk informed development of disturbance and emergency operating procedures and training programmes</td>
<td>For information</td>
</tr>
<tr>
<td>7</td>
<td>Update of PRA documentation and computer model</td>
<td>For acceptance annually or more often.</td>
</tr>
<tr>
<td>8</td>
<td>PRA related procedures and instructions (e.g. use of PRA and its applications)</td>
<td>For information</td>
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</table>

- Log book of changes made to PRA model, basis for changes and impact on results.
- Computer model

### Requirements during Operation 2/2

#### Draft Regulatory Guide YVL A.7

<table>
<thead>
<tr>
<th>#</th>
<th>PRA submittal</th>
<th>To STUK</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Risk assessment for decommissioning phase</td>
<td>For acceptance (well before decommissioning)</td>
</tr>
<tr>
<td></td>
<td>- risk of fuel damage and potential radioactive release shall be considered in the plant design (e.g. fuel cooling system dependencies, transportation, handling, storages)</td>
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<tr>
<td></td>
<td>- systems shared between NPP units</td>
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</table>
3. Use of PRA in Design Process

- PRA are used to identify strengths and weaknesses of plant design and to demonstrate that
  - the safety systems are adequate
  - the plant design is well balanced
  - the defense in depth requirement has been realized
  - the risk estimates meet the quantitative criteria

- In OL3 NPP Project, risk-informed analyses have proven to be very useful in identifying potential design weaknesses and optimizing the design

- As a result of risk informed approach, several design modifications were identified and implemented
  - In addition, risk insights led to further analysis of the adequacy of provisions against internal and external hazards, e.g. fire risks, additional studies (by VTT) on FRNC cables

3.1 Risk Informed design changes in OL3

- Fire risks
  - Changes to MCP design to limit oil spreading and consequences of possible fire
  - Vertical and horizontal walls in the annulus were added between redundant cable routings
  - Cable routings of different redundancies to MCR were separated from each other by fire resistant tunnels
  - Main and auxiliary transformers were provided with sprinkler systems

- External hazards
  - Structures to protect diesel engine combustion and cooling air intakes against weather phenomena and external fire
  - Cooling in case of Loss of Ultimate Heat Sink (72 hours) was improved - additional feed to EFWS tanks from DMW and fire water systems
  - Sea water intake coarse bar screens have to be protected with electrical heating against frazil ice blocking
3.1 Risk Informed design changes in OL3

- Safety classification changes
  - CCWS and ESWS active components in cooling chain, SC3 to SC2
  - RCP trip breakers SC4 to SC2
  - the demineralized water system (DMW) EYT to SC4
- I&C changes
  - Diversification of priority and actuator control (PAC) modules
  - Diverse safety injection system start-up signal (from SAS)
- Other changes
  - Physical protection against floods
    - ESWS pumping stations
    - Flood barriers and drainage in safety building corridors
  - Addition of manual (local) start-up of SBOs
  - The room cooling in the safeguard buildings was diversified by adding new heat exchangers cooled by CCWS

3.2 OL3 PRA Applications, example

- Risk Informed Pre-Service Inspection Program (RI-PSI/ISI)
  - OL3 will to fully apply risk informed methodology for the development of pre- and in-service inspection programs for both the safety classified and the non-safety classified piping
  - RI-PSI Methodologies have mainly been applied to existing NPPs and the detailed guidance concerning for new NPPs is still in progress
    - This has imposed great challenges for the regulatory body, licensee and the vendor in ensuring the adequate scope and coverage of OL3 inspection programs when combining the traditional approach with risk informed
  - Acceptable RI-PSI methods are described in “ASME Code, Section XI Nonmandatory Appendix R”
  - While drawing up the risk-informed in-service inspection program, the results must be evaluated by an expert panel
  - In addition to power operation, low power and shut down states and the transfers between them shall be considered in the RI-PSI approach
3.2 OL3 PRA Applications, example

- OL3 RI-PSI/ISI Methodology
  - A methodology for OL3 RI-PSI/ISI was developed by the vendor
    - Mainly based on EPRI RI-PSI Methodology
  - STUK identified some issues related to the first revisions of the methodology description e.g.
    - Inspection scope (number of welds, inclusions of all safety related systems)
    - Assessment of degradation mechanisms (water hammering etc.)
    - Isolation of breaks
    - Spatial analysis: secondary (indirect) effects of pipe breaks (e.g. humidity, temperature, water jets)
    - The role and use of expert panel
  - After discussions between licensee, vendor and STUK, these issues were adequately addressed in the methodology and the revised methodology description was accepted with a few remarks
  - Combining the consequence evaluation by PRA and the estimation of degradation potential, taking into account the secondary impacts of pipe breaks, the inspections can be focused on risk significant piping segments

- RI-PSI Program, Preliminary inspection Scope
  - Deterministic scope for SC2 piping is at least 7.5% of total number of SC 2 welds/targets
  - Inspection coverage in safety class 1 is 100%
  - After the initial screening, mainly based on the exemptions rules from the ASME Section XI, altogether eleven SC2 systems were analyzed
  - Risk informed process identified potentially important inspections locations on nine SC2 systems.
  - This scope was the bases given to an Expert Panel in charge of the selection of the welds to be included in the RI-PSI program
    - Technical expertise presented in the expert panel: layout, PRA, system design, degradation mechanism, in-service inspection, non destructive examination (NDE) and radiation protections
  - As a result of RI-PSI application, the preliminary pre-inspection scope is 223 welds, which corresponds to ~ 12.7% of all inspectable welds in SC2 systems
Risk Informed Pre Service Inspection targets
(Safety Class 2)

From RCS hot leg

To LHSI pump suction

Risk Informed PreService Inspection targets
(Safety Class 2)
3.3 PRA and OL3 Commissioning

- OL3 commissioning in five phases: pre-operational tests (A, B), nuclear commissioning tests (C, D) and demonstration run (E)
- STUK required PRA to be used to assess the adequacy and coverage of the phase and system commissioning programs, e.g.
  - Assessment of the potential risks related to commissioning tests during nuclear test phase, including potential measures to reduce the risk
- Risk reduction measures could include for example following considerations:
  - Development of specific test procedures and additional precautions, e.g.
    - the test may be replaced by another test
    - the test may be shifted to the non-nuclear commissioning phase B
    - adequate information may be received from other tests
  - Reducing the test related risk 1) by decreasing the probability of potential disturbances or 2) by strengthening the plant response by e.g. additional testing of redundant/diverse system functions
- The licensee will submit risk assessments related to OL3 commissioning tests as a part of phase and system commissioning documentation

4. New NPP Projects

- The Government has granted two DiP’s to TVO and Fennovoima (for a single reactor)
  - The Parliament ratified both granted applications 1.7.2010
- STUK has continued discussions with license applicants on construction licence application requirements
  - some principal design issues under review, especially concerning external hazards (see next slides)
- The applicants shall submit nuclear safety related bid requirements to STUK for information
  - That is the first step for STUK to prepare regulatory project for construction license review
4.1 New Reactor Projects - Teollisuuden Voima Ltd – OL4

- Environmental Impact Assessment procedure for OL4 (1000-1800 MWe) has been completed by the statement of the Ministry of Employment and the Economy (TEM) in June 2008
- Application for Decision in Principle (DIP) was submitted to the Ministry (TEM) in April 2008
- Feasibility studies with potential vendors
  - ABWR, Toshiba Westinghouse
  - APWR, Mitsubishi Heavy Industry
  - AP1400, KHNP (Korea)
  - EPR, Areva
  - ESBWR, GE Hitachi
- STUK’s preliminary safety assessment was issued in May 2009:
  http://www.stuk.fi/

4.2 New Reactor Projects - Fennovoima Ltd - FV1

Fennovoima has two Site candidates

- Fennovoima is a new utility that was established in 2007 to construct a nuclear power plant with one or two 1000–1800 MW units in Finland.
- Feasibility studies with potential vendors are ongoing:
  - ABWR, Toshiba Westinghouse
  - EPR, Areva
  - SWR-1000, Kerena (“German BWR”), Areva
- Environmental Impact Assessment procedure for FV1 (1000-1800 MWe) has been completed by the statement of the Ministry of Employment and the Economy (TEM) February 2009
- Application for Decision in Principle submitted in January 2009
- STUK’s preliminary safety assessment was issued in October 2009:
  http://www.stuk.fi/

Photos: Fennovoima
4.3 Some issues under study for new NPPs

- Geological and seismic conditions in northern part of Finland
  - Fennovoima apply seismic design criteria for Pyhäjoki (PGA=0.2 g) and Simo (PGA=0.35 g)
  - with similar logics OL4 would be PGA=0.11 g
  - STUK requested independent assessments from external experts

- Design basis against harsh environmental conditions
  - high wind, high\&low temperatures, sea water intake blockage (algae, oil, frazil ice)

- Possibility to apply American standards and products in civil engineering
  - TVO\'s application approved with comments on anchorage and crack control of concrete reinforcement

- Composite construction technology of massive concrete structures for modular construction
  - TVO apply the possibility to use Japanese standard JEAC 4618-2008 for designing composite steel and concrete walls.

4.4 Determination of the design basis for external events in new NPP projects

- Design basis earthquake determined with Probabilistic Seismic Hazard Analysis (PSHA)
  - Annual probability of exceedance 1E-5 with 50% confidence level

- For other external events no detailed quantitative requirements are given in current YVL guides
  - General building code is not sufficient for NPPs
  - Quantitative risk targets provide some guidance
    - core damage frequency < 1E-5/a
    - large release frequency < 5E-7/a
    - no single factor shall dominate
  - intensity-frequency distributions have been determined based on available observations
    - reliable observations for ~ 100 years
    - return periods of interest up to 10 000 - 1 000 000 years
    - uncertainties are very large at high return periods
4.5 Design basis for meteorological and hydrological events at new NPP units

- Highest and lowest outdoor air temperature and humidity
  • instantaneous, short term, long term
- Extreme wind speed, including tornadoes (trombs) and downbursts
- Precipitation (rain, snow, snow load)
- Lightning peak current, rise time etc.
- Seawater level, extreme high and low
  • all sites are coastal
  • including seiche, surge high and low
  • effects of global climate change, range of estimates
- Seawater temperature
  • high temperature
  • subcooling, frazil ice formation
- Ice conditions, including ice walls
- Combinations of correlated events are potentially important
  • snow and wind: potential for loss of offsite power and simultaneous failure of diesel generators due to combustion air intake blockage
  • high wind and high seawater and impurities in cooling water are correlated: possibility of simultaneous LOSP and blockage of EDG cooling

5. Summary and Conclusions...

- Strengths of risk informed process
  - OL3 design phase PRA proved to be very useful in identifying design vulnerabilities that eventually led to design and procedural changes e.g. in process systems, electrical systems, I&C systems and in fire protection systems
  - During construction, PRA updates has provided valuable insights into the detailed design of SSCs, which eventually led to further design changes
- Improvements needed
  - Analyses (PRA & other) were not fully utilised in the design process - unintentional dependencies and shortcomings in design process were found in STUK’s review
  - Utilisation of PRA in the technical change management process was not timely, interactive and systematic enough

PRA should be integrated in an iterative design process and not only for demonstration of acceptable risk level after design freeze
5. Summary and Conclusions...

- Experiences from OL3 licensing will be utilised in the revisions of nuclear safety legislation and regulatory guides
- Use of PRA and its applications in licensing process and during plant life time has been described in more detail in the draft regulatory guide YVL A.7
  - Submittal and content of required documentation, computer models, methodology descriptions and applications
- More detailed requirements will be set forth especially concerning the maturity of design and the content and scope of the documentation in various licensing phases, for example
  - Preliminary justification of adequate provisions and design bases against internal & external hazards already in decision in principle (DiP) phase
  - In Construction License Application
    - Layout planning shall be essentially completed, including adequate provisions (and demonstration) against internal and external hazards
    - Design of Structures and Systems shall be mature enough to facilitate the requirements specification for components