Framatome's lessons learned on Risk-Informed Applications

Hervé Brunelière[a], Jean-Yves Brandelet[a], Heiko Kollasko[b], Pierre Lacaille[*a] and Jari Pesonen[c]

[a] Framatome, Paris, France
[b] Framatome, Erlangen, Germany
[c] TVO, Olkiluoto, Finland

Abstract: The EPR plant in Olkiluoto in Finland (OL3) has been designed to comply with up-to-date international safety principles and Finnish regulatory requirements. The OL3 operating license application requires plant-specific full-scope Level 1 and Level 2 PSAs to comply with Finnish regulatory requirements.

In addition to full-scope PSA, Finnish regulations require the development of Risk-Informed Applications (RIA) during design and construction phases of the project. Risk-Informed Applications are developed using PSA level 1 and level 2 models. The objectives of implementing risk-informed applications is to balance the deterministic rules by providing "risk insight". The development, at the design stage, of such Risk-Informed Applications is a first-of-a-kind for a GEN III+ PWR in Europe.

This technical paper presents the experience gained by Framatome implementing RIA during design and construction of OL3 plant.
The objective of this technical paper is to depict methodological outcomes in terms of best practices and lessons learned providing insights to Utilities that are about to implement or have already performed RI applications on their plants.

Keywords: PSA, Risk-Informed Applications

1. INTRODUCTION

The EPR plant in Olkiluoto in Finland (OL3) has been designed to comply with Finnish regulatory requirements. Based on the regulatory requirements set in the Finnish YVL guides [1] and [2], the PSA level 1 and level 2 models shall be used for specific risk-informed applications during the design and construction phases of the project.
The Finnish YVL regulatory guide [2] explicitly depicts several applications of which five are described here more in detail:

- Risk-Informed In-Service Inspection (RI-ISI) detailed here after in section 3. *("The PRA shall be used in the risk-informed development of the in-service inspection programmes of Safety Class 1, 2 and 3 as well as Class EYT system piping.")*
- Risk-Informed Periodic Testing (RI-PT) detailed here after in section 4. *("The PRA shall be used in the risk-informed development of testing procedures for systems and components important to safety")*
- Risk-Informed Technical Specification (RI-TS) detailed here after in section 5. *("The PRA shall be used in the risk-informed development of the Operational Limits and Conditions (OLC) to assess their coverage and balance.")*
- Risk-Informed Classification/categorization (RI-SSC) detailed here after in section 6. *("The PRA shall be applied to determine the safety classification of structures, systems and components.")*
- Risk-Informed Preventive Maintenance[†] (Reliability Centered Maintenance - RCM) detailed here after in section 7. *("The PRA shall be used ... to develop preventive maintenance programmes").*

The development of such Risk-Informed Applications at the design stage is a first-of-a-kind for a GEN III+ PWR in Europe.

2. CONTEXT

Risk-informed applications depicted in section 1, except RI-SSC, are usually developed and implemented on already operating plants for which the design, the related operating experience feedback and the PSA models are stable and fully available.

Considering the specific context of the development of RI application at design and construction of the first EPR plant in Olkiluoto, Finland (OL3), the development of these applications was fully linked-up with the development of the PSA models Level 1 and Level 2.

Detailed results and conclusions of the plant-specific full-scope Level 1 and Level 2 PSAs of OL3 plant for the operating license are described in reference [3].

The Figure 1 here after shows the detailed sequence of development of the PSA and the related risk-informed applications with regards to the licensing schedule required by the Finnish regulator STUK.

Figure 1: Sequence of PSA and RIA development
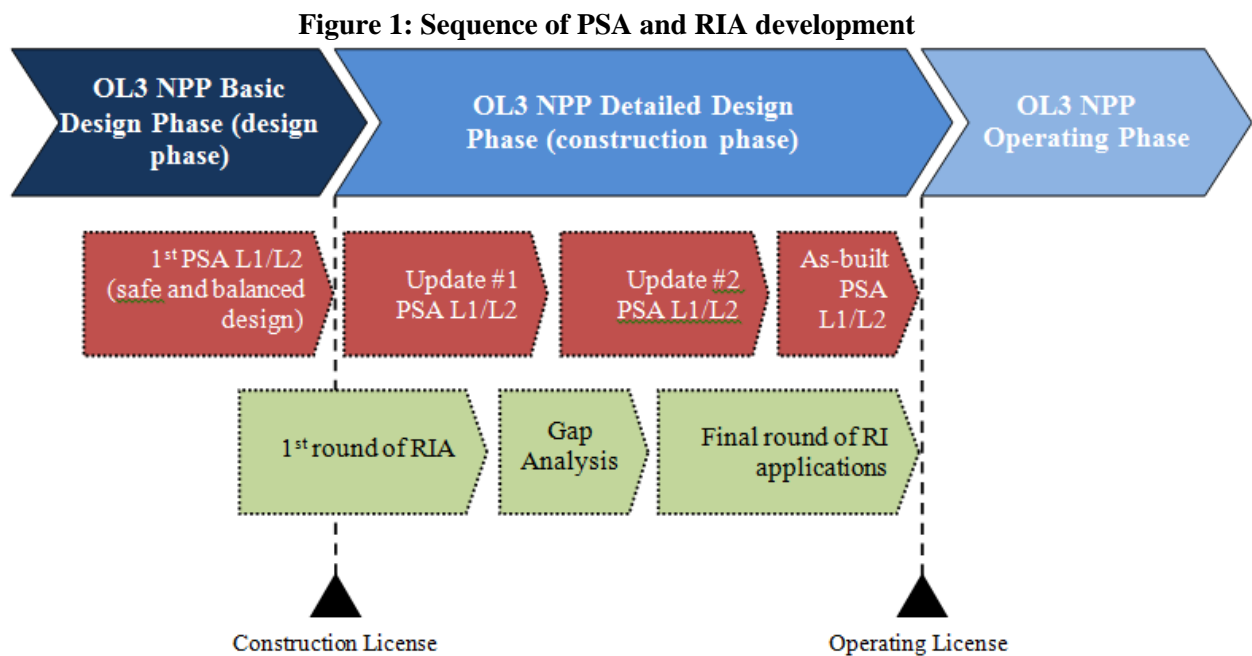
3. RISK-INFORMED In-Service Inspection (RI-ISI)

3.1. Description

The Risk-Informed (RI) In-Service Inspection application supports the determination of the In-Service Inspection (ISI) program of OL3 NPP piping using non-destructive testing methods. The Risk-Informed analysis is conducted according to the Finnish YVL guides E.5 (please refer to [4]), the appendix R of the ASME section XI (please refer to [5]) and the framework document for RI-ISI from ENIQ (please refer to [6]).

As required by the YVL E.5 ([4]), Risk-Informed method is used to ascertain the inclusion in the inspection scope of those piping posing the highest risk. The objectives of the overall evaluation

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optimization of on-line maintenance packages, which has been done separately using up-to-date PSA model is not discussed under section 7.

process are to identify nuclear risk important piping segments, to define the welds that have to be inspected within this risk important piping to:
- Focus on the more "risky" locations to be inspected
- Consideration of radiation doses, accessibility and inspection types

The methodology deployed for this RI-ISI application is depicted in Figure 2 and includes the following steps:
- Step A: Consequence segment definition,
- Step B: Degradation mechanism (probability) assessment
- Step C: Consequence assessment (PSA insights)
- Step D: Risk ranking of the piping segments
- Step E: Selection of inspection locations (Expert Panel)

Figure 2: RI-ISI methodology
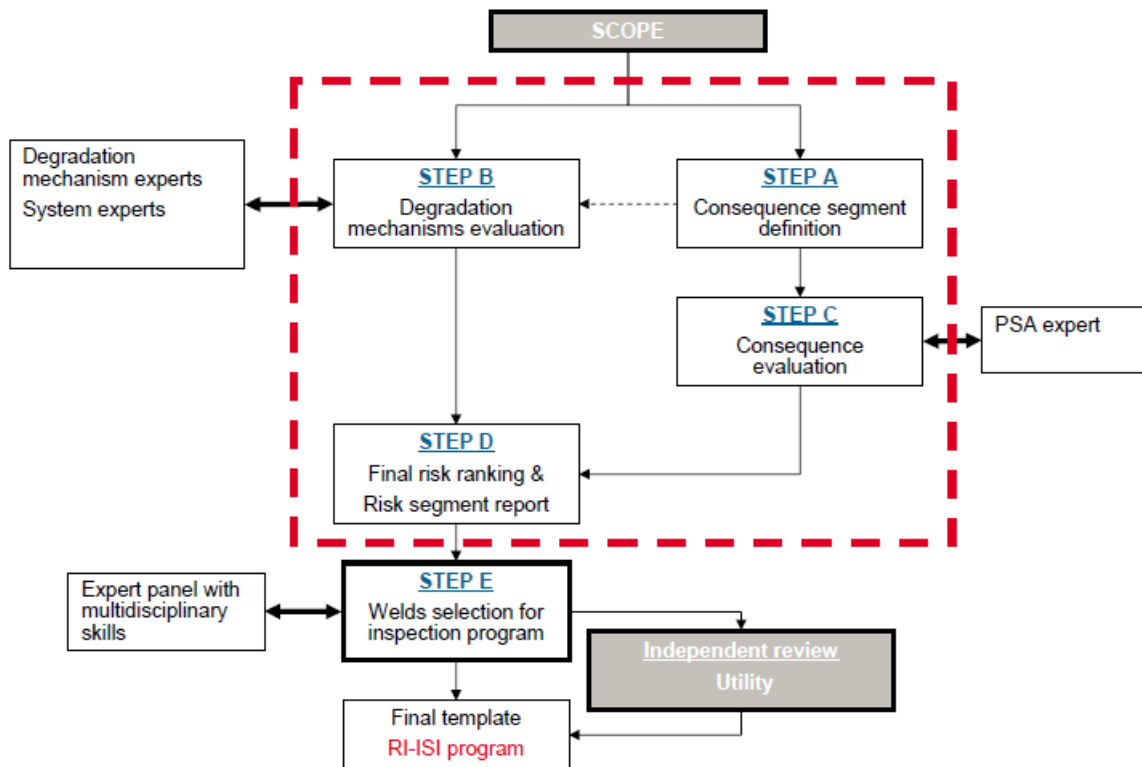
The risk ranking is defined by combination of consequence and degradation mechanisms assessment as depicted in Table 1.

Table 1: STEP D - Risk ranking matrix

RISK RANKING		STEP C - CONSEQUENCE			
		NONE	LOW	HIGH	
STEP B – DEGRADATION MECHANISM	HIGH	LOW	MEDIUM	HIGH	
	LOW	LOW	LOW	LOW	MEDIUM

3.2. Insights & Conclusion

After the RI-ISI application has been performed on OL3 NPP; out of the main coolant system only few systems show "high risk" areas.
The development of Risk-Informed (RI) In-Service Inspection application to OL3 NPP gave real benefits already at design stage:

- Allocating of inspections and justifications for reduction of inspections as well radiation doses
- Risk ranking shows also the need of lower safety classified piping to be included in inspection program - only few cases is recognized
- Using operating experience assessment (OPEX) supported final RI-ISI scope definition

4. RISK-INFORMED Periodic Testing (RI-PT)

4.1. Description

The Risk-Informed (RI) Periodic Testing application supports the determination of the frequency of periodic tests of OL3 NPP systems, structures and components (SSCs). The OL3 application to RI-PT is limited to the systems, structures and components that are part of the technical specifications. The technical specifications focus on systems needed to mitigate the accidents. All the systems, structures and components included in the technical specifications are important to safety and have to be tested periodically to verify their operability.

The Risk-Informed application for Periodic Testing is conducted according to the Finnish YVL guides ([2]) and TVO practices.

The methodology is divided in 2 steps:
- STEP 1: to Check initial Test Intervals Coherence with regards to PSA model.
  The first objective is to check the consistency between the test intervals used in the PSA models and the test intervals proposed by the system engineering team.
- STEP 2: Selection of the final testing strategy by the expert panel.
  This second step aims at balancing the PT frequencies, and reviewing the frequencies of tests to define the Final Testing Strategy.

The step 2 is performed by the expert panel and the PSA team. The risk increase of the testing strategy shall be well balanced. When a modification of the PT program is proposed, the acceptance shall be assessed according to $\Delta CDF/\Delta LERF$ evaluated using the PSA models.
The increase in risk (ΔCDF, $\Delta LERF$) is evaluated with the final testing strategy to check that no periodic test modification cause of a major part of the risk increase. No periodic test modification shall represent more than one tenth of the total risk increase.

The Expert Panel takes into account the insights from the system engineering department and the PSA department to balance in particular the test frequencies. The methodology identifies the input data needed to the Expert Panel. The establishment of the final test strategy and the associated conclusion is performed by an Expert Panel. It groups engineers of different skills:
- PSA.
- System design.
- Operating and maintenance of the plant.
- Radiation exposure.

4.2. Insights & Conclusion

The development of Risk-Informed (RI) Periodic Testing application to OL3 NPP optimizes test intervals and test strategy for important items by allowing focusing resources on high risk items and relaxing testing requirements for less important items. This application supports the final selection of surveillance requirement as defined in Technical Specifications.

It will give real benefits for risk informed decision making from availability and safety perspective of SSCs. At design stage, the gain offered by this application is limited by the relevance of certain reliability data of SSCs modeled in the PSA. Indeed, reliability models used in PSA modelling are established considering a certain "test interval" that is not necessarily the one that is implemented in the plant finally. Therefore, when application has been done for a NPP under construction, the

reliability data used at that time should later be updated considering real feedback of operating experience and application should be updated in order to offer more relevant insights to the NPP.

## 5. RISK-INFORMED Technical Specifications (RI-TS)

5.1. Description

The Risk-Informed (RI) Technical Specifications application supports the determination of allowed outage times for OL3 NPP systems, structures and components (SSCs).
The Risk-Informed application for Technical Specifications is conducted according to the Finnish YVL guides ([2]), the NRC Regulatory Guide 1.177 ([7]) and TVO practices.

In this application, PSA insights are first used to identify potential structures, systems or components (SSC) not yet identified as part of the TS scope according to deterministic rules. Practically speaking PSA importance measures ; Risk increase Factor (RIF) and Fussel-Vesely (FV) ; are used to rank structures, systems or components (SSC). SSCs appearing in HSSC and MSSC, which are not yet identified as part of the TS scope, are added to this TS scope.

Figure 3: SSC ranking matrix
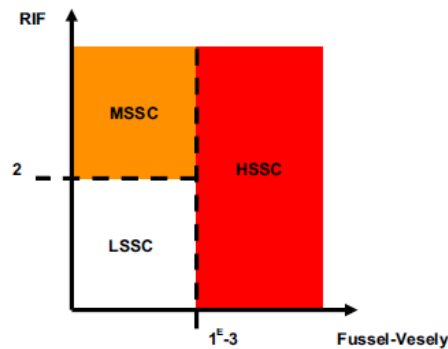
The goal of the applied methodology is to allow flexibility where possible, and always respect the safety objectives, which always prevail. Practically, this methodology:
- Avoids unnecessary plant mode changes (avoids forced shutdowns due to TS requirements),
- Optimizes Allowed Outage times (AOTs),
- Optimizes and defines default modes,
- Allows flexibility in maintenance activities

The definition of the Risk-informed Allowed outage Times (AOT) and Risk-informed default modes is done by an expert panel combining the inputs from both deterministic and probabilistic discipline.

Figure 4: RI-AOT definition
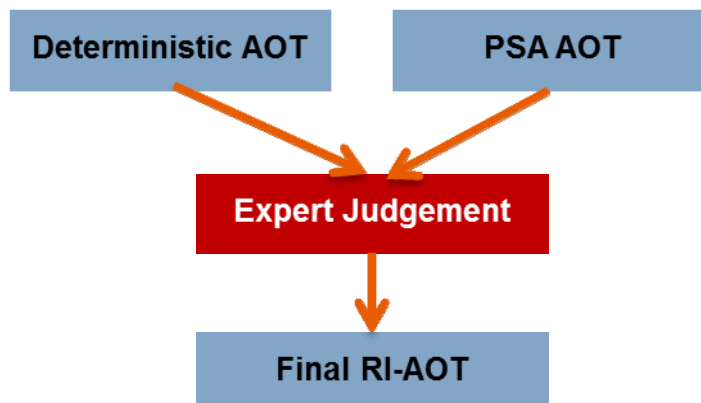
The PSA level 1 and level 2 is used to define the impact on CDF and LERF of the inoperability of a given SSC. An AOT "maximal" is expressed for each inoperability and for each reactor mode. This maximum AOT is assessed following the process detailed below and presented in Figure 5 below. This approach is inspired from TVO practice applied for operating BWR-units OL1 and OL2.

ICCDP and ICLEP which represent the risk increase knowing the component is out of service are defined on RG 1.177 ([7]) and were adapted to OL3 NPP according to CDF/LERF targets from YVL A.7 ([2])

Figure 5: AOT max assessment
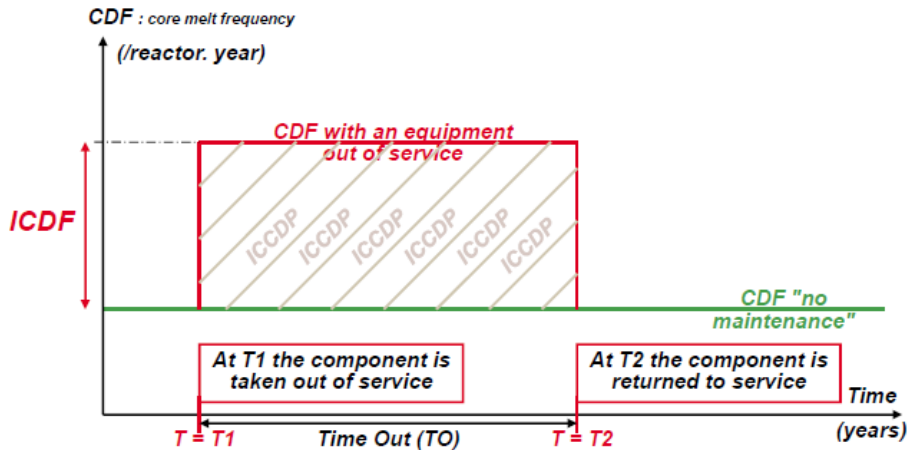
5.2. Insights & Conclusion

The development of Risk-Informed (RI) Technical Specifications application to OL3 NPP gave real benefits already at design stage. It shows clear benefits for:
- 4 times redundant safety trains (possibility to relax)
- TS in electrical systems (reduced AOT in order to improve safety)

It is important to notice that the PSA model includes modeling of the transition between power and RHR modes, which allows the assessment of CCDP due to transition. This specificity comes from TVO and STUK experience requiring identification of situations for which transition to another operating mode may cause higher risk than continued operation in the current mode.

6. RISK-INFORMED Classification/categorization (RI-SSC)

6.1. Description

The Finnish YVL guide ([2]) requires that the PSA shall be used to support determination of the safety class (grade) of SSCs.

The safety classification is first performed according to Finnish YVL guide 2.1. Five deterministic safety classes are defined for OL3 NPP from highest to lowest importance to safety: SC1, SC2, SC3, SC4 and EYT (non-classified).

The deterministic safety class is derived from the deterministic safety analysis and determines the basic requirement level for quality management measures, which are used to prevent and reveal potential design, manufacturing and operation errors. In addition to that the plant-specific risk importance (based on PSA) of the item in question has to be considered. Indeed the determination of an appropriate quality assurance level is the main purpose of safety classification, and therefore, reliability targets (from PSA) provide a good reference value for the level of error-freeness that needs to be ensured.

The methodology of the probabilistic assessment of the safety classification of SSC is based on PSA Level 1 importance measures: Risk increase Factor (RIF) and Fussel-Vesely (FV).
- For those components whose Fussel-Vesely importance is $FV \geq 10\text{-}3$, as second measure for defining the safety importance the risk increased factor RIF is used.
- Safety class 3 is sufficient for $RIF \leq 10$ and Safety class 4 is assumed to be sufficient for $RIF \leq 2$.

In order to prevent a reclassification due to conservative modelling the review of safety classes is performed by a qualitative evaluation of RIF values exceeding the limits in context with the related modeling aspects and the classification of the correlated systems, components and equipment.

6.2. Insights & Conclusion

The development of Risk-Informed (RI) safety classification application to OL3 NPP gave real benefits already at early design stage. Indeed, OL3 NPP having five deterministic safety classes, the use of PSA supported the determination of safety classification and resulted in upgrading some items to a higher safety class.

Here after is a sample of examples:
- CCWS pumps and isolation valves for RHR/LHSI coolers, as well as ESWS pumps are upgraded from SC3 to SC2.
- RCP trip breakers are upgraded from SC4 to SC2.
- Demineralized Water System is upgraded from EYT to SC4.

7. RISK-INFORMED Preventive Maintenance (RCM)

7.1. Description

The Risk-Informed (RI) preventive maintenance application supports the determination of preventive maintenance program (reliability centered maintenance – RCM) of OL3 NPP system, structure and components. The Risk-Informed analysis is required by the Finnish YVL guides A.7 ([2]). The application is conducted based on Framatome experience in France and USA for already running plants but also EPR plants in France and China.

The application of the RCM method at design stage leads to the definition of the Initial Preventive Maintenance Plan. This plan is established by incorporating risk insights in order to provide the required functionality of OL3 NPP to enable a safe and reliable power production:
- Which components have to be maintained and with which priority,
- Which maintenance activities will be effective,
- Which frequency is adapted to each activity (if periodic maintenance activity) or which specific conditions are needed to perform the condition-based activities.

The methodology deployed for OL3 NPP is captured is the **Figure 6**.

Figure 6: RI-PM methodology
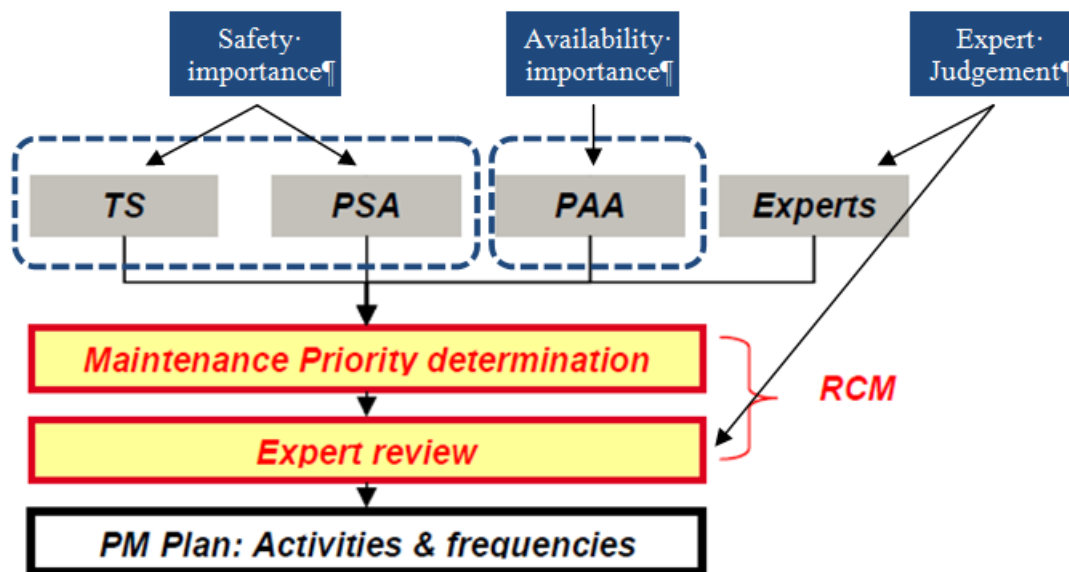
The tasks before the RCM are performed in the frame of both safety analysis, availability analysis. As a result, the RCM analysis uses the Technical Specifications (TS), the Probabilistic Safety Assessment (PSA), the Probabilistic Availability Assessment (PAA) and the expert outputs as inputs.

The definition of the Maintenance Priorities deals with components (i.e. equipment units). According to its failure impact on plant safety and availability, each component is classified in one of the four different categories driving the maintenance effort:

- Maintenance Priority 1: high preventive maintenance effort,
- Maintenance Priority 2: medium preventive maintenance effort,
- Maintenance Priority 3: limited preventive maintenance effort (component supplier's recommendations),
- Maintenance Priority 4: mainly corrective maintenance.

The application of the RCM method at design stage leads to set up guidance and elements for maintenance activities of the OL3 nuclear power plant. These are:

- For each component: the Maintenance Priority.
- For Maintenance Priority 1, 2, 3 or 4 components: the recommended PM activities with the recommended frequencies/conditions (specifically to MP4, supplier's recommendations should still be implemented during the guarantee period).
- For Maintenance Priority 1 or 2 components of systems screened in by PSA or PAA, their critical failure modes and their relevant causes, the recommended PM activities with the recommended frequencies/conditions.

7.2. Insights & Conclusion

The development of Risk-Informed (RI) preventive maintenance application to OL3 NPP gave real benefits already at design stage.

- Systematic and documented means to determine maintenance plan
- Combined safety, availability and experts considerations to define recommended activities
  - Decrease of number of unnecessary PM activities on less important items
  - Increase or confirmation of number of necessary PM activities on important items
  - Experts to give reasoning to increase maintenance effort e.g. due to damage potential of components ("expert significant components")
- It shows clear benefits for 4 times redundant safety trains (relax)

8. CONCLUSION

The Finnish regulations require the development of Risk-Informed Applications (RIA) during design and construction phases of the project. For OL3 NPP, the Risk-Informed Applications are developed using PSA level 1 and level 2 models. The development, at the design stage, of such Risk-Informed Applications is a first-of-a-kind for a GEN III+ PWR in Europe.

Risk-Informed Applications bring out to Utilities the opportunity to gain efficiencies in risk management and in reduction of costs while maintaining or improving safety. In the Finland context the Risk-Informed application are conducted by combining both deterministic and probabilistic (risk) insights; this protocol ensures that safety is always put first.

The main gain of implementing risk-informed applications is to balance the deterministic rules by providing "risk insight". In OL3 NPP applications, the correct balance (increase or relax deterministic rules) is always governed by an expert panel that ensures an independent review and the final decision.

The implementation of Risk-Informed applications on a NPP requires the full consent of the country regulator. In Finland, the safety authority, STUK, oversees and assesses the adequacy and quality of Risk-Informed applications and the use of them during the whole life-cycle of a plant. STUK is clearly promoting and supporting Risk-Informed applications in their regulatory oversight. In the specific context of the OL3 EPR NPP, the implementation of such applications at design stage and for a new plant design offered STUK, TVO and Framatome the opportunity of a fruitful discussion, how to develop adequate methodologies for Risk-Informed applications as well their implementation.

8.1. General lessons learned of RI application for Olkiluoto 3 NPP

- Safety Benefit: identification of possible improvements of deterministic design (e.g. supporting systems)
- Operational benefit: reduction of effort on less important items while maintaining the safety level (graded approach).
- Major importance of Expert Panel gathering relevant competencies (depending on the application) that makes an independent review and takes the final decision using both deterministic and probabilistic insights.
- Specifically to PSA experts, it is of major importance to keep critical awareness with regards to our PSA insights (PSA experts are part of Expert Panel)
- Unique PSA model combining level 1 and level 2 is strongly recommended (importance measures RIF/FV)
- As much as possible, realistic PSA model shall be developed from the beginning in order to allow Risk-Informed Application in decision making, i.e. symmetry modelling, level of detail to avoid unnecessary conservatism, splitting of plant operating modes to be consistent with TS mode definitions, etc…

8.2. Specific lessons learned of RI application for Olkiluoto 3 NPP

- RI-ISI gives real benefits already at design stage
  - Allocating of inspections and justifications for reduction of inspections as well radiation doses
  - Risk ranking shows also the need of lower safety classified piping to be included in inspection program
  - Using operating experience assessment (OPEX) supported final RI-ISI scope definition

- RI-PT gives real benefits to OL3 NPP availability and safety. The reliability data used at the time of the NPP construction should later be updated considering real feedback experience and application should be updated in order to offer more relevant insights to the NPP.
- RI-TS gives real benefits already at design stage. It shows clear benefits for:
  - 4 times redundant safety trains (possibility to relax)
  - TS of electrical systems (reduced AOT in order to improve safety)
- RI-Classification supports the determination of appropriate safety class especially with wide range of safety classes. OL3 NPP having five deterministic safety classes, the use of PSA resulted in upgrading some items to a higher safety class.
- RI-PM gives real benefits already at design stage
  - Systematic and documented means to determine maintenance plan
  - Combined safety, availability and experts considerations to define recommended activities
    - Decrease of number of unnecessary PM activities on less important items
    - Increase or confirmation of number of necessary PM activities on important items
    - Experts to give reasoning to increase maintenance effort e.g. due to damage potential of components ("expert significant components")
  - It shows clear benefits for 4 times redundant safety trains (relax)

References

[1] Guide YVL 2.8[‡], Probabilistic Safety Analysis in Safety Management of Nuclear Power Plants, STUK (2003)
[2] Guide YVL A.7, *Nuclear Power Plant Risk Management*, STUK (2011)
[3] Heiko Kollasko, Roman Grygoruk, Jari Pesonen, Lasse Tunturivuori and Antti Tarkiainen, *"Main results and conclusions of the OL3 Level 1 and Level 2 PSAs for the operating license in connection with the fulfillment of the regulatory requirements"*, PSAM 14, September 2018, Los Angeles
[4] Guide YVL E.5[§], *In-service inspection of nuclear facility pressure equipment with non-destructive testing methods (2014)*
[5] ASME section XI edition 2005 – Non-mandatory Appendix R
[6] ENIQ UR 21581 EN report "European framework document for Risk-Informed In-Service inspection"
[7] NRC Regulatory Guide 1.177 (August 1998) An approach for Plant-Specific, Risk-Informed Decision-making : Technical Specifications

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[‡] YVL 2.8 has been applied for OL3 design. New YVL A.7 has been released during OL3 construction and it replaces former YVL 2.8. The numerical design objectives are kept same in YVL A.7 [1].
[§] YVL 3.8 has been applied in connection of preparation of RI-PSI and RI-ISI programs.