APPLICABILITY OF LIVING PSA IN NPP MODERNIZATION

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SUMMARY

Recently the utility Teollisuuden Voima Oy (TVO) has modernized the Olkiluoto 1 and 2 nuclear units and increased the net electric power by 18 per cent. Level 2 PSA was performed during the modernization project and the living level 1 PSA was used to support the design of the plant modifications. The plant specific living PSA model was a powerful tool when evaluating modernization alternatives. Successive support of safety management with the PSA model requires, that both the utility and the Regulatory Body understand capability and limitations of the model in details.

TVO has prepared an internal procedure that presents in detail the practices and responsibilities concerning living PSA. The procedure is based on general guidelines and requirements on probabilistic safety analysis of nuclear power plants in Finland, released by the Regulatory Body. Living PSA requires that also the procedure for the use of living PSA is living. The recently published USNRC Regulatory Guides on PSA will be taken into account in the next version of the TVO PSA procedure. The PSA Peer Review Certification Process is one way to evaluate the quality of PSA in general, but also to detect the weaknesses of the PSA. However, the Certification Process covers only limited scope of PSA omitting e.g. all other external events except internal floods.

This paper gives an overview on the scope of living PSA for Olkiluoto 1 and 2, and. presents some examples on the real use of PSA concerning the modernization of the plant. Definition of quantitative dependability requirements for renovated systems is possible, but on the other hand, proving of these targets is in some cases extremely difficult, because of lacking dependability data. The problems are mainly concerned in systems with of programmable logic control..

1. INTRODUCTION

The Finnish Regulatory Body STUK has released in the YVL Guide 2.8 general guidelines and requirements regarding probabilistic safety analysis of nuclear power plants in Finland. (1) The utility TVO and the Regulatory Body have mutually agreed, how to apply the guidelines in the use and updating of the PSA for the BWR units Olkiluoto 1 and Olkiluoto 2, recently raised from 710 to 840 MWe,net. The utility has collected the practices in an internal procedure, which has support and acceptance from the management of the utility. The key issue is keeping the PSA living and up-to-date enough, for the purposes it is used. The updating procedure is described in several papers (2),(3),(4). The procedure is updated biannually, and the next version will apply appropriate parts of the USNRC Regulatory Guides concerning risk informed decision making and PSA.(5, 6, 7, 8, 9)

The living PSA of the identical units Olkiluoto 1 and Olkiluoto 2 is a result from the plant specific PSA research program [10] shown in Figure 1. TVO started the program in the year 1984 and the development of living PSA began in the year 1990. The first completely updated version of the level 1 PSA for power operation modes including internal and external initiators was published four years later, in 1994. The modernization of Olkiluoto NPP required another revision of the PSA study. It was prepared simultaneously with the design of plant modifications thus supporting the design work of TVO and of the contractors. PSA was an important tool, when discussing with the Regulatory Body, on safety issues related to the modernization.

2. USE OF PSA

In the office for nuclear safety the utility TVO has at the moment a PSA group of four reliability engineers, who use and update the living PSA – keep the PSA living. However, specialists from the whole organization and external consultants continuously are in cooperation. Topical issues are applications and updating of the model instead of the earlier development and extension of the study. Reliability engineers continuously monitor the development of the safety level and support several kinds of safety improving modifications. From the results of PSA they can identify new safety related issues, evaluate the benefit of modifications and draw comparisons between competing modification alternatives. With rapid calculations they also can support decision making in incident situations.

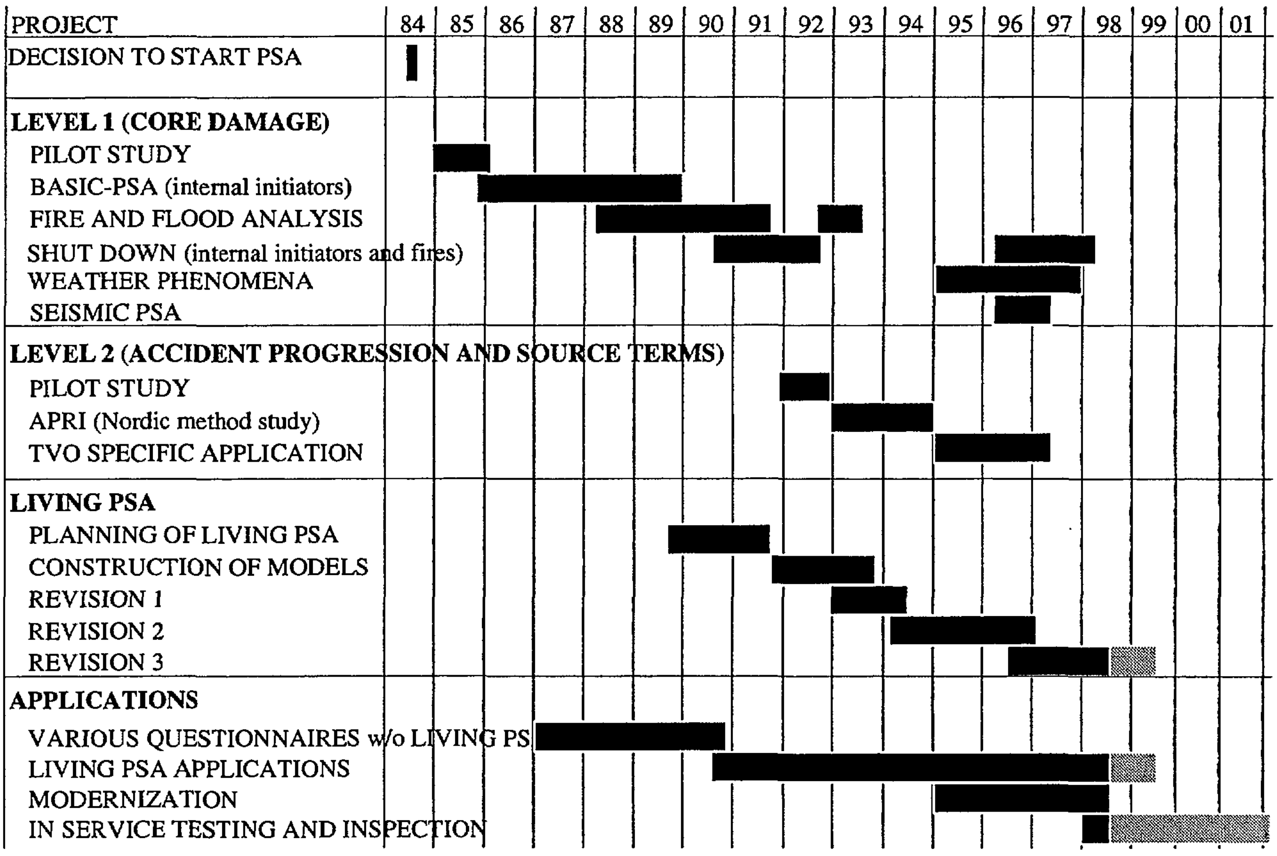

Figure 1: Olkiluoto 1 and 2 PSA research program is in the updating and application phase.

3. PSA PEER REVIEW CERTIFICATION

The Boiling Water Reactor Owners Group (BWROG) has applied PSA Peer Review Certification Process for almost all BWR units in USA[11]. The certification team consists of five to seven persons, with PRA expertise from the manufacturer, other utilities, and industry. Individual attributes of the plants analysis will be categorized in one of four categories:

- Grade 1 - Supports Assessment of Plant Vulnerabilities
- Grade 2 - Supports Risk Ranking Applications
- Grade 3 - Supports Risk Significance Evaluations w/Deterministic Input
- Grade 4 - Provides Primary Basis For Application

The idea is to permit various applications based on the PRA ranking. Similar programs are being established for Pressurized Water Reactors (PWRs). Basically this is an industry effort to assess the quality of PRAs and to establish uniform quality levels for PRAs. The evaluation is done by answering into 10-20 questions for each of the eleven elements of the PSA. Thus inadequacies can be identified in rather small details of the PSA. The elements considered are:

- Initiating Events
- Accident Sequences Evaluation
- Thermal Hydraulic Analysis
- Systems Analysis
- Data Analysis
- Human Reliability Analysis
- Dependency Analysis
- Structural Response
- Quantification and Results Interpretation
- Containment Performance Analysis
- Maintenance and Update Process

In USA the review is performed by an independent specialist team. Such procedure has not been applied into the PSA of Olkiluoto, but the Certification Process can be used also as internal quality assurance guide.

4. USE OF PSA IN THE MODERNIZATION PROGRAM

The modernization program of Olkiluoto 1 and 2 units was conducted during the years 1993-1999. The program was divided into about 40 projects, and the total costs were almost 800 MFIM ($160.000.000). At the beginning of the modernization program, a plan was made to support utility and contractors with PSA based examinations in 13 safety related projects. During the program, the number of supported projects increased to 17.

The core damage frequency before modernization was about $5.9 \cdot 10^{-5}$/reactor year. Without earthquakes, which were analyzed and integrated in the living PSA during the modernization project, the cdf was $3.5 \cdot 10^{-5}$/reactor year. At the moment the total cdf is about $1.3 \cdot 10^{-5}$/ry and the expected value after all improvements due to earthquakes is below $1 \cdot 10^{-5}$/ry. However, the risk profile is changing whole the time, because new risks arise during operation, and some small modifications may have a great decreasing impact on risk.

Figure 2 shows the development of the estimate of the core melt frequency due to various causes of initiating events. Steps upwards represent extensions of the analysis. Decreasing of the estimate originates either from improvement of the model or from modifications on the plant.

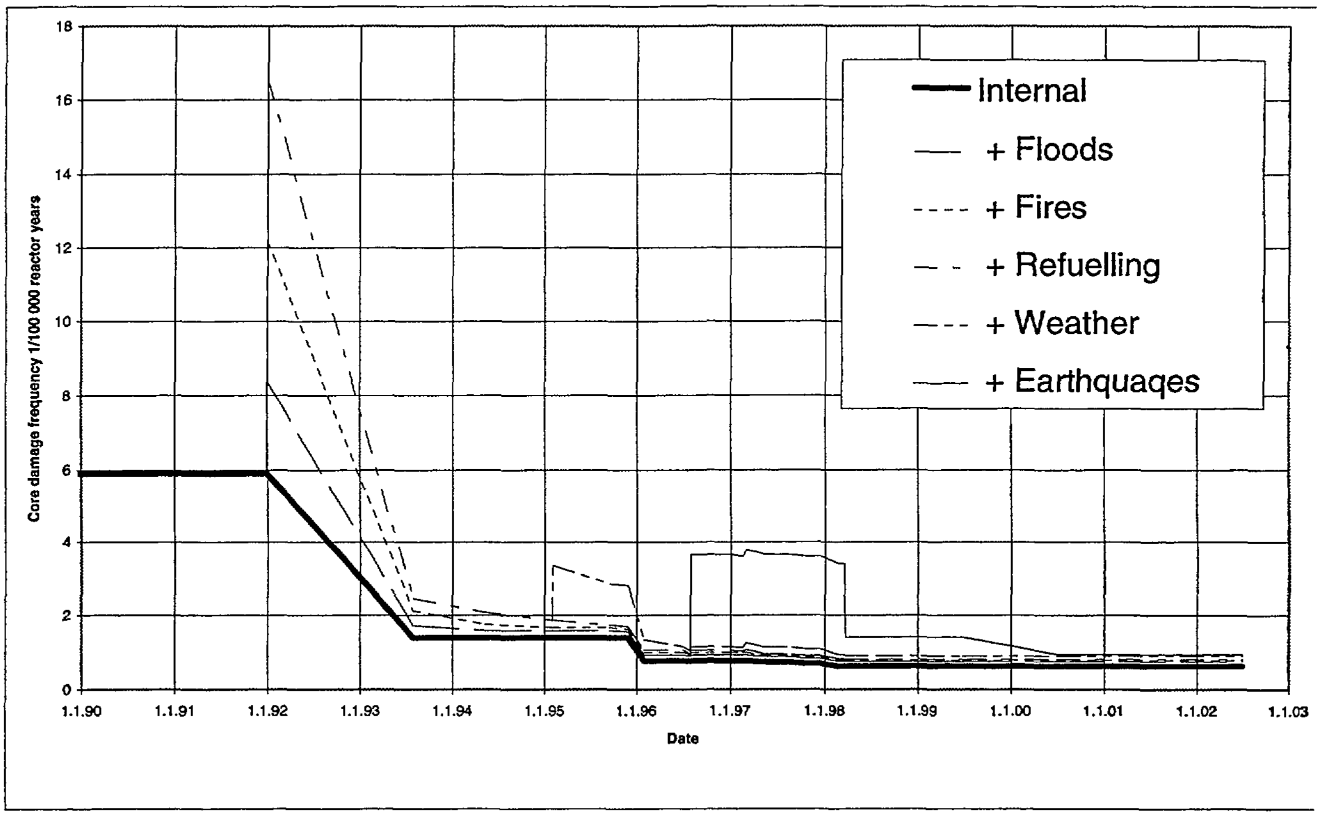

Figure 2: Development of the estimate of the core damage frequency of Olkiluoto 1 and 2.

4.1. Plant test program

Most of the plant tests in connection with power upgrading are necessary. However, some tests may cause remarkable risk compared with the value of test results. Also the test arrangements and procedures may benefit from risk studies. The planned risk increase from one reactor scram test is 5-20% of the annual core damage frequency, depending on the test type, isolations tripped in the test, and the end state (hot or cold shut down). Originally, the scram test was changed to a milder one, but the risk increase might be acceptable in Olkiluoto, especially, if comparing with the USNRC Regulatory Guide 1.174[(5)].

The Olkiluoto PSA is applicable in evaluation of different scram tests, because the hot shut down state after planned shut down, and different isolations have separate event tree models.

4.2. Seismic PSA

Seismic analysis was originally a part of the checking and updating of the design basis of the plant and systems. The seismic PSA revealed about ten weak points at the plant concerning seismic risk. Most important ones were free standing batteries and almost free standing cubicles containing relays and other instrumentation as well as AC bus-bars. Because the core damage frequency of Olkiluoto units is rather low, and earthquakes have not been a design criterion, the relative risk impact from earthquakes became a risk leader. PSA allowed risk based ranking of weak points. TVO decided to modify the most important of them, resulting in the decrease of seismic core damage frequency from $2.5 \cdot 10^{-5}$ to $5 \cdot 10^{-6}$ 1/a.

Seismic analysis is wise to integrate into PSA, because the different risks can be evaluated on the same basis. It is another question, how large uncertainties are involved in the risk models for initiators from different sources.

4.3. Severe accidents and Level 2 PSA

The analysis of severe accidents was performed in connection with the level 2 PSA. The treatment of the phenomena in the severe accident analysis is conservative, but it is realistic in the level 2 PSA. In addition level 2 PSA can treat all phenomena with distributions and add the probabilistic dimension. Because the level 2 PSA and the conventional severe accident analyses were performed in parallel and in cooperation, it was possible to concentrate the further research and plant modifications in the most effective way.

Level 2 PSA is important in realistic risk studies. Most important is to perform a plant specific mapping of risk contributors. This includes:

- detailed structural model of the containment, not only global strength calculations,
- detailed analysis of separate phenomena with accurate codes, not only calculations with an integrated code like MAAP,
- an integrated PSA model (accident sequence analysis and radionuclide transport and release analysis) that allows rapid calculations when some parameters, like operator action times, are changed.

4.4. Freezing of sea water intake strainers

Under-cooled sea water having temperature below zero centigrade can freeze in the intake strainers in the sea water tunnel. This phenomenon has occurred at TVO twice, in the years 1988 and 1995. In January 1995 it caused loss of condenser, and simultaneously it degraded residual heat removal function. Originally the problem was considered as availability problem only, but PSA showed that core melt frequency decreased by more than 60%, when the heating system was built at the inlet of the sea water.

The PSA model of Olkiluoto is applicable in such analyses.

4.5. Increased capacity in safety systems

The upgrading of reactor thermal power from 2160 MW to 2500 MW required capacity increase also in some safety systems. The capacity of the residual heat removal systems was increased by increasing the number of plates in heat exchangers. This modification did not effect on PSA results.

The capacity of the S/R valves would have been too small to fulfill the conservative requirements. Adding two valves of the same type as the old ones would have increased the core damage risk slightly. The requirements for the new valves were specified with the support of PSA. The new valves had to be as diverse as possible compared with the old ones. The installation of two new diverse safety/relief valves did not significantly decrease the total core damage frequency, but it changed the plant damage state profile drastically by decreasing the frequency of high pressure sequences by 60% (frequency of reactor overpressurization was decreased by a factor 50), which resulted in a significant decrease in the source term.

Level 1 PSA with level 2 interface was required for this analysis.

4.6. Instrumentation systems

The old **turbine plant control systems** were replaced with new programmable logic systems. The old "one out of two" (1/2) component protection circuits in the turbine plant were replaced with 2/3 or 2/4 ones. Only a minor part of these systems were important to safety. PSA showed, however, that the importance to core damage risk was some per cents, because the instrumentation failures are expected to cause less inadvertent scrams.

The **neutron flux measuring system** was also replaced with programmable logic. The core damage contribution was calculated to decrease, compared with the old relay logic. A lot of qualitative and quantitative reliability analyses were made to validate the design. However, the requirements of STUK were impossible to fulfill in the safety related parts of the neutron flux measuring system, and hard wired parts were installed in parallel with the programmable systems.

The **speed control system of the main circulation pumps** was replaced with programmable logic. The pumps stop too fast causing probably fuel cladding failures, if they have only their own inertia. Therefore an energy storage is required in case of loss of external grid. The new energy storage is based on flywheels. The requirements based on PSA calculations were easily fulfilled with the new system and even with the old hard wired logic. However, it was impossible to fulfill the deterministic requirements by STUK, and the control system for the soft stop of the pumps was hard wired.

The **instrumentation system of the reloading machine** was replaced with a programmable logic. A comprehensive FMEA was performed for the system, and it revealed a couple of design errors or weaknesses. Difficulties arose in licensing the automatic operation of the reloading machine.

Systems based on programmable logic are at the moment almost the only control systems available. They have a lot of operating experience from the industry use, but only a little from nuclear industry. The basic system solutions are in most cases more than ten years old, and the design of the systems does not fulfill the recent requirements.

PSA is a good tool when analyzing the importance of these systems as a part of the plant, but it is not sufficient tool to analyze the systems themselves. Most of the systems had only minor impact on core damage frequency. At the moment there seems to be no method that would be accepted by the Finnish Regulatory Body, to show the sufficient reliability of these systems qualitatively or quantitatively.

4.7. Safe shut down improvements

This project was initiated late in the modernization program. It includes several diverse safety functions, e.g., automatic depressurization of the primary circuit in case of ATWS or very low level in the reactor tank, and automatic start of boron injection in case of ATWS. PSA showed that this modification decreased the core damage frequency significantly. All modifications were fulfilled with conventional relay logic. The selection of the functions was based partially on PSA results and the design was supported by comparing design alternatives with PSA calculations.

The Olkiluoto PSA was applicable in the analysis of safe shut down instrumentation and logic.

4.8. Electric power systems

A lot of modifications in the electric power systems were performed, but most of them had only minor impact on core damage frequency. The most important one was the building of more rigid support for batteries to tolerate seismic events, discussed in chapter 4.2.

Rather detailed PSA model of electric power system was applicable in the analysis of modifications in the system, and definition of dependability requirements.

5. CONCLUSIONS

Regardless of the tens of man years used for the development of the living PSA, it has proved to be a valuable tool in the management of safety in Olkiluoto nuclear power plant. The utility and the Regulatory Body have the same model and same code. PSA has become a discussion forum between them [12]. One of the most important advantages from PSA is that it allows the arguing on safety issues using quantitative measures. However, the PSA calculations tend not to become as the only criterion when making decisions on safety issues. Some problems arose in connection with the modernization, especially in probabilistic treatment of new technology. In general, the dependability requirements for the modified systems are rather simple to calculate, but the tools are still missing to show quantitatively that the requirements are fulfilled in case of programmable logic systems.

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