Severe Accident Management at the Loviisa NPP
– Application of Integrated ROAAM and PSA Level 2

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1 Introduction

The Risk Oriented Accident Analysis Methodology (ROAAM) was developed for assessment and management of rare, high consequence hazards [1]. The purpose of most ROAAM applications has been to solve major, isolated severe accident issues related to early containment failure such as Mark-I Liner Attack and Direct Containment Heating. In addition to ROAAM in the issue resolution context, the so called Integrated ROAAM approach can be used to provide an overall frame of safety evaluation that allows determination of whether an adequate level of safety has been achieved for a plant. Integrated ROAAM approach brings together quantifications of probabilistic elements based on statistical inference and treatment of deterministic elements based on identification of dominant physics, for severe accident phenomenology, in a well defined and clearly structured way.

Fortum, as an owner of the Loviisa NPP, used the Integrated ROAAM approach when developing and implementing a comprehensive severe accident management (SAM) strategy for the Loviisa NPP. The SAM strategy is based on unique features of this VVER-440 plant with ice condenser containment and it includes hardware modifications at the plant, substantial new I&C qualified for severe accident conditions, new SAM guidelines, a SAM Handbook, revision of emergency preparedness organization, and versatile training approaches.

It could be argued that the resolution of individual severe accident issues is not sufficient for assessing the overall safety of a nuclear power plant, and thus the ROAAM (in an issue resolution context) is not performing the same function as a PSA study (level 2 included). Actually the Integrated ROAAM approach takes on even a more ambitious task than the PSA, since it determines how a balance can be achieved between accident prevention and mitigation of containment-threatening physical phenomena. Thus it provides a tool for implementing a sound diverse defence-in-depth strategy at a plant. Integrated ROAAM also explicitly includes the definition and application of safety goals and acceptance criteria for the entire SAM approach. All this is explained comprehensively in Ref. 3.

PSA studies, on the other hand, give essential information about equipment availability, reliability of hardware, operator actions and connections between operators and equipment. PSA allows us to analyze large, complex reliability models and with PSA (including level 2) also fission product behaviour and radioactive releases to the environment are to be assessed and analyzed when calculating the source term.

Both approaches, PSA and ROAAM, can be used for analyzing severe accidents and Fortum has used them both when ensuring that both the preventive and mitigative parts of SAM strategy for the Loviisa NPP are well balanced and the reliability of equipment used for severe accident management is on an adequate level. PSA level 2 analyses are also used to ensure that radioactive release limits, set by the Finnish safety authority, are not being exceeded[1].

The development and implementation of a SAM strategy for the Loviisa NPP will not be described here in detail. Several papers describe the development [4, 5, 6, 7], implementation [8] and versatile training approaches of Loviisa SAM strategy. This paper will be focused on describing how Integrated ROAAM has been the key element when constructing well balanced SAM strategy and how the use of Integrated ROAAM analysis has affected level 2 PSA studies. The ROAAM approach will also be briefly described in the issue resolution context for treatment of phenomenological uncertainties.

2 SAM strategy in the Loviisa NPP - the Integrated ROAAM approach

2.1 Unique features of the Loviisa NPP

The Loviisa NPP is a two-unit VVER-440 plant with ice condenser containment. Units 1 and 2 were commissioned in 1977 and 1981, respectively. The original plant concept didn't include the containment and since it was definitely required in Finland, ice condenser containments were built on a Westinghouse license. Also other significant modifications to the original plant design were carried out, most notably modifications of the ECCS, the reactor coolant pumps, and the inclusion of Siemens I&C systems.

In the containment (see Figure 1) two ice condenser (IC) sections connect the lower (LC) and upper compartment (UC). In the UC, a dome part and the reactor hall can be separated. The containment is surrounded by the outer annulus (OA). The total free volume of the containment (excluding the dead-ended compartment) is 58 000 m^3. The absolute design pressure of the containment is 1.7 bar. The containment and the global convective loop flow inside the containment are shown in Figure 1.

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[1] In Finland the decision of the Council of the State for the safety of nuclear power plants (395/91) says that the limit for the release of radioactive materials arising from a severe accident is a release which causes neither acute harmful health effects to the population in the vicinity of the nuclear power plant nor any long-term restrictions on the use of extensive areas of land and water. For satisfying the requirement applied to long-term effects, the limit for an atmospheric release of cesium-137 is 100 TBq. The combined fall-out consisting of nuclides other than cesium-isotopes shall not cause, in the long term, starting three months from the accident, a hazard greater than would arise from a cesium release corresponding to the above-mentioned limit.

The possibility that, as the result of a severe accident, the above mentioned requirement is not met, shall be extremely small.

Studies considering severe accident management for the Loviisa NPP have been structured around the identified containment-threatening mechanisms. The aim has been to find solutions that would reliably protect the containment. It has to be recognised that even though there are certain well-known vulnerabilities to severe accident phenomena of the plant, it also presents some unique opportunities for selection of mitigation strategies. For example, water from melting the ice would quickly (and passively) flood the small-sized cavity in an accident. This feature, in combination with the fact that the decay power level is low and the reactor pressure vessel lower head has no penetrations, makes in-vessel retention of molten corium feasible through external cooling of the RPV. A well-known vulnerability is that the ice-condenser containment has a rather low estimated failure pressure in relation to loads that could take place during severe accident (e.g. from global hydrogen deflagrations). On the other hand we have found that the ice condenser configuration would ensure efficient mixing of the containment atmosphere, in case the ice condenser doors were forced open. The containment steel shell makes it possible to control long-term pressurisation through external cooling. All of these elements (and many more) are now part of the overall SAM approach for ensuring the selected SAM safety functions (Section 2.4).

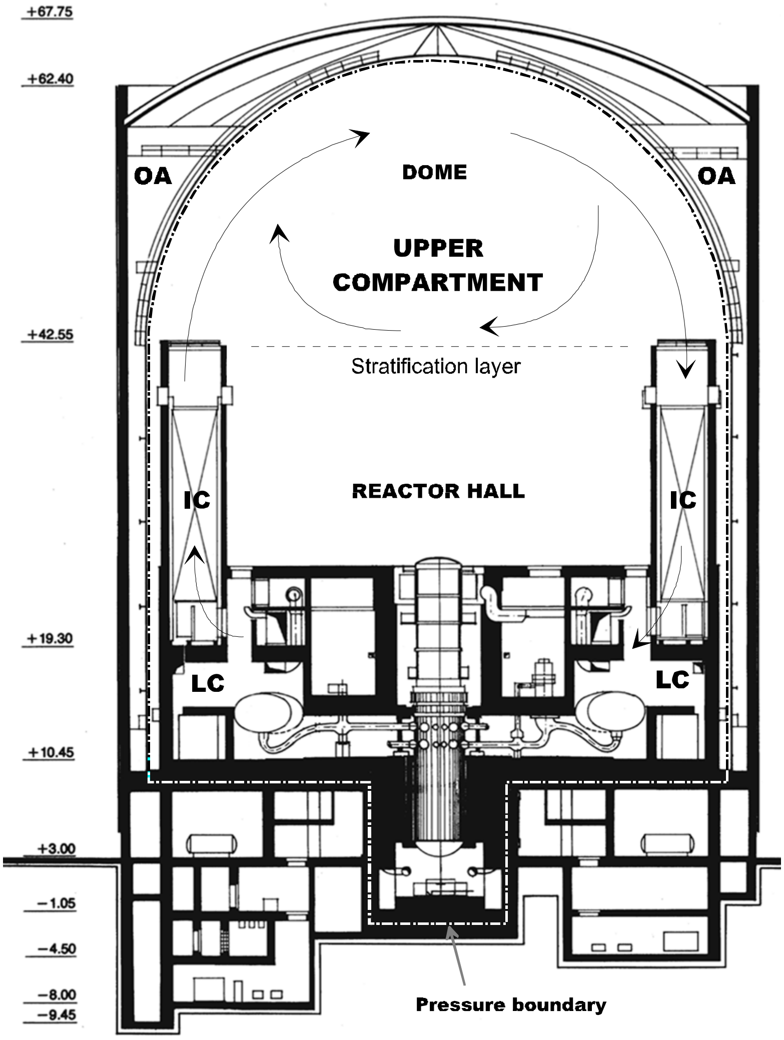

Figure 1. The Loviisa NPP containment

2.2 Main aspects of the Integrated ROAAM approach

The safety goal to be used as a starting point of Integrated ROAAM can be formulated as:

> "Containment failure at the plant is a physically unreasonable event for any accident sequence that is not remote and speculative".

This safety goal requires that sufficient measures have to be taken at the plant to ensure that high consequence hazards can't happen (in case of severe accidents this refers to loss of containment function). According to the safety goal one component of defence-in-depth at a plant is equipment/system based (For any accident sequence that is not "remote and speculative..."), while the other one is focused on physics (...containment failure at a plant is a "physically unreasonable" event). This is a way to ensure that the important diversity feature of defence-in-depth is obtained for severe accident assessment and management at a plant.

Treatment of the deterministic elements in any analyses is based on identification of dominant and quantifiable physics. It can be recognized and accepted that at a sufficient level of evidence to the contrary, certain postulated events or developments can be considered "physically unreasonable". It can also be recognized that at a certain high level of reliability, system failure can be considered as "remote and speculative". Spending resources on acquiring even higher level of reliability is wasted effort and these sequences can be ignored or excluded from further analysis.

In implementation, the Integrated ROAAM begins with a complete system analysis along the lines of a level 1 PSA. It is required that availability of the mitigation systems - that is, the dedicated severe accident management systems - is also defined within the sequence bins or accident classes, which derives from level 1 PSA. For this purpose, an event tree that assesses the availability of systems is constructed. Unlike in a traditional PSA level 2 containment event tree, there are no phenomenological nodes. The mitigation systems event tree (safeguards tree) is quantified by fault tree linking so that the system failure information from the level 1 PSA analysis is preserved and treated consistently.

System analysis is used to define accident classes, success of operator actions and availability of mitigation system, associated plant damage states and respective frequencies. A screening frequency is used to determine which accident classes can be considered as "remote and speculative" i.e. ignored. For the accident classes that cannot be ignored, containment failure must be shown to be "physically unreasonable" (conditional containment probability has to be very low, see also Table 1), or if this is not the case, accident measures must be found to achieve this goal. This is done by applying the ROAAM in the issue resolution context as it will be explained in Section 2.3.

Figure 2 illustrates the idea of Integrated ROAAM. All the input sequences from PSA level 1 have to be shown as remote and speculative. Either their frequency is below the screening frequency, or SAM measures are taken to reduce conditional containment probability of these sequences. Other situations are not acceptable. The use of Integrated ROAAM approach for assessing and evaluating of overall safety and implementation of Integrated ROAAM for the Loviisa NPP is explained in Ref. 9.

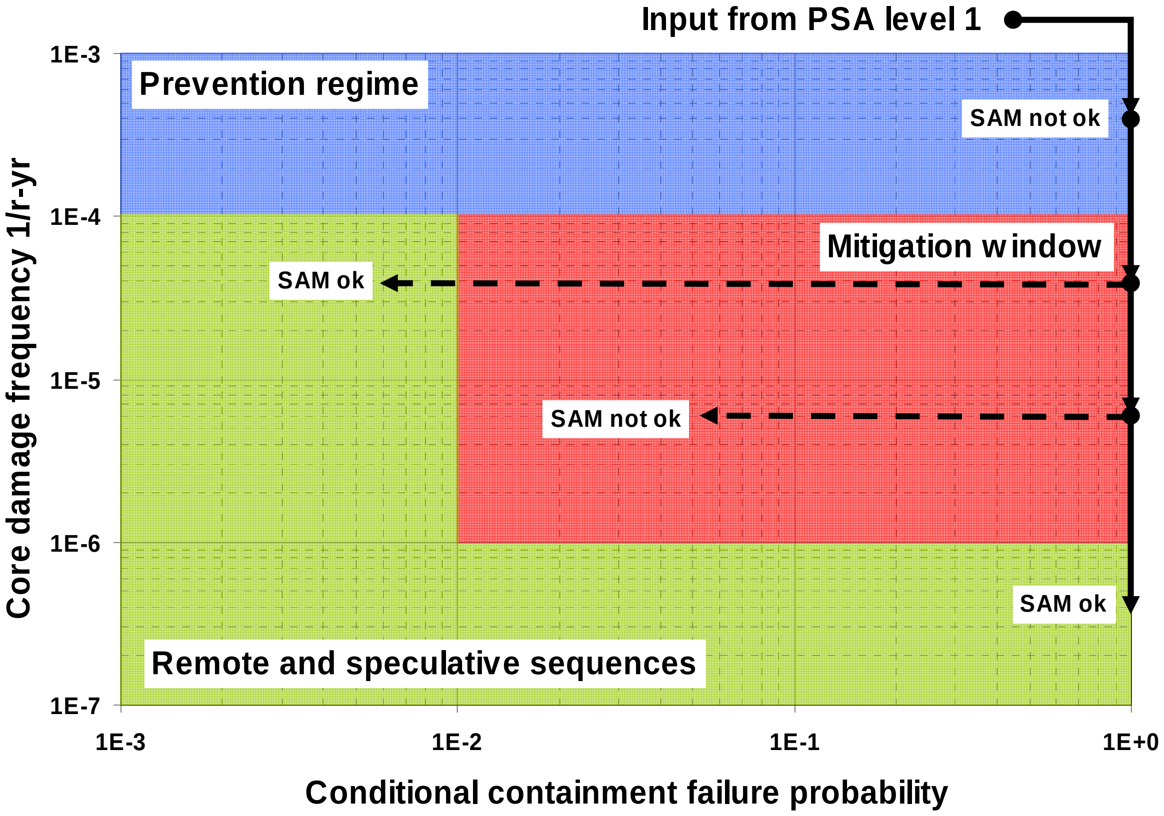

Figure 2. Two dimensions of Integrated ROAAM approach; prevention of core damage when the frequency of sequence is above the accident prevention goal and mitigation of containment threatening phenomena when frequency of sequence is inside the mitigation window.

Mitigation window for the Loviisa NPP is selected to be 10^{-4} 1/r-yr > *f* > 10^{-6} 1/r-yr, which means that the accident prevention goal is 10^{-4} 1/r-yr and the screening frequency, below which the sequence is considered to be remote and speculative, is taken to be 10^{-6} 1/r-yr. Since each accident class, that has to be mitigated, has a frequency < 10^{-4} 1/r-yr, a design target for failure of each safeguards function is formulated to be < 10^{-2} / demand. This way the failure of one or more safeguards system in any accident class meets the screening target (i.e. such a sequence becomes remote and speculative).

A SAM approach was developed to meet the mitigation goal set by Integrated ROAAM. One important component of this approach is in-vessel retention of molten corium, which has been adopted for the Loviisa NPP. An obvious advantage of cooling the molten core inside the reactor pressure vessel is the fact that all ex-vessel phenomena, such as DCH, ex-vessel steam explosions and corium-concrete interactions could be avoided. Thus the only potential containment threats that need to be considered are due to hydrogen combustion and slow pressurization of containment. Mitigation of these threats is also important component of the SAM approach, is explained in more detail in section 2.4.

2.3 Phenomenological uncertainties using ROAAM

The phenomena constitute safety issues such as e.g. hydrogen combustions and high-pressure core melt down sequences involve significant phenomenological and modelling uncertainties (epistemic uncertainties). The purpose of ROAAM in issue resolution context is specifically to deal with these uncertainties in low-probability, high-consequence situations and produce issue resolution that can be widely accepted and approved.

The basic principles of ROAAM are clarity (transparency in separating out the essential portions of epistemic uncertainty), consistency (a screening frequency is used to exclude physically unreasonable situations, the accident sequence and initial conditions must be logical) and completeness (all sequences that cannot be excluded on physical grounds must be considered). ROAAM methodology is comprehensively described in Refs. 1 and 2.

ROAAM is based on understanding the phenomena underlying physics. If the knowledge of physical phenomenon is found to be insufficient, the quantification is not even attempted before careful studies, involving modelling and experimental verification. Briefly, ROAAM can be described as a process in which a complicated physical phenomenon is decomposed in a controlled way into subphenomena, each one of which represents a well-posed technical problem and can be solved independently. This is done with a probabilistic framework, in which central element is one or more causal relationships (CR's), i.e. the models of the physical systems. The parameters in the model are either deterministic or intangible (which are subject to inherently variable behaviour). The intangibles and the uncertainties in the deterministic parameters are presented by means of probabilistic density functions (pdf's). Integration of the causal relationships and probabilistic density curves through probabilistic framework is effected by introducing a physically based probabilistic scale (Table 1) for the temporary quantification of intangibles, and the results are rendered in qualitative terms by applying this scale in reverse. This scale is arbitrary, except for providing the definition of "physically unreasonable" process as one involving the independent combination of an end-of-spectrum with one expected to be outside but cannot be positively excluded.

Table 1. Definition of probability levels [1]

Process Likelihood	Process Characteristics
1/10	"Behaviour is within known trends, but obtained only at the **edge-of-spectrum** parameters"
1/100	"Behaviour cannot be positively excluded, but it is **outside the spectrum of reason**"
1/1000	"Behaviour is **physically unreasonable** and violates well-known reality. Its occurrence can be argued against positively"

As a whole the key elements of ROAAM can be formulated as:

- Physically-based decomposition that allows transparency in separating out the essential portions of epistemic uncertainty
- Probabilistic framework made up of causal relations and intangible parameters
- Causal relations (key physics) represent well-posed problems, i.e., not subject to major discontinuities of a stochastic nature. Uncertainty can be reduced to the parameter level (no major modelling uncertainty)
- "Splinter" scenarios in combination with conservative estimates of epistemic uncertainty, so as to obtain convincingly conservative results

ROAAM process has been formally carried out in the Loviisa NPP when dealing with in-vessel retention of molten corium and hydrogen combustions. These ROAAM analyses will be shortly described below. Also the study of slow overpressurization of Loviisa containment [10, 11] clearly follows the lines of ROAAM, even if it was not formally carried out by using ROAAM, since this was an early effort carried out in the late 1980's.

2.3.1 In-vessel retention of corium

An extensive research program, which included both analytical and experimental studies on heat transfer in molten pool with volumetric heat generation [12] and on heat transfer and flow behaviour at reactor pressure vessel outer surface [13], has been carried out by IVO (precursor of Fortum) for demonstrating the coolability of corium on the lower head of the reactor pressure vessel.

The basic preconditions for reactor pressure vessel (RPV) lower head coolability and melt retention - a flooded cavity, a low decay power level, and a RPV lower head without penetrations - are fulfilled in case of Loviisa [14], 15]. The main questions in the study are 1) whether the heat flux through the wall remains below critical heat flux (CHF) at all locations along the vessel wall and 2) whether - given that CHF is not exceeded - the remaining thickness of the wall is more than a certain critical thickness, below which the vessel fails. Both failure criteria depend strongly on the location (or slope) so in principle the probabilistic framework has to be written for each discrete distance. Though, in our case the most critical location of the vessel is known beforehand (vertical portion of the wall, next to the molten metallic layer) and the probabilistic framework has been made for this critical location. The probabilistic framework for assessing the phenomenological uncertainty of exceeding critical heat flux at certain location is illustrated in Figure 3.

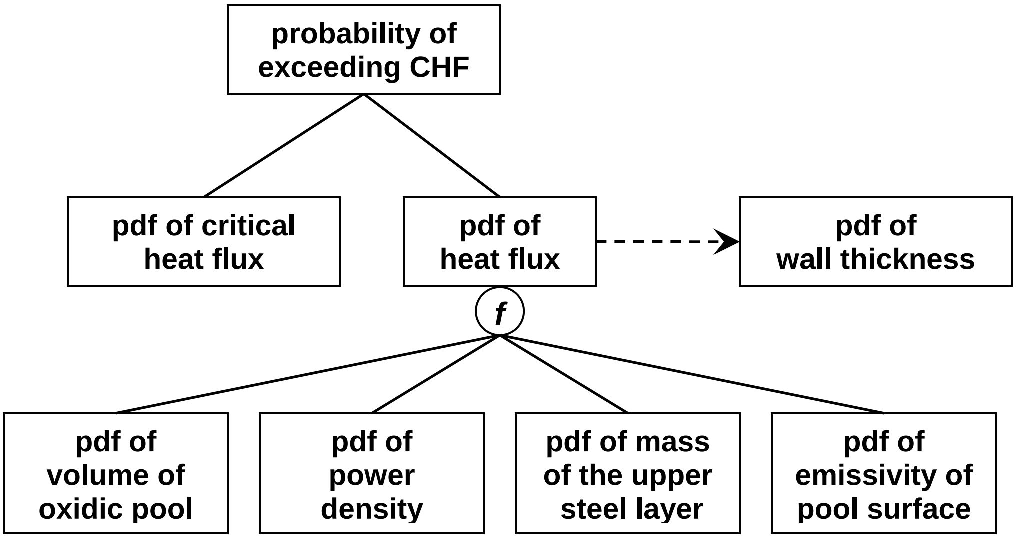

Figure 3. Probabilistic framework

The results of the study of in-vessel retention of molten corium during severe accident [14] demonstrated that margins to the RPV failure are very large and thus the failure can be considered as physically unreasonable situation. As a consequence of the study, some plant modifications were carried out in order to ensure efficient circulation of water around the vessel and in the cavity. During a severe accident situation the operator needs to depressurize the primary system and hydraulically lower the RPV lower head insulation and neutron shield. The Finnish Regulatory Authority STUK approved the in-vessel retention strategy for Loviisa in late 1995 and respective plant modifications were implemented.

2.3.2 Hydrogen management

Significant experimental and analytical efforts have been carried out since early 1990's in order to achieve a sound technical basis for the decision making concerning improvements of the hydrogen management scheme at the Loviisa NPP [16]. The current hydrogen management strategy consist of three different components, which entailed significant plant modifications: A capability to force open ice-condenser doors to ensure efficient containment atmosphere mixing, controlled removal of hydrogen by means of passive catalytic recombination, and availability of deliberate ignition in lower compartment in case to mitigate hydrogen release spikes in connection with flooding a severely overheated core. Figure 4 shows the probabilistic framework of the ROAAM analysis.

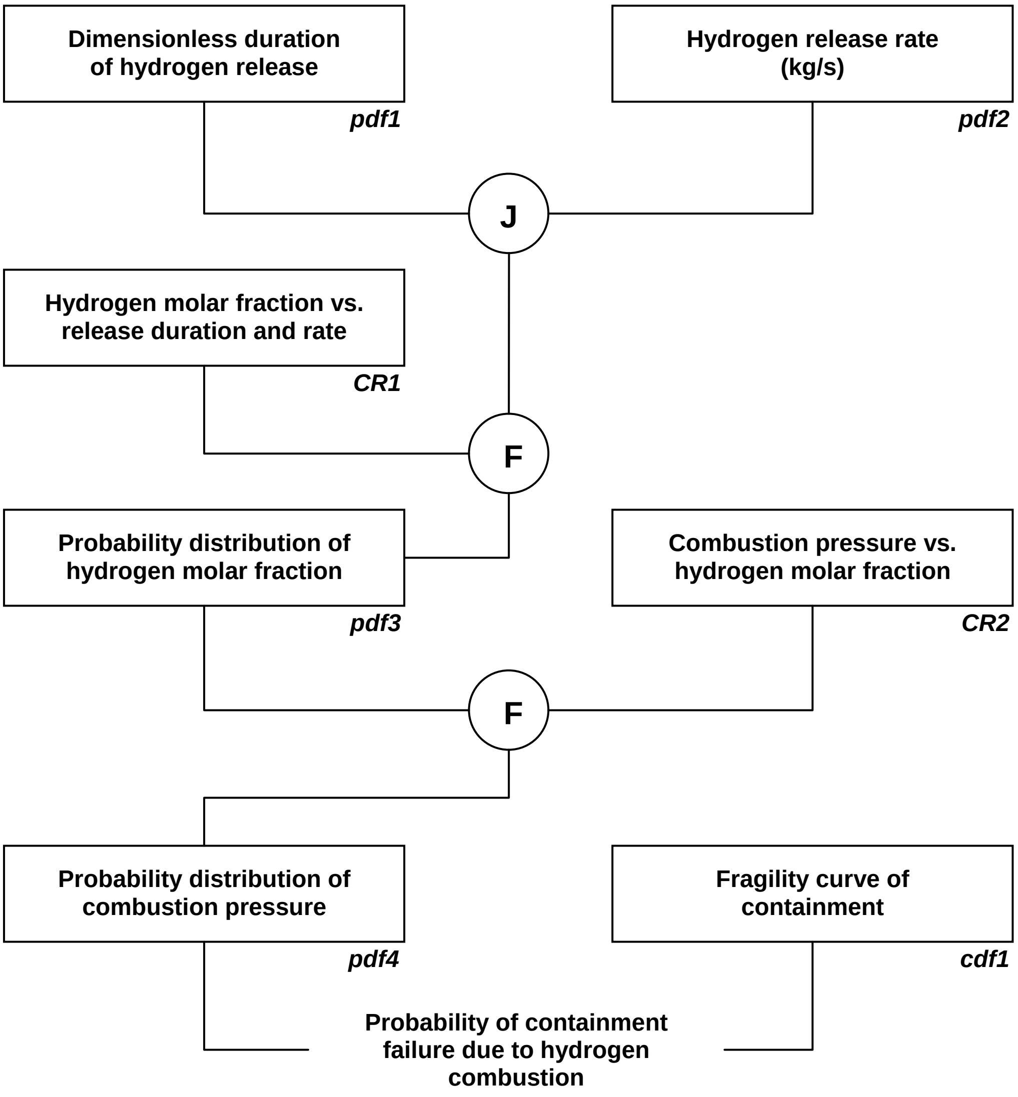

Figure 4. Probabilistic framework for containment failure in H_2 combustion

A ROAAM analyses demonstrated that the containment failure due to hydrogen combustion events is a physically unreasonable event with the new hydrogen management strategy in place.

2.4 Overall SAM approach in the Loviisa NPP

The Integrated ROAAM approach was applied for the development of an overall SAM strategy for the Loviisa NPP. Besides showing that prevention of core damage and prevention of core melt sequences with imminent threat of a large radioactive release (e.g. primary-to-secondary leakages) is reliable, our SAM strategy will also show that mitigation of severe accident phenomena is comprehensive and credible. In order to show a compliance with Finnish safety requirements with regards to SAM, we also have to demonstrate that radioactive release limits are not being exceeded due to normal leakages out of an intact containment in a severe accident.

The mitigation part of Loviisa SAM management strategy is built, along the lines of the Integrated ROAAM study, around the following SAM safety functions:

- Successful containment isolation (we have developed new approaches for actuating isolation signals, ensuring isolation status, and monitoring containment leak-tightness)
- Primary system depressurisation (we have installed high-capacity depressurisation valves, which are separate from the primary system safety relief valves)
- Absence of energetic events i.e. mitigation of hydrogen combustion, since successful in-vessel retention of molten corium excludes other energetic events. (A new hydrogen mitigation scheme [16])
- Cooling of reactor core or core debris (reactor pressure vessel lower head coolability and melt retention). Certain plant modifications were necessary in order to ensure e.g. access of water to the vessel wall and sufficient flow paths for steam at the boiling channel.
- Mitigation of slow containment overpressurisation (long-term containment cooling): The approach was taken to install a containment external spray system instead of filtered venting due to certain Loviisa-specific features such as sensitivity to subatmospheric pressures and low steaming rates [10]. No other non-condensable gases than hydrogen are generated and containment steel shell makes it possible to cool from the outside.

All aspects of the strategy, like hardware and I&C modifications have been targeted towards ensuring the safety functions in a highly reliable manner. The SAM guidelines and procedures and the SAM Handbook have also been structured around the SAM safety functions.

3 Level 2 PSA

At present, the level 2 PSA studies for the Loviisa NPP cover the internal hazards for at-power states for unit 1. In near future, the flood and weather hazards for at-power states are to be analysed, and in upcoming years the internal hazards will be extended to the normal refuelling shutdown states. Fire risks will be studied after the extensive I&C renewal process has proceeded far enough to provide adequate information to update the PSA models. In the following, we will concentrate on the work that has been completed.

Due to ROAAM approach in the SAM strategy it has been possible to simplify the PSA level 2 containment event tree (CET) significantly. The usual way to treat the actions and the phenomenological issues in the CET lead to an extremely large number of CET end states. This further requires extensive binning of the end states to pre-selected release categories, since it is not possible to study each end state of a large CET separately. Our approach with the CET is to avoid questions leading to additional failures in such cases where the SAM strategy has already failed and releases are large.

The CET for the Loviisa NPP is shown in Figure 5, which clearly shows the advantages of the ROAAM approach for PSA level 2 analyses. We call the end points of the CET as Accident Progression Categories (APC), which are treated separately in the source term calculation. The questions in the CET treating the early containment failure phenomena are arranged chronologically. Failure of a specific issue in the CET leads to a downward branch, and no further branching is done until the question of the containment internal spray, which may significantly affect the source term if available.

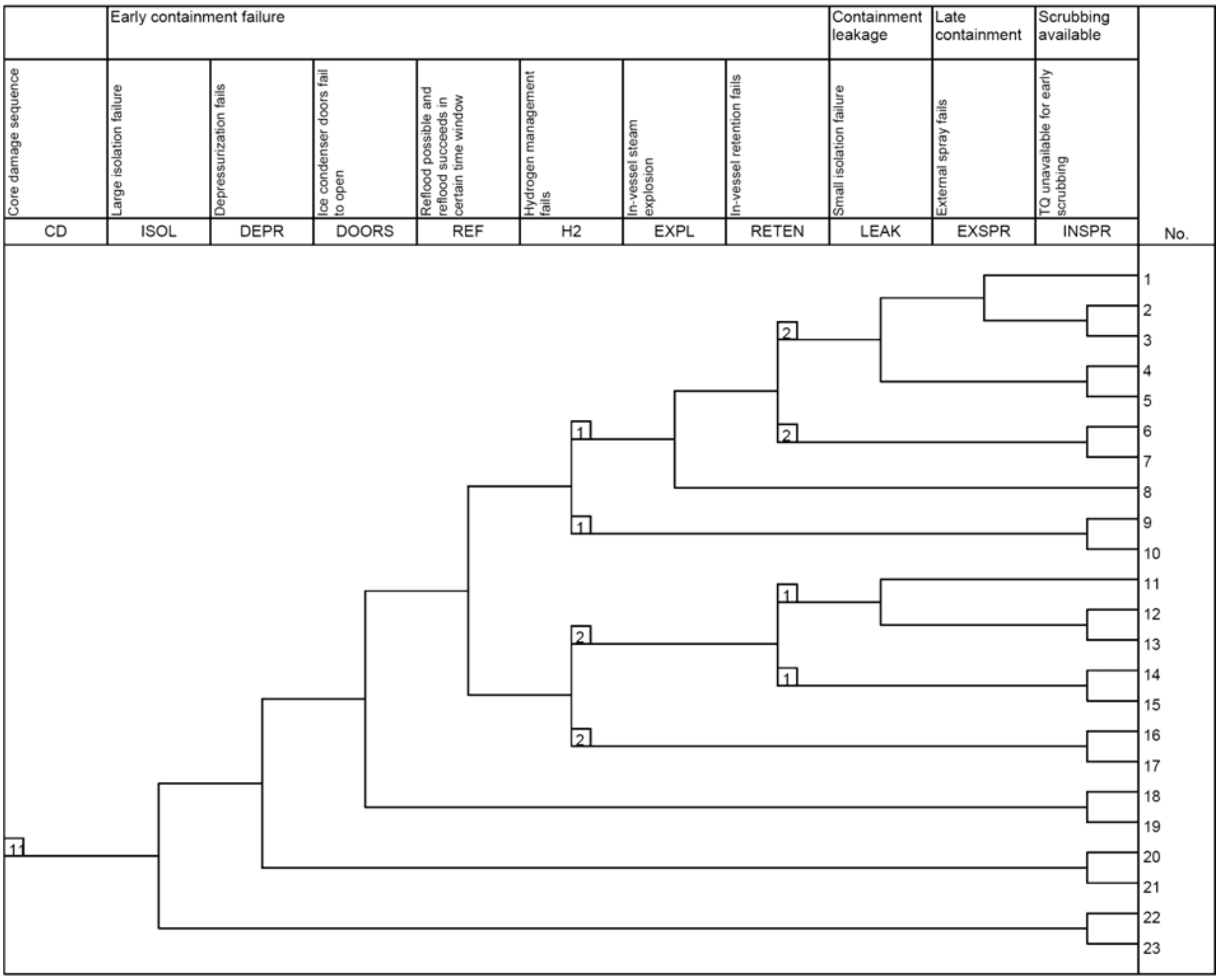

Figure 5. The CET in the level 2 PSA for the Loviisa NPP

This approach can be justified by the fact that, particularly for issues leading to an early containment failure, a failure in one question results in releases clearly above any permissible thresholds. In branches with no additional questions, neither additional failure is assumed, since the more complex treatment of phenomenological issues would not significantly affect the releases from the point of view of the whole study. For example, if there is already a large containment isolation failure, there is no need to ask whether the hydrogen management succeeds or not, as we know that the releases in this case are very large and early in all cases. Furthermore, the frequency of the branches with multiple significant failures would become so low that their importance would be negligible to the overall results. The usage of ROAAM in development of the SAM strategy assures that the phenomenological uncertainties are covered well during this simplification process.

In the CET in Figure 5 there is a question related to the reflooding of reactor core in such a time window that would result in violent hydrogen generation in the overheated core. This kind of hydrogen spike would cause such a rapid increase in hydrogen concentration that the catalytic recombiners would be unable to bring the concentration to a level with no risk of large deflagration. The reflooding in the critical time window actually leads to the downward branch in this question, but it does not necessarily mean that the hydrogen management would fail. Therefore even the lower branch undergoes closer examination by the following questions.

The level 2 PSA goes further than ROAAM by bringing up the issues related to source term evaluation. Of course, the key issue in reducing the environmental releases is to ensure the containment integrity, which is the main goal of the ROAAM approach, as well. As discussed above, this is reflected in the CET when justifying the simplifications in branching. The simplification is utilised even in the source term analyses as the tool used for calculation of environmental releases concentrates on issues, which are essential considering the SAM strategy. Fortum has developed a spreadsheet based tool, SaTu, for source term analyses [17, 19]. The SaTu system is able to calculate representative source terms from a reduced amount of data as user input in less than one minute per sequence, which enables wide uncertainty analyses on built-in parameters of the system. The uncertainty analyses of the source term calculation are carried out as Monte Carlo simulations resulting in specific time dependent confidence levels of released fractions of different fission product groups [21]. An example of the uncertainty analysis results is shown in Figure 6.

Level 2 PSA analyses can be used to test the SAM strategy, as well. Our studies on containment sequences show that the fraction of sequences with failure to follow the SAM procedures is very small. Furthermore, when considering the hydrogen risk from the reflooding it was found that in only a small fraction of the sequences the repair actions could take place to allow the ECCS water injection into the overheated core in the critical time window.

In spite of the fact that the SAM strategy is proven to be adequate with the containment sequences, the Level 2 PSA showed that a specific problem arises with containment bypass sequences. Although the containment bypass itself may or may not lead to significant releases, it was found that there would not be enough of sump water to flood the reactor cavity and ensure the in-vessel retention of the core melt by RPV external cooling. Thus, all of the bypass sequences would eventually lead to cavity failure and significant environmental releases.

The aerosol retention in the bypass route has been studied in co-operation with the Technical Research Centre of Finland (VTT), and specific interest has been put on aerosol retention in the steam generator tubes during primary-to-secondary leakages [18, 20]. However, the in-vessel retention aspect might cause further actions to either bring further down the frequency of the bypass sequences or modify the EOPs to ensure flooded cavity when still having a substantial amount of ECCS water left.

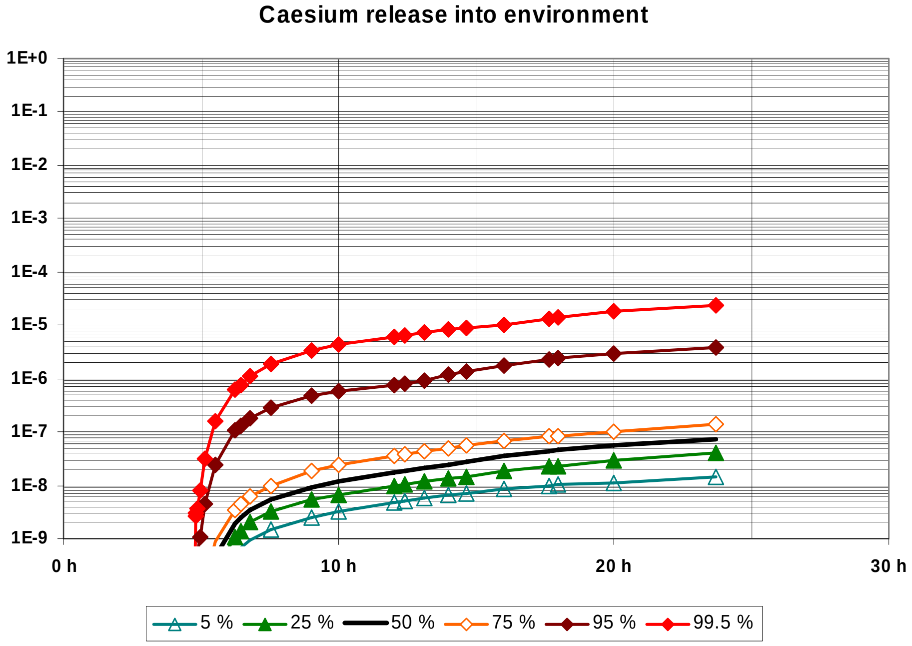

Figure 6. Example of the source term uncertainty results with SaTu

4 Summary and conclusions

Fortum has used both methodologies; ROAAM and PSA level 2, when developing and analysing a SAM approach for the Loviisa NPP. We see significant advantages in combining the two approaches, since they complement each other in several ways. The PSA study is a tool for determining relevant sequences that must be mitigated in the SAM approach, and is therefore strongly integrated in the ROAAM work. ROAAM, on the other hand, increases the credibility and transparency of the level 2 PSA study.

The Finnish requirements clearly communicate that sufficient measures, both preventive and mitigative ones, should be taken at the plant in order to demostrate that containment failure and extensive releases of radioactive material shall be highly unlikely. The Integrated ROAAM safety goal formulation captures the idea behind Finnish safety goal in an ideal way. With Integrated ROAAM the balance between preventive and mitigative measures can be achieved and epistemic uncertainties can be treated in a transparent manner.

ROAAM has significant advantages in dealing with phenomenological uncertainties, especially in the mitigation regime, when a high level of remaining uncertainty cannot be tolerated. ROAAM provides a framework for modelling and quantifying complex physical phenomena that may cause containment failure in a severe accident situation. Furthermore, only with application of ROAAM we have obtained a sufficient and sound basis for determination of the plant modifications needed for successful SAM strategy.

PSA on the other hand, is the obvious choice in the preventive regime, where the unavailability of large and complicated systems if often the key issue. Standard PSA fault and event tree modelling approaches can be meaningfully applied when statistical reliability data are available (which is the case on level 1), and phenomenological issues are not the dominant source of uncertainty. With PSA studies it is also possible to continuously improve the overall safety by noticing possible weak points and study the influences of planned modifications and design improvements.

PSA level 2 is also important because source terms are calculated as the end results, which is not done in the Integrated ROAAM. The source term analysis in PSA level 2 allows us to understand fission product behaviour, which is extremely important when dealing with containment bypass sequences. Source terms can also be directly linked to radioactive release limits set by the Finnish safety authority.

Due to ROAAM approach in the SAM strategy it has been possible to simplify the PSA level 2 containment event tree significantly. The usage of ROAAM assures that the phenomenological uncertainties are covered well during this simplification process.

References

1. Theofanus, T. G., On Proper Formulation of Safety Goals and Assessment of Safety Margins for Rare and High-Consequence Hazards, Reliability Engineering and System Safety 54, pp. 243-257, 1996
2. Structured Approach for the Assessment of Accident Management Strategies: Methods and Case Studies, CEC Project FI4 950015, Report No. AMM-SAMEM (96)-P002, November 1996,
3. Scobel, J. H., Theofanus, T. G. and Sorrell S.W., Application of the Risk Oriented Accident Analysis Methodology to Understanding Uncertainties in Severe Accident Phenomena in the AP600 Advanced Light Water Reactor, Proceedings, PSA'96, Park City, Utah, USA, September 29 - October 3, 1996.
4. Tuomisto, H. and Theofanus T.G., A consistent approach to severe accident management, Nuclear Engineering and Design 148, pp. 171-183, 1994.

5. Tuomisto, H., In pursuit of consistency and completeness in the severe accident assessment and management, OECD Specialist Meeting on Severe Accident Management Implementation, Niantic, Conneticut, USA, June 12-14, 1995.
6. Lundström, P., Tuomisto, H. and Theofanus T. G., Integration of severe accident assessment and management to fulfill the safety goals for the Loviisa NPP, International Topical Meeting on Probabilistic Safety Assessment, Park City, Utah, USA, September 29 - October 3, 1996.
7. Kymäläinen, O. and Tuomisto H., Severe Accident Management Strategy at the Loviisa NPP, Proceedings of the 3rd Finnish-French Colloquim on Nuclear Power Plant Safety, Lappeenranta, Finland, June 27-28, 2000.
8. Lundström, P., Kymäläinen, O. and Tuomisto, H., Implementation of Severe Accident Management Strategy at the Loviisa NPP, OECD Workshop on Implementation of Severe Accident Management Measures, PSI-Villigen, Switzerland, September 10-13, 2001.
9. Structured Approach for the Assessment of Accident Management Strategies: Methods and Case Studies, CEC Project FI4 950015, Report No. AMM-SAMEM (97)-P006, December 1997,
10. Tuomisto, H., Hytönen, Y., Hyrsky, T. and Mattila, E., External Spray Cooling of the Loviisa Containment, OECD/CSNI Specialist Meeting on Selected Containment Severe Accident Management Strategies, Stockholm, Sweden, June 13-15, 1994.
11. Tuomisto, H., Hytönen, Y. and Valencia, L., Application of HDR-Experiments E11.2 and 4 to Demonstrate Effectiveness of External Cooling for Loviisa Containments, 14. Statusbericht des Projektes HDR-Sicherheitsprogramm, Arbeitsbericht 05.48/90, pp. 101-128, Karlsruhe, Germany, 12.12.1990
12. Kymäläinen, O., Tuomisto, H., Hongisto, O. and Theofanus T. G., Heat Flux Distribution from a volumetrically Heated Pool with High Rayleigh Number, Nuclear Engineering and Design 149, pp. 401-408, 1994
13. Kymäläinen, O., Tuomisto, H. and Theofanus T. G., Critical Heat Flux on Thick Walls of Large, Naturally Convecting Channels, ANS Proceedings of 1992 National Heat Transfer Conference, Vol. 6, pp. 44-50, San Diego, California, USA, August 9-12, 1992
14. Kymäläinen O., Loviisa 1&2, In-vessel Retention of Corium during a Severe Accident, LO1-GT1-64, IVO Report, 7 March, 1994
15. Kymäläinen, O., Tuomisto, H. and Theofanus, T. G., In-vessel Retention of Corium at the Loviisa Plant. Nuclear Engineering and Design 169, pp. 109-130, 1997.
16. Lundström, P., Loviisa 1&2, Hydrogen Management Strategy for the Loviisa NPP, LO1-GT1-78, IVO Report, 1 February, 1997.
17. Routamo, T., Eurajoki, T. and Lundström, P. SaTu - Support System for Radiation Experts. Proceedings of the OECD/CSNI SAM Workshop on Operator Training and Instrumentation Capabilities Lyon, France, 12-14 March 2001. NEA/CSNI/R(2001)7.
18. Routamo, T., Jokiniemi, J., Mäkynen, J., Aerosol Deposition in Horizontal Steam Generator Tubes in Severe Accident Conditions. Proceedings of NURETH-10. The Tenth International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Seoul, Korea, October 5-11, 2003.
19. Routamo, T., Siltanen, S., Lundström, P., PSA Level 2 Source Term Approach in the Loviisa NPP. Proceedings of OECD/CSNI International Workshop on Level 2 PSA and Severe Accident Management, Köln, Germany, 29-31 March, 2004.
20. Routamo, T., Auvinen, A. and Jokiniemi, J., Aerosol Deposition in a Horizontal VVER-440 Steam Generator. Proceedings of ICAPP ’05, Paper 5243, Seoul, Korea, 15-19 May, 2005.
21. Siltanen, S., Influence of Uncertainty of Calculation Parameters in Modelling on Radioactive Releases in Severe Accident Conditions. Master's Thesis, Helsinki University of Technology, 2.12.2003. (In Finnish)