A PRA application to support outage schedule planning at OL1 and OL2 units

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Abstract: For Olkiluoto 1 (OL1) and Olkiluoto 2 (OL2) nuclear power plant units, planned outages are done annually. Every second year a refuelling outage (duration about 1 week) and every second year a maintenance outage (duration about 2-3 weeks) is performed. To ensure nuclear safety in such short outage times, well planned outage schedules are required. Because of this, a PRA application to support the outage schedule planning has been developed.

The PRA application for outage risk management has six goals: (1) to support outage schedule planning, (2) to assess plant modifications during outage, (3) to estimate core damage and radioactive release frequencies of the outage, (4) to identify "weak points" of the outage, (5) to teach risk-informed thinking to the outage schedule coordinators and (6) to develop the outage PRA models.

The PRA application is performed hour by hour throughout the whole outage. A risk profile for the outage as a function of time is the main result of the analysis. The assessment is updated when outage schedule is updated. Based on the results, the PRA application to support outage schedule planning is an efficient way to improve risk management during outages.

Keywords: PRA, application, outage, risk management

1. INTRODUCTION

Planned outages are normal part of the plant operation. Planned outages are done annually for Olkiluoto 1 (OL1) and Olkiluoto 2 (OL2). Normal practice is 12 months fuel cycle including every second year a refuelling outage (duration about 1 week) and every second year a maintenance outage (duration about 2-3 weeks). Because the duration of the outage is short, well planned outage schedule is required. The principal schedule of every planned outage is known several years in advance. The preparation of detailed outage schedule starts immediately after completion of the previous outage. The preparation continues whole fuel cycle including monthly organized outage schedule meetings with experts in different engineering areas like maintenance, testing and nuclear safety.

To ensure nuclear safety in such short outage times, a PRA application to support outage schedule planning has been developed. The PRA application for outage risk management is based on the outage PRA models. PRA modelling for "average" outages is explained in the chapter 2. The chapter 3 describes how those PRA models are used in the application for outage risk management including further development areas and the chapter 4 concludes and summaries the work.

2. PRA MODELLING FOR AVERAGE OUTAGE

Finnish Regulatory Body (STUK) requires that all operation modes and transitions between the modes shall be included in the PRA. For the units OL1 and OL2, following operation modes are covered in the PRA: power operation, refueling and maintenance outages, transition from power operation to hot shut-down state, planned shut-down from hot shut-down state to cold shut-down state and start-up from outage to power operation.

The first version of the outage PRA was developed in the early 1990s. After that, several updates have been done to maintain the outage PRA for living PRA purposes. The outage PRA represents kind of an average outage based on operating history since 1990s. Durations of different outages, initiating event frequencies and unavailability of systems due to maintenance are all determined using operating history.

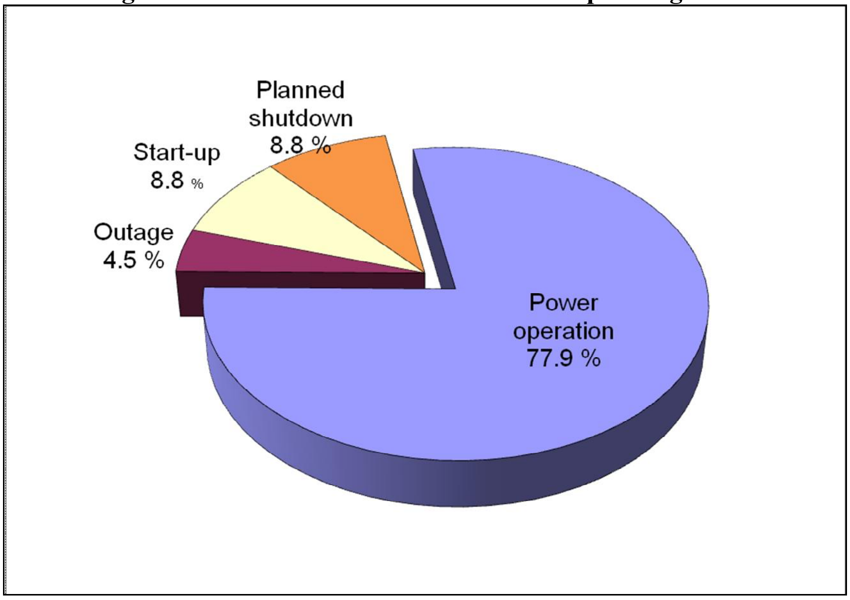
In the PRA models, the outage is divided into six plant operational states (POS). Each POS has unique characteristics, e.g. water level and residual heat removal capacity. Physical behavior after initiating events is studied for each POS and based on those studies success criteria for the event trees are determined. The outage PRA is modelled using "large fault trees - small event trees"-method approach. Table 1 describes POS applied during outage.

Table 1. Description of plant operational states (POS)

POS	Description
T0	Starts from the shutdown state when the reactor pressure decreases below 1,2 MPa and ends when reactor water filling is started.
T1A	Starts when reactor water level is started to lift up and ends when water level reaches flange level.
T1B	Starts when water level reaches flange level and ends when the reactor lid is opened.
T2	Starts when the reactor lid is opened and water level is started to lift up and ends when residual heat removal is done using the systems 321 and 324 (reactor pools are filled up with water)
T3	Starts when residual heat removal is possible using only the system 324 (considering single failure criterion) and ends when water level is back to flange level.
T4	Starts when water level is in flange level and ends when the reactor lid is installed and ends when the control rods are started to pull out from the reactor (criticality).

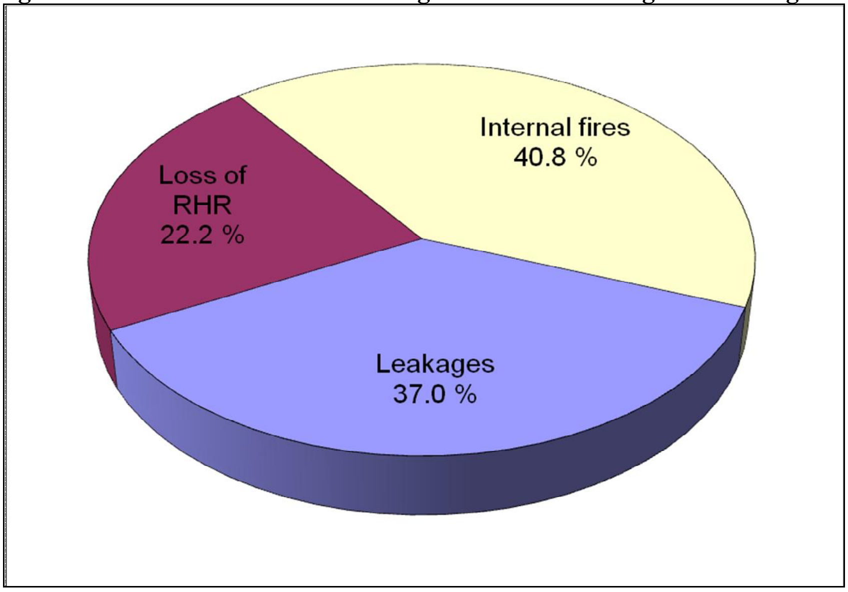
The outage PRA is widely applied for risk-informed assessments e.g. in evaluation of plant modifications, Technical Specifications and plant disturbance events. The current PRA level 1 results for the OL1/OL2 units are shown in figure 1. The overall core damage frequency is 1,2E-5/a, for the power operation 9,4E-6/a, for the planned shutdown 1,1E-6/a, for the start-up 1,1E-6/a and for the outage 5,5E-7/a.

Figure 1. The distribution of the CDF for operating states



The initiating events groups for outages can be divided into three main categories: (1) initiating events causing loss of residual heat removal, (2) initiating events causing leakages from the reactor and (3) internal fires. The relative contribution of the outage core damage frequency for different initiating event groups are shown in figure 2.

Figure 2. The distribution of the outage CDF for initiating events categories



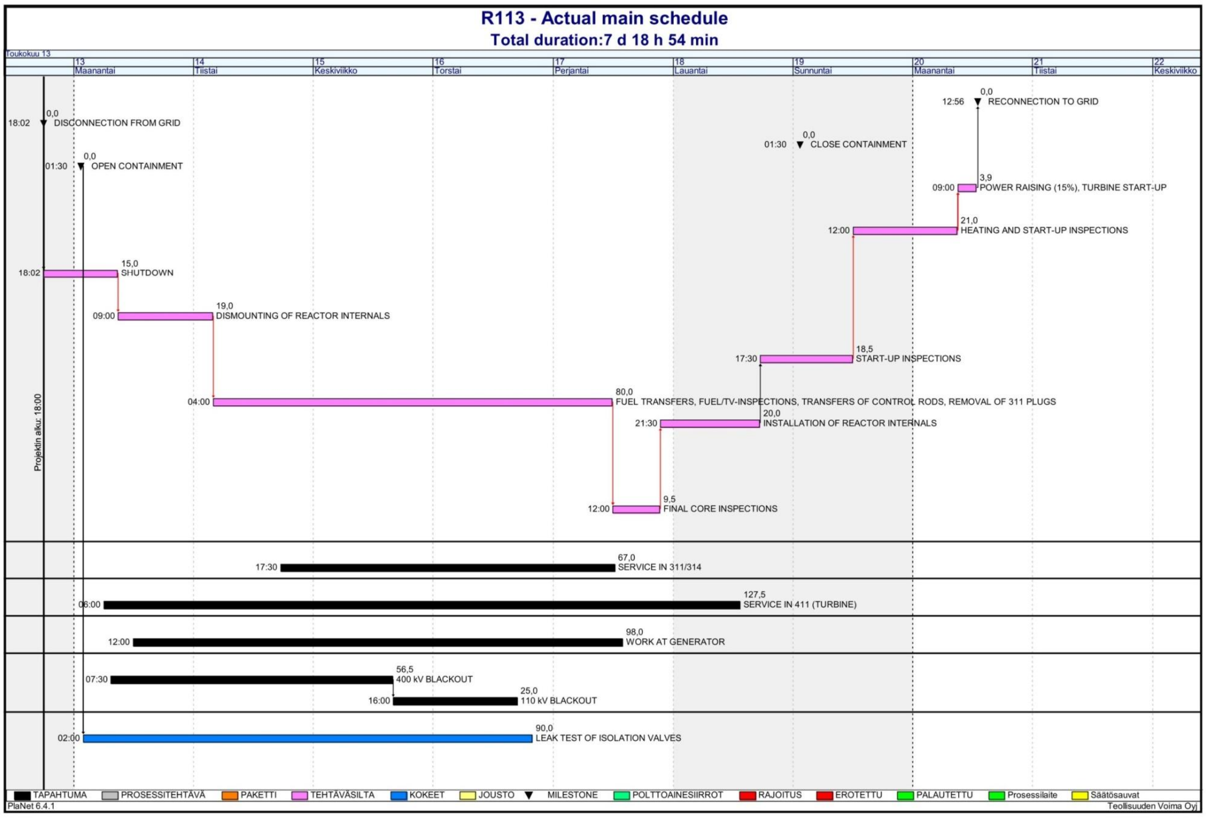
3. APPLICATION FOR SPECIFIC OUTAGES

The main purpose of the application is to support outage schedule planning using the existing average outage PRA models to calculate momentary core damage and radioactive release frequency during the outage. The application was used for the first time in planning of the 2013 outages and several modifications to the outage schedule were done based on the results of the assessment. Good experiences and feedback were received from maintenance and operational personnel. Further development of the application was performed after the year 2013 outages by development of more automated data handling and batch calculations with a MS Excel tool.

3.1. The method description

The application for specific outages is based on the outage schedule printouts printed out in five different forms: (1) Main schedule, (2) Reactor schedule, (3) Residual heat removal schedule, (4) System maintenance schedule and (5) Criticality safety schedule. The main schedule shows the outage schedule in a simplified manner and only the most important information is included. The reactor schedule includes detailed time schedule for work packages in the reactor during outage. The residual heat removal schedule includes planned unavailability of the residual heat removal systems during the outage. The system maintenance schedule includes the time schedule for planned unavailability of the other systems and the criticality safety schedule shows the time schedule for the work packages affecting on criticality safety. An example of the outage schedule (main schedule) is shown in figure 3.

Figure 3. Main schedule

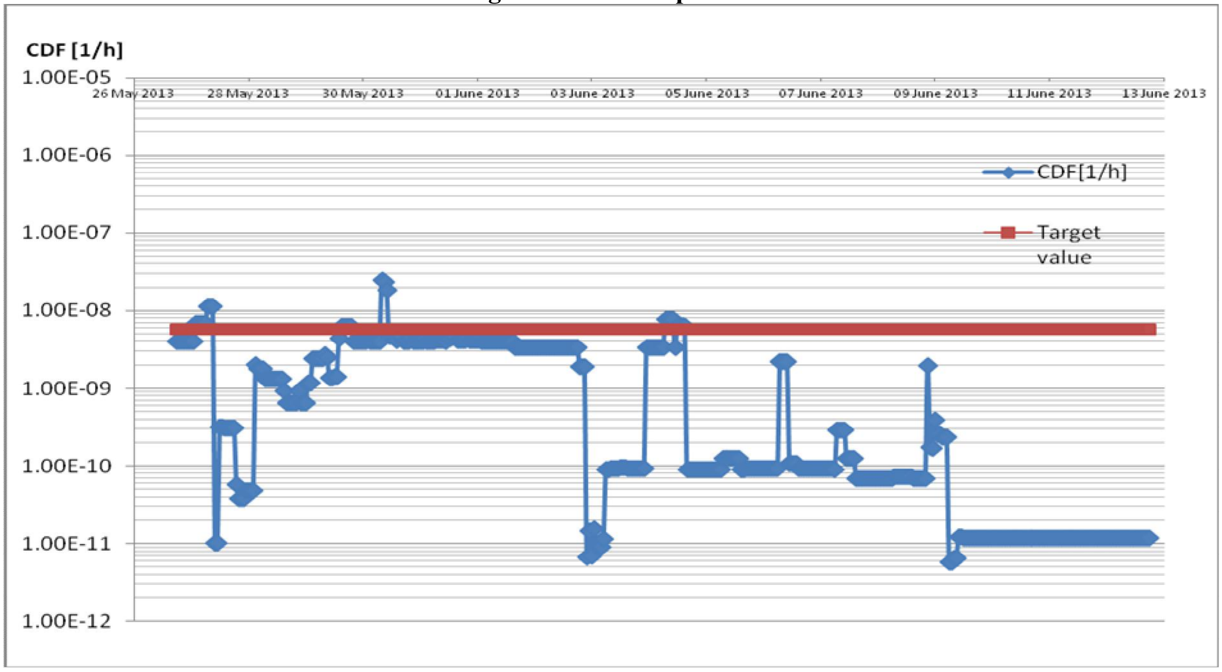


One hour accuracy is used for the outage schedule printouts and for that reason the application includes individual PRA assessment hour by hour throughout the whole outage. The PRA assessment includes five steps for each hour: (1) identification of planned unavailability of systems/subsystems, (2) identification of possible initiating events and estimation of initiating event frequencies (per hour), (3) identification of possible temporary plant modifications, (4) calculation of core damage frequency (and radioactive release frequency) and (5) verification that minimal cut sets are reasonable.

For the step (1), the residual heat removal schedule and the system maintenance schedule is used for identification of planned unavailability of the systems and subsystems. For the step (2), the reactor schedule identifies the work packages which have the possibility to cause initiating event "leakage", e.g. maintenance of the reactor coolant pumps. It is assumed that initiating events "loss of residual heat removal" and "internal fires" have constant initiating frequency during outages. In the step (3), if temporary plant modifications cause changes in the PRA-model, a separate PRA analysis is done. When steps 1, 2 and 3 are done for every hour of the outage, a minimal cut set calculation is executed to get the core damage and radioactive release frequencies for each hour (step 4). Step 5 is executed to ensure that the number of mistakes in the PRA assessment is minimal. The overall outage core damage and radioactive release frequency is a sum of each hour's core damage and radioactive release frequency. As a result, a risk profile for the specific outage can be drawn. An example of the risk profile (blue line) is presented in figure 4.

The probabilistic design objectives for Finnish nuclear power plants are explained in the YVL A.7. The numerical objective for the mean value of the probability of core damage is less than 1E-5/a and for the release exceeding the target value defined in the Government Resolution (716/2013) must be smaller than 5E-7/a. For short term operations, like during plant modifications, preventive maintenance and testing, the design goal can be exceeded. For short term operations, TVO's internal criterion is that average release frequency must not exceed 5E-5/a. Because most of the time during outage the containment is open, meaning that core damage leads directly to radioactive release, the short term objective for radioactive release frequency is used as an internal target value for the application of the specific outage. If the target value 5E-5/a is divided by 8760 hours (one year), the result is the target value for acceptable short-term release frequency, which is about 6E-9/h. The internal target value is shown red in figure 4.

Figure 4. The risk profile



The risk peaks can be easily identified from the risk profile. If the target value is exceeded, actions to decrease the risk peak will be discussed with the outage schedule coordinators.

3.2. Data handling and batch calculations

The application for specific outage requires flexible data handling, because several changes to the schedules are normally implemented between the first version of the schedule and the official, final schedule before the outage. The risk profile is calculated based on the first version of the outage schedule and it is updated when changes to the outage schedule is implemented. A specific program suitable for Microsoft Excel is designed for input data handling. The purpose of the program is to easily feed information from the outage time schedules into a form usable for minimal cut set calculations.

The program includes several features for data handling. Each outage time period (chapter 2) is handled separately in the program. Initiating event frequencies and system unavailabilities can be feed to the program and they can be easily modified if changes to the outage schedule are implemented. Figure 5 shows an example of the PRA assessment for one specific hour.

Figure 5. An example of the PRA assessment for one specific hour

	SYSTEM/SUBSYSTEM UNAVAILABILITY					
	---------- Data records <transfer data> ----------					
	Name	Distribution	Status	Rel model		
30.5.2013 6:00	SIMO_A-SUB_T3	Beta	Failed	Operating	Note: Temporary power supply on	
	327P003M1A	Beta	Failed	Standby	Note: Pump 327P002 unavailable	
	621IRT3..H	Point Value	Failed	Operating	Note: 400kV grid unavailable	
	653G101D1A	Beta	Failed	Operating	Note: Dieselgenerator 653G101 unavailable	
	321IRT3..H-Z	Point Value	Failed	Operating	Note: System 321 unavailable	
	664IRT3..E-B	Point Value	Failed	Operating	Note: Subsystem B of the system 664 unavailable	
	INITIATING EVENTS					
	---------- Data records <transfer data> ----------					
	Name	Distribution	Status	Rel model	RelP1	
	IRT-B3-T3	LogNormal	Normal	Frequency	9.60E-09	Note: Maintenance of the control rod drive unit
	IRT-A1LT3	LogNormal	Normal	Frequency	4.12E-06	Note: Opening of valve 312V5, V6, V7 or V8 would cause leakage
	IRT-A2HT3	LogNormal	Normal	Frequency	1.69E-04	Note: Opening of overpressure valve would cause leakage
	IRT-A1HT3	LogNormal	Normal	Frequency	3.95E-05	Note: Opening of 321 V1 or V2 would cause leakage

The application for the specific outage requires an efficient PRA-program to calculate hundreds of calculations in reasonable time. FinPSA is a PRA tool, developed by STUK and currently maintained by Technical Research Centre of Finland (VTT), containing parallel computation properties and it works with common Windows applications [1]. TVO has FinPSA cluster including three HP servers, each equipped with eight processors (four cores and four virtual cores). OL1 and OL2 PRA level 1 minimal cut set generation time is about two minutes using all 24 processors.

In addition, FinPSA includes a feature to add a task file for batch calculations. The task file enables to do several calculations automatically one after another. For each calculation, a number of unique PRA-model parameters can be set, e.g. fail basic events and set initiating event frequencies. After the steps 1-3 are executed (chapter 3.1) in the Microsoft Excel program, it is possible to do the step 4 by using the FinPSA task file. The Microsoft Excel program can create automatically a suitable task file for FinPSA from the Excel data. The result of the batch calculation is an output file containing results from the minimal cut set calculations. User can choose the output file's information, e.g. the amount of the most important minimal cut sets and the basic event importance measures. The step 5 can be done by using the results of the output file.

3.2. Future development

The PRA application to support outage schedules is in development phase. At the moment, it is used to support outage schedule planning before outage. The plan is to increase the range of usage to calculate core damage and radioactive release frequencies during outage and for verifying calculations after the outage is performed.

The average outage PRA model and documentation will be updated during year 2014. Update of the outage event trees, initiating event frequencies and system unavailabilities based on the operating history will be included in the next update. Weather phenomena's will be also included to the outage PRA model and initiating event frequencies for internal fires during outages will be updated.

4. CONCLUSION

The PRA application to support outage schedule planning is described above. The risk profile during the outage is the main result of the analysis and it shows the possible risk peaks that may occur based on the outage schedule.

The application requires a flexible PRA-model for modifications and an efficient PRA program to calculate hundreds of calculations in reasonable time. FinPSA includes the necessary features e.g. parallel calculation, integration to the Windows Applications and batch calculations, to make minimal cut set calculations possible. TVO has also developed a Microsoft Excel program to ease information transfer from the outage schedules to the PRA tool FinPSA.

Based on the results and feedback, the PRA application to support outage schedule planning is an efficient method to improve nuclear safety during outages.

References

[1] I.Niemelä, "*FinPSA: New features in PRA software*", PSAM9 conference paper, 2008