Spent fuel pool risk analysis for the Dukovany NPP

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Abstract:

ÚJV Řež, a. s. maintains a Living Probabilistic Safety Assessment (Living PSA) program for Dukovany Nuclear Power Plant (NPP) in the Czech Republic. This project has been established as a framework for activities related to risk assessment and to support for risk-informed decision making at this plant. The most extensively used PSA application at Dukovany NPP is risk monitoring of instantaneous (point-in-time) risk during plant operation, especially for the purpose of configuration risk management during plant scheduled outages to avoid risk significant configurations.

The scope of PSA for Dukovany NPP includes also determination of a risk contribution from spent fuel pool (SFP) operation to provide recommendations for the prevention and mitigation of SFP accidents and to be applicable for configuration risk management.

This paper describes the analysis of internal initiating events (IEs) in PSA for Dukovany NPP, which can contribute to the risk from SFP operation. The analysis of those IEs was done more thoroughly in the PSA for Dukovany NPP in order to be used in instantaneous risk monitoring.

1 INTRODUCTION

ÚJV Řež, a. s. maintains a Living Probabilistic Safety Assessment (Living PSA) program for Dukovany Nuclear Power Plant (NPP), a VVER type plant in the Czech Republic containing four units sited in two twin units. Each unit was uprated to 500 MWe.

The PSA Level 1 project for Dukovany NPP (EDU PSA) has been developed in the RiskSpectrum® software. It is regularly updated to reflect the current state of the plant design and operation as well as the state-of-the-art in the probabilistic modelling. This project has been established as a framework for activities related to risk assessment and to support for risk-informed decision making at this plant. The unit specific models for each unit are developed.

The most extensively used PSA application at Dukovany NPP is risk monitoring of instantaneous (point-in-time) risk during plant operation, especially for the purpose of configuration risk management during plant scheduled outages to avoid risk significant configurations.

2 SPENT FUEL POOL RISK ANALYSIS

2.1 PSA Level 1 for SFP

The EDU PSA is an integrated model for all plant operating modes. It therefore includes plant operation with the fuel completely relocated to the spent fuel pool (SFP). Such operation belongs to plan operating mode No. 7 in Dukovany NPP and is assigned to plant operating state (POS) BS in the EDU PSA. Moreover, the risk from the SFP in the other modes (power operation, hot and cold shutdown) is within the scope of the EDU PSA as well. The aim of the SFP risk analysis is determination of a risk contribution from SFP operation to provide recommendations for the prevention and mitigation of SFP accidents and to be applicable for the configuration risk management during outages.

This paper describes the analysis of internal initiating events (IEs) in the EDU PSA, which can contribute to the risk from SFP operation. The analysis of those IEs was done more thoroughly in the EDU PSA to be used in risk monitor. Level 1 PSA methodology and approaches, which were applied in the EDU PSA to analyse the risk from a SFP, are in principle the same as those for the reactor core.

Standard approaches (review of the Safety Analysis Report, systematic analyses, review of plant experience, etc.) were used to select potential events which can challenge safety functions for a SFP (reactivity control, decay heat removal). The definition of an IE from IAEA-TECDOC-719 [1] was therefore modified to be more general to address the risk from a SFP:

“An initiating event is an incident that requires an automatic or operator initiated action to bring the plant into a safe and steady-state condition, where the absence of such action can result in the undesired event”.

Note: The undesired event can be core damage, damage of the fuel in a SFP, damage of the fuel in the storage cask, etc. according to the PSA scope.

Support analyses, mainly from the Safety Analysis Report (SAR), were used to determine whether and upon which condition the safety functions applicable to the SFP can be affected by the particular possible events.

The following types of scenarios were finally included in the EDU PSA:

- LOCA from SFP (resulting also in flooding of SFP cooling system)
- heavy load drops into open SFP
- loss of SFP cooling (without SFP leakage)

Each group contains several separate IEs, which are distinguished based on the different causes of the particular scenario. IEs resulting in a loss of SFP cooling includes also the contribution from internal fires and floods (except the flood caused by LOCA from the SFP).

The support analysis [2] shows that the loss of SFP cooling accident during SFP operation with the fuel in a single layer (during the whole plant operation except the operation with the fuel completely relocated from the core to the SFP) would result in fuel damage in more than 72 hours even using conservative values of decay heat level. The time period 72 hours without fuel damage in the SFP was therefore considered to be a safe state to limit the SFP analysis of internal events/hazards.

The support analysis [2] also shows that fuel uncovery would occur not earlier than 40 hours following a loss of SFP cooling when the fuel is stored in two layers (POS BS). Such scenario would be usually screened out from PSAs (each sequence of such IEs would result in fuel damage after 24 hours), if the restoration of at least minimal set of means to restore safety functions can be reasonably expected (e.g. by expert judgement), see e.g. IAEA SSG-3 [3] (para. 5.49) or IAEA TECDOC-1144 [4] (Sections 3.10.1 and 5.1.5). Such approach has been adopted also in the EDU PSA so far and the negligible contribution from the accident development beyond time period 24 hours from the event occurrence has been assumed for such scenarios.

In spite of that, the plant operation with complete core relocation to the SFP, when the fuel in the SFP is stored in two layers, was included in the analysis. Screening analysis was applied to test, whether the assumption of the negligible risk contribution from IEs resulting in the loss of SFP cooling is credible [5]. The representative event trees (i.e. with and without blackout) were developed for IEs resulting in the loss of SFP cooling considering also the SFP makeup from the low pressure emergency core cooling system (LP ECCS) and from the bubble tower trays.

The long-time window available for the restoration of SFP cooling was addressed by the simplified approach which consists of:

- the adjustment of failure rates for important components which can be potentially used for SFP cooling (just a portion of component failure rates, which is judged to be non-repairable even beyond 24 hours, was applied),
- setting of human failure probabilities to very low values from EPRI TR 1021081 [6]

The failure rate adjustment was done in a conservative manner based on the review of the failure records. On the other hand, the approach taken does not consider the availability of spare parts at the site, difficult access to the site under extreme environmental conditions (earthquake) and human failures to repair components. However, the explicit modelling of the accident response for time period beyond 24 hours is generally very complicated due to possibility of various types of very specific recoveries and due to large uncertainty of human error quantification for long time windows.

Considering the location of the SFP in the reactor hall the IEs with time-averaged fuel damage frequency (FDF) higher than 1×10^{-8}/y were not screened out. The screening was applied also for the instantaneous FDF (without the average fraction of duration of POS BS, but considering typical maintenance activities in POS BS) for the purpose of risk monitoring. The IEs with instantaneous FDF higher than 1×10^{-6}/y were not screened out as well. Four IEs for the loss of SFP cooling were finally included in the EDU PSA, see Table 1, and detailed event tree/fault tree models were developed for them.

The FDF contribution from all internal IEs to the risk from SFP operation of Dukovany NPP Unit No. 1 is given in Table 1. The values are based on the results of Living PSA 2012 [7]. The Level 1 models for the SFPs of each unit were also converted into Safety Monitor™ to calculate a risk profile for POS BS depending on the availability and alignment of plant systems.

Table 1: The contribution of the internal IEs to the risk from SFP operation

Initiating event	Effect on SFP	POSs	FDF [1/y]
Large circulating cooling water leakage in turbine hall (flooding of vital power supply busbars)	loss of SFP cooling	BS(1)	$3{,}4 \times 10^{-10}$
Flooding of room A242 (due to SFP cooling piping rupture)	SFP LOCA resulting in loss of SFP cooling	BS	$4{,}9 \times 10^{-8}$
Heavy load drops to open SFP(2)	loss of fuel cooling due to structural damage of fuel	S1, S8, S9, S10, BS	$4{,}0 \times 10^{-6}$
Loss of the operating essential service water train	loss of SFP cooling	BS	$1{,}3 \times 10^{-10}$
Loss of the operating reserve power supply busbar(3)	loss of SFP cooling	BS	$3{,}9 \times 10^{-8}$
Loss of all SFP cooling pumps	loss of SFP cooling	BS	$2{,}9 \times 10^{-9}$
All			$\mathbf{4{,}1 \times 10^{-6}}$

Note 1: Plant operating mode No. 7 (core completely relocated to the SFP)

Note 2: Event is considered also during plant operation with the fuel in a single layer.

Note 3: Dukovany NPP unit self-consumption is commonly powered from the reserve external power source during plant operating mode No. 7.

Table 1 shows the negligible risk contribution from the loss of SFP cooling (without SFP leakage) to the time-averaged FDF, since time window to fuel damage is longer than 24 hours in this case. However, for the purpose of risk monitoring the respective IEs were not screened out since the instantaneous risk is not negligible, especially when some components are typically taken out of service during POS BS.

2.2 PSA Level 2 for SFP

Fuel damage sequences of IEs, which contribute to the risk from SFP operation, were consequently expanded for the further analysis in Level 2 PSA. The concept of Plant Damage States (PDS) was used for grouping of those sequences which are expected to have the similar accident progression following fuel damage. The first step of a PDS analysis was the identification of a set of PDS attributes to describe a type of scenario, plant parameters, system statuses as well as well as other sequence characteristics on the onset of fuel damage that can affect the progression of a severe accident. Nine attributes applicable for the SFP Level 2 analysis were determined for the Level 2 EDU PSA:

- Type of scenario
- SFP leakage isolation
- Status of SFP normal cooling system
- Location of ECCS water inventory
- Location of bubble tower water inventory
- Status of containment ventilation systems
- Status of reactor hall ventilation systems
- Status of power supply
- Containment and reactor hall isolation

The PDSs were determined based on the SFP accident sequences analysis predominantly using the consequential event trees [8] (additional expansion of the fuel damage sequences). Function events in the consequential event trees were used to determine the system or component success/failure or to determine the status of particular actions in order to find the required attribute characteristics. The sequence (or a group of the sequences) representing the particular PDS was then quantified to obtain the PDS frequency. Each PDS was also characterized by PDS vector (the unique combination of PDS attributes).

Screening criteria were applied to the PDS frequencies to limit the Level 2 analysis only to important FDF contributors. Considering location of the SFP in the reactor hall the PDSs bellow 1 x 10^{-8}/y were screened out. At this stage of the analysis, the screening was done only for time-averaged risk metrics, so the FDF values for PDSs contain the average fraction of POS BS duration over a long period of time. Finally, seven PDSs were further used as an input to Level 2 PSA analyses for the SFP.

The accident progression event tree (APET) for Dukovany NPP [9] was developed in EVNTRE software. The preliminary calculation, see Table 2, showed a very high fraction of the FDF with intact reactor building following fuel damage (only natural releases from the airtight zone are expected). On the other hand, the risk from the hydrogen combustion is low due to a large volume of the reactor hall and high concentration of steam in it. The determinantion of the reactor hall decontamination factor and the magnitudes of the release into environment is still in progress.

Table 2: The contribution of the particular reactor building failure modes

Reactor building failure mode	FDF fraction
non-isolated reactor building	5,0%
late reactor building rupture (due to hydrogen combustion)	3,2%
late SFP melt-through	0,2%
intact reactor building (natural release only)	91,7%

3 POTENTIAL FOR ENHANCEMENT OF SFP RISK ANALYSIS

The next step of the SFP risk analyses in the EDU PSA should be the integration of the PSA Level 2 and Level 1 results. The calculation of the LERF in RiskSpectrum® software using conditional LERF probabilities derived from EVNTRE code for each PDS vector is one of the option (such approach has been used in the EDU PSA for the calculation of the LERF contribution from power operation). A full integration of the Level 2 APET sequences with the PSA Level 1 sequences is another option. The calculation of risk profiles for the SFP in risk monitor using large early release frequencies (LERF) is envisaged as well.

The Level 2 analysis of external events affecting the SFP, including those for other plant operational modes, is planned for the next years. It will be done considering implementation of Dukovany NPP measures based on the stress test results.

4 REFERENCES

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