PSA Applications for Dukovany NPP

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Abstract: Reliability and Risk Department in ÚJV Řež, a. s., the Czech Republic, has developed and currently maintains Living PSA project for Dukovany NPP, a four-unit nuclear power plant in the Czech Republic. RiskSpectrum® PSA software has been used for development and quantification of the Living PSA model. It is an integrated model which comprises all initiating events, including internal and external hazards, for all plant operational modes in the same project. The PSA model is continuously updated and used extensively for various PSA applications at Dukovany NPP, such as risk monitoring, evaluation of Technical Specifications, event analysis, analysis of plant modifications etc. The use of the selected PSA applications to support Dukovany NPP risk management is required by the Czech implementing Decree and supported by the Czech regulatory guides. The paper describes the selected PSA applications at Dukovany NPP that have been performed recently, namely evaluation of Technical Specifications and requirements for availability of diverse and mobile (DAM) equipment. This evaluation follows the respective Czech regulatory guide. Several changes have been subsequently done in the plant Technical Specifications based on this evaluation. The paper also discusses the other recently performed PSA applications at Dukovany NPP as well as their outputs.

1. INTRODUCTION

Reliability and Risk Department in ÚJV Řež, a. s., the Czech Republic, has developed and currently maintains Living Probabilistic Safety Assessment (PSA) project for Dukovany Nuclear Power Plant (NPP), a four-unit VVER type plant in the Czech Republic. RiskSpectrum® PSA software has been used for development and quantification of the Living PSA model. It is an integrated model which comprises all initiating events, including internal and external hazards, for all plant operational modes in the same project. The PSA model is continuously updated and used extensively for various PSA applications at Dukovany NPP.

2. CZECH LEGISLATION

Czech implementing Decree 162/2017 [1] requires to use PSA applications for a support of Dukovany NPP risk management, namely to use the selection of important components, technical specifications (TS) evaluation, event evaluation, analysis of plant modifications and risk monitoring. The use of PSA applications in the Czech Republic is also supported by Czech regulatory safety guide BN-JB-2.5 [2] which is analogous to IAEA Safety Guide SSG-3 [3].

Requirements for TS evaluation cover both evaluation of changes initiated by the plant, such as allowed outage time (AOT) extension or test interval extension, and evaluation to identify needs for TS changes. The corresponding guideline is provided in Czech regulatory safety guide BN-JB-2.7 [4] which proposes the similar principles as specified in RG 1.177 [5]. Safety guide BN-JB-2.7 also specifies conditions for AOT adequacy.

The selection of important components based on PSA importance measures shall be done for various purposes specified in implementing Decree 162/2017. The corresponding guideline is provided in Czech regulatory safety guide BN-JB-2.8 [6].

Safety guide BN-JB-2.7 gives probabilistic criteria which the risk associated with equipment unavailability during AOT should not exceed. This risk is measured with ICCDP (incremental conditional core damage probability) and ICLERP (incremental conditional large early release probability) during AOT duration. ICCDP should not exceed 5×10^{-7} and ICLERP should not exceed 5×10^{-8}.

Safety guide BN-JB-2.7 also provides guideline and discussion for comparison of alternatives when plant would choose this option to justify a temporary or permanent change of limiting condition for operation (LCO). In this case, the risk from continuation at power operation with unavailable component is compared with the risk from shutdown after completion time (CT) expires (CT determines AOT). Approximately the same level of conservatism should be applied in the models for the compared alternatives, otherwise the output of the comparison could be determined by the uneven level of conservatism in the models.

Regulatory safety guide BN-JB-2.6 [7] provides guidance for the use of PSA in the frame of risk-informed decisionmaking (RIDM) for evaluation of plant proposals for changes, including proposals for AOT extensions. This safety guide is analogous to RG 1.174 [8] and contains additional requirements and probabilistic criteria, e.g. increase of yearly fuel damage frequency (FDF) as well as increase of yearly large early release frequency (LERF) should not exceed the prescribed values. FDF is the sum of core damage frequency (CDF) and fuel damage frequency for spent fuel pool. The criteria for the acceptable yearly risk increase are not applicable for evaluation of AOT adequacy (such type of TS evaluation is not related to AOT extension).

3. TS EVALUATION

3.1. Scope of TS Evaluation

Evaluation of Dukovany NPP TS has been performed recently in [9] and [10]. Identification of the eventual need for TS modifications, as required in implementing Decree 162/2017, was the main goal of this evaluation. For this purpose, the risk associated with AOT was compared with the criteria for ICCDP and ICLERP as mentioned in Section 2. The scope of this TS evaluation was limited to power operation (Mode 1) with some exceptions. The 1st unit of Dukovany NPP was considered as the representative unit for the remaining units.

The performed TS evaluation was also used to identify a potential for AOT extensions. For this purpose, the maximal AOT to fulfill the criteria for ICCDP and ICLERP was determined for each evaluated LCO. This allows plant to choose the proper candidates for AOT extension depending on plant intentions. Finally, the evaluation included the comparison of alternatives as specified in Section 2 for the selected cases requested by the plant to investigate the eventual need to change LCO accordingly.

All LCOs in TS for Dukovany NPP that have an impact on the plant risk were evaluated. The risk associated with diverse and mobile (DAM) equipment unavailability was evaluated as well, although plant requirements for DAM availability are not a part of TS.

3.2. Selection of Entry into LCO

The identified most unfavorable (bounding) case of entry into the given LCO was evaluated, but such case was limited only to a single failure or common cause failure (CCF). The impact of unavailability of component from different divisions or redundancies on the plant risk is not always symmetrical at Dukovany NPP. The risk associated with unavailability of the component from each division or redundancy subject to the given LCO was therefore evaluated to find the bounding case. Corrective maintenance was always assumed except for the cases when LCO deals explicitly with preventive maintenance.

Conditioning of CCF was applied when applicable. The conditional probability of failure of the remaining redundant components, when one out of the redundant components fails, is expressed in the following way, see also Appendix E in NUREG/CR-5485 [11]:

$$q_{N_S} = \frac{Q_N}{Q_X} \qquad (1)$$

where:
q_{N_S} = conditional probability of failure of N remaining components, when one (component "X") out of S redundant components fails,
Q_N = probability of the simultaneous failure of N remaining components and component "X" (due to CCF or combination of independent failures or combination of independent failures and CCFs),
Q_X = total probability of failure of component "X" (due to CCF or independent failure),
X = failed component.

These increased failure probabilities were assigned to failure modes of the remaining redundant components that fulfil all of the following conditions:
1) CCF for the failure mode is credited in the PSA model for Dukovany NPP.
2) The failure mode of the redundant components would not be detected by any test following the entry into the respective LCO requirement, when one out of the redundant components fails.
3) The failure mode is not self-revealing.

3.3 Calculation of Risk Associated with AOT

More than 250 cases for various combinations of LCOs and AOTs were evaluated. This number includes sensitivity analyses. RiskSpectrum PSA code was used to calculate the necessary risk measures instead of a risk monitor code. This approach allowed to explicitly address the conditioning of CCF, to make changes in the model for sensitivity analyses as well as to assure the effective iterative process since the proper adjustment of the model was sometimes necessary to remove the excessive conservatism. Multi-threaded calculations [12] using multi-core computer were utilized to handle high number of calculations of the whole model with the sufficient precision (cutoff 10^{-12}/y was set).

The impact of equipment unavailability on the plant response to both internal and external events (including hazards) was evaluated. Winter season was selected as the bounding case for the instantaneous risk calculations since the impact of heavy snow precipitation has higher contribution than the impact of high temperatures in the PSA model for Dukovany NPP. Availability of weather forecast was not considered.

The risk from continuation at power operation with unavailable component was compared with the risk from shutdown after CT expires for the selected cases, see Figure 1 for the example from [9] dealing with unavailability of the 1st division of essential service water (ESW). The total risk of both alternatives should be compared over the same time, and this is considered in the comparison approach. The corresponding profile for instantaneous CDF is provided in Figure 2. Only internal initiating events and internal hazards were included in the comparison of alternatives. Support analyses [13] were performed prior TS evaluation to remove the excessive model conservatism in Mode 5 since approximately the same level of conservatism should be applied to the compared alternatives.

Figure 1: Comparison of CCDP (CLERP) for Alternatives

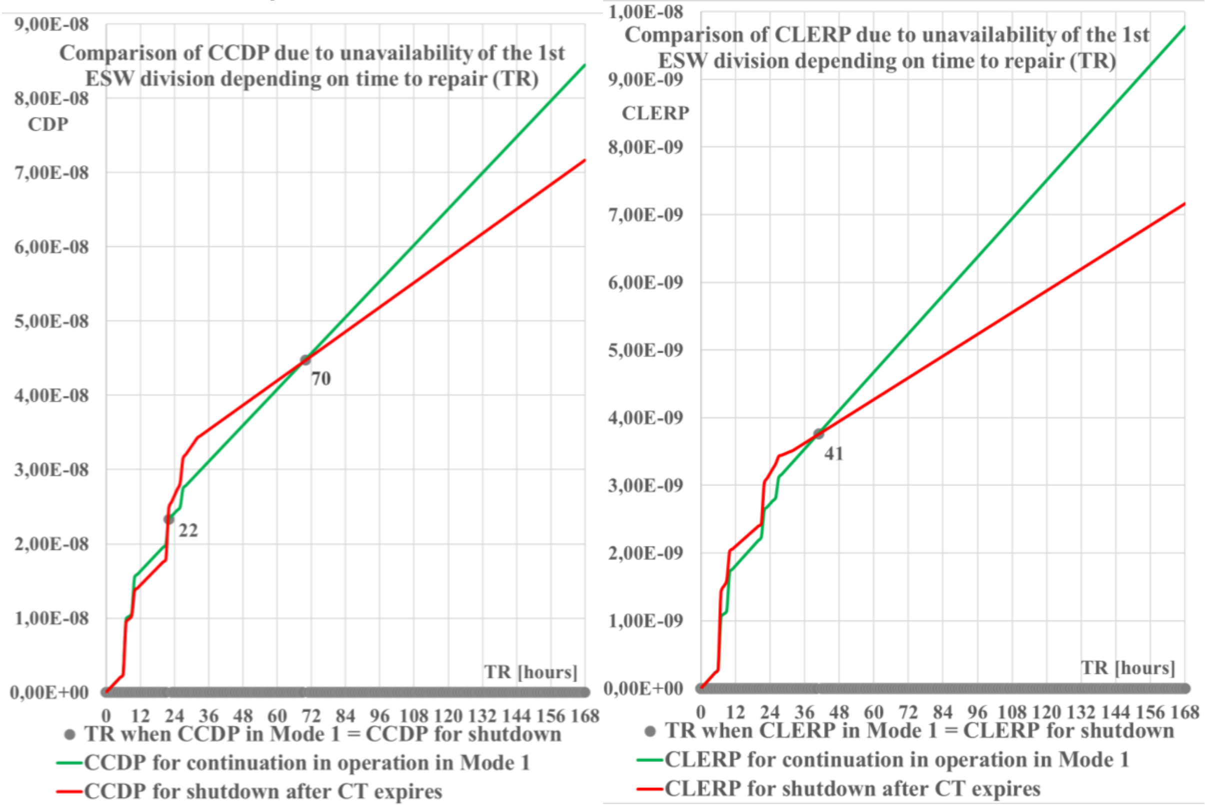
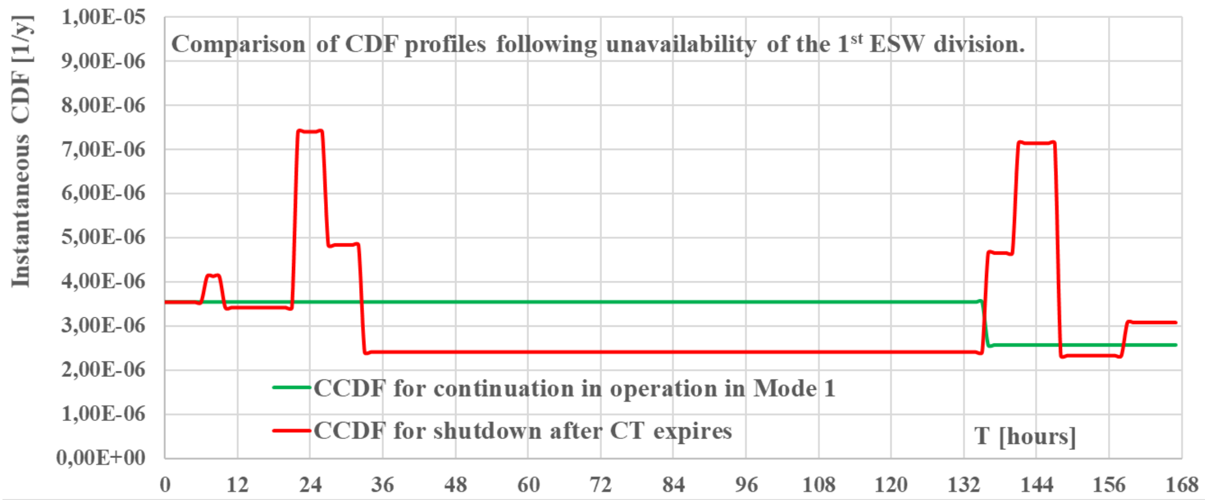


Figure 2: Comparison of CCDF for Alternatives



Notes to Figures 1 and 2:

1) CT expiration is the starting point.
2) Duration of transition modes was taken from an occurred outage for repair in the plant history.
3) For the shutdown case, the risk from plant start-up was added to CCDP (CLERP) values at the beginning of CCDP (CLERP) calculation.
4) For the case with continuation of operation, the risk at power operation over the time, which matches plant start-up in the shutdown case, was added to CCDP (CLERP) values at the beginning of CCDP (CLERP) calculation.
5) The comparison of CCDF profiles is presented for one of TR values and does not include the risk from demand-dependent initiating events.

4. OTHER PSA APPLICATIONS

4.1. PSA Based Selection of Important Components

The selection of important Dukovany NPP components has been done recently both for the plant [14] and for the Czech regulator (SÚJB) [15]. It was based on the integrated PSA model for Dukovany NPP which includes models for shutdown states and hazards as well as models for Level 2 PSA. The same methodology and criteria as specified later in Czech regulatory safety guide BN-JB-2.8 were applied.

The component was considered to be important based on PSA outputs if its importance measures fulfil at least one of the following conditions either in FDF calculation or in LERF calculation (or in both):

a) FV (Fussell-Vesely) importance for sum of its failure modes ≥ 0.005.

b) RAW (RIF in RiskSpectrum software [12]) for at least one its failure mode ≥ 2.

Note: RAW stands for Risk Achievement Worth. RIF is the abbreviation for Risk Increase Factor.

CCF is considered as one of the relevant failure modes for this case. There are not specific criteria for importance measures related to CCF in safety guide BN-JB-2.8.

The respective calculations were done separately for internal initiating events (including internal hazards) and for external events (hazards). The final list of the important components has been then established by merging of the important components from all four calculations.

4.2. Risk Monitoring and Others

The most extensively used PSA application at Dukovany NPP is configuration risk management to avoid risk significant configurations. Safety Monitor™ software is utilized to generate instantaneous risk profiles, especially for on-line maintenance at power operation or for plant outages.

Finally, analysis of events occurred in plant history as well as analysis of plant modifications before their implementations are other frequently used PSA applications at Dukovany NPP.

5. MAIN OUTPUTS

All evaluated LCOs have been found adequate in the performed TS evaluation for Dukovany NPP. Only a few exceptions were identified for the cases of motor operated valve (MOV) unavailability when CCF conditioning was applied, i.e. the cases when the plant enters the LCO with a failure of MOV and the function of the corresponding MOVs on the remaining divisions was not subsequently tested. Modifications of TS to decrease the risk associated with AOT were therefore proposed for these cases. They included new TS requirements to test MOVs in the redundant divisions. Sensitivity analyses to show the benefit of the changes were performed as well.

Possibility to continue in operation at power with unavailable equipment has not been found to be better alternative in the analyzed cases. Moreover, the output of the comparison is often highly dependent on the expected time to repair due to higher instantaneous risk of the transition states as seen e.g. from Figure 1, and on other variables such as duration of transitions states. In some cases, the output based on CCDP comparison gave the results different from the output based on CLERP comparison for the same component unavailability. So the output of the comparison of alternatives was not often decidable.

The list of the important Dukovany NPP components based on PSA importance measures has been derived. Not all safety components have been identified to be important in this list. On the other hand, a few components classified as non-safety components have been found to be important according to specified criteria for PSA importance measures and the graded approach used at plant considers the list of these components.

6. CONCLUSION

The detailed and comprehensive PSA model for Dukovany NPP allowed to evaluate all necessary LCOs in the performed TS evaluation. Based on it, several changes have been made in Dukovany NPP Technical Specifications [16] to enhance plant safety when some specific unplanned component unavailabilities would occur. Moreover, the list of the important components based on PSA importance measures is currently used also by site inspectors of the Czech regulator (SÚJB) as a support to determine the significance of the issues and findings.

PSA is a widely used approach at Dukovany NPP risk management. Recommendations and experience obtained from PSA outputs and from the associated PSA applications at this plant show that PSA is a very effective tool that can provide the support for risk-informed decisionmaking.

References

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