Abstract

The paper describes the methods for risk informed evaluation of the allowed outage times. Applications of the methods are also provided for the safety related equipment of the J.Bohunice V2 NPP.

1. INTRODUCTION

Substantial progress in the probabilistic risk analysis encourages greater use of this analysis technique to improve safety decision making. Support of decisions to modify individual plant technical specification (TS) is important activity in this area. The TS of the nuclear power plants operating all over the world were normally determined using traditional engineering analyses and no risk information was taken into consideration. At the present time, if TS changes are required, both the traditional engineering analyses as well as the risk informed approach are taken into consideration in the regulatory decisions.

Since the mid-1980s, the US NRC (US Nuclear Regulatory Commission) has been reviewing and granting improvements to TS based, at least in part, on risk insights. Typically, the improvements involved the extension or relaxation of one or more allowed outage times (AOT) or surveillance test intervals in TS. The AOT evaluations were performed using only the PSA (Probabilistic Safety Assessment) for full power operation. The risk associated with shutting the plant down because of AOT violations was not considered. The incremental conditional core damage probability (ICCDP) of less than 5.0E-7 was considered small for a single AOT change. This value is based upon the hypothetical situation where the subject equipment at a representative plant is out of service for five hours, causing the core damage frequency (CDF) of the plant, with an assumed baseline CDF of 1.0E-4/y, to conditionally increase to 1.0E-3/y during the five hours period. This basis assumes that the majority of repairs can be made in five hours or less and that this level of risk is acceptable for the operating plants.

Comparison of the full power risk with the shutdown risk provides more precise approach for calculation of the AOTs. The plant should be shut down only in case, if the shutdown risk is smaller than the risk arising from the full power operation with the failed component. During the last years low power and shutdown analysis has come into the focus of nuclear safety considerations. Operational experience and shutdown probabilistic safety analysis have highlighted that the shutdown risk is significant and could contribute more than 50% to a total core damage frequency [3].

Methods comparing the full power and shutdown risk are used to justify the AOT changes for the regulatory authority in Slovak Republic. In addition to the full power PSA, also the shutdown PSA of the plant is required for this purpose. The advantage of the approach is that AOTs can be calculated not only for full power but also for the shutdown operating modes. The paper presents the methods and application for the safety related equipment of the J.Bohunice V2 NPP.

2. CALCULATION OF THE ALLOWED OUTAGE TIMES

The AOT is the time the component is allowed to be out of service during power operation or shutdown operating mode of the plant. If the component is not restored during this time, the plant in operation must be shut down or the plant in a given shutdown mode has to go to safer shutdown mode. When deciding on the optimum strategy, the risk exposure for the current operating mode and the new operating mode
should be compared. Such comparison can be made for all systems involved in the TS using the full power and shutdown PSA model.

2.1. Methods of calculation

The risk in continued operation is compared with the shutdown risk. The AOT is calculated using the following formula:

$$
\tau \leq \frac{P_{sd}^i}{r^i - r^0}
$$

where, $P_{sd}^i$ is the total shutdown risk including the cooling down and start-up of the reactor, for the level 1 PSA it is the core damage probability. $r^0$ is the baseline full power risk, $r^i$ is the full power risk with component $i$ unavailable.

$$
P_{sd}^i = F_{sd} \cdot t_{sd} / 8760
$$

where,

- $t_{sd}$ - the total time the plant spent in shutdown operating modes (h)
- $F_{sd}$ - the total shutdown core damage frequency (1/y).

Similar approach is used when the AOT for shutdown operating mode is optimised. The risk in operating mode $j$ is compared with the risk in operating mode $j+1$.

2.2. Application of the methods

The full power, level 1 PSA model and the low power and shutdown PSA model were harmonised and an integrated level 1 PSA model was developed for unit 3 of J. Bohunicke V2 NPP. This integrated model is used for calculation of the full power and shutdown risk to determine the AOT [1]. The model developed in the RISK SPECTRUM PSA code was modified. Contribution from the test, planned and unplanned maintenance to system unavailability were removed and house events were installed to model the component or train outage.

The full power risk with and without failure of component $i$ and the shutdown risk are calculated. The risk is given in the form of core damage frequency (CDF). Using the full power part of the integrated PSA model, first the CDF is calculated under the condition that all components are known to be available and no repair and maintenance is performed ($r^0$). Then, the CDF is calculated under the condition that the component $i$ is failed ($r^i$).

The shutdown risk depends on the operating modes which must be achieved after manual reactor shutdown with failure of component $i$. The risk calculation during cooling down considers that component $i$ is in failure state but during the start-up this component is considered to be repaired and available to perform safety function. The total shutdown risk is sum of the cooling down and start-up risk.

If the AOT is calculated for the shutdown operating mode, the full power risk is not taken into consideration. Given failure of component $i$, the TS directs the plant to go to higher operational mode. If a component fails in operating mode 3, then the plant goes to operating mode 4. If a component fails in operating mode 4, the plant goes to operating mode 5.

For illustration the calculation of AOTs for the high pressure safety injection system is presented below. The valid TS for the high pressure safety injection system is the following:

- all three safety injection pumps are required to be operable. However one pump can be in maintenance or test for a maximum 72 h;
- at least 2 safety injection pumps are required to be operable. However one pump can be in maintenance for a maximum 24 h;
- at least one safety injection pump is required to be operable.

Limiting condition A is valid for operating mode 1,2,3. Limiting condition B is valid for operating mode 4. Limiting condition C is valid for operating mode 6. If the condition A is not met the plant must be
shutdown to operating mode 4. If condition B is not met the plant must go to operating mode 5. If condition C is not met, it is not allowed for the plant to go to operating mode 4.

The AOT for limiting condition A is calculated using the formula from section 2.1:

\[ \tau = \frac{5.81 \times 10^{-7}}{(1.06 \times 10^{-4} - 1.01 \times 10^{-4})} = 0.1056 \text{ y} = 739 \text{ h} \]

It is assumed that the reactor is 7000 h per year on power operation. Only during this time period the high pressure safety injection pump can fail in operating mode 1. The proposed AOT for limiting condition A is 504 h, e.g. 21 days.

The AOT is proposed in such a way that the calculated value is modified to the value usually used in TS (for example: 8 h, 24 h, 3 days, 5 days, 14 days, 21 days, etc.). The proposed AOT is always the next shorter value to the calculated AOT. If the calculated AOT is longer as 7000 h, it is proposed to allow the unavailability of a train without limitation.

The AOT for limiting condition B is calculated similarly like for full power operation:

\[ \tau = \frac{1.12 \times 10^{-7}}{(2.70 \times 10^{-6} - 1.58 \times 10^{-6})} = 0.09940 \text{ y} = 175 \text{ h} \]

It is assumed that the reactor 1760 h per year is shut down for refuelling. Only during this time period the high pressure safety injection pump can fail in operating mode 4. The proposed AOT for limiting condition B is 168 h, e.g. 7 days.

No calculation was performed for limiting condition C because there is no possibility for the plant to go from operating mode 5 to safer operating mode.

2.3. Risk-informed decision making for AOTs

The regulatory guide [2] issued by NRC provides recommendations for utilizing risk information to evaluate changes to AOTs. In implementing risk-informed decision making, the AOT changes are expected to meet a set of key principles. The principles are the following:

1. the proposed changes meet the current regulations;
2. the proposed changes are consistent with the defense-in-depth philosophy;
3. the proposed changes maintain sufficient safety margins;
4. when the proposed changes result in increase in core damage frequency, the increase should be small and consistent with the intent of the safety goal policy;
5. the impact of the proposed changes should be monitored using performance measurement strategies.

The regulatory guide [2] provides guidance in meeting these principles.

3. CONCLUSIONS

Using the risk based approach the AOTs were evaluated for all safety systems of the plant. The main conclusion from the analysis is that the current deterministic AOTs are conservative and should be extended for the majority of the safety systems. The low power and shutdown risk analysis highlighted that the shutdown risk is significant. This risk was found in some cases up to 50% of the total core damage frequency [3]. The risk based extension of AOTs can prevent the plant to enter into the operating modes with increased risk.

References