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Use of Risk-Informed Technique to Evaluate the Balance of Technical Specifications Events

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Abstract. Risk-informed Technique, combining Deterministic analysis with Probabilistic Risk analysis, could evaluate the whole risk of Nuclear Power Plant, which is more and more deeply used in different areas in NPP, such as Technical Specifications, In-service inspection, GQA and so on. In Risk-informed Technical Specifications Optimization, a three-tiered approach for licensees to evaluate risk associated with proposed TS changes: Probabilistic Risk Assessment Capability and insights, Avoidance of Risk-Significant Plant Configuration, and Risk-Informed Configuration risk management. The Avoidance of Risk-Significant Plant Configuration is one of the essential links, which is also the chief content of Risk-informed Technical Specifications Optimization, so identifying the risk-signification configurations is particularly important for evaluating risk impact. This paper takes one proposed Spray isolation valve TS item change of Containment Spray System in some NPP as an example, to illustrate the method and process of Identifying Risk-significant Configuration from importance analysis result, and gives management suggestions based on the Risk-significant Configuration result, which gives a special way to analysis avoidance of risk-significant configuration, and a well practical lesson for Risk-informed application..

1. Introduction

The Technical Specifications is an important document in Nuclear Power Plant. With the accumulation of operation experience, the shortcomings of traditional Technical Specifications are discovered during its applications in the NPPs, some of the requirements are too conservative, and plant staff may get confused with some requirements in the Technical Specifications. With the development of Probabilistic Safety Analysis technique for NPP safety analysis, the Risk-Informed technique, which combines Deterministic Safety Analysis with PSA, can systematically and comprehensively evaluate the overall risk and dig out the economics and flexibility of NPPs to improve the level of NPPs safety management.

The Technical Specifications in a NPP usually has several items for a system, and in some cases, there are several different plant conditions in the same item. The meaning of balance of Technical Specifications items, is that the items which represent different NPP conditions and the requirements in the TS for these TS items or plant conditions, should be consistent with their impact to plant risk. A simplified Auxiliary Feed Water system and its TS requirement are taken as the example to show the



whole analysis process, which gives the method and practice exploration to TSs Optimization. Combined with the methods and guidelines, this paper identifies different cases in which the TS items are not balanced, which means that they are not consistent with their impact on plant risk, and the suggestions to optimize the TS are also given.

2. Method and Criteria

The Risk-informed Technique is a special analyzing tool with combining Deterministic Safety Analysis with PSA, which is widely used in many areas for NPPs, such as Technical Specifications, In-service inspection, Graded Quality Assurance, and so on. The Risk-informed Technique has been firstly developed and deeply used in USA. To further promote the application of the technique, a series of management guidelines are formulated and published by NRC, and the Standard review Program and the modification of relevant regulations were also added.

The Risk-informed TSs is always carry out based on the method and criteria in RG1.174 and RG1.177. Specifically, the proposed change shall be evaluated corresponding to “five basic principles” and “four-step process”. The five basic principles are as follows: change meets the current regulations unless it is explicitly related to a requested exemption or rule change, change is consistent with a defense-in-depth philosophy, change maintains sufficient safety margins, Proposed increases in CDF or risk are small and are consistent with the intent of the Commission’s Safety Goal Policy Statement, use performance measurement strategies to monitor the change. And the four-step process is as follows: step 1 is to define the proposed change, step 2 is to carry out engineering analysis including traditional engineering analysis and probabilistic risk assessment, step 3 is to define implementation and monitoring program, step4 is to submit the proposed change.

Particularly, when it comes to optimize the NPPs Technical Specifications, the quantitative evaluation is the important basic part according to the guidelines. And the PSA module is the basement to calculate the risk result, during which the ICDP and ILERP are the important risk index, and the equations are as follows:

$$ICDP = (CDF1 - CDF0) \Delta T;$$

$$\Delta ILERP = (LERF1 - LERF0) \Delta T.$$

Where ΔT is the individual allowed outage time; CDF0 is the baseline CDF with nominal expected equipment unavailability; CDF1 is the conditional CDF with the subject equipment out of service and nominal expected equipment unavailability for other equipment permitted to be out of service by the Technical Specifications; LERF0 is the baseline LERF with nominal expected equipment unavailability; LERF1 is the conditional LERF with the subject equipment out of service and nominal expected equipment unavailability for other equipment permitted to be out of service by the Technical Specifications.

The meaning of ICDP is the incremental probability of the occurrence of core damage event during the time when the component is inoperable. ILERP is similar to ICDP and refers to the large early release event. The acceptable criterion for ICDP and ILERP is: $ICDP < 1.0E-6$ with $ILERP < 1.0E-7$. If the proposed AOT can satisfy the above acceptable criterion, the AOT is considered reasonable.

3. Analysis Object

The Auxiliary Feedwater System (AFW for short) of some NPP is taken as an example to illustrate the analysis process. And the functional design and TS requirement of the AFW system are shown in this part to support the following analysis.

3.1. System design and its function

The Auxiliary Feedwater system (AFW) is classified as an engineered safeguard system. The AFW serves as a back-up system for supplying feedwater to the secondary side of the steam generators upon

loss of the main feedwater supply. In the event of one of the normal feedwater systems, the AFW operates to remove residual core heat until the conditions for placing the residual heat removal system in operation are reached. The heat removed from the reactor coolant system is transferred to the secondary system via the steam generators (SG) supplied by the AFW; the secondary system itself is cooled by the GCT (condenser or atmospheric steam drum) system.

Equipment pre plant unit includes a storage tank, a pump subsystem and a set of injection lines equipped with flow control connected to the SG. To meet the single failure criterion, two independent pump trains are set with 100% flow for each. The pump subsystem consists of: Train A, one 100% turbine-driven pump(003PO), which is steam-supplied from main steam lines upstream of the SG steam isolation valves(or from SVA system during pre-operational tests)and exhausting to the atmosphere via a muffler; Train B, two 50% flow motor-driven pumps(001 and 002 PO),powered by emergency busbars(diesel generators). When the unit is in normal operation, the three pumps are all standby. The six control valves corresponding to the pumps keep 100% opening. Simplified flow chart of the system is as below.

Based on the functional design and equipment, the simplified flow chart of AFW system is as shown below according to the function of the key component, such as storage tank, pumps, pipes and so on.

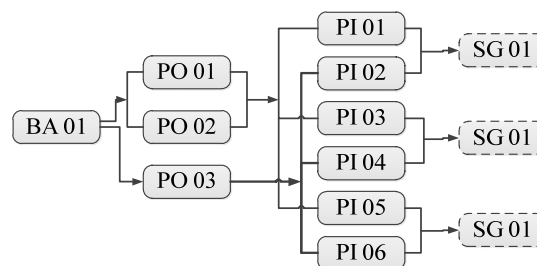


Fig.1 Simplified Flow Chart of the AFW

In the figure above, BA01 is the storage tank of the system, PO01 and PO02 are the motor-driven pumps, PO03 is the turbine-driven pump, the PI01, PI03 and PI05 are the channels corresponding to the special SGs from motor-driven pumps, while the PI02, PI04 and PI06 are the channels corresponding to the special SG from turbine-driven pump.

3.2. Requirement of Technical Specifications

The Technical Specifications defines the basic technical requirements for the unit to meet. It has the following functions:

- (1) Define the limits for normal operation to ensure that the reactor is operated as it is designed;
- (2) define the essential safety functions;
- (3) When the reactor runs out of the limits or some safety functions are inoperable, the required control strategies are defined to modify the situation. A completion time and a mode according to fallback to are also usually defined.

Based on the defense-in-depth principle, the content of TSs is confirmed through the result of DBA and the sight of operation practice, and with continuous improving by the development of safety analysis technique. Generally, the requirements in each mode and the actions for handling the random conditions are always include in TSs, and all the conditions that are not meeting to the safety requirement are defined as “Event”, also known as “inoperable”.

Usually there are multiple random events for some system in TSs, and one event may also include several different situations. Sometimes the events of one system in TSs are listed in terms of different combinations of failures of their system equipment on a gradual increase in risk.

The TSs for the NPP selected is a simplified traditional TSs, in which the requirement and event are set for each mode. There are nine events set for the AFW system in operation mode, and each

event contains one or more situation corresponding to the failure equipment and AOT. The events for AFW system are in the table below.

Table 1. OTS Events and Corresponding AOT

<i>Events code</i>	<i>Content</i>	<i>AOT</i>
AFW1	One required motor-driven pump (001PO or 002PO) inoperable, or, one SG water inoperable from motor-driven pump or turbine-driven pump.	3days
AFW2	Two motor-driven pumps inoperable, or, two or three SGs water inoperable from motor-driven pump.	8hours
AFW3	Turbine-driven pump inoperable, or, two or three SGs water inoperable from turbine-driven pump.	24hours
AFW4	Turbine-driven pump and one motor-driven pump inoperable.	1hour
AFW5	One or two SGs water inoperable from AFW.	24hours for one; 1hour for two
AFW6	Reactor power $>2\%P_n$, storage of AFW tank is: $766m^3 < V < 846m^3$.	24hours
AFW7	Storage of AFW tank is: $V < 766m^3$.	1hour
AFW8	Temperature of water in AFW tank: $50^\circ C$.	1hour
AFW9	One steam inlet line of turbine-driven pump inoperable.	7days

4. Analysis and evaluation process

4.1. The Technical Adequacy of PSA

The latest PSA model (Mode Power Operation Internal Event Level 1) for the NPP selected is used during the evaluation, in which the data is the particular of it. The model uses the large fault tree/small event tree, also known as the linked fault tree, methodology. Basic failure events are modeled down to the component level. The model began to be established in 1980s when the internal general data was used. The Model has been reviewed by Peer Review Group like IAEA and Chinese Nuclear Industry, and received the general recognition. The continuous quality improvement of the PSA model is always carried out, and the updating data, the PSA application, and the review questions during daily application are considered so that the model reflects the real condition of the NPP.

Based on the qualitative analysis, the influence of the internal fire and the internal flood are similar with the internal event, and other external hazard (e.g., earthquake, strong wind, external flooding, aircraft impact, etc.) can be considered little contribution, of which the influence can be negligible. So the result of the evaluation reflects adequately the real risk of the NPP.

4.2. Events Evaluation

In this part, the evaluation of AFW Technical Specifications is carried out. Among the 9 items of AFW, the AFW6, AFW7, and AFW8 are the requirements about the AFW tank. The AFW tank is very important, if it is inoperable, the AFW is inoperable, and when in the AFW tank items, the AFW tank is operable, while in other items there are corresponding equipment inoperable. The evaluation is only about items corresponding equipment inoperable. There some instructions about the evaluation, as follows:

- (1) Power Mode evaluation is taken into account as an example, the other modes are similar;
- (2) The evaluation is based the latest Level 1 internal events PSA module of the selected NPP;
- (3) All the conditions for each item are evaluated;

(4) Two types of indexes are used: the ICDP, and the RIAOT, the ILERP is not selected because it is calculated by Level 2 PAS module which is usually based on level 1 PSA module and always reflects the similar result trend with ICDP;

(5) Select $5E-7$ as the acceptable risk criteria according to the general practice, because the evaluation is only based on the internal events module, the internal fire module, internal water logging module, and the external events module are not included.

Based on the PSA module of the NPP selected, and the acceptable risk criteria, the risk assessment of the condition is performed, and the RIAOTs of each event and its conditions are also calculated. The quantitative evaluation is carried out based on the zero-maintenance PSA module, and the ICDP also meet the demand of the RG 1.177 and the criteria selected, and the results of the condition are showed in the tables as below.

Table2. Risk result of AFW Events selected

<i>Events code</i>	<i>Content</i>	<i>CDF1</i>	<i>AOT(h)</i>	<i>ICDP</i>	<i>RIAOT(d)</i>
AFW1	One required motor-driven pump inoperable	1.12E-05	72	2.83E-08	53.0
	One SG water inoperable from motor-driven pump	9.40E-06	72	1.21E-08	124.1
	One SG water inoperable from turbine-driven pump	1.88E-05	72	9.58E-08	15.7
AFW2	Two motor-driven pumps inoperable,	3.11E-05	8	2.28E-08	7.3
	Two SGs water inoperable from motor-driven pump	1.01E-05	8	2.07E-09	80.4
	Three SGs water inoperable from motor-driven pump	3.11E-05	8	2.28E-08	7.3
AFW3	Turbine-driven pump inoperable,	2.44E-05	24	4.85E-08	10.3
	Two SGs water inoperable from turbine-driven pump	1.91E-05	24	3.30E-08	15.2
	Three SGs water inoperable from turbine-driven pump	2.44E-05	24	4.85E-08	10.3
AFW4	Turbine-driven pump and one motor-driven pump inoperable	1.92E-04	1	2.28E-08	0.9
AFW5	One SGs water inoperable from AFW	9.11E-05	1	1.03E-08	2.0
	Two SGs water inoperable from AFW	1.27E-04	1	1.48E-08	1.4
AFW9	One steam inlet line of turbine-driven pump inoperable	9.22E-06	72	1.04E-08	144.0

According to the evaluation results, the ICDPs of the events and its conditions meet the risk acceptance criteria (the RG1.177 and the selected) and are almost far less than the standard criteria. Intuitively, we found that the RIAOTs of the events evaluated were much larger than the AOT specified by the existing events. Therefore, the system events can be considered conservative from risk sight. For example, if the turbine-driven pump and one motor-driven pump are inoperable, the calculated RIAOT is about 0.9 day, and the AFW system is not completely failed, and there is still one motor-driven pump available, but the corresponding action is obviously conservative to use the most stringent measures with 1 hour AOT.

5. Analysis of Results and Recommendations

The risk results of different TS items for these identified cases are given in former part. This part identifies different cases in which the TS items are not balanced, which means that they are not consistent with their impact on plant risk. Based on the result, the balance analysis is given in this part, and so as to the suggestions to optimize the TS for the AFW system.

5.1. Balance between the items

In accordance with the Technical Specifications practice, the items are in special order that the risk increase in turn, and the different conditions of one item are in the same risk level. Based on the evaluation results, we have found that the items are arranged in order that the risk of each item is generally placed from small to large. Among the items, the AFW1 risk is relatively smaller, the AFW2 and AFW3 risk are in middle, the AFW4 and AFW5 risk are relatively larger. But, the AFW2 and AFW4 are not in the general order, the AFW2 risk is larger than AFW3, and the AFW4 is larger than AFW5. In addition, the AFW9 (part of turbine-driven pump is inoperable) risk is similar with AFW1 risk (in the same level). From the perspective of risk, the items are not balanced, and the real risk order is that, AFW9, AFW1, AFW3, AFW2, AFW5, AFW4 (from small to large).

5.2. Balance between the conditions of one item

The conditions in one item may be different. Among the items, for AFW1 the risk of “One SG water inoperable from turbine-driven pump” is much larger than the other two conditions, for AFW2 the risk of “Two motor-driven pumps inoperable” is same to that of “Three SGs water inoperable from motor-driven pump”, which is obviously different from “Two SGs water inoperable from motor-driven pump”, for AFW3 the risk of “Turbine-driven pump inoperable” is same to that of “Three SGs water inoperable from turbine-driven pump”, obviously different from “Two SGs water inoperable from turbine-driven pump”. From the perspective of risk, the AFW2 and AFW3 are also not balance.

However, the risk of some conditions in different items is at the same level. For example, the risk of AFW9 is comparable to that of “One SG water inoperable from motor-driven pump” in AFW1, the risk of “One SG water inoperable from turbine-driven pump” in AFW1 is similar to that of “Two SGs water inoperable from turbine-driven pump” in AFW3, the risk of AFW4 is a little higher than that of AFW5, which are still in the same risk level. Therefore, we can consider that the conditions of different items are not balanced.

5.3. Optimization suggestions on events balance

Based on the balance analysis of the items and the conditions, all conditions of the items can be divided in to five parts, and the requirement of AFW can be identified as 5 items corresponding to each risk level, the suggested items and the corresponding RIAOT are as below in table 3.

Table3. Optimized AFW Events

<i>Events</i>	<i>Content</i>	<i>RIAOT(d)</i>
AFW1	One steam inlet line of turbine-driven pump inoperable	144.0
	One SG water inoperable from motor-driven pump	124.1
	Two SGs water inoperable from motor-driven pump	80.4
	One required motor-driven pump inoperable	53.0
AFW2	One SG water inoperable from turbine-driven pump	15.7
	Two SGs water inoperable from turbine-driven pump	15.2
AFW3	Turbine-driven pump inoperable,	10.3
	Three SGs water inoperable from turbine-driven pump	10.3
AFW4	Two motor-driven pumps inoperable,	7.3
	Three SGs water inoperable from turbine-driven pump	7.3
AFW5	One SG water inoperable from AFW	2.0
	Two SGs water inoperable from AFW	1.4
	Turbine-driven pump and one motor-driven pump inoperable	1.4

6. Conclusion

Based on the method and criteria of risk-informed technique, the risk for different TS items for these identified cases are evaluated, the items and conditions not match to its risk level, and the suggestions to optimize the TS are also given.

The analysis above shows that, overall the items of the AFW system is identified according to the risk level, in other words the items are in balance, but the items are almost conservative, and there is imbalance in the events and conditions between each other, and in some degree the optimization is needed to make the management more suitable to the real risk when it comes to the items and conditions of AFW, so that the TSs can be carried out more effectively, and the safety management of NPP can be further enhanced. In the next, the proposed changes can be identified base on the analysis result, management suggestions and the operational practice, which can be carried out by risk-informed process.

The evaluation on the balance of the TSs events in this paper use the method and criteria of risk-informed technique in the operation practice in NPP, which provides a way to identify proposed change in risk-informed technique, and gives a new thinking to comprehensively evaluate TSs, and supply meaningful methods and practical exploration for the improvement of TSs in NPPs

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