USE OF RISK-INFORMED TECHNIQUE TO EVALUATE THE BALANCE OF TECHNICAL SPECIFICATION

Tang Qi[1], Zhang Xiang-fei[2], Li Qiong-zhe[2]
[1] *Daya Bay Nuclear Power Operations And Management Co.,Ltd. Shenzhen, Guangdong Province, China*
[2] *Suzhou Nuclear Power Research Insritute Shenzhen, Guangdong Province, China*

The Technical Specification is an important document in Nuclear Power Plant. With the accumulation of operation experience, the shortcomings of traditional Technical Specification are discovered during its application in the NPPs, some of the requirements are too conservative, and plant staff may get confused with some requirements in the Technical Specification. With the development of Probabilistic Safety Analysis technique for NPP safety analysis, the Risk-Informed technique, which combines Deterministic Safety Analysis with PSA, has been widely used in nuclear industry.

The Technical Specification 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 Specification 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. 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. The risk-informed technique is used to evaluate the risk for different TS items for these identified cases, and suggestions to optimize the TS are given based on the risk analysis. A simplified Auxiliary Feed Water system is taken as the example to show the analysis process, and suggestions to optimize the TS for the AFW system is given in this paper.Put abstract text here.

NOMENCLATURE

AFW: Auxiliary Feedwater system
GCT: Condenser or Atmospheric Steam Drump system
NPP: Nuclear power plant
PSA: Probabilistic Safety Analysis
SG: Steam Generator
SVA: Auxiliary Steam Distribution system
TS: Technical Specification
RHR: Residual Heat Removal system
CDF: Core Damage Frequency
ICDP: Increment Core Damage Probability
AOT: Allowed Outage Time
RIAOT: Risk-Informed Allowed Outage Time

I. INTRODUCTION

The Technical Specification is an important document in Nuclear Power Plant. With the accumulation of operation experience, the shortcomings of traditional Technical Specification are discovered during its application in the NPPs, some of the requirements are too conservative, and plant staff may get confused with some requirements in the Technical Specification. With the development of Probabilistic Safety Analysis technique for NPP safety analysis, the Risk-Informed technique, which combines Deterministic Safety Analysis with PSA, has been widely used in nuclear industry.

A simplified Auxiliary Feed Water system of some NPP is taken as the example to show the balance analysis process on the balance of Technical Specification items.

Ⅱ. THE FUNCTION AND TECHNICAL SPECIFICATION REQUIREMENTS OF THE AFW

Ⅱ. A . The AFW 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 drump) system.

Equipment per 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. 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.

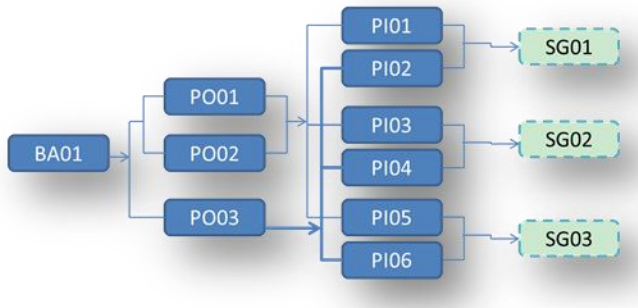

Fig.1 Simplified Flow Chart of the AFW

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.

Ⅱ. B . Technical Specification Requirements of the AFW

The Technical Specification of the selected NPP is compiled based on the format and the habits of France system Technical Specification, the function requirements of which are specific to the equipment. There are two parts in the Technical Specification, one part includes general rules, effect, scope of application, the provisions with which must be complied, different mode, measures needed to be taken when track from operational mode, conditions of the mode change, and so on. The other part includes reactor control, residual heat removal, radiation shielding, auxiliary support function, measures needed to be taken when some random events occur.

For the AFW, not only the first part are complied with, but also there are two requirements in the other part, the sink requirements in the residual heat removal part which demands that the whole AFW are operable except the deaerator, and a limiting condition is included, and the items of the random events in table 1 as below (Mode[1] power operation).

Ⅲ. THE TECHNICAL ADEQUACY OF PSA

The latest PSA model (Mode Power Operation Internal Event Level 1) is used during the evaluation, which data is the special data of the NPP. 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 is considered little contribution, of which the influence can be negligible. So the result of the evaluation reflects adequately the real risk of the NPP.

[1] For this NPP, there are six modes in TS, they are RP, NS/SG, NS/RRA, MCS, RCS, RCD. RP is Power Operation mode, NS/SG is Shutdown with being cooled by SG mode, NS/RRA is Shutdown with being cooled by RHR mode, MCS is Maintenance Shutdown mode, RCD is Refueling mode

Table 1 Measures needed to be taken when the equipment random events occur

Events	Measures
AFW 1 One required motor-driven pump（001PO or 002PO） inoperable, or, one SG water inoperable from motor-driven pump or turbine-driven pump	Group Ⅰ Begin to transform to mode **NS/SG** within 3 days
AFW 2 Two motor-driven pumps inoperable, or, two or three SGs water inoperable from motor-driven pump	Group Ⅰ Begin to transform to mode NS/SG with RHR working within 8 hours
AFW 3 Turbine-driven pump inoperable, or, two or three SGs water inoperable from turbine-driven pump	Group Ⅰ Begin to transform to mode NS/SG with RHR working within 24 hours
AFW 4 Turbine-driven pump and one motor-driven pump inoperable	Group Ⅰ Begin to transform to mode NS/SG within 1 hour
AFW 5 One or two SGs water inoperable from AFW	Group Ⅰ — If one SG water inoperable from AFW, Begin to transform to mode NS/SG within 24 hours — If two SGs water inoperable from AFW, Begin to transform to mode NS/RRA within 1 hour
AFW 6 Reactor power>2％Pn，storage of AFW tank is：766m^3<V<846m^3。	Group Ⅰ Begin to transform to mode NS/SG within 24 hour
AFW 7 Storage of AFW tank is: V<766m^3。	Group Ⅰ Begin to transform to mode NS/SG within 1 hour
AFW 8 Temperature of water in AFW tank: >7℃, or<50℃	Group Ⅰ Begin to transform to mode NS/RRA within 1 hour
AFW 9 One steam inlet line of turbine-driven pump inoperable	Group Ⅰ Begin to transform to mode NS/SG with RHR working within 7 days

Ⅳ. EVALUATION OF AFW TECHNICAL SPECIFICATION ITEMS

In this part, the evaluation of AFW Technical Specification 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:

i. Power Mode evaluation is selected to take as an example, the other modes are similar;
ii. All the conditions for each item are evaluated;
iii. Two index are used: ICDP and RIAOT;
iv. The evaluation is based the latest Level 1 internal events PSA module of the selected NPP ;
v. Select 5E-7 as the acceptable Risk guideline, 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, and the acceptable risk guideline, the risk-informed technique is used to evaluate the risk for different TS items for these identified cases, the results of each condition are showed in table2.

Table 2 Evaluation results of the AFW items

items	contents	CDF1	AOT(h)	ICDP	RIAOT(d)
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

items	contents	CDF1	AOT(h)	ICDP	RIAOT(d)
	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

Ⅴ.BALANCE ANALYSIS OF AFW ITEMS

The Technical Specification of an 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 Technical Specification balance 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. 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.

The risk results of different TS items for these identified cases are given in former part. Based on the result, the balance analysis is given in this part, and so the suggestions to optimize the TS for the AFW system.

Ⅴ. A . Balance between the items

In accordance with the Technical Specification 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).

Ⅴ. B . 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.

Ⅴ. C . Suggestions on optimizing the AFW items in the view of balance analysis

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.

Table 3 Suggested items of the AFW

Items	content	RIAOT(d)
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	0.9

Ⅵ. CONCLUSION

Taking a simplified Auxiliary Feed Water system as an example, 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 unbalanced items is not conducive to security management in NPP.

The risk-informed technique is used to evaluate the risk for different TS items for these identified cases, and suggestions to optimize the TS are given based on the risk analysis, which gives a better way to optimize the Technical Specification for continuous improvement on security management in NPP.

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