Study on the safety measures and risk-informed safety improvement measures implemented at Japan's nuclear power plants

Wataru Oshima[a*], Takeshi Numata[a*], Inui Tomohiko[a*]
[a] The Kansai Electric Power Co., Inc., Japan

Abstract: The Japanese nuclear utilities have implemented various safety improvement measures based on the new regulatory requirements, which were formulated taking into consideration severe accidents (abbreviated as SA hereafter). Regarding earthquakes, the design basis seismic ground motion Ss was increased as the conditions for the evaluation, such as movements in interconnection of faults around the power plant, were conservatively assumed. As a result, seismic reinforcing work was carried out where necessary. As measures against tsunamis, tide gates, sea walls, etc. were constructed against tsunamis of maximum credible scale. Against other hazards, various measures have been taken intensively, for example, installation of protective nets against tornado missiles, after confirming the impacts of respective hazards on the plant based on the nature of these hazards.

To ensure that each of these measures will achieve its functions without any problem in the event of an emergency, we have established the Tech. Specs. stipulating the reliable maintenance management of facilities themselves, training of personnel for the purpose of confirming the effectiveness of procedures drawn up, and confirming that prerequisites for various evaluation methods have not changed, and continues to conduct periodic checks and improve the proficiency of operators according to the provisions in the Tech. Spec.

As described in the above, we have worked on the modification of facilities to comply with the new regulatory requirements. Meanwhile, we conduct probabilistic risk assessments (internal event PRA, seismic PRA and tsunami PRA), which take into considerations the modifications and safety improvement measures. Based on the PRA results, after grouping accident sequences, important accident sequence groups were identified according to the degree of the occurrence frequency, and then additional safety improvement measures were extracted according to the importance of each accident sequence group. Besides risk information obtained from PRAs and other sources, many other key elements were collected and evaluated, including operating experience and resources for implementation (e.g., organization, funding, time, etc.), and based on these factors, decisions on safety improvement measures were made in an integrated manner. In the future, after these safety improvement measures are completed, we will perform risk assessments to analyze the extent to which these additional measures will reduce risks.

Keywords: PRA, RIDM, Internal event PRA, Seismic PRA, Tsunami PRA, Severe accident

1. COUNTERMEASURES AGAINST SA AND ENHANCED TRAINING BASED ON THE NEW REGULATORY REQUIREMENTS

Based on the new regulatory requirements, which were formulated taking into consideration severe accidents (hereafter referred to as SA) caused by the 2011 off the Pacific coast of Tohoku Earthquake, we have enhanced the capability of power supply systems and core cooling functions by introducing redundant and diversified equipment, including the installation of new air-cooled emergency generators and large-capacity pumps, to prevent severe accidents from occurring. At the same time, various measures have been taken against external events (earthquakes, tsunamis, external fires, tornadoes, etc.).

Regarding earthquakes, the design basis seismic ground motion Ss was increased as the conditions for the evaluation, such as movements in interconnection of faults around the power plant, were conservatively assumed. As a result, seismic reinforcing work was carried out where necessary. As measures against tsunamis, tide gates, sea walls, etc. were constructed against tsunamis of maximum credible scale. As measures against external fires (forest fires), trees around the power plant were cut down and firebreaks were established to prevent fire from spreading. As measures against internal fires, additional protective measures were taken for mitigating the impact. As a measure against tornadoes, protective nets were installed against missiles. As mentioned above, various measures were taken intensively after confirming the impacts of respective hazards on the plant based on the nature of these hazards. Examples of measures against earthquakes and tsunamis are shown in Figure. 1.

To ensure that that each of these measures will achieve its function without any problems in the event of an emergency, we have established the Tech. Specs. regarding the reliable maintenance management of facilities themselves, training of personnel for the purpose of confirming the effectiveness of procedures drawn up, and confirming that prerequisites for various evaluation methods have not changed, and continues to conduct periodic checks and improve the proficiency of operators according to the provisions in the Tech. Spec.

This training is carried out on a continuous basis using SA procedures and procedures in case of extensive damage in order to maintain/improve the competence of relevant personnel (employees and those of subcontractors). In addition, drills are conducted assuming various situations such as bad weather conditions and/or high radiation doses to ensure that appropriate responses can be conducted in the event of a severe accident. An example of these drills is shown in Figure.2. Furthermore, after carrying out these drills, we identify issues to be reflected on and provide feedbacks to be incorporated in the procedures so that the effectiveness of SA measures can be improved.

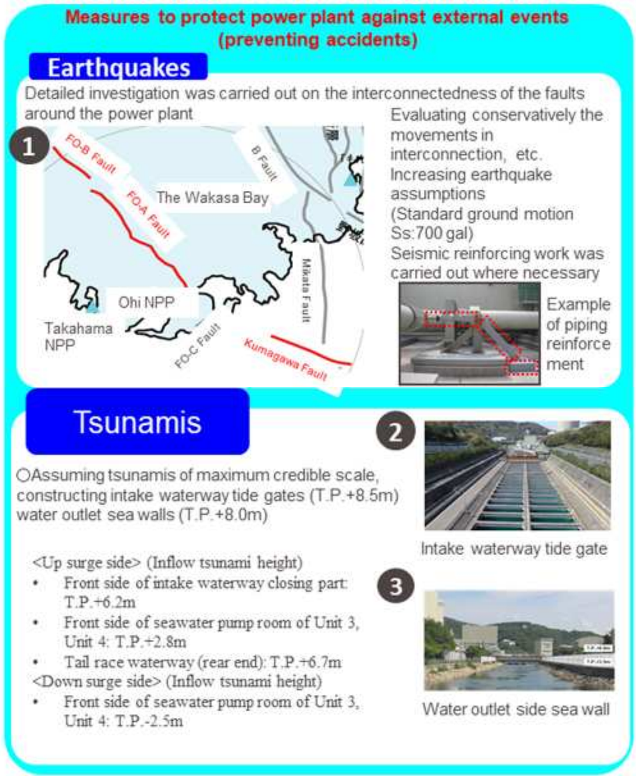

Figure.1 Examples of measures against earthquakes and tsunamis


Figure.2 Training on hose extension assuming an environment with high radiation doses

2. STUDY ON RISK－INFORMED SAFETY IMPROVEMENT MEASURES

As described in Section 1. above, we have worked on the modification of facilities to comply with the new regulatory requirements. Meanwhile, we conduct probabilistic risk assessment (abbreviated as PRA hereafter), which takes into considerations the modifications and safety improvement measures, and the PSA results were analysed from the following two perspectives:

1. Identification of the effectiveness of SA measures
2. Study on the necessity of additional safety improvement measures

2.1 Identification of the effectiveness of SA measures (at Takahama unit 3)

Our study is intended to identify the measures contributing to reducing the risk of core damage (measures that have already been implemented) and their effectiveness utilizing the PRA. Specifically, measures contributing significantly to reducing risk and the effectiveness of those measures were confirmed by comparing the PRA results considering SA measures and those without considering SA measures and analyzing Risk Achievement Worth (abbreviated to RAW hereafter), one of the risk importance indicators. Here, Level 1 PRA results of earthquakes and tsunamis for Takahama unit 3 will be introduced.

As a result of Level 1 internal event PRA for Takahama unit 3, the core damage frequency was reduced from 1.4×10^{-5} (/reactor-year) [without SA measures] to 7.2×10^{-7} (/reactor-year) [with SA measures], showing the effectiveness of the SA measures of reducing the core damage frequency to approximately one-twentieth. Meanwhile, as a result of Level 1 seismic PRA for Takahama unit 3, the core damage frequency was reduced from 3.7×10^{-5} (/reactor-year) [without SA measures] to 1.1×10^{-7} (/reactor-year) [with SA measures], showing the effectiveness of the SA measures of reducing the core damage frequency to approximately one-third. In this case, as a result of confirming RAW, it was revealed that air-cooled emergency power generators contribute significantly to reducing risk. Meanwhile, the core damage frequency calculated for Level 1 tsunamis PRA was reduced from 4.0×10^{-5} (/reactor-year) [without SA measures] to 1.6×10^{-7} (/reactor-year) [with SA measures], showing the effect of SA measures of reducing the core damage frequency to approximately 1/250. In this case, as a result of confirming RAW, it was revealed that the installation of tide gates and water sealing measures in openings contributes significantly to reducing risks.

2.2 Study on additional safety improvement measures (at Takahama unit 3)

For the purpose of identifying effective measures to improve the plant safety furthermore, including the reduction of the core damage frequency, results of PRA after implementing SA measures were analyzed by giving priority to factors with higher contribution to risks. Specifically, we focused on the accident sequence group in Level 1 PRA, while in Level 1.5 PRA, a focus was concentrated on the containment failure mode. The significance of accident sequence groups was sorted out using the classification of accident sequence groups shown in Figure.3 and using the flow for extracting containment failure modes in Figure.4.[4)]。

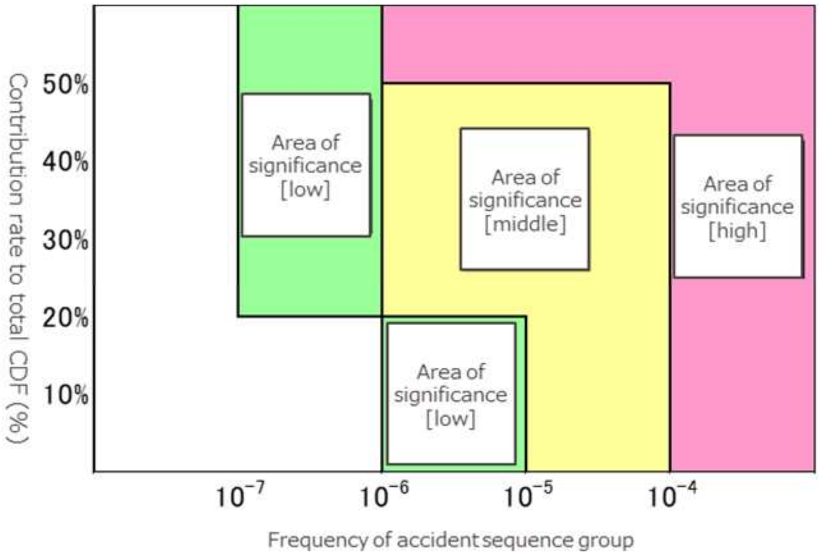

Figure. 3 Classification of accident sequence groups

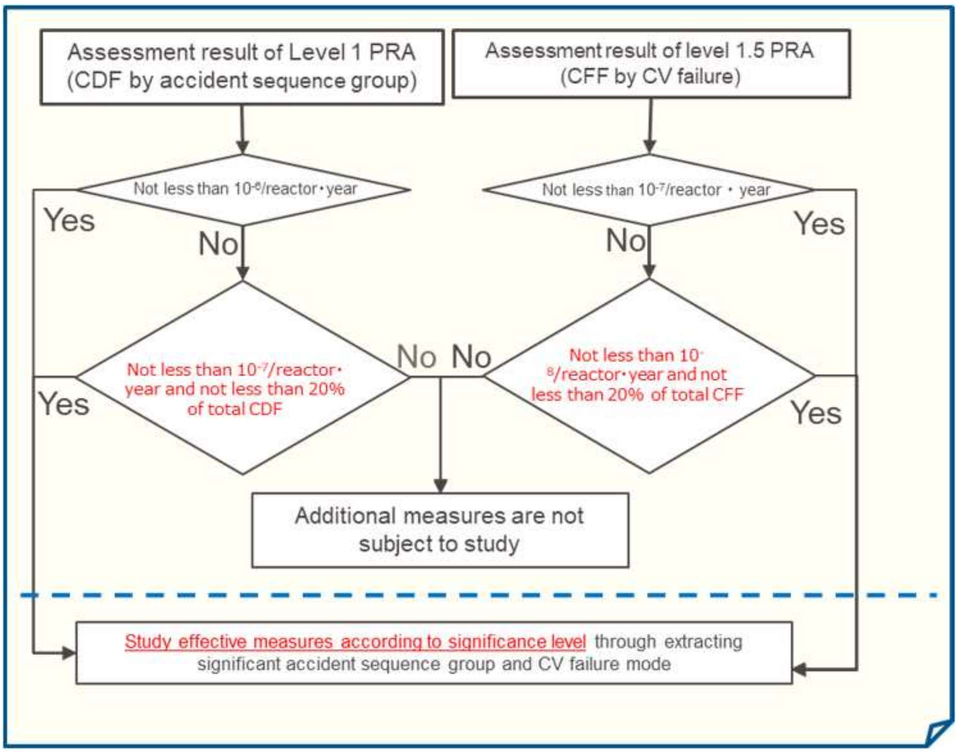

Figure.4 Flow for extracting containment failure modes

According to Figure.3 and Figure.4, following significant accident sequence groups (for Level 1 PRA) and containment failure modes (for Level 1.5 PRA) have been extracted:

【Significance level: high】Level 1.5 (internal event PRA)

- Overpressure CV failure caused by the accumulation of water vapor and incompressible gas

【Significance level: middle】

N/A

【Significance level: low】

Level 1 (internal event PRA)

- Loss of ECCS injection function
- Loss of decay heat removal function (during shutdown)
- Flowing out of reactor coolant (during shutdown)

Level 1 (tsunami PRA)

- Loss of reactor component cooling water

Level 1.5 (seismic PRA)

- Failure to isolate containment vessel
- Overpressure CV failure caused by the accumulation of water vapor and noncondensable gas

Level 1.5 (tsunami PRA)

- Failure to isolate containment vessel
- Overpressure CV failure caused by the accumulation of water vapor and noncondensable gas

Based on these results, additional safety improvement measures were extracted both from tangible and intangible factors. As shown in Figure. 5, in the decision-making process for selecting the safety improvement measures, accident sequences of high significance were extracted considering the PRA results, proposed safety improvement measures were presented from the perspective of probabilistic assessment, and then decisions on whether or not to adopt the safety improvement measures were made by integrating key elements other than probabilistic views.

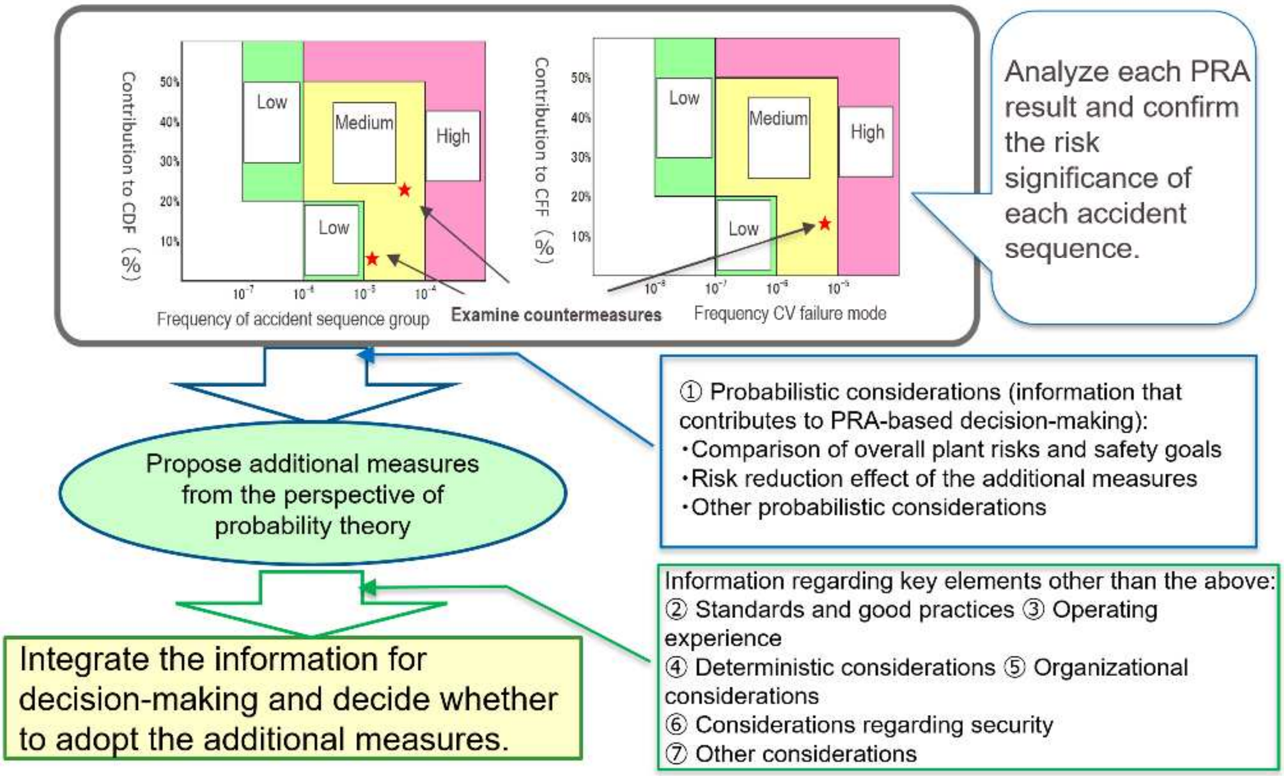

Figure. 5 Flow for examining additional safety improvement measures

As for tangible factors, shutdown seals (a voluntary measure) of the reactor coolant pump (abbreviated as RCP hereafter) was extracted as a safety improvement measure (see Figure.6). This measure is expected to reduce the core damage frequency and containment failure frequency by reducing the risk of RCP seal LOCA, in the event of station blackout. This measure is expected have similar effects for the results of internal PRA, seismic PRA and tsunami PRA. In addition, containment spray (an antiterrorism facility) + filter vent (to meet the new regulatory requirements) was extracted as a safety improvement measure (see Figure.7). This measure is expected to reduce the containment vessel failure frequency by mitigating the risk of CV overpressure failure. This measure is also expected to be effective for the results of internal PRA, seismic PRA and tsunami PRA.

Regarding intangible factors, following measures related to operator actions and activities in the event of an accident were extracted for further improvement of the plant reliability and safety:

- Reliability improvement through addition of integrity confirmation procedures

- Utilization of training for operator actions and emergency responses in establishing the education and training programs (Identifying operator errors in the course of representative accident scenarios through education and training programs provides a means of a risk-informed approach. Through these activities, we will promote the study on better utilization of risk information.)

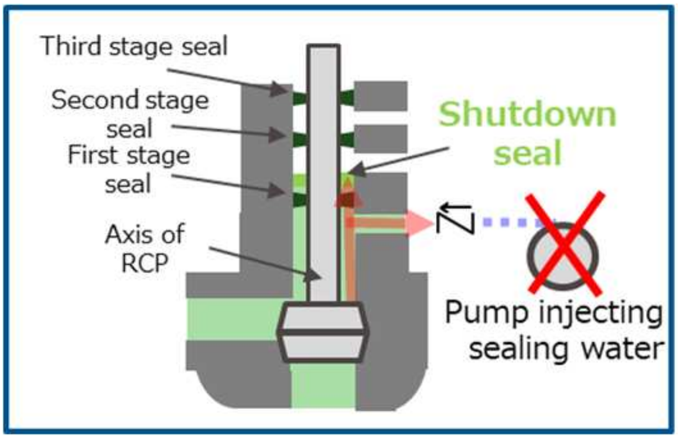

Figure.6 Schematic diagram of RCP shutdown seal (a voluntary measure)

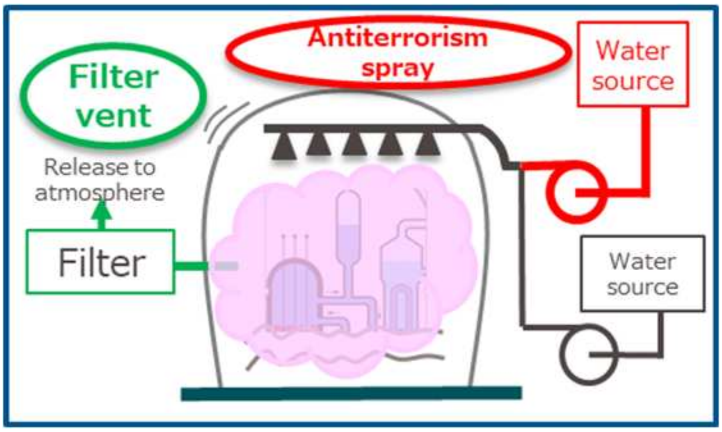

Figure. 7 Schematic diagram of containment spray (an antiterrorism facility) + filter vent (to meet the new regulatory requirements)

2.3 Study on additional safety improvement measures (at Mihama unit 3)

Next, our study on "introduction of automatic recirculation switchover" among the candidate additional safety improvement measures considered for Mihama unit 3 will be introduced. The study of additional safety improvement measures for Mihama unit 3 was conducted in the same way as for Takahama unit 3, based on the flow shown in Figure 5 described in Section 2.2. The PRA results for Mihama unit 3 indicated that loss of ECCS recirculation function was a representative risk-important scenario. Therefore, it was determined that measures to address the failure of recirculation switchover would be most effective in reducing the risk. In Mihama unit 3, operations related valves, pumps, and other equipment for water source switching were conducted manually by operators, and the risk of operator error was a significant factor. Therefore, the introduction of automatic recirculation switching was extracted as a tangible measure. The study was conducted based on the flow shown in Figure 5 as follows:

【① Probabilistic considerations (information that contributes to decision-making in terms of PRA)】

① Representative accident scenarios were analyzed. It was confirmed that the introduction of automatic recirculation switching could reduce CDF by about 20%. On the other hand, the effect of CFF reduction was small, about 1% reduction.

【Information about key elements other than probabilistic aspects】

② Standards and good practices: It was confirmed that the installation of the automatic recirculation switchover does not require the application for the reactor installation permit or construction work approval. In addition, it was confirmed that Takahama units 3/4 and Ohi units 3/4 adopted automatic recirculation switchover in the original design.
③ Operating experience: Since the automatic recirculation switchover will function after the ECCS is activated in the event of LOCA or other accidents, it would have no impact on the plant operation.
④ Deterministic considerations: The introduction of automatic recirculation switchover will contribute to the improvement of the long-term core cooling reliability in the Level 3 of the defense-in-depth.
⑤ Organizational considerations: The introduction of automatic recirculation switchover will reduce workloads on operators.
⑥ Security considerations: not applicable

3. CONCLUSION

The Japanese nuclear utilities have implemented various safety improvement measures based on the new regulatory requirements, which were formulated taking into consideration severe accidents, against external events (earthquakes, tsunamis, external fires, tornados, etc.) as well as internal events. To ensure that each of these measures will fulfil its functions without any problem in the event of an emergency, we have established the Tech. Specs. stipulating the reliable maintenance management of facilities themselves, training of personnel for the purpose of confirming the effectiveness of procedures drawn up, and confirming that prerequisites for various evaluation methods have not changed, and continues to conduct periodic checks and improve the proficiency of operators according to the provisions in the Tech. Spec.

Meanwhile, for the purpose of examining effective measures to improve the plant safety furthermore, we analyzed the PRA results, which take into considerations the modifications and safety improvement measures, and then identified safety improvement measures to be prioritized by focusing on factors with higher contribution to total risk. Besides risk information obtained from PRAs and other sources, many other key elements were collected and evaluated, including operating experience and resources for implementation (e.g., organization, funding, time, etc.), and based on these factors, decisions on safety improvement measures were made in an integrated manner. In the future, after these safety improvement measures are completed, we will perform risk assessment to analyze the extent to which these additional measures will reduce risks.

References

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