Status of Risk Informed Approach in TEPCO(KK Plant)

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Abstract: Based on the lessons learned from the Fukushima Daiichi nuclear power plant accident, TEPCO has stipulated in its safety regulations that it will not stop at compliance with regulatory standards, but will implement voluntary initiatives to improve the safety of nuclear power plants. The basic policy of RIDM was established in FY2021, and the promotion of RIDM will be carried out in two phases, Phase 1 and Phase 2. In Phase 1, RIDM issues will be resolved to continuously respond to the ROP and lay the groundwork for the expansion of RIDM, including the establishment of standard values for PRA results for decision-making, the implementation of PRA training to ensure the understanding and penetration of PRA among technical staff, and the use of PRA results in operations and maintenance departments. PRA training was conducted to ensure the understanding and penetration of PRA among technical staff, and a system was established to utilize PRA results in operations and maintenance departments. As described above, Kashiwazaki Kariwa NPP has implemented various initiatives to improve safety through the use of PRA and has accumulated experience in the use of PRA. Therefore, now, as Phase 2, we have also started activities for both improving nuclear safety and optimizing plant operation by using PRA, and are promoting activities such as reorganizing equipment protection targets and reorganizing maintenance importance levels by using PRA. This paper presents a case study of RIDM at TEPCO's Kashiwazaki-Kariwa nuclear power plant, which is being implemented in the above-mentioned Phase 1 and Phase 2.

Keywords: PRA, RIDM, Kashiwazaki-Kariwa,

1. INTRODUCTION

In the Fukushima Daiichi nuclear power plant accident that occurred on March 11, 2011, a tsunami that far exceeded the previous design-basis tsunami height caused the loss of power and the loss of reactor cooling functions. One of the reasons for this situation was the lack of a system for collecting, analyzing and utilizing information on overseas safety improvement measures, as well as efforts to continuously improve the safety of facilities based on the knowledge gained.

Tokyo Electric Power Company Holdings, Inc. As a party to the accident, TEPCO Holdings (hereinafter referred to as "TEPCO") has been promoting voluntary safety improvement initiatives that go beyond national regulatory standards to further improve nuclear safety based on lessons learned from the accident. One of these efforts is to strengthen risk management, including the use of probabilistic risk assessment (PRA).

In risk management, it is important to introduce the process of "risk informed decision making" (RIDM), which combines risk information obtained from PRA and other sources, in addition to the conventional knowledge of deterministic evaluation, for decision making related to plant maintenance and operation. The introduction of RIDM is considered to be an effective approach to improve the safety of power plants and the quality of risk management operations, because RIDM makes it possible to quantify risks and evaluate the importance of risks according to the current plant conditions and use them as information for decision making (risk informed performance based). Therefore, the implementation of RIDM is considered to be an effective approach to improve the quality of operations for power plant safety and risk management.

MHI has reaffirmed the importance of utilizing risk information in power plant operation and maintenance, and is promoting the introduction of RIDM in power plant risk management. This paper presents an example of the use of risk information at MHI's Kashiwazaki-Kariwa nuclear power plant.

2. TEPCO's BASIC POLICY ON RIDM

In FY2021, TEPCO established the "Basic Policy on Integrated Decision-Making Using Risk Information," which defines the goal of using risk information and clarifies the RIDM process to be implemented to realize the goal and the implementation strategy of activities to achieve the goal. Currently, activities related to RIDM are being developed in accordance with this policy.

The goal of RIDM is to achieve the world's highest level of safety and to continue to improve the safety and efficiency of power plant operations in a rational manner by widely incorporating the use of risk information into power plant operations and by continuously improving operations. To achieve this goal, we believe it is important to take a step-by-step approach. In light of the current situation and the technical and institutional challenges, we will set interim goals and work to achieve them.

The interim goals are set in two phases, Phase 1 and Phase 2. Phase 1 is to improve safety through the use of risk information, and thus to continuously respond to nuclear regulatory inspections (ROP) and improve safety. Specifically, we will solve technical and institutional problems and improve safety by promoting the following three activities: (1) Preventing performance degradation by identifying, evaluating and taking countermeasures against risks in advance; (2) Implementing necessary countermeasures based on risk information even when risks become healthy; and (3) Acquiring high risk sensitivity among nuclear personnel. Phase 2 of the PRA is to further expand the scope of the PRA. In Phase 2, the scope of the PRA will be further expanded to optimize plant operations while ensuring safety and to prioritize the use of resources in high-risk areas.

Phase 2 is currently underway, as Phase 1 has resulted in the implementation of safety improvement measures that contribute to a continuous response to ROP, and Phase 2 has begun efforts to optimize plant operations. Because there is a wide variety of initiatives being implemented and many are ongoing, this report focuses on those that have been completed and are ongoing.

3. TEPCO's SPECIFIC APPROACH TO RIDM

3.1. Establishment of Plant Guards Using Risk Information

TEPCO has implemented an initiative called "Equipment Guard" to physically or visually guard safety-critical equipment to protect the equipment from malfunction or failure due to accidental contact, etc., in light of equipment problems caused by worker contact that have occurred in the past. Figure 1 shows an example of equipment guarding.

Figure 1: Equipment Guarding Example

Traditional equipment guarding was implemented for equipment with operating restrictions specified in safety regulations or equipment that was qualitatively identified as high-risk according to in-house manuals. The goal was to improve plant safety by optimizing equipment subject to guarding by incorporating risk information from PRA knowledge into equipment guarding implemented from a qualitative perspective.

One of the PRA analysis methods is importance analysis, and RAW (Risk Achievement Worth) is a typical risk information obtained from importance analysis. RAW is an index that indicates how much the risk would increase if a specific equipment failure or human error occurred. In other words, preventing the failure of equipment with a high RAW is an effective approach to improving plant safety. For this reason, equipment with a large RAW has been extracted as equipment guard targets.

When selecting equipment to be guarded based on RAW, we conducted a survey on the reference value of RAW to determine whether the risk is high or low. As a result of the investigation, in the maintenance management guidelines for nuclear power plants [1], a RAW of 2 or higher was exemplified as one of the indicators for selecting equipment with a high reactor safety risk.

Therefore, in this study, facilities with RAW≥2 were considered as facilities to be guarded based on the maintenance management guidelines for nuclear power plants. On the other hand, facilities with RAW < 2 were excluded from equipment guarding because the risk to reactor safety was considered low. Table 1 shows an example of the RAW evaluation for Kashiwazaki-Kariwa Unit 6.

Table 1. Excerpts from the list of RAWs during the inspection of Unit 6, System A at the Kashiwazaki-Kariwa Nuclear Power Plant.

Rank	comment	RAW
1	CSP-Low Water Level False Signal	1.29E+03
2	125V DC - 6B - Bus-bar failure	3.41E+02
3	ST6D-1-Transformer failure	3.39E+02
4	P/C-6D-1_2A-Circuit breaker mis-open	3.39E+02
5	M/C-6D_4A-Circuit breaker mis-open	3.39E+02
6	P/C-6D-1-Bus-bar failure	3.39E+02
7	M/C-6D-Bus-bar failure	3.39E+02
8	P/C-6C-1-Bus-bar failure	2.17E+01
9	ST6C-1-Transformer failure	2.17E+01
10	P/C-6C-1_2A-Circuit breaker mis-open	2.17E+01
⋮	⋮	⋮
215	Fire extinguishing system - Electric pump manual start signal failure	1.90E+00
216	Fire extinguishing system - Failure to start electric pump(Emergency - fresh water)	1.90E+00
217	Fire extinguishing system - Failure to continue operation of electric pump (fresh water)	1.90E+00
218	Fire extinguishing system - Control unit failure	1.90E+00
219	Fire Suppression System-F009-Manual Function Closures	1.90E+00
220	Fire extinguishing system-F009-Forgot to open manual valve	1.90E+00

The facilities shown in orange were selected as facility guard targets because they have a RAW≥2.

After the above selection of facilities to be guarded, further screening was done from a qualitative point of view. Specifically, among the facilities with a RAW≥2, those facilities that were not considered to contribute effectively to risk reduction through facility guarding were excluded from the facility guard target. Table 2 shows which facilities were excluded. On the other hand, among facilities with RAW<2, facilities considered to be effective in complying with safety regulations were not excluded from the facility guarding target.

Table 2: Equipment excluded from Equipment Guard

Equipment	Qualitative reasons for exclusion	Example of equipment
Equipment without drive unit	Less likely to fail due to contact	Strainer, orifice, heat exchanger
Equipment with a relatively simple structure	Less likely to fail due to contact	Manual valves, check valves
Outdoor equipment	Plenty of space for installation	Switching station equipment
Central control room	Constant monitoring by a person on duty	Central control panel

As a result of the extraction of equipment guarding targets using the PRA evaluation results and qualitative screening, several pieces of equipment were extracted as new equipment guarding targets in addition to equipment previously subject to equipment guarding, as shown in the examples below.

a) Permanently metal-clad switchgear to receive external power
b) Condensate storage tank water level gauges

a) Permanent metal clad switchgear for receiving power from an external power source was selected because loss of external power is the most important event during plant shutdown among events that could propagate to fuel damage (i.e., initiating events), and failure of the permanent metal clad switchgear would directly result in loss of external power. The failure of the permanent metal clad switchgear is considered to be a direct cause of the loss of external power.

b) The reason for selecting the condensate storage tank water level indicator is that the condensate storage tank (CSP) is expected to be the water source for water injection facilities such as the condensate replenishment water system (MUWC) and the fuel pool replenishment water system (MUWF), and if the condensate storage tank water level indicator fails, the reliability of these multiple water injection facilities will decrease simultaneously.

However, if the condensate storage tank water level indicator fails, the reliability of these multiple water injection systems will simultaneously decrease. In addition, the fuel pool cooling and cleaning system (FPC) was identified as one of the components to be considered for exclusion from the equipment guard because of RAW<2. This is considered because the decay heat of spent fuel is sufficiently low during long-term shutdown, and the cooling functions other than the FPC are diversified and multiplexed, and the importance of the FPC for fuel damage has decreased. On the other hand, the FPC is not excluded from equipment protection because the FPC is the primary heat removal equipment for the fuel pool when all the fuel is in the fuel pool and because it is necessary to maintain the fuel pool at 65°C or lower in accordance with safety regulations. As described above, we were able to optimize the facilities for equipment protection by taking into account not only qualitative aspects, such as operational limitations in the safety regulations, but also quantitative aspects, such as the risk of fuel damage.

3.2. Utilization of Risk Information in Periodic Inspection Process Management

During the periodic inspection of a facility, the condition of the equipment changes from time to time, and the risks of the facility change as well. Therefore, it is important for periodic inspection risk management to formulate a risk reduction process at the planning and preparation stage of the inspection process and to understand the risks of the plant during the inspection period.
As part of the effort to understand the risk status of the plant, the daily plant status is risk assessed from the perspective of CDF evaluation by PRA and compliance with safety regulations, and the assessment results are summarized in a "weekly risk forecast" and disseminated within the plant. Figure 2 shows an extract of the weekly risk forecast.

Figure 2: Extract from the weekly risk forecast

On the other hand, at the planning and preparation stage of the periodic inspection process, since effective risk reduction can be expected by considering risk information when formulating the periodic inspection process, we have just begun to work on the use of risk information at this stage. Here we would like to introduce our efforts to use risk information in the management of the outgoing inspection process.

As part of the safety department's efforts at the time of creating the periodic inspection process, the CDF for the planned periodic inspection process is evaluated using PRA, and if a period is identified in which the CDF increases significantly, the process is revised to reduce the CDF for that period. In the previous workflow, the safety department conducted the risk assessment of the planned inspection process, which was adjusted by the maintenance and operations departments, but there were problems such as rework, delays in notifying the public of risks, and difficulties in making detailed adjustments. Therefore, the work flow has been improved, and a risk review meeting is now held at the process planning stage, bringing together the operations, maintenance, and safety departments. Figure 3 shows the workflow in formulating the periodic inspection process. In the study meeting, each department identifies potential risks in the draft process created by the maintenance department and discusses measures to reduce the identified risks.

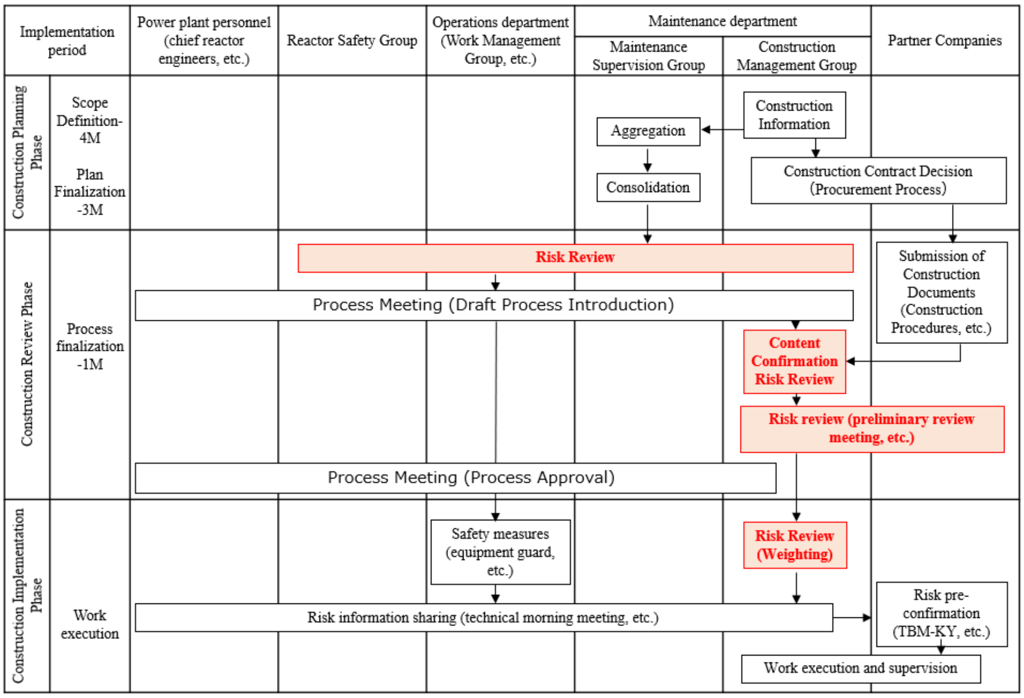

Figure 3:Workflow for periodic inspection process development

At the risk review meeting, the safety department presents the results of the criticality assessment in addition to the CDF of the proposed process. The Fussell-Vesely (FV) criticality is an index that indicates how much the core damage frequency decreases when the failure probability of the target component or system is set to zero (in other words, when the target component or system is assumed to never fail). For equipment with a high RAW, the CDF increases significantly due to loss of function, and therefore equipment protection by equipment guards, etc. is recommended, and alerts are issued for work to be performed near the equipment. For equipment with high FV importance, the report recommends increased monitoring during patrol inspections, lubrication of equipment, and vibration diagnosis of rotating machinery.

As an actual example of risk study, the renewal of 125 VDC storage batteries is planned for the post-approval construction of Kashiwazaki Kariwa Nuclear Power Station Unit No. 6, and while it would take approximately nine months to renew the DC batteries in series A to C one by one, a risk assessment was conducted when two systems were put on standby simultaneously to study the optimal process period. Based on the comparison of the CDFs and the results of the importance evaluation, we proposed risk reduction measures and examined whether the process could be shortened after a qualitative evaluation from the perspective of safety regulations. Figure 4 shows a schematic diagram of the DC system.

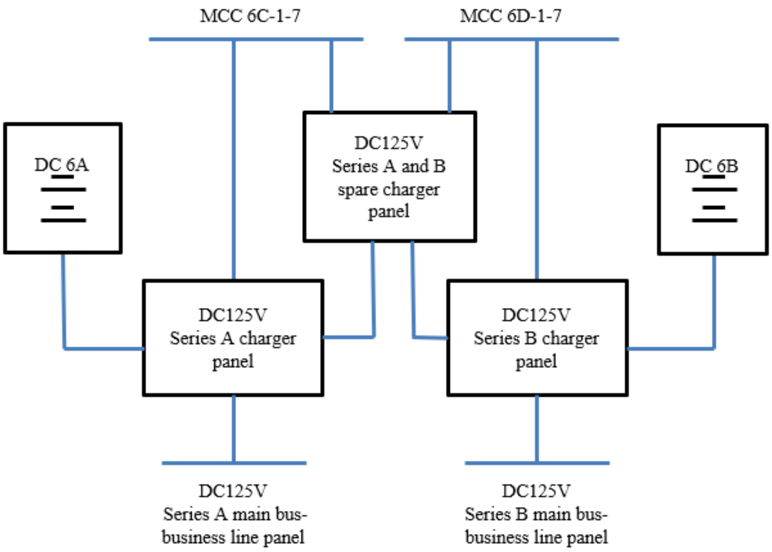

Figure 4: Schematic diagram of the 125 V DC systems for the A and B systems at the Kashiwazaki Kariwa Nuclear Power Station Unit 6

The parameters to be considered as evaluation conditions are the amount of decay heat from the fuel, the state of the storage battery to be replaced, and the state of the plant when the storage battery is replaced. The decay heat was assumed to be in a long-term outage state, the charger panel of the storage battery to be replaced was assumed to have only the storage battery itself not ready because a spare circuit is used, and the plant states compared were normal operation state, A system inspection state, B system inspection state, C system inspection state, AC system inspection state, and BC system inspection state. The results of the CDF evaluation are shown in Figure 5. The results of the importance evaluation are shown in Table 3.

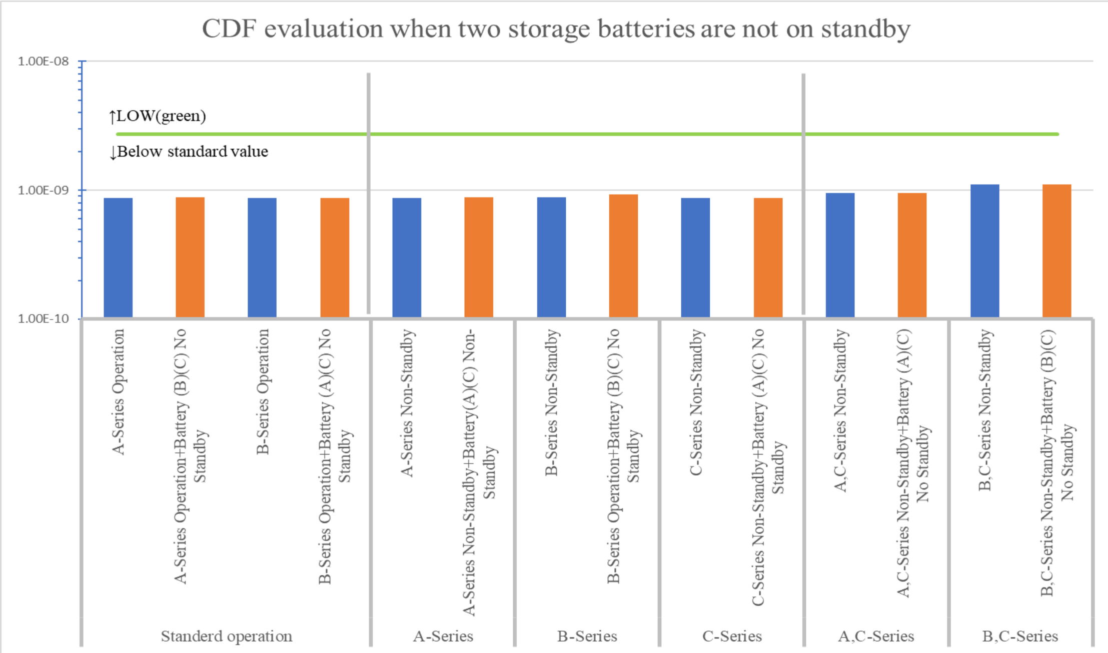

Figure 5: CDF Evaluation Results

Table 3. Importance evaluation results (left: when AC system is not in standby mode, right: when BC system is not in standby mode)

Rank	System	RAW	CDF	Risk
1	FPC	433	4.1E-07	HIGH
2	MUWC	399	3.8E-07	HIGH
3	DC7B	20	1.9E-08	MID
4	KAIHEI	9	8.6E-09	LOW
5	NB	5	4.8E-09	LOW
6	P/C7C	5	4.6E-09	LOW
6	STr	5	4.6E-09	LOW
8	DC7A	5	4.6E-09	LOW
9	M/C7C	3	3.1E-09	LOW
9	M/C6S	3	3.1E-09	LOW

Rank	System	RAW	CDF	Risk
1	DC7A	98	7.5E-07	HIGH
2	P/C7C	76	5.9E-07	HIGH
3	M/C7C	62	4.8E-07	HIGH
4	FPC	61	4.7E-07	HIGH
5	MUWC	55	4.2E-07	HIGH
6	FP	43	3.3E-07	HIGH
7	HVAC-M/C	27	2.0E-07	HIGH
8	DG7A	26	2.0E-07	HIGH
9	HECW-A	26	2.0E-07	HIGH
10	HVAC-C/B	26	2.0E-07	HIGH

From the results of the importance evaluation, the risk of coolant leakage from the SFP due to mechanical failure is dominant for the CDF in a long-term outage plant, so the means of injecting water into the SFP is more important. Therefore, it can be seen that in both storage battery inspections during AC angle BC angle inspections, it is important to secure the MUWC supply line and it is important to avoid any disturbance to the MUWC supply line. In addition to the above, the M/C(C) system, D/G(A) system, and fire suppression system are identified as high risk equipment during the BC corner inspection. If these items fail during the inspection, the risk increases to an unacceptable level. The results of the CDF evaluation also showed that the CDF did not increase significantly even if two storage batteries were kept off standby, so it is acceptable to renew the storage batteries by keeping two systems off standby at the same time.

In addition to the risk assessment of each process for each unit as described above, it is desirable to manage risk by considering the entire Kashiwazaki-Kariwa Nuclear Power Plant. The Kashiwazaki-Kariwa Nuclear Power Plant has seven units, and we have developed a process that considers the risks of the entire plant. Specifically, when the annual process for periodic inspection of each unit was established, the CDF of each unit was evaluated by PRA, and the evaluated CDF was summed, and the period during which the CDF would increase was analyzed. As a result of the analysis, it was found that the simultaneous inspection of the B and

H systems at the BWR-5 plant causes a significant increase in the CDF. Therefore, with the exception of the intake channel inspection, which is required to be performed simultaneously, the B and H system inspections were generally not performed simultaneously and the time periods were staggered to avoid overlap. For intake channel inspections, the FV significance level for the period was also evaluated, and measures were taken to increase the reliability of equipment with high FV significance levels, thereby minimizing risk.

As a result of the above efforts, a common understanding of risk was established among departments in the planning phase of the outage inspection process, and outage inspections could be conducted after risk mitigation measures were considered and implemented. Continued use of risk information in managing the outage inspection process is expected to improve the safety of power plants and increase the risk awareness of plant personnel.

4. SUMMARY OF THE RIDM FOR THE KASHIWAZAKI-KARIWA NUCLERA POWER PLANT

MHI is promoting RIDM activities to further improve the safety of its power plants, and this paper introduces some of the activities that have been implemented at power plants and are ongoing. While activities were previously conducted from a qualitative perspective, quantitative risk information is now being incorporated based on PRA, and measures are being taken according to the level of risk, thereby effectively improving nuclear safety. In the future, we will enter Phase 2 to optimize plant operations and further expand the scope of PRA. This will enable us to allocate resources to higher-risk areas on a priority basis, contributing to further safety improvements.

REFERENCES

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