

Domestic Trends Toward the Introduction of On-Line Maintenance and Guideline for On-Line Maintenance

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Abstract: Since on-line maintenance is effective in ensuring stable plant operation and improving the quality of maintenance to maintain a stable supply of electricity and improve plant safety, studies are underway to introduce on-line maintenance in Japan. In this context, guideline have been established to define safety management and other measures to reduce the temporary increase in risk during the performing on-line maintenance. The guideline defines the process of on-line maintenance, risk assessment and risk management measure. The guideline will continue to be revised based on feedback from the application results to actual plants and the continued collection of new knowledge after the introduction of on-line maintenance.

Keywords: On-Line Maintenance, PRA, Deterministic Assessment

1. INTRODUCTION

To achieve energy security and carbon neutrality, nuclear power must be used continuously and efficiently, and utilities must improve the facility utilization ratio to ensure safety. Efforts to improve the facility utilization ratio include preventing plant shutdowns due to troubles and extending the operation period. One approach to achieving these goals is "On-Line Maintenance," in which facility inspections, repairs, etc. are performed during reactor operation. The workload can be leveled out by performing inspections and repairs during operation, which are usually concentrated during shutdown, and the work quality and work environment can be improved. In addition, reducing problems and other abnormal situations can prevent serious accidents, leading to improved safety.

However, in principle, on-line maintenance for facilities subject to limiting conditions for operation (LCO) is not permitted under Japanese licensing, and is limited to unavoidable cases, such as when signs of deterioration are observed. Therefore, it is necessary to establish a framework that allows utilities to perform on-line maintenance as part of their maintenance plans, without being limited to unavoidable cases.

The Nuclear Risk Research Center (NRRC) of the Central Research Institute of Electric Power Industry (CRIEPI) has established guideline that define common management methods for utilities to safely perform on-line maintenance, assuming that on-line maintenance is permitted for licensing purposes. The guideline provides concepts and procedures for performing maintenance work, such as screening to determine whether or not to perform on-line maintenance for LCO subject facilities corresponding to the operating conditions, risk assessment and appropriate risk management measure according to the results, and contingency plans.

2. DOMESTIC TRENDS IN ON-LINE MAINTENANCE

In October 2023, the Chief Nuclear Officer (CNO) of the utilities and the Nuclear Regulatory Authority (NRA) held a meeting to exchange opinions on the introduction of on-line maintenance. In this meeting, the utilities explained the expansion of the scope of application of on-line maintenance utilizing risk information, including the improvement of work quality and the outline of the on-line maintenance guideline, and based on these explanations, the two parties discussed the issue. Subsequently, the Atomic Energy Association (ATENA) and NRA practitioners have been meeting since February 2024. In the meetings, the safety benefits of on-line maintenance, a review of the discussions on on-line maintenance that took place between utilities and NISA before 2011, and the details of the guideline for on-line maintenance are explained and discussed based on these discussions. After discussions between the utilities and the NRA regarding the position of on-line maintenance in the Technical Specifications (Tech Spec), the NRA will revise the Tech

Spec examination criteria and the utility will examine changes to the Tech Spec, and on-line maintenance will be introduced in FY2025 or later.

Table 1. Schedule for Introduction of On-Line Maintenance

	FY2023	FY2024			FY2025		
Schedule for Introduction	▼CNO-NRA Meeting			▽CNO-NRA Meeting (Schedule)	▽Pilot Plant Application (Schedule)		
	Explanation of CNO-NRA Meeting Results, etc.						
		Explanation to NRA Practitioners			Tech Spec Change Examination		
				Procedures for Revision of Tech Spec Examination Criteria			
						▽ Approval of Change in Tech Spec	
							Sequential Introduction from Pilot Plant

3. ABOUT ON-LINE MAINTENANCE GUIDELINE

The guideline for on-line maintenance provides a series of processes for performing on-line maintenance. In this guideline, probabilistic risk assessment and deterministic risk assessment are used for screening to determine whether work can be performed and for setting risk management measure for the work to be performed. The on-line maintenance is performed in such a way that the total time removed from service in one cycle per system is within the Allowed Outage Time (AOT) for the completion of the required measures.

3.1. On-Line Maintenance Process

On-line maintenance consists of the processes of screening process, planning process, preparation process, execution process, and review process.

In the screening process, the target system is selected, the clearance package is identified, and whether on-line maintenance can be performed is screened after confirming that the on-line maintenance will improve the quality of the work and other benefits.

Screening on whether on-line maintenance can be performed is conducted by Probabilistic Risk Assessment (PRA) (Table 2) and by consultation with experts.

Table 2. Criteria of Screening by PRA [1]

CDF [✓/reactor · year]	CFF [✓/reactor · year]
< 10 ⁻⁴	< 10 ⁻⁵

Screening by consultation of experts will make decisions based on the concept of defense-in-depth and the risk of plant trips etc. Specific examples may include whether there is a possibility of exceeding the AOT, whether there are any problems with redundancy in safety functions, whether the plant requires tests that cannot be performed during operation, whether there is any risk of exposure, and so on.

In addition, on-line maintenance of multiple systems simultaneously may be performed only when the following conditions are satisfied in addition to those listed above.

- In Tech Spec, the action required during a simultaneous removal from service is not a plant shutdown.
- Maintain a sound classification (train) for the safety system of Design Basis (DB) equipment, such as by performing only systems within the same classification (same train).
- The risk level is "green". (detailed in 3.2)

In the planning process, the timing of work should be set after considering work resources (human resources and materials), events such as periodic tests and system switchovers etc., and appropriate reductions in work time.

In the preparation process, work procedures such as operating procedures and maintenance procedures, and schedule should be prepared, risk assessment (detailed in 3.2) should be conducted based on them, and risk management measure (detailed in 3.3) should be established based on the results of the assessment.

In the execution process, isolation of the target system, maintenance work, tests, and restoration of the target system will be performed. During the execution process, the progress of the work and the plant status are monitored promptly, and risk monitoring is conducted. In the event of a contingency, the contingency plan outlined in the risk management measure will be performed.

In the review process, the differences between planned and actual results, the occurrence of and responses to contingencies, and good practices are reviewed by stakeholders as feedback for the subsequent on-line maintenance.

3.2. Risk Assessment

Conduct a risk assessment of internal event and external event, and identify risk level (Table 3).

Table 3. Definition of Risk Level [2]

Risk level	Definition
Red	Level not to perform on-line maintenance
Yellow	Level to perform on-line maintenance upon performing risk management measures to compensate for the functionality
White	Level to perform on-line maintenance upon performing risk management measure
Green	Level to perform risk management according to normal work management

For internal event risk assessment, incremental core damage probability (ICDP) and incremental containment failure probability (ICFP) are calculated using level 1 PRA and level 1.5 PRA in the probabilistic risk assessment, and risk level category is identified. The risk level criteria (thresholds) are shown in Table 4.

Table 4. Risk Level Thresholds for Internal Event PRA [3][4]

Risk level	Threshold ICDP	Threshold ICFP
Red	$>10^{-5}$	$>10^{-6}$
Yellow	$\leq 10^{-5}$	$\leq 10^{-6}$
White	$\leq 5 \times 10^{-6}$	$\leq 5 \times 10^{-7}$
Green	$\leq 10^{-6}$	$\leq 10^{-7}$

For risk assessment of hazard that do not have a PRA model, such as external event, risk is assessed by comparing with the criteria established for hazard increase factors[†] and hazard barrier degradation[‡] in the deterministic assessment, and the risk level category is identified. The risk level criteria are shown in Table 5.

[†] Carrying in combustible materials (internal fire), Inspection of equipment containing cooling water (internal flooding) etc.

[‡] Watertight doors being kept open (physical barrier against internal flooding), Fire detector removed from service (detection function against fire) etc.

Table 5. Risk Level Criteria for External Event

Risk level	Hazard increasing factors	Hazard barrier deterioration
Red	There are hazard increasing factors and/or hazard barrier deterioration, Structure, System, Component (SSCs) with safety functions on standby is affected, and effective risk management measures cannot be set	
Yellow	There are hazard increasing factors and/or hazard barrier deterioration and SSCs with safety functions on standby are affected, but risks equal to that of design basis can be maintained by performing risk management measures	
White	–	
Green	There are no hazard increasing factors and hazard barrier deterioration that could affect SSCs with safety functions on standby	

3.3. Risk Management Measure

Risk management measure is set according to the risk level obtained from the results of risk assessment of each internal event and external event. Policy and examples of actions of risk management measure are shown in Tables 6 and 7. In addition, the contingency plan is established to strengthen the response to increased risk in case of contingency events during on-line maintenance. The items to be considered in the contingency plan are shown in Table 8.

Table 6. Policy of Risk Management Measure According to Risk Level

Risk level	Internal event	External event
Red	On-line maintenance cannot be performed. (Conduct re-assessment upon revising the work plan or work procedures)	
Yellow	<ul style="list-style-type: none"> • Disseminate risk-critical SSCs and procedures, and take measures to maintain and improve reliability. • Perform compensatory measures for risk-critical SSCs functions. • Gain approval from senior management. • Take necessary measures in consideration of defense-in-depth, plant trip, etc. 	<ul style="list-style-type: none"> • For SSCs with safety functions, set effective risk management measures. • Gain approval from senior management. • For SSCs (including support system) included in the same safety functions as equipment subject to on-line maintenance, confirm that there is no hazard increasing factors and hazard barrier deterioration due to other work in the periphery, etc.
White	<ul style="list-style-type: none"> • Disseminate risk-critical SSCs and procedures, and take measures to maintain and improve reliability. • Take necessary measures in consideration of defense-in-depth, plant trip, etc. 	–
Green	<ul style="list-style-type: none"> • Disseminate risk-critical SSCs and procedures. • Take necessary measures in consideration of defense-in-depth, plant trip, etc. 	<ul style="list-style-type: none"> • For SSCs (including support system) included in the same safety functions as equipment subject to on-line maintenance, confirm that there is no hazard increasing factors and hazard barrier deterioration due to other work in the periphery, etc.

Table 7. Examples of Actions of Risk Management Measure

Risk management measure	Examples of actions
Perform measures required by the Tech Spec.	Perform the required actions when the equipment is entered into LCO for removal from service.
Protect SSCs that are critical to the plant configuration during on-line maintenance is in place. (Measures to maintain and improve reliability (Equivalent to risk level “White”))	Suppress the possibility of plant configuration risks significantly increasing, by disseminating and calling attention to systems and compartments important for risk management and work that requires attention to be performed.
Satisfy the effectiveness of the function concerning SSCs included in the same safety function as the equipment subject to on-line maintenance. (Measures to compensate for function (Equivalent to risk level “Yellow”))	Compensate for functions of SSCs that were removed from service with different SSCs, confirm in advance effectiveness of response actions for a scenario expecting SSCs removed from service, and maintain system functions that respond to core damage or PCV damage.

Table 8. Risk Management Measure for Enhancing Response to Contingencies and Examples of Its Actions

Risk management measure for enhancing response to contingencies	Examples of actions
Improve the speed of response to a contingency and the accuracy of decision making by improving the organization's response framework when work is delayed due to a contingency.	<ul style="list-style-type: none"> • Disseminate and confirm notification framework and summoning requirements • Secure night duty notification framework • Stop work and set the deadline to transition to restoration work
Ensure effectiveness of response to an actual contingency and improve its speed, by assuming contingencies that lead to increased risks of internal events and external events assumed during the on-line maintenance work period and determining response actions according to the risk level in advance.	<ul style="list-style-type: none"> • Check the equipment, other than the equipment subject to on-line maintenance, for which on-line maintenance must be stopped and the equipment under on-line maintenance must be restored due to its failure by Tech Spec • Organize procedures for failure that result in unacceptable plant configuration • Set the decision-making process for identifying response actions according to the risk level • Set the number of summoned personnel and notification framework

3.3.1. Details of Risk Management Measure for Internal Event

The following shows the response according to the risk level obtained from the internal event risk assessment results.

At the risk level "green", inform plant personnel of the SSCs, and procedures that have been identified as requiring risk management action, using risk importance measures such as Fussell-Vesely (FV) importance and Risk Achievement Worth (RAW) etc. in the plant configuration at the time of on-line maintenance being performed. In addition, considering the concept of defense-in-depth and plant trip risks, measures such as access restrictions and work restrictions should be performed for equipment deemed necessary.

At the risk level "White", in addition to the measures at the risk level "Green", measures to maintain and improve the reliability of risk critical SSCs and procedures shall be performed. In the plant configuration at the time of on-line maintenance, measures to improve the reliability of SSCs and procedures related to events that have a high FV importance and in which the FV importance has increased from a state in which all safety functions are available, shall be performed. Specific examples are as follows.

- Visual inspections of critical equipment to check condition and close-up records

- Confirmation of the contents of critical operation procedures

In the plant configuration at the time of on-line maintenance, measures to improve the reliability of SSCs related to events that have a high RAW and in which the RAW has increased from a state in which all safety functions are available, shall be performed. Specific examples are as follows.

- Access restrictions to critical equipment, caution signs (work restrictions)

At the risk level "Yellow", in addition to the measures at the risk level "Green" and "White", measures to reduce risk by providing functional compensation to risk-significant SSCs should be performed. In addition, approval from senior management will be obtained.

3.3.2. Details of Risk Management Measure for External Event

The following shows the response according to the risk level obtained from the results of the risk assessment of external event.

At the risk level of "Green", as a management measure against the deterioration of reliability of safety functions including the equipment subject to on-line maintenance, the SSCs and its support system, which have the same functions as those of the equipment subject to on-line maintenance, shall be checked for hazard increase factors and hazard barrier deterioration. In addition, access restrictions and work restrictions are imposed during on-line maintenance.

At the risk level "Yellow", in addition to the measures at the risk level "Green", management are performed for hazard increase factors and hazard barrier deterioration. Examples of risk management measures for hazard increase factors and hazard barrier deterioration are shown in Table 9. In addition, approval from senior management will be obtained.

Table 9. Examples of Risk Management Measure for Hazard Increase Factors and Hazard Barrier Degradation [5]

Impact of work		Examples of risk management measure
Hazard increasing factors		<ul style="list-style-type: none"> • Removal of other dangerous materials • Addition and continuous monitoring of detection system • Additional mitigation equipment and personnel on standby to enable quick response to an event
Hazard barrier deterioration	Impact on physical barrier	<ul style="list-style-type: none"> • Use of temporary barrier in place of hazard barrier (If the temporary barrier ensures enough time for response personnel to mitigate the event, the temporary barrier does not require the same capabilities as the original barrier.) • Continuous monitoring to detect hazard (Continuous monitoring is appropriate only when the external event progress slowly enough to allow for effective response (for example, closing the opened barrier and convening the response team)) • Use of additional detection system to enable early discovery
	Detection equipment removed from service	<ul style="list-style-type: none"> • Use of alternative detection system to detect hazards • Continuous monitoring to detect hazards
	Mitigation equipment removed from service	<ul style="list-style-type: none"> • Alternative mitigation equipment and personnel on standby to enable quick response to an event

4. CONCLUSION

In Japan, the industry as a whole has been taking steps toward the introduction of on-line maintenance, including discussion between utilities and NRA. Discussion is still ongoing, and we will continue to take action to change the Tech Spec, and on-line maintenance will begin at the plant where the Tech Spec change has been completed. The on-line maintenance will be conducted according to the guideline established by the NRRC, which provides information on the process and risk management for the performing on-line maintenance. It enables on-line maintenance to be performed by all utilities in a common manner and at an

appropriate level of safety. The guideline will be revised as necessary after the introduction of on-line maintenance, based on feedback from the results of its application.

References

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