Study on methods for assessing risk importance considering the effects of radiation exposure at the Rokkasho Reprocessing Plant

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ABSTRACT

In the Rokkasho Reprocessing Plant (RRP), it is required by regulation to implement accident measures against specific severe accidents, such as “Loss of cooling function (LOCF)” and “Loss of Hydrogen Scavenging Function (LOHSF)”. The LOCF event may involve about 50 tanks that share common safety system equipment. In addition, some tanks require both cooling and hydrogen scavenging. Therefore, there is a possibility of severe accidents occurring simultaneously in multiple storage tanks and different types of severe accidents. We are conducting a PRA study to identify vulnerabilities associated with equipment and operations to prevent and mitigate severe accidents at reprocessing plants. In this study, we selected the “Multi-unit Event Combinations Approach (MECA)” as an evaluation method. In the reprocessing plant, the impact of radiation exposure in a severe accident varies depending on the risk source (e.g., storage tanks). In addition, some equipment failure affects multiple tanks and/or scenarios (multi-unit events), while some affect a single tank (individual events). For the risk assessment, it is important to use a methodology capable of evaluating the important measures that consider the impacts of radiation exposure. In this study, we referred to the concept of importance based on point estimate of risk and exceedance frequency of consequence described in the ASME/ANS PRA standards for non-light water reactors. In this study, we used Fussell-Vesely (FV) importance as a measure of importance and examined methods for evaluating the importance of both multi-unit events and individual events, considering the impact of radiation exposure.

Keywords: Multi-Unit, Multi-Event, Reprocessing, Risk Importance

I. INTRODUCTION

Probabilistic risk assessment (PRA) is an effective measure to quantitatively understand the risks associated with nuclear facilities. There are a number of PRA evaluation reports and utilization reports covering nuclear power plants.

On the other hand, there are very few PRA evaluation reports targeting reprocessing plants. The reason is thought that the limited number of reprocessing plants and the differences in facility characteristics between nuclear power plants and reprocessing plants. Reprocessing plants handle various types, quantities, and forms of nuclear fuel materials, which are widely distributed across multiple processes. Consequently, as shown in Figure 1, a wide variety of severe accidents are anticipated.

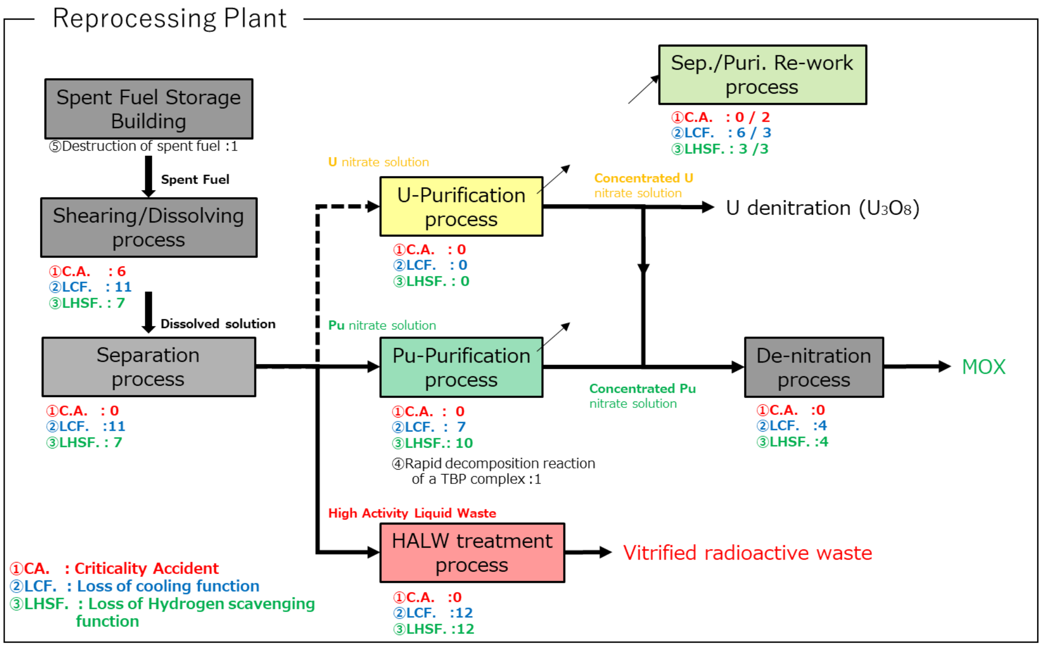


FIGURE 1. The reprocessing process outline and the number of equipment which severe accidents expected to occur

We have implemented various safety measures to prevent severe accidents in compliance with regulatory requirements. To investigate further safety improvements, we are advancing the development of PRA to identify vulnerabilities related to severe accident counter measures. Currently, we are developing internal event PRA models for severe accidents, focusing on "The Loss of cooling function (LOCF)" and "The Loss of Hydrogen Scavenging Function(LOHSF)". In this development, we are developing PRA models for each individual tank. However, since safety equipment related to design basis accidents and severe accidents is shared among multiple tanks, it is necessary to study for PRA methods that can evaluate the simultaneous occurrence of multiple severe accidents (multiple events) across multiple tanks. Therefore, in order to evaluate the simultaneous occurrence of multiple storage tanks and multiple events accidents, the preceding case in which nuclear power plants were targeted was confirmed in the previous studies by the authors[1]. As a result, we selected Multi-unit Event Combination Approach (Hereinafter referred to as "MECA".) as the evaluation method suitable for the application to reprocessing plants. This method does not require the creation or recalculation of event trees and fault trees, and the calculation load is reduced compared with other methods.

In the authors previous study [1], in order to sort out the technical challenge related to the first two items among the following challenges in the application of MECA to actual machines, we studied the case of two tanks, which is the most basic system configuration among multiple storage tanks and multiple events.

Challenge (1): The existence of a large number of multi-unit events in reprocessing plants compared to nuclear power plants

Challenge (2): Large Number of Radioactive Sources (Tanks) have to be evaluated

Challenge (3): Establishment of a Method to Calculate Importance Considering Radiation Exposure Impact

As a result of the examination, we were able to confirm the applicability of MECA in the case of two tanks. Therefore, we were able to organize the issues for further examination of Challenge (1) and (2).

In this study, a method to evaluate the " risk importance of basic events considering the effects of radiation exposure " was studied in order to summarize the technical challenge mentioned above in Challenge (3). The applicability of the proposed method is verified by case studies using the evaluation results of the authors previous study.

II. Evaluation method of importance based on characteristics of reprocessing plants and investigation of precedent cases

II.A. Necessity of importance assessment considering the effects of radiation exposure

In risk-informed decision making for nuclear power plants, importance relative to the occurrence frequency of accidents such as core damage frequency (CDF) and containment failure frequency (CFF) is used as general measures[2] [3].

On the other hand, reprocessing plants have the following features.

(1) There are large number of radioactive sources (storage tanks etc.) that may cause severe accidents, and the type and quantity of radioactive materials contained in these storage tanks differ from tank to tank.

(2) In addition to LOCF and LOHSF, a wide variety of severe accidents, such as Explosion of chemical substances and Criticality, may occur.

The above characteristics affect the "exposure impact on the public" in the event of an accident. For example, assume an accident at two storage tanks (independent of each other) with the same accident frequency. If the effect of radiation exposure from a single storage tank accident is large in either one of the two tanks, the risk, which is the product of the frequency of the accident and the effect at the time of the accident, is different among the tanks even if the accident frequencies are the same. Therefore, in order to advance the study on the identification of vulnerability in the facilities and operations of reprocessing plants using PRA, it is necessary to carry out Challenge (3) "Establishment of a method to calculate importance considering radiation exposure impact" mentioned in the previous chapter.

II.B. Investigation of precedent cases of significance considering radiological consequence.

The ASME/ANS "PRA Standard for advanced Non-light water reactor nuclear power plants" [4] of the United States provides the following two examples of relative significance considering radiological consequence.

(1) Point estimate of risk method

This method evaluates the importance of accident sequences by weighting the occurrence frequency of accident sequences by the exposure effect.

The importance evaluated by this method has the following features.

a. The importance tends to be higher for equipment of those involved in sequences with greater frequency.

b. The importance tends to be higher for equipment of those involved in sequences that has a greater effect on exposure.

c. Equipment involved in frequent but low-impact sequences may result in high importance. For this reason, depending on the magnitude of the exposure effects of interest, equipment of high importance may not necessarily be important in terms of the exposure effects.

(2) Exceedance frequency of consequence method

In this method, the threshold value of the exposure effect (Hereinafter referred to as "reference point".) is determined, and the exceedance frequency of "the sequence in which the exposure effect exceeds the reference point" in the accident sequence is focused. Then, the degree to which the occurrence frequency of each accident sequence group contributes to the excess frequency is calculated as the importance.

The importance evaluated by this method has the following features.

a. The significance for the exposure effect of interest is evaluated.

b. The effects of equipment that only affects sequences with small exposure effects can be eliminated.

c. The reference point for calculating the excess frequency should be set appropriately according to the purpose.

In the ASME/ANS "PRA Standard for advanced Non-light water reactor nuclear power plants", technology neutral PRA methods for reactor types such as molten salt reactors and gas-cooled reactors, where there is no clear definition of core damage, are proposed by using the Level 3PRA evaluation method for existing LWRs. In addition, as mentioned above, examples of importance evaluation considering the effects of exposure are also mentioned. As described in the previous chapter, in PRA for reprocessing plants, it is important to evaluate the radiation exposure impact. Therefore, this standard is a very useful reference. In the previous studies[5], "multi-module interaction" was considered for SMRs. However, it is expected that the number of multiple storage tanks and multiple events corresponding to multi-module interaction will increase in reprocessing plants.

The ASME/ANS evaluation example focus on event sequences occurring in a single reactor core. In contrast, in a reprocessing plant, simultaneous releases from multiple tanks are anticipated, necessitating information on the frequency of event sequences occurring at multiple storage tanks, their aggregated release effects, and importance measures within the event sequences. Therefore, in this study, we established a method to evaluate occurrence frequency of release from multiple tanks, and expanded it to a method to evaluate basic event level risk importance with consideration of exposure effects.

III. Definition of importance analysis for reprocessing plants

Referring to evaluation methods of the significance of the accident sequence exemplified in the ASME/ANS standard in order to simplify the evaluation described in Chapter 2, evaluation methods of the significance of basic events were examined considering the exposure effects in reprocessing plants. It should be noted that the two evaluation methods exemplified in the ASME/ANS standard can achieve a high level of analysis by using the appropriate methods according to the purpose of evaluation. The "(1) Point estimate of risk method" has the advantage of being straightforward, but does not distinguish the importance of SSC that contribute to high frequency but small consequence accidents between those that contribute to low frequency but large consequence accidents. On the other hand, "(2) Exceedance frequency of consequence method" has the advantage that it provides importance with consideration of the magnitude of the consequence or exposure effects of interest. Therefore, a study was made so that both methods can be used as evaluation methods for multiple storage tanks and accident events in RRP.

Method (1): Importance for exposure effect risk (corresponds to (1) Point estimate of risk method of the ASME/ANS standard)

As an importance measure showing the extent to how significantly a specific basic event (Equipment failure, human error, etc.) contributes to the exposure risk from the entire reprocessing plant, the " Fussell-Vesely importance(FV) " of basic events with regards to the exposure risk from the entire reprocessing plant was defined.

The formula for defining the importance of basic event "A" to the exposure effect risk is as follows.

$$I_{Risk}(A) \equiv \frac{R_{total} - R_{total_{QA=0}}}{R_{total}} \tag{1}$$

where

$I_{Risk}(A)$: Risk importance of basic event "A" considering the effects of radiation exposure (-)

Q_A : Probability of occurrence of basic event "A"

R_{total} : The risk of the radiation exposure impact from the entire Reprocessing Plant (mSv/y etc.)

$R_{total_{QA=0}}$: The risk of the radiation exposure impact from the entire Reprocessing Plant when the probability of occurrence of a basic event "A" is set to zero (mSv/y etc.)

Method (2): Importance for the exceedance frequency of reference point (corresponds to ASME standard (2) Exceedance frequency of consequence method)

For accident events that result in exposure effects exceeding a reference point, as an importance measure to show the degree of contribution of a specific basic event, the FV of the basic event with regards to "the exceedance frequency of exposure effects" in the entire reprocessing plant was defined.

We defined "the excess frequency of exposure effects" as follows

The exceedance frequency of exposure effects: Frequency of accident events involving the release of radioactive material that exceed the reference point

The formula for defining the importance of basic event "A" relative to the exceedance frequency of exposure effect "X" is as follows.

$$I_{DC}(A, X) \equiv \frac{F_{total}(X) - F_{total}(X)_{QA=0}}{F_{total}(X)} \tag{2}$$

where

$I_{DC}(A, X)$: Importance of basic event "A" relative to the exceedance frequency of exposure effect "X" (-)

X : Magnitude of the radiation exposure impact(mSv etc.)

Q_A : probability of occurrence of the basic event "A" (-)

$F_{total}(X)$: The exceedance frequency of exposure effect "X" in the entire reprocessing plants (/ year)

$F_{total}(X)_{QA=0}$: The exceedance frequency of exposure effect "X" in the entire reprocessing plants when the probability of occurrence of a basic event "A" is set to zero(/ year)

IV. Study of calculation method for risk importance considering the effects of radiation exposure

IV.A. Assumptions applied in this study

On the premise of using the analysis results by MECA, we examined the method to evaluate the accident frequencies of the system described chapter I, and the method to evaluate risk importance with consideration of radiation exposure. Methodologies are respectively described in IV.B and IV.C,.

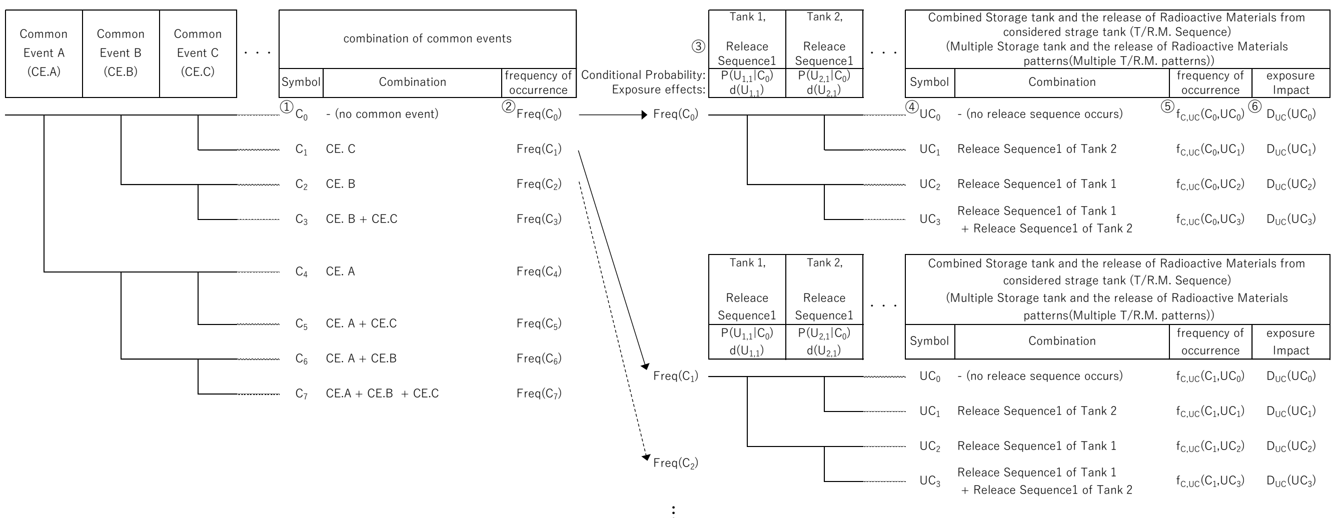
In this study, as the simplest case, we focused on two Storage tanks and considered scenarios where release sequence of radioactive materials in each Storage tank (storage Tank and the release of Radioactive Materials (T/R.M.) Sequence) occurs simultaneously or independently.

In addition to the above, the following assumptions were also applied in this study to simplify the evaluation.

a. The probability of occurrence of each T/R.M. Sequence is assumed not to be affected by the occurrence of the other T/R.M. Sequence (There is no causal influence between T/R.M. Sequences).
b. Multi-unit events are assumed to be independent of each other.
c. It is assumed that the occurrence probability of the multi-unit event is not affected by the occurrence of a particular T/R.M. Sequence.
d. The radiation exposure impact of "a combination of T/R.M. Sequences (Hereinafter referred to as Multiple T/R.M. patterns.) " are assumed to be the simple sum of the exposure effects when each T/R.M. Sequences included in Multiple T/R.M. patterns occurs.

IV.B. Evaluation scheme of MECA and evaluation method of occurrence frequency

Figure 2 shows the concept of calculating the frequency of occurrence by MECA, the frequency of occurrence of each Multiple T/R.M. patterns for each multi-unit event scenarios, and the relationship between the radiation exposure impacts when each Multiple T/R.M. patterns occurs.



Locat	Symbol	Description	Supplement
①	i	Sequence number for the combination of common events	-
	C_i	Symbol representing the i-th common event scenarios	-
②	Freq(C_i)	Frequency of ommon event scenarios Ci (/year)	Values calculated by the MECA
③	j	Serial number for the storage tank	-
	k	Serial number for the releace sequence	-
	$U_{j,k}$	Symbol representing the k-th release sequence in the j-th reservoir	-
	$P(U_{j,k}\|C_i)$	Conditional probability of Uj,k occurring when Ci occurs (-)	Values calculated by the MECA
	$d(U_{j,k})$	Radiation exposure impact when Uj,k occur (mSv, etc.)	Value set based on the results of the radiation exposure impact
④	n	Sequence numbers for Multiple T/R.M. patterns	-
	UC_n	Symbol representing the n-th Multiple Storage tank and the release of Radioactive Materials patterns(Multiple T/R.M. patterns))	-
⑤	$f_{C,UC}(C_i,UC_n)$	Frequency of Multiple T/R.M. patterns UCn with occurrence of common event events Ci (/year)	-
⑥	$D_{UC}(UC_n)$	Exposure effects when Multiple T/R.M. patterns UCn occur (mSv, etc.)	Values calculated according to the following $D_{UC}(UC_n) = \sum_{U_{j,k} \in UC_n} d(U_{j,k})$

FIGURE 2. Relationship between analysis results from MECA, frequency of Multiple T/R.M. patterns, and radiation exposure impact

As shown in Figure 2, for each multi-unit event scenario "Ci", several Multiple T/R.M. patterns may occur. In the absence of causal dependency between T/R.M. Sequence, the frequency of occurrence of Multiple T/R.M. patterns with the occurrence of any T/R.M. Sequence can be calculated by the following equation:

$$f_{C,UC}(C_i, UC_n) = Freq(C_i) \times \prod_{U_{j,k} \in UC_n}^{U_{j,k}} P(U_{j,k}|C_i) \times \prod_{U_{j,k} \notin UC_n}^{U_{j,k}} \{1 - P(U_{j,k}|C_i)\} \quad (3)$$

where
n : identification number for Multiple T/R.M. patterns
UC_n: n-th Multiple T/R.M. pattern
$f_{C,UC}(C_i, UC_n)$: Frequency of Multiple T/R.M. patterns with occurrence of multi-unit event scenario ”Ci”
$Freq(C_i)$: Frequency of multi-unit event scenario ”Ci”
$\prod_{U_{j,k} \in UC_n}^{U_{j,k}}$: Symbol representing the multiplication of all T/R.M. Sequence “Uj,k”'s in Multiple T/R.M. pattern ”UCn”
$\prod_{U_{j,k} \notin UC_n}^{U_{j,k}}$: Symbol representing the multiplication of all T/R.M. Sequence “Uj,k”'s in “Uj,k” that are not in Multiple T/R.M. pattern ”UCn”

IV.C. Assessing the Exposure effect risk and Importance of exposure effect risk

(1) Consideration of exposure effect risk

Since exposure effect risk is the product of “frequency of occurrence of the accident” and “the radiation exposure impact”, exposure effect risk for the occurrence of Multiple T/R.M. pattern ”UCn” accompanied by the occurrence of any multi-unit event scenarios(Ci) is as shown in Eq. (4).

The occurrence probability of Multiple T/R.M. patterns differs depending on multi-unit event scenarios. Also, the radiation exposure impact differs according to Multiple T/R.M. patterns. Therefore, it is necessary to calculate the frequency, the radiation exposure impact and exposure effect risk for each multi-unit event scenarios and Multiple T/R.M. patterns.

$$r_{C,UC}(C_i, UC_n) = f_{C,UC}(C_i, UC_n) \times \sum_{U_{j,k} \in UC_n}^{U_{j,k}} d(U_{j,k}) \quad (4)$$

where
$r_{C,UC}(C_i, UC_n)$: The exposure effect risk of Multiple T/R.M. patterns””UCn with development of multi-unit event scenario””Ci(mSv/y etc)
$f_{C,UC}(C_i, UC_n)$: Frequency of Multiple T/R.M. patterns with occurrence of multi-unit event scenarios ” Ci”(/y)
$d(U_{j,k})$: The radiation exposure impact when T/R.M. Sequence ”Uj,k” occurs
$\sum_{U_{j,k} \in UC_n}^{U_{j,k}}$: Symbol representing the sum of all T/R.M. Sequence “Uj,K”'s in Multiple T/R.M. patterns

In addition, when exposure effect risk calculated by equation (4) is summed for all Multiple T/R.M. patterns and all multi-unit event scenarios, the overall exposure effect risk is obtained.

$$R_{total} = \sum_i \sum_n r_{C,UC}(C_i, UC_n) \quad (5)$$

where
R_{total} : Overall exposure effect risk of reprocessing plant

(2) Consideration of the exceedance frequency of exposure effects

In evaluating the exceedance frequency of exposure effects, the examination proceeded as follows,

a. Set the magnitude of the radiation exposure impact X as criteria for evaluating the exceedance frequency according to the radiation exposure impact when Multiple T/R.M. patterns ”UCn” occurs.
b. Sum all frequencies of Multiple T/R.M. patterns ”UCn” that exceed the magnitude of the radiation exposure impact X.
c. When the frequency of occurrence in equation (3) is summed for all multi-unit event scenarios ”Ci” and the radiation exposure impact ”X”, the frequency of exceedance exposure effects for the entire reprocessing plant can be obtained using the equation below.

$$F_{total}(X) = \sum_i \sum_{D_{UC}(UC_n)>X}^{n} f_{C,UC}(C_i, UC_n) \tag{6}$$

where

$F_{total}(X)$: Exceedance frequency of the radiation exposure impact X in the entire reprocessing plant (/ year)

X : Magnitude of the radiation exposure impact

$\overset{n}{D_{UC}(UC_n) > X}$: Symbol representing the summation of the series number n for which the exposure effect due to Multiple T/R.M. patterns"UCn" exceeds the radiation exposure impact "X"

$f_{C,UC}(C_i, UC_n)$: Frequency of Multiple T/R.M. patterns with occurrence of multi-unit event scenarios" Ci"(/y)

$D_{UC}(UC_n)$: Exposure effects in the event of Multiple T/R.M. patterns "UCn"

In order to calculate the importance based on equations (1) and (2), $R_{total_{QA=0}}$ and $F_{total}(X)_{QA=0}$ is required in addition to $R_{total}$and$F_{total}(X)$. $R_{total_{QA=0}}$ and $F_{total}(X)_{QA=0}$ is obtained by recalculating Equations (3) to (6) in the same manner as in previous section a. and section b, setting the probability of occurrence of the basic event to zero.

In the PRA model of a reprocessing plant, multi-unit event(basic events associated with multiple tanks/events) and individual event(basic events associated only with a single tank/event) exist. Since the multi-unit event is included in the multi-unit event scenario, $R_{total_{QA=0}}$ and $F_{total}(X)_{QA=0}$ can be calculated only by recalculating $Freq(C_i)$ with the probability of occurrence of the basic event set to zero.

On the other hand, since individual events are not included in the multi-unit event scenario, they cannot be calculated in the same way as multi-unit events. At present, if the assumption which referred to in 4.(1) "There is no causal influence between T/R.M. Sequences" is applied, the importance for exposure effect risk of individual events with T/R.M. Sequence can be calculated by the following equation.

$$I_{Risk}(A) = \frac{d(U_{J,K}) \times f_{SU}(U_{J,K}) \times FV_{SU}(A, U_{J,K})}{R_{total}} \tag{7}$$

where

$d(U_{J,K})$: Exposure effects in the event of Multiple T/R.M. Sequence "Uj,k" (mSv etc.)

$f_{SU}(U_{J,K})$: Analysis result of frequency of T/R.M. Sequence "Uj,k" using the single-unit PRA model (/ year)

$FV_{SU}(A, U_{J,K})$: Analysis result of FV for individual events "A" of T/R.M. Sequence "Uj,k" using the single-unit PRA model

V. The case study of risk importance considering the effects of radiation exposure

(1) Explanation of evaluation system for trial evaluation

Using the evaluation system set for the calculation of the frequency of simultaneous accidents (as reported in the authors previous study [1]), we conducted the analysis of the risk importance discussed in the previous chapter. Outline of the event and evaluation case used for the methodology verification is shown below.

a. Target Events for Verification

(a) Loss of Cooling Function in the Safety Cooling Water System

The safety cooling function prevents radioactive solution in the tank from boiling due to decay heat. If the cooling function is lost, the temperature of the solution increases and lead to boiling. When the solution boils, radioactive materials will be transferred along with vapor and release into the atmosphere. The safety cooling water system consists of an internal loop (including the internal loop pump, intermediate heat exchanger, and connecting pipes) and an external loop (including the external loop pump, cooling tower, and connecting pipes). From the perspective of accidents in multiple tanks, it has the characteristic of sharing an external loop among all tanks. The system configuration is illustrated in Figure 3.

(b) Loss of Hydrogen scavenging Function in the Safety Compressed Air System

The hydrogen generated by the radiolytic decomposition of the radioactive solution in the tank is scavenged to the ventilation system by compressed air. If the scavenging function is lost, the hydrogen concentration increases and lead to hydrogen explosion. When hydrogen explosion occurs, radioactive materials are released into the atmosphere. The safety compressed air system consists of hydrogen scavenging pipes and valves, and an air compressor that produces compressed air. The air compressor is cooled by the safety cooling water system. The related system configuration is illustrated in Figure 3.

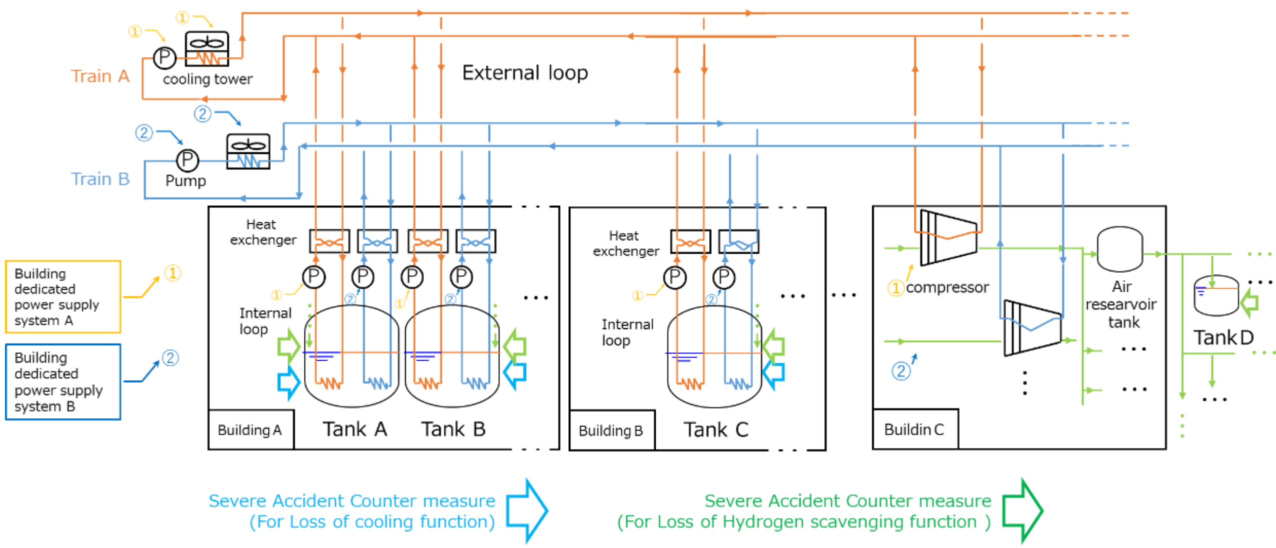


FIGURE 3. Illustration of systems related to Loss of Cooling Function and Loss of Hydrogen scavenging Function

b. Evaluation Case

Evaluation Case 1:Loss of cooling function events in the same building.

We focused on the event of loss of cooling function in Tank A and Tank B, both located in Building A, as illustrated in Figure 3. In this case, the fraction of accidents occurring in individual tank is very small, and the fraction of accidents occurring simultaneously in two tanks is more than 99% [1].

Evaluation Case 2: Loss of cooling function event and loss of hydrogen scavenging function event

We focused on the events of loss of cooling function in Tank A located in Building A, and loss of hydrogen scavenging function in Tank C in Building B, as illustrated in Figure 3. In this case, the fraction of accidents occurring in each individual tank is relatively large, and the percentage of accidents occurring simultaneously in two tanks is approximately 1% [1].

(2) The case study analysis results of risk importance

a. Results of importance for exposure effect risk

The top 10 basic events(Equipment failure, human error, etc.) with the highest risk importance for each evaluation case are shown below.

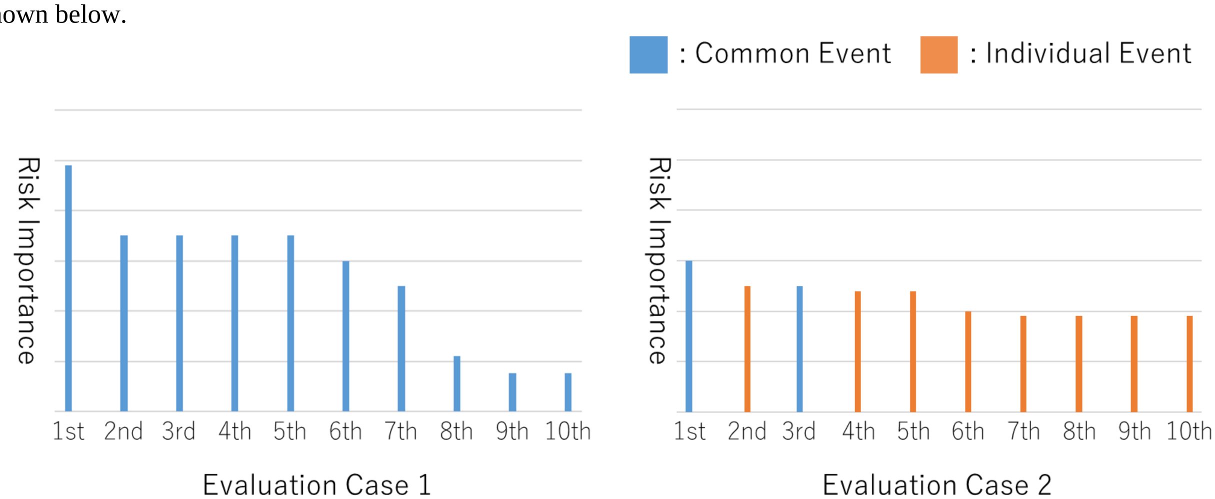


FIGURE 4. The importance for exposure effect risk of each evaluation case (top 10 basic events)

In evaluation case (1), the top 10 events were all multi-unit events (mitigation measures commonly used in the two storage tanks). The two storage tanks in evaluation case (1) share many equipment, and the scenario in which the two set of T/R.M. Sequence occur simultaneously due to the occurrence of a multi-unit event was dominant. Therefore, the risk importance of multi-unit events tended to be high.

On the other hand, in the evaluation case(2), the top events were individual events (mitigation measures used separately for each storage tank) except for the first and third. The two storage tanks in evaluation case (2) share relatively little number of equipment, and the contribution of the scenario in which two T/R.M. Sequences occur separately is larger than that in Case (1). Therefore, the risk importance of individual events was also high. As mentioned in (1), the fraction of simultaneous occurrence in two T/R.M. Sequences is high in the evaluation case (1), and the fraction of simultaneous occurrence in two T/R.M. Sequences is low in the evaluation case (2). Therefore, the trend of the case study results in this study is consistent with the trend expected.

b. Results of importance for the exceedance frequency of reference point

Fig. 5 shows the result of the importance for the exceedance frequency of reference point when the reference points are set as shown in Table 1 for the evaluation case (1). Table 1 shows correspondence between reference points and T/R.M patterns categorized by whether an accident occurred in storage tank A or B, or both. Here, the “reference points” indicates the threshold value of the exposure effect depending on the occurrence of the accident. The results of evaluation case (2) is not shown in this paper because most of the basic events with high risk importance are individual events, and the evaluation method examined in this study cannot calculate the risk importance of individual events.

TABLE I. Reference Points to evaluate exceedance frequency

Reference Points	Multiple T/R.M. patterns (1: occur, 0 : no-occur)	
	Tank A (LOCF)	Tank B(LOCF)
1	0	0
2	1	0
	0	1
3	1	1

As shown in Fig. 5, the importance for the exceedance frequency of reference point was calculated. In evaluation case (1), there was no difference in the exceedance frequency at each reference point because the fraction of simultaneous occurrence of accidents in two storage tanks within the total accident frequency was high, majority of the probable accident scenarios in case (1) involves release from two tanks.

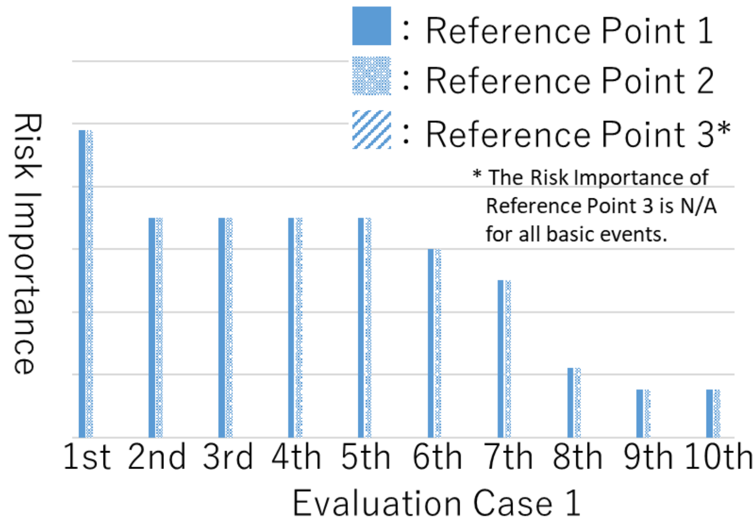


FIGURE 5. The Importance for the exceedance frequency of reference point (top 10 basic events) for the Evaluation Case 1.

VI. CONCLUSION

In this paper, calculation method of risk importance considering the effects of radiation exposure was examined using the evaluation result of MECA, to promote the utilization of risk informed decision making based on the characteristics of reprocessing plant.

As a result of the examination, we developed methods to evaluate "importance for exposure effect risk" and "importance for exceedance frequency by exposure effect category" for reprocessing plants, referring to the ASME/ANS PRA standards for non-light water reactors which is a precedent case. In addition, it was confirmed that the importance in the case of two T/R.M. Sequences could be calculated by case study evaluation using the developed evaluation method. Using the risk importance evaluated by the two methods, system and component important not only in terms of accident frequency but also from the viewpoint of exposure effect from multi-sources can be assessed. This will contribute to a higher level of risk-informed decision making for future reprocessing plants.

On the other hand, in order to simplify the evaluation, the number of storage tanks were limited to two, and consequential effects of release that can impact accident progression or system reliability were omitted. In the future, we will streamline these limitations. Furthermore, we will further explore to expand this methodology to evaluate risk importance considering the effects of radiation exposure when the evaluation target is expanded to three or more T/R.M. Sequence, and also to evaluate importance of individual events.

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