Study of risk analysis methodology by using the insight from Internal flooding PRA

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Abstract: Kansai Electric Power Co., Ltd. (KEPCO) is continuously studying the use of quantitative risk insights from Internal Flooding PRA (IFPRA) to improve the plant safety. The results of risk analysis by using IFPRA will be reflected in a "Safety improvement Assessment Report (SAR)" in the future. The SARs by KEPCO in the past, it has been conducted PRAs for internal events, earthquakes, and tsunamis, and risk analysis has been conducted with referring to the standard published by Atomic Energy Society of Japan (AESJ), "Implementation Standard Concerning Preparation, Maintenance and Improvement of Severe Accident Management in Nuclear Power Plants: 2013". Since risk analysis utilizes the result from IFPRA, which covers a very large number of scenarios, the risk analysis should be performed from multiple perspectives. In this paper, we summarize results from the study of the basic concepts for conducting future IFPRA and its risk analysis in a systematic manner.

Keywords: PRA, Internal Flooding, Safety improvement Assessment Report, Risk Analysis

1. INTRODUCTION

Kansai Electric Power Co., Ltd. (KEPCO) is continuously studying the use of quantitative risk insights from Internal Flooding PRA (IFPRA) to improve the plant safety. The results of risk analysis by using IFPRA will be reflected in a "Safety improvement Assessment Report (SAR)" in the future. The SARs by KEPCO in the past, it has been conducted PRAs for internal events, earthquakes, and tsunamis, and risk analysis has been conducted with referring to the standard published by Atomic Energy Society of Japan (AESJ), "Implementation Standard Concerning Preparation, Maintenance and Improvement of Severe Accident Management in Nuclear Power Plants: 2013". Since risk analysis utilizes the result from IFPRA, which covers a very large number of scenarios, the risk analysis should be performed from multiple perspectives.
Therefore we were organized the following information to consider the method of identifying important accident sequences in IFPRA as a basic approach to systematically conduct Internal Flooding risk analysis based on the results from IFPRA. Subsequently, based on the characteristics of IFPRA, with reference to the following, we studied the method of identifying important accident sequences in IFPRA. Details will be provided in the sections below.

- Identifying important accident sequences in domestic existing PRA.
- Identifying important accident sequences through PRA in the United States.

2. Identifying important accident sequences in domestic existing PRA

In the existing domestic PRA (internal events, earthquakes, and tsunamis), the main scenarios and their causes leading to core damage and containment vessel failure are analyzed and additional measures for safety enhancement are being considered with the aim of further improving the safety of the current plant. To give priority to additional measures for accident sequences with significant risk contribution, we have organized the risk indicators under the current plant conditions and analyzed the following indicators. Then, using the flow shown in Figure 2-1[1], we selected accident sequence groups and containment vessel failure modes to be considered for additional measures.

- CDF for each accident sequence group
- Contribution of each event to the total CDF
- CFF of each containment vessel failure mode
- Contribution of each event to the total CFF

In the selection process, reference is made to the "Implementation Standard Concerning Preparation, Maintenance and Improvement of Severe Accident Management in Nuclear Power Plants: 2019"[2] issued by the Atomic Energy Society of Japan (hereafter referred to as the SAM standard). The key points for identifying important accident sequences in the SAM standard are shown in 2.1.

In addition, in the existing domestic PRA (internal events, earthquakes, and tsunamis), accident sequence groups are set as shown in Table 2-1.

2.1. The key points for identifying important accident sequences in the SAM standard

In Section "5.3.1.3 Identifying important accident sequences by Probabilistic Risk Assessment" of the SAM Standard, the following steps are presented for identifying important accident sequence groups and determining important accident sequences based on the frequency of occurrence for each group:

a) Grouping of accident sequences:

Group accident sequences in a way that ensures all accident sequences relevant to important assumed events are included, and that the plant response and system damage leading to end states such as core damage or fuel damage are similar. Consideration should also be given to ensuring that the groups are mutually independent, with no duplication of accident sequences.

b) Screening based on Frequency of Accident Sequence Groups:

Establish screening criteria based on the magnitude of occurrence frequency for each accident sequence group, or the percentage of occurrence frequency relative to the total occurrence frequency of all accident sequences. Perform screening and extract important accident sequence groups that require accident management.

c) Identification of Important Accident Sequences within Important Accident Sequence Groups:

Analyze accident sequences within the accident sequence groups that exceed the screening criteria established in step b) to identify important accident sequences based on their contribution to the total occurrence frequency of all accident sequences.

In addition, in Appendix G of SAM Standard, "Concept for Identifying Important Accident Sequences by Probabilistic Risk Assessment within Japan", screening criteria for the occurrence frequency of accident sequence groups related to core damage frequency resulting from internal events within Japan can be set as follows:

a) If the core damage frequency for a specific accident sequence group is equal to or greater than 1×10^{-6} per reactor-year, it is considered as an important accident sequence group.

b) If the core damage frequency for a specific accident sequence group is equal to or greater than 1×10^{-7} per reactor-year, and the core damage frequency for that sequence group is 20% or more of the total core damage frequency from internal events, it is considered as an important accident sequence group.

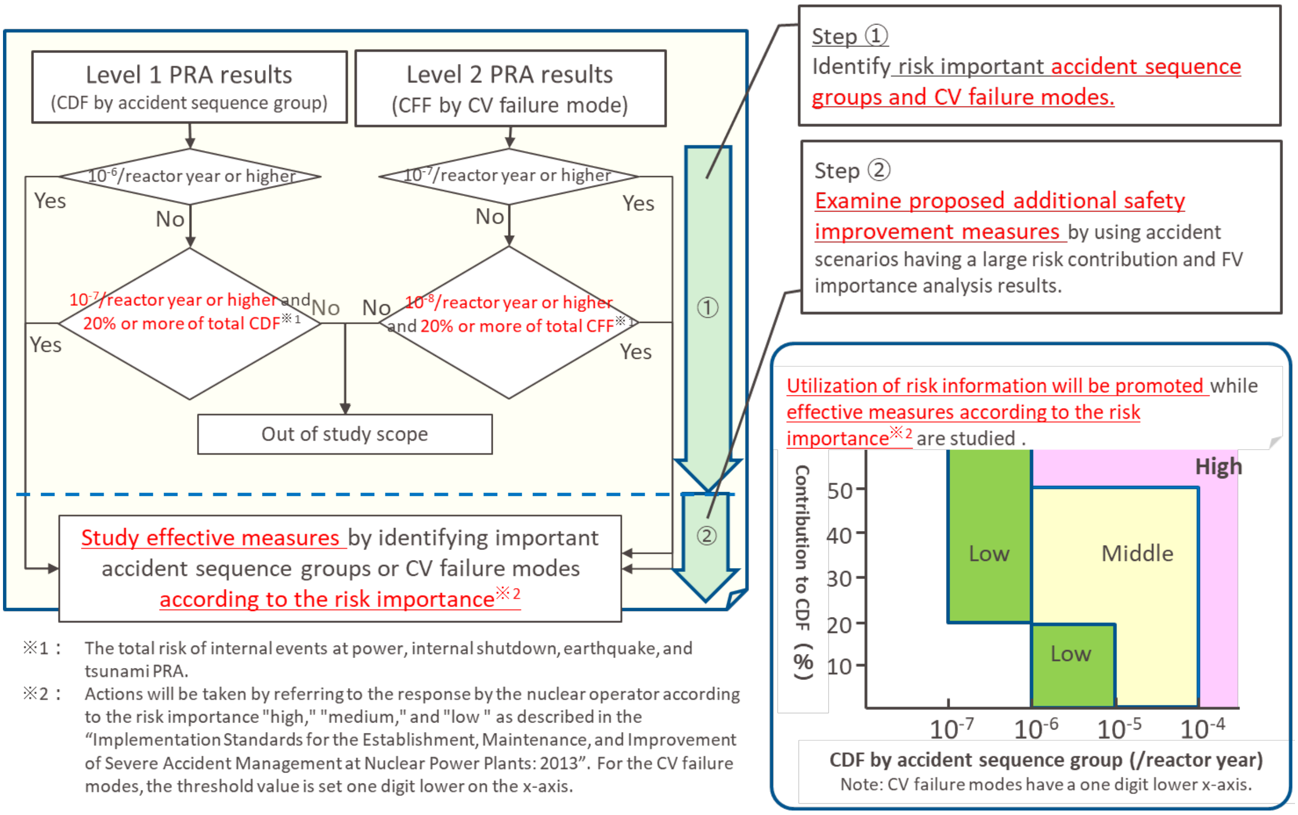

Figure 2-1: Flow for Selecting Additional Measures in Domestic Existing PRA [1]

Table 2-1: Accident Sequence Groups in Domestic Existing PRA (Internal Events, Earthquakes, and Tsunamis)

Accident sequence group	Internal event(at power)	Earthquakes	Tsunamis
Loss of secondary system heat removal	○	○	○
Station blackout	○	○	○
Loss of CCW cooling	○	○	○
Loss of CV heat removal	○	○	○
Loss of reactor shutdown function	○	○	-
Loss of ECCS water injection	○	○	○
Loss of ECCS recirculation	○	○	○
CV bypass	○	-	-
Damage to reactor building	-	○	-
CV failure	-	○	-
Multiple steam generator tube ruptures	-	○	-
Multiple signal system failures	-	-	○

○ Designate as an accident sequence group
- Not designated as an accident sequence group

3. Identifying important accident sequences through PRA in the United States

The NEI guide [3] provides a method for identifying important accident sequences, which is the same as the identification method of important accident sequences in the SAM Standard described in Section 2.1. Other notable points in grouping accident sequences, as stated in the NEI guide, are as follows:

- Each accident sequence group should be made up of an initiating event plus a set of plant faults.
- It is sometimes practical to group sequences with a common initiator as a separate sequence group even though the functional response may vary somewhat among accidents.
- Past PRAs have generally been successful in grouping their results into 10 to 15 group definitions for the purposes of reporting and evaluating results.

In the NEI guide, "Appendix C EXAMPLE ACCIDENT SEQUENCE GROUPINGS FOR IPE OF EXTERNAL EVENTS," an example is provided for defining accident sequence groups based on initiating events caused by earthquakes or fires. Additionally, in the SAM Standard, "Appendix F EXAMPLES OF IDENTIFICATION OF IMPORTANT ACCIDENT SEQUENCES IN US IPEEE BASED ON PROBABILISTIC RISK ASSESSMENT," an example is given for the identification of important accident sequences related to earthquakes and fires as a result of the IPEEE evaluation of the Columbia Nuclear Power Plant. In this example, earthquakes are considered as accident sequences involving specific mitigating function failures (combinations of initiating events and specific mitigating function failures), while fires are generally determined on a regional basis, with specific combinations of initiating events and mitigating function failures set for each region.

4. Methods for identifying important accident sequences in IFPRA

As mentioned in Chapter 2, important accident sequences in existing domestic PRA were identified with reference to the NEI guide (SAM Standard). Additionally, as mentioned in Chapter 3, the identification of important accident sequences through PRA is also conducted by the U.S. IPEEE with reference to the NEI guide. Accordingly, it is appropriate to follow the NEI guide (SAM Standard) in identifying important accident sequences in IFPRA.

Therefore, we studied methods for identifying important accident sequences in IFPRA as a basic approach to systematically conduct Internal Flooding risk analysis based on the results from IFPRA according to the NEI Guide (SAM standard), based on the characteristics of IFPRA. The study was divided into the following sections. Details are given in the following sections.

- Grouping of accident sequences in IFPRA
- Screening of accident sequence groups based on the occurrence frequency

4.1. Grouping of accident sequences in IFPRA

We studied how to group accident sequences in IFPRA. The results of the study are presented below. The concept of accident sequence grouping, the concept of loss of mitigation function in accident sequence grouping, and the unit of accident sequence grouping are shown in 4.1.1 through 4.1.3.

[Grouping of accident sequences in IFPRA]
Accident sequence groups in IFPRA are basically the same as those in the internal event PRA, with some accident sequence groups specific to IFPRA. In IFPRA, grouping is carried out by the unit of the flooding scenario due to the loss of mitigation functions caused by internal flooding.

4.1.1. Concept of accident sequence grouping

As shown in Table 2-1, in domestic seismic PRA and tsunami PRA, the accident sequence groups in internal events PRA are used as a basis, with some accident sequence groups specific to seismic PRA and tsunami PRA respectively. For the sake of consistency and comparison, it is appropriate to follow the same approach for IFPRA as for seismic PRA and tsunami PRA. This means that the accident sequence groups in internal events PRA will serve as a basis, and specific accident sequence groups for IFPRA will be set as necessary.

4.1.2. Concept of loss of mitigation function in accident sequence grouping

The purpose of identifying important accident sequences, as stated in Chapter 2, is to efficiently improve the safety of the current plant. The additional measures for enhancing safety derived from IFPRA are primarily aimed at addressing internal flooding (such as reducing the probability of important equipment being lost due to internal flooding and reducing the frequency of internal flooding events). Therefore, the grouping of accident sequences is based on the loss of mitigation functions caused by internal flooding, rather than random equipment failures or human errors.

4.1.3. Unit of accident sequence grouping

According to the requirements for "accident sequence grouping" in the NEI Guide (SAM Standard), there are three points to be considered:

（1） Plant responses and system damages leading to end states such as core damage or fuel damage should be similar within each accident sequence group.
（2） Each accident sequence group should consist of a set of initiating events and the corresponding loss of mitigation functions.
（3） Groups should be mutually exclusive, with no overlapping of accident sequences.

In the case of IFPRA, a flooding scenario, which is the smallest unit for the evaluation, consists of the following elements:

- Flooding location (area)
- Flooding source system
- Scale of flooding (flooding flow rate)
- Possibility to stop flooding (success or failure)

Therefore, a flooding scenario can be considered as representing the plant's response and system damage leading to end states. Grouping by the unit of flooding scenario satisfies the requirements of (1) and (2). Additionally, since the flooding scenario is the smallest unit in IFPRA, ensuring that each flooding scenario is included in one of the accident sequence groups will fulfill the requirement of (3).

4.2. Screening based on occurrence frequency of accident sequence groups

As described in Chapter 2, in the existing domestic PRA, accident sequence groups to be considered for additional measures are selected using the flowchart shown in Figure 2-1. The flow shown in Figure 2-1 is consistent with the screening criteria of NEI guide and SAM standard, and it is also used in internal events, earthquakes, and tsunami PRAs in domestic safety improvement evaluations. Therefore, we will apply it to IFPRA as well.

Note that, even for flooding scenarios included in the same accident sequence group, the extracted additional measures may differ depending on factors such as the flooding source system, initiating events, and loss of mitigation functions. Therefore, the accident sequence groups are further subdivided into subgroups based on the following points and consider additional measures. The flow of considering additional measures are shown in Figure 4-1.

- Flooding source system:
  Additional measures may differ depending on whether the flooding source system is a firewater system, in which initiating events do not occur directly and/or mitigation functions are not lost due to direct impacts.
- Cause of initiating events and cause of loss of mitigation functions:
  Additional measures for safety improvement can be classified into measures that mitigate direct impacts and measures that mitigate indirect impacts. Therefore, even for the same initiating event, the extracted additional measures may differ depending on whether the initiating event occurs due to direct impacts or indirect impacts. The same applies to the mitigation functions lost due to flooding impacts.
- Equipment that causes indirect impacts:
  Additional measures may differ depending on the equipment that causes indirect impacts.

Here,

- Direct impacts:
  The impacts caused by the loss of fluid from the system where flooding occurs, affecting the flooding source system.
- Indirect impacts:
  The impacts caused by the released fluid on the areas and SSCs.

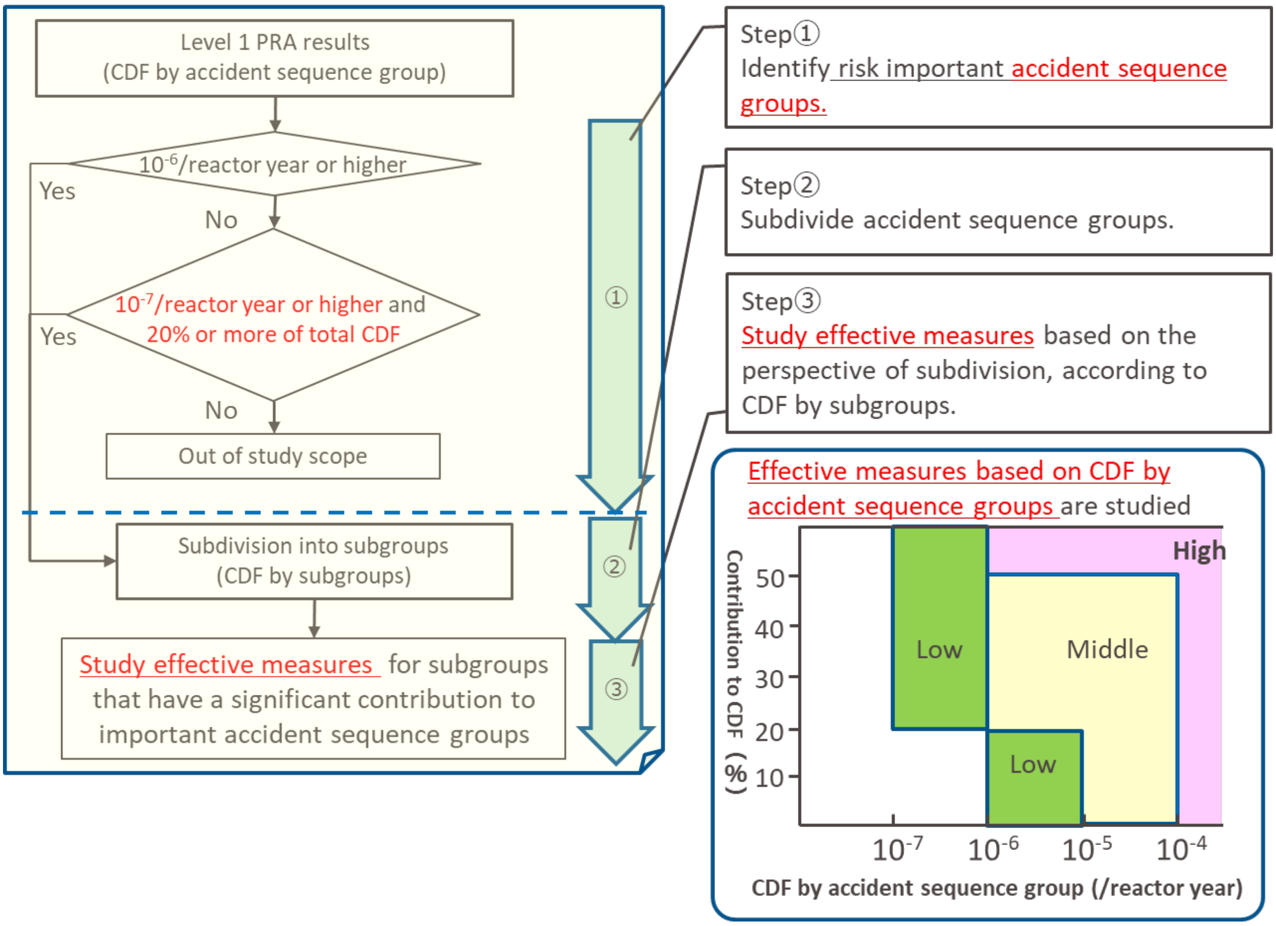

Figure 4-1: The flow of considering additional measures in IFPRA

5. Example of identifying important accident sequence groups in IFPRA

We grouped flooding scenarios as described in section 4.1. The results of this grouping are presented in Table 5-1. The Accident Sequence Group, Total Loss of Safety-Related High Voltage AC Bus was individually set as an accident sequence group specific to IFPRA, considering that the frequency of occurrence due to internal flooding effects is greater than that of occurrence due to random factors.

Table 5-1: Example of Accident Sequence Groups

No.	Accident Sequence Group
1	Total Loss of Safety-Related High Voltage AC Bus
2	Loss of secondary system heat removal
3	Loss of CCW cooling
4	Loss of ECCS water injection
5	Negligible Impact from Flooding

6. CONCLUSION

We studied methods for identifying important accident sequences in IFPRA as a basic approach to systematically conduct Internal Flooding risk analysis based on the results from IFPRA with reference to the following.

- Identifying important accident sequences in domestic existing PRA.
- Identifying important accident sequences through PRA in the United States.

Specifically, we studied the grouping method of accident sequences in IFPRA and screening method based on occurrence frequency of accident sequence groups.

Acknowledgements

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References

[1] The Kansai Electric Power Co. Takahama Unit 3 Fourth Safety improvement Assessment Report, 2023.
[2] The Atomic Energy Society of Japan "Implementation Standard Concerning Preparation, Maintenance and Improvement of Severe Accident Management in Nuclear Power Plants: 2019", 2019.
[3] NEI Severe Accident Issue Closure Guidelines (NEI 91-04 Revision 1), 1994.