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A Study of Risk Evaluation Methodology Selection for the External Hazards

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ABSTRACT

Since the accident at Fukushima Daiichi Nuclear Power plant caused by the Great East Japan Earthquake in March 2011, there has been growing demands for assessing the effects of external hazards, including natural events, such as earthquake and tsunami, and external human behaviours, and taking actions to address those external hazards. The newly established Japanese regulatory requirements claim design considerations associated with external hazards. The primary objective of the risk assessment for external hazards is to establish countermeasures against such hazards rather than grasping the risk figures. Therefore, applying detailed risk assessment methods, such as probabilistic risk assessment (PRA), to all the external hazards is not always the most appropriate. Risk assessment methods can vary in types including qualitative evaluation, hazard analysis (analyzing hazard frequencies or their influence), and margin assessment.

The Risk Technical Committee of Atomic Energy Society of Japan comprehensively identified the external hazards which had potential risks bringing to the nuclear power plants, and has established the implementation standard for the identification of assessment methods for risks associated with external hazards.

This paper discusses the comprehensive and systematic identification process described in the implementation standard which has potential risks leading to core damage, and the approaches of selecting an appropriate assessment method for each external hazard. This paper also describes some practical applications of specific risk evaluation methodology selection.

KEYWORDS

External hazards, Risk evaluation, methodology, PRA

1. INTRODUCTION

The accident at Fukushima Daiichi nuclear power plant followed the Great East Japan Earthquake in March 2011, which resulted in growing concerns for the consideration of external hazards. For controlling the nuclear risk whole spectrum of the external hazards are to be adequately investigated and assessed using appropriate methodologies. The scope of the external hazards includes natural events as well as external man-made events to address the nuclear risk management.

The Risk Technical Committee under Atomic Energy Society of Japan (AESJ) has been discussing the approaches for selecting an appropriate risk assessment technique for the external events, and has introduced these approaches to AESJ sessions and international conferences for feedback.[1][2] Since the accident at Fukushima Daiichi Nuclear Plant, the demands and necessity of such activities are growing ever in light of the urgent need to secure safety at nuclear power plants against such external hazards that may not be frequent but significant and the increasing demands for identifying specific events as the Nuclear Regulation Authority (NRA) has already included in its new safety standards natural events and external man-made events.

Based on such background, "Implementation Standard Concerning the Risk Assessment Methodology Selection for the External Hazards" comprehensively identifies external hazards including the ones that were once quantitatively determined to have no significant risk of core damage and establishes a series of assessment processes for selecting appropriate risk assessment methods for the external hazards in terms of their frequency and core damage risks. Since the risk assessment of these external hazards is not intended solely for identifying the scale of risk but largely for establishing measures against them, not all external hazards necessarily requires detail risk assessments such as Probabilistic Assessment (PRA). Instead, various risk assessment techniques such as quantitative assessment, hazard analysis (frequency or effect), safety margin evaluation and deterministic core damage frequency evaluation method are also applicable to the evaluation of external hazards. For this purpose, the Implementation Standard identifies the external hazards that may have a risk of core damage at plants and establishes the process for selecting the proper risk assessment technique for each external hazard in terms of its frequency and effects on plants. The establishment of the Implementation Standard is expected to contribute to correctly determining the safety of individual plants against every external hazard of concern and developing appropriate measures each hazard.

2. IMPLEMENTATION STANDARD FOR RISK EVALUATION METHODOLOGY SELECTION

2.1. Applicable Scope of the Implementation Standard

The Implementation Standard comprehensively identifies external hazards that may cause a risk of core damage to nuclear power plants (“plants”) and specifies the procedures for selecting proper risk assessment methods concerning such external hazards in terms of their scenario, frequency and effects on plant. In such selection, intentional man-made hazards such as terrorist attacks are outside of the scope of this standard and shall be separately addressed as it is hard to analyze and identify such scenario due to its difficulty in identifying their scale and effects on the plants.

The Implementation Standard may be applicable for any nuclear facilities other than nuclear power plants as well as for risks other than core damage at plants if core damage risk is appropriately replaced with any other risk of concern. For plants under the design phase, the Implementation Standard should be applied in accordance with the progress level of the design as the design information as well as its evaluation result is subject to changes.

2.2 Details of the Implementation Standard

2.2.1 Structure of the Implementation Standard

This standard is composed of the 9 chapters below, and the specification items are clearly described in the text and the appendixes (specifications) of each chapter. In addition, in the appendices (references) and interpretations, the actual evaluation examples and the applicable methods are provided to help users understand the specification items of the standard as necessary.

This Standard is composed of 9 chapters as follows, and the actual evaluation procedures are explained in Chapters 5 through 8, as shown in Fig. 1. Some results of each process will be fed back and reviewed, or some processes may be implemented in parallel.

Chapter 1. Scope and applicability
Chapter 2. Cited standards
Chapter 3. Terms and definition, abbreviation glossary
Chapter 4. Selection procedure

Chapter 5. Collection of information
Chapter 6. Identification of potential external hazards
Chapter 7. Classification by characterization
Chapter 8. Selection of quantitative risk assessment method
Chapter 9. Documentation

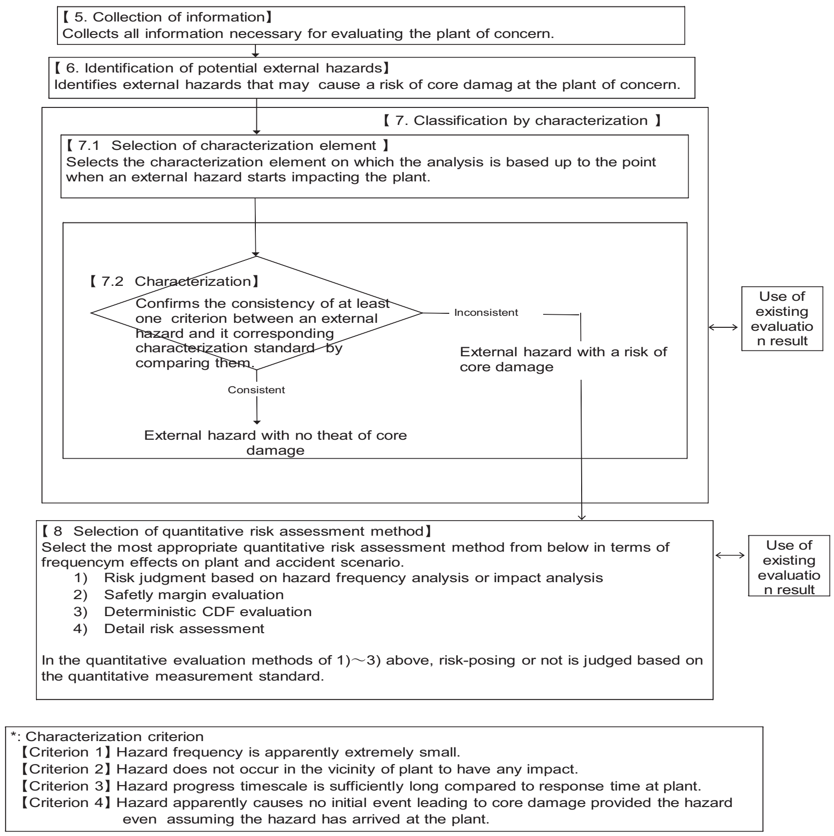

Figure.1 Flow of Selecting Risk Assessment Method for External Hazards

The provisions are clearly described in both the text and the appendices (requirements). In addition, in the appendices (rules and references) and explanation, the actual evaluation examples and the applicable methods are provided to help users understand the provisions of the Standard as necessary. Details from Chapter 5 to Chapter 8 are shown in 2.2.2.

2.2.2 Requirements for Each Evaluation Step

2.2.2.1 Collection of Information [Chapter 5]

Such information as plant design document, meteorological records of the surrounding area, facility installation status and legal restrictions concerning aircraft and vessel route that are necessary in performing evaluation on the plant of concern should be collected. Plant walkdowns shall be performed to grasp the current facility installation situation at the plant of concern.

2.2.2.2 Identification of Potential External Hazards [Chapter 6]

The external hazards that may cause a risk of core damage to the plant of concern are identified in accordance with natural or man-made hazards as well as single hazards or combined hazards. The external hazard list indicated in the implementation standard may be used for such identification. The existence of other external hazards which are specific to the plant site of concern, newly observed and assumed under the new observation should be verified before adding them to the list.

The external hazards that may have impact on the plant are classified between natural hazards and man-made hazards. The combination of multiple hazards as well as single hazards should be taken into account. Accordingly, the following procedures were taken to systematically examine external hazards to generate the external hazard list.

At first single hazards (both natural and man-made) were identified. While individual hazards are addressed in ASME/ANS Standards[3], IAEA NS-R-3[4] and IAEA SSG-3[5], it is still necessary to specifically identify the characteristics of the external hazards specific to Japan including their form of occurrence, the mechanism of their effects on other objects and secondary damage caused by such hazards in order to be able to evaluate their impacts on the safety of nuclear power plants in Japan. Accordingly, a literature survey was conducted on all external hazards that have occurred in Japan in the past in order to identify all potential external hazards that may have some impacts on plants and to characterize each external hazard, and its result was incorporated into the external hazard list.

In conducting the literature survey, several documents regarding natural hazards and man-made hazards respectively were selected which were considered to contain extensive information on hazards that have occurred in Japan and then narrowed down to a few each which were most suitable for the purpose of comprehensively extracting external hazards, and the events extracted from those documents were sorted out.[6] [7] [8] Further, external hazards addressed in ASME/ANS Standards, IAEA NS-R-3 and IAEA SSG-3, as well as those recently recognized as external hazards (due to meteor shock wave, etc.) were added to create the list of single hazards. After identifying single hazards, all theoretically possible combinations of hazards have been examined so as to identify possible combinations of hazards that should be taken into account.

As the result of above examination, single hazards and combinations of hazards have been identified and a list of external hazards, which is applicable nationwide.

The External Hazard List shall continue to be updated and enhanced reflecting experiences and new findings here and abroad. Such update or enhancement takes place when a new external hazard is detected having some effects on plants, existing standards issued by ASME/ANS and IAEA are revised and also when this Standard is revised by reflecting then current status.

2.2.2.3 Classification by Characterization [Chapter 7]

1) Selection of characterization element

There are three elements associated with an external hazard from the point of occurrence to impacting the plant as identified in Section 2.2.2.2. In performing the analysis of an external hazard, one of the three elements has to be chosen as the focal point.

<u>Element 1</u>: "Occurrence" of an external hazard

- Chose this element for a hazard whose occurrence is judged extremely rare.

<u>Element 2</u>: "Arrival" of an external hazard

- Chose this element for a hazard which may occur but whose effects may be judged not to reach the plant.

Element 3: "Impact on the plant" of an external hazard

- Chose this element for a hazard that may reach the plant but may be judged to have no significant impact on plants.

For some external hazard several elements may be taken into consideration. Any external hazard whose characterization is considered difficult as the result of the element selection attempt shall be skipped to Section 2.2.2.4.

The frequency of the most frequently occurring external event among the ones composing a combined event shall be chosen as the frequency of that combined event and/or characterization shall be performed as described in the next paragraph 2) after selecting a element of focus by conservatively treating the multiplying effects of each composing external hazard as the effects of that combined event.

2) Characterization

Each external hazard shall be characterized in comparison between its focus element selected in the preceding paragraph 1) and the characterization criterion indicated below. Accordingly, the possibility of causing apparent core damage risk to the plant of concern is examined. An external hazard consistent with at least one characterization criterion shall be determined to have no risk of core damage.

- When Element 1 is selected, "The hazard frequency" is evaluated.
  Criterion 1: The frequency of the hazard is apparently extremely low.
- When Element 2 is selected, either "The distance between the hazard and the plant" or "The hazard progression time" is evaluated.
  Criterion 2: No hazard occurs in the proximity of the plant to have any impact.
  Criterion 3: Time scale for hazard progression is sufficiently longer than the time it takes to respond to such hazard at the plant.
- When Element 3 is selected, "The effects of the hazard on the plant" are evaluated.
  Criterion 4: It is apparent that no hazard, assuming it has reached the plant, will cause any initiating event leading to core damage.

Historical records of hazards in the areas surrounding the plant location as well as the deterministic assessment result that used in filing the application for the permission of installation of a nuclear power generation facility, if any, shall be used in the characterization. In such cases, changes between the past and current plant status should be taken into account in performing the characterization. Listening to experts' opinions is also effective.

Any hazard determined to have a risk of core damage as a result of the above characterization process shall move to "2.2.2.4 Selection of Quantitative Risk Assessment Method"

2.2.2.4 Selection of Quantitative Risk Assessment Method [Chapter 8]

Each external hazard determined to have a risk of core damage in Subsection 2.2.2.3 shall be subject to one of the following quantitative risk assessments depending on its frequency, effects on the plant and accident scenario. Some hazards accompanying a complex accident scenario may be subject to more than one risk assessment.

1) Risk assessment based on the hazard frequency analysis or hazard impact analysis

- This assessment is performed when the concerned external hazard may be determined to have no significant risk of core damage as the result of a quantitative evaluation of its frequency or effects on the plant without taking into account any accident scenarios after such hazard has impacted the plant.
- In performing the hazard frequency analysis, the hazard level which may have impact on the plant is established (a design basis, if any, shall be applicable for some external hazards), and an external hazard whose frequency exceeds this level is quantitatively evaluated based on a conservative analysis. If the result indicates that such frequency is below a reference value, this hazard shall be determined to pose no significant risk of core damage.
- In performing the hazard impact analysis, it is verified based on a deterministic evaluation that there is no initiating event leading to core damage at the plant and no possibility of damage to the SSC having safety functions even under a conservative assumption of hazard's impact on the plant. If such verification is made, this hazard shall be determined to pose no significant risk of core damage.
- This risk assessment may be applicable to such external hazards as "strong wind" and "pressure change".

2) Safety margin evaluation

- This safety margin evaluation is performed when it is necessary to take into account all accident scenarios after an external hazard has impacted the plant but it is difficult to perform hazard frequency evaluation or when the uncertainty associated with the frequency is significantly high and it is considered appropriate to evaluate the safety margin of the external hazard against core damage risk.
- For multiple accident scenarios, the hazard level at which core damage risk definitely occurs and a dominant accident scenario are identified by deterministically assessing the effects of the individual hazards on the occurrence of an initiating event leading to core damage and the loss of functions of SCC having safety functions. Accident scenarios associated with internal events may be used in this evaluation.
- The ratio of the hazard level derived here to the hazard level with the possibility of having effects on the plant is calculated as the safety margin of the hazard against core damage.
- If the calculated safety margin exceeds a reference value, this hazard shall be determined to have no significant risk of core damage.
- One example of a safety margin evaluation method for core damage can be seen in the seismic safety margin assessment procedure for seismic events [3].
- This risk assessment may be applicable to such external hazards as "tsunami".

3) Deterministic CDF evaluation

- This risk assessment is performed when it is necessary to take into account all accident scenarios after the hazard has impacted the plant and hazard frequency evaluations can be performed.
- For the dominant accident scenario which leads to core damage, the Conditional Core Damage Probability (CCDP) of the plant caused by the hazard is quantitatively evaluated by deterministically establishing the effects of the hazard on the occurrence of the initiating event leading to core damage and the effects of the hazard on the loss of functions of SSC having safety functions, and the calculated CCDP is multiplied by the frequency of the external hazard exceeding the hazard level at which the plant may be affected to determine the CDF. In calculating the CCDP a bounding analysis or conservative analysis can be performed using the PRA models for internal events.
- If the evaluation result indicates the CDF lower than a reference value, this hazard shall be determined to pose no significant risk of core damage.
- This risk assessment may be applicable to such external hazards as "volcanic ash".

4) Detail risk assessment such as PRA

- External hazards determined to have a risk of core damage as a result of any one of the preceding evaluations specified in 1) through 3) shall be subject to detail risk evaluation applying such methods as Probabilistic Risk Assessment (PRA).
- External hazards determined to have a risk of core damage shall be subject to detail risk evaluations using the Probabilistic Risk Assessment (PRA) approach. It is desirable to apply the PRA to all of those external hazards. However, deterministic evaluations and/or evaluations based on engineering judgment can replace when it involves complex accident scenarios or combined events for which no advanced evaluation technique is available.
- One example of deterministic evaluation and evaluation based on engineering judgment is FIVE [9] technique applied to internal fire. For NPPs in Japan, the Comprehensive Assessment of the Safety [10] (so-called 'Stress Test') was performed following the accident at Fukushima Daiichi Nuclear Power Plant to evaluate the effects of earthquakes, tsunamis and combined events on the plant safety. The assessment to identify dominant core damage sequences using the Stress Test results is also one example of deterministic evaluations and/or evaluations based on engineering judgment.
- This risk assessment may be applicable to such external hazards as "seismic ground motion".

In performing the quantitative evaluations 1) through 3) , the decision on whether the concerned external hazard has risks of core damage or not is made by establishing quantitative criteria. When none of these evaluations is able to determine the core damage risks, alternative methods will be discussed and further evaluation is performed using such an alternative method if judged applicable.

The possibility of simultaneous occurrence of single hazards is also evaluated in the quantitative evaluations 1) through 3). Various combinations of a hazard determined to pose core damage risk and other individual hazards are evaluated in a quantitative way.

3. PRACTICAL APPLICATION FOR RISK EVALUATION METHODOLOGY SELECTION

3.1 Current situation of the risk evaluation methodology selection for the external hazard

The Implementation Standard shown in Chapter 2 was published by the Atomic Energy Society of Japan in December 2014 after going through the public comment period.

Apart from the fact above, NRA enforced the new regulatory requirements for commercial nuclear power reactors on July 8, 2013. The new regulatory requirements specify that the electric utilities should consider the countermeasures for nuclear safety against all kinds of the external hazards.
Therefore, Japanese electric utilities identified the external hazards that might affect the plants, and they selected the appropriate evaluation methods for those external hazards based on the ASME/ANS Standards in order to evaluate the effects of external hazards on plants qualitatively or quantitatively. In addition, they identified single hazards, combined hazards and combinations of random single hazards.

Regarding the selection of risk evaluation methodologies, we reviewed the applications for the installation of reactor facilities submitted by the Japanese utilities and evaluated whether the risk evaluation methodology selected for the single hazard was consistent with the Implementation Standard or not.

First, we organized the evaluation methods for individual hazards described in the applications submitted by the Japanese electric utilities. Second, we classified the evaluation methods according to the Implementation Standard in Chapter 2.

As the result of above examination, we could confirm that the risk evaluation methodology for the single hazard in the applications was generally consistent with the Implementation Standard. However, we identified following problems.

No.1. There are several external hazards that are included in the list of the implementation standard but not subject to the evaluation. Among those external hazards, there are several external hazards for which quantitative evaluation methods have been established yet.

No.2. There are several external hazards whose justification of current evaluation methods should be enhanced (For example, external hazards which are not determined to have a risk of core damage based on the classification by characterization, further justification is needed.).

No.3. There are several external hazards whose mechanism has not yet cleared by present scientific knowledge (For example, its generation is unknown).

No.4. Regarding the identification methods for combined hazards and combinations of random single hazards, there are some differences between the description in the Implementation Standard and utilities' applications. Therefore, it is necessary to clarify such differences, and confirm that their difference result in difference in hazards.

No.5. It is necessary to collect and sort out more evidences that are required in determining whether the classification by characterization or the quantitative risk assessment should be selected.

3.2 Challenge of Applying Risk Evaluation Methodology Selection based on the Implementation Standard

The Implementation Standard comprehensively identifies external hazards that may cause a risk of core damage to nuclear power plants and specifies the procedures for selecting proper risk assessment methods systematically.

It is recommended that the utilities select an appropriate method to evaluate each hazard according to the Implementation Standard and implement the evaluation when evaluating the external hazards from now onward By meeting this requirement, the pending problems shown in Section 3.1 above are expected to be resolved.

With regard to the applying risk evaluation methodology selection based on the Implementation Standard, the Japanese nuclear industry is currently working on the improvement of future two strategies below:

(1) Prepare a hazard report in order to systematically select the most appropriate risk evaluation method according to the Implementation Standard

With the aim of systematically selecting of risk evaluation method and ensuring the results more reasonable, the Japanese electric utilities are planning to prepare a report summarizing the items necessary for the selection of risk evaluation methods (information), selected methods, and the reasons for the selection (hereafter referred to as the "hazard report"). We are also planning to summarize the following items.

- The improvements necessary to enhance the justification for currently selected evaluation methods
- The mechanism that has not cleared by present scientific knowledge

A concrete set of the items to be described in the hazard report is shown in Table.1.

First of all, we prepared one hazard report for the single hazards.In preparing it, the evidences were collected and sorted out. Also, a literature survey and discussion with experts were done to select suitable the evaluation methods for the external hazards as in No.1, Section 3.1.

Above work clarified that organizing the evaluation methods according to the Implementation Standard using hazard reports is an effective method.

It is necessary to prepare hazard reports for all the Potential External hazards, and an example of the single hazards was shown above. However the reports for combined hazards and the combinations of random single hazards have not been prepared. In the future, we will consider a way to prepare reports for them using the results of those for the single hazards. It will lead to selecting the risk evaluation methods for all types of hazards after all.

(2) Clarify the unclear points by the literature survey and discussion with experts

With regard to the hazards for which the evaluation methods have not been established or the hazards whose mechanism has not yet cleared by present scientific knowledge, the literature survey and discussion with experts will be continued. By doing improvement above, we will be able to select the appropriate evaluation methods for all external hazards.

Table1: A concrete set of the items of the hazard report

No.	Item	Content
1	Plant name	Fill out the name of the plant
2	External hazard name	Fill out the name of the external hazard which is listed in the Implementation Standard.
3	Explanation of the external hazard	Fill out the explanation about the external hazard corresponding to item No.2.
4	Overview of the evaluation	Fill out the evaluation method for the external hazard.
5	The results of the classification by characterization	Fill out the selected characterization items and the classification by characterization based on the item No.4.
6	The reason why the element and criterion are selected.	Fill out the reasons for the judgment made in item No.5
7	The result of the selection of quantitative risk assessment method	Regarding each external hazard determined necessary to perform quantitative risk assessment, show which assessment method has been selected from the 4 quantitative risk assessment methodologies described in the AESJ Implementation Standard.
8	The reason why the quantitative risk assessment method is selected.	Fill out the reasons the judgment made in item No.7.
9	The items that need to be considered in the future.	Fill out the improvements necessary to enhance the justification for currently selected evaluation methods or the mechanism that has not cleared by present scientific knowledge
10	Reference	Describe the names of the documents/materials used in preparing a hazard report.

4. CONCLUSION

The Risk Technical Committee under AESJ published the Implementation Standard for the selection of risk evaluation methodology for risks associated with external hazards in terms of frequency and effects on plant incorporating the opinions of experts from all related fields.

The Implementation Standard specifies the requirements and specific procedures related to the selection of risk evaluation methods.

Appearing below is a current Japanese way to select an appropriate evaluation method. It shows that its evaluation is consistent with the requirements of the AESJ Implementation Standard.

Regarding the selection of risk evaluation methodologies, we reviewed the applications for the installation of reactor facilities submitted by the Japanese utilities and evaluated whether the risk evaluation methodology selected for the single hazard was consistent with the Implementation Standard or not. As a result, we could confirm that the risk evaluation methodology for the single hazard in the applications was generally consistent with the Implementation Standard. However, we identified several problems.

Therefore, we are planning to prepare the hazard report and perform the literature survey and discussion with experts in order to solve the problems. We have prepared the hazard reports for the single hazards so far. Preparing them proved that organizing the evaluation methods according to the Implementation Standard using hazard report is an effective method.
In the future, we will consider how to prepare the hazard reports for combined hazards and the combinations of random single hazards using the results of the hazard reports for the single hazards. We will prepare the hazard reports in order to identify the risk evaluation methods for these types of hazards. Also, the literature survey and discussion with experts will be continued. Above improvements will allow selection of the appropriate evaluation methods for all external hazards.

It is expected that these Implementation Standards will contribute to deeper understanding of the plant safety against every external hazard and help prepare appropriate countermeasures against each potential hazard.

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