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 behaviors, 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.
To resolve these issues, a process has been established that enables us to identify the external hazards in a comprehensive and systematic manner, which have potential risks leading to core damage and to select an appropriate evaluation method according to the risks associated with each of the external hazards.
This paper discusses the comprehensive and systematic identification process for the external hazards which have potential risks leading to core damage, and the approaches of selecting an appropriate evaluation method for each external hazard. This paper also describes some applications of specific risk evaluation methods.

KEYWORDS

External hazard, 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 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 require 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. 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.

3. DETAILS OF THE IMPLEMENTATION STANDARD

3.1. STRUCTURE OF THE IMPLEMETATION 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

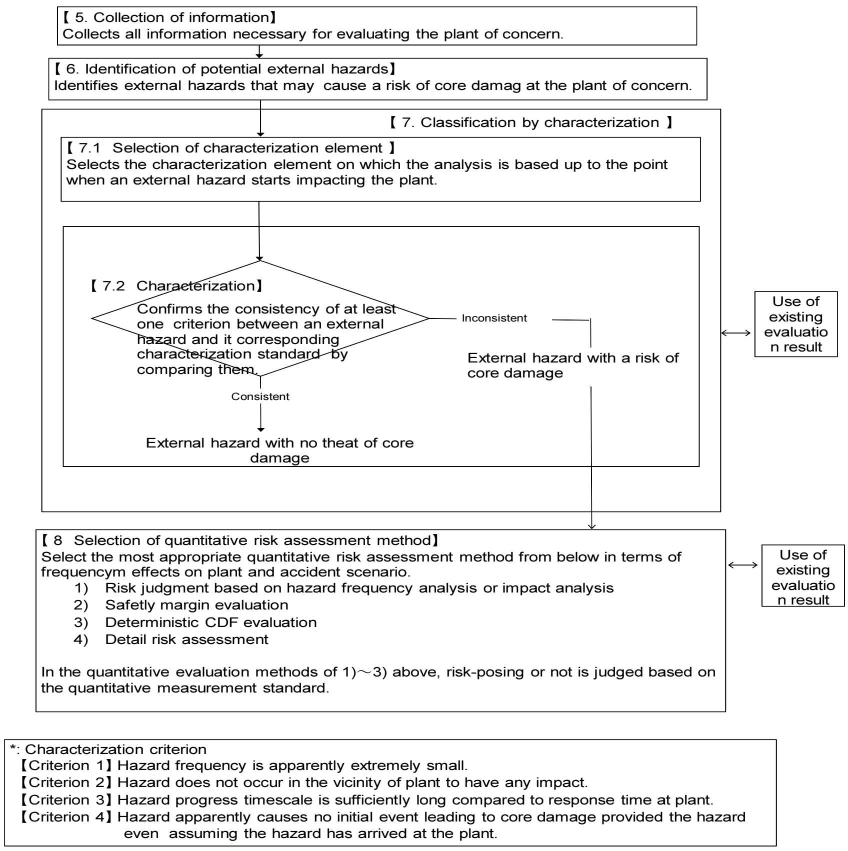

Fig. 1 Flow of Selecting Risk Assessment Method for External Hazards

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 9 are shown in 3.2.

3.2. REQUIREMENTS FOR EACH EVALUATION STEP

3.2.1. 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.

3.2.2. 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 Table 1 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 as shown in Table 1.

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 incorporating both types of hazards as indicated in Table 1 was formulated, 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.

Table 1. External Hazard List (1/3)

Type of hazard		External hazard	
Natural hazard	Earthquake	Seismic motion	
		Ground deformation	Land subsidence
			Land uplift
			Ground crack
			Liquidation
			Landslide
			Debris flow
			Flood caused by earthquake
			Fire caused by earthquake
	Tsunami	Tsunami	Tsunami caused by seismic hazard
			Tsunami caused by volcanic hazard
			Tsunami caused by meteor
	Storm and flood	Tidal change	Seiche
			Tidal wave
			Ocean/tidal waves
			Abnormal sea level
			Flood tide
			Abnormal change in current
			Low sea level
		Strong wind	Storm (Typhoon)
			Tornado
			Fire caused by windstorm
			Sand storm caused by windstorm
		Pressure change	High pressure
			Low pressure
			Sudden pressure change
		Heavy rainfall	Flood caused by heavy rainfall
			Flash flood caused by heavy rainfall
			Landslide caused by heavy rainfall
			Sand storm caused by heavy rainfall
		Thunderbolt	Thunderbolt (electric current)
			Fire caused by thunderbolt
	Storm and wind damage	Temperature change	High temperature
			Low temperature
			High seawater temperature
			Low seawater temperature
			Ice crystal
			Ice wall
			Freezing
			Drought
			Frost, rime fog
			Fog
		Hailstorm	Hailstorm

Table 1. External Hazard List (2/3)

Type of hazard		External hazard	
Natural hazard	Volcano	Volcanic eruption	Volcanic bomb (large cinders)
			Volcanic lapilli (small cinders)
			Pyroclastic flow
			Lava flow
			Debris flow
			Pyroclastic surge
			Blast
			Flood
			Volcanic ash
			Fire (forest fire)
			Accumulation of volcanic gas
			Scalding water
			Sector collapse
	Snow damage	Heavy snow fall	Snow fall
			Avalanche caused by heavy snow fall
		Snowmelt	Avalanche caused by snowmelt
			Flood caused by snowmelt
			Landslide caused by snowmelt
	Other	Biological event	Animals
			Marine creatures (shellfish, jelly fish, etc.)
			Seaweeds
		Salt damage	Dielectric breakdown caused by sea-salt particles
			Corrosion
		Meteor	Rocks
			Shock wave caused by meteor
			Fire
		Coast erosion	Coast erosion
		Underwater erosion	Underwater erosion
		Karst	Karst
		River clogging caused by sea ice	River clogging caused by sea ice
		Drawdown of lake or river water	Drawdown of lake or river water
		Magnetic storm caused by solar flare	Magnetic storm caused by solar flare
	Compound event	Seismic motion/ground deformation/tsunami (common cause event /accompanying event)	
		Volcanic eruption/seismic motion/ground deformation/tsunami (common cause event /accompanying event)	
		Temperature change/ drawdown of lake or river water (accompanying event)	
		Tidal change/strong wind/heavy rainfall/thunderbolt/salt damage (common cause event)	
		Tidal change/strong wind/heavy snowfall/thunderbolt/salt damage (common cause event)	
		Tidal change/strong wind/snowmelt/thunderbolt/salt damage (common cause event)	
		Tidal change/strong wind/hailstorm/thunderbolt/salt damage (common cause event)	

Table 1. External Hazard List (3/3)

Type of hazard		External hazard
Man-made hazard	Marine accident	Oil spill caused by marine accident
		Chemical substance release from vessel
		Vessel explosion
		Vessel collision
	Aviation accident	Aircraft fall
	Railroad accident	Explosion caused by railroad accident
		Chemical substance release caused by railroad accident
		Train collision
	Road accident	Explosion caused by traffic accident
		Chemical substance release caused by traffic accident
		Automobile collision
	Hazardous object	Explosion caused by industrial accident
		Chemical substance release caused by industrial accident
		Explosion caused by mine accident
		Chemical substance release caused by mine accident
		Explosion caused by construction accident
		Chemical substance release caused by construction accident
		Explosion caused by military base accident
	Forest fire	Fire in forest, wildland and grassland
	Widespread fire	Fire in urban area
	Other	Artificial satellite fall
		River flow change
		Flood and wave caused by damage on flood control structure
		Electromagnetic interference

3.2.3. 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 3.2.2. In performing the analysis of an external hazard, one of the three elements has to be chosen as the focal point.

Element 1: "Occurrence" of an external hazard

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

Element 2: "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 3.2.4.

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.
  (Example of characterization: hazard related to temperature change (high temperature in summer or freezing (low temperature)) is unlikely under the weather conditions in the regions where the plant of concern is located.)
- 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.
  (Example of characterization: No volcanoes exist within the geographic region (a 160 km radius from the plant) and therefore no hazards related to "volcanic eruption" excluding "volcanic ash" are expected to occur.)
  Criterion 3: Time scale for hazard progression is sufficiently longer than the time it takes to respond to such hazard at the plant.
  (Example of characterization: "Coast erosion" hazard takes significant hours to progress and it gives sufficient time to take countermeasures.)
- 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.
  (Example of characterization: "Frosting" hazard, even if occurs, will not pose a threat of core damage to the plant.)

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 "3.2.4 Selection of Quantitative Risk Assessment Method".

3.2.4. SELECTION OF QUANTITATIVE RISK ASSESSMENT METHOD [Chapter 8]

Each external hazard determined to have a risk of core damage in Subsection 3.2.3 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.

3.2.5. DOCUMENTATION [Chapter 9]

The candidate risk assessment methods, conditions on the selection and selected methods shall be documented for easier understanding in the application of the result of the, update and experts' review.

4. CONCLUSION

The Risk Technical Committee under AESJ is getting ready to prepare the final draft of and officially issue 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 upcoming implementation standard specifies requirements and specific procedures related to the selection of risk evaluation methods.

Also in the future, the Risk Technical Committee will continue to discuss the requirements and specific procedures concerning the quantitative risk evaluation methods described here to be included in the additional implementation standards or the guidelines.

It is expected that these implementation standards will make it possible to fully understand the plant safety against every external hazard and help prepare appropriate countermeasures against each potential hazard.

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