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A Study of Screening Method for the Risk Significant Combinations among the External Hazards

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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 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.

The purpose of our study is to develop the extracting method for the risk significant combinations of external hazards and to perform the trial evaluation on the representative NPP, based on "Implementation standard concerning the risk analysis methodology selection for the external hazards" established by the Risk Technical Committee of Atomic Energy Society of Japan (AESJ).

The first approach is to examine the information related to each external hazard and investigate the approaching process of the external hazards to NPP. In reference to their information, the combinations of external hazards are investigated using the risk matrix method. This method calculates the risk score of the combination of external hazards by assessing the frequency and impact to the plant of each external hazard and the correlations between external hazards. The risk significant combinations of external hazards are extracted in the case that the risk score is high.

As the results of having extracting the risk significant hazard combinations based on the risk matrix methods among one hundred hazards, approximately fifty hazard combinations were extracted. The correlations of external hazards associated with the seismic event are especially high, and these combinations are extracted as the high risk score. As the next step, it is necessary to assess the fifty hazard combinations of the external hazards extracted by this risk matrix method.

Based on the risk matrix method developed by this study, the risk significant combinations of external hazards have been extracted. It is important to determine the frequency and impact to the plant of each external hazard and the correlations among external hazards on each NPP when this method is applied. Additionally, it is necessary to argue with the experts about the risk score setting and the screening criteria. Moreover, it is necessary to assess the risk significant combinations of the external hazards extracted by this risk matrix method in detail.

I. INTRODUCTION

The purpose of our study is to develop the extracting method for the risk significant combinations of external hazards and to perform the trial evaluation on the representative NPP, based on "Implementation standard concerning the risk analysis methodology selection for the external hazards" established by the Risk Technical Committee of Atomic Energy Society of Japan (AESJ)[1〜12].

The first approach of screening method is to examine the information (source, influence mode to the plants, protective facilities, etc.) related to each external hazard and investigate the approaching process of the external hazards to NPP. In reference to their information, the combinations of external hazards are investigated using the risk matrix method. This method calculates the risk score of the combination of external hazards by assessing the frequency and impact to the plant of each external hazard and the correlations between external hazards. The risk significant combinations of external hazards are extracted in the case that the risk score is high.

As the results of having extracting the risk significant hazard combinations based on the risk matrix methods among one hundred hazards, approximately fifty hazard combinations were extracted. The correlations of external hazards associated with the seismic event are especially high, and these combinations are extracted as the high risk score. As the next step, it is necessary to assess the fifty hazard combinations of the external hazards extracted by this risk matrix method.

Based on the risk matrix method developed by this study, the risk significant combinations of external hazards have been extracted. It is important to determine the frequency and impact to the plant of each external hazard and the correlations among external hazards on each NPP when this method is applied. Additionally, it is necessary to argue with the experts about the risk score setting and the screening criteria. Moreover, it is necessary to assess the risk significant combinations of the external hazards extracted by this risk matrix method in detail.

II. SCREENING METHOD FOR THE SIGNIFICANT COMBINATIONS AMONG THE EXTERNAL HAZARDS

The combinations of external hazards are investigated using the risk matrix method in the base of the information (source, influence mode to the plants, protective facilities, etc.) related to each external hazard. This method calculates the risk score of the combination of external hazards by assessing the frequency and impact to the plant of each external hazard and the correlations between external hazards. The risk significant combinations of external hazards are extracted in the case that the risk score is high.

The purpose of this screening method is that the combinations of external hazards are comprehensively extracted. In the following sections, "Screening flow of the significant combinations among the external hazards" and "Definition of external hazards risk matrix" and "Characterization and correlative factor of external hazards" is described for this screening method.

II .A. SCREENING FLOW OF THE SIGNIFICANT COMBINATIONS AMONG THE EXTERNAL HAZARDS

Screening flow of the significant combinations among the external hazards is shown in Fig. 1. This flow is considered that the combinations are more than two external hazards. It is explained by the following,

Step1. Set the frequency and impact of each external hazard
Step2. Excluding the external hazards of the following items for no plant damage
- The frequency of the hazard is apparently extremely low. (Criterion 1)
- No hazard occurs in the proximity of the plant to have any impact (Criterion 2)
- Time scale for hazard progression is sufficiently longer than the time it takes to respond to such hazard at the plant.（ Criterion 3)
- The impact of the single hazard is Crushing (Criterion 4)

Step3. Set the characterization of each external hazard (Variables of Season and Source Group)
Step4. Set the correlation factor between the combination hazards belonging the same source group or same season
Step5. Calculate the risk between two external hazards
- Equation for Risk factor calculation of combination between no corrective external hazards
  : $F_a \times F_b \times (I_a + I_b)$
  , F_x: frequency of x hazard, I_x: impact of x hazard

Step6. Excluding impossible combinations form the characterization of the external hazards
- Exp. Different seasons between hazards

Step7. Excluding the external hazard combinations of lower risk than the screening criteria
- It is used that the screening criteria is 1 for this investigation.

Step8. Calculate the risk of the combinations of three external hazards, in the base of the external hazard combinations of higher than the screening criteria, calculate the risk of the combinations of three external hazards
Step9. Iterate from step 5 to step 8 until the risk factor of the external hazard combinations is lower than screening criteria
Step10. Review the results of the extracted combinations of external hazards in the base of the following items,
- Do the extracted hazard combinations occur on the evaluated NPP?
- Do the extracted hazard combinations have the significant impact on the evaluated NPP?
- Don't the important external hazards exclude on the evaluated NPP?

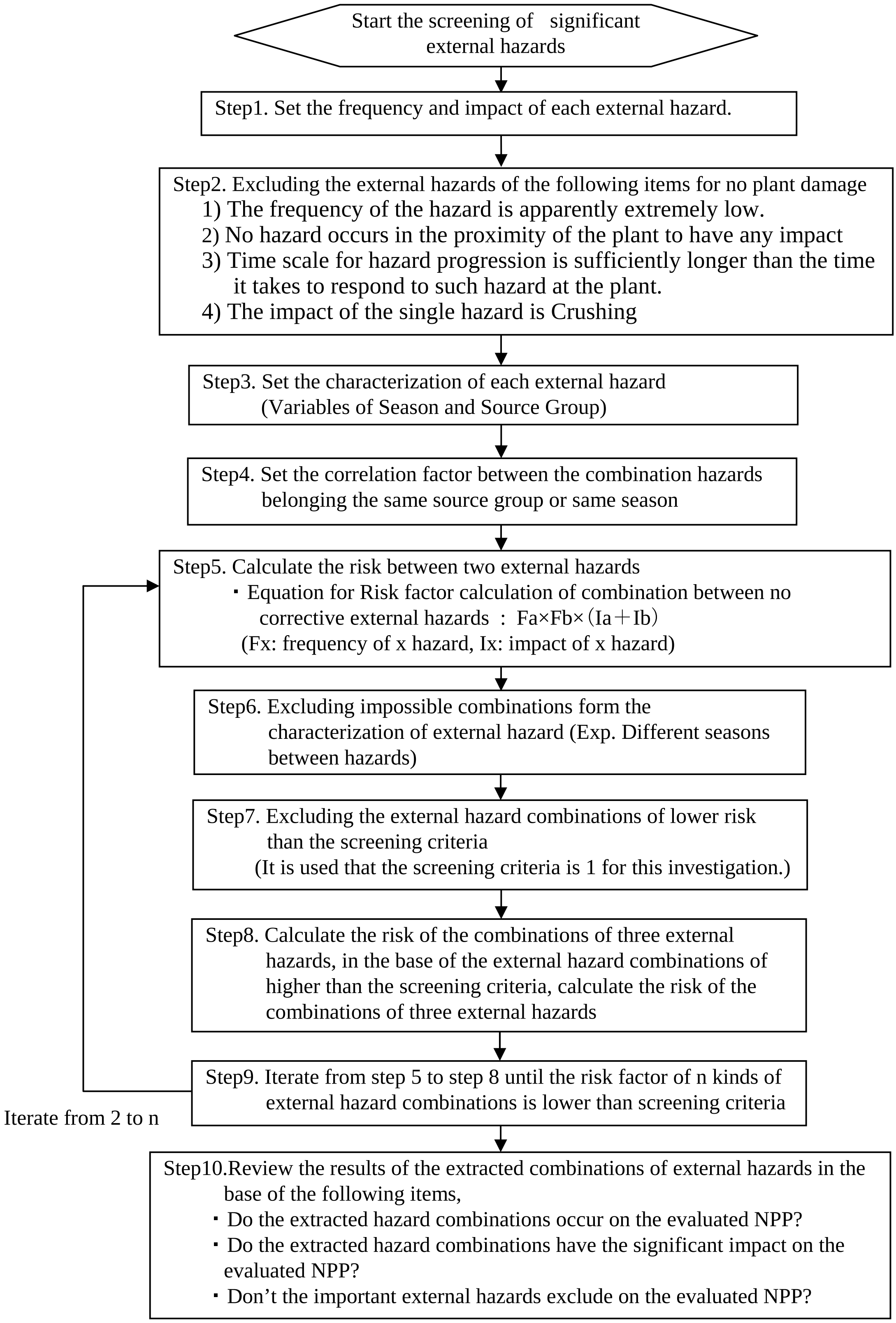


Fig.1. Screening flow of the significant combinations among the external hazards

II .B. DEFINITION OF EXTERNAL HAZARDS RISK MATRIX

As first step for the purpose of extracting the combination of the external hazards, the risk (frequency and impact) is set for the each external hazard for the evaluated NPP. In this screening method, it is assumed that the general house

In this screening method, it is assumed that the general Structure (for example, it is general house or building) which does not have special protective facilities for the external hazard is located to the evaluated NPP and the frequency and impact of the external hazard are set. It evaluates the combinations of external hazards conservatively by doing such an assumption. In addition, in the judgment for the frequency and impact of the external hazard, the risk is assessed by the engineering judgment when it is difficult by the lack of the evidence and other reasons.

Therefore, the risk of each external hazard set by this assumption is only used for the extraction of the combination of external hazards and is not used for the detailed evaluation for the extracted external hazard.

Table 1 Risk matrix for combinations of external hazards

Items		Frequency			
		Zero (0.0)	***Low*** ***(0.001)*** (=1/1000year)	***Intermediate*** ***(0.01)*** (=1/1000year)	***High*** ***(0.1)*** (=1/10year)
Impact	***Devastating*** (Significant and Devastating impact to general structure)	0	—	—	—
	Large (=1000) ・Crushing impact to general structure ・Serious impact and Impossible to live in general structure	0	1	10	100
	Middle (=100) ・General structure is partially destroyed. ・Large-scale repair is necessary for General structure	0	0.1	1	10
	Small (=10) ・Slight damage for General structure ・Possible to live in general structure	0	0.01	0.1	1

II .C. CHARACTERIZATION AND CORRELATION FACTOR OF EXTERNAL HAZARDS

II.C.1. CHARACTERIZATION OF EXTERNAL HAZARDS

It is defined that the source group (variable G) and season group (variable S) in each external hazard to consider the correlation between the external hazards as shown in Table 2 and Table 3.

Season group is classified in three categories (high temperature season (HS), low temperature season (LS) and all season (AS)) to exclude impossible combinations of external hazards.

Also, the external source group is defined in the same cause event and the accompanying event. The external hazards of the same external source are grouped.

The outbreak time and the influence period of each external hazard are supposed that the influence period to the plant is only considered because it is possible for influence period to continue for a long time even if it is when outbreak time of the external hazard is short (e.g.,: a thunderbolt).

The influence period is around one month, and it is assumed that the functions of the plant are recovered among the period.

Table 2 Categories of season group (variable S)

Category	Condition
HS	External hazards in high temperature season
CS	External hazards in low temperature season
AS	External hazards occur regardless of temperature

Table 3 Categories of source group (variable G)

Category	Source
G1	Atmospheric depression, Cyclone, Typhoon
G2	Earthquake
G3	・・・・・

II.C. II . CORRELATIVE FACTOR OF EXTERNAL HAZARDS

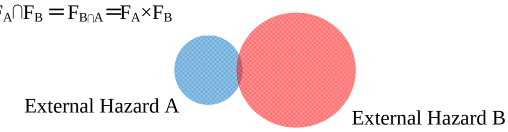
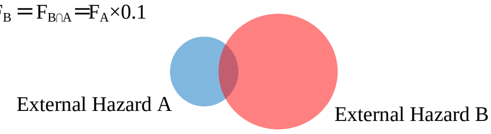
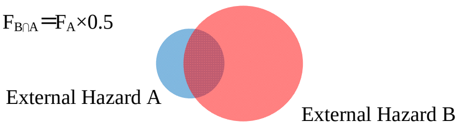
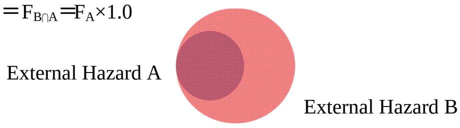
It is considered that external hazards belonging to the same source group or the same season group are correlated to the frequency of the hazards.

The correlative factor as a parameter to express their correlations between two kinds of external hazards is set to model their correlation.

In addition, it is supposed that there is not the correlation between external hazards except the above correlation. The definition of the correlative factor is assumed with "conditional probability of the high frequency external hazard in condition with generating the external hazard of the small frequency in two kinds of external hazard”. The corrective factor is defined in Table 4.

The correlative factor is selected from the type (e.g. A~D as shown Table 4) for external hazards belonging to the same source group or the same season group are correlated to the frequency of the hazards.

Table 4 Categories of Correlative factor

Type	Correlation	Correlative factor	Image diagram of Corrective factor
A	No	－	$F_A \cap F_B = F_{B\cap A} = F_A \times F_B$ 
B	Low	0.1	$F_A \cap F_B = F_{B\cap A} = F_A \times 0.1$ 
C	High	0.5	$F_A \cap F_B = F_{B\cap A} = F_A \times 0.5$ 
D	Complete	1.0	$F_A \cap F_B = F_{B\cap A} = F_A \times 1.0$ 

Fx: Frequency of x hazard

Ⅲ. TRIAL EVALUATION FOR THE COMBINATION OF EXTERNAL HAZARDS

The trial evaluation is performed based on the screening flow (cf. figure 1) of the combination of external hazard for approximately 100 hazards. The representative plant adjacent to the sea is assumed to set the frequency, impact and etc. of each external hazard.

The example of the frequency, impact and category of season group and source group set on this trial evaluation are shown in Table 5. And the example of the corrective factor is shown in Table 6.

On the representative plant adjacent to the sea, there are 49 kinds of hazards to evaluate the extraction of the combination of external hazards.

The number of combinations of hazard that should calculate a risk becomes enormous with up to 10^{-14} order. Therefore this trial evaluation is calculated except the combination that risks became lower than 1 by all means clearly without calculating mechanically. Risk score result is shown in Table 7. It is described that results of the combinations of external hazards higher than criteria (=1.0).

Table 5 Characterization of each external hazard
(The representative nuclear power plant adjacent to the sea)

External Hazard	Source Group	Season Group	Risk Score	
			Frequency	Impact
Seismic motion	Earthquake	AS	Intermediate	Large
Ground deformation		AS	Intermediate	Large
Slope failure near important facilities		AS	Intermediate	Large
Slope failure except important facilities		AS	Intermediate	Small
Debris flow		AS	Zero	-
Flood caused by earthquake		AS	Zero	-
Fire caused by earthquake (inside site)		AS	Intermediate	Middle
Fire caused by earthquake (outside site)		AS	Low	Middle
Tsunami caused by seismic hazard		AS	Intermediate	Large
Tidal wave	Atmospheric depression	AS	High	Small
Ocean/tidal waves		AS	High	Small
Storm (Typhoon)		AS	High	Small
Tornado		AS	Intermediate	Middle
Flood caused by heavy rainfall (inside site)		AS	High	Small
Flood caused by heavy rainfall (outside site)		AS	High	Small
Landslide caused by heavy rainfall		AS	Intermediate	Middle
Thunderbolt		AS	High	Small
Fire caused by thunderbolt		AS	Intermediate	Middle
Snow fall		CS	High	Small
Avalanche caused by heavy snow fall		CS	Intermediate	Middle
Landslide caused by snowmelt		CS	Low	Large
High temperature	High temperature	HS	Intermediate	Small
High seawater temperature		HS	Intermediate	Small
Low temperature	Low temperature	CS	Intermediate	Small
Low seawater temperature		CS	Zero	-
Ice crystal		CS	Intermediate	Small
Frost, rime fog		CS	Intermediate	Small
Fog		CS	High	Small
Volcanic bomb	Volcano	AS	Zero	-
Pyroclastic flow		AS	Zero	-
Lava flow		AS	Zero	-
Blast		AS	Zero	-
Volcanic ash		AS	Intermediate	Middle

Table 6 Corrective Factor of each external hazard
(The representative nuclear power plant adjacent to the sea)

Correlative Group	Hazard A	Hazard B	Frequency of Hazard A	Frequency of Hazard B	Correlative Factor
High temperature	High temperature	High seawater temperature	Intermediate	Intermediate	High
Low temperature	Low temperature	Ice crystal	Intermediate	Intermediate	Complete
	Low temperature	Fog	Intermediate	High	Low
	Ice crystal	Fog	Intermediate	High	Low
Earthquake	Seismic motion	Ground deformation	Intermediate	Intermediate	Complete
	Seismic motion	Slope failure near important facilities	Intermediate	Intermediate	Complete
	Seismic motion	Slope failure except important facilities	Intermediate	Intermediate	Complete
	Seismic motion	Fire caused by earthquake (inside site)	Intermediate	Intermediate	Complete
	Seismic motion	Fire caused by earthquake (outside site)	Intermediate	Low	Complete
	Seismic motion	Tsunami caused by seismic hazard	Intermediate	Intermediate	Complete
Atmospheric depression	Tidal wave	Ocean/tidal waves	High	High	High
	Tidal wave	Flood caused by heavy rainfall (outside site)	High	High	High
	Tidal wave	Storm (Typhoon)	High	High	High
	Tidal wave	Tornado	High	Intermediate	High
	Ocean/tidal waves	Flood caused by heavy rainfall (outside site)	High	High	High
	Ocean/tidal waves	Storm (Typhoon)	High	High	Complete
	Ocean/tidal waves	Tornado	High	Intermediate	High
	Storm (Typhoon)	Tornado	High	Intermediate	High
	Storm (Typhoon)	Flood caused by heavy rainfall (outside site)	High	High	High
	Storm (Typhoon)	Thunderbolt	High	High	High
	Storm (Typhoon)	Snow fall	High	High	High
	Tornado	Flood caused by heavy rainfall (outside site)	Intermediate	High	High
	Tornado	Thunderbolt	Intermediate	High	High
	Flood caused by heavy rainfall (outside site)	Landslide caused by heavy rainfall	High	Intermediate	Complete
	Flood caused by heavy rainfall (outside site)	Thunderbolt	High	High	High
	Thunderbolt	Fire caused by thunderbolt	High	Intermediate	Complete
	Thunderbolt	Snow fall	High	High	High
	Snow fall	Avalanche caused by heavy snow fall	High	Intermediate	Complete
	Snow fall	Landslide caused by snowmelt	High	Low	Complete

Table 7 Risk score results for the combinations of external hazards higher than 1.
(The representative nuclear power plant adjacent to the sea)

Combination Type	Single hazard A or Group hazard A	Hazard B	Risk Score
Seismic Group (Six hazards)	Seismic motion, Ground deformation and Slope failure near or except important facilities, Flood caused by earthquake, Fire caused by earthquake (inside site)	-	41.1
Seismic Group (Seven hazards)	Seismic Group (Six hazards) and Fire caused by earthquake (outside site)	-	4.2
Seismic Group (Six hazards) and high frequency hazard except atmospheric depression	Seismic Group (Six hazards)	Flood tide or Fog, etc.	4.1
Seismic Group (Six hazards) and some frequency hazards of atmospheric depression	Seismic Group (Six hazards)	Tidal wave, Thunderbolt, Snow fall, Ocean/tidal waves, Storm (Typhoon), Flood caused by heavy rainfall, etc.	1.0
Combination of Atmospheric depression hazards	Tidal wave, Tornado, Thunderbolt	Thunderbolt, Snow fall, Avalanche caused by heavy snow fall, Flood caused by heavy rainfall, Landslide caused by heavy rainfall, Landslide caused by snowmelt	1.1~1.6
	Ocean/tidal waves, Storm (Typhoon), Flood caused by heavy rainfall, Landslide caused by snowmelt	Snow fall, Thunderbolt, Landslide caused by snowmelt	1.0~1.1
	Snow fall	Avalanche caused by heavy snow fall, Landslide caused by snowmelt	1.1

Seismic Group : Seismic motion, Ground deformation, Slope failure near important facilities, Slope failure except important facilities, Fire caused by earthquake (inside site), Tsunami caused by seismic hazard

Ⅳ. CONCLUSIONS

As the results of having extracting the risk significant hazard combinations based on the risk matrix methods among one hundred hazards, approximately fifty hazard combinations were extracted. The correlations of external hazards associated with the seismic event are especially high, and these combinations are extracted as the high risk score.

In this study, it is assumed that the general Structure which does not have special protective facilities for the external hazard is located to the evaluated NPP and the frequency and impact of the external hazard are set. Also, the correlative factor as a parameter to express their correlations between two kinds of external hazards is set to model their correlation.

Based on the risk matrix method developed by this study, the risk significant combinations of external hazards have been extracted. It is important to determine the frequency and impact to the plant of each external hazard and the correlations among external hazards on each NPP when this method is applied.

As the next step, it is necessary to assess the fifty hazard combinations of the external hazards extracted by this risk matrix method. Additionally, it is necessary to argue with the experts about the risk score setting and the screening criteria. Moreover, it is necessary to assess the risk significant combinations of the external hazards extracted by this risk matrix method in detail.

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