The Systematic Evaluation of Combining Extreme Hazards for Lungmen Nuclear Power Plant

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In March 2011, a massive earthquake with a magnitude of 9.0 and a tsunami struck a wide area of coastal Japan. At the Fukushima Daiichi nuclear power plant, the combined effect led to the loss of electrical power and caused the radionuclides released from the plant. By the lesson learned from the Fukushima nuclear accident in Japan, it's necessary to re-evaluate the combined effect due to multiple extreme hazards in Taiwan. With a systematic and deterministic method, the potential combination of extreme hazards which would possibly strike beyond the safety of Lungmen nuclear power plant will be found out in this paper. The combining extreme hazards matrix of Lungmen nuclear power plant would be derived with ANSI/ANS-2.12-1978. According to the probabilities of occurrence from hazard combinations and the deterministic screening analysis, it can be decided whether further detail stress test for the plant safety about the identified hazard combinations would be necessary or not. The scope of extreme hazards are included both natural hazards and external man-made hazards. These hazards were obtained from ASME/ANS RA-Sa-2009、ANSI/ANS-2.12-1978 and IAEA NS-G-1.5 report. The total amount about 39 extreme hazards was considered in the initiate screening analysis. About 5 of them were retained and need to perform the 2x2 hazard matrix. It contains typhoon, precipitation, tsunami, earthquake and volcanic activity. With the 2x2 matrix evaluation for these 5 extreme hazards, only one combination event with occurrence of typhoon and precipitation simultaneously should be considered in the scope of stress test of Lungmen nuclear power plant. However no combination events with 3 hazards were retained from the 3x3 matrix evaluation. Most of single extreme hazards would be screened out according to the characteristic of site in Taiwan. By implementing a systematic approach for combining extreme hazards, this paper identified the most critical combination hazard which is combined from typhoon and precipitation. This hazard combination would possibly strike beyond the design base about flooding of the plant site and need further detail stress test to confirm the safety of Lungmen nuclear power plant.

I. INTRODUCTION

In March 2011, a massive earthquake with a magnitude of 9.0 and a tsunami struck a wide area of coastal Japan. At the Fukushima Daiichi nuclear power plant, the combined effect led to the loss of electrical power and caused the radionuclides released from the plant. By the lesson learned from the Fukushima nuclear accident in Japan, it's necessary to re-evaluate the combined effect due to multiple extreme hazards in Taiwan.

In March 2013, TPC (Taiwan Power Company) had finished the stress reports of operating nuclear power plants in Taiwan and also invited OCED/NEA (Organization for Economic Co-operation and Development/Nuclear Energy Agency) review team to make peer view of these stress report. The OECE/NEA reviewers recommended that the external extreme natural hazards should be considered the combined effect by a systematic evaluation.

The purpose of this paper is to find out the potential combination of extreme hazards which would possibly strike beyond the safety of Lungmen nuclear power plant with a systematic and deterministic method. The priority of combination events should also be conducted by experience level (High/Medium/Low) in the frequency or the consequences of the hazard events and select which combination events should be considered in the scope of stress test.

Ⅱ. METHODOLOGY

The combining hazards matrix analysis was evaluated by summarizing the Methodology of ANSI/ANS-2.12-1978 (Ref. 1) and ASME/ANS RA-Sa-2009 (Ref. 2). The procedure of evaluation contains five major steps which are shown as followings:

Step1: Buildup the individual natural or external man-made hazard list and conduct the initial screen of these individual hazards by exclusion criteria for individual hazards.

Step2: Compute the probabilities of independent or involving dependent combining events and screen these combining hazard events with exclusion criteria for combination.
Step3: Buildup the 2x2 matrix for all of hazards retained from step 2
Step4: Buildup the 3x3 matrix for all of hazards retained from step 3
Step5: Prioritize the candidate combination events and check which combination events should be considered in the scope of stress test or design basis

The details of these five major steps are shown as followings:

Ⅱ.A. Individual Hazard List and Initial Preliminary Screening Analysis

In order to consider the site specific characteristic and to complete the individual hazard list, it was buildup by summarizing the individual hazards which was mentioned from NUREG-1407 (Ref. 3),NUREG/CR-2300 (Ref. 4) and ASME/ANS RA-Sa-2009.

The initial preliminary screening analysis was implemented to identify which individual hazards would impact the plant safety directly. Five exclusion criteria for individual hazards were followed the guidelines of ASME/ANS-RA-Sa-2009 section 6-2 EXT-B1. It was shown as below:

Criterion 1: The event is of equal or lesser damage potential than the events for which the plant has been designed. This requires an evaluation of plant design bases in order to estimate the resistance of plant structures and systems to a particular external hazard.

Criterion 2: The event has a significantly lower mean frequency of occurrence than another event, taking into account the uncertainties in the estimates of both frequencies, and the event could not result in worse consequences than the consequences from the other event.

Criterion 3: The event cannot occur close enough to the plant to affect it. This criterion must be applied taking into account the range of magnitudes of the event for the recurrence frequencies of interest.

Criterion 4: The event is included in the definition of another event.

Criterion 5: The event is slow in developing, and it can be demonstrated that there is sufficient time to eliminate the source of the threat or to provide an adequate response.

Ⅱ.B. Exclusion Criteria for Combining Hazards

The exclusion criteria used in this screening analysis is from ANSI/ANS-2.12-1978.Combinations of two or more natural or external man-made hazards need not be considered in plant design, if one or more of the following criteria are satisfied:

Criteria 1: Acceptably small probability of occurrence

If the probability of simultaneous occurrence of the combination of hazards is equal to or less than $1x10^{-6}$ per year at the plant site, the combination need not be considered in plant design.

Criterial 2: Hazard effects are non-additive:

Where the effects due to the individual hazards in a postulated combination do not produce load on the same part of the plant, the need to consider this combination is the plant design is eliminated by giving due consideration to each of the individual hazards comprising the postulated combination.

Criterial 3: Effects bounded by another design combination

Where the effects on the plant due to one combination are determined to be less severe than the effects of another combination, which are part of the plant design basis, then the documentation of this determination constitutes the necessary consideration of the less severe combination in the plant design.

Criterial 4: Mutually Exclusive Hazards

Combinations of hazards which occur simultaneously due to the physical laws of nature shall be excluded from consideration in plant design.

Ⅱ.C. Probabilities Calculation for Combining Hazards

The probability for the simultaneous occurrence of two independent events is shown in Eq. (1):

P {2 events combination} = P1P2 (t1 + t2)/Y (1)

P1 and P2 are the probabilities of occurrence, per year, of the two events; t1 and t2 are the event durations (in minutes); Y is the number of minutes in one year. This formula is valid when it is assumed that the durations of these events (t1 and t2) are much less than one year and P1 and P2 << 1.

The probability for the simultaneous occurrence of two involving dependent events is shown in Eq. (2):

P {2 events combination} = P (2/1) $_{P1}$ (2)

P (2/1) is the conditional probability for the occurrence of event 2, during the occurrence of event 1, given the occurrence of event 1.For completely dependent events, P (2/1) = 1; while for completely independent events, P (2/1) = P2 (t1 + t2)/Y.

Ⅱ.D. Buildup Combining Hazard Matrix

After the initial preliminary screening analysis was implemented, the 2x2 combining hazard matrix would be buildup. It can be determined the combination events from the potential hazards in the matrix and candidate combination events with 2 hazards. It should be noted that the matrix do not expand if there are not reasonable combination events.

After the 2x2 combining hazard matrix analysis was completed, the combination events with 2 hazards from 2x2 hazard matrix can also be combined with another individual event to buildup 3x3 combining hazard matrix. The Candidate combination events with 3 hazards can be identified. This procedure of expanding the matrix would be finished when all the combination in combining hazard matrix could be screened.

Ⅱ.E. Design Basis or Stress Test Reviewed

According to the result of combining hazard matrix analysis, the candidate combination events would be identified. It was necessary to determine the priority of combination events by experience level (High/Medium/Low) in the frequency or the consequences of the hazard events and select which combination events should be considered in the scope of stress test.

Ⅲ. INITIAL PRELIMINARY SCREENING ANALYSIS FOR LUNGMEN NPPS

In order to consider the site specific characteristic and to complete the individual hazard list, it was buildup by summarizing the individual hazards which was mentioned from NUREG-1407, NUREG/CR-2300 and ASME/ANS RA-Sa-2009. The individual hazard should be considered was shown in TABLE Ⅰ and was classified into natural hazards and man-made hazards two types.

TABLE I. Individual Hazard List

Type	Individual Hazards
Natural Hazards	Avalanche, Coastal Erosion, Drought, External Flooding, Extreme Winds and Tornadoes, Internal Fire, Precipitation, River Diversion, Sand Storm, Seiche, Earthquake, Snow, Soil Shrink/Swell, Storm Surge, Tsunami, Volcanic Activity, Waves, Biological Events, Fog, Forest Fire, Frost, Hail, High Tide/High Lake Level or High River Stage, High Summer Temperature, Hurricane, Ice Cover, Internal Flooding, Landslide, Lightning, Low Lake or River, Stage, Low Winter Temperature, Meteorite/Satellite Strikes
Man-made Hazards	Aircraft Impact, Release of Chemicals from On-site Storage, Transportation Accidents, Toxic Gas, Turbine Generated Missiles, Industrial or Military Facility Accident, Pipeline Accident

The preliminary screening result is shown in TABLE Ⅱ. There were 7 individual hazards could be screened by Criterion 1 because most of these individual hazards were equal or lesser damage potential than the events for which the Lungmen plant has been designed. About 14 individual hazards could be screened by Criterion 3 because of site specific meteorological or Geological condition of Lungmen plant. About 4 individual hazards could be screened by Criterion 5 because these hazards were slow in developing and there were sufficient time to eliminate the source of the threat or to provide an adequate response.

The further bounding analysis was implemented for the 5 external man-made hazards (such as Aircraft Impact, Toxic Gas, Transportation Accidents, Industrial or Military Facility Accident, Pipeline Accident). All of these hazards could be screened due to the low impact frequency or sufficient distance from hazard source to Lungmen Plant (above 8 km).

The rest 9 individual hazards which remained from the preliminary screening analysis are Internal Flooding, Internal Fire, External Flooding, Extreme Winds and Tornadoes, Precipitation, Earthquake, Tsunami, Volcanic Activity, Hurricane. Because internal fire and flooding PRA of Lungmen plant had been conducted, Both Internal Flooding and Internal Fire hazards would not been discussed in the followings. The effect of Extreme Winds and Tornadoes could be included in Hurricane and the External Flooding event contains Precipitation and Tsunami so that actually there are 5 individual hazards which are Precipitation, Earthquake, Tsunami, Volcanic Activity and Hurricane should be considered in the following combining hazard matrix analysis.

TABLE Ⅱ. The Preliminary Screening Result

Preliminary Screening	Individual Hazard
Screened by Criterion 1	Release of Chemicals from On-site Storage, Storm Surge, Turbine Generated Missiles, Forest Fire, Hail, Landslide, Lightning
Screened by Criterion 3	Avalanche, Drought, River Diversion, Sand Storm, Seiche, Snow, Soil Shrink/Swell, Waves, Frost, High Tide/High Lake Level or High River Stage, Ice Cover, Low Lake or River Stage, Low Winter Temperature, Meteorite/Satellite Strikes
Screened by Criterion 5	Coastal Erosion, Biological Events, Fog, High Summer Temperature
Screened by Further Bounding Analysis	Aircraft Impact, Toxic Gas, Transportation Accidents, Industrial or Military Facility Accident, Pipeline Accident
Can't be Screened	Internal Flooding, Internal Fire(Lungmen existing PRA modal) External Flooding, Extreme Winds and Tornadoes, Precipitation, Earthquake, Tsunami, Volcanic Activity, Hurricane

Ⅳ. THE 2X2 COMBINING HAZARD MATRIX FOR LUNGMEN PLANT

The design basis of nuclear power plant was always considered the occurrence of single hazard and the plant was designed to be able to safety shutdown from the single hazard striking. Most of this single hazard were always considered the extreme situation and with long return period. The point of combining hazard matrix analysis is to evaluate the combined effect due to multiple extreme hazards whose individual return period might be less the plant design but are possible to beyond the design basis. The potential combination of extreme hazards would also be identified in this paper.

The methodology of combining hazard matrix was according to ANSI/ANS-2.12-1978 (Ref. 1) which was discussed above and the process would be shown below.

Ⅳ.A. Discuss the dependence of two individual hazards

According to ANSI/ANS-2.12-1978, the calculations of probability of the probability for the simultaneous occurrence of two independent events or dependent events are different. The relation among each individual hazard should be clarified at first and the dependence matrix of two individual hazards was buildup as shown in TABLE Ⅲ.

TABLE Ⅲ. The Dependence Matrix of Two Individual Hazards

	Precipitation	Hurricane	Earthquake	Tsunami	Volcanic Activity
Precipitation	-	D	I	I	I
Hurricane	-	-	I	I	I
Earthquake	-	-	-	I	D
Tsunami	-	-	-	-	I
Volcanic Activity	-	-	-	-	-

I: Independent combining event
D: dependent combining event

For common sense, the Hurricane always comes with precipitation and Volcanic Activity always leads to Earthquake so the relations of these two hazard combinations were defined as dependent event. As regard to Precipitation to (Earthquake/Tsunami/Volcanic Activity) or Hurricane to (Earthquake/Tsunami/Volcanic Activity), the relation of these two individual combining hazards was defined as independent event because different cause of formation.

In general, the relation between Earthquake and Tsunami seem to be dependent. But by further consider the Lungmen site specific geography environment, the relation between Earthquake and Tsunami could be defined as independent event. It is because that the research showed the most severe damage to Lungmen plant with Earthquake will be caused by the inland Sanchiao fault rupture which is close to Lungmen site. In the other hand, the big scale Tsunami will occur when the Ryukyu Trench ruptures which is far from the Lungmen site location. Briefly, as regard to big scale Earthquake and Tsunami, they have different major cause of fault or trench so the relation between Earthquake and Tsunami could be defined as independent event for Lungmen plant.

Tsunami and Volcanic Activity were defined as independent combining event because big scale Tsunami and Volcanic which could impact the safety of Lungmen plant are caused by different resource. For Lungmen site, big scale Tsunami induced with Volcanic Activity is major by erupting of the Submarine volcano which is far from the Lungmen site. But as regard to the directly damage to the plant with Volcanic Activity (such as Volcanic ash, Magma), the inland Tatun Volcano Group will cause much more damage than the Submarine volcano which is far from Lungmen site. So the relation between Volcanic Activity and Tsunami could be defined as independent for Lungmen plant.

Ⅳ.B. Duration Time of Individual Hazards and Frequency of Occurrence

Before buildup the 2x2 combining hazard matrix, the duration time and frequency of occurrence of individual hazards should be defined and the result is shown as TABLE Ⅳ.

TABLE Ⅳ. The Duration Time and Frequency of Occurrence of Individual Hazards

Individual Hazard	Hazard Definition	Frequency of Occurrence	Estimated Duration
Precipitation (mm/hr)	PMP	10^{-4}	1 day
	100-years	10^{-2}	1 day
Hurricane (m/s)	1000-years	10^{-3}	12 hours
Earthquake (PGA)	SSE	6.8×10^{-4}	60 seconds
	OBE	5.6×10^{-3}	30 seconds
Tsunami (Flooding Hight)	PMT	10^{-5}	2 days
	100-years	10^{-2}	18 hours
Volcanic Activity (volume)	100000-years	10^{-5}	1 day~3 months
	1000-years	10^{-3}	1 day

Precipitation:

Precipitation was considered the PMP (Probable Maximum Precipitation) of the Lungmen design basis and the 100 years return period Precipitation. The frequencies of occurrence for both hazard definitions are 10^{-4} per year and 10^{-2} per year respectively. Both of the duration time was given as 1 day due to the classification standard of extremely heavy rain which was defined by Taiwan Central Weather Bureau.

Hurricane:

Hurricane was considered the wind effect herein. According to the Lungmen FSAR(Final Safety Assessment Report), Transmission tower have the lowest protective ability of wind and which is 50 m/s. The frequency of occurrence was available from checking the hazard curve of wind in Lungmen FSAR and was about 2.22×10^{-4} per year. For conservative concern, the frequency of occurrence of Hurricane was took the bounding value 10^{-3} per year for following analysis. The duration time was given as 12 hours which was according to ANSI/ANS-2.12-1978.

Earthquake:

Earthquake was considered the SSE (Safety Shutdown Earthquake) and OBE (Operating Basis Earthquake) of the Lungmen design basis. The frequencies of occurrence for both hazard definitions are 6.78×10^{-4} per year and 5.61×10^{-3} per year respectively. It was available from the seismic hazard curve which was including in Lungmen FSAR. The duration time was given 60 seconds for SSE and 30 seconds for OBE which was according to ANSI/ANS-2.12-1978.

Tsunami:

Tsunami was considered the PMT (Probable Maximum Tsunami) of the Lungmen design basis and the 100 years return period Tsunami. The frequency of occurrence was about 10^{-5}~10^{-6} per year for PMT (available from Tsunami Hazard Curve which was including in Tsunami hazard analysis report for Lungmen Nuclear Power Plants) and 10^{-2} per year for 100 years return period Tsunami. For conservative concern, the frequency of occurrence of PMT was took the bounding value 10^{-5} per year for following analysis. The duration time was given 2 days for PMT and 18 hours for 100 years return period Tsunami which was according to ANSI/ANS-2.12-1978.

Volcanic Activity:

Volcanic Activity was considered the big scale eruption and small scale eruption of Tutun Volcano. The last big scale eruption time was about 20000~800000 years before and the small scale eruption time was about 5000~20000 years before. The data was available from Taiwan General Affairs Department of Yangmingshan National Park. For conservative concern, the frequency of occurrence of big scale eruption was took the bounding value 10^{-5} per year for following analysis and small scale eruption was took the bounding value 10^{-3} per year. The duration time was given 3 months for big scale eruption and 1 day for small scale eruption.

Ⅳ.C. Buildup the 2x2 Combining Hazard Matrix for Lungmen Plant

If the relation of two individual hazards is independent, the probability for the simultaneous occurrence of these two independent events is shown in Eq. (1). But for two involving dependent events, the probability of occurrence should be further discussed because it is difficult to clarify the involving degree of two dependent events. In this paper, we took conservative way and assumed the involving dependent events as completely dependents events directly and took the higher frequency of occurrence between two individual hazards as representation for analysis. The calculation result of probability for the simultaneous occurrence of hazard combination is shown in TABLE Ⅴ.

TABLE Ⅴ. The Calculation Result of Probability for the Simultaneous Occurrence of Hazard Combination

Individual Hazard	Hazard Definition	Precipitation		Hurricane	Earthquake		Tsunami		Volcanic Activity	
		PMP	100year	50m/s	SSE	OBE	PMT	100year	100000year	1000year
Precipitation	PMP	-	-	*1.00E-03	1.86E-10	1.53E-09	8.22E-12	4.79E-09	2.49E-10	5.48E-10
	100year	-	-		1.86E-08	1.53E-07	8.22E-10	4.79E-07	2.49E-08	5.48E-08
Hurricane	50m/s	-	-	-	9.33E-10	7.68E-09	6.85E-11	3.42E-08	2.48E-09	4.11E-09
Earthquake	SSE	-	-	-	-	-	3.73E-11	1.40E-08	*Screened	
	OBE	-	-	-	-	-	3.07E-10	1.15E-07		
Tsunami	PMT	-	-	-	-	-	-	-	2.52E-11	8.22E-11
	100year	-	-	-	-	-	-		2.49E-08	4.79E-08
Volcanic Activity	100000year	-	-	-	-	-	-	-	-	-
	1000year	-	-	-	-	-	-	-	-	-

*The hazard combination of two dependent individual hazards

All the hazard combinations of two dependent individual hazards would be screened out because the probability of simultaneous occurrence was equal to or less than 1×10^{-6} per year at the plant site.

Hurricane and Precipitation were defined as complete dependent events. The most serve case was considered (PMP & 1000 years return period hurricane). The higher frequency of occurrence between these two individual hazards was 10^{-3} per year and was decided by Hurricane. The consequence of this combination would result loss of offsite power and external flooding event for Lungmen plant and the combined effect due to multiple extreme hazards might beyond the design basis.

According to the Open-File Report 87-297 (Ref. 5) issued by United States Geological Survey, The scale of Most Earthquake induced by Volcanic Activity is small and will not cause serious damage to the plant. The other hand, the big scale Earthquake which would impact the plant safety seriously will not be caused by Volcanic Activity. So the combination of these two individual hazards could be screened out.

The result of 2x2 Combining Hazard Matrix analysis for Lungmen Plant is shown in TABLE Ⅵ. Most hazard combination could be screened out and only the combination of Hurricane and Precipitation should be considered in stress test.

TABLE Ⅵ. The 2x2 Combining Hazard Matrix for Lungmen Plant

Individual Hazard	Precipitation	Hurricane	Earthquake	Tsunami	Volcanic Activity
Precipitation	-	Yes	Screened	Screened	Screened
Hurricane	-	-	Screened	Screened	Screened
Earthquake	-	-	-	Screened	Screened
Tsunami	-	-	-	-	Screened
Volcanic Activity	-	-	-	-	-

Ⅴ. THE 3X3 COMBINING HAZARD MATRIX FOR LUNGMEN PLANT

After the 2x2 combining hazard matrix analysis for Lungmen plant was completed, the combination events with 2 hazards from 2x2 hazard matrix can also be combined with another individual event to buildup 3x3 combining hazard matrix. Because the combination of Precipitation and Hurricane is independent to Earthquake, Tsunami or Volcanic Activity, the probability for the simultaneous occurrence of these three individual events was calculated with Eq. (1).The frequency of the combination from DBT and PMP was taken as single event and was 10^{-3} per year which was discussed above. Because the duration time of the combination between two individual events was difficult to define clearly, the longer duration time between two individual events would be selected for the calculation. The duration time was 12 hours for Hurricane and 1 day for Precipitation. Thus for conservative concern, the duration time of combination between Hurricane and Precipitation was given as 1 day. The calculation result of probability for the simultaneous occurrence of hazard combination with three individual hazards is shown in table Ⅶ.

TABLE Ⅶ. The Calculation Result of Probability for Hazard Combination with Three Individual Hazards

Individual Hazard	Hazard Definition	Precipitation	Hurricane	Earthquake	Tsunami	Volcanic Activity
		PMP	50m/s	SSE	PMT	100000year
Hurricane and Precipitation	DBT&PMP(10^{-3})			1.86E-09	8.22E-11	2.50E-09

All the hazard combinations of three individual hazards would be screened out because the probability of simultaneous occurrence was equal to or less than $1x10^{-6}$ per year at the plant site. There were no potential hazard combinations with three individual hazards for Lungmen plant and it will not be necessary to drive the higher level combining hazard matrix (such as 4x4 matrix).

Ⅵ. CONCLUSIONS

The combining hazards matrix analysis of this paper was evaluated with the methodology of ANSI/ANS-2.12-1978.The result shows 39 extreme individual hazards were considered in the initiate screening analysis and Most of them could be screened out according to the specific site characteristic for Lungmen plant. Only 5 of the total individual hazards were retained and need to perform the 2x2 hazard matrix. It contains typhoon, precipitation, tsunami, earthquake and volcanic activity.

With the 2x2 matrix evaluation for these 5 extreme hazards, only one combination event with occurrence of typhoon and precipitation simultaneously should be considered in the scope of stress test of Lungmen nuclear power plant. However no combination events with 3 hazards were retained from the 3x3 matrix evaluation and it will not be necessary to drive the higher level combining hazard matrix (such as 4x4 matrix).

By implementing a systematic approach for combining extreme hazards, this paper identified the most critical combination hazard which is combined from typhoon and precipitation. This hazard combination would possibly strike beyond the design base about flooding of the plant site and need further detail stress test to confirm the safety of Lungmen nuclear power plant.

REFERENCES

1. ANSI, "Guidelines for Combining Natural and External Man-Made Hazards at Power Reactor Sites, " ANSI/ANS-2.12-1978, July 1978.
2. ASME, Addenda to ASME/ANS RA-S-2008, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications," ASME/ANS RA-Sa-2009, February 2009.
3. USNRC, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities, " NUREG-1407, June 1991.
4. USNRC, "PRA Procedure Guide, A Guide to the Performance of Probabilistic Risk Assessment for Nuclear Power Plants," NUREG/CR-2300, January 1983.
5. US Geological Survey," Volcanic Hazards with Regard to Siting Nuclear-Power Plants in the Pacific Northwest, Open-File Report 87-297, 1987