Study of risk assessment methodology for tornado

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Abstract: The Central Research Institute of Electric Power Industry (CRIEPI) is currently conducting research to advance the methodology for Level 1 tornado probabilistic risk assessment (PRA) for nuclear power plants. The primary objective of this study is to develop a methodology for conducting tornado PRA for nuclear power plants in Japan. Currently, the applicability of the simplified evaluation method developed in this study is being examined with reference to the guidelines issued by the Electric Power Research Institute (EPRI). In this paper, the selected representative Pressurized Water Reactor (PWR) plant is evaluated in detail using the developed high wind equipment lists and the PRA model developed for internal event PRA. Additionally, we present the development of the tornado PRA methodology using a graded approach that includes a simplified evaluation without detailed PRA.

Keywords: High wind PRA, Tornado, Graded Approach, Risk Analysis

1. INTRODUCTION

In domestic nuclear power plants, countermeasures against tornadoes have been implemented from a deterministic perspective and their safety has been confirmed. In the U.S., on the other hand, the tornado PRA method has been developed for probabilistic risk analysis of tornadoes and applied to nuclear power plants. It is useful to assess the risk of tornadoes from a probabilistic perspective in Japan as well, and the establishment of a domestic tornado PRA method is considered important. In this paper, to estimate tornado risk without a PRA model, the results of a detailed risk assessment and a simplified risk assessment were examined for a representative plant, referring to the guidelines of the Electric Power Research Institute (EPRI) in the U.S. [1,2].

2. Organizing information for the implementation of the tornado PRA

Based on the EPRI guidelines, each item necessary to conduct a detailed tornado PRA is summarized. The concepts, key conditions, and assumptions necessary to conduct a tornado PRA in this study are listed below.

2.1. Wind hazard assessments

To understand the risks associated with tornadoes, both the potential extent of failure and the frequency of their occurrence should be evaluated. There are several methods for assessing the extent of potential failure and probability of occurrence of tornadic missile attacks on nuclear power plant structures, systems and components [3]. The tornado PRA model also needs to consider the range of wind speeds in the analysis that could cause potential core damage or failure of key mitigation components. The wind speed classifications were set based on licensing documents (documents attached to the application for permission of changes in the reactor installation and approval of the construction work plan) The risk analysis perspective is very important to quantitatively assess the residual risks associated with beyond design basis events. Potential residual risks include scenarios such as the occurrence of a major F-scale tornado, which has never been experienced in Japan. To assess such risks, the tornado wind speed hazard model for limited area (TOWLA) has been developed to analyze wind hazards [4]. Information on the area under assessment was organized and the probability of each wind speed class was calculated by linear interpolation for the logarithm of the probability of exceedance for the wind speeds as calculated using TOWLA, and by subtracting the probability of the upper wind speed from the lower wind speed limit. The area of influence was defined as a circle of 1000 m^2. For wind speeds outside the integral range, values were predicted by linear extrapolation from the edge values of the integral range to the logarithmic values of the probability of exceedance. The tornado frequencies for each wind speed classification at the representative plant assessed using TOWLA are shown in Table 1 below.

Table 1 Average frequency of tornadoes by wind speed classification

Wind speed classification	Lower limit wind speed [m/s]	Upper limit wind speed [m/s]	Average frequency[/year]
F'2	46	60	1.18E-4
F'3	60	75	1.73E-5
F'4	75	93	2.03E-6
F'5a	93	100	1.03E-7
F'5b	100	124	5.88E-8
F'6	124	134	1.72E-9

2.2. Missile impact probability

This section presents the concept assessing the flying object impact probability. A simplified evaluation was conducted to determine the probability of failure for each wind speed classification. The Tornado missile risk evaluator (TMRE) developed by the Nuclear Energy Institute (NEI) [5] is a simplified method for evaluating equipment failure probability due to tornadic flying debris. For the missile impact probability (MIP), two tables are provided, one for the height of the installation of the facility and the other for the number of flying objects and the MIP. Therefore, to calculate the impact probability of flying objects, information on the surface area and installation height of the facility is required. If the equipment is found to be robust, some flying objects with low impact energy are considered to have no damaging effects, and a correction factor for the number of flying objects is given. Taking these factors into consideration, information on the surface area, installation height, and robustness of equipment and protective equipment affected by tornadic flying debris was extracted from the licensing documents and other sources, and equipment failure probabilities were calculated based on the TMRE methodology. In addition, the study assumes that equipment installed outdoors is certain to be failed. The results of the evaluation is shown in Table 2 below.

Table 2: Equipment Failure Probability by Wind Speed classification

Equipment / classification	Equipment Failure Probability（Failure probability per unit）					
	Seawater pump	Strainer	Diesel Generator	Condensate tank	Main steam pipe	Outside equipment
F'2	2.71E-04	1.42E-04	8.91E-06	5.82E-03	4.03E-06	1.0
F'3	2.95E-03	1.61E-03	9.55E-05	5.56E-02	4.78E-05	1.0
F'4	1.46E-02	8.00E-03	4.87E-04	2.22E-01	2.40E-04	1.0
F'5a	1.11E-01	6.43E-02	4.11E-03	7.35E-01	2.11E-03	1.0
F'5b	2.52E-01	1.22E-01	8.93E-02	7.35E-01	3.64E-02	1.0
F'6	3.63E-01	1.82E-01	1.35E-01	8.72E-01	5.39E-01	1.0

The same values are used for the probability of tornado occurrence and the factor that causes the mitigation system to lose functionality due to a tornado, "probability of failure due to a tornado," in both the detailed evaluation and the simplified evaluation. The quantified evaluation results are then compared and confirmed.

2.3. Plant response modeling

2.3.1 Initiating event analysis

In nuclear power plants, it is believed that the offsite power is one of the most vulnerable components to tornadoes. Therefore, it is assumed that the offsite power will be lost due to tornadoes of all wind speed classification, and the loss of offsite power (LOOP) is designated as an initiating event that is certain to occur.

2.3.2 Accident sequence analysis

Since LOOP is assumed to always occur in the event of a tornado, the event tree for LOOP modeled in the internal event PRA, is used for the accident sequence analysis. Headings and expected mitigation measures in each event tree are the same as those for internal event PRAs, and the fault trees associated with each heading will model the equipment selected in the equipment list in the next section to account for the tornado impact. When an assessment that the building is always failed by a tornado is implemented, a branch to determine if there is a loss of function is added. If the function is lost, it is treated as core damage.

2.3.3 Consideration of wind equipment list

The method of developing an equipment list was studied with reference to EPRI-3002008092, and an equipment list for tornado PRA (High Wind Equipment List: hereinafter referred to as HWEL) was developed for this study. In EPRI-3002008092, Structures, Systems and Components (SSCs) that affect the sequence to be evaluated for the tornado PRA are extracted from the basic event modeled in the internal event PRA, and SSCs installed at locations that could be failed by a tornado strike are to be included in the HWEL. In addition, SSCs that are not extracted from the basic event of the internal event PRA and are vulnerable to tornadoes are to be identified through design drawings or by conducting plant walkdowns and should be included in the HWEL. For this evaluation, the HWEL was developed using the method shown in Figure 1 with reference to EPRI-3002008092.

For the mitigation system to be evaluated for the tornado PRA, the SSCs that affect that system and the buildings in which they are installed are listed. The list of equipment for the Tsunami PRA, which was created based on the internal event PRA, is referred to organize SSCs that affect mitigation components and the buildings in which they are installed. First, using this equipment list as a reference, buildings that are robust against tornadoes are selected from the licensing documents. Then, SSCs that are not installed in the selected robust buildings are added to the HWEL. This procedure produces results similar to the selection of SSCs based on the basic event of the internal event PRA of EPRI-3002008092, and the target SSCs in the HWEL can be extracted. Next, SSCs that are not extracted from the basic events of internal events can be identified based on the design drawings and do not need to be examined again.

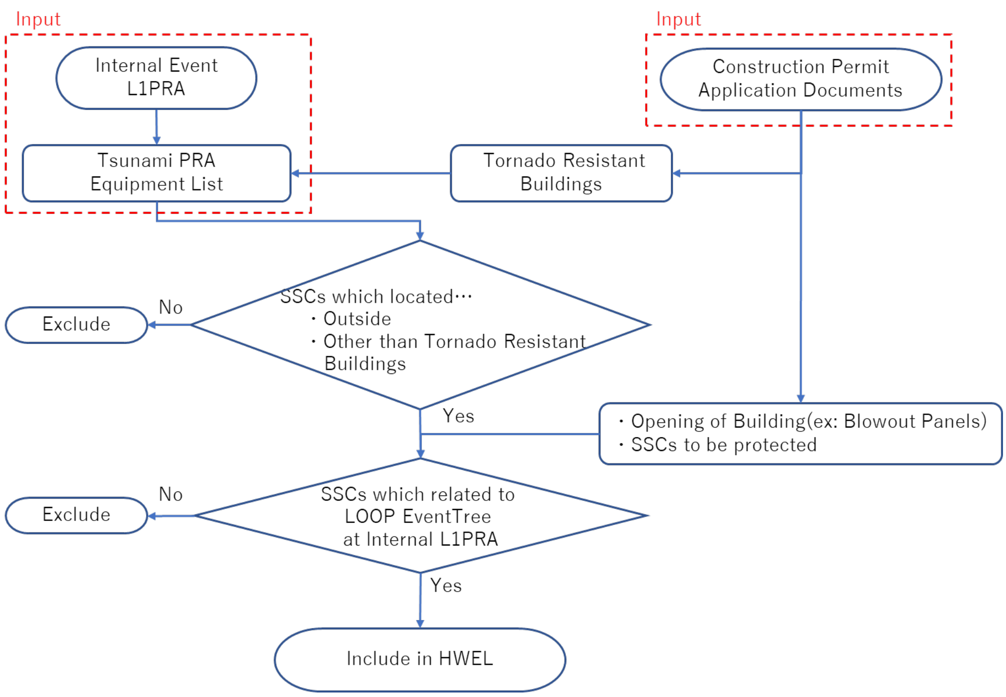

Figure 1 Workflow diagram

2.3.4 Human reliability analysis

If the potential for a tornado that affects operator actions or certain proceduralized actions taken during and after a tornado event affect the risk analysis, they should be added to the model. For this study, the human failure events (including human error probability) of the internal event PRA are used, because the tornado duration is generally short and mitigation measures utilizing outdoor facilities are not credited. In addition, operator action performed inside the building during a tornado event are assumed to be unaffected by the tornado as long as the building is not failed.

3. Study on tornado PRA methodology

3.1. Detailed assessment using PRA models developed for internal event PRAs

The tool used for the detailed evaluation is RiskSpectrum PSA. Using the internal PRA model, a tornado effects organized in Chapter 2, will be included in the fault tree as shown below;

- The equipment that is given an MIP for each wind speed classification represents failure according to each wind speed classification by placing the basic event of the MIP at a position on the fault tree that is equivalent to the basic event that represents its loss of function.
- The equipment is not credited, is represented as the basic event has probability of 1.0.

Other parameters (equipment failure rate, common cause failure parameters, percentage of the period during which the equipment is placed out of service for testing or maintenance) and mission times remain the same as those for the internal event PRA. No uncertainty analysis is performed at this stage of the study.

3.2. Simplified risk evaluation without detailed PRA

The core damage frequency (CDF) due to a tornado strike is calculated as the product of the tornado occurrence frequency, the probability of occurrence of an initiating event, and the probability of loss of safety function. In the simplified risk evaluation, the values as those in the detailed evaluation are used for the probability of occurrence of an initiating event, while a simplified values are used for the probability of loss of safety function. Loss of function factors in the mitigation system can be classified into “tornado failure” and “loss of safety function due to random failure”. For “tornado failure,” the SSCs considered in the simplified risk evaluation are the same as those in the detailed evaluation, and multiple identical facilities are conservatively assumed to be failed due to complete correlation. For “Loss of Function due to Random Failure,” the dominant failure factors are analyzed based on the cut-set obtained from the internal event PRA model, and the probability of loss of safety function is determined. The event tree used in the simplified evaluation is same as that used in the detailed evaluation and the calculation is made simply by setting the following conditions.

■ Occurrence of the initiating event

Based on the assumption that equipment related to the offsite power supply is certain to be failed by a tornado, the initiating event is assumed to be “loss of offsite power supply due to tornado”.

■ Occurrence of building failure

Based on the assumption that buildings with important safety functions (e.g., reactor building, auxiliary reactor building, etc.) will not be failed by the tornado, affect of building failure is excluded from the evaluation.

■ Occurrence of loss of total AC power supply

The event resulting in the LOOP requires the emergency diesel generator (hereinafter referred to as “EDG”) to restore AC power in order to avoid a total loss of AC power supply (hereinafter referred to as “SBO”). The failure of EDGs are categorized into failure to the SSCs caused by a tornado and random failure, and two headings are separately modeled in the event tree.
Since the simplified evaluation does not credit SSCs without tornado protection measures and does not credit severe accident (SA) measures involving outdoor work, no core damage prevention can be credited during SBO sequence. Therefore, in the simplified evaluation, both tornadic and random SBO sequences are treated as leading to core damage.

■ Number of EDGs that are successful/failed

Even in a sequence in which an SBO occurrence is prevented, the subsequent event progression is different between when one EDG is successful and when two EDGs are successful. Therefore, an event heading for loss of partial EDG is provided to account for sequences in which one EDG of one train loses its functionality. Since the failure to the SSC by the tornado is assumed to be caused in complete correlation, partial loss of EDG is only caused by random failure of EDG.

■ Occurrence of pressurizer relief valve/safety valve loss of coolant accident

After a reactor shutdown, the pressurizer relief valve/safety valve may be operated by an increase in the primary coolant pressure. If these valves open and then become stuck open, primary coolant may flow out, leading to a pressurizer relief valve / safety valve loss of coolant accident (hereinafter referred to as “PORV/LOCA”). In the event of a PORV/LOCA, the auxiliary feedwater (hereinafter referred to as “AFW”) and the emergency core cooling system (hereinafter referred to as “ECCS”) for injection and recirculation operations are required to prevent the core damage. Since the impact on subsequent mitigation components is different, the heading "PORV/LOCA" is modeled in the event tree.

■ Success or failure of auxiliary feedwater supply

AFW is required for the core cooling by the secondary cooling system after the occurrence of LOOP. Therefore, a heading on AFW is provided in the event tree. The failure of AFW is categorized by failure to SSCs caused by tornadoes, and random failure and two headings are separately modeled in the event tree.

■ Success or failure of ECCS

In case of AFW failure sequence or PORV/LOCA occurrence sequence, core water injection (including feed-and-bleed operation) and recirculation operation by ECCS are required for core cooling. Therefore, an ECCS heading is provided in the event tree. The failure of ECCS is categorized by failure to SSCs caused by tornadoes, and random failure and two heading are separately modeled in the event tree.
In the internal event scenario, the feed-and-bleed operation will always fail because the success criteria for the pressurizer relief valve cannot be satisfied in the event of a partial loss of the EDG. In the accident sequence involving a partial loss of EDG , the failure of the AFW always results in core damage, and no ECCS branch is provided.
These sequences are compiled to calculate the CDF for each wind speed classification.

3.3. Comparison of simplified risk evaluation and detailed assessments

The purpose of this study is to understand the risk level at each plant due to tornadoes by comparing and analyzing the detailed and simplified assessments at the representative plant, and by developing a simplified evaluation for each plant without the need for a detailed PRA model. For representative plants, a detailed PRA model will be developed in addition to the simplified assessment, and further refinement will be made step by step to achieve a realistic risk assessment. Figure 2 shows an image of the transition of evaluation results. As shown in Figure 2, the simplified evaluation adopts conservative conditions, so the values are higher than those of the detailed evaluation using the internal event PRA. In this method, if the risk is judged to be small compared to other external event CDFs in the simplified evaluation, the evaluation is completed. On the other hand, if the risk cannot be judged to be small compared to other external event CDFs, the information is organized as described in Chapter 2, and the Case detailed evaluation is conducted using the PRA model. If the risk cannot be determined to be small, the risk from tornadoes is estimated by analyzing and refining the sensitivity analysis or dominant minimum cut set as shown in Case detailed 1 and 2 in Figure 2 and feeding it back into the model. If the risk is determined to be high even after feedback from the cut set analysis, the final risk is determined by refining the tornado occurrence frequency (hazard) and flying object impact probability as shown in Case detailed 3 in Figure 2.

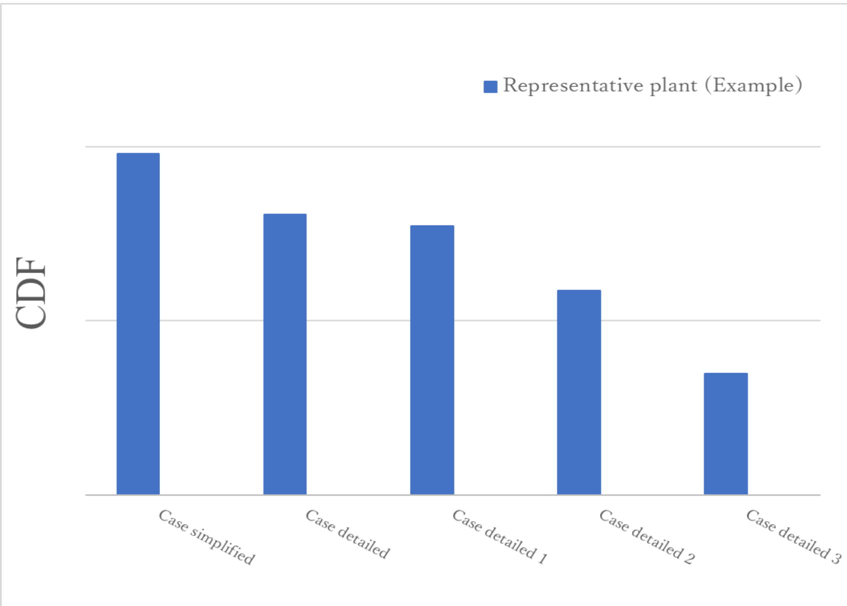

Figure 2: Image of the transition of evaluation results

The degree of conservatism of the simplified evaluation is confirmed by analyzing the difference between the simplified evaluation and the detailed evaluation. In addition, the simplified evaluation will be reviewed and the updated to remove the conservatism caused by the model simplification.
The simplified evaluation will be conducted for Plants B and C, which are located in different site. Since differences in plant configuration and plant response cannot be confirmed, the impact on risk due to the simplified treatment of plant configuration and plant response at Plants B and C are estimated with reference to the analysis results before and after the simplified evaluation review at the representative plant. Based on the comparative analysis of the simplified evaluation and detailed evaluation at the representative plant through this process, the degree of tornado risk is determined by the simplified evaluation. An image of the simplified evaluation plant deployment is shown in Figure 3.

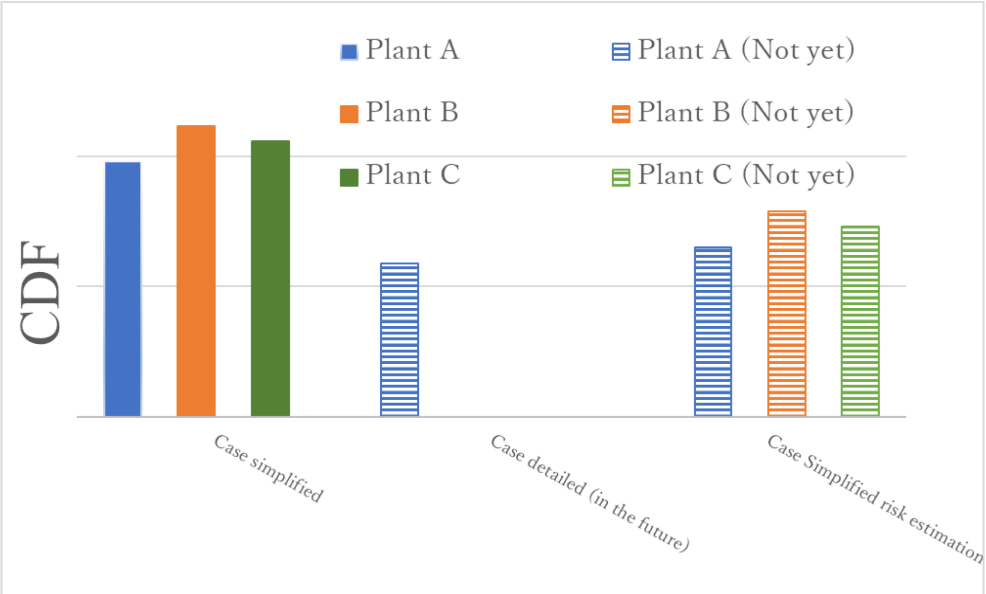

Figure 3 Image of the evaluation results reflecting the analysis results

Finally, we are now confirming the validity of the simplified risk estimation that reflects the findings from the detailed assessment conducted at the selected plant and the characteristics of each plant. As shown in Figure 3, Case Simplified Risk Estimation, we believe it is possible to estimate risk without using a detailed PRA model. Moreover, through this study, risk assessment methods for tornadoes will be developed according to risk level by findings from the results of the simplified and detailed assessments.

4. CONCLUSION

The methodologies for detailed PRA and simplified evaluations to estimate the risk level due to tornadoes were investigated in representative domestic PWR plants. Going forward, implementation guidelines for detailed PRA will be established and the guidelines will be updated to estimate the risk level due to tornadoes in domestic PWR plants using simplified methods. This will contribute to the promotion of tornado risk assessments using various methodologies in line with the hazard and risk levels in Japan.

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