# (1) Overview of the Extension of the Level 2 PRA Standard to Tsunami Events in Japan

**Koichi NAKAMURA[a*], Ryoichi HAMAZAKI[b], Yoshinori YAMAKOSHI[c]**
[a]Central Research Institute of Electric Power Industry, Tokyo, Japan
[b]Ex-Toshiba Corporation, Yokohama, Japan
[c]Mitsubishi Heavy Industries, Ltd., Kobe, Japan

**Abstract:** This paper presents an overview of the revision of the "Standard for Probabilistic Risk Assessment for Nuclear Power Plants at Power (Level 2 PRA)" established and published by the Atomic Energy Society of Japan to extend the application to tsunami events. The first edition of this standard was published in 2008 after discussions at the Level 2 Subcommittee of the Risk Technical Committee of the Standards Committee. This Standard specified the requirements to be met by a Level 2 PRA for accidents resulting from internal events for nuclear power plants at power. After the first edition was published, this standard was extended to seismic events at power in 2021.

The importance of Level 2 PRAs increased after the accident at the Fukushima Daiichi Nuclear Power Plants in March 2011, which resulted in not only core damage but also loss of containment boundary function and release of radioactive materials into the environment. The experience of the accident has strongly recognized the importance of Level 2 PRAs for external events and safety improvement measures based on PRAs. Based on the recognition, the scope of application of the Level 2 PRA standard was extended from internal and seismic events to tsunami events in this revision. In the revision, lessons learned and findings from the Fukushima Daiichi Nuclear Power Plant accident were incorporated as much as possible (e.g., consideration of flood in buildings, direct containment failure by tsunami, and tsunami fragility evaluation for SSCs affected in Level 2 PRA, etc.), and the latest PRA standards and guides for external flooding in Europe and the United States were investigated and reflected in the Level 2 PRA standard for tsunami events. Besides the extension to tsunami events, we investigated U.S.NRC, Regulatory Guide 1.200 and ASME/ANS PRA standards, and their requirements were reflected in the Level 2 PRA standard.

This paper also presents plans for future updates of the standard, including the extension to shutdown operation and the structure change for hierarchy of mandatory requirements/guidelines/annexes.

**Keywords:** Standards, Level 2 PRA, Tsunami Events

## 1. INTRODUCTION

Based on the experience of the Fukushima Daiichi Nuclear Power Plant accident, it has become an urgent issue to extend the scope of Level 2 PRA to external events. In light of this, the Level 2 PRA Subcommittee under the Risk Technical Committee of the Standards Committee of the Atomic Energy Society of Japan has extended the “Standard for Probabilistic Risk Assessment for Nuclear Power Plants at Power (AESJ Level 2 PRA Standard)” from internal events to seismic events. In this revision, it has been extended to tsunami events. The expanded edition was established in 2022 and published in 2023 as the fourth edition [1]. In addition to expanding the scope of application to tsunami events, the purpose of this revision is to make it applicable to the assessment of the large release frequency (LRF) or the large early release frequency (LERF) used in Europe and the United States, in addition to the containment failure frequency (CFF), which has been used as a risk indicator for Level 2 PRA standards. In the work to revise the tsunami expansion, we collected and analyzed a wide range of relevant information, including relevant standards, practices, and research results in Japan and overseas, including the analysis of the Fukushima Daiichi Nuclear Power Plant accident, and carefully extracted issues related to standard formulation. These include assessment of building flooding, consideration of tsunami-specific containment failure modes, assessment of tsunami fragility of Level 2 PRA-related structures, systems, and components (SSCs), and consideration of the impact of the tsunami on equipment, systems, and operations. The revision work was carried out mainly on the extracted issues, but those that are technically premature or under development, including technical background and examples, were included in the annex to the standard as reference information to support the application of

the standard. The ASME/ANS PRA standard and the report of the European PSA project "ASAMPSA_E" were used as references for the revision of the standard. In addition, it noted the consistency of the Level 2 PRA standard with another related standard, the Tsunami Level 1 PRA standard.

Regarding the revision of the LRF or LERF for the purpose of applying it to the evaluation, we examined relevant standards in the United States that use LERF as a regulatory risk indicator and took note of the consistency.

This article provides an overview of the revision of the AESJ Level 2 PRA standard, the use of international knowledge, and major issues in the revision process.

## 2. AESJ LEVEL 2 PRA STANDARD OVERVIEW

### 2.1. Purpose of the Standard

The AESJ Level 2 PRA standard aims to specify the technical requirements and procedures for Level 2 PRA to assess the frequency of accident sequences leading to containment failure and their source terms in order to assess the overall safety of nuclear power plants.

The final output of a Level 2 PRA, the technical procedures for obtaining it, and the level of quality assurance may vary depending on the implementer's objectives, depending on how the risk profile resulting from the Level 2 PRA is applied. For example, if implementation of the Level 3 PRA is the ultimate goal, a full set of output from the Level 2 PRA is required, including containment failure frequency (CFF) and source terms for all release categories with uncertainty. On the other hand, when applying large early release frequency (LERF) as an alternative indicator, the procedure is more simplified. The AESJ Level 2 PRA standard sets out the technical requirements required to achieve Level 2 PRA for these various implementer's objectives. The implementer may achieve Level 2 PRA in whole or in part, depending on the purpose.

### 2.2. Revision History and Scope

The revision history of the AESJ Level 2 PRA standard is shown in Table 1. There have been four editions of the AESJ Level 2 standard. After the first edition was published in 2008, the Fukushima Daiichi Nuclear Power Plant accident increased the importance of Level 2 PRA. Under these circumstances, the second edition was published in 2016, reflecting the findings of the Fukushima Daiichi Nuclear Power Plant accident (such as hydrogen combustion in reactor buildings) and international standards (ASME/ANS PRA standard, IAEA SSG-4, etc.). In addition, the third edition, published in 2021, expanded the scope to include seismic events in addition to internal events. The main objective of the fourth edition covered in this paper is to extend the scope to tsunami events in addition to internal events and seismic events.

Table 1. Revision History of the AESJ Level 2 PRA Standard

| *Edition No.* | *1st edition* | *2nd edition* | *3rd edition* | *4th edition* |
|---|---|---|---|---|
| **Published year** | 2008 | 2016 | 2021 | 2023 |
| **Application scope** | Internal events | Internal events | Internal events<br>Seismic events | Internal events<br>Seismic events<br>Tsunami events |
| **Major revision points** | – Initial version | – To reflect the latest findings from the Fukushima Daiichi nuclear power plants accident and international knowledge | – To extend the application scope to seismic events<br>– To update the knowledge | – To extend the application scope to tsunami events<br>– To update the knowledge |

### 2.3. Configuring Level 2 PRA Standards

The standard body consists of the following three parts.

- Body text
  Describe the technical requirements for implementing Level 2 PRA. The requirements in each of the processes in this part correspond to obligations.
- Annex (Informative)
  Provide technical reference information for implementing Level 2 PRA. Although not a requirement, it describes specific methods and technical options for implementing the requirements in the text.
- Commentary
  Provide additional information, including the interpretation and background of the standard. Issues discussed in the revision process, processes to be resolved, and outstanding issues are also included.

### 2.4. Overall Level 2 PRA Procedures

Figure 1 shows the implementation flow of the tsunami level 2 PRA as shown in the AESJ Level 2 PRA standard. The body consists of 10 processes shown in the blue box in the figure. This procedure assumes that the Level 1 PRA has already been completed and that the information required to implement the Level 3 PRA will eventually be available in this procedure. On the other hand, as mentioned above, in the case of implementers whose objectives differ from those of achieving Level 3 PRA, outputs can be obtained in some of the procedures. Inputs from Level 1 PRA results are depicted by green boxes and blue arrows. Feedback from the subsequent process is reflected by the blue arrows. Quality assurance, including the use of expert judgment and peer review, is depicted with white boxes and red arrows. The final output of Level 2 PRA is CFF, release category (RC) and source term. The latter two are transferred as level 3 PRA inputs. The difference with internal level 2 PRA is that tsunami hazard is required for CFF assessment in tsunami level 2 PRA.

## 3. MAJOR DOCUMENTS REFERRED TO FOR THE REVISION

In reviewing the revision process, relevant domestic and international standards and guides were carefully consulted, and technical findings to be reflected in the new Level 2 PRA standards were extracted. The technical feasibility and the necessity in light of the situation in Japan were taken into consideration as the criteria for deciding whether to apply the technical knowledge obtained. In addition, technically useful information for implementers was actively included in annexes and commentaries. The followings are the items investigated and incorporated in each document.

### 3.1. AESJ Tsunami Level 1 PRA Standard

Tsunami Level 2 PRA is assumed to be Tsunami Level 1 PRA, so the Tsunami Level 1 PRA standard was investigated. Regarding tsunami-specific requirements that are common to Level 2 PRA, we emphasized consistency with the Tsunami Level 1 PRA standard [2] by citing the Tsunami Level 1 PRA standard.

### 3.2. Fukushima Daiichi Nuclear Power Plant Accident Investigation Report

Various investigation reports [3] [4] [5] of the Fukushima Daiichi Nuclear Power Plant accident issued by domestic and foreign organizations were investigated, and the contents to be reflected in the Tsunami Level 2 PRA standard were extracted. The main contents are shown in Chapter 4.

### 3.3. ASME/ANS Level 1 PRA Standard

External flood PRA (Part 8) was investigated in RA-Sb-2013 [6] (ASME/ANS Level 1 PRA Standard), which is a standard for Level 1 PRA and LERF. This part mainly assumes the hazard of river flood. Although the nature of the hazard is different from that of a tsunami, it has some similarities because the hazard is based on the flooding height. Therefore, we investigated whether there are any requirements that can be reflected in the tsunami level 2 PRA standard. The results show that the requirements for external flooding are largely enveloped by the requirements of the AESJ Tsunami Level 1 PRA standard [2].

### 3.4. European PSA Project (ASAMPSA_E)

ASAMPSA_E [7], a European PSA project summarizing good practices on external events, was examined especially on external flooding (Report 2). This technical guide provides definitions and modelling of the impact of flood events on SSCs, multi-unit modelling, how to apply HRA, and how to credit additional emergency responses. Although this technical guide is not a standard, the contents were examined to see if there are any technical contents that can be reflected in the Tsunami Level 2 PRA standard. The results show that the requirements for external flooding are largely enveloped by the requirements of the AESJ Tsunami Level 1 PRA standard [2].

### 3.5. US NRC Regulatory Guidelines and ASME/ANS Level 1 PRA Standards

The US NRC Regulatory Guide [8] and Part 2 of the ASME/ANS Level 1 Standard [6] were reviewed to examine the requirements for the definition and evaluation of LERF/LRF and to inform the definition and provisions of the AESJ Level 2 PRA Standard.

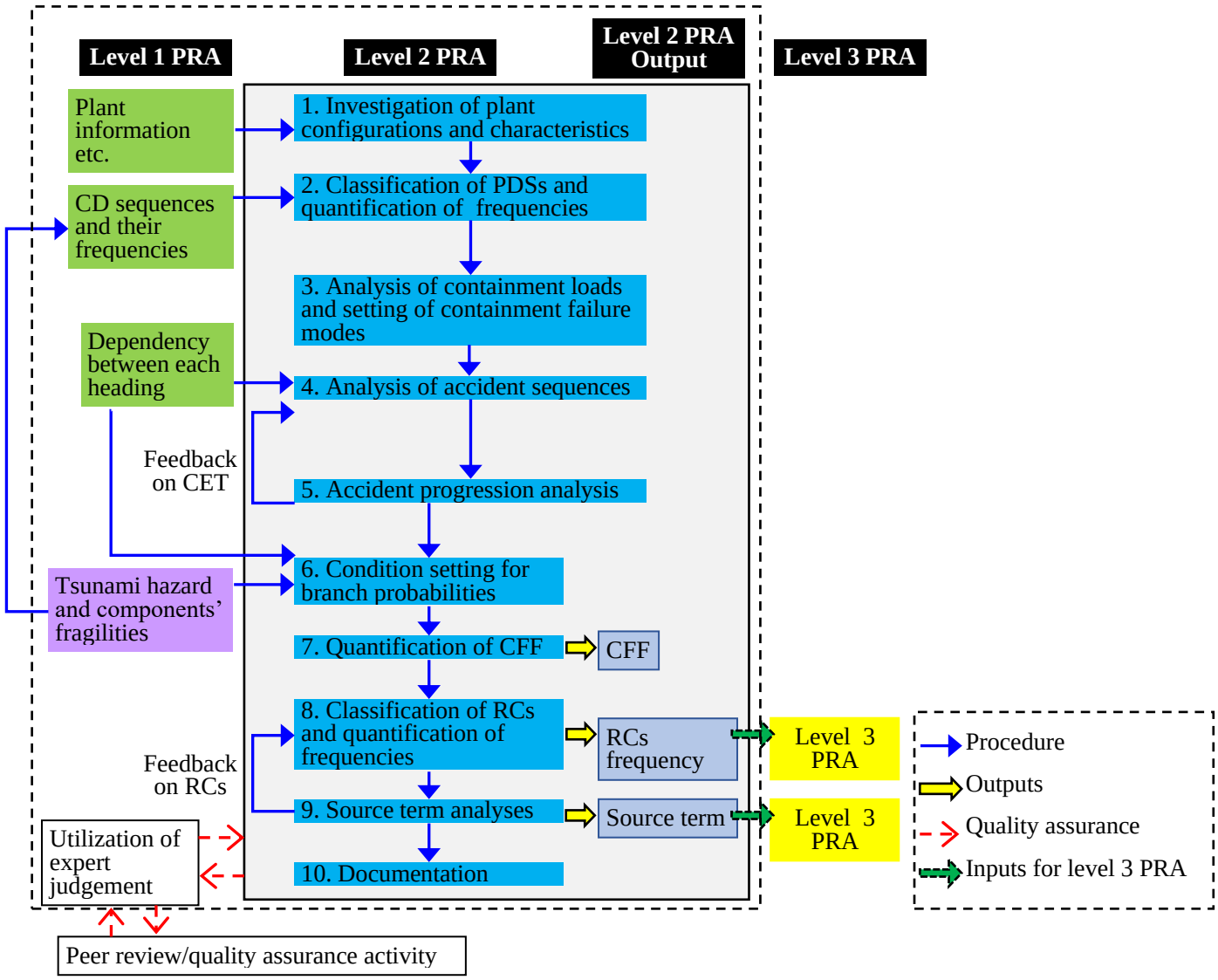


Figure 1. Overall Procedure Required by the AESJ Level 2 PRA Standard

## 4. KEY ISSUES DISCUSSED IN THE REVISION PROCESS

Based on the content extracted from the referenced documents, various technical issues were discussed during the revision process as to whether and how to incorporate it into the standard. The following is a summary of the discussion on each issue.

### 4.1. Scope of the Tsunami Level 2 PRA Standard

Tsunami Level 2 PRA is based on Tsunami Level 1 PRA. Tsunami generated by earthquakes and tsunami generated by factors other than earthquakes were included in the scope of application as in the AESJ Tsunami Level 1 PRA standard [2].

The Tsunami Level 2 PRA standard covers light water reactors (LWRs), but excludes fast breeder reactors (FBRs). Although severe accident phenomena after core damage in LWRs and FBRs are common, phenomena different from those in LWRs, such as the occurrence of re-criticality due to the relocation of core materials and chemical reactions related to sodium coolant, are considered important in FBRs. For these reasons, the Level 2 PRA standard has traditionally excluded FBRs. The Tsunami Level 2 PRA standard adopted the same approach and excluded FBRs.

In Europe and the United States, various flood hazards (Dam collapse, local heavy rain, etc.) are assumed as external flood hazards, and there was a discussion on whether to include external flood hazards other than tsunami in the scope of the Tsunami Level 2 PRA standard. The Tsunami Level 2 PRA standard assumes tsunami hazards, so external flood hazards other than tsunami are not covered.

### 4.2. In-Building Flooding Assessment

In order to determine the loss of function of SSCs installed in the building, it is considered necessary to evaluate the flooding in the building caused by the tsunami. Based on the results of the accident at the Fukushima Daiichi Nuclear Power Plant, it was concluded that this was appropriate. It was decided that the evaluation accuracy should be selected according to the purpose but the detailed evaluation was not necessarily required. The in-building flooding assessment is explicitly stated in the Tsunami Level 2 PRA standard because the time variation of the in-building flooding height affects the loss of function time of the SSCs, the load on the containment vessel (for some containment vessel types), and the heading configuration of the containment event tree.

### 4.3. Consideration of Tsunami-Specific Containment Failure Modes

When the inside of the building is flooded, loads due to water pressure, buoyancy, and water flow occur in the torus chamber of the Mark-I type containment vessel. In consideration of the damage caused by these loads, “damage to the containment vessel body caused by tsunami” was added to the containment failure mode. The system evaluation based on the load of structures generated by water pressure, buoyancy, and water flow due to flooding shall be carried out in accordance with the AESJ Tsunami Level 1 PRA standard [2].

### 4.4. Tsunami Fragility Assessment of SSCs Involving Level 2 PRA

The Tsunami Level 2 PRA standard requires tsunami fragility assessment of SSCs associated with Level 2 PRA in accordance with the AESJ Tsunami Level 1 PRA standard [2]. Specifically, the following items are required to be considered.

- Multiple damage modes
- Analysis of uncertainty factors
- Time dependency of the indicator
- Damage and performance degradation due to multiple tsunamis and aftershocks

However, the Tsunami Level 1 PRA standard states that “technical knowledge is completely lacking” regarding the evaluation of cumulative damage due to multiple tsunamis and aftershocks, and therefore “it is

realistic to proceed with the examination and accumulation of evaluation cases for multiple damage modes." The same position was adopted in the Tsunami Level 2 PRA standard.

### 4.5. Effects of Tsunami on Equipment, Systems and Operations

The assessment is required in accordance with the AESJ Tsunami Level 1 PRA standard [2]. Because the time to containment failure is longer than the time to core damage, the impact of the tsunami on equipment, systems and operations is expected. In addition, the investigation report of the accident at the Fukushima Daiichi NPP was examined, and the following factors were listed. Therefore, Level 2 PRA-specific analysis (loss of accessibility, impact on recovery, etc.) was required.

- Loss of function of power supply facilities due to flooding in buildings
- Damage to outdoor equipment
- Loss of accessibility after tsunami
- Work suspended due to aftershocks
- Loss of monitoring and control functions due to loss of power

### 4.6. Application to LERF/LRF Evaluation

The following content has been added to enable application to LERF/LRF assessment in Level 2 PRA for internal events, seismic events or tsunami events.

- Added LERF/LRF and related terms to the definition.
- Added to the requirement for classification of plant damage state, referring to the mode of release of radioactive material into the environment, to include in the classification accident sequences that may lead to large early release and/or large release.
- Based on the release mode, it was required to sort into LERF/LRF from the release time of radioactive materials to the environment in each accident sequence.
- Large early scale damage due to earthquake ground motion and tsunami was added.

### 4.7. Concept of Classification of Containment Vents in Containment Failure Mode

The classification of containment failure modes for containment vents in Level 2 PRA for internal events, seismic events or tsunami events has been revised. The containment vent is a countermeasure to prevent the overpressure failure of the containment vessel and the large release of radioactive materials associated with the containment failure by releasing the gas in the containment vessel to the environment through a filter, etc., thereby preventing long-term contamination of the site and the environment. On the other hand, containment vents may cause public health effects by releasing radioactive materials (mainly noble gases) into the environment that cannot be removed by filters.

Based on the merits and demerits of containment venting described above, there was a discussion on whether or not containment venting should be included in the loss of containment function, and the following ideas were presented.

- If the containment function is maintained, it may mean a containment condition that does not include controlled releases and does not involve a major release of radioactive material into the environment, or it may mean a containment condition that does not include controlled releases and does not involve a large release of radioactive material into the environment.
- Depending on the purpose of the Level 2 PRA, the CFF should be able to be evaluated for each containment condition.

Based on these ideas, the purpose of CFF evaluation and the treatment of containment vents are summarized as follows.

- The purpose of the CFF assessment is to assess the frequency of loss of the containment radioactive containment function. The CFF is the sum of the frequency of events in which the radioactive material

containment function is lost. The containment vent is included in the CFF because it releases most of the noble gases.
- The purpose of the CFF evaluation is to assess the frequency of loss of the containment source term suppression function. CFF is the sum of the frequency of events in which the source term suppression function is lost. Containment vents are not included in the CFF because radioactive materials that cause long-term environmental effects are thereby removed by filters etc.

The description of the Level 2 PRA standard has been revised based on the treatment of containment vents according to the purpose of the Level 2 PRA. The main changes are as follows:

- A “containment vent” has been added to the containment state in containment failure mode to distinguish it from other states, thereby enabling the selection of whether to include a “containment vent” in the CFF calculation, depending on the purpose of the Level 2 PRA.
- Required clarification of whether containment vents are included in the containment loss of function in light of Level 2 PRA objectives.

Even if containment vents are not included in the loss of containment function, containment vents are classified as a release category. If containment venting had to be performed before off-site emergency response and protective measures were effectively implemented, and the radioactive attenuation of noble gases was not sufficient, then this would be subject to LERF evaluation as well as other containment loss modes.

## 5. FUTURE WORKS

Following the establishment and publication of the fourth edition of the AESJ Level 2 PRA standard, work is under way to expand it to a shutdown state and revise it to a structure for hierarchy of mandatory requirements / guidelines / annexes.

The Risk Technical Committee is planning to revise or formulate the PRA standard, and is laying the foundation for future use of risk information.

Japanese utilities and other organizations are gradually accumulating experience with Level 2 PRAs, and it is important to reflect that experience in the standards. As a result, it is expected that the practicality and usefulness of the standard will be improved.

## 6. CONCLUSIONS

Under the circumstances in the increasing importance of Level 2 PRA, work has been undertaken to revise the AESJ Level 2 PRA standard. The scope of the standard has been previously limited to internal events and seismic events, but has been extended to include tsunami events and a new fourth edition has been published. In this revision work, the findings of relevant standards and related literature were reviewed and the results reflected in the standards through discussion. In addition to the issues specific to Tsunami Level 2 PRA (flooding assessment in buildings, consideration of tsunami-specific containment failure modes, tsunami fragility assessment of Level 2 PRA-related structures, systems and components (SSCs), impact of tsunami on equipment, systems and operations, etc.), the issues discussed during the revision process included the requirement for evaluation of the large release frequency (LRF) and the large early release frequency (LERF) required for various risk information applications.

The necessity of the application to the tsunami level 2 PRA standard was examined according to the following concept. In other words, the tsunami level 2 PRA standard reflects the new findings that have a significant impact on the level 2 PRA and should be considered in the revision process. At that time, the method of application to the standard (Body text, Annexes (Informative), Commentary) was examined according to the maturity of the technology.

The purpose of the next stage of the revision process is to reflect the extension to the shutdown state and the structure for hierarchy. Japanese electric power companies have gradually accumulated experience with

Level 2 PRA. It is important that these experiences be reflected in the AESJ Level 2 PRA standard in the future. As a result, it is expected that the practicality and usefulness of the standard will be improved.

## Acknowledgements

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## References

[1] AESJ, AESJ-SC-RK012:2022, A Standard for Procedures of Probabilistic Risk Assessment (PRA) of Nuclear Power Plants during Power Operation (Level 2 PRA): 2022, September 2023 (in Japanese)
[2] AESJ, AESJ-SC-RK004:2016, A Standard for Procedure of Tsunami Probabilistic Risk Assessment (PRA) for Nuclear Power Plants: 2016, May 2019 (in Japanese)
[3] National Diet, Report of the Investigation Committee for TEPCO's Fukushima Nuclear Power Plant Accident, June 2012 (in Japanese)
[4] Government, Report of the Accident Investigation and Verification Committee at TEPCO's Fukushima Nuclear Power Plant, July 2012 (in Japanese)
[5] TEPCO, Fukushima Nuclear Accident Investigation Report, June 2012 (in Japanese)
[6] ASME/ANS PRA, RA-Sb-2013, Addenda to ASME/ANS RA-S-2008, Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, 2013
[7] ASAMPSA_E guidance for level 2 PSA Volume 2, Implementing external Events modelling in Level 2 PSA, Technical report ASAMPSA_E WP40/D40.7/2017-39 vol 2. Reference IRSN PSN-RES/SAG-2017-0002
[8] U.S.NRC, Regulatory Guide 1.200, An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities, Revision 2, March 2009