Revision of the AESJ Standard for Seismic Probabilistic Risk Assessment (1): Extension and enhancement of accident scenario

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Abstract: This session consists of a four-part presentation on the amendment of the Standard for Procedures of Seismic PRA for NPPs and introduces significant additions/updates in three chapters, Seismic Hazard Evaluation, Building and Component Fragility Evaluation, and Accident Sequence Evaluation. This presentation introduces the purpose, background, and discussed points of the amendment, e.g. extending scope of application to seismic induced events. Upon the revising the previous standard, we updated various requirements in view of advancements in PRA techniques based on new technological findings after the publication of the 2007 version standard and to improve the quality and transparency of this standard. In particular, the amendment reflects the lessons learned and new findings from Fukushima Dai-ichi accident (the 1F accident) as much as possible: e.g. events caused by earthquake, combined seismic and tsunami events, accident management measures, impact to fuel in spent fuel pool, multi-reactor effects, impact of aftershocks, and impact of land sliding.

Keywords: Seismic PRA, Implementation Standard, Fukushima Accident, Seismic-induced complex event, Accident Scenario

1. INTRODUCTION

Japan has been continuously carrying out research on earthquakes from the first, because of the fact that Japan is one of the countries frequently hit by earthquakes and a world-leading seismically active country. In the earthquake-resistant designs of nuclear power plants, research findings related to earthquakes have been reflected and improvements to analytical evaluation techniques have actively continued. With regard to the seismic PRA as well, the development of its methodology has been advanced in research institutions and some industries. The Standards Committee (SC) of the Atomic Energy Society of Japan (AESJ) developed a standard for Procedure of Seismic PRA for nuclear power plants in 2007, with due consideration to the importance and usefulness of a seismic PRA methodology, through the discussion at the seismic PRA subcommittee under the Risk Technical Committee (hereafter called "RTC") of the SC. The standard specifies the requirement which should have the PRA regarding incidents resulting from earthquake as the initiating events at nuclear power plants during power operation, and the concrete method of filling it as an enforcement standard based on the PRA procedure.

2. Process of Revision

The previous standard published in 2007. At the time, the Nuclear Safety Commission (then) revised "the Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities" and required a seismic hazard analysis and a seismic PRA. The RTC (the Power Reactor Technical Committee at that time) decided to prepare the draft of a seismic PRA standard ahead of other countries and started in July 2004. The RTC established three working groups, the seismic hazard evaluation Working Group (WG), the building and component fragility evaluation WG, the accident sequence evaluation WG, under the Seismic PRA Subcommittee (S-PRA SC) at that time.
The RTC reopened the S-PRA SC and three WGs and resumed the discussion of the Seismic PRA Standard at the timing of regular revision and updating requirements based in the 2011 off the Pacific coast of Tohoku Earthquake. The organizational chart is the Table 1 below.

Table 1: The Organizational Chart of Seismic PRA Subcommittee

Sub Committee	Working Group	Roles and Chapter
The Seismic PRA Sub Committee		• Direction and summarization of conclusions of three WGs • Common chapters (Foreword, Scope of Application, Definition of Technical Terms, Normative references, Evaluation Process) • Collection information and analysis of accident scenarios • Documentation
	the Seismic Hazard Evaluation WG	• Collection of information related to seismic hazard evaluations • the methods for seismic hazard evaluation • the methods for developing seismic ground motions from the seismic hazard evaluation results for use with fragility evaluation
	the Building and Component Fragility Evaluation WG	• Establishing Targets of Evaluation and Damage Modes • Selection of Evaluation Method • Actual Fragility Evaluation • Evaluation of Actual Response • Fragility evaluation
	the Accident Sequence Evaluation WG	• Establishing the Initiating Event • Simulation of the Accident Sequence • Simulation of the Systems • Quantification of the Accident Sequence • Analysis of the Containment Vessel Function Loss Scenario

3. Outline of Updated Points

The revised Seismic PRA Standard can provide risk information to improve safety level of nuclear power plant. The standard includes the important and useful points. Many requirements were updated in view of advancements in Seismic PRA techniques based on new technological findings after the publication of the 2007 standard and the quality and transparency of this standard were improved. Some updated points are as follows:

1) The lessons learned and new findings from severe accidents of Fukushima Dai-ichi nuclear power plants, which were occurred on March 11 of 2011
2) Expansion of the standard scope to complicated events, e.g. an fire caused by earthquake PRA
3) Adding a lots of Appendix (Reference), which are references related to issues that can't be required in the standard because of immature methods

4. Scope of Application

The 2007 standard focused on the earthquake-related accident sequences that lead to serious core damage. The internal fire, internal flood, and tsunami related events that may occur as a result of earthquake were excluded from the scope of the 2007 standard. At that time, the RATC was going to develop a fire PRA standard and an internal flood PRA standard after the seismic PRA standard.

However several complicated events occurred in the 1F accident and the RATC needed to expand the scope of the seismic PRA standard to events caused by earthquake and events related to SFP.

1) SFP

In the 2007 standard, the most important event was core damage, but the 1F accident made it clear that there was a possibility that nuclear fuels in SFP were damaged. In this revised standard, fuel damage sequences in SFP are added to core damage sequences.

2) Events caused by earthquake

The 1F accident showed it important that earthquake occurred various complicated events at the same time including fire or internal flooding event. However requirements of events caused by earthquake PRA are mutually related. The revised standard takes partial charge of full requirements of those PRA and assumes the responsibility of providing seismic hazard evaluation and fragility evaluation of special equipments in earthquake induced events PRA. It is possible to implement those complicated PRAs using both the seismic PRA standard and each external PRA standard.

The relation between external PRA standards is Table 2 below. In case of complicated PRA, it is possible to select adequate requirements and combine them to implement PRA. For example, in case of a fire caused by earthquake PRA, users should select requirements according to guidance sentences "if you evaluate internal fire caused by earthquake," which are marked "FireE" in Table 2.

Table 2 The relation among contents of external event PRA

	Collection Information & Accident Scenario	Hazard Evaluation	Fragility Evaluation	Accident Sequence Evaluation
Seismic PRA Standard	FireE FloodE	<u>FireE</u> <u>FloodE</u> (seismic hazard analysis)	FireE(seismic fragility of SSCs related to internal fire PRA) FloodE(seismic fragility of SSCs related to internal flooding PRA)	
Internal Fire PRA Standard	FireE	(Occurrence frequency of internal fire)	FireE (internal fire fragility of SSCs related to internal fire PRA)	<u>FireE</u>
Internal Flooding PRA Standard	FloodE	(Occurrence frequency of internal flooding)	FloodE (internal flooding fragility of SSCs related to internal flooding PRA)	<u>FloodE</u>

Note: FireE : Internal fire caused by earthquake, FloodE : Internal flooding caused by earthquake
An underlined part : the PRA standard mainly provides the information

5. Evaluation Process

The outline of seismic PRA process is the Figure 1 as below, and is almost same as the 2007 standard. Differences between the 2007 standard and the revised standard are as given below;

- Upgrade of requirements for site & plant walk down
- Additional information; lessons learned from the 2011 off the Pacific coast of Tohoku Earthquake
- Upgrade of accident scenarios

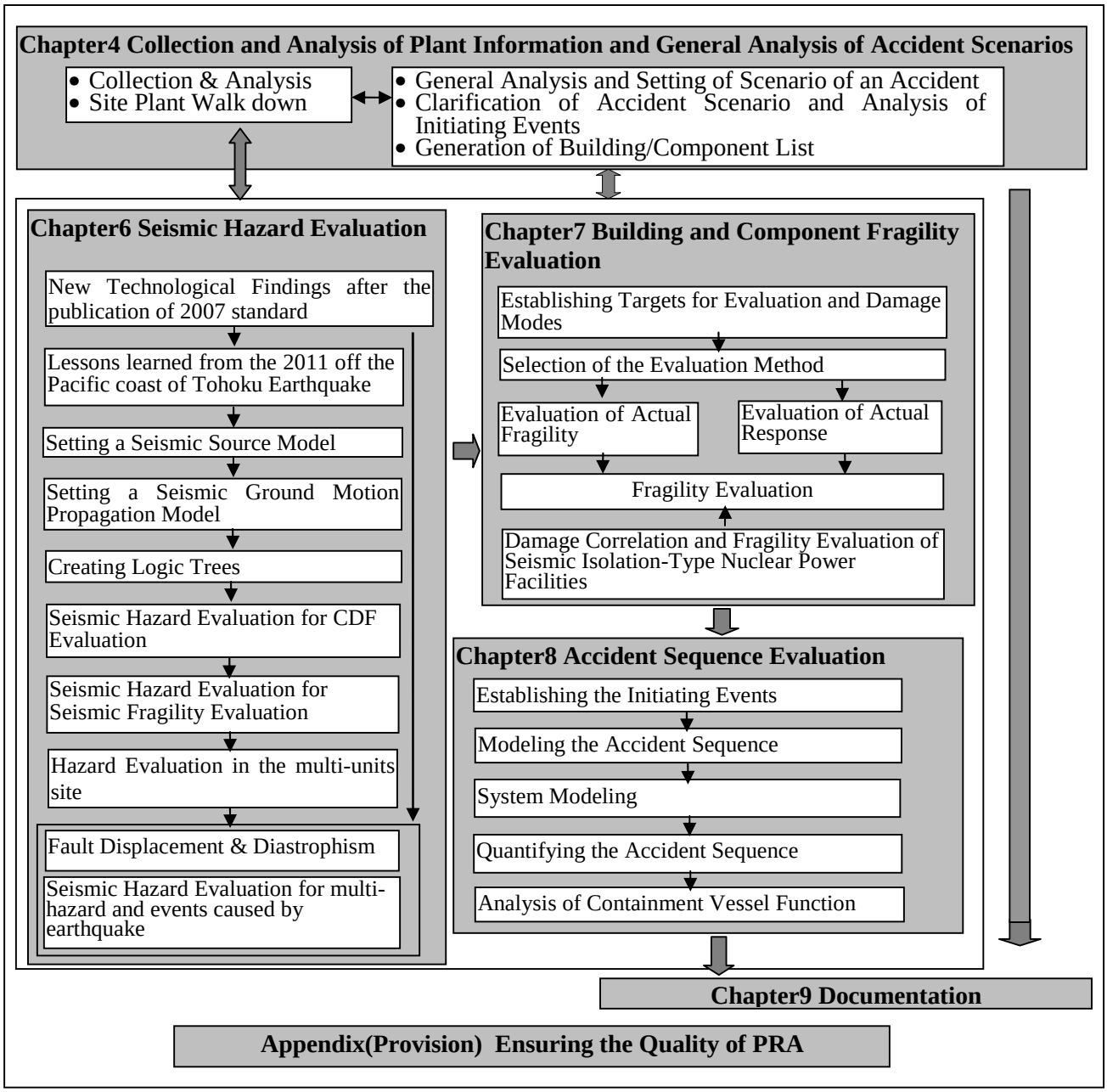

Figure 1 Evaluation Process (the revised Seismic PRA standard)

6. Collection and Analysis of Plant Information

6.1 Procedure of Collection and Analysis of Plant Information

Requirements related to the collection of plant information and the general analysis of accident scenarios are provided in Chapter 5. Outline of the process is Figure 2 as below.

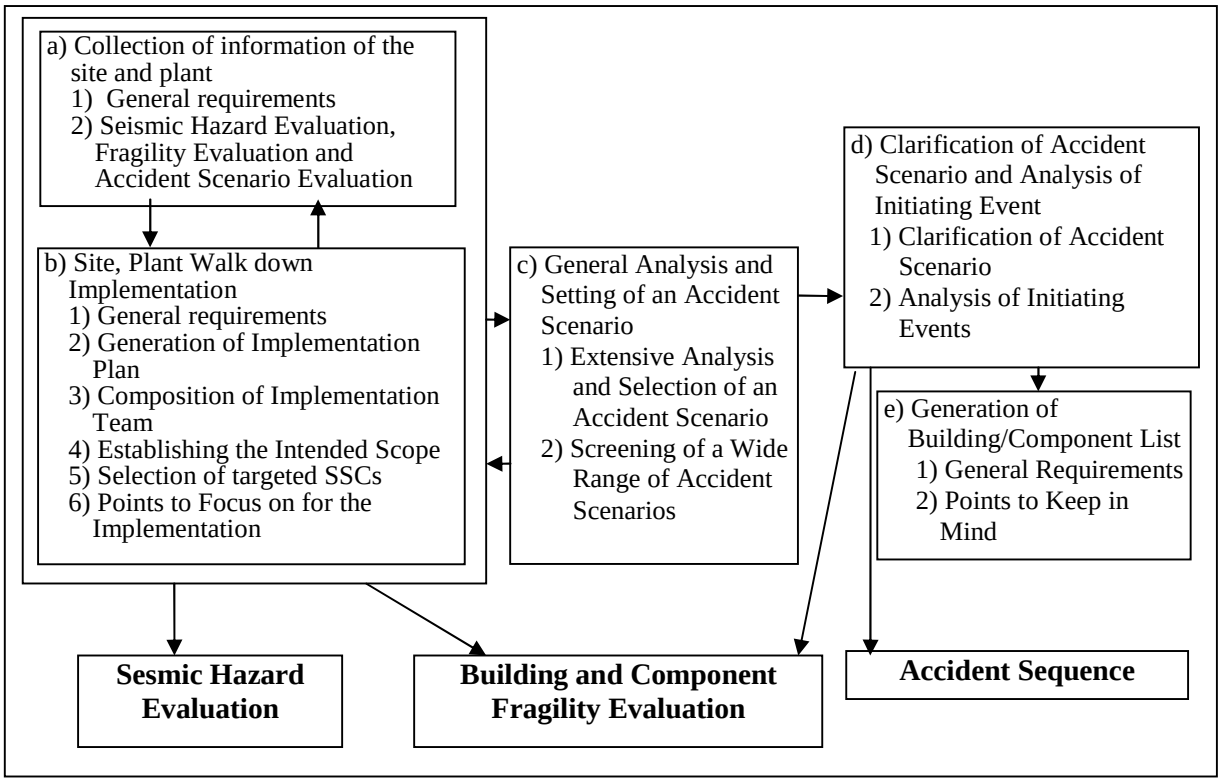

Figure 2 Flow of Collection of Information and Analysis of Accident Scenarios

6.2 Collection of information of the site and plant

Giving sufficient scrutiny to the scope of the information gathered and the amount of detail is provided in case of collecting and analyzing information of site and plants. Next, in accordance with the scope of the information collected, it is provided to check related information in such a way that recent plant conditions, operation experience and new knowledge. Especially, it is important to gather and analysis carefully the information and findings related to recent earthquake disaster including the 2011 earthquake off the Pacific coast of Tohoku. In addition to that, information and documents related to circumstances caused by combined with earthquake and tsunami, situation of components for accident management measures, mutual effects among plants in the same site, and effects of aftershocks.

In addition to information related to unique plant designs, operation, management and operation experience, collect a wide range of general information such as information related to existing seismic PRAs. Analyze the collected information to see whether it is sufficient from the perspective of reliability; if insufficiencies are found, collect additional information. When collecting additional information, implement additional inspections or tests as necessary.

When information that is not unique to plants is used in evaluation, it must be shown to be appropriate and rational by analysis of similarities and differentiae between general information and unique one. Essential information for seismic PRA is listed in Table 3 below.

Table 3 Essential information for seismic PRA

Evaluation Work	Required Information	Major Information
Understanding the design and operation of the plant	and operation management needed to perform the PRA • basic specifications • structural characteristics of the system facilities • characteristics of the seismic design • characteristics of the plant layout	• Basic plant specifications • Configurations and characteristics of system components • Seismic design features • Plant layout features • Various operating procedures • Domestic and foreign examples of seismic damage
Seismic hazard evaluation	Consider earthquake occurrence mode in the area surrounding the target site.	• Nuclear reactor facility permit applications

Evaluation Work	Required Information	Major Information
	Information on • seismic source characteristics that can be used to establish the seismic source model • seismic motion propagation characteristics that can be used to establish the seismic motion propagation mode	• Active fault and historic earthquake catalogs • Handbook of Japanese seismic fault parameters • Seismic area geological structure map • Records of seismic observations for the assessment site
Building and component fragility evaluation	Ultimate strength evaluation of buildings and components belonging to the plant, and information pertaining to response evaluations	• Permit application for installation of a nuclear reactor • Application for construction permit • Design /construction standards • Technical Guidelines for Seismic Design of Nuclear Power Plants by the Japan Electric Association • Relevant guidelines of the Society of Mechanical Engineers, Architectural Institute of Japan and the Society of Civil Engineers • Seismic design data, past test results, examples of earthquake damage, etc.
Accidents sequence evaluation a) Analysis of accident scenarios and classification of the initiating events	Plant conditions hypothesized at the time of a large scale earthquake	
b) Analysis of accident sequences • Establishment of the success criteria • Creation of event trees	• Conditions for use of systems such as the safety system • Realistic performance of systems • Mitigating operations undertaken by operators • Component failure mode and operation status for the target plant • Information that can be used to confirm the validity of evaluation results	• Realistic performance evaluation reports for systems related to the success criteria • Inspection procedures following an earthquake • Operating procedures (operating procedures for each facility, operating procedures for use during accidents, severance procedures) • Periodic inspection instructions • Training program for operators • Past PRA reports and other reports related to these following an earthquake
c) System modeling		
d) Quantification of the accident sequences		
e) Evaluation of containment integrity	Information on the isolation functions of the containment vessel	

6.3 Site-Plant Walk-down Implementation

The purpose of the walk-down for seismic PRA is collection of information that is hard to gather by paperwork. It is fine to carry out walk-downs multiple times as needed, but clarify the interdependent positioning of each (component) and the connections during each walk-down, for the walk-down's effective execution.

1) Generation of Implementation Plan
It is necessary to make implementation plan including list of walk-down team members, scope, targeted SSCs, procedures, and points of walk-down. In accordance with the purpose of each walk-down, it is possible to arrange the plan.

2) Composition of Implementation Team
The specialized ability, knowledge and experience are needed to the members of walk-down team. However anyone of members doesn't need to have all ability, knowledge and experience. Contents are as follows:

- Related to the systems, safety design and earthquake-resistant design for the plant targeted for assessment
- Related to vibration tests and seismic damage investigations related to the behavior of the components when there is seismic ground motion, as well as the damage sites and modes
- Related to seismic hazard evaluations, fragility evaluations (buildings, structures and components) and accident sequence evaluations

3) Establishing the Intended Scope
Items to keep in mind related to the establishment of the intended scope are indicated below.

- Include SSCs in the intended scope, where it is judged that they can not be assessed with the (already) collected information.
- It's useful to use past seismic PSA results to add SSCs.
- It's fine to exclude from the walk-down components for which fragility is clearly minor when compared to other components.
- If grasping the overall level of risk to the plant, focus on safety-critical components.
- If verification of the fragility of individual components that would have an impact on overall plant risk, it's focus on components for which a determination is made that the impact will be significant.
- Include SSCs that are common among plants or adaptable in case of accident management.
- Include SSCs that are evaluated in complicated PRA, e.g. a fire caused by earthquake PRA.

4) Points to Focus on for the Implementation
From the standpoint of fruitfulness, carry out a site-plant walk-down, focusing on the following.

- Safety Verification of Earthquake-Resistance - If it is judged that further information needs to be added within the design information necessary for the fragility assessment, carry out a review and verify the structures and components subject to assessment.
  - Ø Compare the design documentation (system layout diagrams, instrumentation, piping system diagrams, single-line wiring connection diagrams, etc.) to the actual state of the plant, verifying the points that were judged to be insufficient in the information collected from paperwork. In particular, carry out a focused investigation and verification of the foundation sections of the subject components.
  - Ø If there are items with relatively less probability of damage than other structures and components, which you can't decide whether to include in the assessment, verify the fragility of those items.
- Mutual Interference Between Components Due to Seismic Ground Motion – Verify unique characteristics of the plant such as mutual interference between components, mutual interference between systems and dependencies between systems.
- Verification of Secondary Impacts - Focus on verifying the secondary impacts of interference and collisions triggered by deformation, dislocation and movement through damage to components that are in functionally subordinate relationships.
- Verification of Accessibility After an Earthquake - Upon system assessment, verify accessibility when obtaining credit for components that need to be started-up on site and for components that can be expected to have functions restored with the recovery work on-site,.

7. General Analysis and Setting of an Accident Scenario

7.1 General Analysis

It's provided to analyze and set the scenario of an accident, using plant related information and information obtained in the site-plant walk-down. In analyzing and selecting a broad range of accidents, distill down specific accident scenarios at the time of an earthquake and select them, without overlooking any. For that purpose, it's necessary to consider the main factors such as follows:

- It's necessary to consider huge seismic ground motion occur several kind to components at the same time including not only preventive systems but also mitigation systems.
- It's meaningful to consider accidents that are directly linked to core damage by failure of reactor vessel or reactor building.
- It's necessary to analyze and select secondary accident scenarios that are not directly linked to the reactor core's damage, and where the damage exerts a direct impact on the damage to SSCs critical to safety and are possibly indirectly related to the reactor core's damage.
- Furthermore, in this section, requirements based on new lessons such as seismic caused complex events, SFP, impact of aftershocks, fault Displacement.

7.2 Clarification of an Accident Scenario

The focus is on the following 3 items to be ordered and clarified the accident scenario where it has been determined that accident sequence assessment is required .

- Clarification of the events for which there is a significant probability of their occurrence at the time of an earthquake and which lead to nuclear reactor core damage (hereinafter named "Accident scenarios that are characteristic during earthquakes.")
- Adjustment of accident scenarios those are characteristic during earthquakes and accident scenarios being considered for the internal event PRA.
- Setting of the minimum range for the subject earthquake strength in the seismic PRA.

It is point to keep in mind to clarify the accident scenarios generated by the following three damages.

- Damage by seismic ground motion to large static components for buildings, structures, piping etc. that are important for safety
- Damage by seismic ground motion to components, etc., that exert critical, wide-ranging impacts on safety functions
- Secondary impacts that have an impact on safety functions

7.3 Analysis of Initiating Event

In the analysis of the initiating events, characteristics that are specific to earthquakes are considered. Initiating events are classified according to the following six aspects:

- Multiple initiating events are classified as one initiating event when the same kind of mitigating equipment is required, the progressions of the events are similar, and the impacts are similar even if those initiating events are distinguish one from other.
- When it is difficult to rigorously analysis accident scenarios, it is fine to simplify these conservatively.
- When the possibility of damage to SSCs is extremely small, and it is determined that the probability of the occurrence of the initiating event is negligible, it is fine to exclude these as initiating events.
- When there are multiple causes of the initiating event, when the contribution to the occurrence probability of the initiating event is extremely small compared to other causes and when it is determined that the initiating event is negligible, it is fine to exclude these as initiating events.
- If the dependency of the initiating events were considered in the previous internal event PRA, it is necessary to keep them in mind with the seismic PRA as well.
- In events involving damage to containment vessels directly from seismic ground motion, because often the initiating event leads to an early release of FP, they are clearly segmented from other events.

7.4 Generation of Building/Component List

The work of generation of building/component list consists of collection/analysis of the plant information and general analysis of accident scenarios, the building/component fragility evaluation, and the accident sequence evaluation.

In the collection/analysis of plant information and the general analysis of the accident scenarios, first, collect the plant walk-down information and plant related information. Next, along with analyzing/setting a wide range of accident scenarios, screening those scenarios are implemented based on this information. Targeting the accident scenarios that remain from the screening, analysis of the initiating event and clarification of the accident scenario are implemented. These results create a target building/component list for the seismic PRA.

In the building/component fragility evaluation, structural screening of the evaluation events is carried out based on a damage mode analysis and a categorization of piping/components in the establishment of the subject of the evaluation. Then this information in the adjustments is reflected to the building/ component list.

In the accident sequence evaluation, the information of SSCs required for the modeling of the accident sequence in the ET or FT.

In generation of building/component list, it's necessary to keep in mind four items below.

- Selecting SSCs required to achieve the prevention of core damage sequence:
  In consideration of the items such as the features of the system configuration, it is fine to provisionally exclude a portion from the assessment as is shown next.
  - Ø SSCs with strong fragility are excluded in a system that has a serial architecture, with multiple SSCs that are dependent/subordinate.
  - Ø SSCs with weak fragility are excluded in a system that has a parallel architecture, with multiple SSCs that possess redundancy.
- Gaining an understanding of the relative importance between SSCs:
  In case where the relative importance between SSCs is understood by provisionally evaluating the area targeted for evaluation, based on representative component data or data used in a previous PRA representing the structural areas of SSCs with weak fragility, it's necessary to keep in mind that both the data that is applied from previous PSA s as a standard and the data of the representative components do not provide results on the non-conservative side. The note is clearly stated that in evaluation at a latter stage a needed modification can be carried out as a provisional assessment.

8. CONCLUSION

The revised Seismic PRA Standard is now (in March 2014) open to public inspection by the SC (Standard Committee). The standard has several remarkable points to provide upgraded seismic PRA method. First of all, this standard covers the all area on seismic PRA and includes not only seismic events but also events caused by earthquake. In case of implementation of a fire caused by earthquake PRA, seismic hazard evaluation method comes from this standard, accident sequence evaluation method is based on the fire PRA standard, and fragility evaluation method of SSCs (structure, system and components) is based on the fragility chapter of this standard. Next, important information and findings from Fukushima Dai-ichi accident are added to this revised standard.

Seismic PRA or events caused by earthquake PRA can provide a lots of important and useful risk information to improve safety level of a nuclear power plant. After this revision the RTC ahs a plan to improve this seismic standard to implement a seismic shutdown PRA and a seismic at-power level 2 PRA.

References

[1] AESJ, "*A Standard for Procedures of Seismic Probabilistic Safety Assessment for nuclear power plants,*"AESJ-SC-P006, (2007).