OUTLINE OF SEISMIC PSA IMPLEMENTATION STANDARDS ON THE ATOMIC ENERGY SOCIETY OF JAPAN

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ABSTRACT :

In September 2004, the Atomic Energy Society of Japan started to develop Seismic PSA implementation Standard and the standard was approved in June 2006. Meanwhile, in July 2001 the Nuclear Safety Commission of Japan started the project to revise Examination Guideline for Seismic Design and the Guideline was decided in September 2006. In this report, process of the formulation activities as well as the formulation policies / composition related to the above-mentioned Seismic PSA implementation standards are shown. In addition, the main characteristics of specific items consisting the implementation standards are described.

KEYWORDS: Seismic PSA, Standard, Seismic hazard, Fragility, Accident sequence, Nuclear power plants

1. INTRODUCTION

In September 2004, the Atomic Energy Society of Japan has established 3 working groups (Seismic Hazard Evaluation, Building & Component Fragility Evaluation, Accident Sequence Evaluation) under the Seismic PSA working group in Technical Group on Nuclear Power Plant in Standards Committee with the purpose to develop its Seismic PSA implementation standards. The standards were approved by the Seismic PSA working group in December 2005 and by Technical Group on Nuclear Power Plant in June 2006.

Meanwhile, the Nuclear Safety Commission of Japan established a working group for reviewing seismic design guidelines under the Technical Group on Nuclear Safety Standards and Guidelines in July 2001 so that the project to revise Examination Guideline for Seismic Design could be started. After the deliberation of almost 5 years, the final draft of the Examination Guideline for Seismic Design (Draft Seismic Guideline) was compiled in the working group meeting in April 2006. After a period of public comment submission for 2 months, the Guideline were decided in September[1]. In the Guidelines, the risk by the extension of the effect of the seismic ground motion that exceeds the design basis seismic ground motion Ss is defined as “residual risk”, and the efforts to minimize "the residual risk” as low as practically achievable should be made. Also, the Commission published the Draft Interim Report for Safety Goals in December 2003[2] and the performance goal in May 2006[3] as a part of the projects related to “the residual risk”.

In this report, process of the formulation activities as well as the formulation policies / composition related to the above-mentioned Seismic PSA implementation standards are shown. In addition, the main characteristics of specific items consisting the implementation standards are described.

2. PROCESS OF THE FORMULATION ACTIVITIES AND THE FORMULATION POLICIES / COMPOSTION RELATED TO SEISMIC PSA IMPLEMENTATION STANDARDS

2.1.Process of Seismic PSA working group activities

The main Process of Seismic PSA working group activities are as below:

1) Investigation and review of the domestic and international seismic PSA methodologies (International: IAEA, OECD/NEA, USNRC, etc. Domestic: previous Japan Atomic Energy Research Institute, Japan Nuclear Energy Safety Organization, industries, etc.) were conducted.

2) "External Events PRA methodology" standard developed by American Nuclear Society (ANS) were reviewed.
3) Based on above 1) and 2), "formulation policies for implementation standards" were developed, a table of contents composition was determined and adjustment was achieved for the items common to all three working groups.

2.2.Formulation policies for implementation standards

Main implementation policies are as below:

1) From the standpoint of seismic safety evaluation for the nuclear power plant, the review shall be conducted using a wide variety of proven methods, where evaluation of applicability for safety goal / performance goal, choice of AM counteractions against earthquake and confirmation of their effectiveness, refinement of seismic design method and confirmation of its efficacy etc. shall be included in the scope of operation so that the methods can be chosen which enable consideration for specific levels suitable for operation purpose.
2) To clarify the specific implementation procedures, standards shall be formulated in the form of specification. However, adequate consideration shall be given to reflect points of importance such as prevention of omitting high-level requirements and the confirmation of Japan-specific requirements.
3) The scope shall be the evaluation of core damage frequency (including preceding damage of containment vessel) in LWR operation and the identification of scenarios in the case of loss of containment function at the time of earthquake. By this identification of scenarios, it is possible to evaluate incidence of earthquake-related loss of containment function, source term, individual risks and others thereafter, using the level 2 and level 3 PSA implementation standards for internal events.
4) Upon listing as much as possible a wide variety of accident scenarios under seismic ground motion, screening shall be conducted on practical basis and scenarios for quantitative evaluation shall be chosen.
5) Uncertainty factors in each stage of the Seismic PSA shall be categorized into randomness uncertain factors related to natural phenomena and the epistemic uncertain factors related to insufficiency of knowledge and information, then the factors shall be clearly described and examples for each factor shall be shown as much as possible.
6) Many evaluation examples shall be described with the purpose to promote understanding and effective operation of implementation standards.

2.3. Composition of implementation standards

The implementation standards are consisted from following 8 chapters.

Chapter 1. Scope of application
Chapter 2. Definition of technical terms
Chapter 3. Evaluation process
Chapter 4. Collection / Analysis of plant information and general analysis for accident scenarios
Chapter 5. Seismic Hazard Evaluation
Chapter 6. Building & Component Fragility Evaluation
Chapter 7. Accident Sequence Evaluation
Chapter 8. Documentation

3. OUTLINE OF EACH CHAPTER

3. 1.Scope of application

Scope of application for Chapter 1 is as below. The standards focus on the earthquake-related accident sequences that lead to serious core damage among the Probabilistic Safety Assessments (PSA) of nuclear power plant in operation states as their scope. They prescribe the requirements for the method to perform the level 1 PSA to obtain their frequencies and the method to identify the earthquake-related accident sequences that lead to containment damage as well as specific methods to satisfy these requirements based on the implementation procedure. However, the fire-, flood- and tsunami-related events that may occur as a result of an earthquake shall be excluded from the scope of application of these standards.

3.2.Definition of technical terms

The technical terms listed in Chapter 2 are those with high frequency of appearance or those with possibility of multiple interpretations.

3.3.Evaluation process

Chapter 3 "Evaluation process" is dedicated to take general view of the composition of the current Seismic PSA implementation standards as well as to facilitate understanding the mutual correlation among chapters from Chapter 4 to Chapter 8. The procedure of Seismic PSA is shown in **Figure 1**.

In the section of "Collection / Analysis of plant information and general analysis for accident scenarios", while collecting / analyzing information necessary for Seismic PSA and conducting plant walk-down, a wide variety of earthquake-specific accident scenarios are defined, initiating events that trigger core damage accidents are analyzed and a component list is formulated as a preparation of quantitative evaluation of core damage (defined as the status where maximum fuel cladding temperature reaches 1200˚C), which is the most serious type of accident in nuclear power plant accidents.

In the section of "Seismic Hazard Evaluation", by generating a model of location / size / occurrence frequency of earthquakes that may occur in vicinity of the site in the future, the exceedance frequency of seismic ground motion caused by the earthquakes at each strength level are obtained. In the section of "Building & Component Fragility Evaluation", by using their realistic response and capacity, accumulated failure probability for each strength level of seismic ground motion are obtained. In the section of "Accident Sequence Evaluation", accident scenarios that lead to core damage are analyzed, and, by using the seismic hazard evaluation result, fragility evaluation result and plant system information, occurrence frequency of core damage accident sequence is obtained. In these evaluations, while reflecting domestic seismic design information, adequate considerations are given to uncertainty related to evaluation models and database.

In "Documentation", the ground / judgment of adopting a specific model or data in the process of evaluation is stated. As a consequence, uncertain factors that seriously influence to core damage, accident scenarios, mitigation systems and components are identified and clearly described. From the standpoint of assuring clarity of explanation and transparency, these elements are summarized in the report.

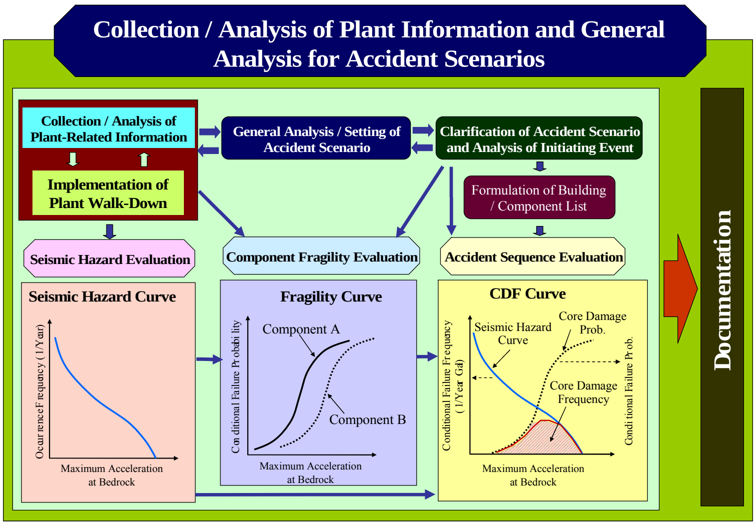

Figure 1 Procedure of Seismic PSA

3.4. Collection / Analysis of plant information and general analysis for accident scenarios

3.4.1 Composition

"Collection / Analysis of plant information and general analysis for accident scenarios" (Chapter 4) is described in the following 6 sections:

- **4.1** Analysis process
- **4.2** Collection / Analysis of plant-related information
- **4.3** Implementation of plant walk-down
- **4.4** General analysis / setting of accident scenario
- **4.5** Clarification of accident scenario and analysis of initiating event
- **4.6** Formulation of building / component list

Collection / Analysis of plant information and general analysis for accident scenarios are extremely important processes that should be conducted in order to prevent omission of any earthquake-specific accident scenario as well as to enable effective implementation of various evaluations such as the seismic hazard evaluation, fragility evaluation and accident sequence evaluation. These processes should take place prior to the above-mentioned evaluations.

3.4.2 Main characteristics

Main characteristics are as below:

1) Implementation of plant walk-down is introduced in order to supplement insufficient desk information and to confirm consistency of analysis models with the actual site situation.
2) Implementation of qualitative and qualitative screening is introduced based on setting / analysis of wide variety of accident scenario in order to prevent missing earthquake-specific accident scenarios.
3) Scenarios in which event process leading to core damage is unknown or in which screening is infeasible due to insufficient evaluation technique are recorded in a report to ensure transparency and clarity of explanation.

3.5. Seismic Hazard Evaluation

3.5.1 Composition

"Seismic Hazard Evaluation" (Chapter 5) is described in the following 7 sections:

- 5.1 Process of Seismic Hazard Evaluation
- 5.2 Treatment of uncertainty in vertical motion and Seismic Hazard Evaluation
- 5.3 Setting of seismic source model

5.4 Setting of seismic ground motion propagation model
5.5 Formation of logic tree
5.6 Evaluation of seismic hazard
5.7 Formation of seismic ground motion for fragility evaluation

In "Process of Seismic Hazard Evaluation", modeling of location / size / incidence of earthquakes that may occur in the vicinity of the site is conducted using active fault data and historical earthquake data as shown in **Figure 2**. Then, the propagation of seismic ground motion caused by the earthquakes is evaluated based on distance attenuation model or fault model in order to obtain the relationship between the strength of seismic ground motion and the exceedance frequency / probability. The uncertainty in the modeling is treated by using a logic tree.

3.5.2 Main characteristics

Main characteristics are as below:

1) Seismic source models are categorized into a specific seismic source model and an area seismic source model.
2) Either the distance attenuation model or the fault model can be used as a seismic ground motion propagation model. It is possible to set both horizontal seismic ground motion and vertical seismic ground motion.
3) Logarithmic-standard deviation to represent dispersion of seismic ground motion and the maximum value of seismic ground motion are set.
4) Uncertain factors related to the seismic source model and the seismic ground motion propagation model are categorized into randomness uncertain factors related to natural phenomena and the epistemic uncertain factors related to insufficiency of knowledge and information. Then, the uncertainty evaluation method is introduced by using a logic tree targeted for the latter factors (see **Figure 3** for example).
5) A method is used where seismic ground motion for response analysis in the building / component fragility evaluation is evaluated based on the seismic uniform hazard spectrum.
6) To promote understanding of seismic hazard evaluation, quantitative evaluation results are indicated as much as possible.

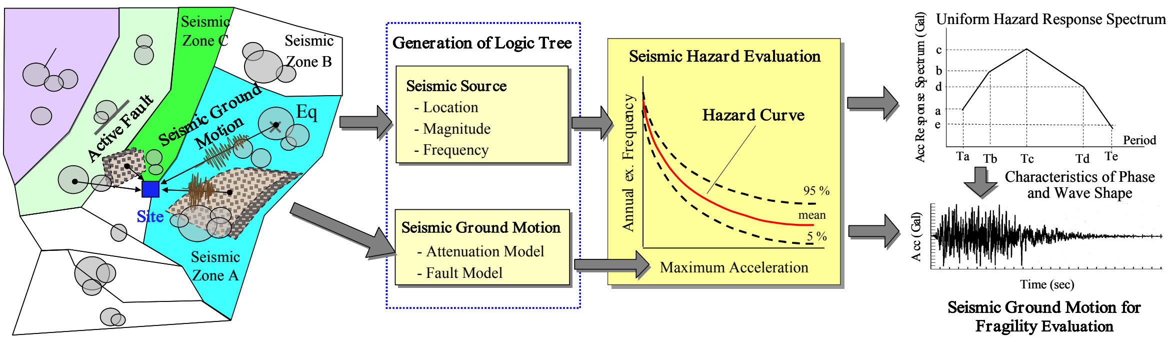

Figure 2 Procedure of Seismic Hazard Evaluation

Seismic Source Characteristics					Seismic Ground Motion Characteristics		
Probability of Existence	Fault Length	Estimation Model of Magnitude	Source Location	Occurrence Frequency Model	Selection of Attenuation	Logarithmic Standard Deviation	Upper Limit of Acceleration
P1	x 1 km	Matuda Eq.	Uniform Distribution	Poisson Process	Taitokui Eq.	σ = 0.3	Non
P2	x 2 km	Utsu Eq.	Shortest Distance	Non-Poisson Process	Annaka Eq.	σ = 0.5	Mean +2σ
P3	x 3 km	Others			Fukusima and Tanala Eq.		Mean +3σ

Figure 3 Example of Logic Tree

3.6. Building & Component Fragility Evaluation

3.6.1 Composition

"Fragility Evaluation" (Chapter 6) is described in the following 7 sections:

6.1 Fragility evaluation process
6.2 Selection of evaluation target and failure mode
6.3 Selection of evaluation method
6.4 Evaluation of realistic capacity
6.5 Evaluation of realistic response
6.6 Evaluation of fragility curve
6.7 Correlation of failures and fragility evaluation for seismic isolation type nuclear power plants

In the fragility evaluation procedure, the relationship of the strength of seismic ground motion and the conditioned failure probability where realistic response of the buildings / components to the seismic ground motion should exceed their realistic capacity is obtained, which practically the accumulated curve of the conditioned failure probability (fragility curve) as shown in **Figure 4**. Both the realistic response and the realistic capacity are represented as median value / logarithmic-standard deviation by assuming that they are based on log-normal distribution. Uncertain factors related to response / capacity are categorized into the randomness uncertain factors related to natural phenomena and the epistemic uncertain factors related to insufficiency of knowledge and information. The logarithmic-standard deviation of the former factors are represented as the gradient of fragility curve, while that of the latter factors are represented as the curve width (such as 5, 50, 95%).

3.6.2 Main characteristics

Main characteristics of the implementation standards are as below:

1) Methods of categorizing buildings / components in scope are indicated so as to enable accurate evaluation of core damage frequency based on the small number of buildings / components.
2) Any evaluation method can be chosen from "detailed evaluation", "a moderate detailed evaluation" and "a simplified evaluation" depending on the objective of concern in the evaluation.
3) With the purpose to allow detailed capacity evaluation, methods of setting failure mode / failure section of the categorized buildings / components in detail are indicated.
4) Response evaluation method for vertical seismic ground motion is shown.
5) Correlation evaluation method is introduced in order to allow evaluation of simultaneous failure of multiple components under strong seismic motion.
6) Evaluation methods that can reflect scenarios that may lead to secondary core damage such as collapse of the slope in vicinity or damage of stacks are considered in addition to accident scenarios that directly lead to core damage.
7) Methods that can reflect aftershock, aging and seismic isolation structure are considered.
8) To promote understanding of the fragility evaluation, quantitative evaluation results are indicated as much as possible (**Figure 5**).

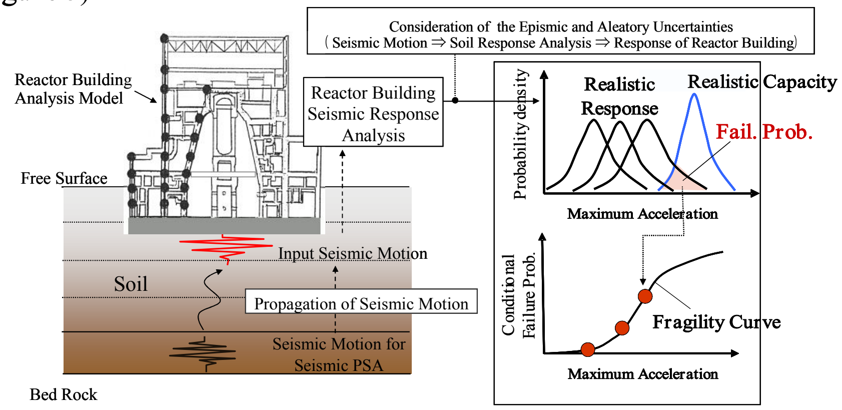

Figure 4 Procedure of Fragility Evaluation

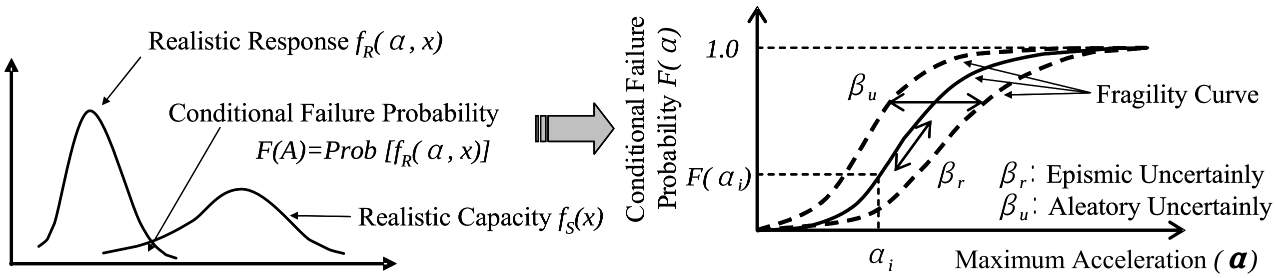

Figure 5 Illustration and Concept of Fragility Evaluation

3.7. Accident Sequence Evaluation

3.7.1 Composition

"Accident Sequence Evaluation" (Chapter 7) is described in the following 6 sections:

- 7.1 Evaluation process
- 7.2 Setting of initiating event
- 7.3 Modeling of accident sequence
- 7.4 Modeling of systems
- 7.5 Quantitative evaluation of accident sequence
- 7.6 Analysis of loss of containment function scenario

In the procedure of accident sequence evaluation as shown in **Figure 6**, initiating events are determined first of all, and modeling of accident sequence is conducted as Event Tree (ET) for these initiating events. Next, modeling of the logic models for evaluating earthquake-related loss of function of the mitigation systems included in the ET heading is conducted. Then, by using the evaluation results of ET, FT, human errors, fragility evaluation and seismic hazard evaluation, probability / frequency of core damage for the concerned accident sequences that may lead to core damage is obtained considering the uncertainty. Finally, by multiplying these probabilities / frequencies, core damage probability / frequency (CDF) is obtained. If necessary, by performing importance analysis, important accident sequences, mitigation systems and components that dominantly contribute to CDF are obtained.

3.7.2 Main characteristics

Main characteristics are as below:

1) The method of accident sequence evaluation is introduced that covers simultaneous failure of multiple components under strong seismic motion.
2) The method of evaluating mitigation operation under high-stress condition after strong seismic motion is introduced.
3) In order to identify accident sequences, mitigation systems and components that are critical in safety aspect and contribute significantly to CDF, methods to evaluate their importance such as Fussell-Vesely index, risk reduction worth and risk achievement worth are described.
4) Analysis contents of loss of containment function scenarios are indicated as a preparation of seismic level 2 PSA.
5) To promote understanding of accident sequence evaluation, quantitative evaluation results are indicated as much as possible.

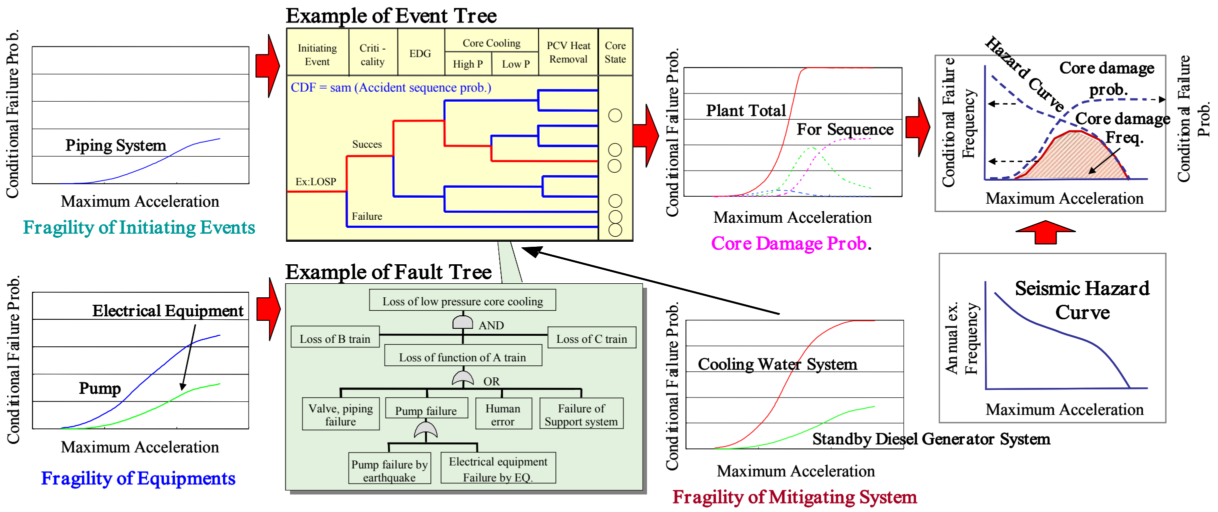

Figure 6 Procedure of Accident Sequence Evaluation and Core Damage Frequency

3. 8. Documentation

"Documentation" (Chapter 8) is prepared so as to satisfy the followings:

- Necessary information can be obtained in case of utilization in decision making etc.
- General image of evaluation can be understood and appropriateness of evaluation contents / results can be easily reviewed by professionals other than the evaluators.

4. COMCLUSION

The Seismic PSA technologies in our country are in the phase of utilization. The Atomic Energy Society of Japan Standards Committee has compiled requirements for Seismic PSA and specific methods to satisfy the requirements as the implementation standards.

To conclude this report, the points to be addressed in the future for further refinement of the standards are mentioned below:

- Decrease of logarithmic-standard deviation representing the dispersion of seismic ground motion and a detailed modeling of setting the maximum limit need to be addressed.
- Detailed definition of fragility evaluation method reflecting the effect of aging and expansion of capacity data concerning local components / piping need to be addressed.
- Refinement of correlation evaluation model among multiple components as well as the refinement of evaluation method for core damage frequency in the multiple units site need to be addressed.

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