Preparation of Implementation Standard Concerning Severe Accident Management in Nuclear Power Plants

Shinya Kamata[a*], Koji Okamaoto [b], and Tomoyuki Sugiyama [c]

[a] Japan Nuclear Safety Institute, Minato-ku, Tokyo, Japan

[b] The University of Tokyo, Tokai-mura, Naka-gun, Ibaraki, Japan

[c] Japan Atomic Energy Agency, Tokai-mura, Naka-gun, Ibaraki, Japan

Abstract: The Great East Japan Earthquake with a magnitude of 9.0 (The 2011 off the Pacific coast of Tohoku Earthquake) occurred on March 11, 2011, and the beyond design-basis tsunami descended on the Fukushima Daiichi Nuclear Power Plant by the earthquake. Eventually, the core cooling systems of the units 1, 2 and 3 could not operate stably, they all suffered severe accident, and hydrogen explosions were triggered in the reactor buildings of units 1, 3 and 4.

In the light of these circumstances, Atomic Energy Society of Japan (AESJ) decided to establish a standard that consolidates the concept of maintaining and improving severe accident management. The standard also provides technical requirements for renovation and addition of the equipment, the formulation of procedures, and strategies. All these items enable the minimization of risks so as to prevent severe accidents, or otherwise enable the mitigation of impacts of severe accidents once occurred.

Keywords: Earthquake, Tsunami, Severe Accident, Accident Management, PRA, Risk

1. INTRODUCTION

The Severe Accidents Management (SAM) Standard has been under discussion since December 2011, while Severe Accidents Management Subcommittee was set up under the System Safety Technical Committee (STC) for the Standards Committee (SC) of AESJ.

The standard provides technical requirements and satisfactory methods concerning maintenance and improvement of severe accidents management in existing nuclear power plants.

With the primary purpose of maintaining and improving the accident management capability, the standard demands strategies, in both hardware and software aspects, which include the effective use of risk information based on PRA as a tool and the upgrading of hardware, as well as the placement of highly-skilled resident staff at power plants, plus the on-going assessment of skills required, including education, and enhanced training and development of skills to respond accordingly to various scenarios of severe accidents, including the low-frequency, high-impact events.

The standard may have applicability to other nuclear facilities such as spent fuel reprocessing facilities. However, if the standard will be applicable to other facilities, the feature (specification and replacement of components, systems, building, and structures) of facilities in safety design should be considered.

The paper describes the basic concept of the SAM Standard and exemplification which will be formally issued soon.

2. DETAIL OF THE SEVERE ACCIDENT MANAGEMENT STANDARD

2.1. Structure of Severe Accident Management Standard

The standard is composed of the 12 chapters by reference to the requirements of NS-G 2.15[1], and the specification items are clearly described in the text and appendixes of each chapter. In addition, in the appendices and interpretations, the applicable examples are provided to help users understand the specification items of the standard as necessary.

The 12 chapters are as follows.

* kamata.shinya@genanshin.jp

1. Scope and application
2. Citation standard
3. Glossary
4. Principal requirements of the SAM standard
5. Extraction of nuclear power plant vulnerabilities
6. Identification of nuclear power plant capability
7. Development of accident management strategy
8. Accident management guidelines
9. Establishment of emergency response organization
10. Verification and validation
11. Education and training
12. Maintenance and update of accident management strategies

2.2. Requirements for Evaluation Step

2.2.1. Principal Requirements of the SAM Standard

The objectives of accident management for prevention and mitigation in this standard are as follows:

a) Preventing core damage; b) Terminating severe accident progression; c) Maintaining containment integrity; d) Minimizing radioactive material release; e) Achieving long term stable state.

In order to accomplish these objectives, accident management should be established and improved according PDCA (Plan-Do-Check-Act) cycle. As shown in Figure 1, this standard is composed of the 12 chapters describing requirements associated with appendices, and each steps of PDCA cycle are approximately as follows.

- Identification of vulnerabilities and capabilities of the plant ;
- Development of accident management in order to reduce those vulnerabilities following a structured approach, and confirmation of the feasibility ;
- Classification of each element of developed accident management (hardware and software) based on the importance from the view point of risk reduction;
- Verification and validation of the effectiveness of the developed accident management, considering risk reduction by integration of hardware and software;
  Reflecting findings obtained through education and training on the improvement of the accident management so that it leads to capability enhancement;
- Maintaining the up-to-date knowledge and insights, and incorporating them into accident management as appropriate.

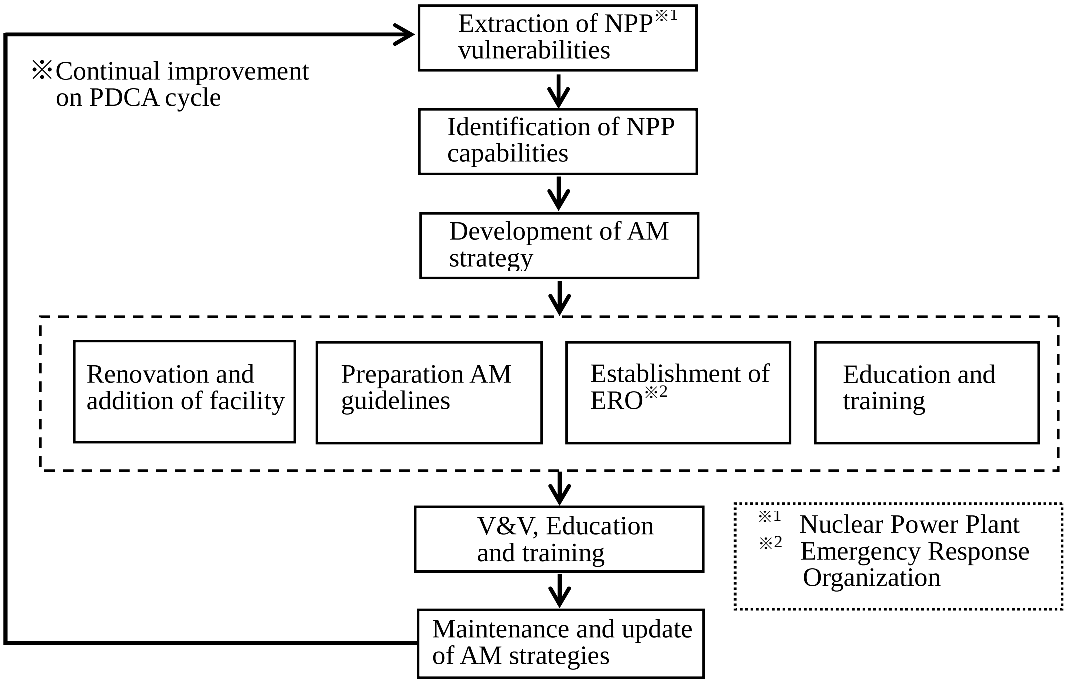

Figure 1 PDCA cycle for Accident Management

2.2.2. Extraction of Nuclear Power Plant Vulnerabilities

Plant vulnerabilities should be extracted by identifying the important accident sequences which may lead to a severe accident beyond the design basis according to the flow in Figure 2.

(1) Assumption of events

Events should be assumed according to the following items a) and b) with an aim to assure comprehensiveness as much as possible:

a) Following events should be considered as the initiating events leading to the loss of safety function at the target plant:

1) single events (internal events and external events), 2) combined events, 3) events leading to the significant loss of safety functions

b) Following events should be considered with a view to support, replacement or recovery of safety function:

1) loss of social infrastructure, 2) damage to multiple plants

(2) Extraction of important events to be assumed

From the single events and combined events among those assumed in the above item a) of item (1) excluding events leading to the significant loss of safety functions, important events should be extracted by performing the "preliminary qualitative screening" and then "quantitative screening based on a bounding or demonstrably conservative analysis" in a stepwise manner.

(3) Identification of important accident sequences

Important accident sequences should be identified for each of the important events to be assumed which were extracted in item (4) by performing a probabilistic risk analysis (PRA) (Level 1 and Level 2), deterministic assessment or engineering judgment, or a combination of these methods.

PRA is used to identify important sequences at least for internal events. The use of PRA is desirable to identify important sequences for external events, too. However, for an event for which an applicable evaluation method has not been fully developed, a deterministic assessment or engineering judgment should be used to identify important sequences.

(4) Identification of important sequences through PRA

When PRA is applied, important sequences should be identified by defining the individual groups, extracting important sequence groups according to the degree of frequency of occurrence, and identifying important sequences accordingly.

(5) Identification of important sequences through deterministic assessment and engineering judgment

In applying the deterministic assessment and engineering judgment to an external event, accident sequence groups are set referring to the accident sequence groups set for internal events, and a sequence that is judged to occur most frequently in the group is identified as an important sequence. Deterministic assessments and assessments using engineering judgment for external events include the FIVE method for internal fire events and seismic margin assessment method.

(6) Extraction of plant-specific vulnerabilities

Plant-specific vulnerabilities should be extracted according to the systems and components which may cause the important accident sequences identified in item (4), (5). Regarding the events which may lead to the significant loss of safety functions, plant-specific vulnerabilities should be extracted using the deterministic assessment and engineering judgment.

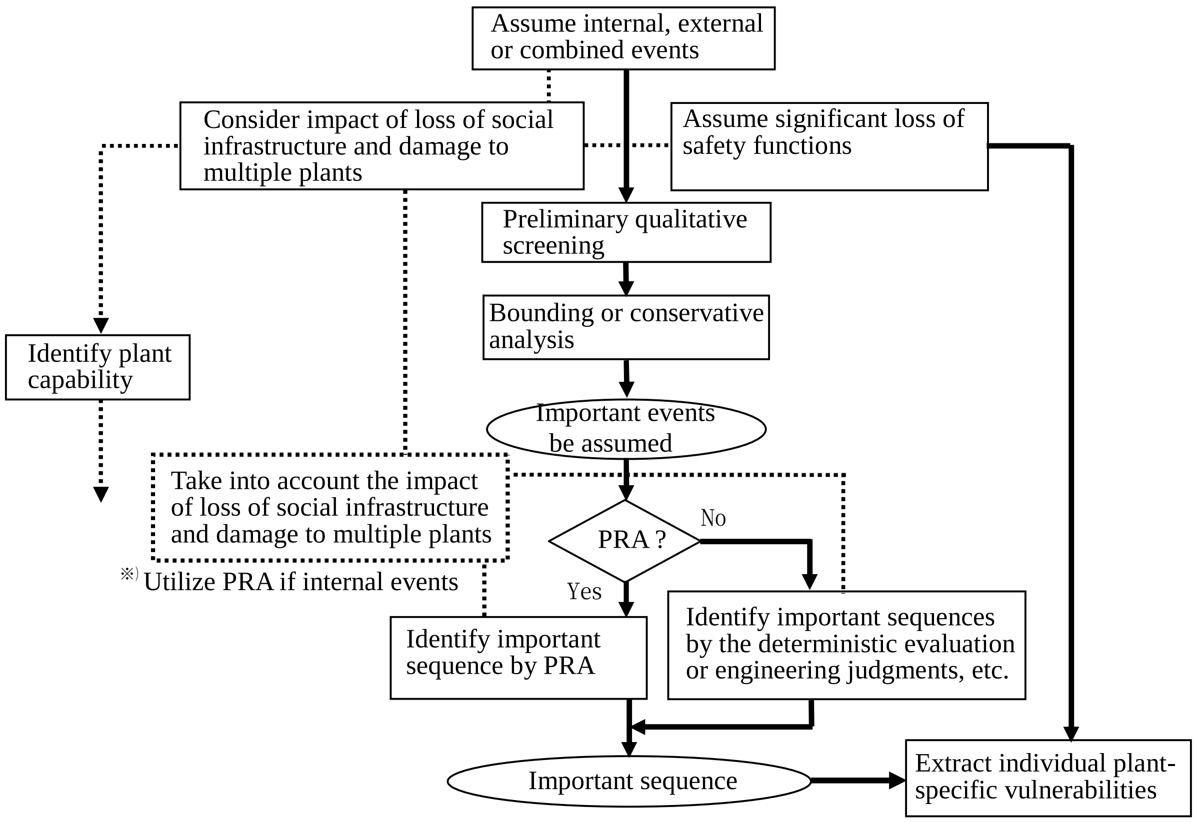

Figure 2 Flow chart of extraction of NPP vulnerabilities

2.2.3. Identification of Nuclear Power Plant Capability

In parallel with the identification of dominant accident sequence and the plant vulnerability described in the previous section, all the plant capability which is effective for prevention and mitigation of severe accident should be identified as the basis of accident management development.

(1) Available system and procedure

All the potential use of system capabilities such as non-dedicated function, beyond-design basis performance, recovery of damaged equipment and temporary lineup should be investigated. It should be also examined whether those systems have adequate performance to prevent core damage or containment failure, or at least, delay the timing of failure in case they do not have sufficient capability.

(2) Organization, personnel competence, and working environment

The plant organization should be functional with high confidence for emergency response even during night-time or days off. Under the degraded environmental condition caused by the postulated hazard, the adequacy of personnel competence and training experience for the accident management should be confirmed.

(3) On-site and off-site support

If any support relies on the adjacent plants within the site, the availability should be verified considering external hazard which may affect multi units or damage propagation by the shared system among plants.

2.2.4. Development of Accident Management Strategies

(1) Formulating an accident management strategies

Feasible accident management strategies should be formulated based on the results of Section 2.2.2, "Extraction of nuclear power plant vulnerabilities," and Section 2.2.3, "Identification of nuclear power plant capabilities."

Typical considerations for formulating an accident management strategy are as follows.

- Formulate actions that prevent severe accidents, suppress the progress of accidents, maintaining the integrity of the containment as long as possible, minimizing releases of radioactive material and achieving a long term stable state;
- Allow for independence from those facilities that are likely to have lost function in a target sequence, which may or may not cover all the capabilities of the plant;
- Consider available equipments with the restriction on access root to get to the field, operation time and severe accident environmental condition and etc.;
- Ensure the accident management strategy which is properly formulated to respond to external events as they occur, by choosing where to install and store to retain the effectiveness of accident management.

(2) Systematic assessment of accident management priorities

The actions should be selected to take by considering their importance to meet the progress of a target sequence and also assess the priorities of their implementation.

(3) Effectiveness of accident management

In formulating an accident management strategy, analyses and assessments should be conducted to prevent the occurrence of severe accidents or verify the effective functioning of accident management from the perspective of mitigating the impacts of severe accidents. Typical considerations for validating accident management are as follows.

- Use widely verified analysis codes when conducting thermal-hydraulic analyses;
- Adhere to optimal analysis assessments in principle, interpreting the analysis results with the limits and uncertainties of the models taken into account; and
- Assess the positive and negative effects that the formulated risk management strategy may have upon mitigating the risks of uncovered vulnerabilities quantitatively or qualitatively via a probabilistic risk assessment or alternative method.

(4) Establishment of Management Classes

a) Defining Management Classes

In order to ensure reliability of accident management, application of management classes are required as follows.

- Define management classes based on awareness of weightings, risks and other relevant factors, to make intensive and positive use of hardware and software key for safety;
- Establish criteria for assigning management classes to reflect individual plant risk assessments and severe accident environmental conditions; and
- Review the management classes as accident management modifications to reflect the application of the latest available knowledge.

b) Applying management classes

In implementing management classes in accident management, the following concepts should be adhered:

- Ensure that accident management measures conform to basic safety requirements according to the management class level, including facility independence, quake resistance and positional separation.
- Assign management classes to reflect their definitions.

Management classes should be assigned to reflect the required considerations for plant risk assessments and accident management. Figure 3 shows a typical example of management class assignment flow.

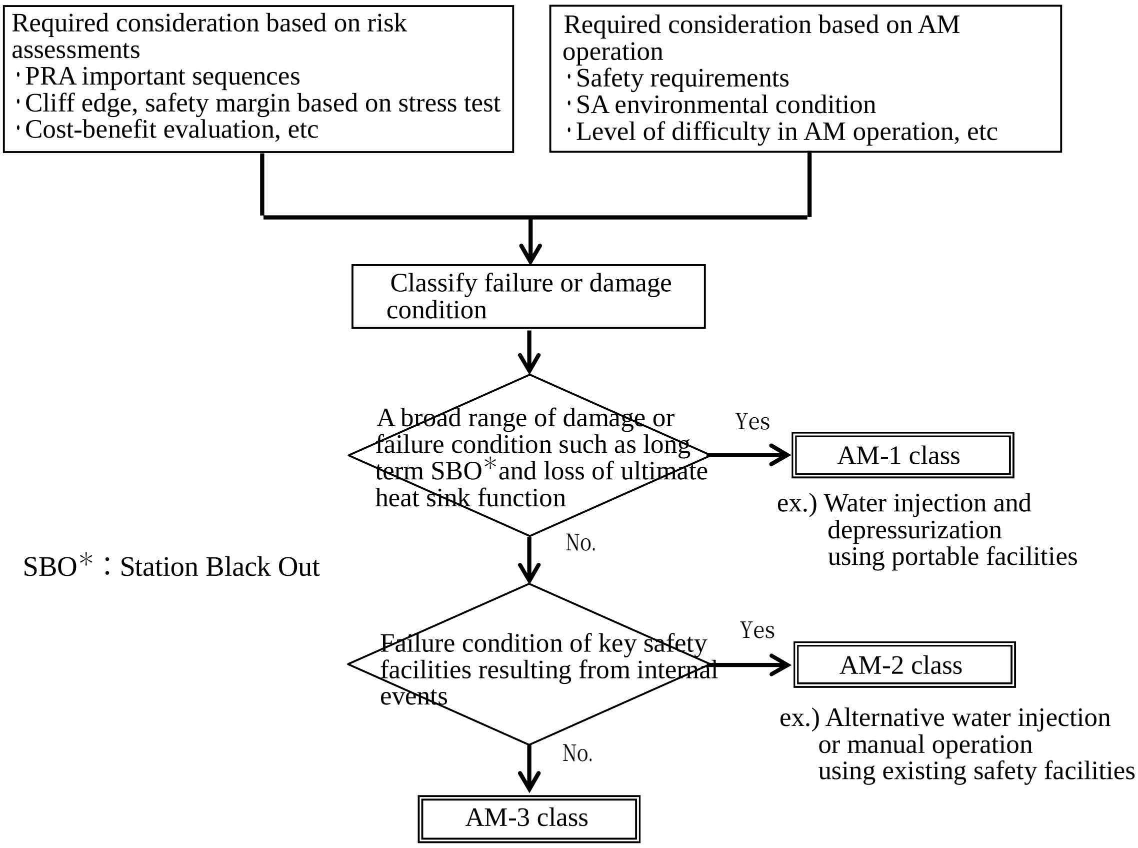

Figure 3 Typical example of management class assignment flow

2.2.5. Accident Management Guidelines

The procedures and guidelines for prevention and mitigation are prepared based on the information about identified vulnerability, plant capability, and developed accident management as a result of process described in the previous sections. Specifically in the mitigative domain, procedures and guidelines should be flexible (rather than prescriptive) so that possible consequences and associated uncertainties following candidate actions can be examined.

(1) Identification of plant condition

The procedures and guidelines should contain the description of necessary plant parameters, criteria for candidate actions, and their priorities. Where the direct readout of measurements is not available, alternate means for parameter estimation (ex. simple formula, pre-calculated diagram) should be provided.

(2) Prioritization and implementation

The procedures or guidelines should describe anticipated (both positive and negative) impact by candidate action, and prioritization of candidates should be revisited according to the progression of accident. When the candidate measure is not available, procedures or guidelines should provide alternative means or mitigative options. Transition conditions among procedures or guidelines for various accident stages should be clearly defined. They should also include attention to required actions for achieving long-term stable state.

(3) Consideration of environmental condition

Habitability of main control room or technical support center, or environmental condition (radiation, cooling, ventilation, lighting, structural damage) under severe accident which may affect the accessibility to other locations should be taken into account. Power supply for instrumentation, computer, or communication device should be secured as well. In case of multi-unit site, procedures and guidelines should anticipate simultaneous occurrence of severe accident.

2.2.6. Establishment of Emergency Response Organization

In order to promote the effective application to the prevention and mitigation, for severe accident, the emergency response organization should be preliminary defined within the documentation of the accident management program.

The roles of personnel involved in severe accident management should be considered in three categories as follows.

The emergency director recognizes plant states including impact to off–site and the impact by decision making, and is responsible for results of response with decision making.

The technical support center staff evaluates accident management and its validity and proposes it to the emergency director. He exchanges information on phenomenon progress, presence or absence of available facility and the degree of impact with control room staff based on knowledge of severe accident and procedure.

The control room staff provides input to evaluations of the technical support center on the basis of their knowledge of the capabilities of plant equipment and instrumentation. He implements a part of accident management which emergency director decided.

Concerning transfer of responsibilities and decision making authority, the transfer should be made at the time that the response can be continued. For example, the transfer should not be made if new decision maker can not prepare first direction of the decision making.

2.2.7. Verification and Validation

(1) Verification of accident management

The department in charge of developing accident management measures should verify accident management.

Developed accident management measures which secure nuclear safety based on defense in depth approach[2] should be checked for plant operation and shutdown states. In verification, it is recommended that risk information based on the probabilistic method as probabilistic risk assessment is referred.

(2) Validation of procedures and guidelines

Validation should be carried out to confirm by staff not involved in developing accident management that the actions specified in the procedures and guidelines can be followed by staffs to manage emergency events. Possible methods for validation of the procedures and guidelines are the use of a full scope simulator or plant analyzer code (if available).

(3) Validation of accident management by independent third party

Independent third party review should be performed in order to check the validation of accident management as follows.

a) A review team should be consisted of members with expertise, independence and fairness.
b) A review should be performed at least once every ten years. The second review should be considered if accident management is changed significantly even fewer than ten years after the previous review.

c) Several items of review might be skipped if the result of independent review performed at the same nuclear power plant site exists. etc.,

2.2.8. Education and Training

The education and training are primary elements to maintain competence and enhance capability for accident management.

(1) Role and required competence

Individuals of the personnel (from top management to engineer including member from contractor supporting plant operation) at site should have required competence for the accident management according their assigned role, and continue to enhance their capability. The education and training should be commensurate with the tasks and responsibilities of members during accident management, and the program (objectives, basis, implementation and feedback) should be systematically developed.

(2) Practicality and flexibility

In order to promote practicality, the training condition (plant behavior, working environment and human factors) should simulate actual situation to the extent reasonable, and the drill of communication and corporation with external organization should be also planned during appropriate period in the program.

The extremely low-frequency, high-impact events are usually excluded from vulnerability identification and accident management development. However, they should not be disregarded in the course of education and training without pursuing the promotion of flexible ability for mitigation. Those extremely low-frequency, high-impact events should be revisited as exercises to explore novel management.

(3) Update and feedback

In order to maintain the latest knowledge and insights, and incorporate them into accident management where needed, planning of education should be programmatic. The latest knowledge is not limited to new findings, but also includes design change of plant systems. The education should also be performed without delay on the occasion of new assignment. The lessons learned and good practice obtained through education and training should be shared among utilities.

2.2.9. Maintenance and Update of Accident Management Strategies

(1) Search and surveillance

About the following items that may affect the development, the availability, and the validity of accident management strategies, they should be supervised continuously.

a) Change of equipment of plant, manuals, and implementation structure
b) Change of the environmental conditions (peripheral people's state, an external hazard factor, etc.) around plant
c) Revision of the reference engineering documentation drawn up and used when deciding upon accident management strategies
d) Research on the phenomenon of a severe accident, the latest knowledge of analysis tools in and outside the country
e) New knowledge based on an accident and a trouble example in and outside the country

(2) Check of effects

The followings will be checked when it is judged as a result of search and survey that it has significant effect on the development, the availability, and the validity of accident management strategies.

a) Identification of dominant sequences and plant vulnerability performed in section 2.2.2 "Extraction of nuclear power plant vulnerability"
b) Effectiveness assessment performed in section 2.2.4 "Development of accident management strategies"
c) Adequacy validation performed in section 2.2.7 "Verification and validation"

(3) Reexamination

In the following cases, it reexamines about maintenance of accident management strategies.

a) When it is judged that there is a problem by the adequacy validation performed in section 2.2.7 “Verification and validation”
b) When it is judged that reexamination is required among what was judged that an improvement is required in section 2.2.8 "Education and training"
c) When significant effect is identified in item (2)
d) Within at least ten years after the last examination

3. CONCLUSION

The SAM standard provides risk assessment based hardware measures as well as software measures for staff education/training and updating procedures in order to enhance the staff’s capability for dealing with safety issues. The combination of hardware and software measures based on the risk assessment enables a scientific and rational approach to apply to scenarios of various severe accidents including low-frequency, high-impact events, and assures safety with functionality and flexibility. Furthermore, the standard requires the accident managements to be continuously improved by implementation of the PDCA cycle.

The AESJ is asking for public comment on the draft version of the SAM standard as of the end of February, 2014. After establishment and publication of the SAM standard, with regard to effectiveness assessment for accident management and V&V of severe accident analysis code, the detailed guideline will be prepared as appendices of the standard.

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