The Circumstances of Severe Accident Measure Implementation and "The Residual Risk"

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The examination of the direct factor(s), cause(s), and root cause(s) of the Fukushima Daiichi Nuclear Power Plant Disaster are the responsibility of the "Hatamura Committee" (Investigation Committee on the Accident at the Fukushima Nuclear Power Plants of Tokyo Electric Power Company, Chairman: Dr. Yotaro Hatamura), but it is clear that there were insufficient measures taken regarding the tsunami. Following this unprecedented and major accident, examinations are being undertaken in regard to revising the safety design guidelines and severe accident (SA) measures as regulated requirements. This study revisits the course and changes in the SA measures, implemented as voluntary protection under governmental guidance, including the introduction of "residual risk" in the seismic resistant design examination guidelines that were aimed toward the expansion and completion of the SA measures. The author believes that the lessons learned from this study will help improve safety in nuclear power facilities in the future.

Introduction

The Fukushima Daiichi Nuclear Power Plant Disaster caused catastrophical damage, and the restoration activity is still in progress. Some opinions hold that the cause and effect of the disaster are different from those of the former Soviet Union's Chernobyl Accident, but as one of the personnel involved with nuclear power, the author feels remorse and has significant concern for the people who had to evacuate and give up their residences, agricultural lands, and farms and for the damage caused to agricultural crops and livestock products in areas far from the plants. The examination of the direct factor(s), cause(s), and root cause(s) of this unprecedented accident are the responsibility of the Hatamura Committee, but it is clear that there were insufficient countermeasures taken in regard to the tsunami; therefore, this commentary aims to learn lessons as a staff member involved in this severe accident (SA) measures, including those related to "residual risk."

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I. Course of Establishment of SA Countermeasures

Based on the lessons learned from the Three Mile Island Reactor 2 (TMI-2) Accident (March 1979) and Chernobyl Accident (April 1986), many countries have implemented countermeasures for severe accidents (SA), which lead to serious core damage that is the dominant risk factor in nuclear reactor facilities, and have studied how to reduce risks by preventing the occurrence and mitigating the impact of SA.

(1) The Nuclear Safety Commission extracted lessons (52 items) based on the investigation of the cause of TMI-2 Accident, including (i) reinforcement of education and training of operators, (ii) review of accident management procedures, (iii) establishment of a power plant emergency countermeasures office, and (iv) establishment and reinforcement of measurement instruments, and reflected the same in the nuclear safety policies in Japan.

(2) After the Chernobyl Accident, which caused radiation damage beyond the border, it was concluded that there was no lesson to be immediately reflected in the European-style light-water reactor in term of facility aspect, since the causes were mainly RBMK reactor design faults such as a positive void reactivity coefficient and a positive scram besides deviations from regulations and the operation plan. With the advent of safety culture, however, international attention has been focused not only on correct plant operation but also on the systems and organizations that prioritize safety.

(3) Based on the recognition of the importance of SA prevention measures and impact mitigation measures in case of SA in terms of improving safety, the Nuclear Safety Commission established a common problems conference and examined SA countermeasures, SA research, probabilistic safety assessments (PSAs), etc. A common problems conference report states, "Assuming that the safety of a nuclear reactor facility has been secured through safety activities corresponding to design basis events and that the risk of radiation to the surrounding public by reactor facility is sufficiently low, appropriate SA countermeasures (accident management: AM) based on PSA will significantly reduce the possibility of SA and alleviate its impact on the public, hence the risk will eventually be further reduced, even if SA or an event leading to SA occurs in the nuclear reactor facility." [1)]

(4) Based on this report, the Nuclear Safety Commission published a decision in May 1992 with the following points. [2)]

1) Nuclear reactor installers should voluntarily prepare effective AM to improve the safety of nuclear reactor facilities, and ensure an appropriate implementation of management in case of emergency.
2) The administrative agency should identify its role in terms of the promotion and preparation of AM and continuously conduct specific examinations.
3) As a temporary measure, the following matters should be reported by the administrative agency.
   i) An AM implementation plan prior to fuel installation for new nuclear reactor facilities (facility specifics, preparation of manuals, staff education and training, etc.)
   ii) A future AM implementation plan for nuclear facilities in operation or construction
   iii) A PSA to be implemented in i) and ii)
4) It is necessary for related organizations and nuclear reactor installers to continuously study SA. The Nuclear Safety Commission tracks the results of the above effort and conducts necessary investigations.

(5) Based on the decision of the Nuclear Safety Commission, the Ministry of International Trade and Industry made the following request (July 1992) for SA countermeasures to electric utilities and established an SA countermeasures meeting to use expert opinions for evaluating

the validity of the AM proposed by the companies [3).

1) Implementation of PSA and corresponding preparation of AM
   i) Implement Level 1 and Level 2 PSAs, understand the characteristics of each nuclear power plant, and investigate the candidate AM by the end of FY 1993. In addition, investigate the technical requirements of AM, such as primary containment vessel (PCV) measures including a PCV venting system and hydrogen control, an operation manual, and staff training.
   ii) Strategically and quickly prepare the necessary AM based on the investigation results.
   iii) Evaluate the validity of the above AM in the periodic safety reviews (PSRs), etc.

2) Others
   i) Electric utilities will implement shutdown PSAs (Level 1 PSA) within a year in representative nuclear power plants, and take appropriate actions based on the results.
   ii) Electric utilities will continue to improve the accuracy of PSA methods, conduct research to expand its scope, and develop the database with information such as instrument malfunction probability.

Below are some points that the government discussed with electric utilities in regard to the topic of voluntary safety.

a) It is agreed that Level 1 and Level 2 PSAs required from individual plants are Level 1 and Level 1.5 PSAs (up to the failure of the PCV) during power operations of the internal event, which was based on the PSA technology development status in Japan at that time.

b) Initially, the primary containment vessel countermeasures such as the PCV venting system and hydrogen control were required, regardless of the PSA results, but it was decided that the decision is made by efficacy evaluation with PSA.

c) The PSA implemented during shutdown is also carried out on representative reactors; if required, the appropriate response is sought out. Furthermore, based on the recognition of the significant risk of earthquakes in this country, electric utilities are requested to conduct research and development on PSA for external events such as earthquakes, i.e., expanding the scope of the research.

Item 1) c) is expected of electric utilities, but the government is to follow up. (See PSR in Chapter III)

(6) Posterior events

In March 1994, electric utilities reported the PSA results and the candidate AM to the Ministry of International Trade and Industry. The Ministry of International Trade and Industry and The Nuclear Safety Commission verified the validity of the same, and the electric utilities began preparation of AM on existing reactors with a goal of completion by 2000.

Electric utilities reported the completion of AM preparations on existing reactors in May 2002 and submitted the results of a quantitative efficacy evaluation of AM based on individual plant PSA by March 2004. The Nuclear and Industrial Safety Agency (with technical support from the Japan Nuclear Energy Safety Organization (JNES)) and the Nuclear Safety Commission reviewed them based on the basic requirements of AM preparation (April 2002) and deemed them to be valid.

II. Prepared SA Countermeasures

Figures 1 and **2** show an example of the procedure of the extraction of AM measures.

The procedure identifies an accident scenario in which core damage or PCV damage occurs, and prepares a system to replace the major loss of safety functions being a major cause of above accidents, and accident countermeasure procedures, which were most systematic among the SA countermeasures in many other countries.

This commentary does not mention the specific details of AM countermeasures; however, as Figure 2 indicates, the AM countermeasures for station blackouts caused by internal events

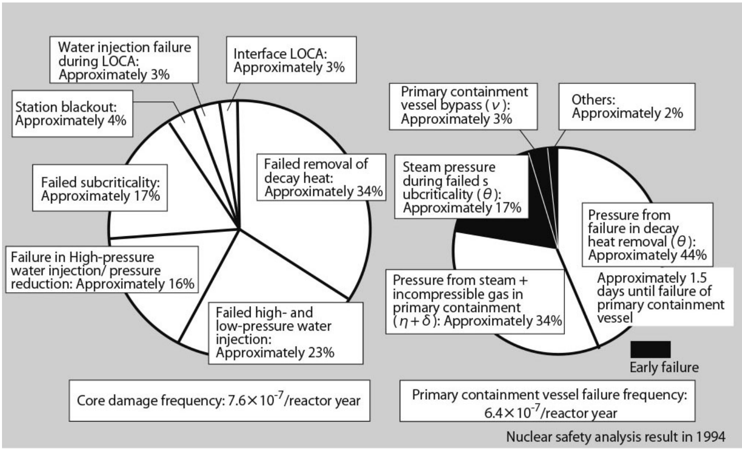

Figure 1 PSA example of Plant BWR5 (internal event, during output)

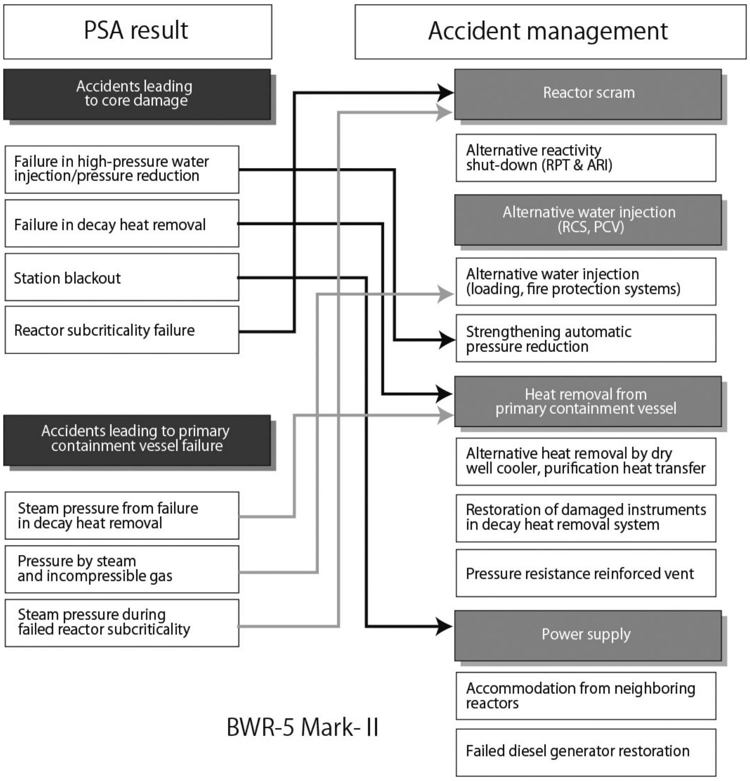

Figure 2 Extraction of accident management measures

involve the restoration of the damaged emergency diesel generator (D/G) and accommodation from adjacent reactors. This explains the lack of a complete implementation of cooling by alternative water injection and the PCV vent, which have been heatedly debated in Fukushima Daiichi Nuclear Power Plant. However, AM is a “knowledge-based” treatment based on technical knowledge of the electric utilities, and it is desired that AM be carried out based on such knowledge and the situation in a flexible fashion. This makes research necessary for expanding its scope, as previously mentioned.

Preparation of AM on new reactors and a review of its validity by the government have been continued, and a review on Shimane Plant 3 was recently carried out in 2010. The SA countermeasures for the new reactors are basically the same as those proposed in 1994, and reflections of latest knowledge by SA research and expansion of the scope of examination, as mentioned in 4) in (4) and 2) in (5), were not made, except for the fact that the instrument malfunction probability used in PSA was based on the national data prepared with the standard set by the Atomic Energy Society of Japan.

III. Periodic Safety Review (PSR)

Following a request by the Ministry of International Trade and Industry around the time of the request for SA countermeasures[4)], a PSR for the overall evaluation (in terms of the points below) of the safety of existing nuclear power plants was initiated as part of electric utilities’ efforts toward quality assurance, based on new technical knowledge accumulated over approximately 10 years. The following points were taken into consideration:

1) A holistic evaluation of operational experience, 2) understanding and reflecting latest knowledge and planning necessary countermeasures, and 3) implementing PSA, understanding the efficacy of SA countermeasures, and establishing necessary countermeasures.

The result was to be evaluated by the administrative agency, who established a PSR committee based on expert opinions and conducted an evaluation in regard to the condition of the preparation of SA countermeasures as part of item 3). In fact, this evaluation involved verification of the condition of the SA countermeasure facility and operator education and training at the site, improved the stand-by exclusion facility configuration management procedures, and added the instrument for it, for PSA at the time of shutdown (after March 2001) considering the SA countermeasures based on the PSA during power generation. Furthermore, there was a preliminary agreement with the fire PSA during the following fiscal year, followed by discussion with the earthquake PSA, which slowly but steadily expanded and reinforced the SA countermeasures expressed by research for expanding its scope.

Following the incident inappropriately described by Tokyo Electric Power Company (the so-called shroud issue, August 2002), the regulations on commercial reactors were revised (October 2003), which made the PSR a requirement by law as a safety requirement. However, there was not enough technical knowledge regarding item 3) (related to PSA) to make a legal requirement, which remained a voluntary requirement with no evaluation by the administrative agency. Due to this, efforts aimed toward the periodic assessment of the condition of the preparation of SA countermeasures and expansion of the scope of SA countermeasures practically stopped.

Following this, experts in this country concerned with the risk of earthquakes introduced the idea of “residual risk” in the revision of seismic resistant design review guidelines, as a step aimed toward enhancement and expansion of SA countermeasures.

IV. Background and Course of the Revision of Seismic Resistant Design Guidelines

Since 1981, when the previous seismic resistant design guidelines were established, valuable knowledge has been accumulated regarding fault activity behavior, earthquake-motion characteristics, and seismic resistance of buildings from the results of survey research, in particular that conducted for the earthquake in south Hyogo in 1995 (Great Hanshin earthquake). In contrast, citizens requested a more transparent explanation regarding seismic safety for nuclear power plants due to the occurrence of large earthquakes, whose hypocenters have not necessarily been identified preliminarily, and the measurement of earthquakes of a scale beyond the expectations of the previous seismic resistant design guidelines that occurred at some sites.

Based on the domestic and international trends in terms of seismic safety, the seismic resistant design subcommittee established by the Nuclear Safety Commission worked on the following three points: categorizing the matters to be investigated and discussed into 23 items; establishing a basic WG (basic ideas aimed at ensuring seismic safety), a facility WG (facility design method), and earthquake/earthquake-motion WG (evaluation method of design basis seismic ground motion) ; and surveying and organizing the up-to-date knowledge regarding the said items. Based on the reports from each WG, the revised seismic resistant design guidelines (new seismic guidelines) were established on September 19, 2004, after 5 years and a few months of investigation and discussion.

V. Characteristics and Significance of the New Seismic Guidelines

Compared to the previous guidelines, following are the characteristics of the new seismic guidelines:

(1) They are based on a reliable geological and ground survey and decisions regarding design basic seismic ground motion Ss that incorporate uncertainty, and refer to exceedance probability.

(2) It does not deny the possibility of earthquake motions larger than Ss, recognizes the “residual risk,” and minimizes the risk reasonably.

For decisions regarding design basis seismic ground motion Ss in above (1), besides considering uncertainty (variance) appropriately in the decision process, exceedance probability is also considered. This is from the perspective that it is desirable to consider using it for understanding and reducing “residual risk” and to understand to what extent the decided response spectrum of Ss corresponds to exceedance probability.

Introduction of “residual risk” in (2) is an innovative revision for SA countermeasures, given the fact that regardless of the definitions and expressions in the previous guidelines, which assumed that there would not be a seismic ground motion of a scale beyond design basis seismic ground motion S2 based on maximum probable earthquake.

This is because the framework of the revised seismic resistant guidelines with the proposed risk by the basic WG was almost accepted after many discussions. The following section shows the outline of these ideas.

1. Characteristics of Events Induced by Earthquake

In general, the safety of nuclear reactor facilities is achieved through deterministic measures and evaluations based on the principles of defense in depth. Events induced by earthquakes have different features from internal events (events induced by instrument malfunction and human error, etc.).

(1) Earthquakes and ground motion are natural phenomena that cannot be controlled by humans.

(2) Even with the up-to-date technology acquired after the earthquake in south Hyogo (Great Hanshin earthquake), it is difficult to accurately estimate, with small uncertainty, the scale, frequency, and characteristics of earthquakes and ground motion.

(3) Large ground motions can cause simultaneous damage to important systems, instruments, and buildings, disabling the multiple layered protection.

2. Basic Framework

There are various guidelines for "preventing disasters" as written in the Reactor Regulation Act (Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors). **Figure 3** shows the positioning of the seismic guidelines.

(1) The nuclear reactor site review guidelines include the following points:

A. A nuclear reactor must be designed, constructed, operated, and maintained in a way that prevents accidents.

B. Considering the events around the facility site, reactor characteristics, and safety protection facilities, it should be ensured that the surrounding public is not affected by radiation, even assuming that a serious accident can technically occur in the worst case (SA).

C. Furthermore, it should be ensured that the surrounding public is not affected significantly by radiation, even if an inconceivable accident (virtual accident) beyond SAs, which cannot be considered from technical perspectives occurs (e.g., emission of radioactive materials corresponding to a malfunction of some of the safety protection facilities during a SA).

The guidelines require the subject facility to limit the influence on the surrounding public

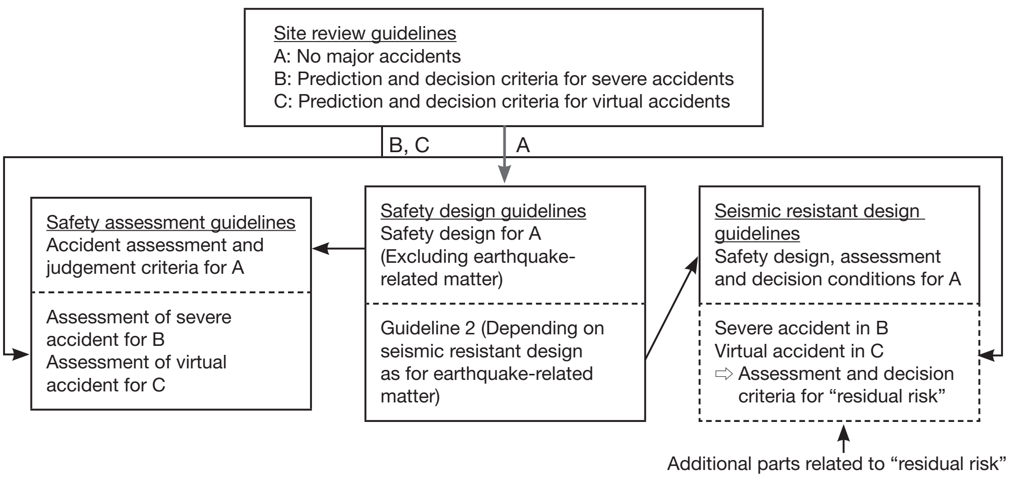

Figure 3 Role of seismic resistant design guidelines

for each of the three conditions with different occurrence probabilities.

It is commonly recognized that B and C are regulations for SA beyond the design basis event.

(2) The safety design guidelines require safety design so as to satisfy condition A, but the explanation of section 1 of guideline 2 expects the seismic resistant design guidelines to specifically ensure seismic safety. In other words, it expects the design measures for A in the seismic resistant design guidelines.

(3) The safety assessment guidelines specify the method of safety assessment in regard to B (SA) and C (virtual accident) in addition to that for the design basis event for the validity of design (A), but clearly assumes internal events and not earthquakes.

(4) Therefore, the seismic safety that is deemed valid by the seismic resistant design guidelines should be congruent with the "relationship between occurrence probability and damage" allowed by guidelines such as nuclear reactor site review guidelines, and the congruency should be prescribed clearly.

There have been many discussions on the basic framework, which finally led to the introduction of "residual risk."

3. Concepts for New Seismic Guidelines to Maintain Safe Functions

The new seismic guidelines (1) account for the prevention of disasters listed in the Reactor Regulation Act by deciding on the design basis seismic ground motion Ss with consideration given to uncertainty and designing the important systems, instruments, and buildings in such a way that safety functions are maintained. As a result, (2) they request that the "residual risk" will remain low in addition to implementation of necessary countermeasures. "Residual risk" is a provision in a commentary, but Supreme Court case precedents show that it is often as binding as main text in regard to ensuring safety.

It is necessary to understand the "residual risk" by using methods such as seismic PSA in order to ensure that "residual risk" is small.

VI. Handling of "Residual Risk"

1. Definition and Requirement of "Residual Risk"

"Residual risk" involves ground motion exceeding design basic seismic ground motion Ss extending to facilities so that 1) event(s) involving serious damage to the facility occur(s), 2) a large amount of radioactive materials is emitted, and 3) the surrounding public is exposed to radiation, which leads to disaster. Efforts should be made to understand the existence of the "residual risk" and make it as low as reasonably achievable.

2. Assessment Method and Decision Indicator of "Residual Risk"

The PSA method, which was developed and prepared in Japan's research institutions, regulatory support organizations, and industries, and used for analysis of commercial plants, is the implementation standard at the Atomic Energy Society of Japan, as shown in **Figure 4**. In particular, the seismic PSA implementation standards have been explained several times in the seismic resistant design subcommittee. Given that Japan is an earthquake-prone country, IAEA, NRC, and other organizations have deemed this method to be the most advanced globally.

It is valid to use the safety goals (draft) and performance goals (draft) established by the Nuclear Safety Commission as the judgment criteria. However, there is an increasing trend in the international community toward further reducing the risk of nuclear power plants, and it is necessary to review the performance goals.

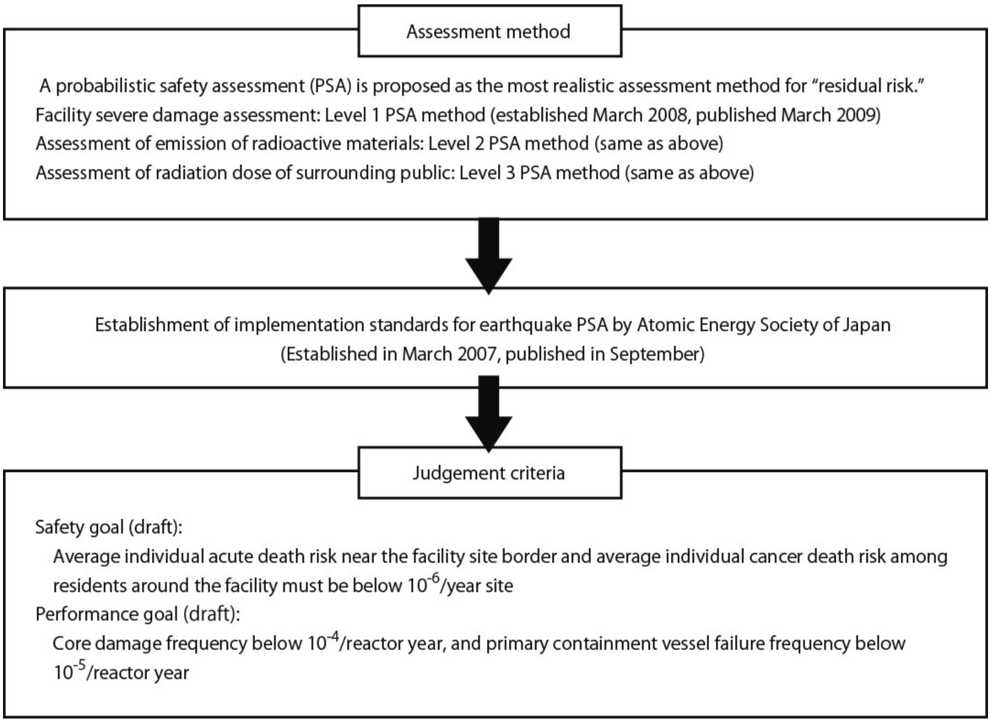

Figure 4 Assessment method and judgment indicator of "residual risk"

3. Information from Seismic PSA and Reduction of "Residual Risk"

(1) High transparency and explanatory power, clearly indicating assessment conditions, assessment models, used data, and assessment results.

(2) Enables obtaining and using the following information important for seismic safety.

- Appropriate seismic resistance importance classification for structures and instruments from the perspective of core damage frequency (CDF).
- Understanding of common-cause failure where multiple instruments are damaged during ground motion.
- Understanding of system redundancy and efficacy of multilayer protection by understanding the system and accident sequence important to CDF.
- Understanding the scale of ground motion leading to cliff edges such as core damage and damage in PCV.
- Comparisons among "residual risk" and safety goal, performance goal, and international standards.

In other words, the seismic PSA enables focus on buildings, instruments, and systems that considerably impact on CDF, and executes improvements in seismic safety with plant remodeling and SA countermeasures aimed at reducing “residual risk.” For example, reinforcement of structures involves strengthening support structures (basic anchor bolts and piping supports) for static parts such as tanks and pipes, and reduction in response by damping and isolating structures for dynamic instruments such as pumps and electric boards.

VII. Seismic Resistance Back Check

(1) The Nuclear Safety Commission (September 19, 2006) concluded that the seismic safety of nuclear power facilities is secured not only through basic design but also detailed design, a construction process based on such design and appropriate operation management. The commission decided that it would receive reports from the administrative agency in regard to the assessment of seismic safety, including “residual risk,” in addition to safety review.

(2) The Nuclear and Industrial Safety Agency ordered a seismic resistance back check to electric utilities (September 20, 2006).

◯**Stage 1 (Swift implementation)**

- Decisions on Ss considering uncertainty and safety assessments of buildings and instruments
- Decisions on tsunami formulation considering uncertainty and safety assessments of buildings and instruments.

◯**Stage 2 (After preparation)**

Table 1 Status of seismic resistance back check

Company	Facility	Discussion status	Company	Facility	Discussion status
Hokkaido Electric	Tomari	△	Kansai Electric	Ooi (Reactor 3, 4)	◎
Tohoku Electric	Onagawa (Reactor 1)	◎		Takahama (Reactor 3, 4)	◎
	Totsu	△	Chugoku Electric	Shimane (Reactor 1, 2)	◎
Tokyo Electric	Kashiwazaki kariwa (Reactors 1, 5, 6, 7)	◎ (Final Report)	Shikoku Electric	Ikata (Reactor 3)	◎
	Fukushima Daiichi (Reactor 3)	◇	Kyushu Electric	Genkai (Reactor 3)	◎
	Fukushima Daiichi (Reactor 5)	◎		Sendai (Reactor 1)	◎
	Fukushima Daini (Reactor 4)	◎	Japan Atomic Power Company	Tokai Daini	○
Chubu Electric	Hamaoka	△ (Final Report)		Tsuruga	△
Hokuriku Electric	Shiga (Reactor 2)	◎	Japan Atomic Energy Agency	Monju	◎ (Final report)
Kansai Electric	Mihama (Reactor 1)	◎		Reprocessing	△
			Japan Nuclear Fuel Limited	Rokkasho	◎ (Final report)

◎ : Verified by NSC ◯ : Discussed by NISA and under discussion by NSC
△ :Under discussion by NISA ◇ : Specially treated and verified by NISA
NSC: Nuclear Safety Commission NISA: Nuclear and Industrial Safety Agency
※Except for the final report, the interim report is used for discussion, which does not include assessment of the tsunami

- Quantitative assessment of "residual risk" using seismic PSA.

Table 1 shows the advancement status of the seismic resistance back check in stage 1.

The plan was that the electric utilities would begin implementation within three years of request from the government. However, the floor response was accelerated by two times the design floor response based on the previous seismic resistance guidelines in Kashiwazaki-Kariwa Nuclear Power Plant buildings due to Chuetsu offshore earthquake in July 2005. Mainly due to this event, Stage 1 took a long time and there was a delay in laterally, reflecting new knowledge from the cause analysis (ground motion amplification and building floor flexibility, etc.) to each site and plant. In addition, the assessment of ground motion was prioritized, and there were discussions on the Jogan tsunami (the 869 Sanriku earthquake) in association with earthquake motion at the Fukushima Daiichi site. However, most interim reports do not include assessment of the tsunami. There are also no reports by electric utilities regarding "residual risk."

The results are difficult to predict, but the delay in the seismic resistance back check is deeply regretted, given the seriousness of the accident at the Fukushima Daiichi Nuclear Power Plant.

Conclusions

There are 28 lessons learned from the accident in the report by the Japanese government published in June 2011[5]. The lessons directly related to SA countermeasures include group 1 (8 items: reinforcement of severe accident prevention measures) and group 2 (7 items: severe accident countermeasures), but many of them are related to SA, and this country needs to take the matter seriously.

This commentary discusses the earthquake/tsunami that is the direct cause of the accident and the safety culture, which forms the basis for accident response.

○Lesson 1: Reinforcement of earthquake/tsunami countermeasures

The summary is stated as follows: "The earthquake was extremely large with multiple hypocenters, but the seismic resistant design assumed 120,000–130,000 years for the active period of the active faults of concern and appropriately considered the re-occurrence of large earthquakes. As a result, there was no significant damage recognized in important facilities and instruments for safety (further inspection is needed. The seismic resistance back check has not been completed at the Fukushima Daiichi site). The tsunami was 14–15 m in height, exceeding the predicted height (5.7 m) based on lore/clear traces of the previous tsunami by the tsunami design, indicating that the tsunami countermeasures were not sufficient.

Future plans include deciding on the tsunami design with a predicted occurrence frequency and height of re-occurring tsunamis as well as formulating a safety design of buildings for preventing inundation. We shall also recognize the existence of the risk of tsunami of scales larger than the tsunami design reaching the facility (residual risk), and plan countermeasures to maintain the important safety functions."

A ground motion larger than the design basis seismic ground motion S2 predicted by the maximum probable earthquake of the previous seismic resistance guidelines was observed in some sites. In the Kanazawa District Court decision which ordered the suspension of Unit 2 of Shiga Nuclear Power Plant, it has been pointed out there was not enough consideration given to the danger of active faults, which made the calculation method less valid. Given the above observations, there was insufficient discussion on tsunami, though there was an urgent need for revision of seismic resistance guidelines.

However, the new seismic guidelines state the following about tsunamis as by-products of earthquakes and it is important for related personnel involved in design and review to recognize that "there is little possibility of significant damage to safety functions of facilities, even by tsunamis that are extremely rare occurrences with finite probability during the operation period of the facility," which is the same requirements to the primary requirements for seismic ground motion.

◯Lesson 28: Establishing Safety Culture

The summary of the Japanese Government Report also stated as follows. "'Nuclear safety culture' is 'the integrated recognition, mindset, and attitude that organizations and individuals should have in order to ensure that important matters are prioritized in regard to safety issues concerning nuclear energy'. It is the starting point, duty, and responsibility of staff responsible for nuclear energy to internalize such culture. For organizations and individuals involved in nuclear industries and nuclear regulation, it is important not to neglect the slightest doubts about safety and to seriously reflect if they sensitively and swiftly respond to new knowledge.

Hereafter, the following points are expected: nuclear safety staff shall return to a basic understanding of the importance of pursuing defense in depth for nuclear safety, and learn expert knowledge regarding safety, repeatedly seek for improvement in safety, and establish a safety culture."

The root cause of the accident is not so much the insufficient setting of the design basis events and guidelines and standards for unexpected events as the lack of safety culture among the persons who design, construct, operate, review and regulate. For example, the seismic resistant design guidelines request that efforts be made to reduce the "residual risk" due to seismic ground motion of magnitudes higher than the design basis seismic ground motion Ss. Those engaged in nuclear safety must have this view regarding tsunamis, which are by-products of earthquakes. It is necessary to understand and reduce the "residual risk" while considering both seismic ground motion and tsunami.

In retrospect, the implementation of the first individual plant PSA in early 1990s by our predecessors and the development of SA countermeasures were not inferior when compared to international standards in terms of SA research and the maturity of risk assessment technology. Japan's new seismic guidelines, including the introduction of "residual risk," are considered to be the most advanced in the world and referred to in IAEA safety requirements and guidelines.

Points to reflect upon are not only that the following generation did not hold governmental review of PSRs but also that there was no implementation of an expansion of the scope of SA countermeasures based on SA research and new knowledge in PSA technology, and that the seismic resistance back check was not implemented as planned.

In the future, there will likely be revisions of guidelines and standards as well as regulated requirements for SA countermeasures. In addition to the establishment of a sound framework, more important is a safety regulation system based on a high safety culture in both industries and regulators who will accomplish and improve the framework.

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