Initiatives of Japanese nuclear industry to improve nuclear safety after the Fukushima Daiichi accident

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Abstract: The Fukushima Daiichi accident provided strong lessons to the nuclear industry in Japan from the aspect that the industry must not be just satisfied with meeting the national regulatory requirement but that they should pursue further efforts towards higher performance without complacency. The Japan Nuclear Safety Institute (JANSI) was established in November 2012, as an independent organization from the nuclear industrial organizations in Japan, to lead them in making continuous efforts to realize the highest level of safety in the world. The current activity initiated by JANSI has been the reformation of organizational management in the nuclear industry to recognize safety culture with more commitment from top leaders to enhancing nuclear safety and the related human resource development than before the Fukushima Daiichi accident.

Keywords: nuclear safety; defense-in-depth; safety culture; human resource development

1. Introduction

The Fukushima Daiichi accident which caused devastating damage and halted Japan's nuclear power generation has brought worldwide social and economic impact. To date, several societies and associations have published their comprehensive views [1-10]. In particular, the overseas reports have concluded that the Fukushima Daiichi accident occurred due to the scale of the natural phenomena involved. However, they also concluded that it was largely a preventable accident. For example, one of these reports states that "It would be wrong to conclude that the accident at Fukushima revealed a fatal and uncovered intrinsic risk associated with nuclear power technology and infrastructure" [6]. It could have been prevented if appropriate equipment and organizational training had been in place, which should have been available with current light water reactor technology. In other words, they have also mentioned the necessity of in-depth researches into the impact of initiating events that are extremely rare, but have an extreme impact based on the concept of defense-in-depth after verifying that light water reactors can be controlled with the current technology so that they will not present a threat to public safety.

The ASME Report said that "However, the Fukushima Daiichi accident reveals the need for additional steps to further reduce the potential for socio-political and economic consequences resulting from radioactivity releases" [5].

Japanese electric utilities have already taken the initiative in making arrangements to immediately improve the safety of their own nuclear facilities, firstly by enhancing the multiplicity and diversity of power supplies and cooling functions, and taking flood prevention measures, so that they can withstand any great earthquake and great tsunami of the magnitude that struck the Fukushima Daiichi nuclear power station (NPS). In addition, they are making preparations to meet the new regulatory requirements from the Nuclear Regulation Authority (NRA) that have come into effect, and to take the necessary steps such as installing filtered vent systems and other measures to meet those standards within the periods of grace.

Considering the magnitude of potential hazards involved in nuclear energy that could inflict enormous damage on surrounding environments should an accident occur, the Fukushima Daiichi accident taught us that we must not be satisfied with just tackling day-to-day issues. We are required to continue striving for improved safety, eliminate

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complacency, benchmark world-class current practices, and develop an autonomous structure that will never fail to perform self-inspection, thereby promoting safety improvement. It is utilities who are responsible to upgrade and perform accident management. They need to take the initiative in this regard.

In the following part of this article, the concept of nuclear safety and safety goals is introduced in section 2, need for drastic reform of Japanese electric utilities for nuclear safety is described in section 3, organizational design and functions of the Japan Nuclear Safety Institute (JANSI) as the output based on the need of Japanese electric utilities in section 4, JANSI's present activities and human resource development in section 5, and then the conclusion in section 6.

2 Concept of nuclear safety and safety goals

In Japan, the safety of nuclear reactors has been traditionally explained to the general public by both the nuclear industry and the government with a simple sentence: "Stop, cool and contain". This means every nuclear reactor has reliable functions to "stop" nuclear fission, "cool" nuclear fuel with water and "contain" radioactive release from the reactor containment without any failures. For well educated persons, this is explained by provision and maintenance of five layers of defense - what is known as the "defense-in-depth" concept [11], with the organizational campaign within nuclear organizations to stimulate all members to foster a "safety culture".

How can safety of nuclear systems be assured in cases which are hereafter called "uncertain" cases in this paper of "impossible situations" caused by *a priori* set "beyond assumptions" or "unknown scenarios"? This is where defense-in-depth should also be considered. Defense-in-depth should be prepared for any kind of uncertain case. Severe accident management is required to prepare for various situations involving such uncertainties, and those uncertainties should be identified and be resolved in advance of their occurrence. Methods to cope with such uncertain cases may be predicted through conducting extensive probabilistic safety assessment. And even if severe accident management has been studied by taking into account of a variety of scenarios and plant conditions, emergency preparedness is also required for mitigating the consequence of radioactive release to the environment caused by severe accidents.

The importance of safety culture in ensuring nuclear safety has been anchored, confirmed, and advocated by the International Nuclear Safety Group (INSAG) of the International Atomic Energy Agency (IAEA) which investigated and examined the Chernobyl accident that occurred in 1986 in the former Soviet Union. According to INSAG, the basic tenet of safety culture is that those who are concerned with nuclear power must realize the value and the importance of safety at all levels, and make decisions and take actions putting safety as the first priority. This general attitude must be embodied by each individual and be shared across the organization. In particular, the following items are provided by INSAG as the pattern of declining performance in safety culture [12].

Stage 1: Over-confidence
This is brought about as a result of good past performance, praise from independent evaluations, and unjustified self-satisfaction.

Stage 2: Complacency
Minor events begin to occur at the plant and insufficient self-assessments are performed to understand their significance singly or in totality. …

Stage 3: Denial
Denial is often visible when the number of minor events increases further and more significant events begin to occur. However, there is a prevailing belief that they are still isolated cases.…

Stage 4: Danger
Danger sets in when a few potential severe events occur but when management and staff tend consistently to reject criticisms coming from internal audits, regulators or other external organizations.…

Stage 5: Collapse
Problems have become clear for all to see and the regulator and other external organizations need to make special diagnostic and augmented evaluations. …

We should review above mentioned signals repeatedly. For the Japanese nuclear industry, which experienced the Fukushima Daiichi accident in March 2011, the key lesson learned from the accident is that the Japanese nuclear industry lacked awareness about risks caused by external events such as earthquakes, tsunamis, fires, terrorism, *etc*. While lacking preparation for beyond-design base accidents, they only focused on decreasing the possibility of trouble and accidents caused by internal factors such as equipment failure and operator error. Even if equipment functions are maintained with high reliability, we cannot entirely eliminate latent defects and human errors.

There were a number of nuclear power plants at Onagawa, Fukushima Daini and Tokai NPS in Northeast Japan, which also were also struck by the same earthquake, and with almost the same height of tsunami on March 11, 2011. Unlike Fukushima Daiichi NPS, those plants withstood the effects of the strong earthquake and maintained sufficient robustness even though off-site power was lost for a certain period of time after the earthquake. In view of the existence of the reactors which survived the Northeast earthquake disaster in March 2011, it is not true to say that the current light water reactor technology was irrevocably flawed.

It may be posited that even Fukushima Daiichi NPS may have avoided serious core damage, if preparations had been well-implemented - such as enhanced provision of portable equipment and proper emergency training. Also, if responses had been diversified based on the concept of defense-in-depth with prior practical training, the core melt accident may have been avoided.

In other words, the Fukushima Daiichi accident taught us a lesson about safety culture - that we must not be negligent in making preparations for disasters that may have an extremely low probability but lead to tremendous damage if they occur.

It is a basic tenet of nuclear safety to complement these uncertainties by developing independent and redundant layers of protection, *i.e.* the so-called "defense-in-depth" design concept, rather than relying on a single layer of protection. In U.S.A., a performance-based approach is taken (in light of risk information) in evaluating defense-in-depth measures. This is an effective way of finding relative weaknesses.

However, NRC commissioner Mr. Magwood further argued that defense-in-depth should be introduced to ensure the achievement of safety goals [13]. Without safety goals, regulators can make whatever requirements they come up with, resulting in the piling up of unlimited layers of safety requirements. Safety goals may be necessary to decide what level of measures is required and to what extent probabilistic safety assessment should be put into practical use.

3 Need for drastic reform of Japanese electric utilities for nuclear safety

It is needless to say that nuclear safety must be ensured to protect the general public, nuclear workers and the environment from radiation hazards that may occur in the course of nuclear operations.

It has been pointed out as one of the major reasons of the Fukushima Daiichi accident that the design and preparations of the responsible electric company were insufficient for extremely low-probability external natural phenomena such as large earthquakes and tsunamis. The electric company's top management is said to lack a sound philosophy of nuclear safety for dealing with nuclear issues which might cause significant risks to corporate management [5, 10, 14]. This caused a delayed response or ignorance to several precursory warning messages from both domestic and international sources about the possibility of such a major accident.

The Fukushima Daiichi accident has made the Japanese nuclear industry realize their fundamental failure in having neglected (or not taken serious notice of) the knowledge and information on preparing for floods, tsunamis, and terrorist attacks that had been experienced by nuclear and other facilities around the world. This may be ascribed to false self-righteousness of the Japanese nuclear industry in the past that their technology level was so

high that it was no longer necessary to strive for further improvement.

During the period from the Chernobyl accident until the Fukushima Daiichi accident, the Japanese nuclear industry was dormant with regards to preparing for the threat of those risks while the international community had steadily made considerable efforts to reduce risks that would pose a threat to the safety of nuclear power stations. Table 1 shows the comparison of preparedness of electric power sources, while Table 2 shows the alternative heat sinks stipulated in different countries which were reported as international best practices - and which, had Japan acted upon them, would have enabled Fukushima Daiichi NPS to survive the accident (by Carnegie Endowment for International Peace).

The reality of the Fukushima Daiichi accident made the Japanese nuclear industry finally realize how far their safety culture had deteriorated. They completely ignored the potential magnitude of nuclear hazards and fell into a trap of assuming that the "safety of light water reactors had been completely established, and it is not necessary to further prepare for the potential risks" [1, 3]. They thought it was enough to limit the safety countermeasures to within the requirement of nuclear regulations, and even worse, they resisted the tightening of regulations on nuclear safety measures so that the safety measures of Japanese nuclear power stations against severe accidents dropped to the lowest level among the nuclear countries.

In order for the Japanese nuclear industry to survive the harsh business and social situation brought on by the Fukushima Daiichi accident, they need to undertake a drastic reformation of their attitude towards nuclear safety. They have to learn with humility about good practices and useful experiences from other industries both domestic and abroad to pursue the world's highest level of nuclear safety. Above all, it is absolutely essential that the top management of electric utilities should be aware of nuclear safety and put it as the top priority of running the corporation. They should not ignore the nuclear risk from severe accidents due to the lack of accident management.

Table 1 Measures implemented before the Fukushima Daiichi accident [Power Supply]

Country	Extra Backup Power Supplies*1	Higher Ground*2	Bunkers*3	Others
Finland (Olkiluoto)	O	O	-	-
Taiwan (Chinshan,Kuosheng)	O	O	-	-
Belgium (Doel1through4)	O	-	O (#3, #4)	O*4 (#1, #2)
Germany (All plants)	O	-	-	O*5
Japan	-	-	-	-

*1-4: Extra backup power supplies are:
- reinforcement of power supplies that are designed to expressly cope with external events. (*1)
- located above the design -basis flood level for the station. (*2)
- placed in watertight bunkers. (*3)
- located in a separate "emergency systems building," that has been upgraded to be protected against external events. (*4)

*5: All German plants have at least one additional standby grid connection and more emergency diesel generators, with at least two of them being protected against external impacts.
Source: Report by Carnegie "WHY FUKUSHIMA WAS PREVENTABILE" (Mar. 2012)

Table 2 Measures Implemented before the Fukushima Daiichi accident [Alternative Heat Sink]

Country	Air-cooled Heat Exchanger	Wells*1	Reservoirs*2
U.K. (Sizewell B)	O	-	-
Netherlands (Borssele)	-	O	-
Switzerland (Several plants)	O*3	O	-
Taiwan (Chinshan,Kuosheng)	-	-	O
Japan	-	-	-

*1: groundwater wells were equipped for alternate heat sinks that would be available in the case of a severe external event.
*2: water reservoirs were installed above the design -basis flood level for the station.
*3: One plant has an emergency cooling tower.
Source: Report by Carnegie "WHY FUKUSHIMA WAS PREVENTABILE" (Mar. 2012)

However, this awareness, which may be high at the beginning, may fade away with time as a situation of uninterrupted accident-free performance continues. Even ignoring the regulatory side, an important thing that Japanese nuclear industry should always keep in mind is to discuss the practice of nuclear safety with

the nuclear industries of other countries and to keep pace with the relevant international standard - in other words, consistent self-regulation. It is a prerequisite to at least monitor world trends regarding nuclear safety and compare them with the practice of Japanese nuclear industry in order to strive for safety improvement.

This activity must be continued "tirelessly". This is one of the ideas that every Japanese nuclear industry participant will have to provide objective reviews from the outside. Accordingly, all the members of the Japanese nuclear industry including electric utilities, decided to establish an independent organization that has advanced engineering capability and discernment into nuclear safety and can make scientific and technical judgments without being affected by the specific intentions of electric utilities. This is why the independent JANSI was established with the cooperation of the whole Japanese nuclear industry. Figure 1 summarizes the objectives and activities of JANSI in order to raise the level of nuclear safety across Japan as a whole.

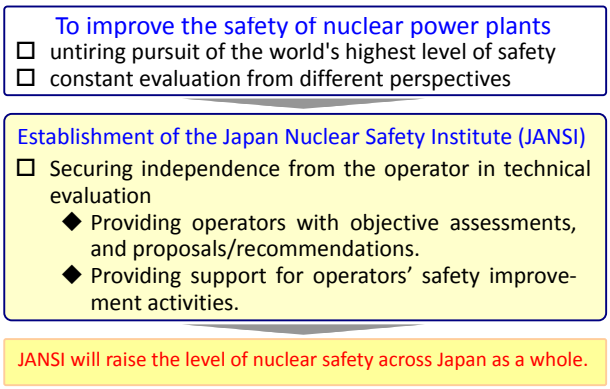

Fig. 1 Mission of JANSI.

4 Organizational design and functions of JANSI

The model of JANSI is based on the Institute of Nuclear Power Operators (INPO). In U.S.A. just after the TMI accident in 1979, the President's "Commission on the Accident at Three Mile Island" made numerous proposals to improve nuclear safety in U.S.A. [15]. These included a proposal to establish a special organization that would play a central role in dealing with various operational issues such as operator training and operating technology improvement. This proposal led to the establishment of INPO in 1979 to reflect the lesson that the TMI accident had occurred due to inadequate knowledge and skills of plant operators and management to carry out four cornerstone activities: (i) plant evaluations, (ii) training and accreditation, (iii) event analysis and information exchange and (iv) technical assistance. However, INPO did not initially have the respect of either nuclear utilities or regulatory authorities in the U.S.A. It is said that it took more than ten years for INPO to build up the respected status it presently shares in U.S.A. [16, 17].

JANSI is going to begin its own activities based on INPO as a good model. Its mission is to "pursue the world's highest level of safety in Japan's nuclear power industry" and "untiringly pursue the highest standards of excellence".

As seen in the upper part of Fig. 2, there are two pillars in JANSI's activities. One is assessing operation and management among peers (plant assessment, proposals and directions, and support activities through peer reviews), while the other is evaluating utilities' safety improvement activities in light of international trends.

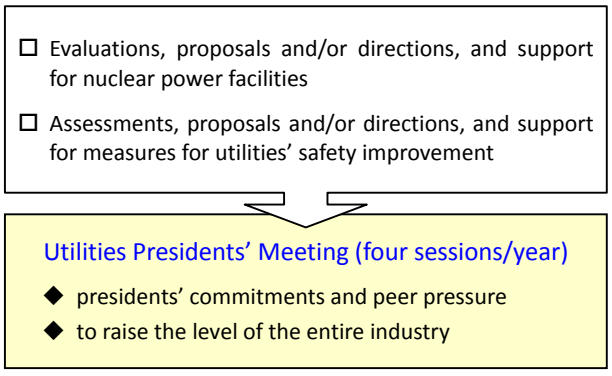

Fig. 2 Initiatives of JANSI.

In order to conduct the above pillars effectively, JANSI requires strong technical expertise and independence so that JANSI will not be affected by the values of the target utilities, in order to make proposals objectively by standing apart from the corresponding electric utilities.

Attention must be paid not only to day-to-day operation and management of the facility, but also to

the status of design and equipment as a whole, so as not to allow any plant to again reach such a bad situation as that experienced during the Fukushima Daiichi accident.

To attain this purpose, all the staff of JANSI requires the ability to understand about electric utilities' operation and management skills, plant manufacturers' design technology, and the state-of-the art technology of nuclear safety research from an international perspective. JANSI will therefore have many internal and external staff that has close coordination with other organizations and researchers.

As shown in the lower part of Fig.2, another feature of JANSI is that it has developed a mechanism to have direct communication with the top management of electric utilities. This is expected to accelerate the implementation of safety measures, promote a sense of responsibility, and share safety issues that have been dealt with by individual companies.

The three key features in the activities of JANSI are introduced in the subsequent sections of this chapter.

4. 1 Commitment of Top Management

Admiral J. Ellis, former CEO of INPO, pointed out at a lecture at Georgia Tech in 2011 that the key to organizational success is the commitment of top management [18]. The success of JANSI's activities will also depend on the commitment of the top management of electric utilities that are responsible for nuclear safety.

Accordingly, JANSI, modeling itself on INPO, has decided to gather utilities' presidents in a venue to draw out the active commitment of the top management of electric utilities by reporting the results of safety reviews of utilities' power stations and to propose necessary improvement measures. This opportunity is expected to encourage individual presidents to question the reviews, discuss with each other on support measures, and make active commitments to implement improvement measures proposed by JANSI. It is also expected that company-wide efforts will be made with top management's direct involvement for the safety of nuclear power generation.

4.2 Peer reviews centering on reviewing and supporting activities

JANSI will periodically conduct peer reviews about the operating status of each power station to evaluate its operating experience and equipment conditions, the soundness of safety culture, and activities to make improvements in comparison with best practices, and make proposals to raise the level of safety.

Moreover, in view of the implementation of safety improvement measures and the results of peer reviews, JANSI intends to conduct various activities such as (i) comprehensive evaluations of the safety level of each power station in Japan based on the latest knowledge, (ii) presentation of the results to utilities, (iii) supporting utilities' activities, and (iv) raising the level of safety by providing industry-wide support, in particular for those power stations whose performance shows a trend towards degradation.

JANSI believes that a certain period of time will be required until full-scale operation because the quality of the peer reviews that will serve as input for evaluation needs to be enhanced, the method of evaluation needs to be decided upon to obtain the utilities' acceptance, and these need to introduce gradually through experimental stages.

To achieve all this, it is necessary to pay close attention to world-class levels and gain full understanding of best practices including their background, through reciprocal visits. Communication ability to exchange opinions freely is also required. The development of this kind of communication ability will also be needed for JANSI staff.

4.3 Active introduction of overseas knowledge

JANSI thinks it is necessary to promote active coordination with overseas experts and organizations, so as to constantly pursue the latest knowledge about overseas nuclear safety that has been belatedly introduced to Japanese utilities due to the lack of quantity and quality of information, and to provide utilities with reviews and directions for activities to

improve safety based on such knowledge. In the light of its mission JANSI should also accomplish this internally. The raison-d'être of JANSI cannot be established unless JANSI has built up more expertise and insight than the utilities. It is also necessary to verify that JANSI's proposals/directions are not inconsistent with the state-of-the art knowledge.

Accordingly, JANSI intends to develop proposals that will lead to the improvement of nuclear safety from a comprehensive perspective by promoting coordination with overseas experts, paying special attention to the areas of seismology and seismic engineering, probabilistic safety assessment, safety analysis of severe accidents, emergency preparedness, and physical protection, because so far nuclear experts of electric utilities in Japan remain at a relatively low position and have had limited opportunities to deepen their expertise.

5 Present activities and human resource development at JANSI

At present, JANSI's activities center on reviewing activities, making directions and providing support through peer reviews, review of safety improvement measures, and making directions and providing support mainly with regards to severe accident measures.

For those activities to be effective, a relationship of mutual trust must be developed between the reviewer and reviewee. This begins with mutually recognition of the ability of the other party. The reviewer needs extensive knowledge about overseas good practices and deep insight into the nature of the problems the other party has.

It is also a challenge for JANSI to build a network of connections with overseas organizations and overseas experts on a daily basis, and to establish a relationship in which overseas safety information can be obtained constantly in the same way as domestic information. To build such a relationship, JANSI staff must first show their enthusiasm, passion, conscientiousness and respect as well as sharing information and a sense of fellowship to be accepted by the other party.

In any case, a high sense of responsibility and ceaseless efforts are essential. It is challenging to work out how to secure and develop human resources who possess such qualities, how to secure personnel who are carved in lessons concerning nuclear safety so as to make use of Japan's nuclear power, and how to build up the sound safety concept which takes root in the top management to make them focus on accident management for severe accidents as significant risks to the existence of the company.

6 Conclusion

Nuclear power generation is a very complicated system in terms of operating equipment as well as operating organization. The highest level must be pursued for the overall system. At this moment in the initial stages of JANSI's development, accomplishing the highest level is far from sight. However, the path towards the highest level begins to become visible.

Commitment of top management is indispensable. We should be aware that there is always a risk that we will fall into the pitfall of being satisfied with small improvements. To maintain an attitude of constant questioning is essential. All we must do is to continue making efforts for the best in terms of technology and organizational management. We believe such efforts will be socially acknowledged by the public, which will be the first step toward social confidence in nuclear power generation.

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