Lessons Learned from Fukushima for PSAM Community: Leadership and Responsibility to Assess and Inform Risk for Safety Assurance

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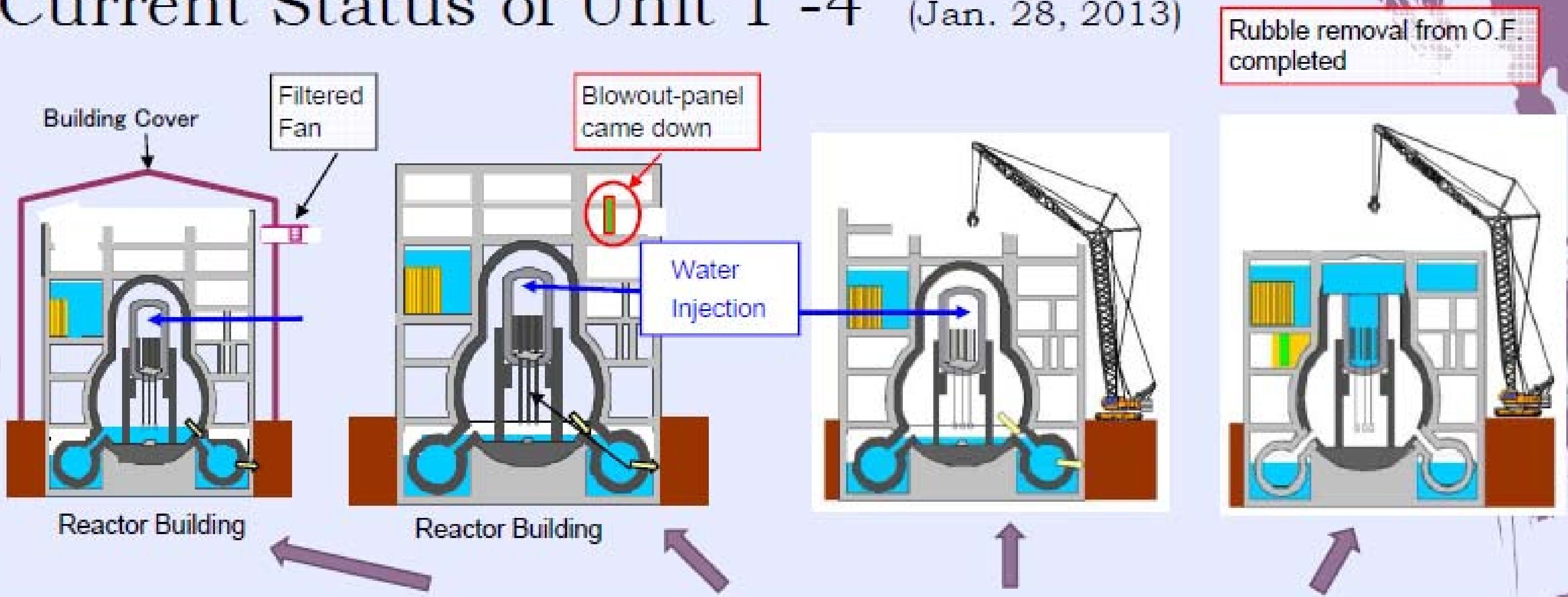
On March 11, 2011 the Great East-Japan earthquake and the resulting tsunami hit people and facilities including nuclear power plants located on the Pacific coast of Japan.

Nightmarish Events At the Plant

- The plant was hit by Magnitude 9.0 earthquake and 15 m tsunami.
- A loss of all off-site power and on-site power left the unit 1-4 without any emergency power.
- The resultant damage to fuel, reactor, and containment caused a release of radioactive materials to the region surrounding the site over an extended period of time.
- Emergency response activities were executed in high radiation environment without any power supply, using roads on which the residue of tsunami and that due to hydrogen explosions in reactor buildings (RBs) housing units 1, 3, and 4 were scattered.

Current Status of Unit 1 -4 (Jan. 28, 2013)



	Unit #1	Unit #2	Unit #3	Unit #4
Core Melt	Y	Y	Y	N
Hydrogen Explosion	Y	N	Y	Y
RPV Temp. (°C)	18	31	31	NA
PCV Temp. (°C)	20	32	31	NA
PCV Water level (m)	+2.8	+0.6	Unknown	NA
Dose rate O.F.(mSv/h)	53.6	880	500	1.3
# of SPF	392	615	568	1.533
SFP Temp. (°C)	10	12	9	20

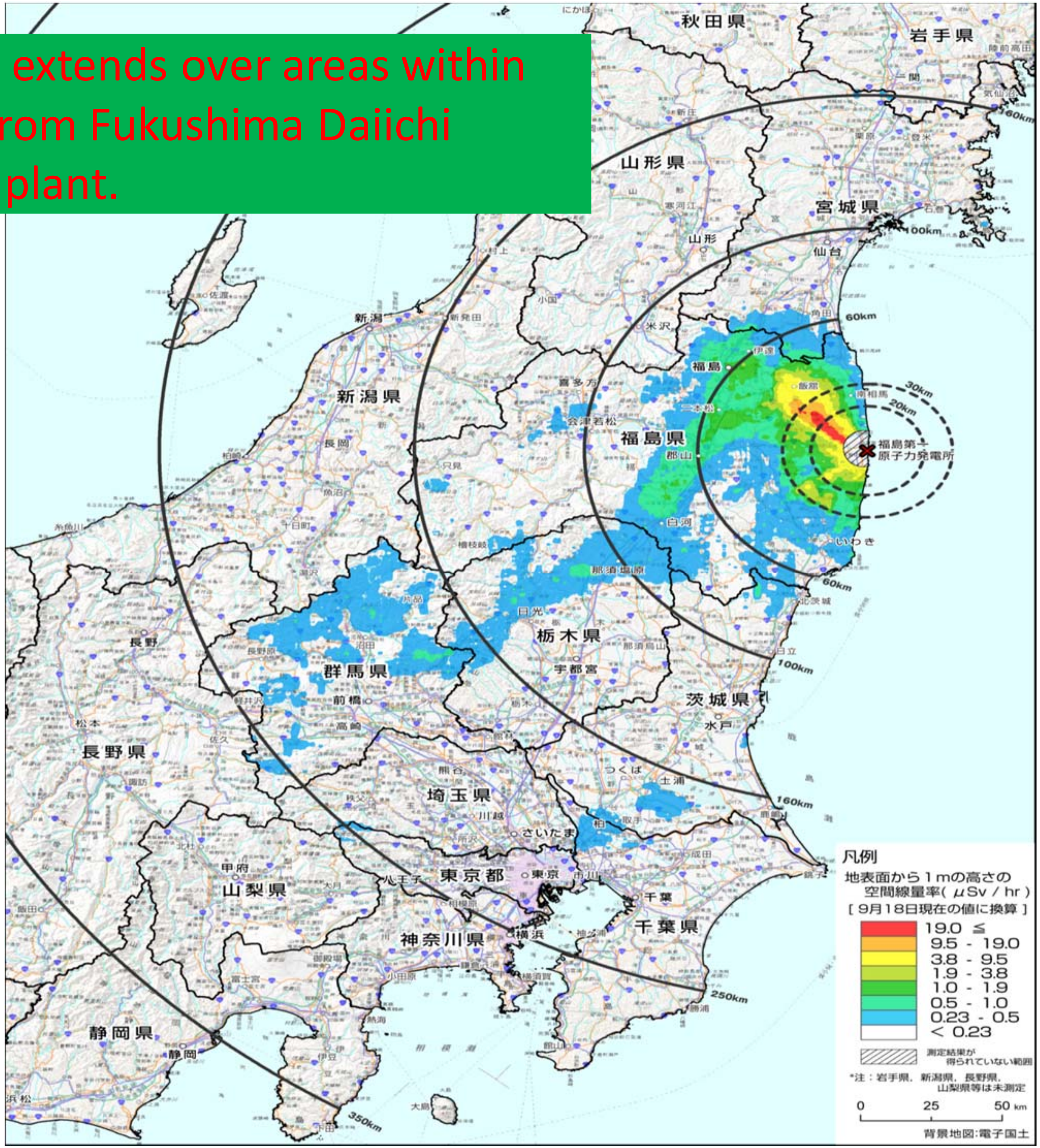
Current Status of the Site

- Major short-term challenges:
  - Improve the reliability of reactor cooling system.
  - Manage accumulating contaminated water due to the intrusion of underground water into RBs.
  - Reduce environmental radiation dose due to accumulated radioactive wastes in the site.
  - Improve working conditions and assure human resources for cleanup activities.
- A Roadmap for Decommissioning of TEPCO's Fukushima Daiichi jointly decided by the Government and TEPCO in December, 2011 defined three phase decommissioning activities that included necessary R&D projects, as well as efforts to meet major short-term challenges:
  - Phase 1 to commence fuel removal from spent fuel pools within 2 years:
  - Phase 2 to commence fuel debris removal from RPVs within 10 years:
  - Phase 3 to complete the decommissioning process within 30 to 40 years.

Major R&D Projects

- Develop various robots and remote manipulation devices for cleanup activities:
- Develop equipment/device to observe the fuel/debris in RPVs and PCVs, and characterize them with a view to preparing for their removal.
- Develop robust models and simulation tools for the analysis of severe accidents, focusing on post accidental heat removal, coolability of relocated reactor core, in-vessel core melt progression, in-vessel molten corium retention, molten-core-concrete-interaction, and corium stabilization in containment:
- Develop technologies for conditioning and storing radioactive waste generated in these activities.

Contamination extends over areas within about 250km from Fukushima Daiichi nuclear power plant.



Off–Site Consequences

- Some 80,000 people are still requested to be out of home and about the same number of peoples have made choice to leave home. They are suffering from a psychological agony due to the fear of radiation exposure, separation of family, disruption of communities etc.
- Though anyone has not been hurt by the radiation so far, the accident has caused several hundred deaths due to the worsening of diseases owing to dislocation, including emergency evacuation from hospitals, and/or stress in the life in a shelter after dislocation.
- Production of agricultural and marine produce is still restricted depending upon circumstances. In addition, the sales of the products from Fukushima Prefecture have plummeted due to consumer fear, even though they are not contaminated.

Off–Site Consequences (Cont'd)

- In the areas where additional exposure is less than 20mSv/y, the Government is supporting the decontamination of people's living environment with a view to reducing estimated annual exposure of people by 50 % and that of children by 60 % in 2 years.
- In the areas where additional exposure is higher than 20mSv/y, in which 11 municipalities are located, the Government is promoting decontamination to reduce annual exposure there below 20mSv/y in two years, excluding areas where doses are higher than 50mSv/y.
- The Government is making utmost efforts to start the operation of Interim Storage Facility(s) that will store 15-28 million m^3 waste generated by these decontamination activities.
- Three municipalities have decided, however, that they would not return to hometown in five years, appealing for the uniform remediation of whole area. One of the biggest issues in this respect is the appropriate measure for and level of decontamination of forests that cover more than 70% of the areas.

Communication of Risk of Radiation

- Almost all of off-site and on-site activities necessarily involve issues related to management and communication of risk of radiation exposure among people and parties concerned.
- The Government has established safe levels of radiation exposure below which the situations may be considered relatively harmless.
- However, the Government has decided to present them with a caveat stem from a linear non-threshold model adopted in radiation protection.
- This caveat has caused psychological effects on people living in the environment where radiation level is higher than before the accident, even if it is below that at some areas of Europe or USA.

A big PSAM issue got to our heart!

Publication of Various Accident Investigation Reports

- *The IAEA International Fact-Finding Expert Mission*
  - There were insufficient defense-in-depth provisions for tsunami hazards.
- *The Independent Investigation Commission of RJIF (NPO)*
  - The crisis was essentially a man-made disaster caused by TEPCO's systematic failures and weaknesses in the government's regulatory regime.
- *The Government's Investigation Committee*
  - The government and TEPCO failed to prevent the disaster because they were reluctant to invest time, effort and money in protecting against a natural disaster considered unlikely: they were overly confident that events beyond the scope of their assumptions would not occur.
  - A culture of complacency about nuclear safety and poor crisis management led to the nuclear disaster.

The Past Role of PSAM Community in Japan

- Most investigation reports judged that though the accident was triggered by a massive force of nature, it did unfold as such due to existing weaknesses regarding defence against natural hazards, regulatory oversight, accident management and emergency response.
- PSAM community in Japan has recognized all the time that the effectiveness of these measures in making sure that the occurrence frequency of severe accident is low enough could be ascertained by the use of PSA.
- PSAM community in Japan should make a new start, answering for the results before us and appreciating various lessons in these reports.

Report of NAIIC

- *National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission (NAIIC) chaired by Dr. Kurokawa*
  - The accident was clearly "manmade." It was the result of collusion between the government, the regulators and TEPCO, and the lack of governance by said parties. They supported faulty rationales for decisions and actions and effectively betrayed the nation's right to be safe from nuclear accidents.
  - What must be admitted - very painfully - is that this was a disaster 'Made in Japan'. Its fundamental causes are to be found in the ingrained conventions of Japanese culture: our reflexive obedience, our reluctance to question authority, our devotion to 'sticking with the program', our groupism and our insularity.

Where We Are Today

- The release of such judgment made it difficult for the Government to allow nuclear power plant operators to restart their plants after introducing emergency measures to cope with the tsunami attack, directed by the regulator at that time, NISA.
- The Government decided to wait the action to be taken by the Nuclear Regulation Authority, NRA, a newly established independent commission body that solely exercises regulatory authority in the field of nuclear safety and security in Japan.
- The Government is expecting the restart of the operation of idling nuclear power plants, after satisfying the new safety regulation rules to be set by the NRA before July, as an important power source.

My Interpretation of Dr. Kurokawa's Verdict

- For us all in the nuclear enterprise, we play a role in the enterprise, and we know that our roles require us to act in a responsible manner, never betraying the nation's right to be safe from nuclear accidents.
- Dr. Kurokawa's verdict is asking us do what we should do at the right time in a right manner, never betraying the nation's right to be safe from nuclear accidents.

Safety: State Without Failure?

- In 1980s, regulator, when reported by an operator a failure of safety-related SSCs, requested all the operator that the recurrence of such failure should be prevented by stringent Total Quality Control (TQC) activities.
- The top management of operating companies then asked workers to strengthen *Kaizen* activities on the spot. This was the reason why the scram frequency and fail-to-start probability of EDG of Japanese plants had been extraordinary low in the 1980s: proudly spoken story, it was.
- It was gradually recognized in this culture that safety was a state without any failure in fact. Such culture, however, did not motivate regulator, who had been trained based on deterministic regulation that is represented by design-basis events and single failure criterion, to be anxious about risk-information against beyond design events, which information can be obtained by making the most of PSAs.

Voluntary Nature of Severe Accident Management (SAM)

- After Chernobyl accident, nuclear safety regulator was wavering how to expand its scope to the realm where severe core damage and PCV venting are examined, co-opting risk-informed approach PSAM community proposed with a view to pushing the cliff-edges further away.
- As a compromise, regulator agreed in 1990 or so to introduce severe accident management capability as a voluntary initiative of the industries under the condition that the PCV venting should be delayed as practicably as possible and the inadvertent venting should be prevented reliably.
- Operators developed SAMGs that put emphasis on delayed venting and requested the insertion of rupture disk in the venting line and implemented necessary equipment and training before 2000.
- *In retrospect, a relation between the choice of delayed venting strategy and the accumulation of hydrogen in PCV, of which leakage into Reactor Building caused the hydrogen explosions at Fukushima, should have been studied more thoroughly.*

SBO Events in SAMG

- Operators prepared SAM procedures to cope with the station blackout (SB) of which duration was less than 8 hours, emphasizing high reliability of AC power at multi-units sites equipped with both double off-site power transmission lines and double EDGs and extensive features to cross-tie and share electrical power sources among the units, in addition.
- PSAM community in Japan should have not missed the opportunity to induce regulator and operators, *recognizing the significance of the event at Blayais NPP in France and others,* to review the significance of a disproportionate increase in consequences from SBO sequences of longer duration caused by external natural events or human malicious activities (cliff-edge).

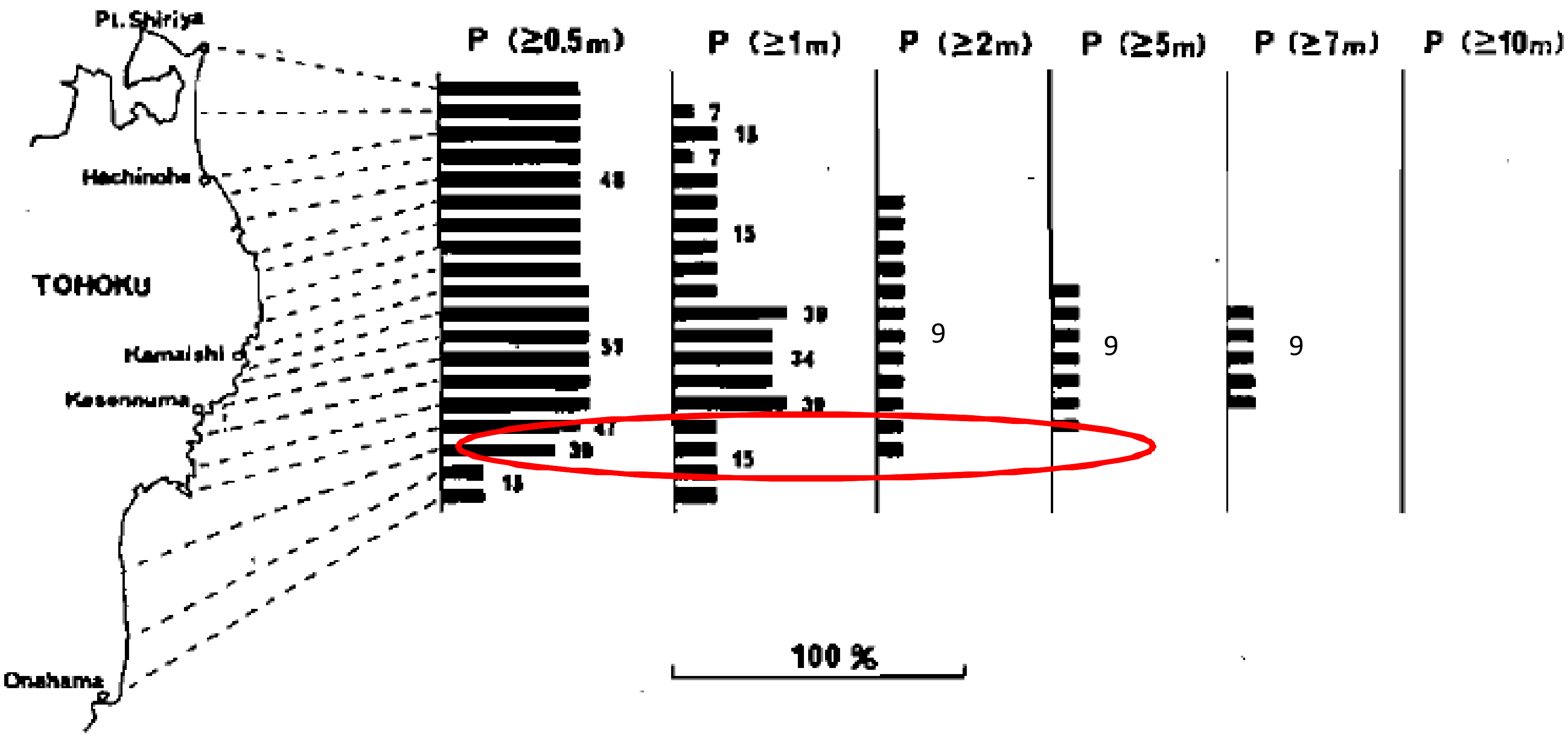
Trust Crisis: Lack of Guardians For Voluntary SAM Initiatives

- After 2000 or so Japanese society experienced large scale earthquakes, several large-scale blackouts due to strong typhoons (though no LOOP at NPPs, fortunately) on the one hand, and several fail-to start of EDG events at NPPs owing to the introduction of new designs, on the other. At least these should have been reflected in PSAs in the second round Periodic Safety Review (PSR) activity.
- However, regulator and operators became busy in dealing with the discovery and acknowledgment of various data falsification events not only at NPPs but also at other EPPs. This events brought regulator to a crisis of trust on operators at the depth of its consciousness.

Regulator tended to solely request operators to prevent error and to pay low attention in the second round PSR in which SAM strategy should be reviewed again based on external (seismic) PSA this time.

Tsunami at Fukushima

- Prediction of tsunami height at Fukushima coast before 1990 was quite modest as shown in the Figure below that gives probability for the Pacific coast of Tohoku being hit by a tsunami of which wave height exceeds specified values during a period of 2000 to 2010 estimated by T. Rikitake (1987):



Tsunami at Fukushima (cont'd)

- The Headquarter for Earthquake Research Promotion (HERP) of Ministry of Education Culture, Sports, Science and Technology (MEXT) published in 2002, an evaluation that the occurrence probability of tsunami earthquake of M8.2 along the Japan Trench off Fukushima coast in 10 years is 7%.
- Recognizing that the severity of tsunamis expected by this earthquake would be significant, tsunami experts started to estimate it. In 2008, calculations in which a tsunami source similar to that of Meiji-Sanriku-Oki earthquake was assumed at off Fukushima coast resulted in a maximum tsunami height of sea level plus 15.7m at the Daiichi site.
- TEPCO's Top management, however, decided to postpone the consideration of mitigation measures to the flooding to be caused by this height of tsunami, asking a tsunami expert group of Japan Society of Civil Engineers (JSCE) to review the validity of this assumption.

It was too late!

- Regulator recognized in the seismic design evaluation rule revised in 2006 that licensed plants had non-zero seismic risk even if they could withstand design basis earthquakes, and requested licensees to confirm the residual risk is sufficiently small by seismic PSAs.
- This change induced regulator and operators to be vigilant in reviewing the contents of the debate held in the academic circles related to earthquake and tsunami.
- It was too late, however: the "predicted tsunami" came before proper actions were taken, and emergency procedures based on the unprepared SAMG were not sufficient to mitigate the consequences of a prolonged loss of AC and DC power caused by the flooding due to tsunami.

What PSAM Community in Japan Should Do?

1. Recognize the importance of professional leadership in nuclear organizations that manage potentially hazardous activities to maintain risk to peoples and the environment as low as reasonably achievable without compromise, thereby assuring stakeholder trust.
   - Only leaders can cultivate a questioning attitude and challenging assumptions, make decisions based on a safety-first principle and deploy resources based on the consideration of risks associated with the activities.
2. Overcome Japanese insularity, actively participating in international gatherings and dialogues and making best use of operating experiences and information shared in international society:
   - Receive constructive challenges to their approaches by those with diverse viewpoints and perspectives in the international community
   - Consider capable scenarios in Japan that bring about the same consequences in foreign countries, and take action to strengthen defenses against such vulnerabilities.

What PSAM Community in Japan Should Do? (cont'd)

3. Periodically redefine design basis external events in risk-informed manner, using methodologies and data available that are well vetted and have a strong consensus of experts in relevant fields.
4. Ensure the existence of a robust capacity to protect against a beyond-design-basis accident, often in a form of an additional layer of protection to prevent a severe accident regardless of the initiating event. Make sure, however, the objective to do so is to make the risk as low as reasonably achievable through a prudent combination of defense-in- depth and risk insights, but not to strengthen defense-in-depth approach itself.
5. Develop new SAM strategies and their implementing guidelines and emergency operating procedures that are consistent with the safety objectives in collaboration with international community, and completely master them. Decision to deviate from international professional consensus should be made only after rigorous technical reviews.

Reflection

- As the ultimate responsibility for the safety of a nuclear power plant rests with the operating organization, the operating organization should establish, under top management leadership, a strong safety culture to maintain risk to peoples and the environment as low as reasonably achievable by prevention and mitigation, and retain a competent, fit and fully trained staff, thereby assuring stakeholder trust.
- There is no credible nuclear industry without a credible regulator. Regulator must have the independence to make regulatory decisions that are open, effective, efficient, realistic, and timely; and the authority to implement them. As its mission is to enable industries to use and manage nuclear fuels for beneficial purposes in a manner that protects public health and safety and the environment, regulator should conduct its business in a transparent and predictable manner, enabling stakeholders to contribute ideas and expertise so that its decisions can be made with the benefit of information from a wide range of stakeholders.

Leadership and Responsibility of PSAM Community to Inform Risk for Safety Assurance*

- PSAM community should recognize that risk information its supplies is vital for regulators and operators to fulfill their mission of assuring safety of a system in a responsible manner.
- Key questions PSAM experts should answer to prepare risk information are "What can happen in and to the system?" "How likely is it to happen?" "What are its consequences, given that it occurs?" and "What an impact does a change in the system have on these answers?
- As it is not possible to test the system in all conditions to answer these questions, PSAM experts rely on models, both continuous and discrete event ones that have been supported by test data and expert judgment.
- PASM experts should present their answer in the form of risk curves including uncertainty in frequencies, comprehensively treating model and parametric uncertainties and executing sensible sensitivity studies.
- You should ascertain that your answer would be useful for decision-makers to make rational decisions, including that on changes, in the <u>risk management of the system</u> for the benefit of human society.

* This page was revised after presentation.


IAPSAM & AESJ
Organizing Committee
Technical Program Committee
Dedicated Individuals
Their Organizations
Participants
Thank you!

Probabilistic Safety Goals

- A risk assessment, and PSA, in particular, is an important step in activities to maintain risk to peoples and the environment as low as reasonably achievable or practicable, thereby assuring stakeholder trust.
- The outcome of a PSA is a combination of qualitative and quantitative results.
- Probabilistic Safety Criteria (PSC) are often used for the interpretation of quantitative results and the assessment of their acceptability.
- Strict use of PSC is usually avoided, however, as there are a large number of different uncertainties in a PSA model and a lot of changes in PSA results over time due to scope extensions, method development, or increases of level of detail.
- That said, PSC are valuable tools for the interpretation of results from a PSA, and they tend to enhance the realism of a risk assessment, which is a key step in risk management.

B.5.b Requirements

- In the aftermath of the 9/11 terrorist attacks, the NRC moved quickly to ensure that safety margins would be maintained under extreme conditions like fires and explosions. The so-called B.5.b requirements do provide extra margin for preventing, minimizing and managing reactor accidents.
- Dr. Nils J. Diaz said at ICONE19 in October 2011 that B.5.b-type safety enhancements, if effectively and timely implemented in Japan, should have mitigated the events facing the operator of the Fukushima Daiichi reactors, and very specifically dealt with “station blackout” and cooling of core and fuel pools.
- Japanese regulators were briefed by the USNRC on the move but did not take any action. Operators also had not done any assessment of security threats at NPPs that might lead them to provide margin for maintaining safety under extreme conditions such as a prolonged station blackout after Aum attack and 9.11.

Multi-units Site

- As safety goals are usually defined in terms of frequency of exposure around the site higher than a threshold value per site-year, it is required that in the case of two unit site,
  - The frequency of the releases from one unit that brings about such exposure should be less than half of the goal frequency, if such releases from a unit occurs independently, and
  - If the simultaneous releases from two units are probable, the frequency of the release that brings about exposure higher than a half of the threshold exposure from each units should be less than a small fraction of the goal frequency.
- Therefore in the case of multi-unit site, we should carefully check smallness of the occurrence probability of simultaneous large releases from multiple units, especially in the case of external events such as earthquake and tsunami that induce common cause failures as initiating events, as well as making effort to reduce the CDF of each unit.

Data Required for Evaluation of Geological, Seismological, and Engineering Characteristics

Appendix A to Part 100--SEISMIC AND GEOLOGIC SITING CRITERIA FOR NUCLEAR POWER PLANTS

- Vibratory ground motion based on PSHA and reference probability of 10-5 per year.
- Tectonic surface deformation to determine whether surface faulting must be taken into account: when establishing the design basis for surface faulting on a site, evidence concerning the regional and local geologic and seismic characteristics of the site and from any other relevant data.
- Nontectonic deformation,
- Earthquake recurrence rates,
- Fault geometry and slip rates,
- Site foundation material, and
- Seismically induced floods, water waves, etc.