Lessons Learned From the Severe Accident at Fukushima Daiichi

- JAEC's Struggle Since the Accident -

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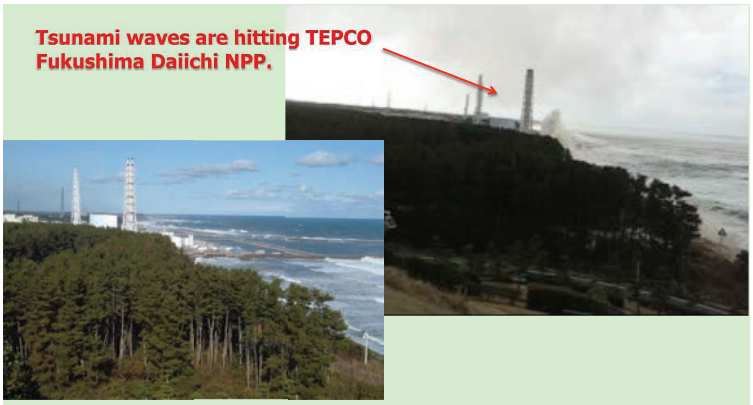
Former Chairman
Japan Atomic Energy Commission (AEC)



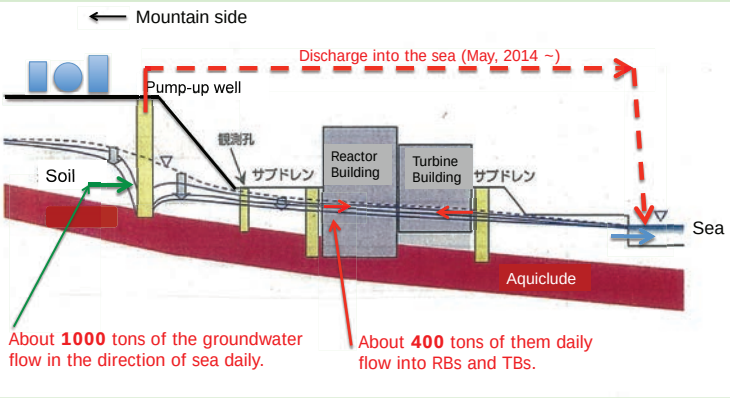
The earthquake and tsunami hit 15 nuclear power plants (NPPs) and triggered a major accident at TEPCO Fukushima Daiichi unit 1-4.

On March 11, 2011 the Great East-Japan earthquake and the resulting tsunami attacked the Pacific coast of the northeast district of Japan.

Since the Accident, JAEC Has All the Time Advised the Government, TEPCO and Other Nuclear Operators;

Actions to manage the disaster in the first place and then,

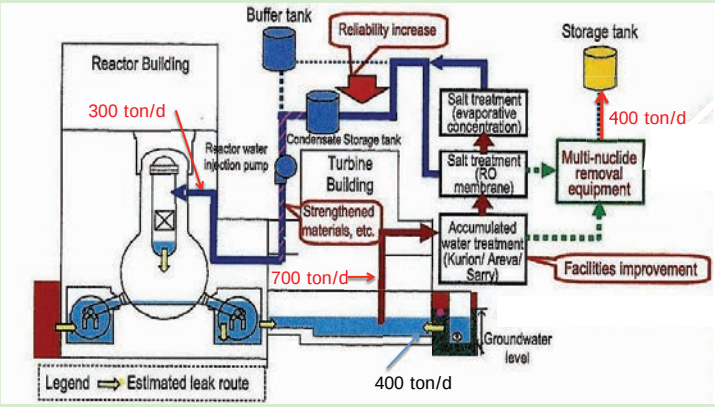
- On-site decommissioning activities
- Off-site remediation activities
- Critical review of defect in the risk management activity of nuclear community in Japan



The groundwater table (-------) and groundwater flow in the aquifer at the Fukushima Daiichi site

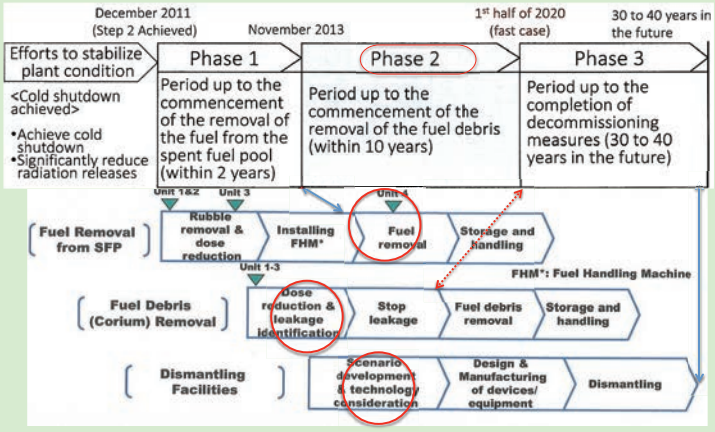
Satellite View of the Site

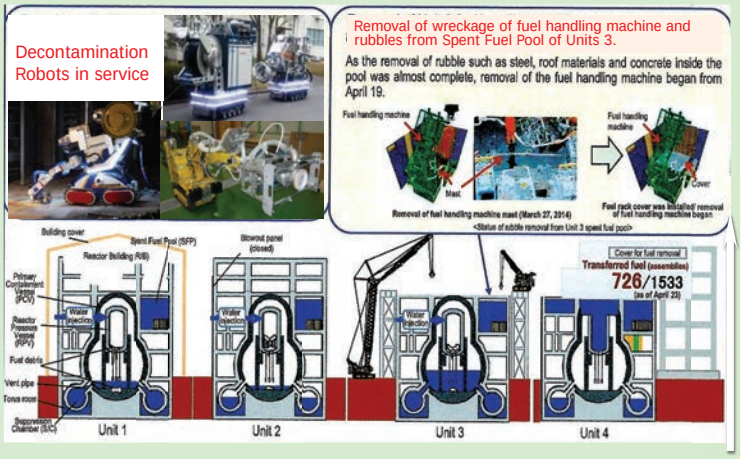
Site-wide risk management is key for sustainability!



Reactor cooling water circulation, decontamination and storage

Mid-to-Long Term Roadmap for Decommissioning Fukushima Daiichi (○ as of May, 2014)





Current status of each unit

International Research Institute for Nuclear Decommissioning: IRID

Aim:

- Conduct R&D for resolving the urgent issues concerning the decommissioning of the reactors at the Fukushima Daiichi in an effective and efficient manner.
- Develop and acquire human resources.

Current activity:

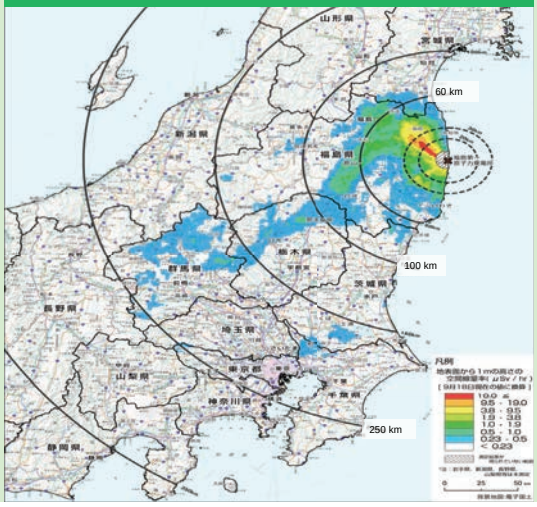
- Recently finished Request for Information (RFI) for conceptual study (C/S) & technology feasibility study (F/S)
  - Topic-A: Innovative approach for fuel-debris retrieval
  - Topic-B: Internal PCV/RPV status investigation
- Soon start RFP on the technologies identified worth challenging to C/S & F/S

Capability of Severe Accident Analysis Codes Used for Level 2 PRAs

- Benchmark to reproduce the evolution of accident at Fukushima Daiichi NPP by severe accident analysis codes MAAP, SAMPSON, and MELCOR **with a view to estimating core debris distribution in RPVs and PCVs.**

Location of Core Debris (tons at RPV/ Pedestal Floor / Drywell Floor)			
Code	Unit 1	Unit 2	Unit 3
A	72 / 88 / 0	152 / 74 / 0	144 / 82 / 0
B	0 / 91 / 89	0 / 97 / 142	0 / 58 / 164
C	---	180 / 57	156 / 88

Land contamination (>1 mSv/y) extended over areas within 250 km or so from Fukushima Daiichi NPP.



Off–Site Consequences

Evacuees

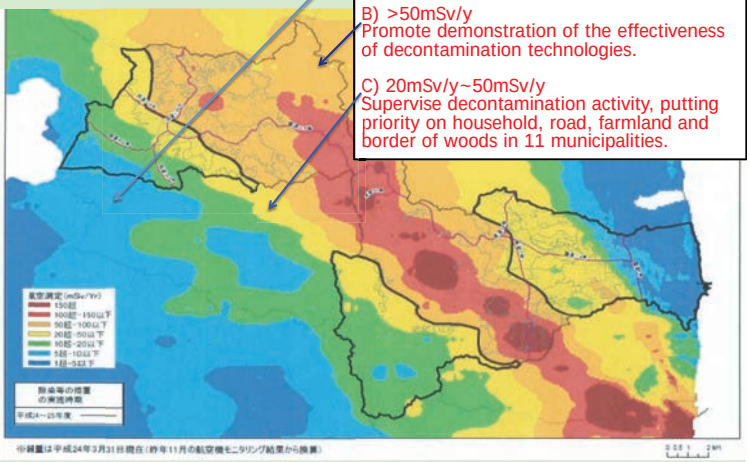
- About 80,000 people are still requested to evacuate from their home and about 60,000 people, many of whom are families with children, have left their home, having made up their own mind to do so.
- They are suffering from a psychological agony due to the fear of radiation exposure, separation of family, separation from their communities, disruption of communities, loss of work, uncertainty in the future etc.
- We should recognize that the accident has not only deprived people of their homes and lives but also destroyed their communities and caused them to feel the loss of personal pride and dignity.

Decontamination Strategy In Contaminated Area

A) <20mSv/y
Support 110 municipalities to decontaminate people's living environment.

B) >50mSv/y
Promote demonstration of the effectiveness of decontamination technologies.

C) 20mSv/y~50mSv/y
Supervise decontamination activity, putting priority on household, road, farmland and border of woods in 11 municipalities.



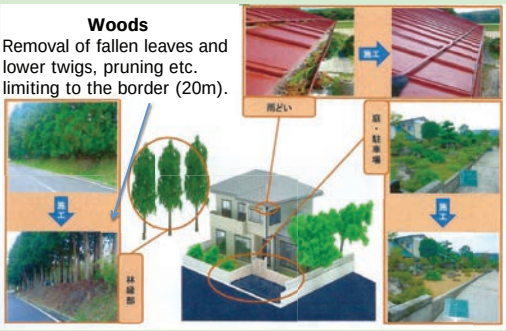
Off–Site Consequences

Fatalities Indirectly Related with the Accident

- The accident has caused 2,911deaths (Dec. 2013) due to the worsening of diseases owing to dislocation, including careless emergency evacuation from hospitals, and/or physical and psychological stress in the life in a shelter after dislocation, being separated from communities and/or families. 90% of who died were over the age of 66.

Decontamination of Houses Rain gutter, Garden, Border of Woods

Woods
Removal of fallen leaves and lower twigs, pruning etc. limiting to the border (20m).

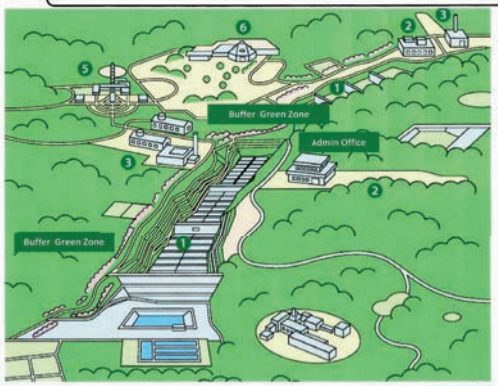


Temporary storage of decontamination waste

These activities can be started only **after agreeing with the residents** on the methods of decontamination of their houses and gardens and the place for temporary storage of decontamination waste to be generated as a result.

ISF: Interim Storage Facility

ISF will be consisted of facilities with various functions



①Storage Facility

②Emplacement & Segregation Facility

③Volume Reduction Facility

④24-hour monitoring Equipment(placed in several points, not specifically indicated in the figure)

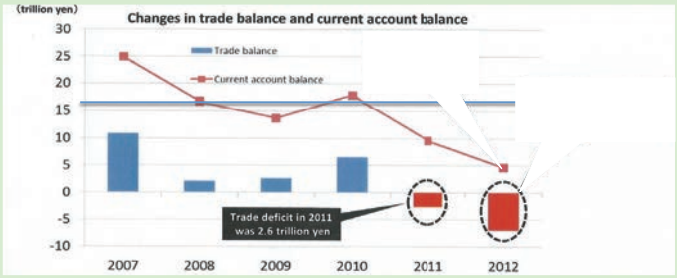
⑤R & D Facility

⑥Public information Center

Scale of the whole facility (estimation)
Total storage volume ranges between 15-28 million ㎥, which is 12-23 times big as a baseball stadium(approx. 1.24million ㎥)

Shutdown of Nuclear Power Plants

- A raise in the electricity rate
- 26% increase of CO_2 emission in electricity generation sector (about 8% increase in total) over 2010.
- Deterioration of trade balance due to increase in fuel import



Economic Impact

The agricultural and fishery businesses

- They are still banned in the neighborhood of Fukushima Daiichi.
- The sales of products from Fukushima Prefecture are still damaged in general due to consumer fears, though they are not contaminated as competent authorities restrict the trade of contaminated products, adopting the most stringent standard for food and water in the world.

Tourism in Fukushima

- Its sales had reduced more than 90% in April, 2011: though it has started to recover since then, the level of sales is still about 80% or so of that before 2011.

Verdicts of Various Accident Investigation Teams

- Various accident investigation teams published their judgment on the causes of the accident and lessons learned.
- Most of their judgment: though the accident was triggered by a massive force of nature, it was existing weaknesses regarding defense against natural hazards, regulatory oversight, accident management and emergency response that allowed the accident to unfold as it did.

Message from the Chairman of NAIIC* Dr. Kurokawa

- Our report catalogues a multitude of errors and willful negligence that left the Fukushima plant unprepared for the events of March 11.
- What this report cannot fully convey is the mindset that supported the negligence behind this disaster.
- 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, reluctance to question authority, devotion to 'sticking with the program', groupism and insularity.

*** National Diet of Japan Accident Independent Investigation Commission**

A "Manmade" Disaster

- The accident was the result of **collusion** between the government, the regulators and TEPCO, and the lack of governance by said parties. Therefore, we conclude that the accident was clearly "**manmade**."
- The nuclear regulators lacked the expertise and the commitment to assure the safety of nuclear power: their independence from the ministries promoting nuclear energy and the operators was a mockery: they were in the state of **regulatory capture**, in which the industry had too great an influence over the regulator.

Responses

- The Government established a new nuclear regulatory organization, Nuclear Regulation Agency (NRA), unifying two nuclear regulatory organizations and completely separating it from the administrative organization for promotion of nuclear energy.
- AEC asked all individuals and organizations performing or overseeing activities involving nuclear materials in Japan to promote a positive safety culture, recognizing past defects.

Continuous and Self-imposed Drive for Reducing Accident Risks

- AEC also asked to persistently promote a continuous and self-imposed drive for reducing accident risks as low as reasonably practicable, fully recognizing;
  - the psychological agony of evacuees and socio-political and economic disruptions we have been observing as the consequence of large releases.
  - the reality that even events that do not have extensive radiation-related health consequences can impose grievous damage.

Quality First Culture Distorted the Perception of Safety

- Promotion of QC circle activities, i.e. Kaizen activities in nuclear industry in 80's, which resulted;
  - Low scram frequency
  - Low fail to start probability of EDGs
  - Low defective fuel element rates
- The success gave rise to nuclear safety myth: a trouble-free nuclear power station designed based on DBEs is safe.

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Lack of Vigilance: Captured by Quality: Deficiency in the Diversity of Expertise

- ✓ Long hour power supply suspension events due to a large scale transmission line failure caused by typhoon occurred in 1991, 2002, 2005 etc.
- ✓ No action was taken to revise this guideline: the investigation team for these failures concluded "they were caused by the defect in the quality of pylon construction processes" and **proposed the check of others**. They cared about quality but not risk from global warming.

Complacency

- Guideline 27 of L-DS-I.0 (NSC) requires safe shutdown and proper cooling of the reactor after shutting down can be ensured in case of a short-term total AC power loss. The duration for a short-term AC power loss should be 30 minutes.
- The commentary on this guideline explains that no particular considerations are necessary against a long-term total AC power loss because the repair of troubled power transmission line or emergency AC power system can be expected in a short time, **according to the track record.**

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Reflexive Obedience / Sticking with the Program?

- **Hanshin-Awaji Earthquake in 1995**
  - ➢ The validity of design basis earthquakes for nuclear power plants became a critical issue in public domain and therefore a major regulatory concern: promotion of IPEEE was put aside:
- **9/11 terrorist attack:**
  - ➢ Quickly deliberated measures for preventing such unlawful acts: increase in security, increase in the severity of its punishment etc.
  - ➢ The discussion of vulnerability and mitigation measure was not done, being afraid that such action would cut through the psychological and political fogs that surround this disgusting issue for the nation: reflexive obedience?

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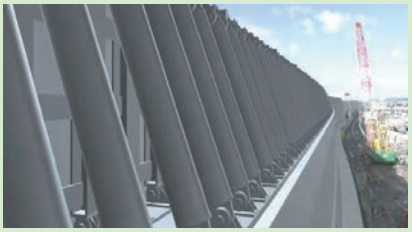
- Defect in Mindfulness to Unexpected -

- When TEPCO's expert obtained inundation height of 15.7m in one hypothetical case study, the CNO were embarrassed and ordered to consult with JSCE expert group since
  - It had been previously thought that subduction zone off-Fukushima coast could not generate megaquakes. It was just a few years before the Great East Japan earthquake hit Japan, the seismological community had accepted that all subduction zones of sufficient length could generate megaquakes.
  - No tsunami residue was found around the site.
- The CNO should have been attentive to the frontline!

Defense-in-Depth: Tsunami

Prevent – Protect – Diversify

a) Seawall designed based on design-basis tsunami
b) Water-tightness of safety-significant buildings
c) Bunkered system for essential safety function



Seawall that protects flooding by tsunami

Watertight door that prevents water intrusion into the building

The Importance of a Philosophy of Defense-in-Depth

- Occurrence of severe external events is not subject to accurate prediction or control: the design basis for a nuclear power plants can no longer be taken for granted.
- Strengthen **defense-in-depth** for preparing ourselves for **uncertainties**.
- Undertake the analysis of **design extension condition** by identifying ways to enhance the plant capability to withstand more challenging events or conditions than those considered in the design basis and ensuring sufficient margins to cliff-edge effects.

Accident Response at 1F

<Challenging Condition in Main Control Room>

Checked instrumentation in near-complete darkness.

Supervised operation wearing full-face mask.

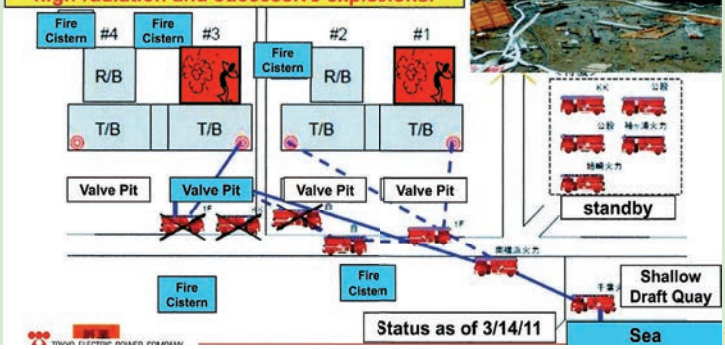
Brought in heavy batteries to restore instrumentations.

- **Lack of:**
  instrumentation, communication means, lighting, food, water, sleep, ...
- **Increase in:**
  radiation level, fatigue, fear, despair, ...

TOKYO ELECTRIC POWER COMPANY

Emergency Response at Fukushima Daiichi

- Fire trucks played critical role in injecting water into reactors and spent fuel pools.
- 24 fire trucks deployed.
- Fire brigade operated fire trucks amidst high radiation and successive explosions.



SAM and Emergency Preparedness and Response: Manage Unexpected

- **Ensure flexibility and resilience** against logistical, organizational and human challenges **resulting from unexpected harsh situations**
  - **Staffing levels for extended multi-units events**
  - Emergency response center and its organization that can provide responders with **flexible response options**
- **Assistance from off-site** in a timely manner, under the disastrous conditions on-site and off-site.
  - Make available **last recourse equipment at regional off-site response centers**, with a view to providing flexible backup in the events of extreme unexpected events.

Severe Accident Management (SAM) and Emergency Preparedness and Response

- Design SAM, taking the wide spectrum of situation caused by BDB events into consideration.
  - **Combinations of hazards** (earthquake and tsunami/ landslide, heavy rainfalls/snowfalls and high winds etc.) that cause threats triggering common mode failure of safety significant components and or multi-unit events
  - **Avoidance of CMFs due to BDBEs**: separation, diversity etc
  - **Robust and reliable instrumentation** for safety related parameters even during the severe accident
  - **Diverse and redundant communication capabilities** between plants, emergency management centers and regulators.

Emergency Plan

✧Exercise

- Essential to prove the plan workable:
- Live exercises are particularly useful for testing logistics, communications and physical capabilities and providing responders with the opportunity to practice execution of their responsibilities mentally as well as physically.

✧Off-site emergency plan

- **Support new municipalties** who became responsible for preparing an off-site emergency plan with an operator's emergency plan due to the expansion of emergency planning zone.
- Educating and instructing the population within the new planning zones: **not easy but essential for the restart**.

Site-level PRA

- **Nuclear operators should conduct multi-unit PRA** to check the effectiveness of safety improvements owing to these upgrades and check the risk is ALARP periodically.
- Challenge will be to;
  - Define the factual base for severe accident management in such harsh environment, **overcoming the apparent complexity of the messy situation to be expected**.
  - Take the interconnections and interdependencies among support systems and troubled systems into account in the assessment in such situation: these relationships may dramatically affect event consequences and the results of the assessment**.**

I sincerely hope that the **PSAM community** will continue to contribute to those who will live for humanity all over the world by **strengthening science and technology for good risk management** and promoting activities to assure relevant human resources and knowledge basis in this area.

Thank you for your kind attention!

Conclusions

- **Strong leadership** in all the institutions involved in nuclear power should ensure continuing and mindful vigilance and attention to safety/risk and continuing efforts to understand the threat and improve the resistance of technology to it.
- To address the implication of the accident at Fukushima **forthrightly and aggressively** is the condition for nuclear operating organization in Japan to survive in post-Fukushima society: hope the proverb "**adversity will make you wise**!" will be true in this case.

Prevention of Regulatory Capture

- Regulatory Capture
  - Special interest influence in the regulatory process including industry pressure to reduce the scope of regulation, though regulatory capture should not be an all-or-nothing affair.
- Prevention
  - ✓ Notice-and-comment rulemaking; transparency
  - ✓ Multiple regulators / competition among regulators
  - ✓ Consumer empowerment and the promise of diffuse Interests.
  - ✓ Diversifying the sources of expertise in regulatory decision making: requiring a diversity of viewpoints,"
  - ✓ Judicial review of regulatory decisions.

Daniel Carpenter & David Moss: Preventing Regulatory Capture; Cambridge University Press, 2014.