Strengthening safety by learning lessons from the accident at TEPCO's Fukushima-Daiichi NPP

Fukushima-Daini-1

Fukushima-Daiichi-4

Dr. Akira OMOTO
Project Professor, University of Tokyo
Commissioner, Atomic Energy Commission

Key onsite recovery actions (Stabilization phase, by 2011/E)

1. **Cooling**
   - ✓ Stable cooling to low reactor temperature

2. **Minimizing release of radioactive materials to the environment**
   - ✓ Recycling of water recovered from Turbine Building
   - ✓ Water inventory control
   - ✓ Installation of Reactor Building cover
   - ✓ Isolation of surrounding area by walls to prevent spill-over
   - ✓ Corrosion control of structures and components

3. **Minimizing residual risk**
   - ✓ Assure structural integrity of damaged Reactor Building
   - ✓ Assure reliability of power/water supply
   - ✓ Control hydrogen

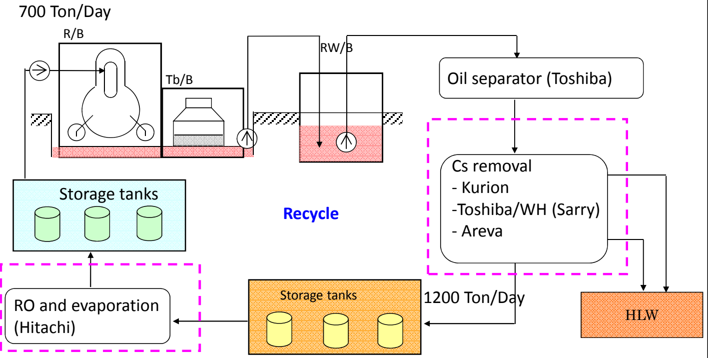
✓ ***Part I Medium- and Long-term onsite and offsite activities***

Part II Key Lessons Leaned

Part III Actions to strengthen safety

Recycling of water

Inventory control to avoid spill-over to the environment, Removal of Cs, Removal of Cloride



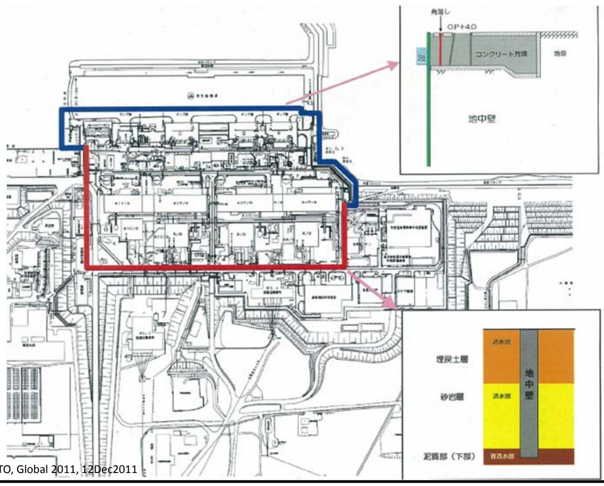
Reactor Building Cover

Beyond stabilization phase

- Planned actions
  1. Remove Spent Fuel from the Spent Fuel Pools
  2. Remove core debris
  3. Decommission
  4. Dispose generated wastes at final disposal facilities

- AEC's experts' committee on medium- & long- term plan by end of 2011
  - ✓ What are the required technologies?
  - ✓ How and who to develop?
  - ✓ Who is going to manage the overall project?
  - ✓ How long it will take?

Isolation of surrounding area by walls

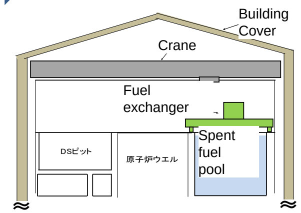


Removal of SF from SF pool

SF remain covered by water during and after the accident: sipping analysis suggests that SF is mostly intact, though some might be damaged by falling objects due to hydrogen explosion

1. Remove rubbles by crane

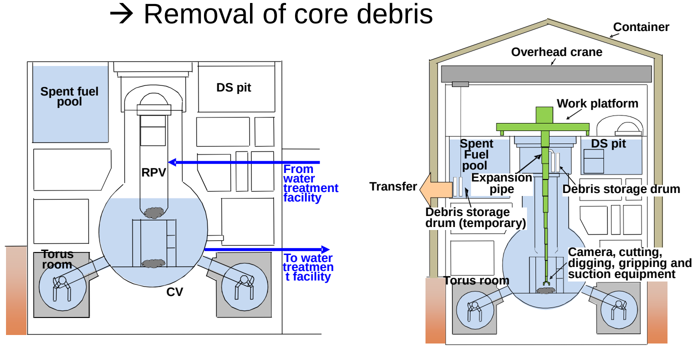
2. Install refueling machine & overhead crane



3. SF transfer by cask

Removal of core debris

Decontamination (to reduce exposure)
→ Plugging the leaky holes
→ Flooding the containment
→ Removal of core debris



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Offsite decontamination

Government announced "Basic Policy for Emergency Response on Decontamination Works " (August 26th Nuclear Emergency Response Headquarters); Specific purpose law was enacted, followed by particulars on technical standards, classification of areas

a) Zone I & II :
Government to reduce areas of dose higher than 20 mSv/yr quickly
b) Zone < 20mSv/yr: government to work with municipalities and local residents for effective decontamination, target to 1mSv/yr
c) Specific Target: 50% reduction (including weathering effect) in contamination level within 2 years
d) High priority to schools and parks and so on
e) Temporary storage of removed soil etc for later disposal

Agriculture

- ✓ 5000Bq/Kg as threshold soil contamination level
- ✓ Currently 83km2 above 5000Bq/Kg level
- ✓ Scraping surface soil (5cm) to bring contamination level to below this level in 2 years
- ✓ Removed soil for later treatment (separation of Cs-rich clay/silt)

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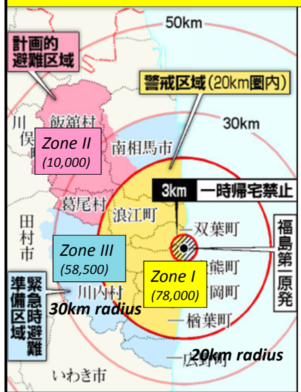
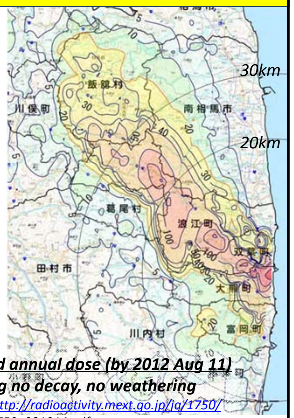
Offsite : Emergency Planning Zone and predicted first year dose



More than 110,000 evacuees



Predicted annual dose (by 2012 Aug 11)
Assuming no decay, no weathering
[SOURCE] http://radioactivity.mext.go.jp/ja/1750/2011/08/1750_081914.pdf

EPZ
Zone I (20km); "evacuation" → To be reviewed after end of Step II
Zone II (North-west): "Planned evacuation" → To be reviewed after end of Step II
Zone III (20-30km); "prepared for evacuation" → Lifted on Sept 30th, 2011

Part I Medium- and Long-term onsite and offsite activities

✓ ***Part II Key Lessons Leaned***

Part III Actions to strengthen safety

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Lessons Learned

- Government report to the IAEA (September) : update 28 Lessons in 5 specific areas (Prevention of Severe Accident, Severe Accident Management (SAM), Emergency response, Safety infrastructure, culture) and implementation status

  http://www.meti.go.jp/earthquake/nuclear/backdrop/20110911.html

Key points are;

1. Design considerations against natural hazards
2. Design considerations against SBO (Station Blackout) and Isolation from UHS (Ultimate Heat Sink)
3. Completeness/effectiveness of SAM
4. Emergency Management
5. Safety regulation and safety culture
6. Multiple unit installation
7. Spent Fuel Pool design
8. International aspects

- This presentation goes a bit further through personal deliberation and to specifics by focusing on key LL
- Need further in-depth study on root causes

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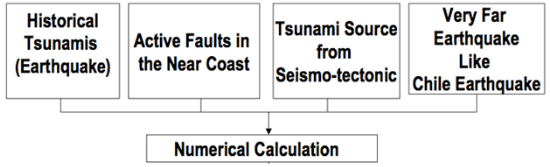
(Tsunami)

- 2002 Tsunami design guideline



- Evolution of Probabilistic Tsunami Hazard analysis
  - ✓ In late 2000's, but not considered as matured
  - ✓ Methodology guide from JSCE (2009) using logic tree to represent epistemic uncertainties
- Superposition of waves from multiple earthquakes with time delays

[SOURCE] T. Annaka, "A method of Probabilistic Tsunami Hazard analysis", 12th Civil Engineering Society meeting, 2006

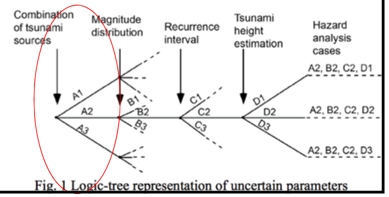


Fig. 1 Logic-tree representation of uncertain parameters

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Key Lessons Learned
A) Safety regulation and safety culture

Regulation:

✓Responsibilities not in a single regulatory body
✓Regulatory standards, Independence, competence (Government report to IAEA)
✓Decision by Cabinet (2011Aug15) on reorganization

- Transfer of NISA, NSC, and other authorities (security, transportation safety) to MoE (Environment) except for Safeguard

Regulation/Utility:

✓Focus on Quality Assurance/Compliance rather than risks (after 2002)
✓Use of risk information using Probabilistic Safety Assessment by Owner/operator to address vulnerabilities of its asset
✓Continuous improvement
[Example in hindsight] of SAM through drill and information from outside considering "Accident can happen here"
✓"Sensitivity "to safety-related issues/information
[Example in hindsight] B5b, Kalpakkam Tsunami workshop
✓ Attitude towards "uncertainties" such as on Tsunami height

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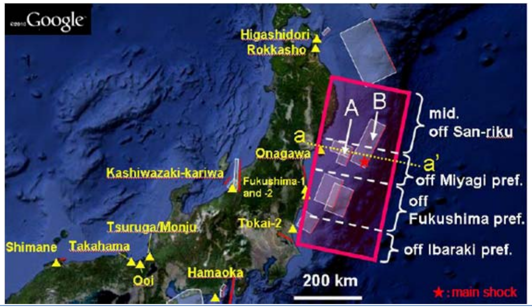
(3.11 Earthquake)



Statement by the Headquarter for Earthquake Research, 11March2011
…..but occurrence of the earthquake that is linked to all of these regions is "out of hypothesis".
[SOURCE] http://www.jishin.go.jp/main/index-e.html The 2011 off the Pacific Coast of Tohoku Earthquake

Government Report to the IAEA, June2011 : The Headquarter had alerted … but had not correctly estimated the size of the source area (400km x 200km) nor the magnitude (M9) nor the amount of slip *[SOURCE] Gov. Report to the IAEA, June2011*

Yet, some papers indicated possibilities….Prof. Kanamori (2006), Dr. Sieh on Earthquake SuperCycle (2008)

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Key Lessons Learned
B) Workable SAMG (Severe Accident Management Guideline)

14.46	Earthquake, Loss of offsite power, Start of EDG, IC/RCIC
15.38-41	Tsunami followed by Loss of AC/DC, Isolation from UHS

Given this situation, operation to avoid core damage

Short term

- Reactor water makeup by AC-independent IC/RCIC/HPCI

Require workable/effective SAM

Then, while trying to restore AC/DC power and Heat Sink

- Depressurize Reactor Coolant System by Safety/Relief Valves
- Activate Low Pressure injection systems
- Containment vent to avoid over-pressure failure

Failure of RCIC/HPCI on the 3rd and 4th day
Delayed venting, de-pressurization of RCS and LP injection

Core degradation
Hydrogen explosion

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Workable/effective SAMG (Severe Accident Management Guideline)

1. SAMG not robust enough to cover possible plant damage conditions
   → Consider
   a) integration of three Guidelines (internal event, external event and security-related event), and
   b) implementation of recovery actions in harsh radiation environment
2. Provisions of Onsite or National/Regional Nuclear Crisis Management Center for storage of mobile equipments & drill

(Supporting provision)

3. Accident instrumentation
   [Ex] What is the Water Level in the containment?
4. Prevention of hydrogen detonation/deflagration outside of the Containment Vessel
5. Simulation of plant behaviour (Real-time or faster-than-real time) as a decision aid and knowledge basis

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Limited available resources under harsh environment

Loss of communication tool (PHS) and plant safety parameters (SPDS)

1) Use of limited available resources
   - ✓ Fire Engines
   - ✓ Flashlights/Cables/Tools
   - ✓ Batteries taken from cars
   - ✓ Mobile small Generators
   - ✓ Mobile Engine-driven Air Compressors
   - ✓ Mobile pumps/motors
2) Usage limited by scattered debris/tanks
3) Field works under devastation & damage by hydrogen explosions and aftershocks




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TMI and Fukushima core uncover: estimation

	TMI		Fukushima
Day 1	00	Tb trip, Loss of FDW	00 Earthquake LOOP, EDGs start, IC/RCIC operation
	03 sec	SRV stuck open	
	3 min	HPI stop	1 hr Tsunami Blackout &loss of UHS
	100 min	Coolant circulation stop	
	174 min	B pump start (fuel collapse)	
	113-174 min	Core uncover	
	200 min	HPI restart	(1F1) (1F2) (1F3)
	224 min	Slumping to RPV bottom	(1F1) 4-15* hrs
Day 2			
Day 3			(1F3) 40 -43* hrs
Day 4			(1F2) 75 -77* hrs

*Estimated time from start of core uncover to start of successful injection

[SOURCE] Based on Gov. report to the IAEA and TEPCO May 23 report

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Lessons Learned
C) Emergency management

- Loss of communication tool and plant information at NPP
- Dissemination of information
  - ✓ Damage to social infrastructure by earthquake hampered dissemination of information to local government and residents
  - ✓ Lack of Information sharing
    - with local residents on dispersion of FP (SPEEDI) and risk of radiation
    - with neighboring countries on release of slightly-contaminated water
  - ✓ "Data but not information"
- Who is in charge?
  - ✓ Ambiguity in delineation of responsibility
  - ✓ "Why not transport mobile Diesel Generators & others by Self Defense Force"
  - ✓ Offsite center: function was lost by loss of electricity and radiation
- Effective channeling of emergency supports
  - ✓ Systematize domestic/foreign helping hands for logistics/experts

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Lessons Learned
D) Design

Gedankenexperiment

What safety design could have saved Fukushima?

1. Protection against natural hazard
   - ✓ Adding safety margin to the results of probabilistic Tsunami hazard analysis
   - ✓ Location of essential safe systems considering Tsunami/Flood
2. Plant capability against SBO and isolation from UHS
   - ✓ Highly reliable assurance of 3 cooling functions (Core, CV, SFP) including enabling systems (power/air/water source) such as backup air supply to SRV
   - ✓ Passive systems
3. SAMG (coupled with relevant design provisions)
   - ✓ Mobile equipments in onsite/offsite emergency center
   - ✓ Robust SAMG workable under internal events, external events and security-related events and drill
4. Enhanced system for aversion of "land contamination"
   - ✓ Dependable scrubbing vent
   - ✓ 2ndary containment filtration/H_2 management system

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Onsite ERC by TEPCO: seismic isolation structure

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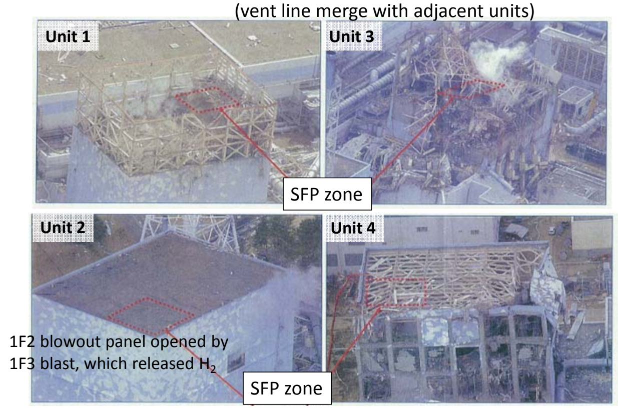
Hydrogen explosions

Hydrogen leak path 1 : Excessive leakage by over-pressure at CV flange/airlocks
Hydrogen leak Path 2: Vent line→ SGTS→R/B HVAC
(vent line merge with adjacent units)



FP escape path to the environment by R/B hydrogen explosion

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Hydrogen from adjacent unit caused Unit 4 explosion

The fact that there was no fuel in the RPV core (in preparation for shroud replacement) led to many speculations on the source of H_2

Pool
✓SF in the SFP covered by water during/after the accident
✓SFP water sipping revealed FP from recent fissions (not from Unit 4 SF)
SGTS (Standby Gas Treatment System) filter train
✓Higher FP deposition in outlet side that inlet side (suggests FP came from Unit 3)
Initiation of explosion
✓Explosion started not on the top floor (5th FL) but one floor below (4th FL) and in HVAC duct

5th floor lifted upward

HVAC duct on the 4th floor

Actions to strengthen safety

1. Global actions for strengthening nuclear power safety in post-Fukushima era would be built around the IAEA action plan (endorsed by the IAEA GC September 22)

2. In specific country and NPP
✓ Overall assessment of NPP safety and reflection of Fukushima LL in the light of principles in INSAG-12 (safety culture, defense-in-depth etc)
✓ Specific plant assessment by IPE, IPEEE and security-related events, for identifying vulnerabilities and for continuous safety improvement
✓ International peer review for comprehensiveness, objectivity and confidence building.

3. …and to restore public confidence through transparency

Part I Medium- and Long-term onsite and offsite activities

Part II Key Lessons Leaned

✓ ***Part III Actions to strengthen safety***

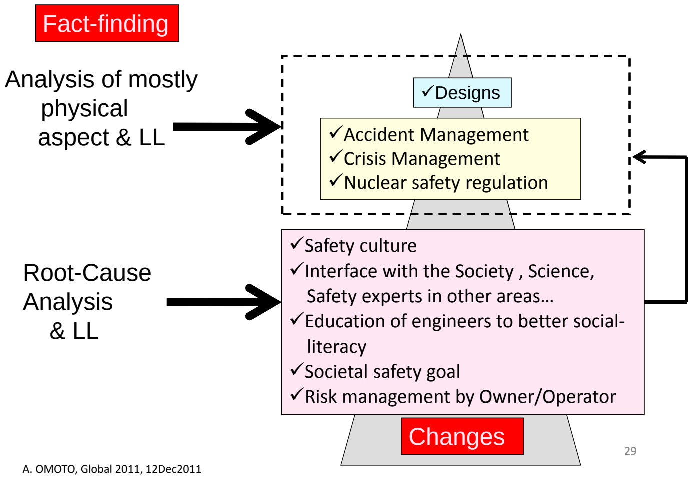
Consideration will go further to…

1. To revisit design in terms of defense-in-depth for its completeness & effectiveness, while utilizing insights from risk assessment
✓Line 1 (material selection(Zr), site selection)
✓Line 3 (protection against Common Cause Failure by natural and man-made hazard and enhanced passive safety features)
✓Line 4 (beyond-DBE capability and protection against land contamination)

2. To cooperate in building safety infrastructure in new entrants

3. To build internationally harmonized and cooperative scheme for liability, especially CSC (Convention on Supplementary Compensation) , and potentially use it as a leverage to build safety infrastructure

Fact-finding , LL and Changes



Thank you for your attention

CONCLUSIONS

1. **Stabilization phase to end this year at Fukushima, followed by offsite remediation and onsite 3D (Decontamination /Defueling/Decommissioning)**
2. **Strengthening safety by learning lessons in**
   - Regulation and Safety culture
   - Workable/effective SAMG
   - Emergency management
   - Design

   AND further by Revisiting Defense in Depth, Building safety infrastructure in newcomers and global liability scheme
3. **RCA is required to help identify vulnerabilities, which could lead to changes in safety culture, organization, and risk management**