Accident at TEPCo's Fukushima-Daiichi NPP
- LL for Operator/Industry -

Akira OMOTO, University of Tokyo & AEC

✓ ***Part I Key vulnerabilities***

Part II Lessons learned for Operator/Industry

Key vulnerabilities (1)

1. Protection against natural hazard and resultant CCF "SBO+ Isolation from UHS"

(Tsunami)

- Original Tsunami design basis upgraded in 2002
  - ✓ Using JSCE (Japan Society of Civil Engineers) guideline
  - ✓ Deterministic approach considering 4 elements (Historical data, Seismo-techtonics, Near-coast active faults, Very far earthquake)
- Probabilistic Tsunami Hazard analysis
  - ✓ Evolution 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

(SBO)

- For extended time period
- Power center, battery: mostly located in lower level of Tb/B and submerged in seawater
- Only one EDG (1F6 air-cooled EDG) survived

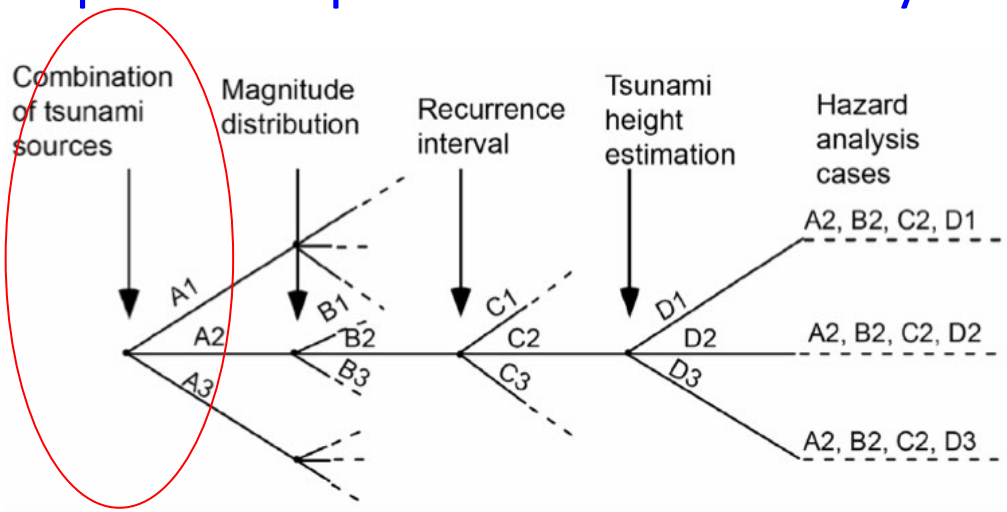
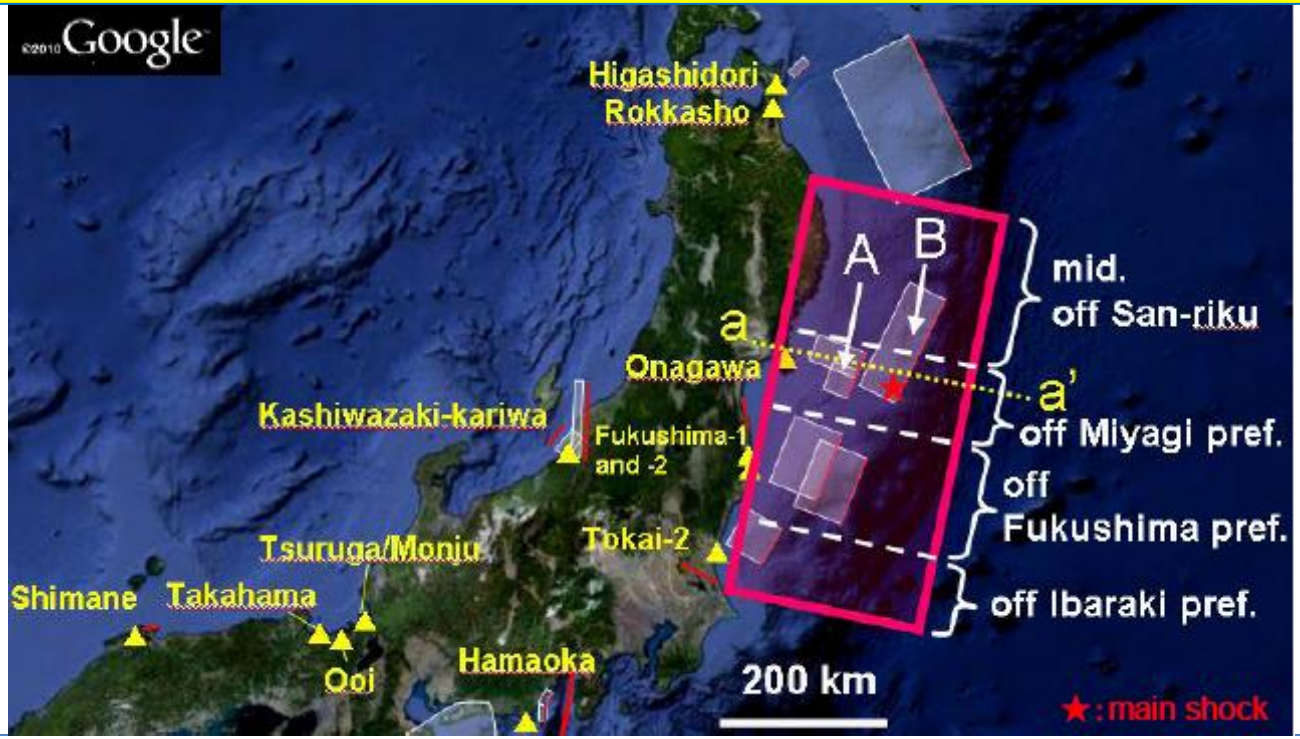


Fig. 1 Logic-tree representation of uncertain parameters

3.11 earthquake



Statement by the Headquarter for Earthquake Research, 11March2011

The Committee evaluated earthquake motion and tsunami for the individual region off-shore …..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 : Initiation from B, then propagated westwards to area A, and further to the North and South. The Headquarter had alerted 99% probability of occurrence within 30 years for the A region with a magnitude of M7.5, 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

3.11 Earthquake

At the Basement of Reactor Building

Nr.	MWe	3.11 Observed (max. gal)			Design (Ss) (max. gal)		
		N-S	E-W	Vertical	N-S	E-W	Vertical
1Fuku1	460	460	447	258	487	489	412
1Fuku2	784	348	550	302	441	438	420
1Fuku3	784	322	507	231	449	441	429
1Fuku4	784	281	319	200	447	445	422
1Fuku5	784	311	548	256	452	452	427
1Fuku6	1100	298	444	244	445	448	415

Note 1: **Damage by the earthquake**:

- ✓Not fully inspected but maybe not significant damage to safety systems, considering the KK earthquake (2007) where no damage to safety functions even though the observed acceleration exceeded design basis by factor 2-3.
- ✓However, all the 6 offsite power lines to 1F were lost due to failure of breaker, and collapse of transmission line tower
- ✓One of the offsite power lines remained intact @2F
- ✓In KK earthquake (2007), 3 out of the 4 offsite power lines remained intact.)

Note 2: **Reactor Scram by the earthquake**

Set points by acceleration at R/B basement: Horizontal=135 gal, Vertical=100 gal

Key vulnerabilities (2)

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

Existing BWR's capability for extended SBO

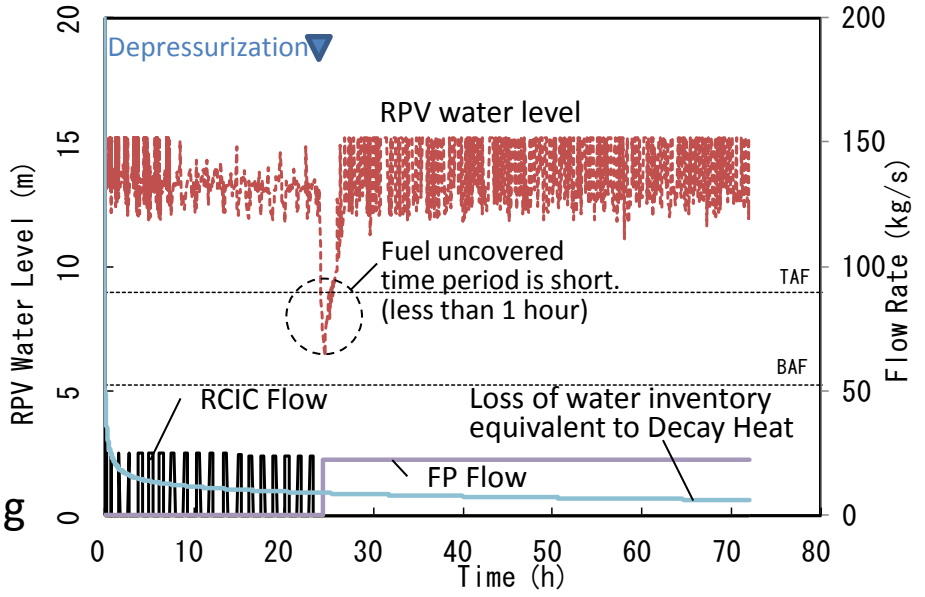
Operation

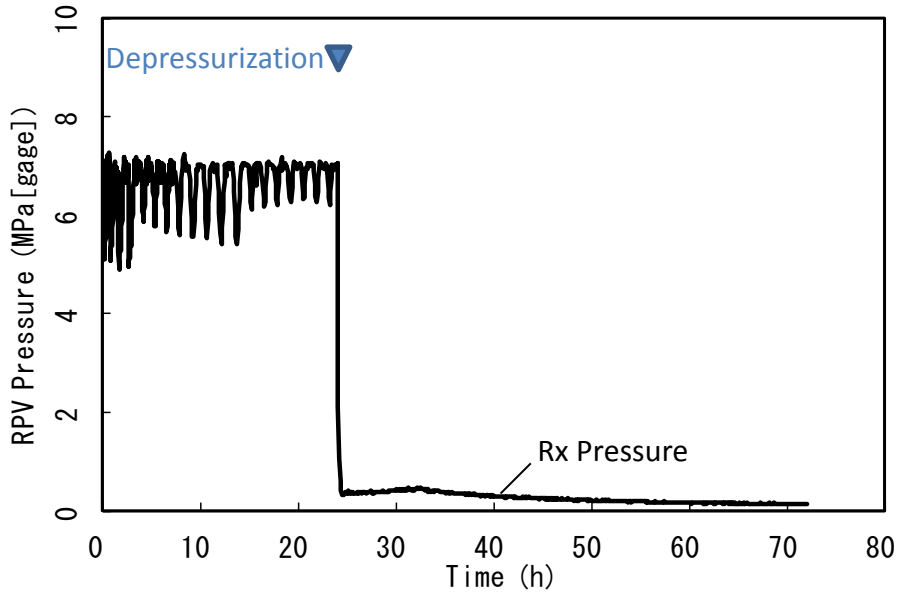
✓0-24hrs into the accident:
Core water makeup by stored energy (RCIC)

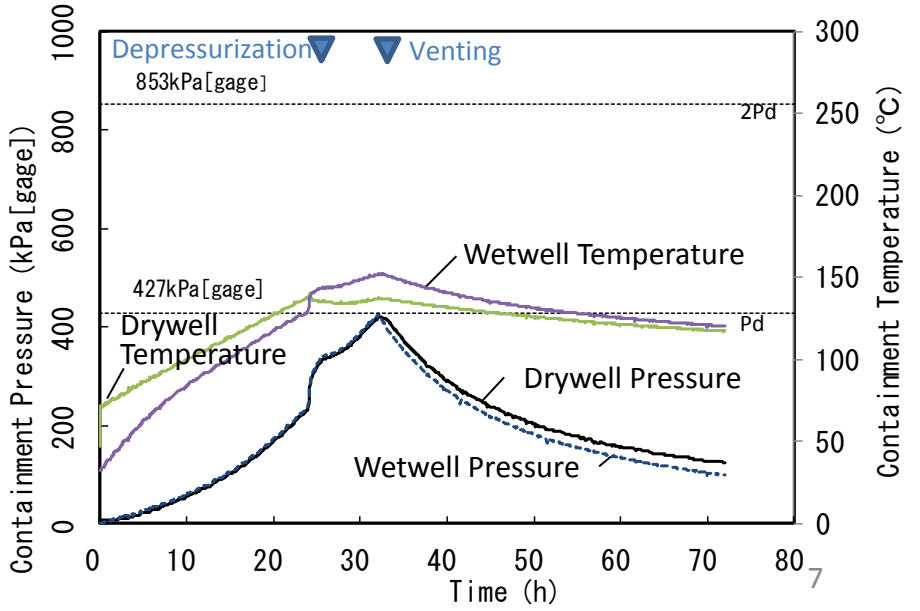
✓24 hrs: Depressurize RCS and LP injection(SAM)

✓32 hrs: Heat dissipation to the alternative heat sink by Containment scrubbing venting (SAM)

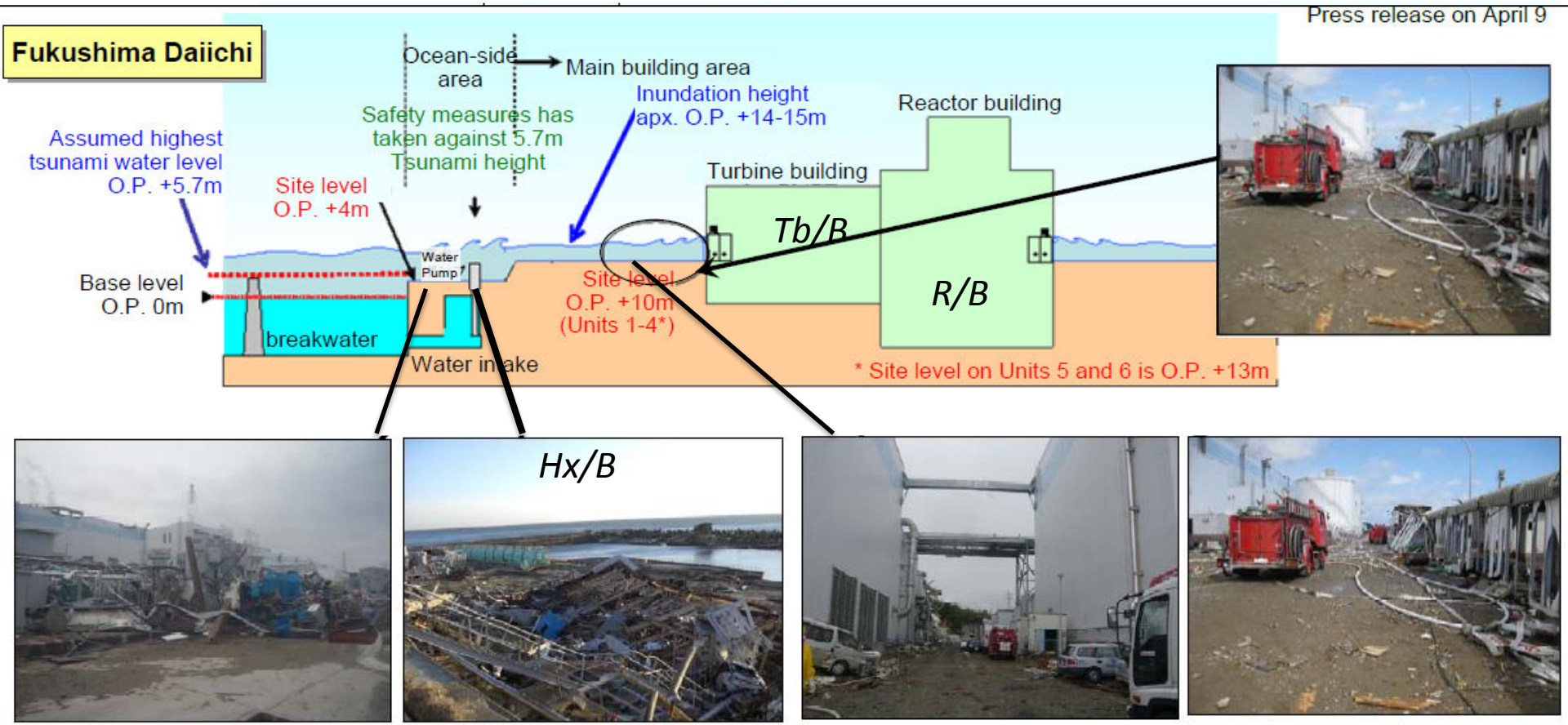
Battery to support operation of RCIC or essential valves has 8-10 hours capability. RCIC kept running for almost 3 days (1F2)







Devastation by Tsunami



[SOURCE]
http://www.tepco.co.jp/cc/press/betu11_j/images/110618l.pdf and
TEPCO May 23 report

Limited available resources under harsh environment

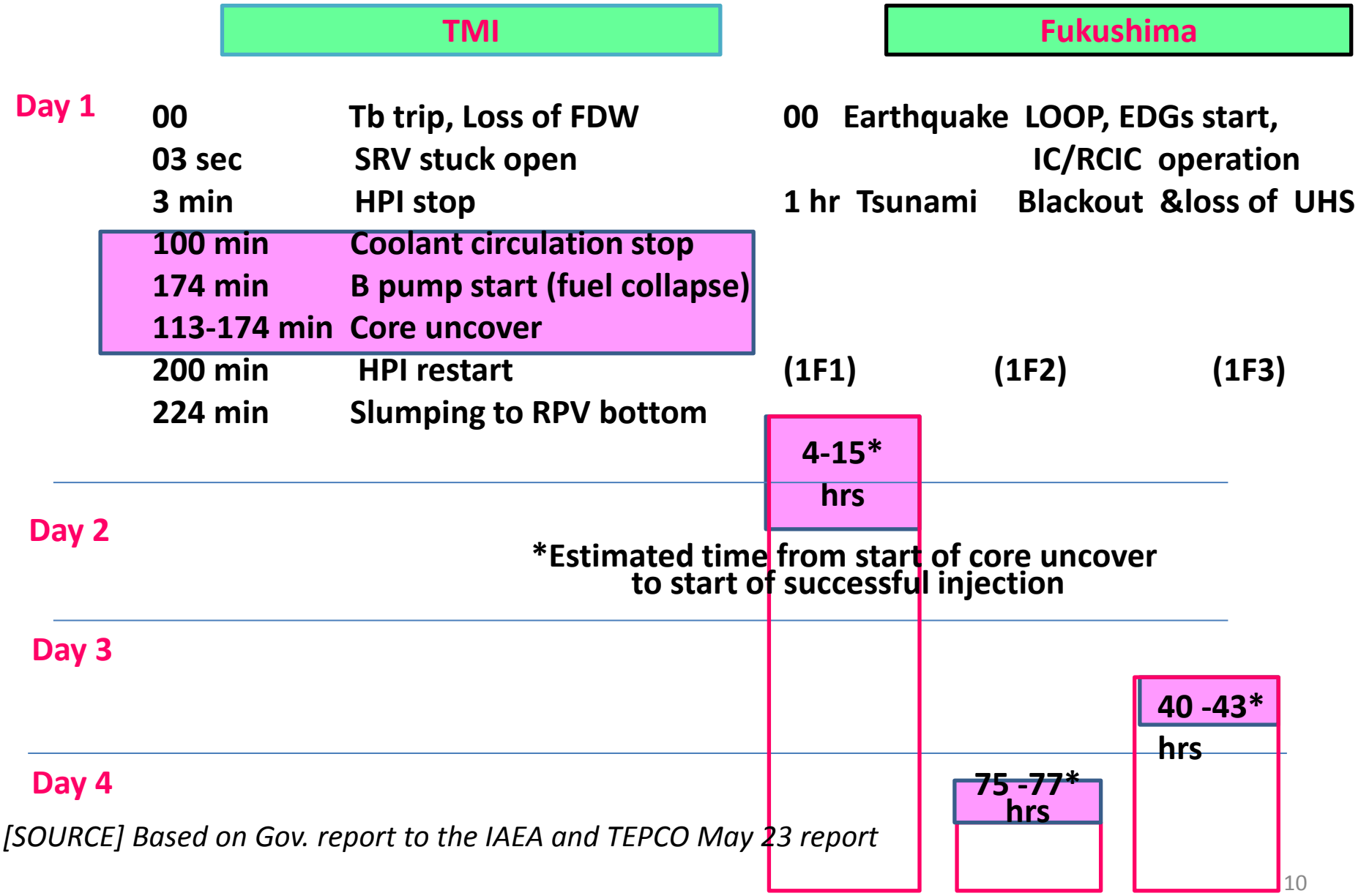
Loss of communication tool (PHS) and plant safety parameters (SPDS)

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

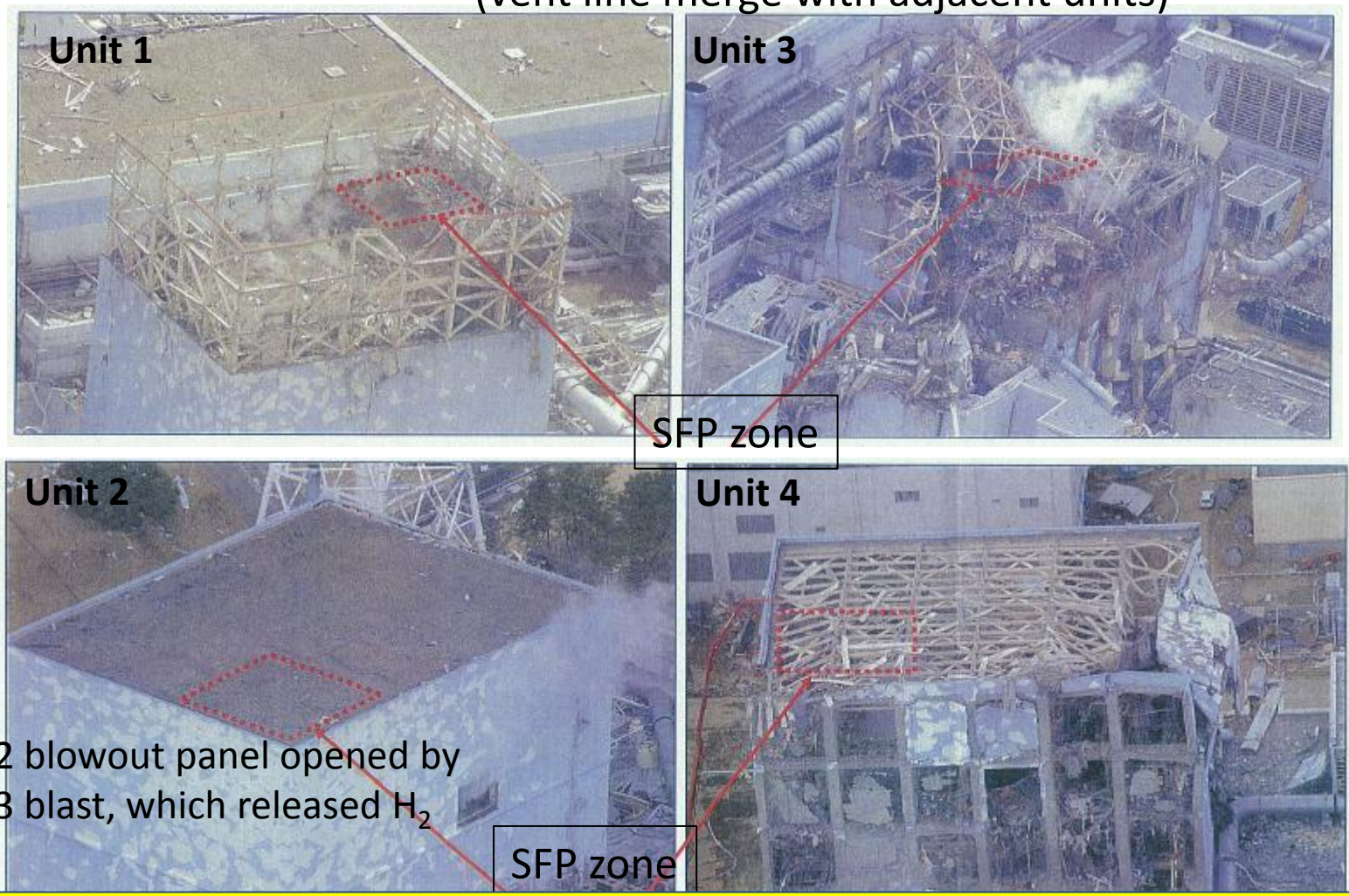
TMI and Fukushima core uncover: estimation



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

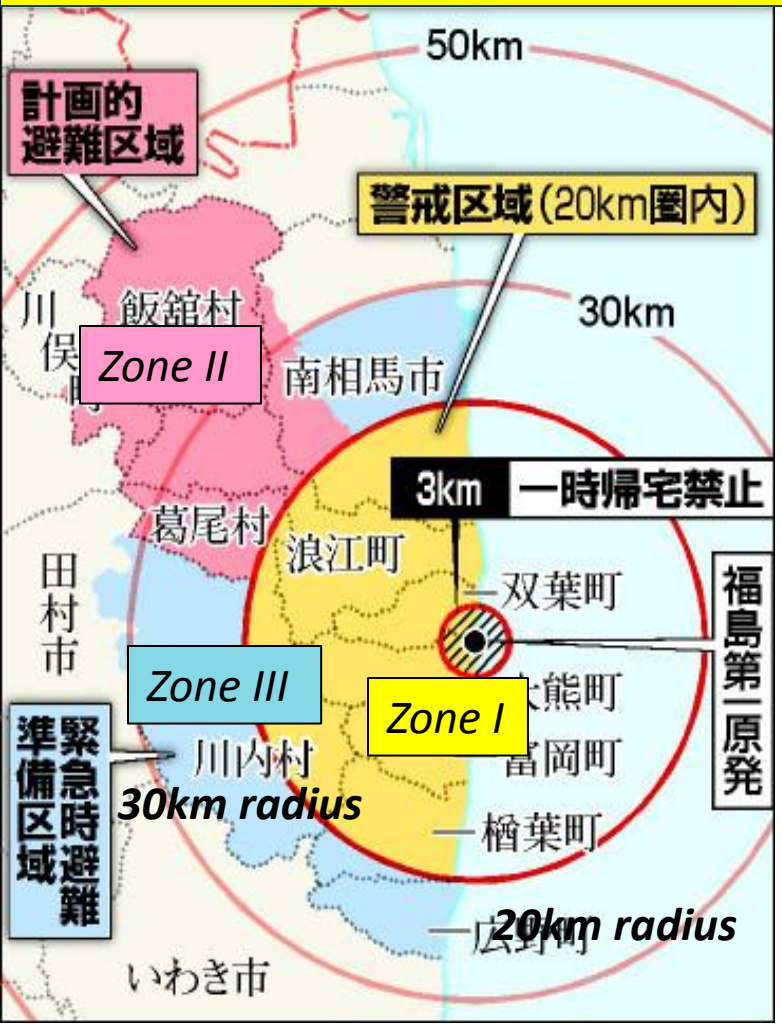
Key vulnerabilities (3)

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)

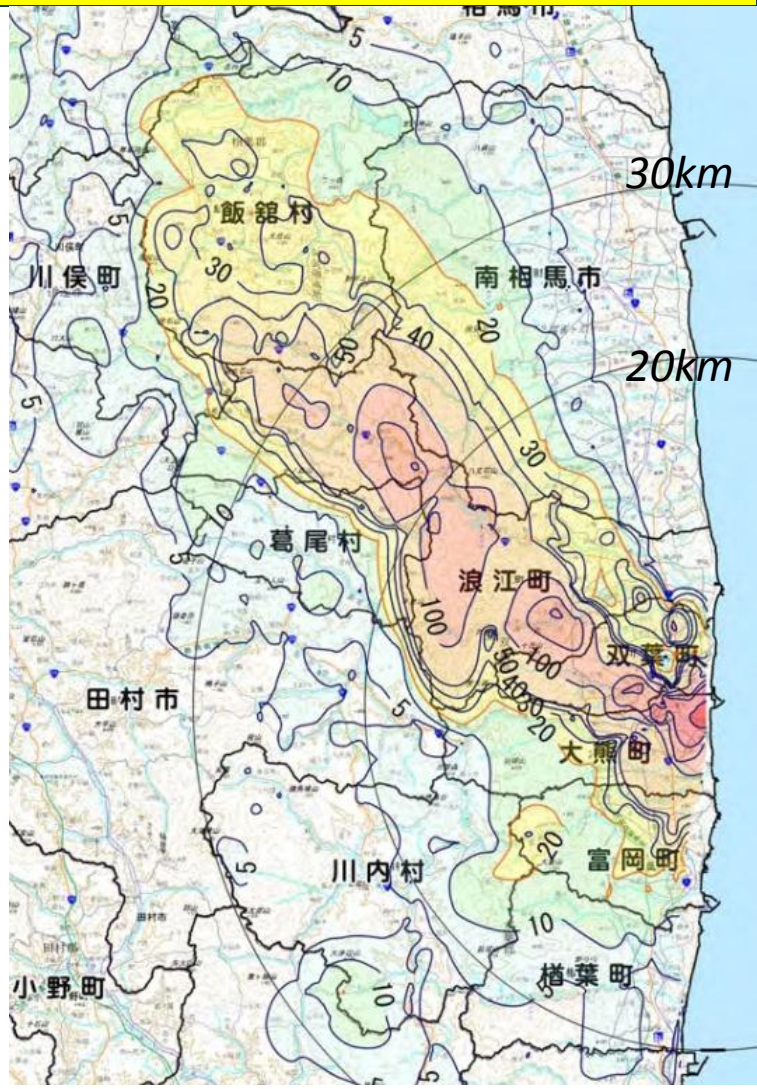


FP escape path to the environment by R/B hydrogen explosion

Offsite : EPZ and predicted first year dose



More than
80,000 evacuees



EPZ

Zone I (20km); "evacuation"

Zone II (North-west): "Planned evacuation"

Zone III (20-30km); "prepared for evacuation"

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

12

Part I Key vulnerabilities

✓ ***Part II Lessons learned for Operator/Industry***

Lessons Learned

- **Government report to the IAEA (September) : update 28 Lessons in 5 specific areas (Prevention of SA, 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 and Isolation from UHS
3. Completeness/effectiveness of SAM
4. Emergency Management
5. Safety regulation and safety culture
6. Multiple unit installation
7. SFP design
8. International aspects

- **This presentation goes a bit further through personal deliberation and to specifics by focusing on LL to Industry/Utility**
- **Need further in-depth study on culture & history necessary to avoid accidents by other causes**

Lessons Learned
A) Safety regulation and safety culture

Safety regulation and safety culture in nuclear community

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 SG
- Statement by AEC (2011Aug30) on safety-first, public trust, technical competence etc.

Regulation/Utility: Focus on QA/Compliance rather than risks (after 2002)

Utility

✓Use of risk information using PSA by Owner/operator to address vulnerabilities of its asset

✓Understanding of safety by every employees

✓Continuous improvement : [Ex] of SAM through drill and information from outside considering "Accident can happen here"

✓"Sensitivity "to safety-related issues/information
(Many understood the meaning of B5b in hindsight)

✓ Attitude towards "uncertainties"

Safety Culture

Three-level model of Safety Culture

Artefacts-Visible Signs

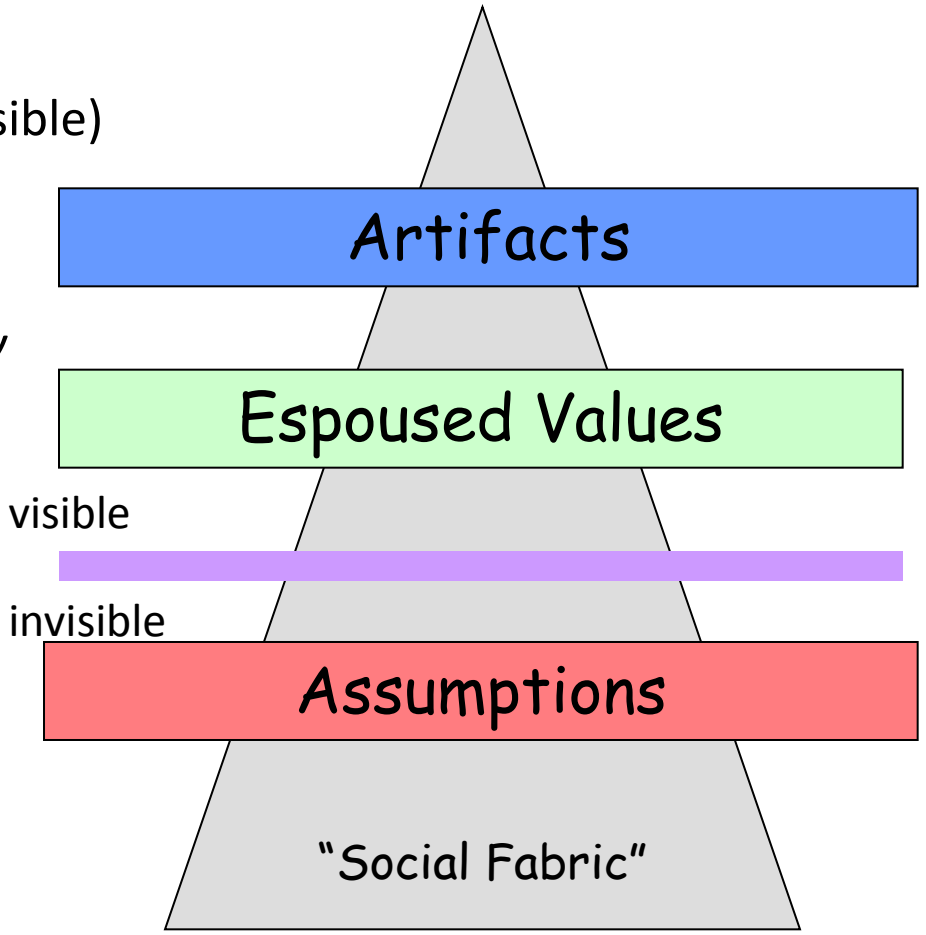
(greeting rituals, dress, housekeeping – visible)

Espoused Values

(values that are adopted and supported by a person or organization based on strategies/ goals)

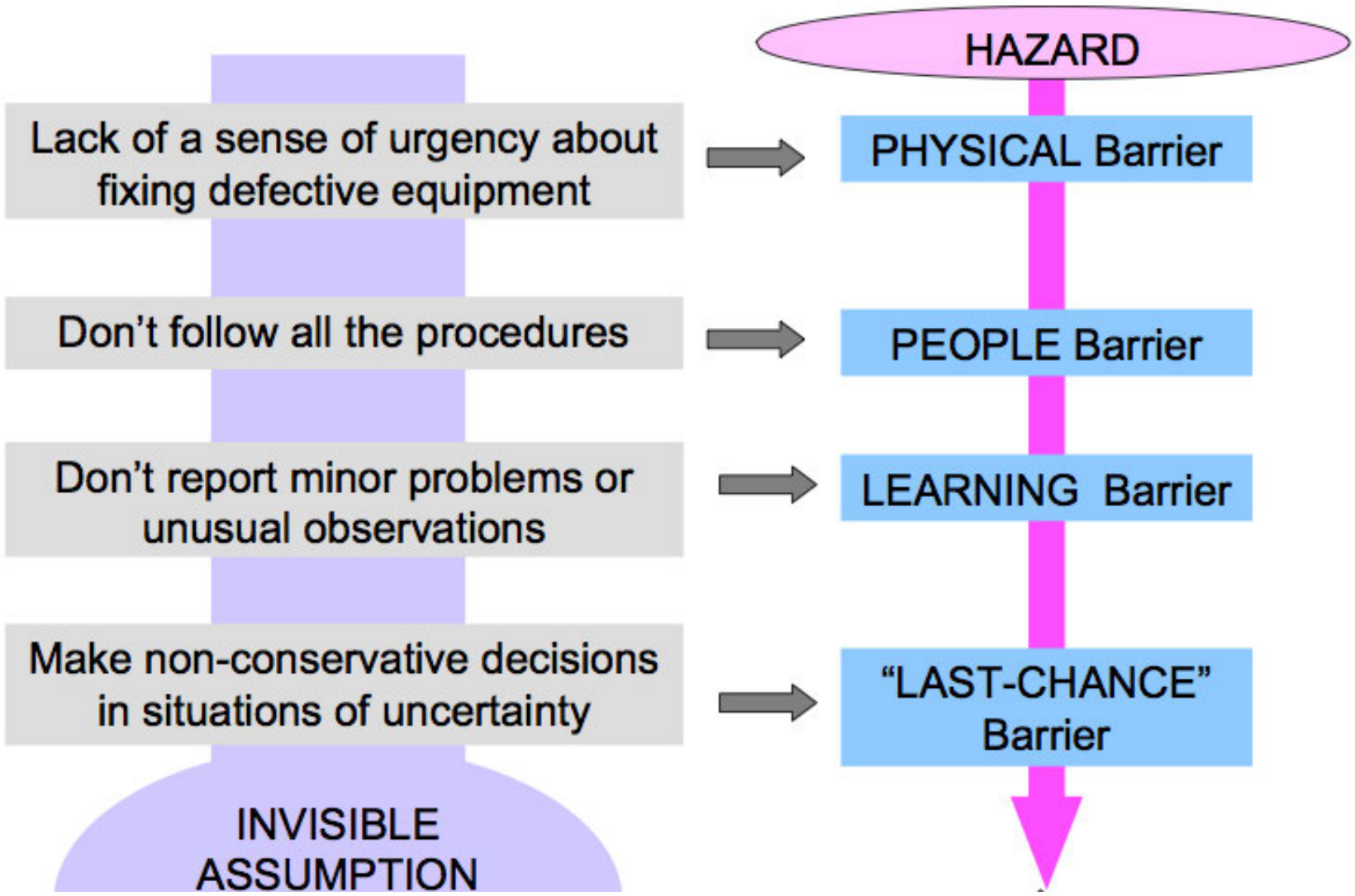
Basic Assumptions

(Such as "human nature good or evil")



[SOURCE] Edgar Schein, former professor at the MIT Sloan School of Management, expert on organizational culture

According to experts: ASSUMPTIONS (BELIEFS) MATTER
(Not describing Fukushima case)



"The plant is robust, it has safety margin."

[SOURCE] Charles Packer, Cherrystone Management

Lessons Learned
B) Workable/effective SAM

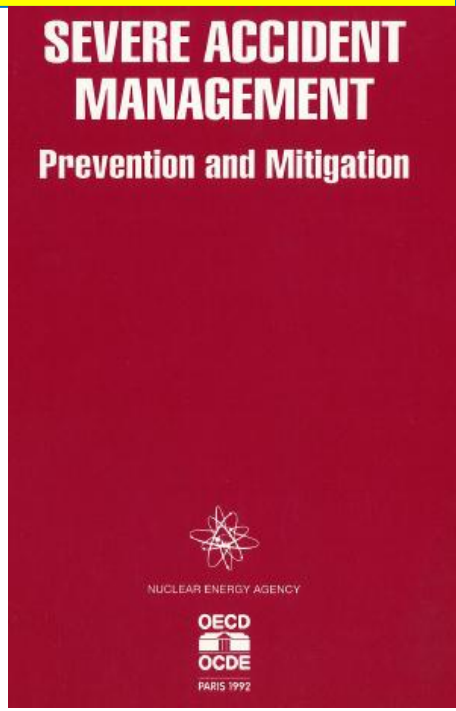
1. SAMG not robust enough to cover possible plant damage conditions
   → Consider
   a) integration of three Gs (internal event, external event and security-related event, and
   b) implementation of recovery actions in harsh radiation environment

2. Provisions of Onsite or National/Regional Nuclear Crisis Management Center for storage of mobile equipments & drill
   ✓under coordination by WANO?

(Supporting provision)

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

What SAM (Severe Accident Management) was in place?



(OECD/NEA)

In the aftermath of Chernobyl, OECD/NEA organized a series of meetings by SESAM (Senior Expert for Severe Accident Management)

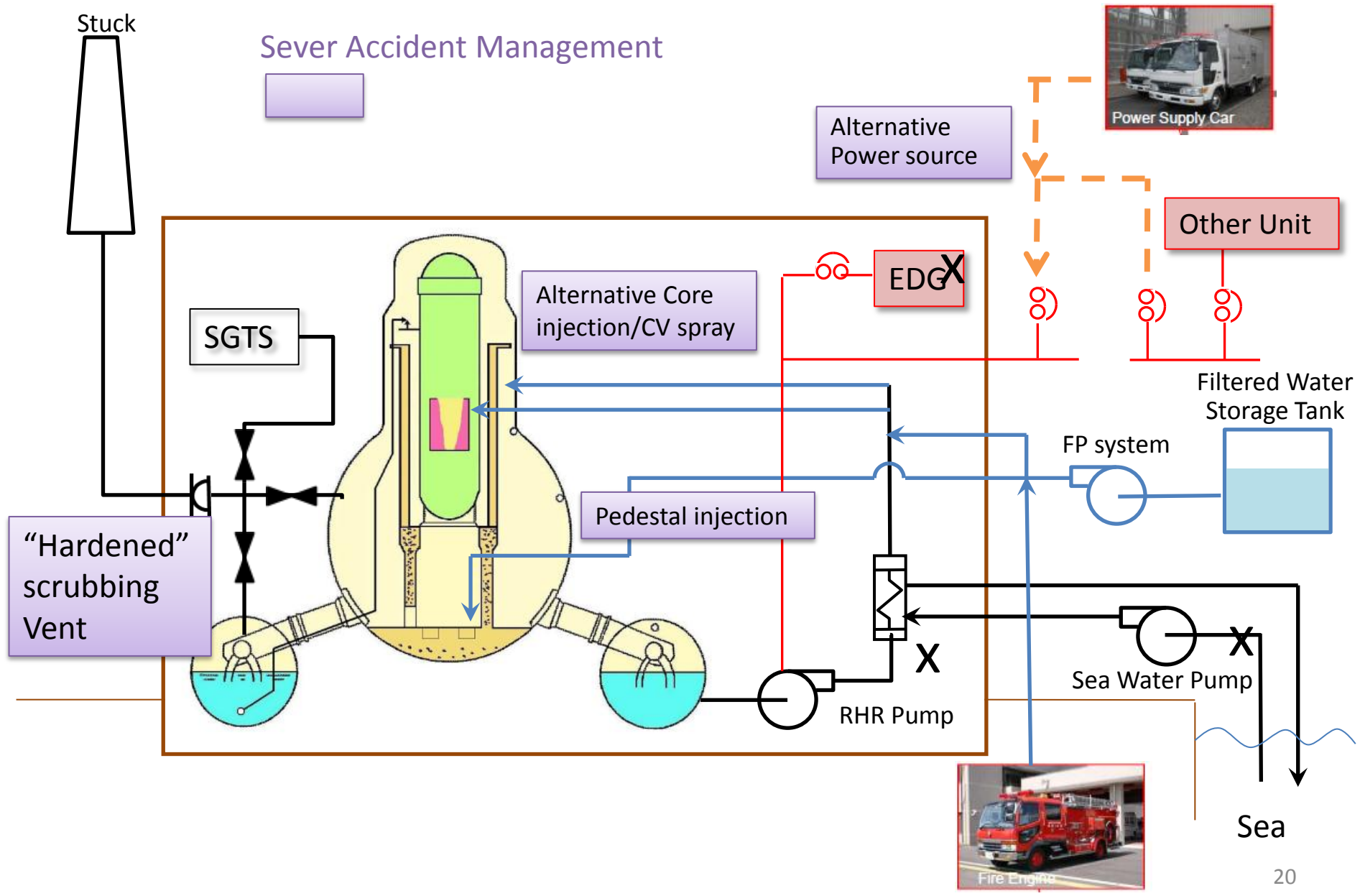
"Severe Accident Management": published in 1992

"Implementing Severe Accident Management in Nuclear Power Plants", published in 1996

(Japan)

- NSC recommendation (1992)
- SAM study followed by SAMG and modifications (hardened vent, injection to RPV and RPV-pedestal region etc)
- Submittal of Utility report to NISA, followed by evaluation by NISA
- Later improvements such as onsite Fire Engines, UG water tanks and new ERC with seismic isolation (KK experience 2007)

What SAM (Severe Accident Management) was in place?



Onsite ERC by TEPCO: seismic isolation structure

Lessons Learned
C) Emergency management

- Loss of communication tool and plant information (SPDS) 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
  - ✓Recognized role by Joint (Government and TEPCO) ERC and local resources center 20—30km away from NPP
- Offsite center: function was lost by loss of electricity and radiation
- Effective channeling of emergency supports
  - ✓Systematize domestic/foreign helping hands for logistics/experts

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
   - ✓ 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

Supplementary IAEA request for information

- ✓National nuclear power plant's response and assessment (ex. safety test results)
- ✓Role of operators at the plant under extreme conditions
- ✓On-site and off-site emergency responders under extreme conditions

- ✓Current and future cooperation with the IAEA,
- ✓Cooperation with other international organizations, countries

National nuclear power plant's response and assessment

NISA Emergency Safety Measures

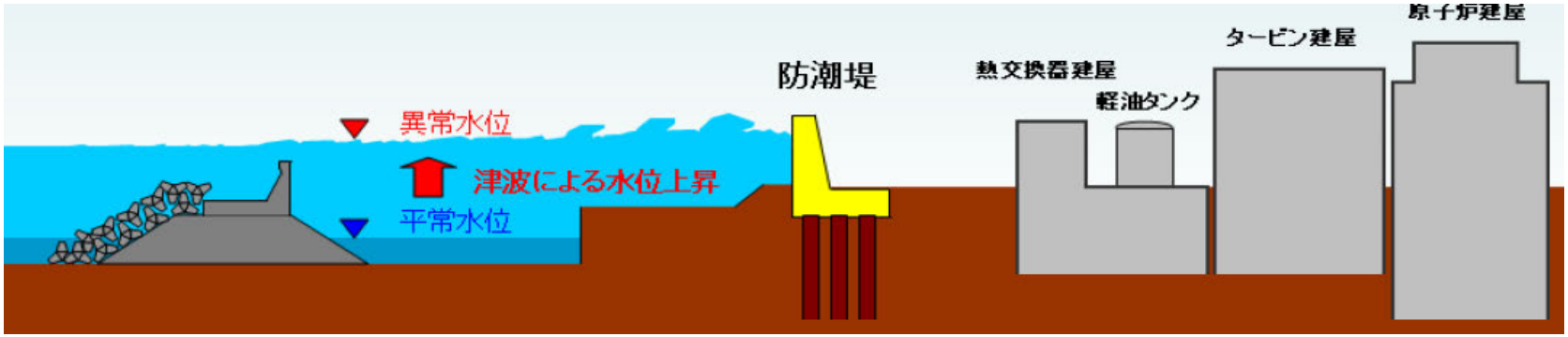
- **Directive to each NPP from NISA:** March 30th, April 9th, April 15th
- **Utility's responses and evaluation completed :** May 6th

Short term

- ✓ Ensure emergency power supply and train
- ✓ SAM improvements (such as hydrogen, mobile sea water pumps)

Medium-to-Long term

- ✓ Countermeasure against anticipated Tsunami height
  - → (Example) KK to install 15-meter-tall wall by 2013

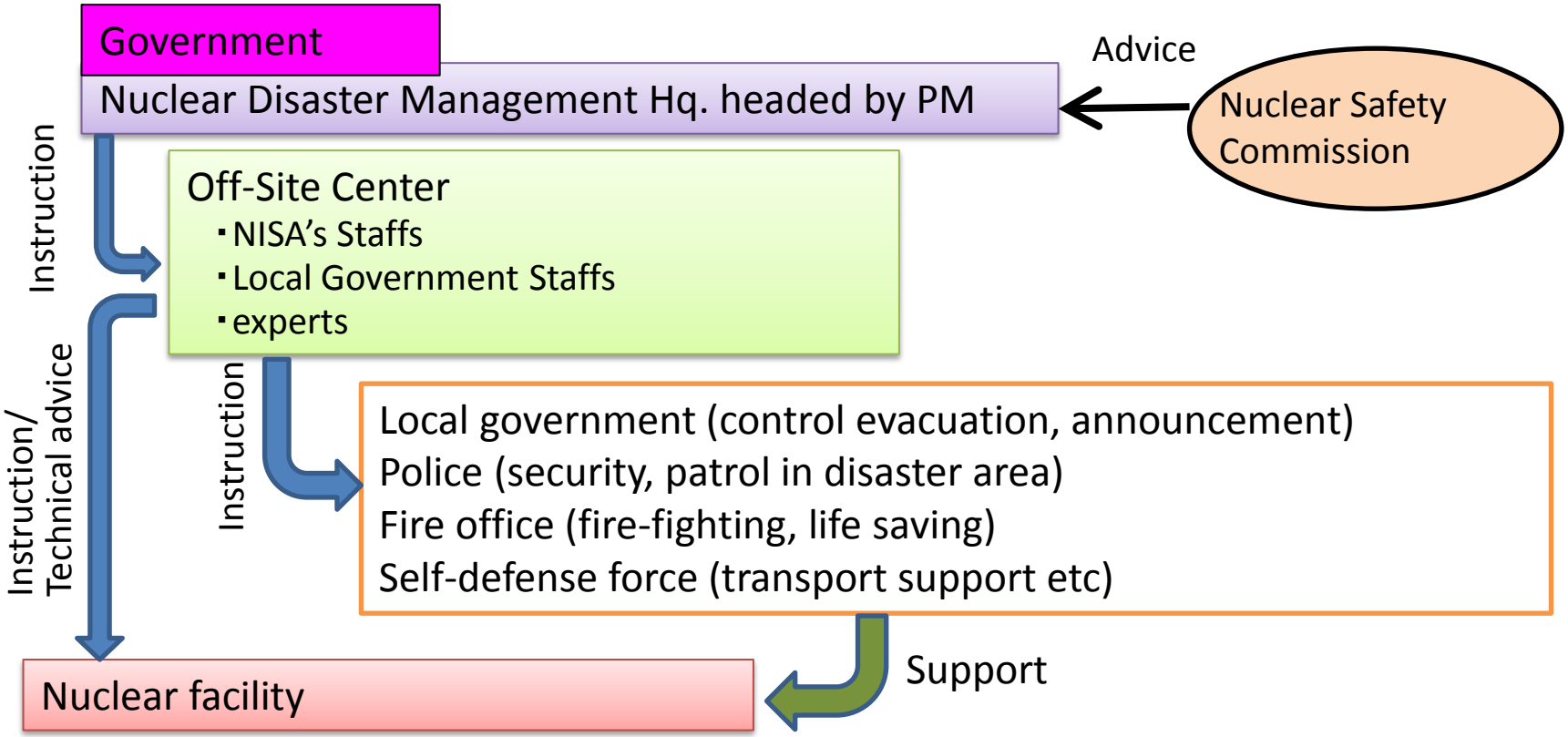


Stress test

- Announced by the Minister (METI) (July 6th) and the Cabinet (July 11th) as an additional tool to verify safety of existing NPPs
  - ✓ Phase I: plants ready for restart (assessment of safety margin)
  - ✓ Phase II: All plants (integrated safety assessment) to determine continued operation or not

Emergency Response

- Law “Special Countermeasure against Nuclear Disaster”
  a) On Notification, off site center is set up
  b) On Declaration of Emergency, PM is in charge
- In reality, off-Site Center was not functional and relocated



Simplified scheme based on White paper on Nuclear Safety 2003 (the Japanese Nuclear Safety Commit ion)

26

Never, Ever Again anywhere in the world

http://www.asahi.com/photonews/gallery/fukushimagenpatsu/