Inside Japan's Nuclear Meltdown

~A TEPCO Nuclear Engineer's Perspective~

Program on U.S.-Japan Relations
Harvard University

Cambridge, Massachusetts
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TEPCO

My Background

- **'90~'96: Kyoto University**

  BS/MS in Nuclear Engineering

- **'96~: TEPCO**

  '96~'00: **Fukushima Daini NPS**

  '00~'02: **Nuclear Engineering Dept., Tokyo-H/Q (severe accident analysis)**

  '02~'04: **MBA, Stanford Graduate School of Business**

  '04~'05: **Nuclear Engineering Dept.**

  '05~'11: **International Affairs Dept.**

  Mar.~Sept.'11: **Fukushima Response Int'l Team, Tokyo-H/Q**

  Sept. '11~: **Washington DC Office**

TEPCO class of '96 in Naraha-town, Fukushima (Jan. 2000)

Pursued "Nuclear Renaissance" in Texas (June 2010)

My Background (cont'd)

- '90~'96: Kyoto University

  BS/MS in Nuclear Engineering

- '96~: TEPCO

  '96~'00: **Fukushima Daini NPS**

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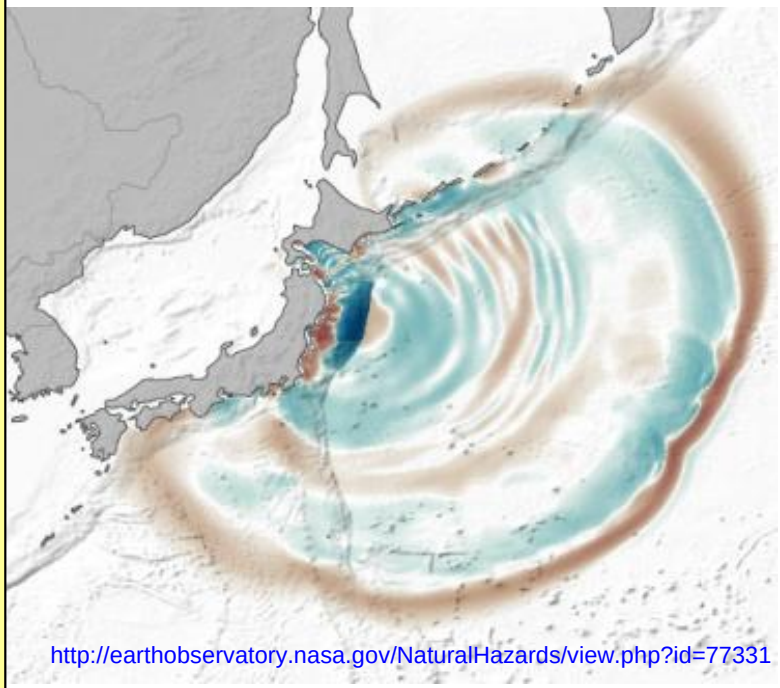
  Sept. '11~: **Washington DC Office**

Then, everything changed…



http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=77331

Great East Japan Earthquake (March 11, 2011)

My Post-Accident Activities

IAEA Preliminary Mission (4/6/2011@Fukushima Daiichi NPS)

IAEA: International Atomic Energy Agency

My Post-Accident Activities (cont'd)

U.S. INPO-Led Industry Support Team (8/19/2011@Fukushima Daini)

Reinforcing US-Japan Ties w/ Ambassador John Roos
(6/15/11@Tokyo)

Reinforcing US-Japan Ties w/ NRC Chuck Casto
(4/7/13@Austin)

INPO: Institute of Nuclear Power Operations
NRC: Nuclear Regulatory Commission

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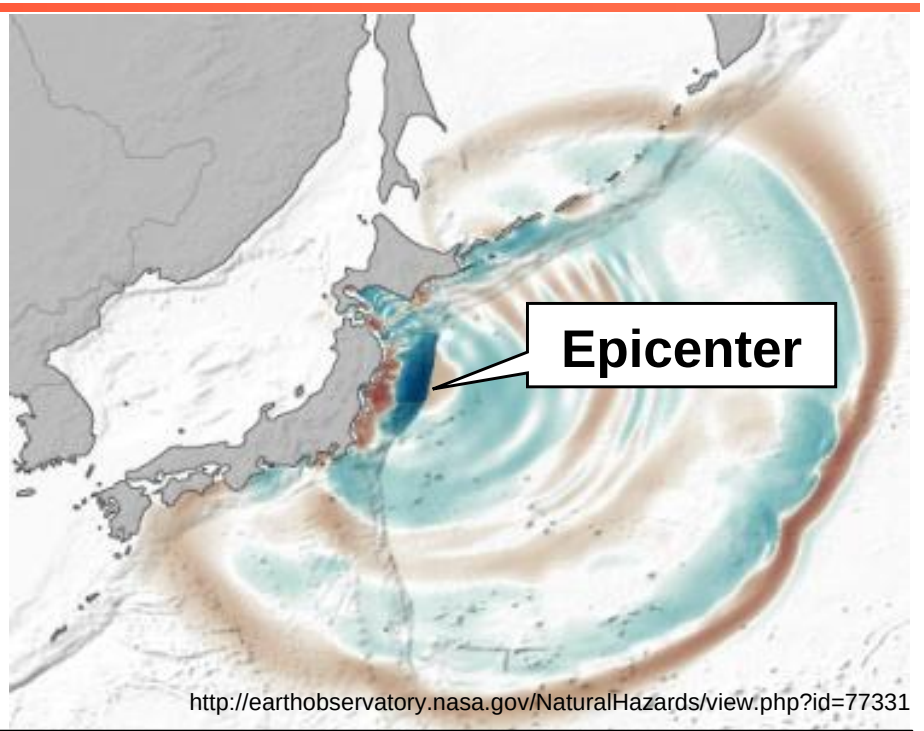
TEPCO

The Great East Japan Earthquake (GEJE)



- ***Largest* earthquake (M9.0) and tsunami (M9.1) in recorded history of Japan**
- ***20+ m* tsunami run-up in coast line spanning *200 km***
- **560 km^2 flooded (*10x Manhattan*)**
- ***19,000 dead/missing***

Operation *Tomodachi* (“Friends”) by U.S. Armed Forces


http://www.defense.gov/home/features/2011/0311_japan/


http://www.defense.gov/home/features/2011/0311_japan/

http://www.defense.gov/home/features/2011/0311_japan/

http://www.defense.gov/news/newsarticle.aspx?id=63439

U.S. Armed Forces’ disaster relief efforts were highly appreciated by the Japanese people

Impact of GEJE to TEPCO Facilities

Shutdown:

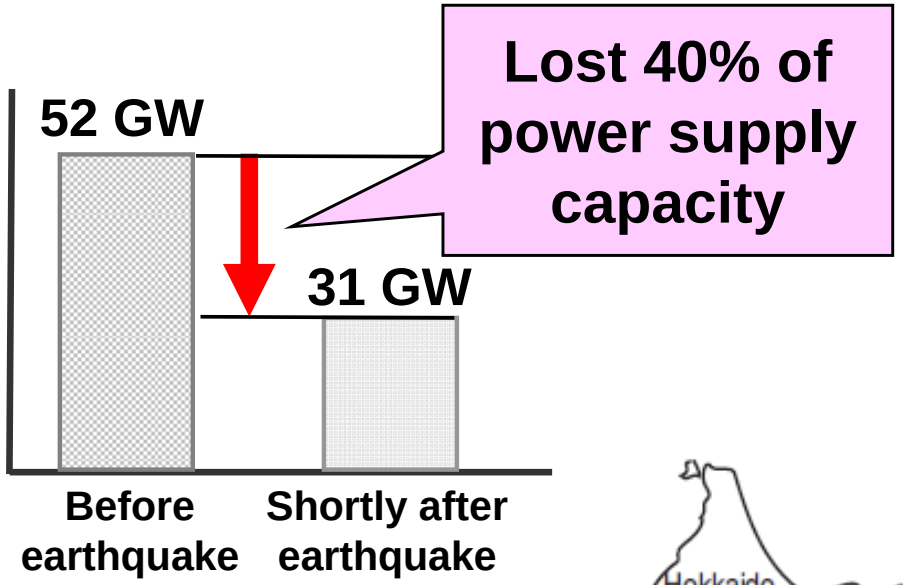
- Nuclear power: **7** units
- Thermal power: **12** units
- Hydro power: **25** units
- Substations: **8**

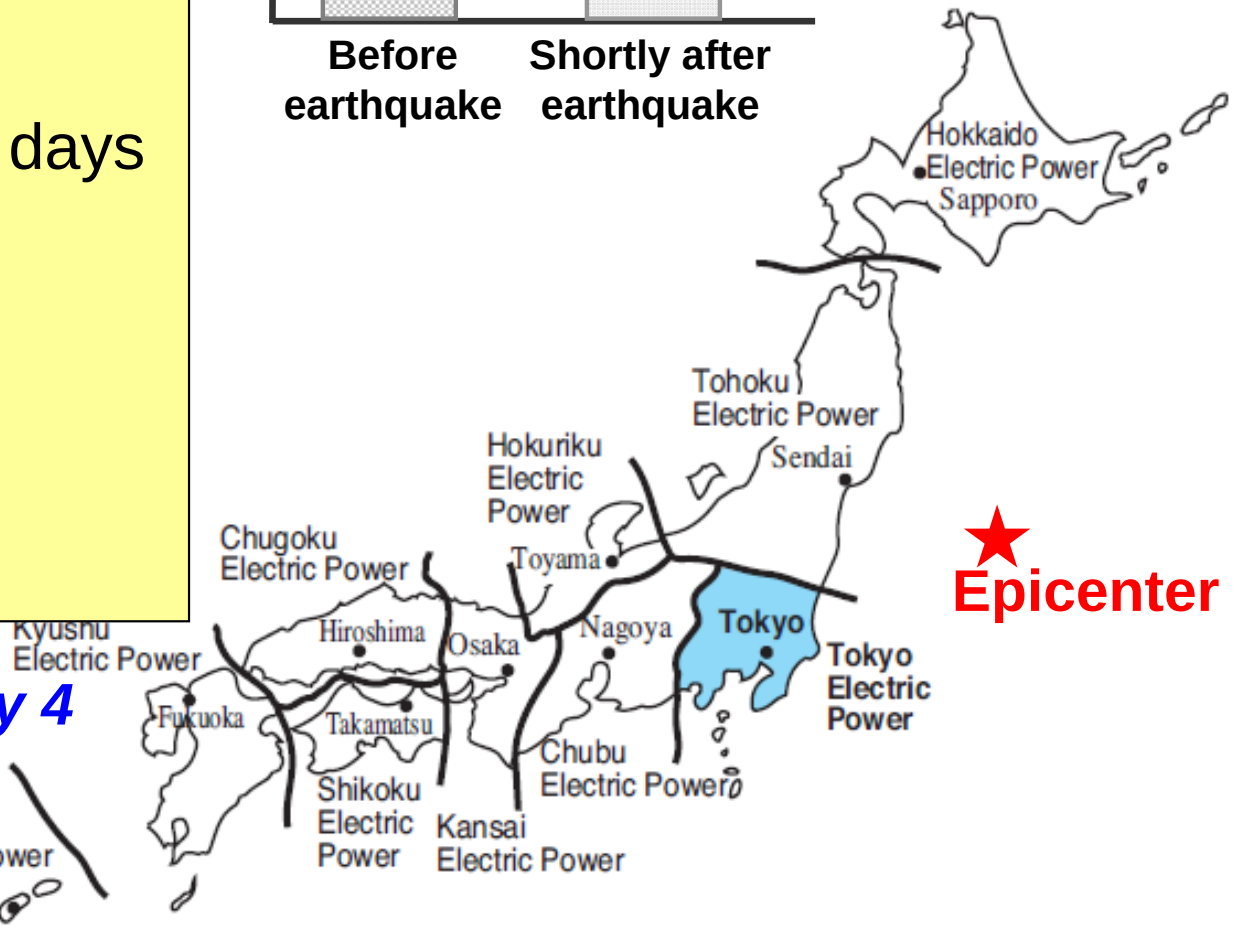
Power outage:

- **4 million households**
- Rolling blackout for 10 days

Massive interruption of infrastructure:

- Public transportation
- Telecommunication
- Food/water supply





Restored >99% of power by day 4

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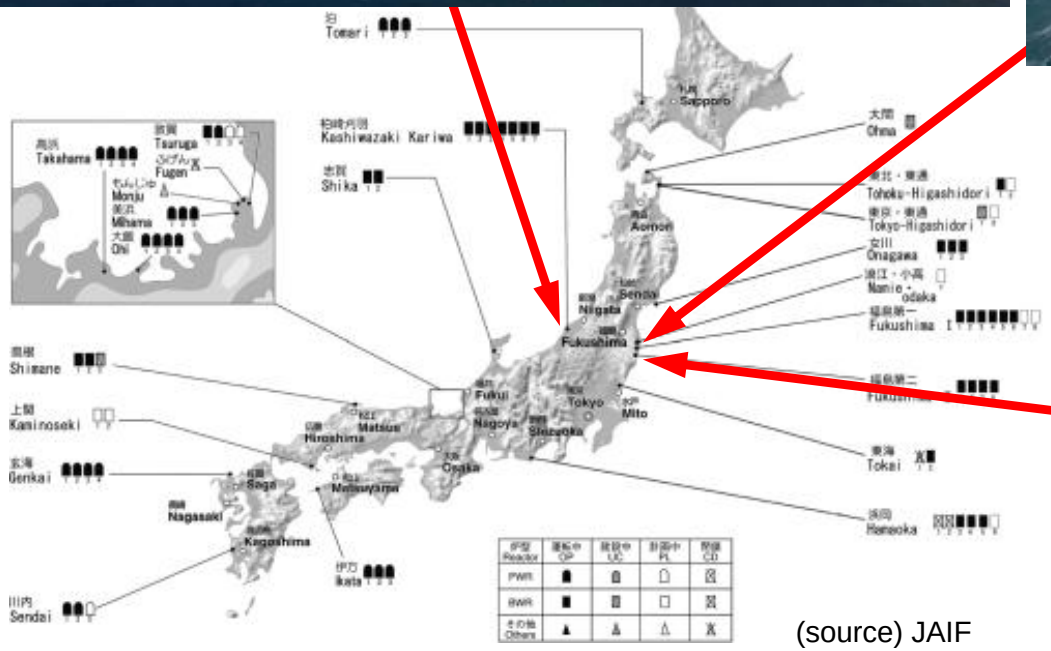
TEPCO's Nuclear Power Stations (17 BWR Units)



(source) JAIF

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TEPCO's Emergency Response Centers (ERC)

Tokyo H/Q

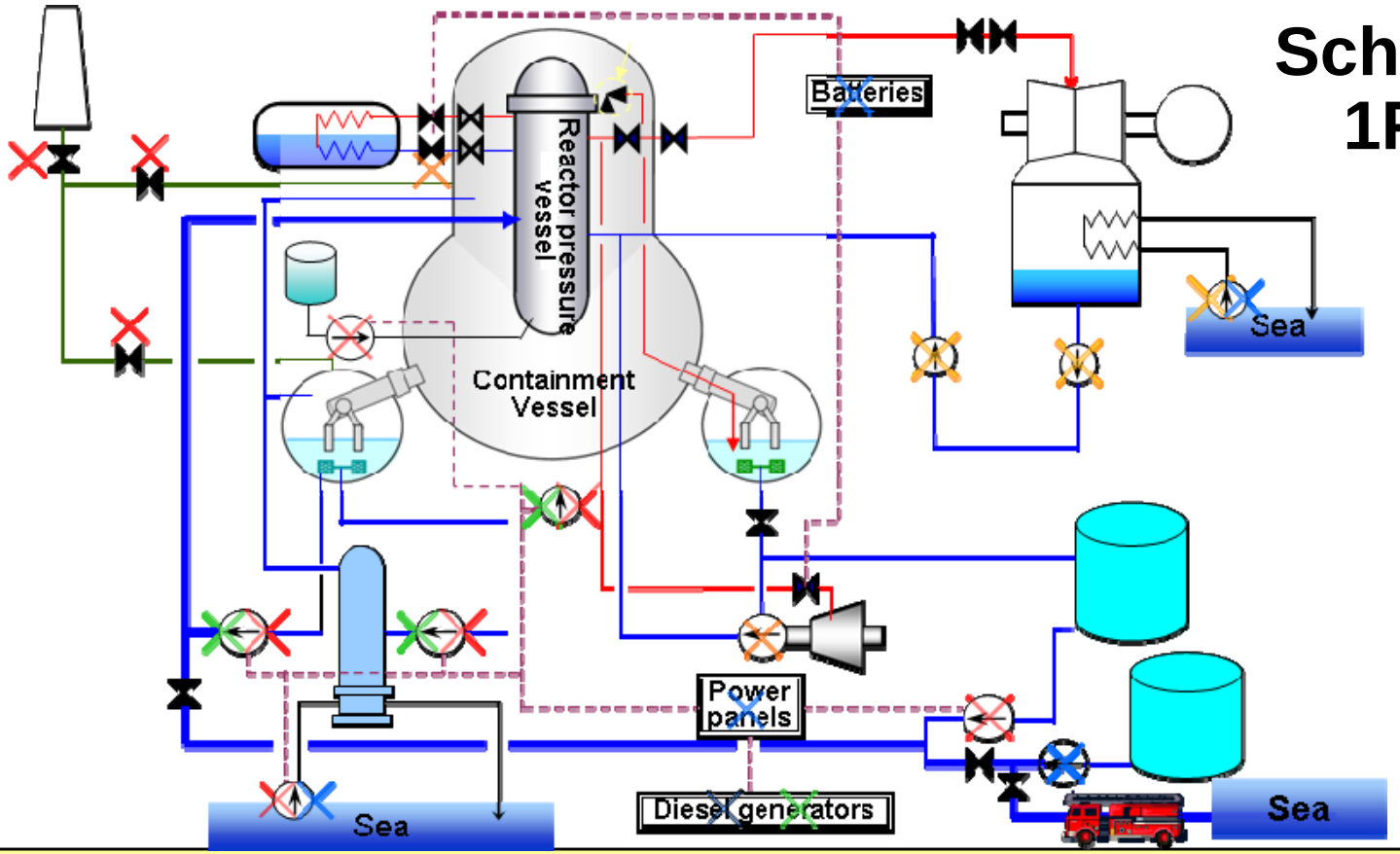
Video conference among multiple ERCs played instrumental role

Fukushima Daiichi

Tsunami at Fukushima Daiichi (1F)

Estimated Tsunami Height:
13.1 m = 43 ft. (4-Story Bldg.)
4x historical-high and 2x design-basis

Plant Status After Tsunami



- All reactors **shutdown automatically as designed** after earthquake
- Tsunami led to **Station Black Out** and loss of core cooling capability
- **Core melt** and metal-water reaction led to **H_2 explosion** in reactor buildings
- **Stabilization by sea water** injection via fire trucks

Accident Response at 1F: In the Field

Roads damaged by earthquake

Roads blocked by tsunami debris

Continual aftershocks, tsunami alerts, open manholes, etc. exacerbated the situation

Accident Response at 1F: In the Main Control Room

Checked instrumentation in near-complete darkness

Supervised operation wearing full-face mask

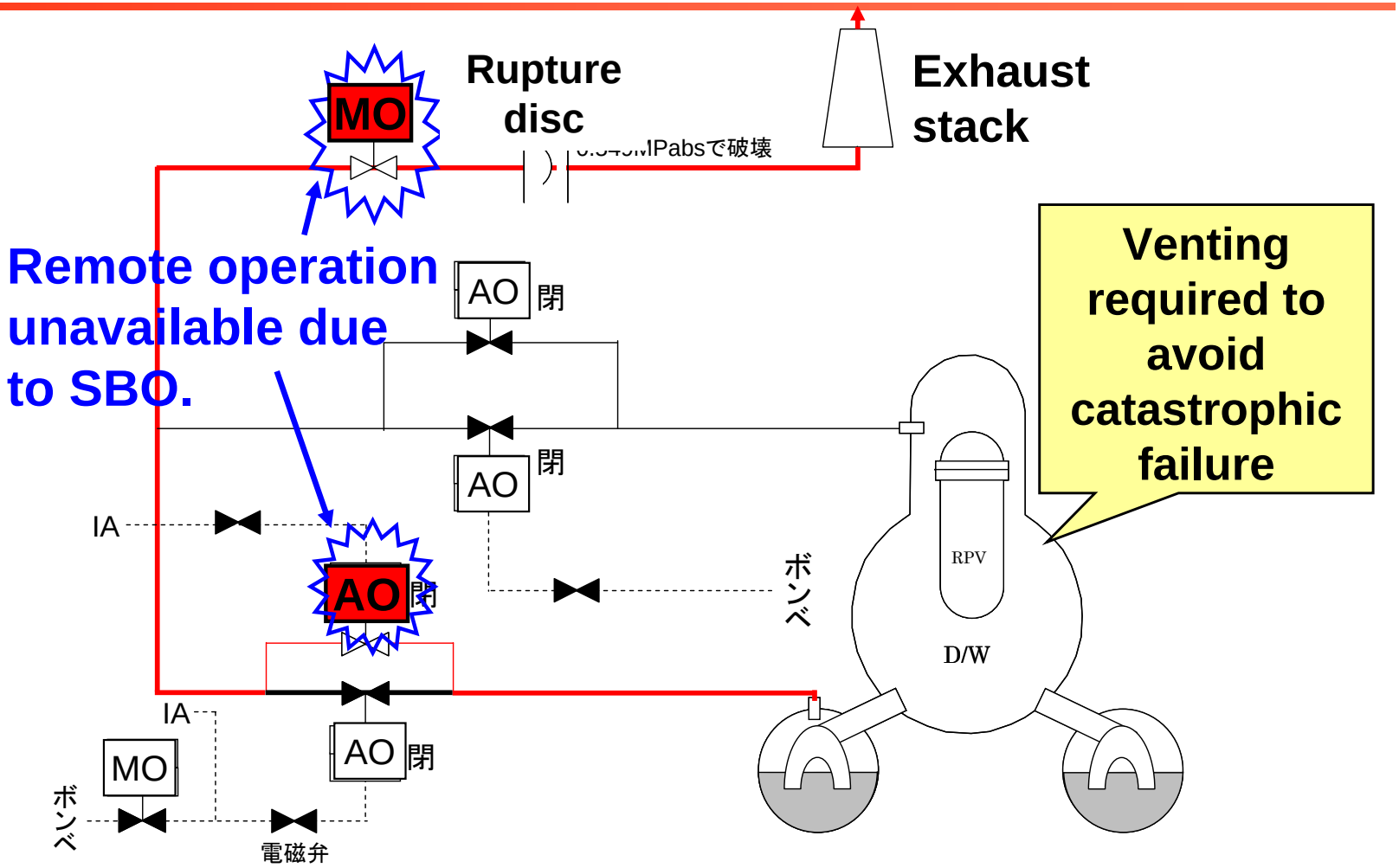
Brought in heavy batteries to restore instrumentations

Lack of: instrumentation, communication means, lighting, food, water, sleep, ...

Increase in: radiation level, fatigue, fear, despair, ...

→*Yet, operators stayed behind to carry through their duties*

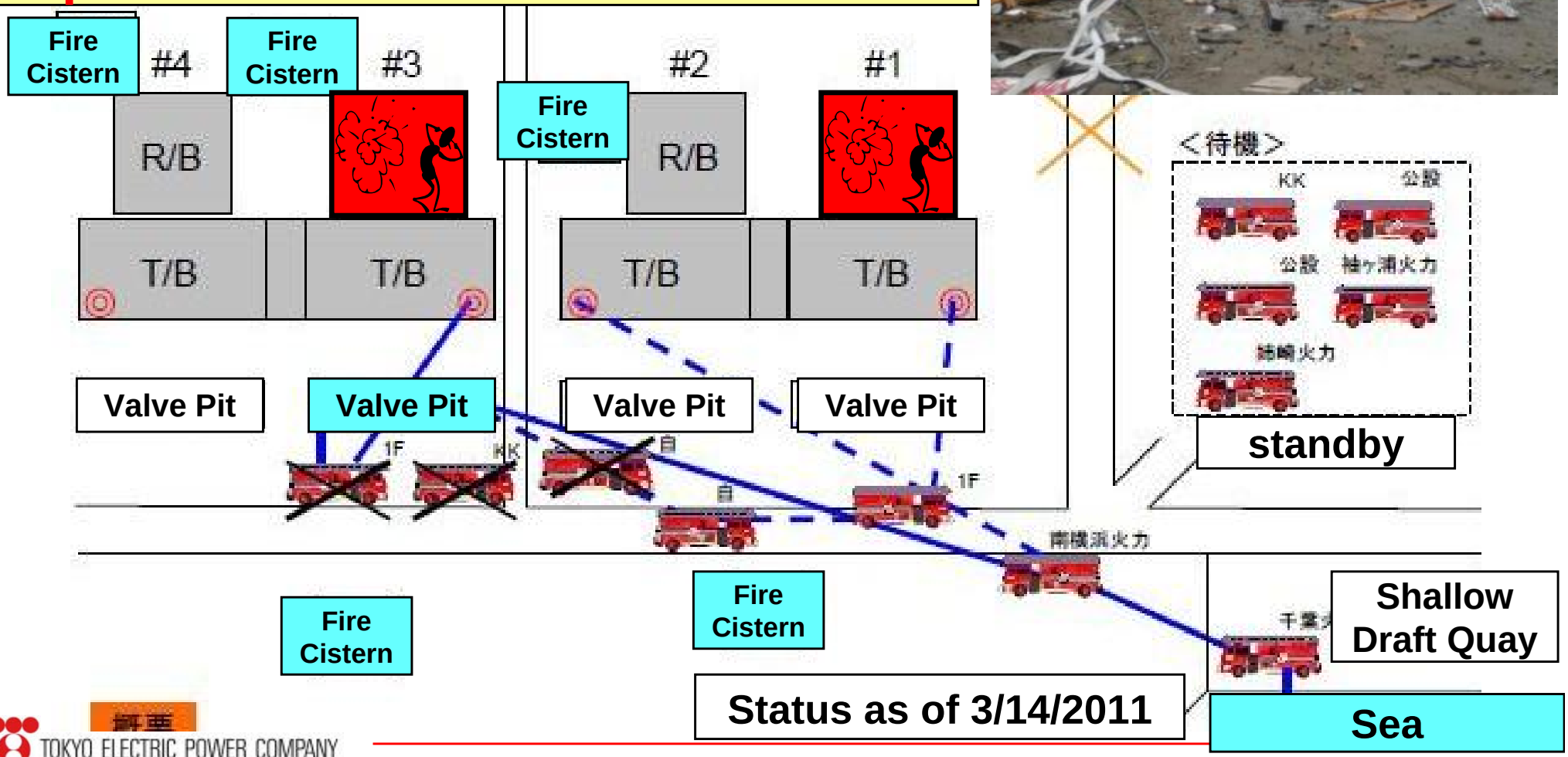
Accident Response at 1F: Unit 1 Containment Venting



- Six men formed 3 "last-resort teams" to manually open 2 valves in highly-radioactive area
- Core damage already progressing by this time (3/12 9:04-9:30)

Accident Response at 1F: Water Injection by Fire Trucks

- **Fire trucks played critical role in injecting water into reactors**
- **Fire brigade operated fire trucks amidst high radiation/successive explosions**

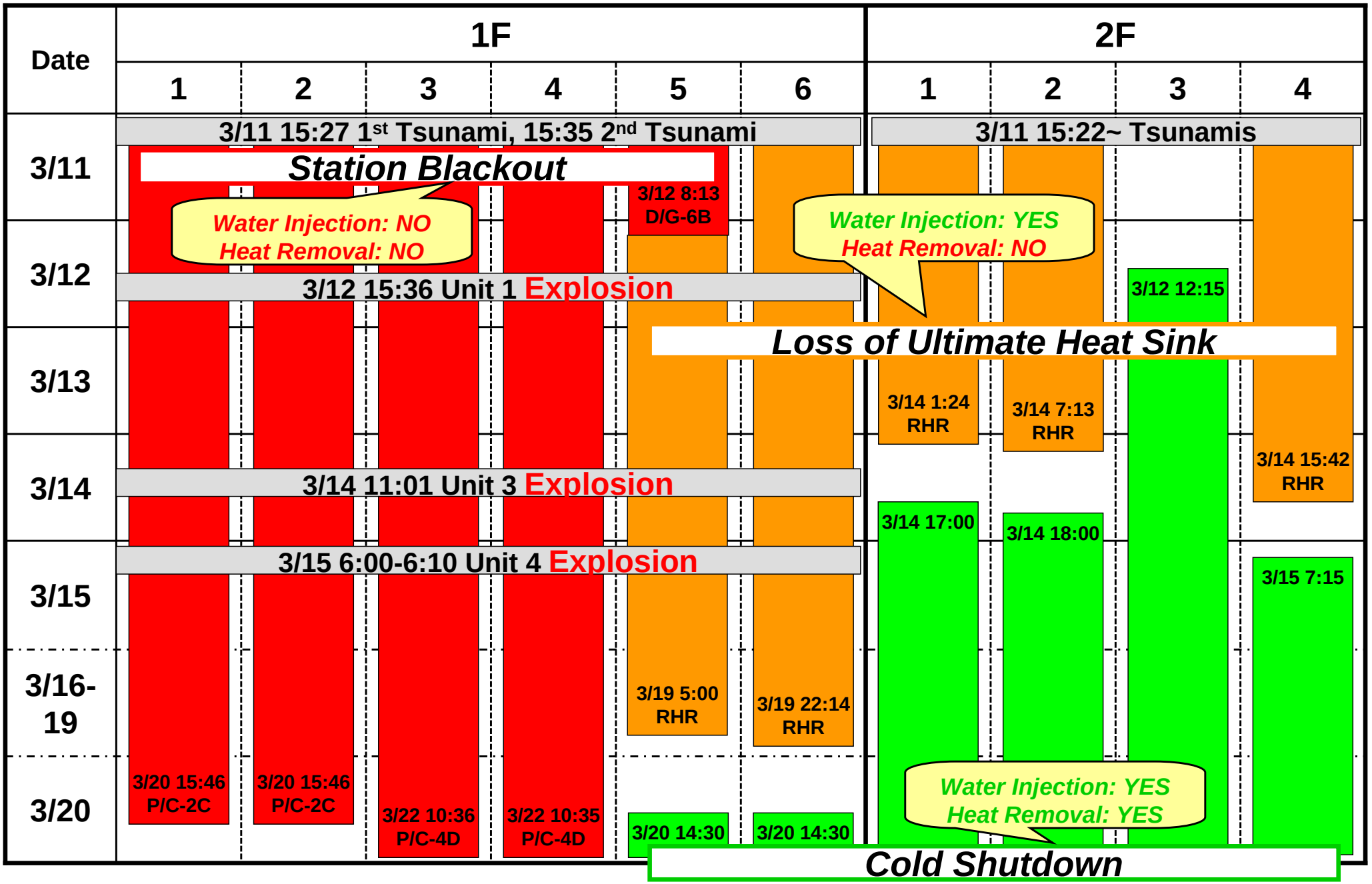


Accident Response at 1F: Water Injection by Fire Trucks (cont'd)

Fire Truck of
Tokyo Fire Department

Fire Truck of
Japan Self Defense Force

Overview of the 10-Unit Simultaneous Accidents



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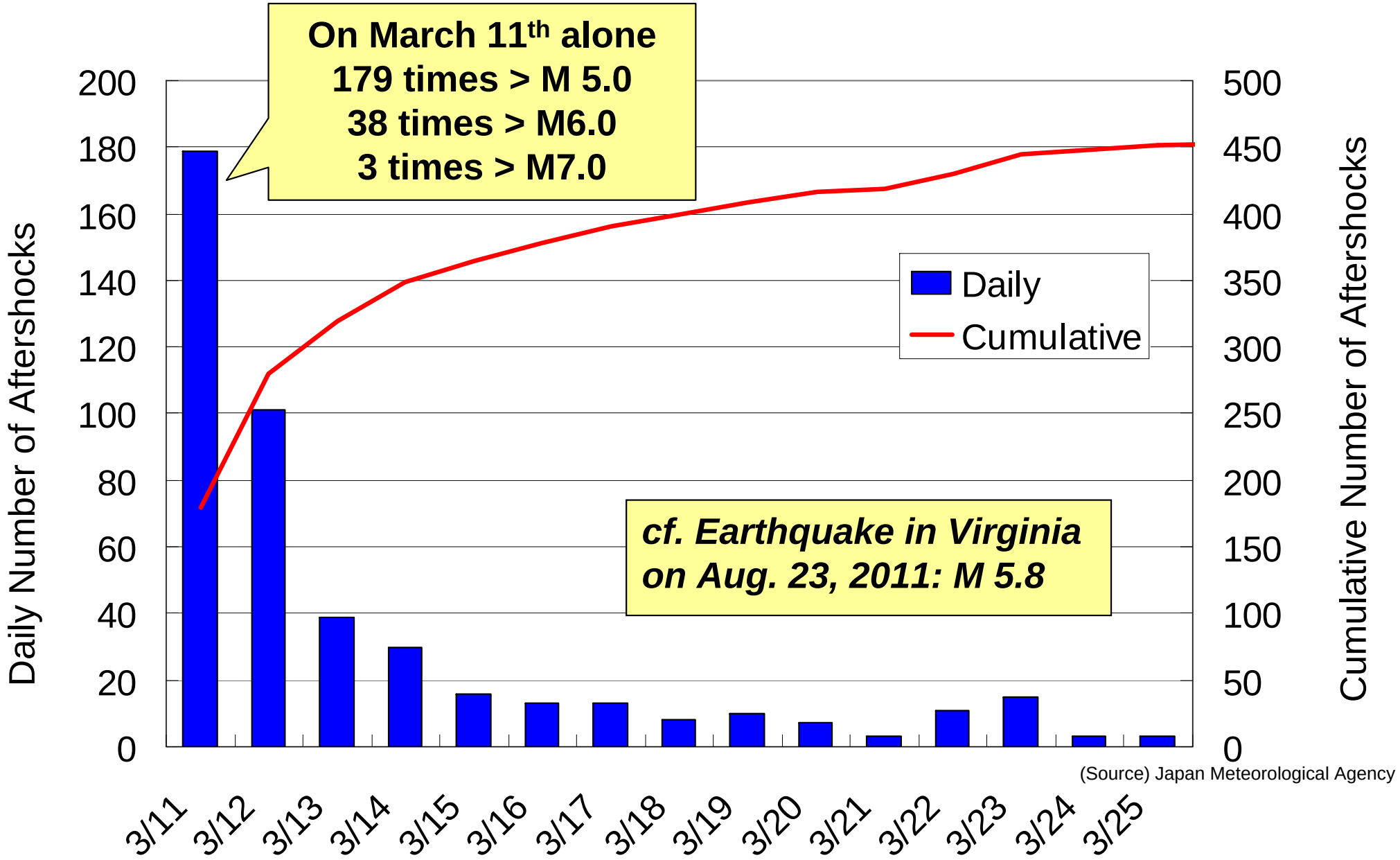
Hundreds of Aftershocks Greater than M 5.0



(Source) Japan Meteorological Agency

Visualization of earthquakes in 2011

http://www.youtube.com/watch?v=eKp5cA2sM28

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Voices from the Field (First Responders at 1F)

- **"In an attempt to check the status of Unit 4 D/G, I was trapped inside the security gate compartment. Soon the tsunami came and I was minutes away from being drowned, when my colleague smash opened the window and saved my life."**
- **"In total darkness, I could hear the unearthly sound of SRV dumping steam into the torus. I stepped on the torus to open the S/C spray valve, and my rubber boot melted."**
- **"Unit 3 could explode anytime soon, but it was my turn to go to the main control room. I called my dad and asked him to take good care of my wife and kids should I die."**

Torus Room

Unit 1 Main Control Room

Voices from the Field (First Responders at 1F) (cont'd)

"At that time, I was conjuring up faces of fellow colleagues who would die with me."
(Masao Yoshida, Site Superintendent)

"I was determined to stay behind to my death; however I was resolved to send my men back home alive."
(Ikuo Izawa, Shift Manager)

"Let me go and vent the containment. I know where the valve is and I can run fast. Let me protect the unit that I love."
(Kazuhiro Yoshida, Deputy Shift Manager)

"The Man Who Saw The Brink of Death"

"Book reveals human drama in Fukushima No. 1 crisis"
The Japan Times 12/11/2012
http://www.japantimes.co.jp/news/2012/12/11/national/book-reveals-human-drama-in-fukushima-no-1-crisis/

TEPCO Internal Investigation Committee Final Report

➢ Issued on June 20, 2012

http://www.tepco.co.jp/en/press/corp-com/release/2012/1205638_1870.html

"Tangible" Countermeasures

- Flood Protection
- High-pressure Injection System
- Depressurization System
- Low-pressure Injection System
- Heat Removal/Cooling System
- Power Supply for Instrumentation
- Post-Core Damage Mitigation
- Common Items
- Mid-to-Long Term Items

"Intangible" Countermeasures

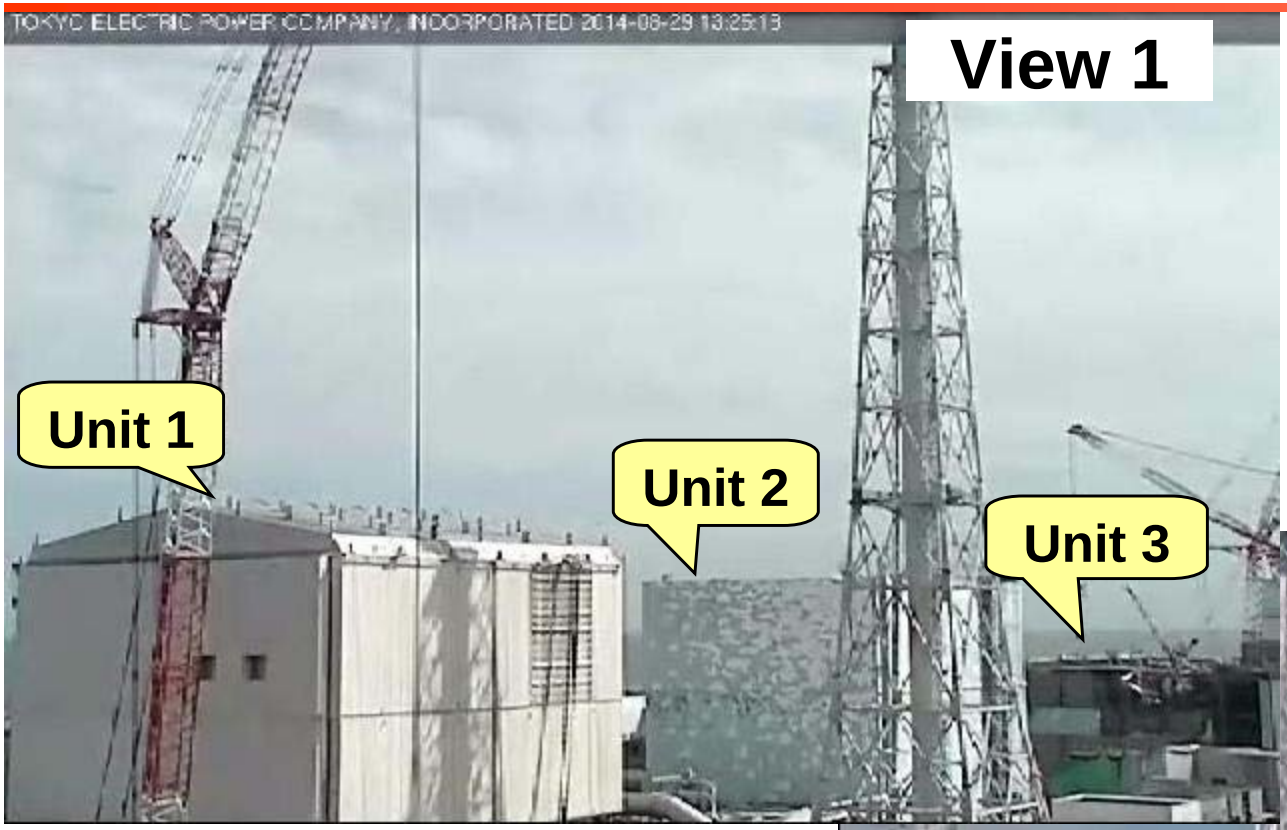
- Operational Measures in Relation to Tangible Modifications
- Emergency Preparedness
- Info. Dissemination and Sharing
- Roles and Responsibilities
- Information Disclosure
- Transportation of Resources
- Access Control
- Radiological Protection
- Plant Status Recognition
- Suggestions to the Government

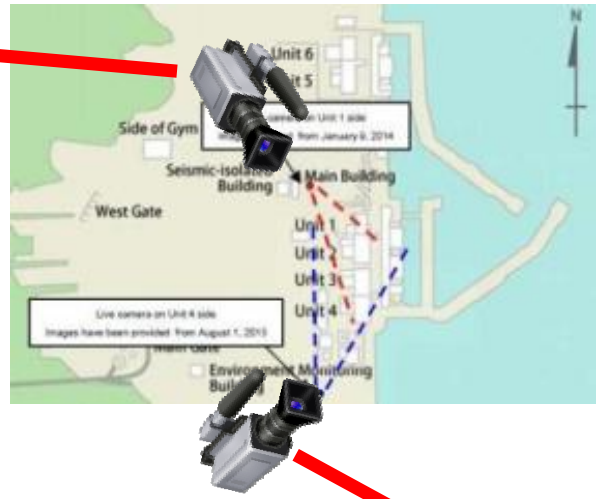
Major Lessons Learned:

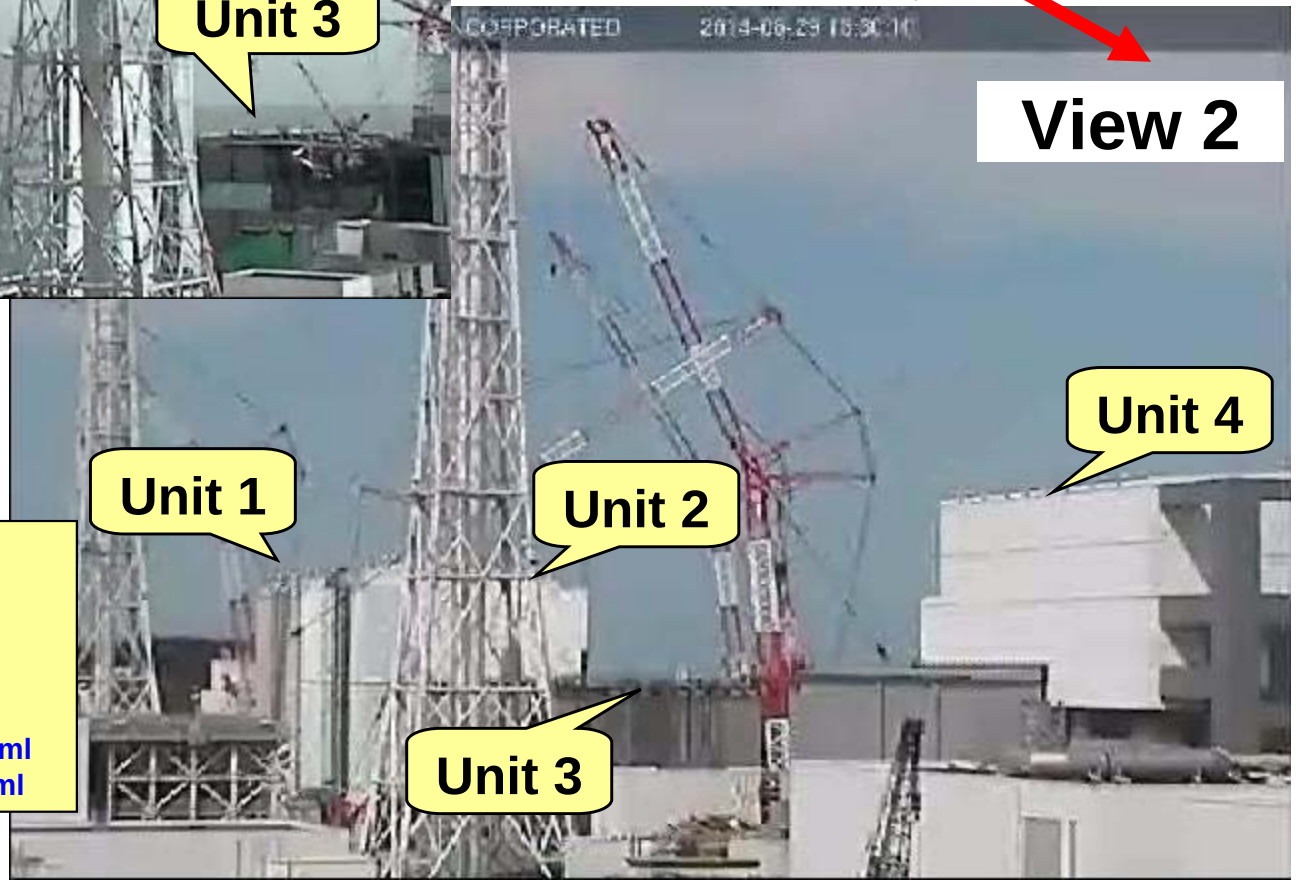
➢ Recognize large uncertainty in external events

➢ Prepare for the unexpected

Current Status of Fukushima Daiichi (1F)



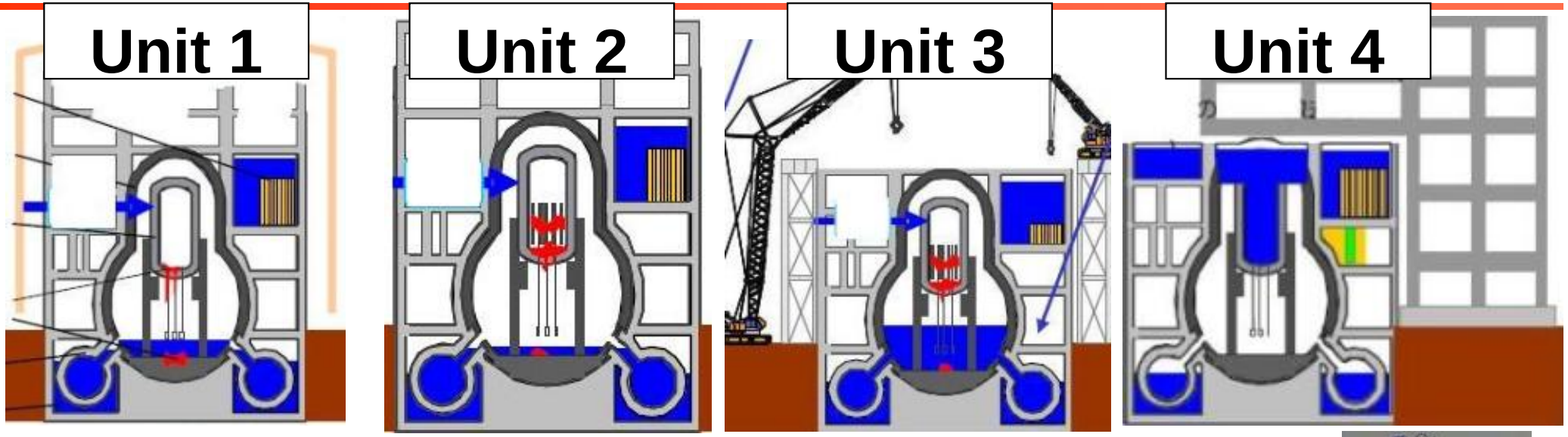




Live Camera View (as of 8/29/2014)

http://www.tepco.co.jp/en/nu/f1-np/camera/index2-e.html
http://www.tepco.co.jp/en/nu/f1-np/camera/index-e.html

Progress Made at 1F



- All reactors and spent fuel pools **stably cooled**
- **Robots utilized extensively** to investigate and decontaminate inside reactor buildings
- **77% of fuel bundles transferred** from Unit 4 to common fuel pool **(as of Sept. 2014)**

Tackling Water Issues at 1F

Emergency and fundamental measures taken to:

- **Prevent groundwater from being contaminated**
- **Prevent contaminated groundwater from flowing into sea**
- **Reduce groundwater inflow into buildings**

Decommissioning Roadmap for 1F

Cold Shutdown Condition Achieved (Dec., 2011)

Within 2 years

Within 10 years

30 to 40 years

Phase-1

Begin removal of fuels from spent fuel pools

Unit 4: Nov. 2013

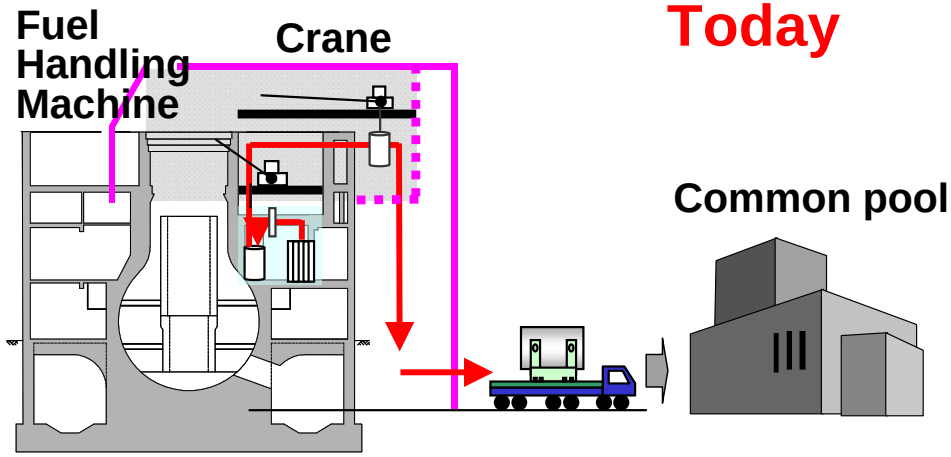
Phase-2

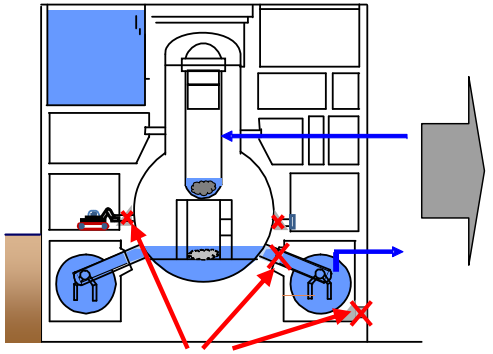
Begin retrieval of fuel debris

Phase-3

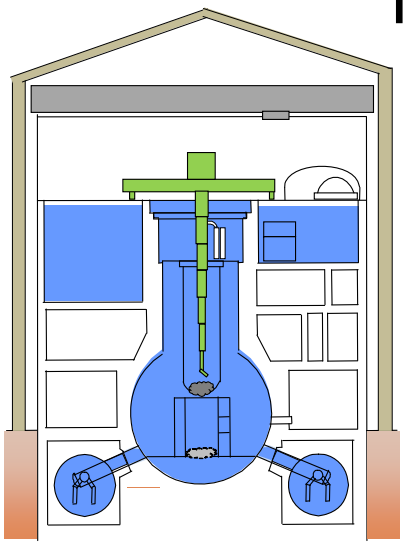
Complete decommissioning

Today





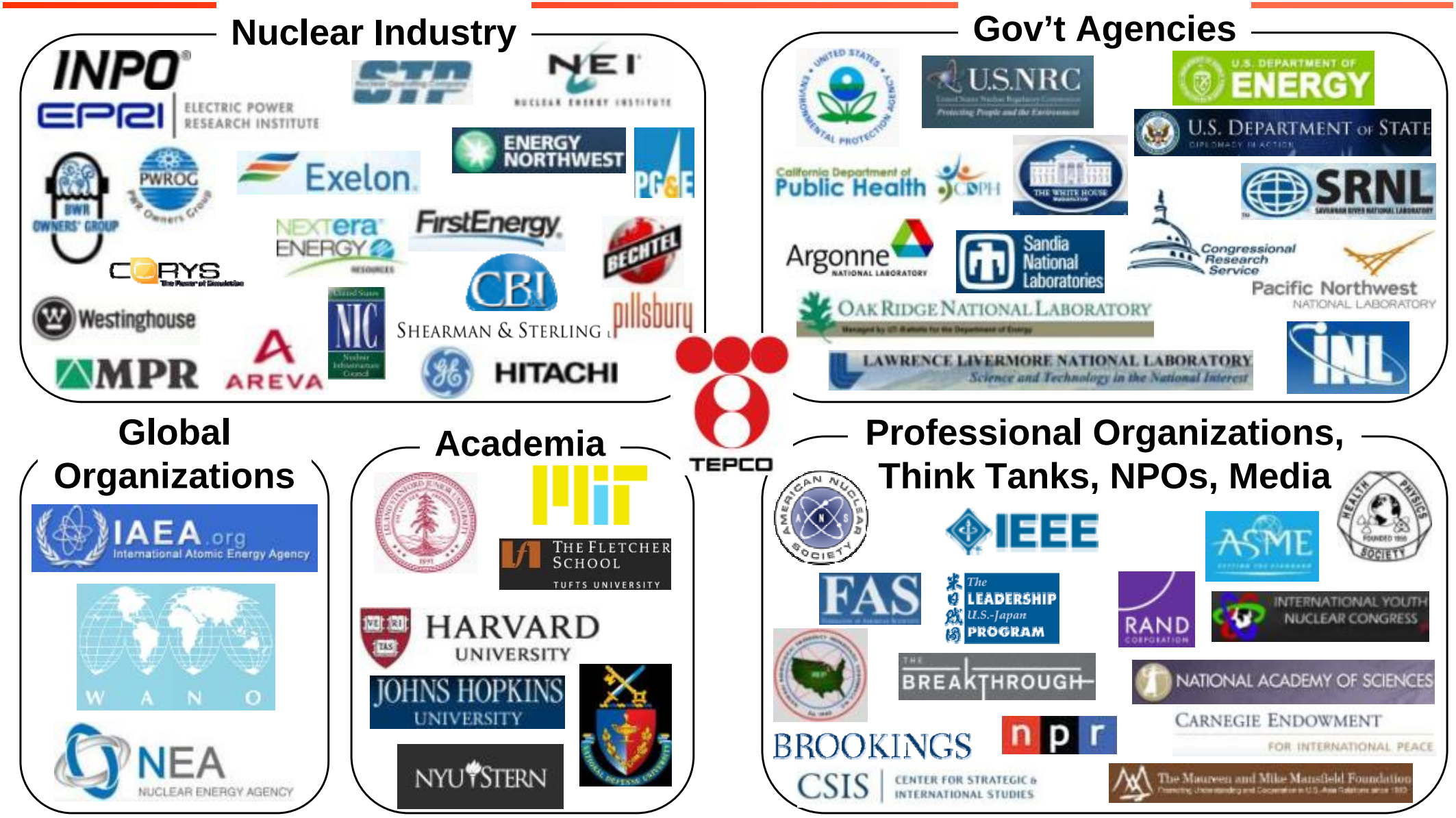
Stop Leakage



Flood PCV and Remove Fuel Debris

Global collaboration vitally important to tackle this unprecedented undertaking

TEPCO's Post-Accident Activities in the U.S.



Committed to sharing lessons learned; making nuclear power plants safer; carrying out decommissioning safely

References

[Japan]

- Tokyo Electric Power Company (TEPCO)
  http://www.tepco.co.jp/en/nu/fukushima-np/index-e.html
  http://www.tepco.co.jp/en/decommision/index-e.html
- Nuclear Reform Monitoring Committee of TEPCO
  http://www.nrmc.jp/en/index-e.html
- Ministry of Economy, Trade and Industry (METI)
  http://www.meti.go.jp/english/earthquake/
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  http://www.genanshin.jp/english/index.html

[USA]

- Institute of Nuclear Power Operations (INPO)
  http://www.nei.org/Master-Document-Folder/Backgrounders/Reports-And-Studies/Lessons-Learned-from-the-Nuclear-Accident-at-the-F
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  http://safetyfirst.nei.org/japan/
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  http://www8.nationalacademies.org/cp/projectview.aspx?key=49465
  http://www.nap.edu/catalog.php?record_id=18294

[International]

- International Atomic Energy Agency (IAEA)
  http://www.iaea.org/
- World Association of Nuclear Operators (WANO)
  http://www.wano.info/
- United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)
  http://www.unscear.org/unscear/en/publications/2013_1.html
- World Health Organization (WHO)
  http://www.who.int/mediacentre/news/releases/2013/fukushima_report_20130228/en/