

# **Fukushima Nuclear Accident**

*~A TEPCO Nuclear Engineer's Perspective~*

*Presentation for the American Nuclear Society  
Washington DC Local Section*

*Rockville, Maryland*

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# 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)*



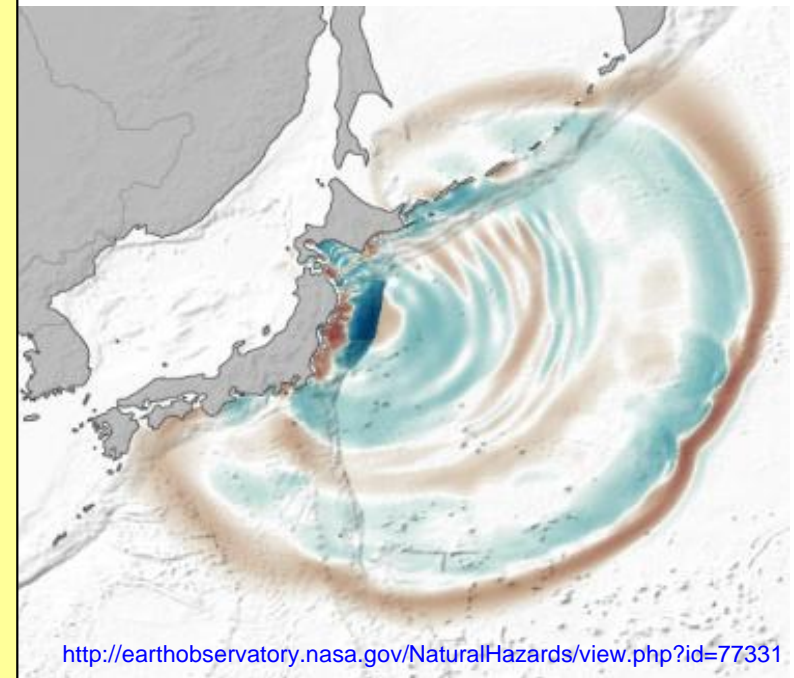
*Pursued "Nuclear  
Renaissance" in Texas  
(June 2010)*



# My Background (cont'd)

- '90~'96: Kyoto University  
BS/MS in Nuclear Engineering
- '96~: TEPCO
  - '96~'00: Fukushima Daini NPS
  - '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**

**Then,  
everything  
changed...**



***Great East Japan  
Earthquake  
(March 11, 2011)***

# My Post-Accident Activities



# My Post-Accident Activities (cont'd)



**Preparation for IAEA Fact-Finding Mission  
(5/21/2011 @Fukushima Daiichi “*Bedroom*”)**

# My Post-Accident Activities (cont'd)



***“Nothing has been more important in my career than supporting TEPCO”***

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



# Damage Due to Great East Japan Earthquake (GEJE)

Houses Swept Away



<http://archive.shinsai.yahoo.co.jp/>

- **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<sup>2</sup>** flooded (10x Manhattan)
- **19,000 dead/missing**

Cruise Ship Stranded



<http://archive.shinsai.yahoo.co.jp/>

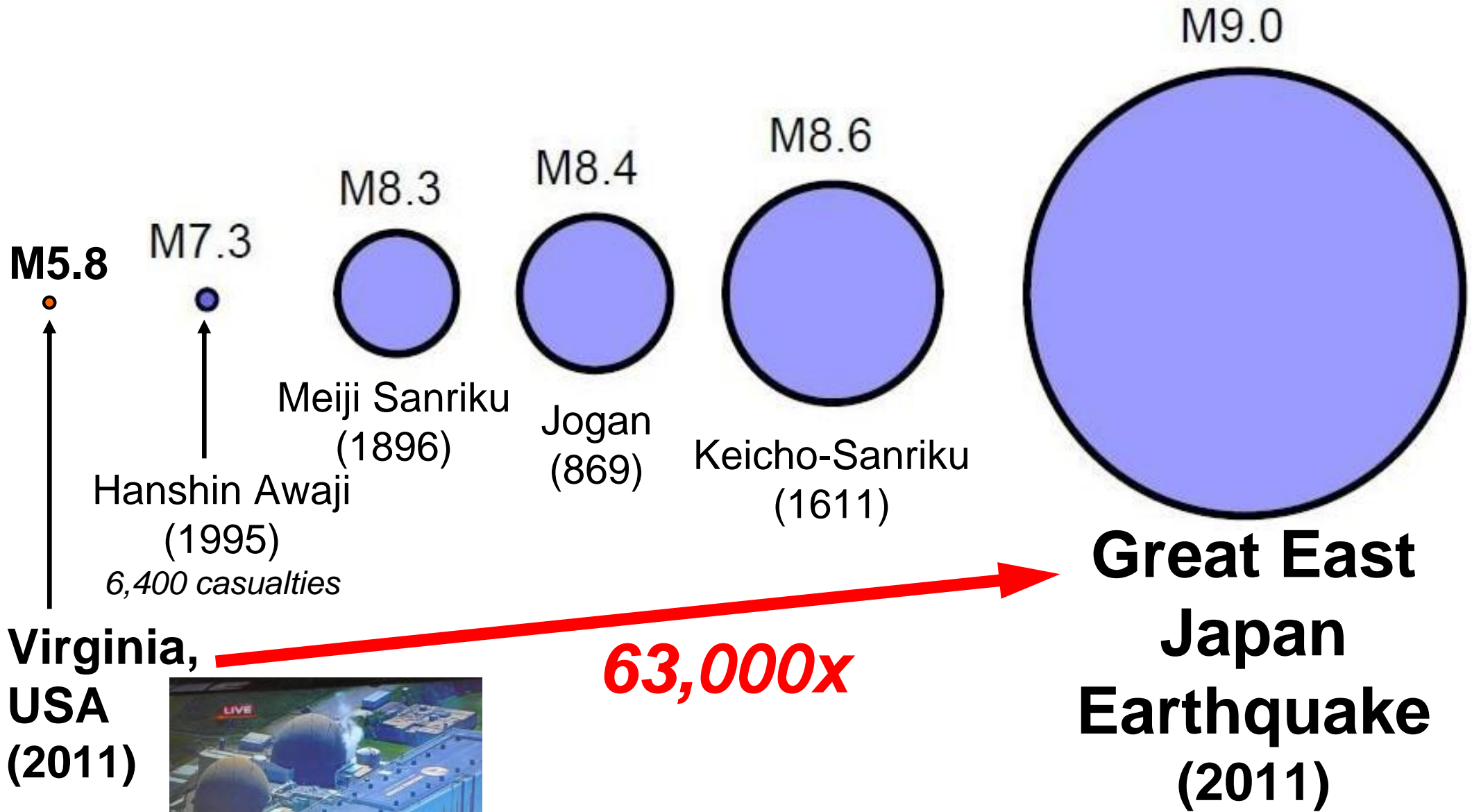
# Operation *Tomodachi* (“Friends”) by U.S. Armed Forces



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



# Comparison of Seismic Energy (Magnitude)



# Impact of GEJE to TEPCO Facilities

## Shutdown:

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

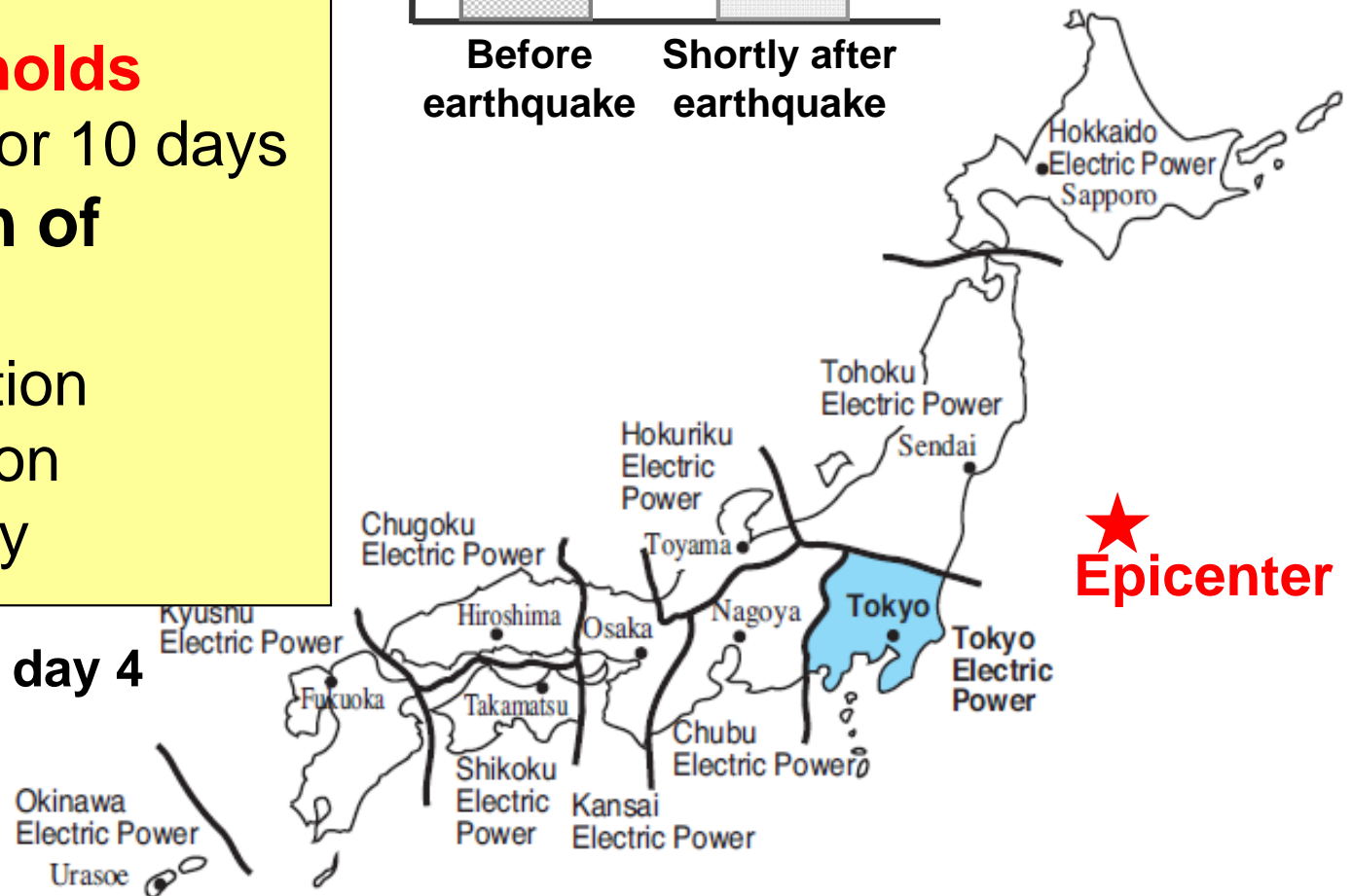
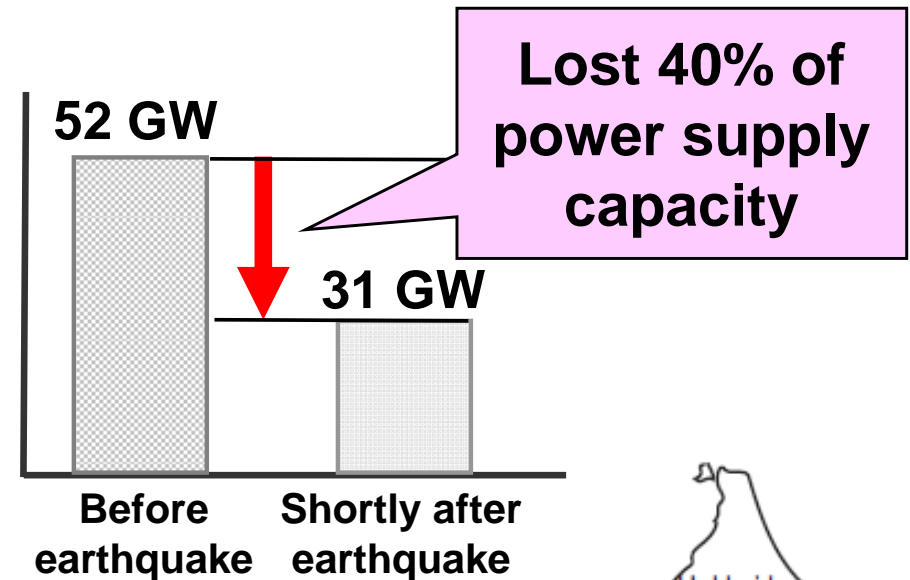
## Power outage:

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

## Massive interruption of infrastructure:

- Public transportation
- Telecommunication
- Food/water supply

>99% of power restored by day 4



# TEPCO's Nuclear Power Stations (17 BWR Units)

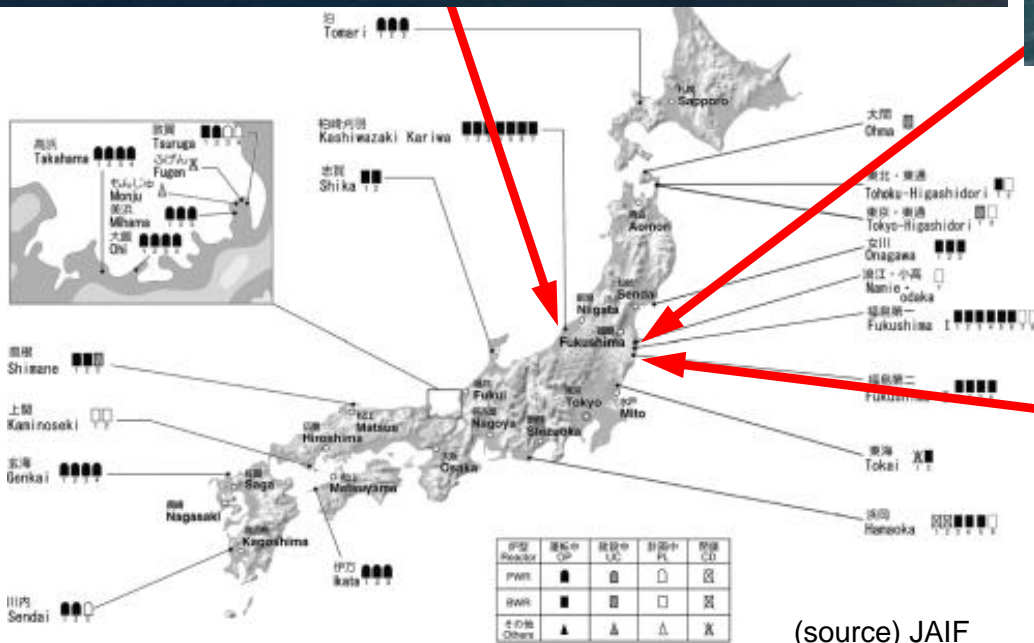
## Kashiwazaki-Kariwa (KK)



## Fukushima Daiichi (1F)

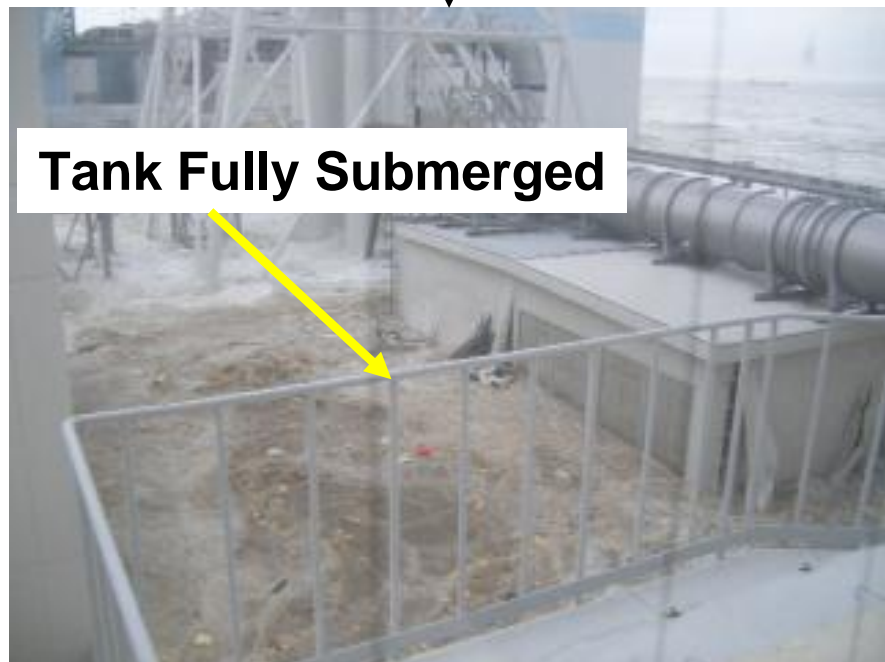
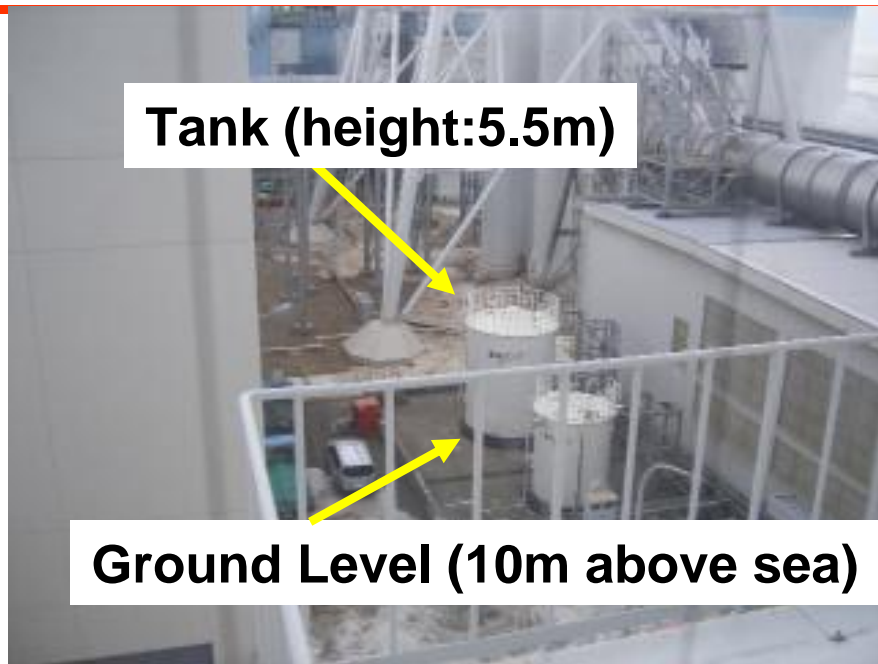


## Fukushima Daini (2F)





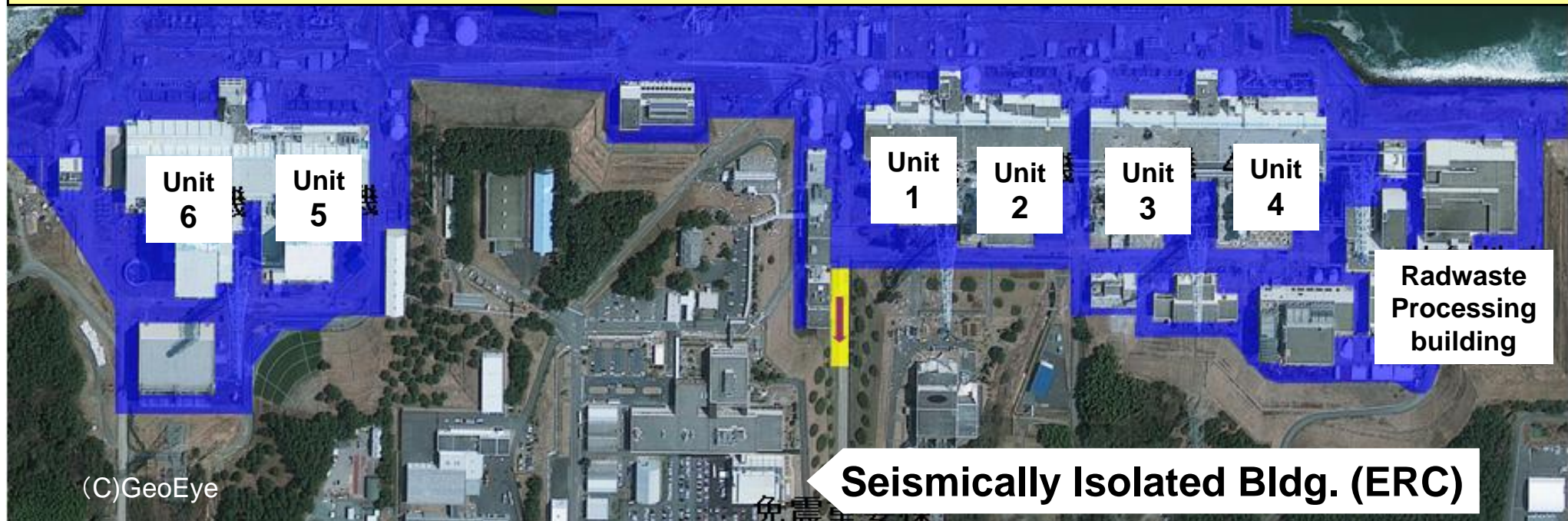
# Tsunami Observed at 1F



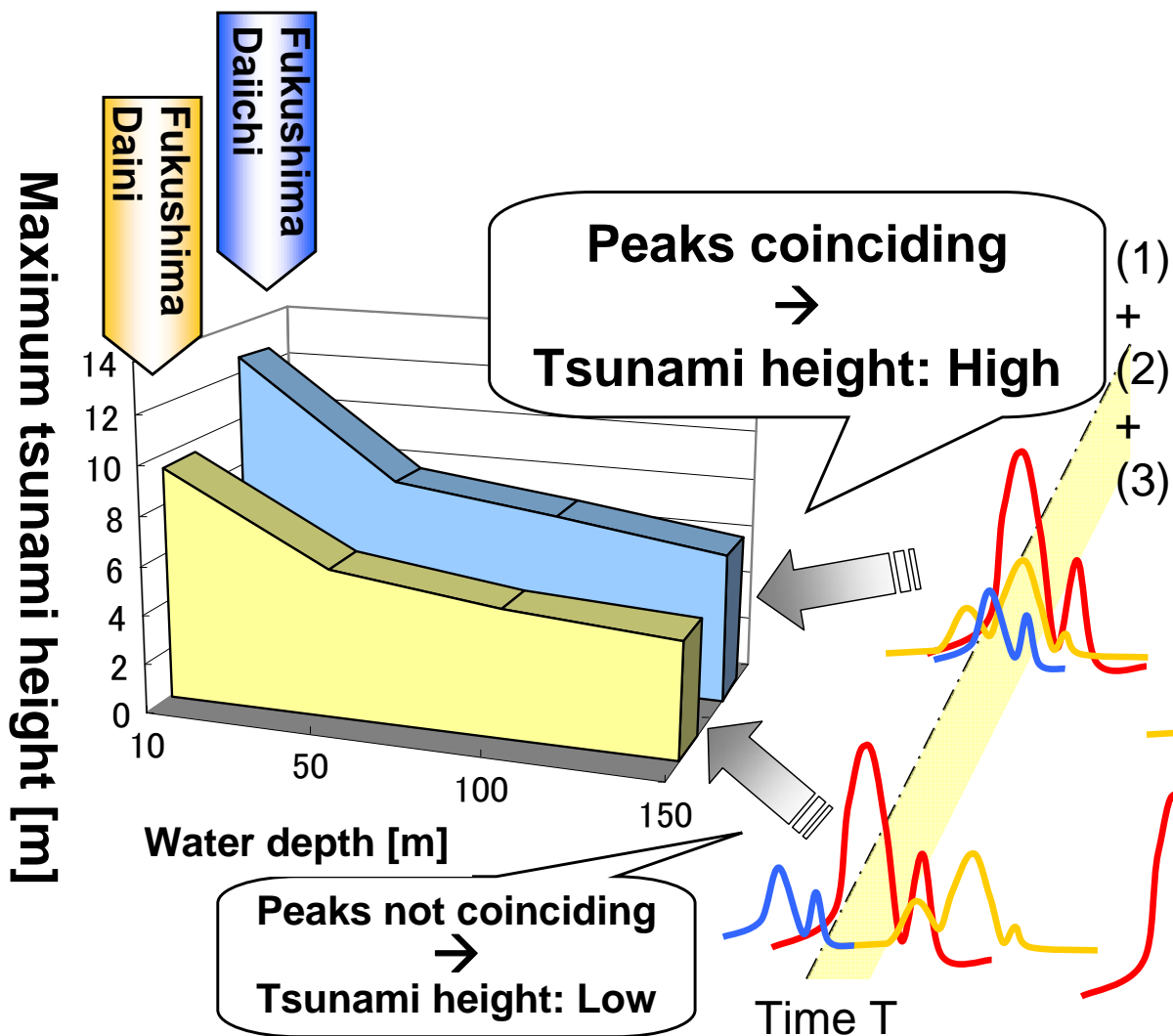


# Impact of Earthquake/Tsunami at 1F

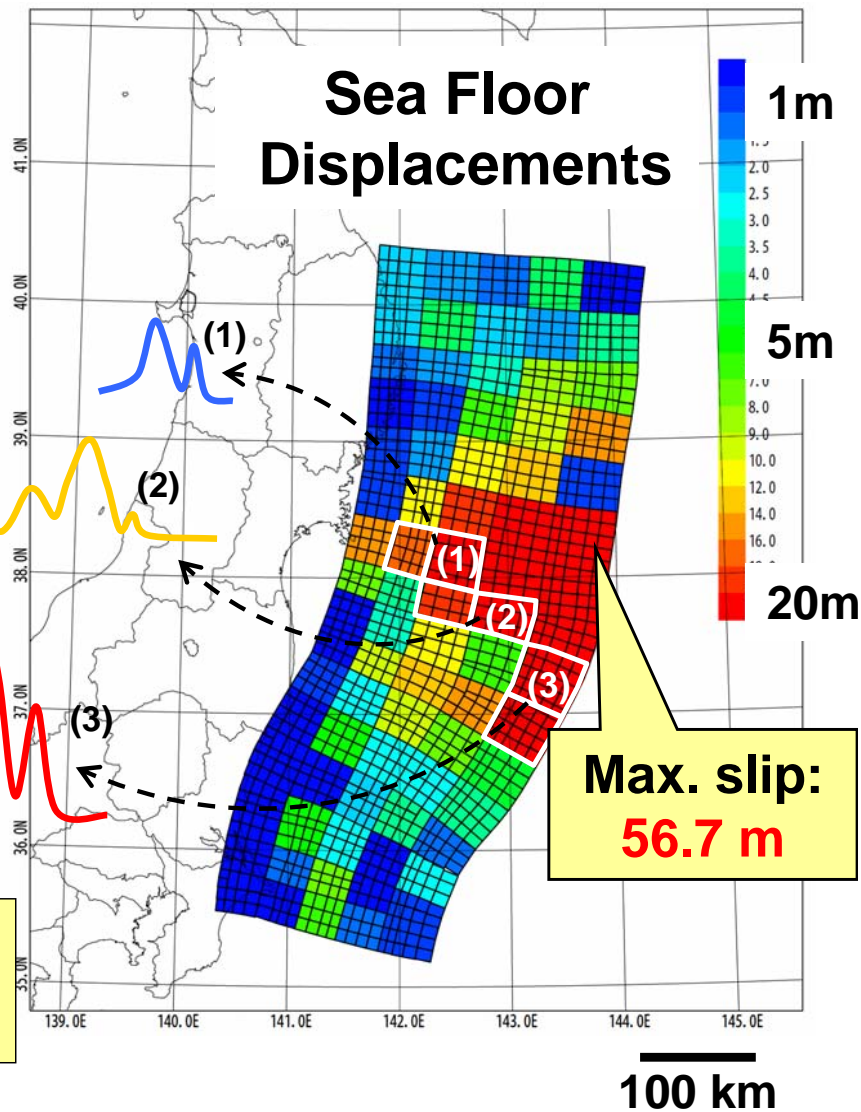
- **After the Earthquake (near design-basis):**
  - ✓ **Loss of all off-site power**
  - ✓ **Plant responded as designed** (automatic shutdown of operating units/startup of EDGs)
- **After the Tsunami (beyond design-basis):**
  - ✓ Tsunami height (13.1 m): **4x historical-high** and **2x design-basis**
  - ✓ **Station Black Out (SBO)** for 5 out of 6 units
  - ✓ **Loss of almost all safety system, instrumentation, lighting, etc.**



# Amplification of Multiple Tsunami Waves Due to Large-scale Earthquake



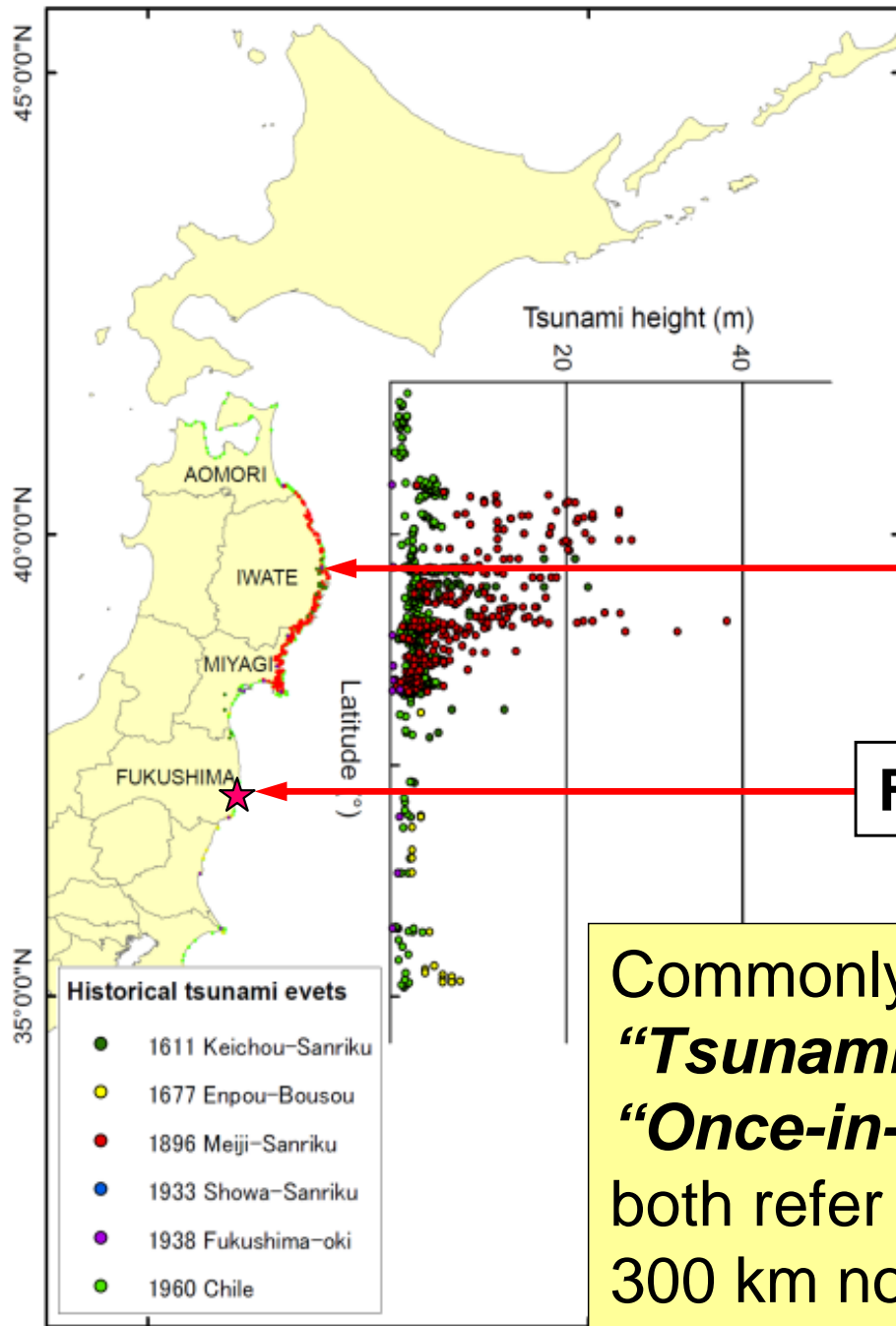
## Postulated Tsunami Model



**No expert/institution predicted large-scale tsunami source of this magnitude**



# No Historical Evidence of Huge Tsunamis Near Fukushima NPSs



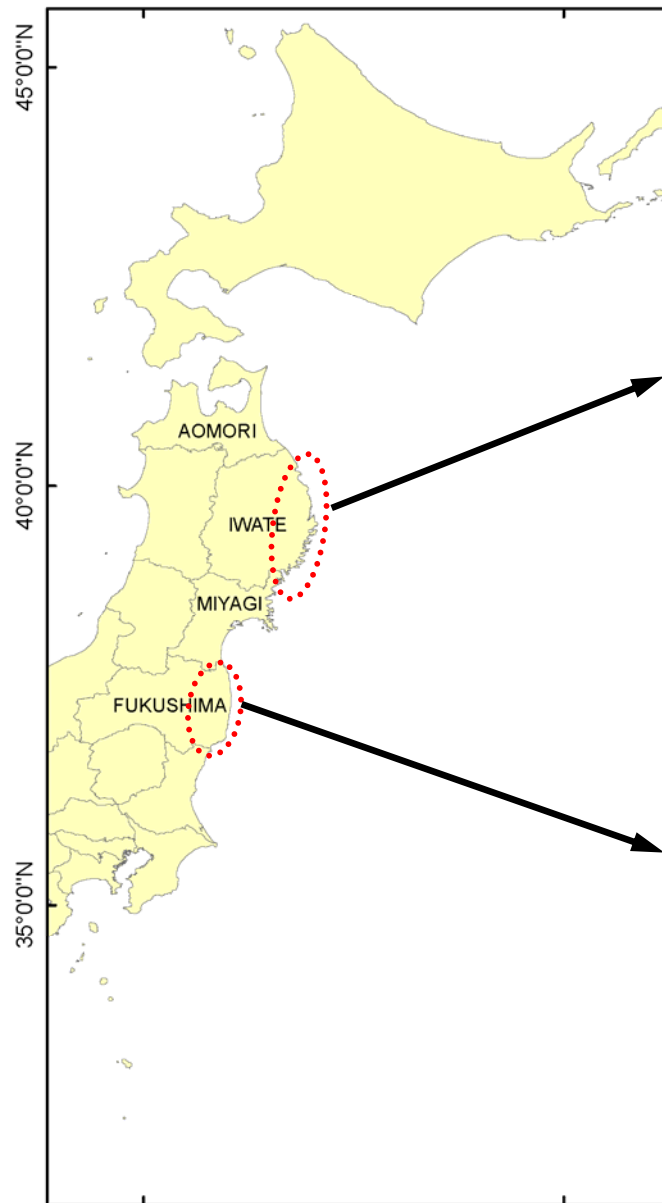
**Tsunami Warning Stone  
(Miyako, Iwate Pref.)**

(source) <http://blog.miyakomall.jp/2012/04/>

**Fukushima NPSs**

Commonly **misquoted**  
***“Tsunami Warning Stone”*** and  
***“Once-in-400-year recurrence of 7-m tsunami”***  
both refer to **locations in Iwate Prefecture**,  
300 km north of Fukushima NPS

# Tsunami Height Heavily Dependent on Coastal Topography



**Iwate has deep-indented coastline that tends to magnify tsunami height**

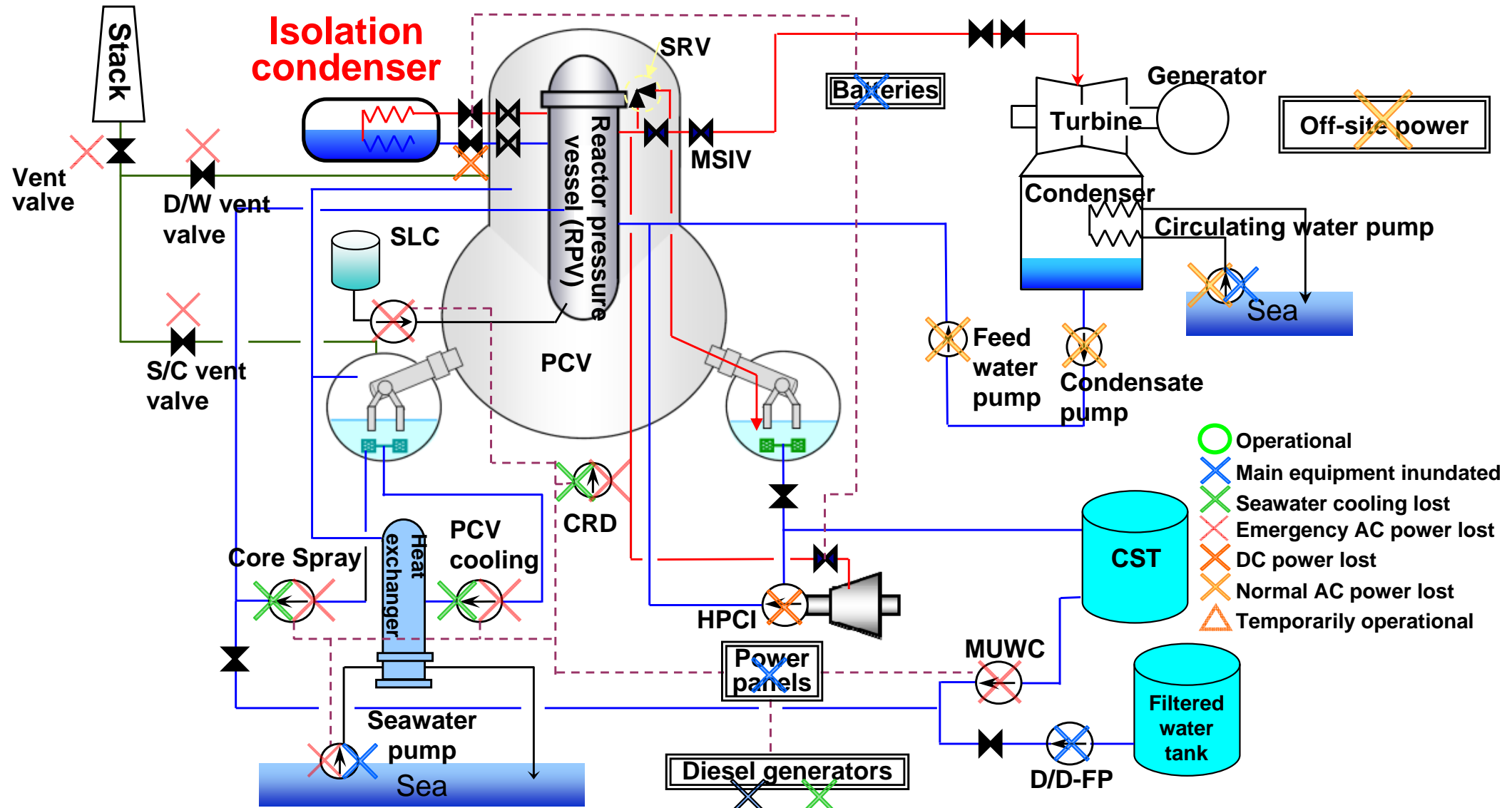


**Fukushima has flat coastline and historically experienced significantly lower tsunami height compared to Iwate**

**However, we should have been prepared for the unexpected**

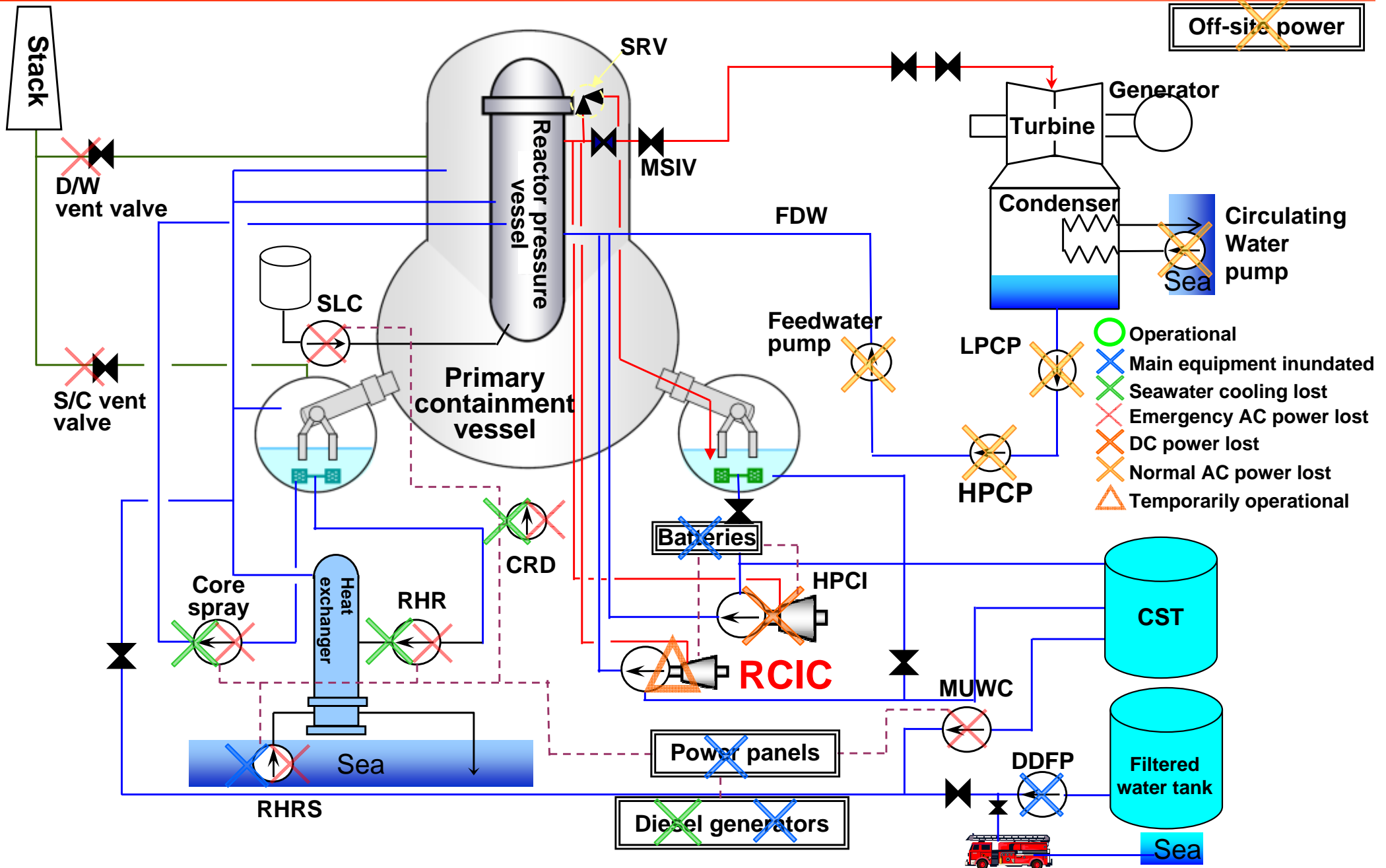


# Plant Status After Tsunami (1F Unit 1: BWR-3/Mk-I)



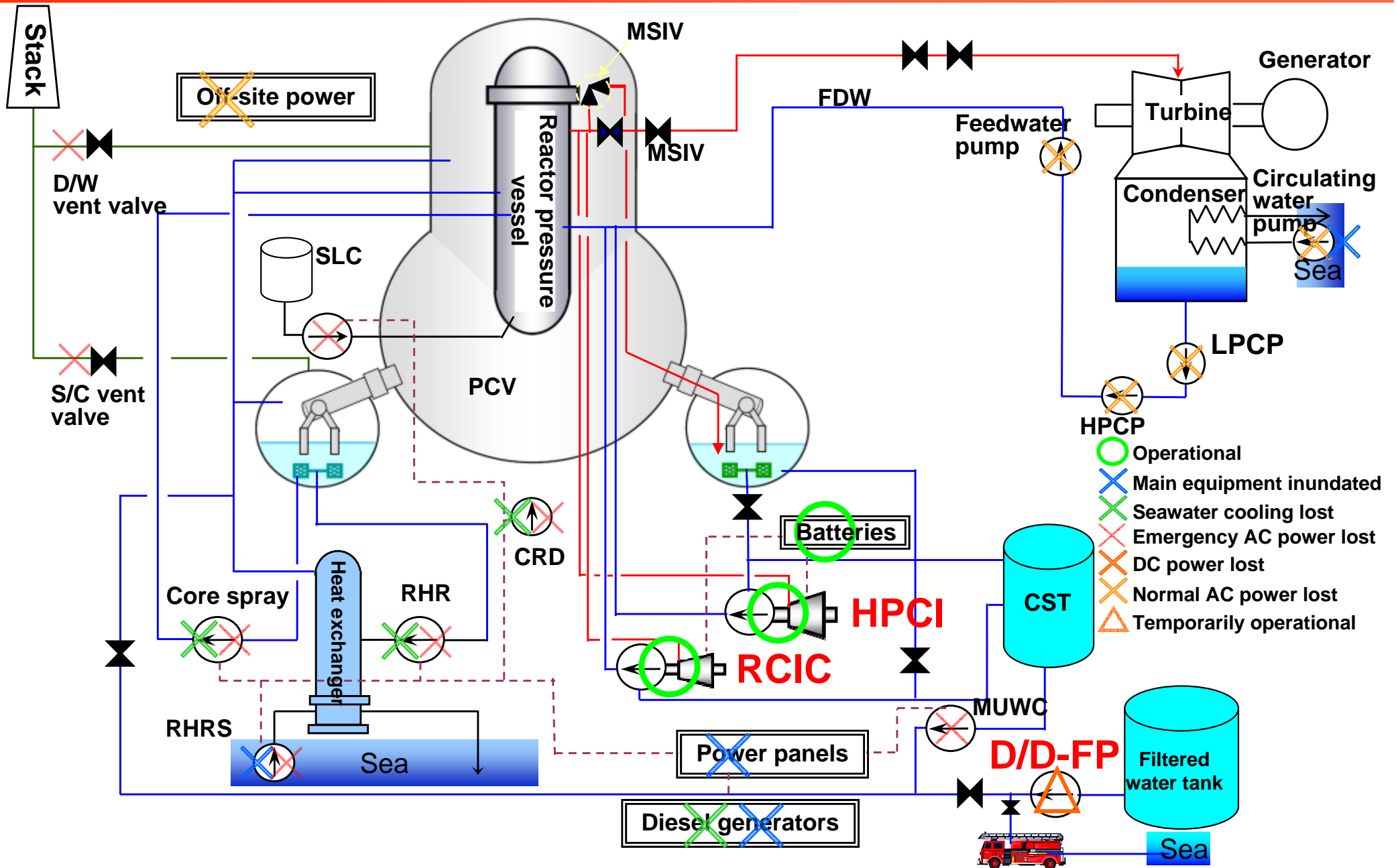
- **Reactor automatically shutdown** after earthquake
- **Loss of all AC/DC power + core cooling capability** due to tsunami
- **Core melt** and Zr-water reaction led to **H2 explosion** in R/B
- **Stabilization by sea water injection** via fire trucks

# Plant Status After Tsunami (1F Unit 2 : BWR-4/Mk-I)



**Turbine-driven RCIC continued to cool core for about 3 days**

# Plant Status After Tsunami (1F Unit 3 : BWR-4/Mk-I)



**Turbine-driven RCIC and HPCI continued to cool the core for about 1.5 days**

# Accident Response at 1F: In the Field



Roads damaged by earthquake

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



Roads blocked by tsunami debris



# Accident Response at 1F: In the Main Control Room



Checked instrumentation in near-complete darkness

Supervised operation wearing full-face mask

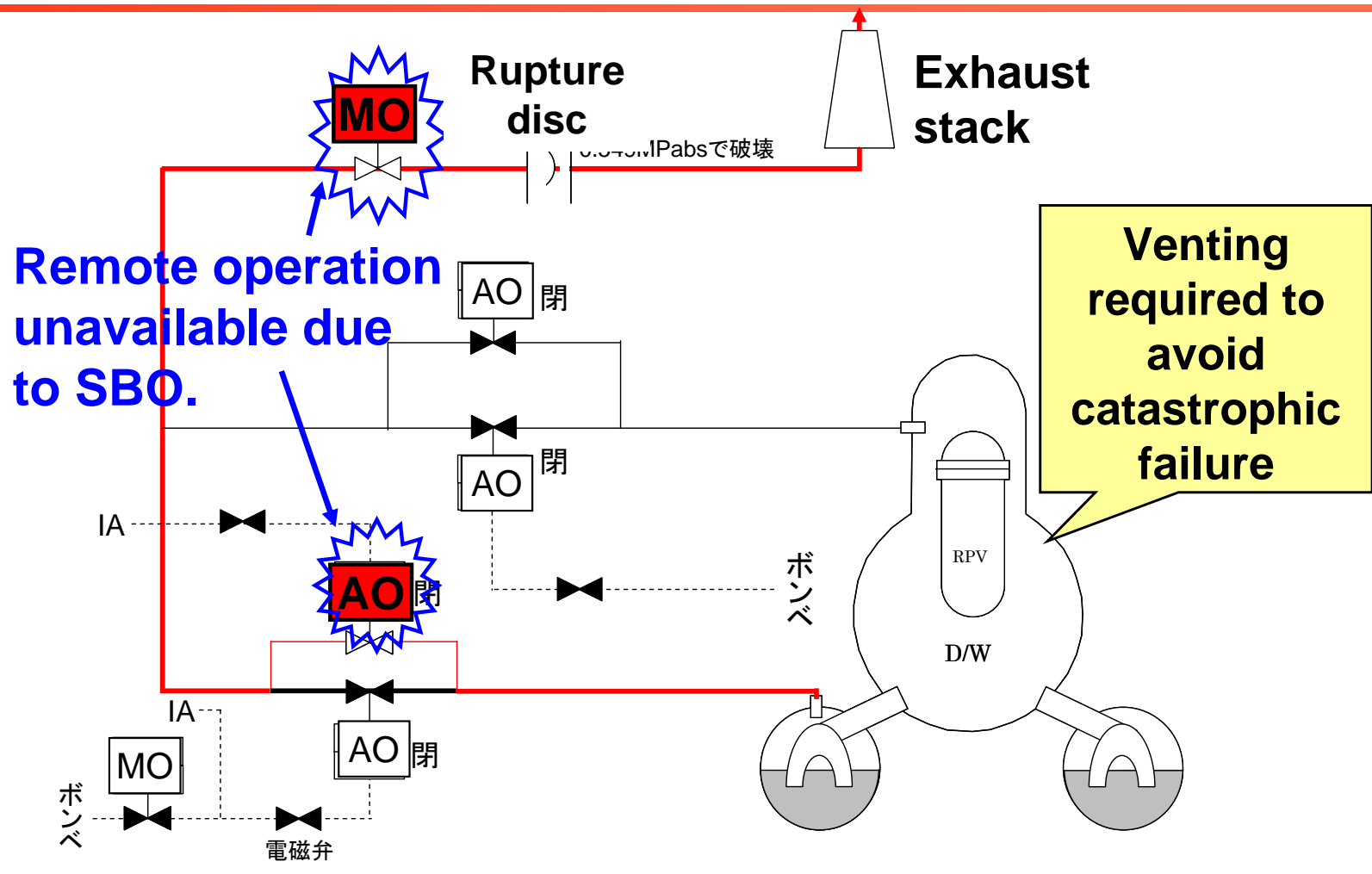


Brought in heavy batteries to restore instrumentations



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

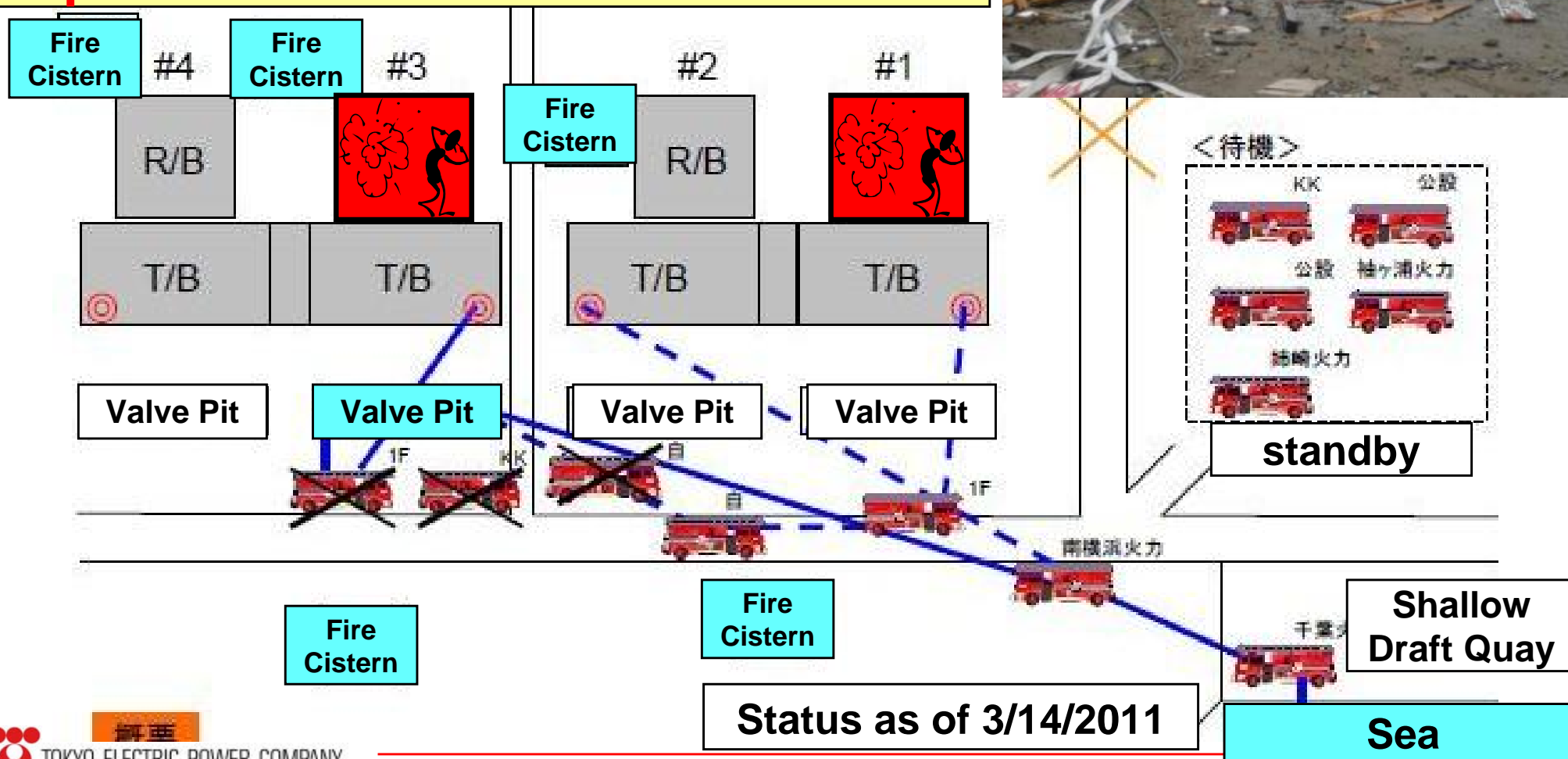
# Accident Response at 1F: Unit 1 Containment Venting



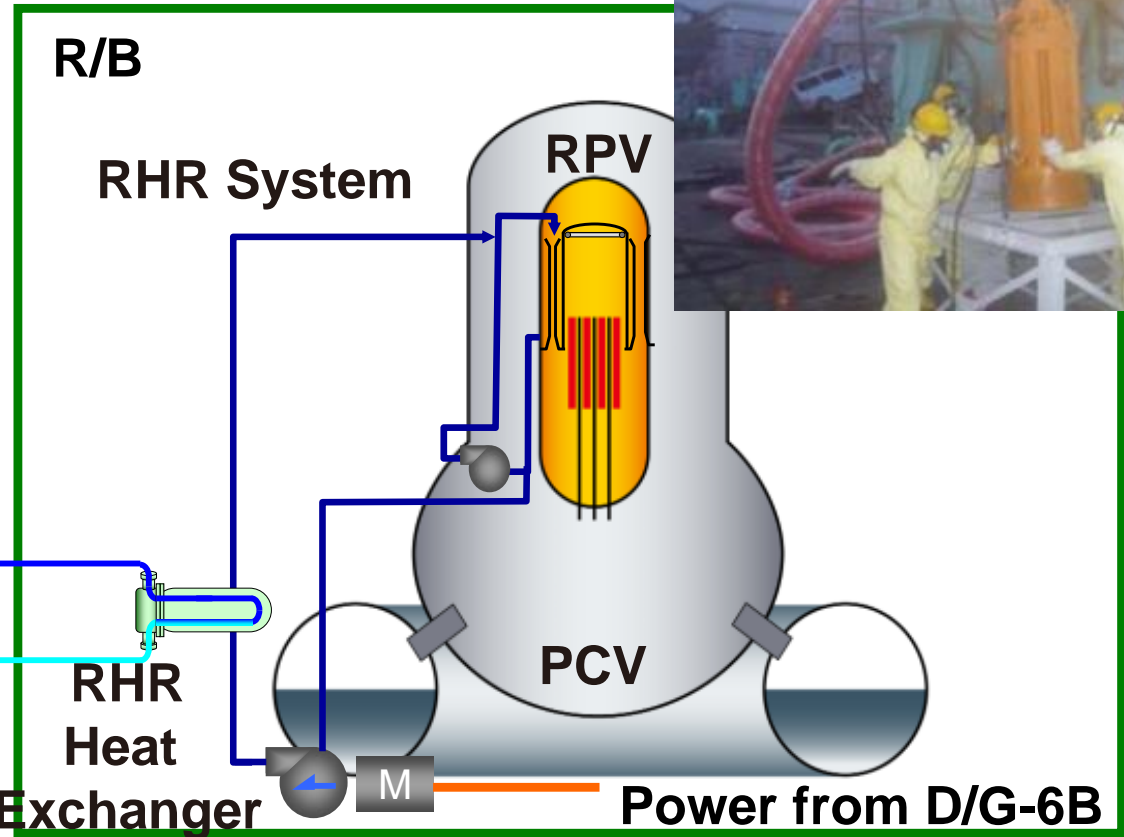
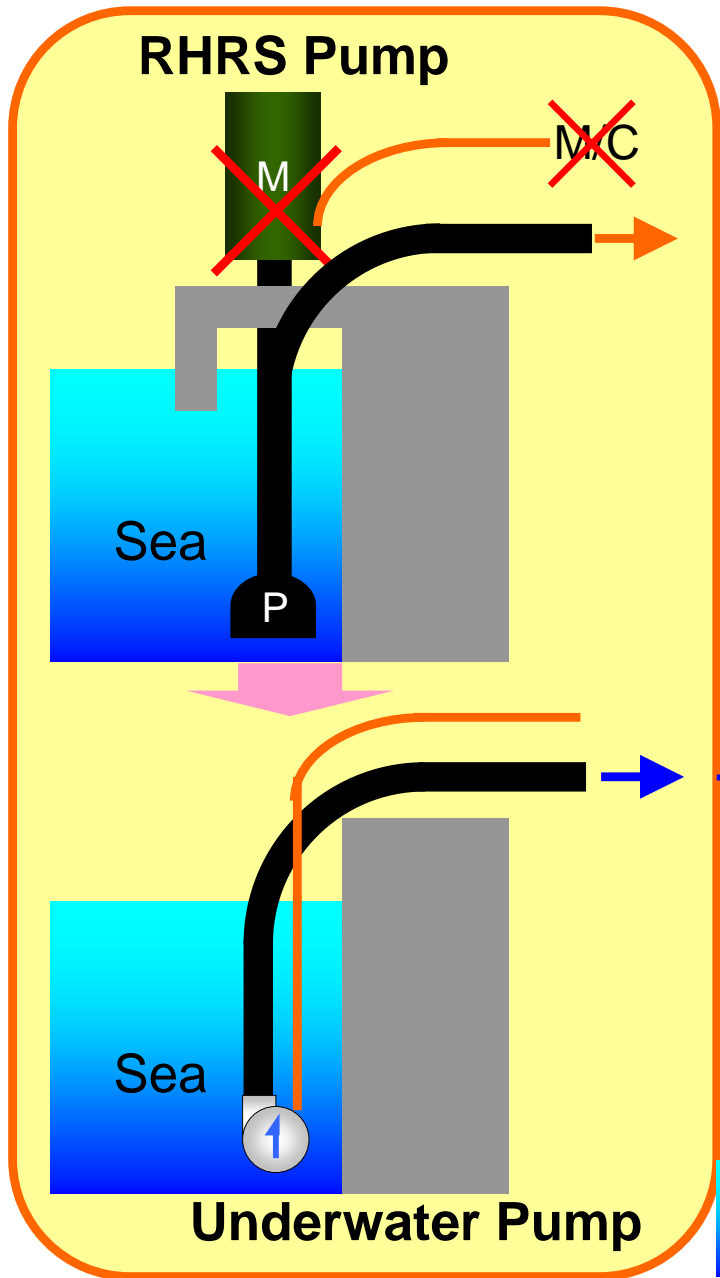
- Six men formed 3 “**last-resort teams**” to manually open 2 valves in **highly-radioactive area**
- Core damage already progressing by this time (3/12 9:04-9:30)

# 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: Protecting Units 5&6

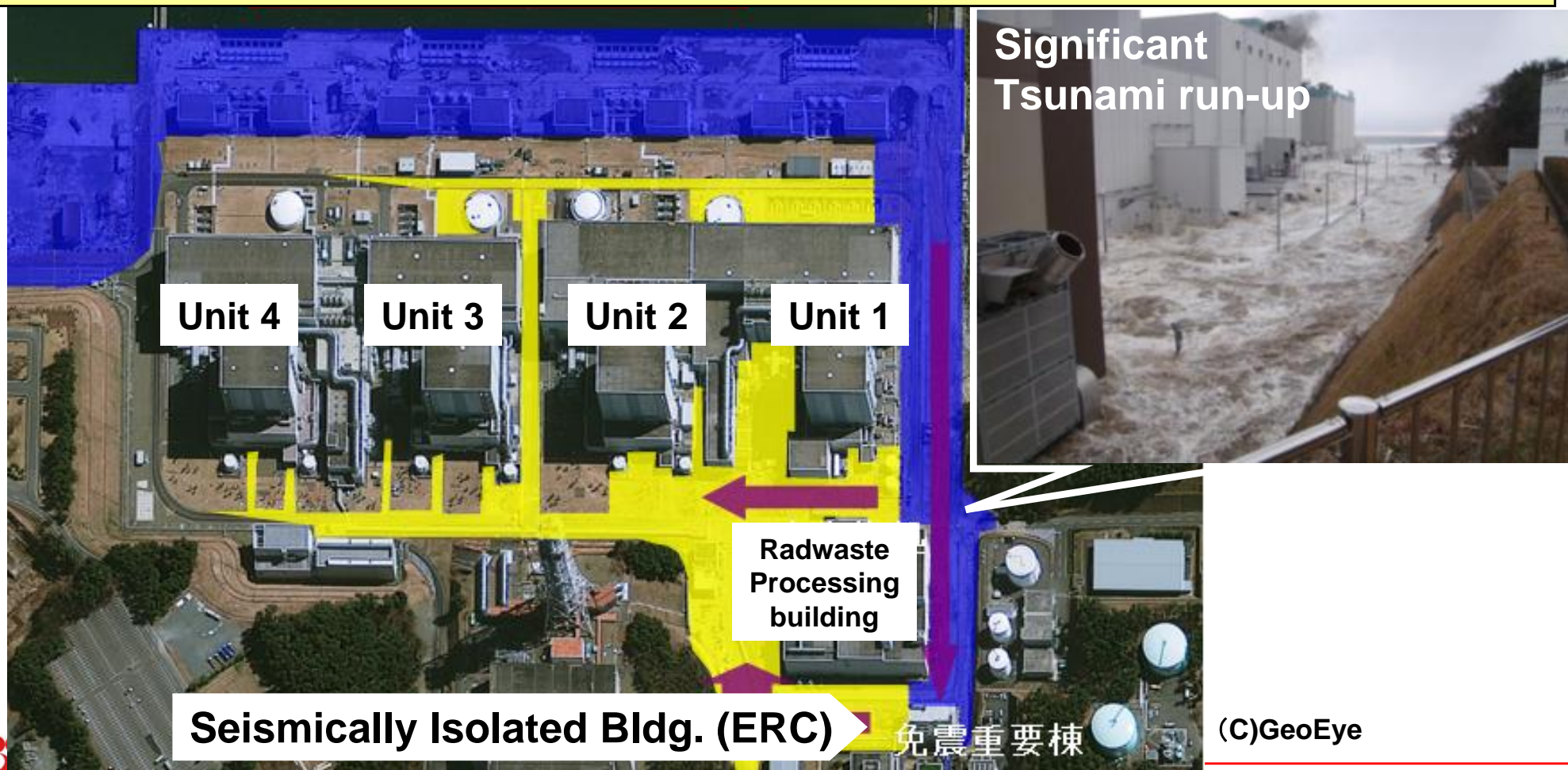


- Ultimate heat sink restored: 3/19
- Cold shutdown achieved: 3/20
- ➔ **Determination to save Units-5/6**



# Impact of Earthquake/Tsunami at 2F

- After the Earthquake (smaller than design-basis):
  - ✓ Loss of all but one line of off-site power
  - ✓ Plant responded as designed
- After the Tsunami (beyond design-basis):
  - ✓ Loss of Ultimate Heat Sink for 3 out of 4 units



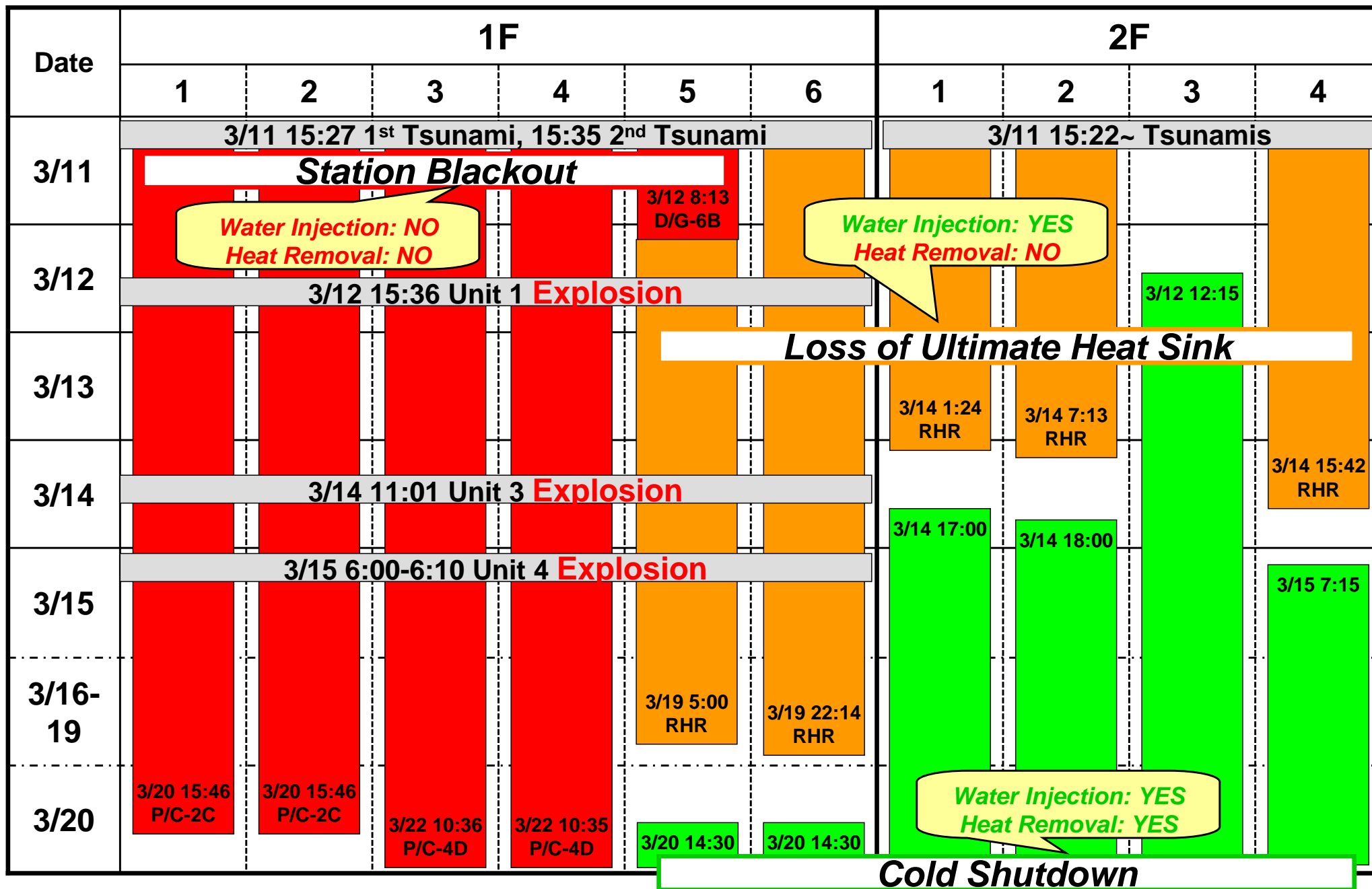
# Accident Response at 2F: Recovery from Tsunami



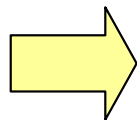
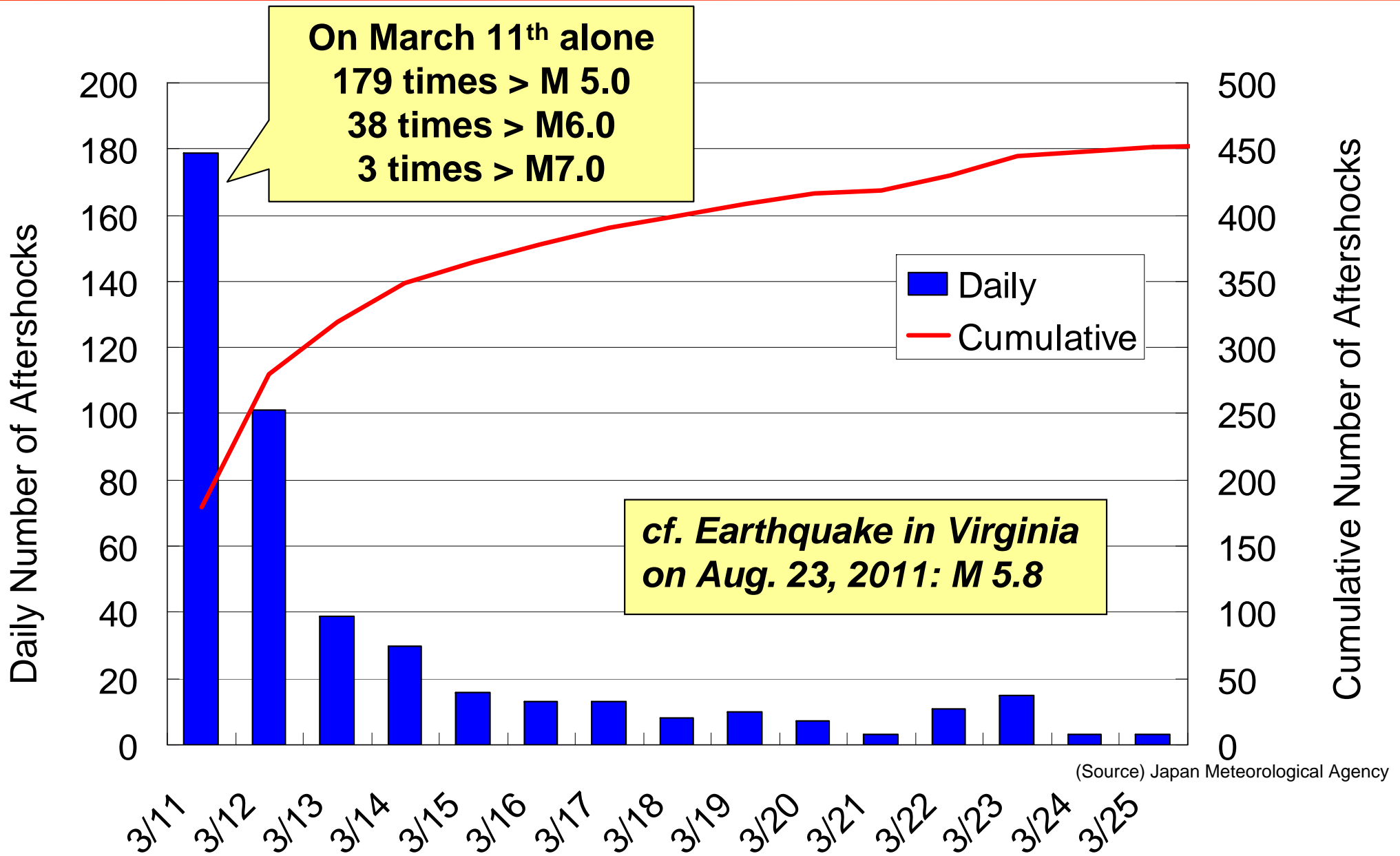
- Restored ultimate heat sink by:
  - ✓ Laying 9 km of heavy power cables by hand
  - ✓ Rapidly procuring and replacing motors
- Executed **“FLEX On-The-Fly”**



# Overview of the 10-Unit Simultaneous Accidents



# Hundreds of Aftershocks Greater than M 5.0



**Visualization of earthquakes in 2011**

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



# Voices from the Field

- “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 (1F)

“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](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**

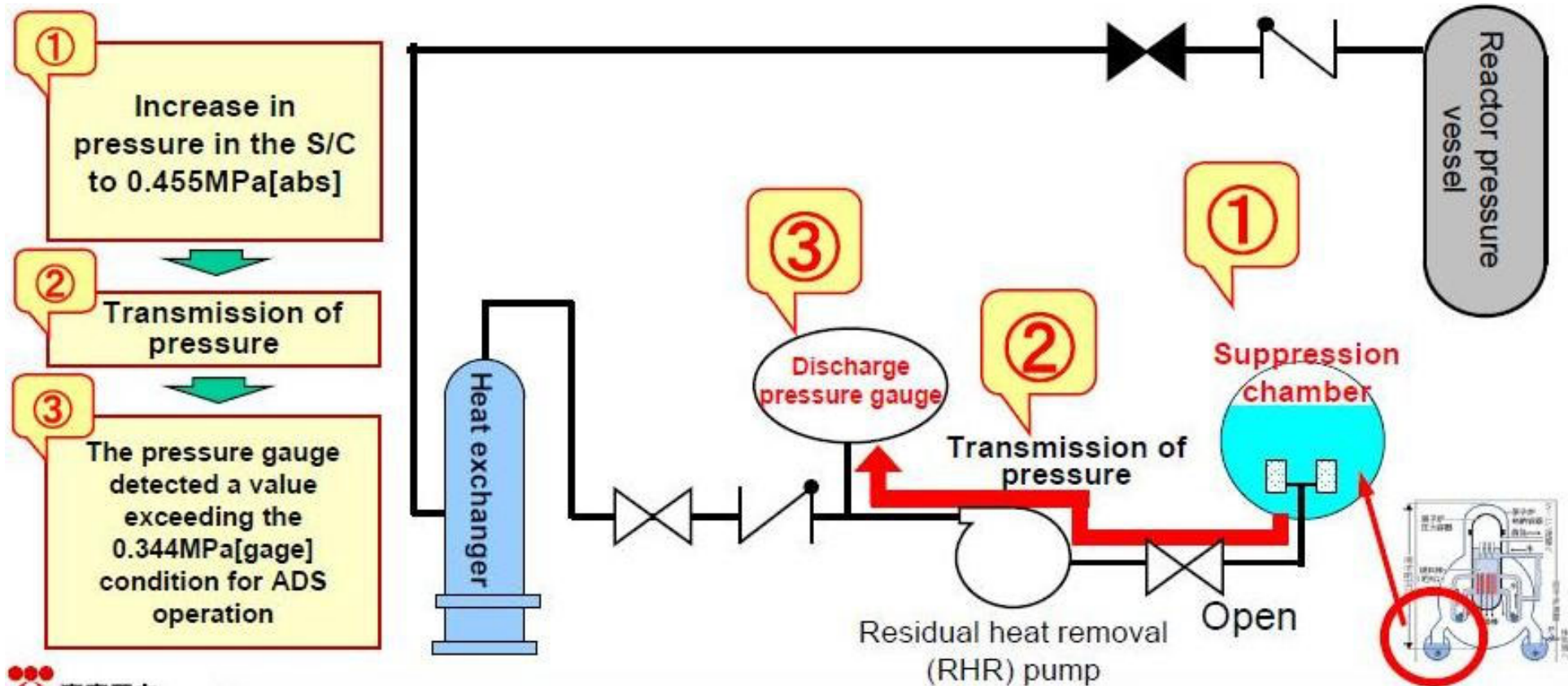


# Follow-up Study on 1F Accident Unresolved Issues

## ➤ 1st Progress Report Issued on Dec. 13, 2013

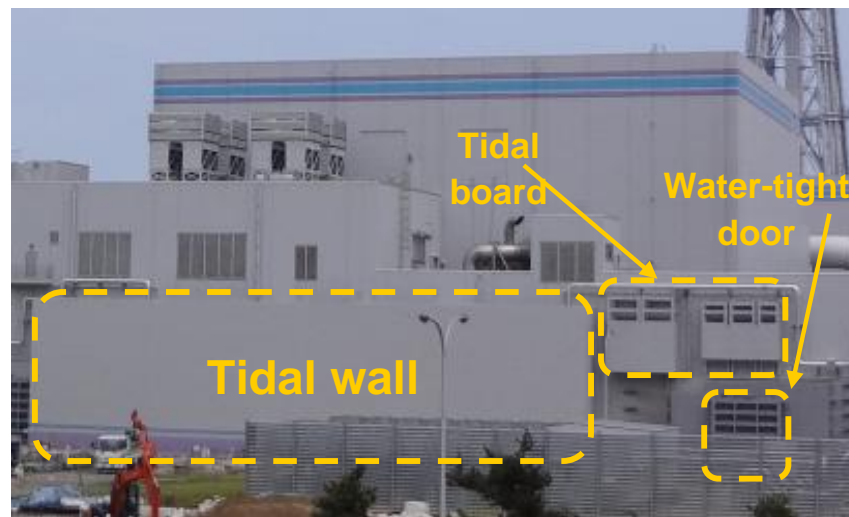
[http://www.tepco.co.jp/en/press/corp-com/release/2013/1233101\\_5130.html](http://www.tepco.co.jp/en/press/corp-com/release/2013/1233101_5130.html)

## ➤ 10 out of 52 Issues Resolved



**Rapid depressurization of Unit 3 RPV caused by **inadvertent ADS actuation**; not by RPV breach**

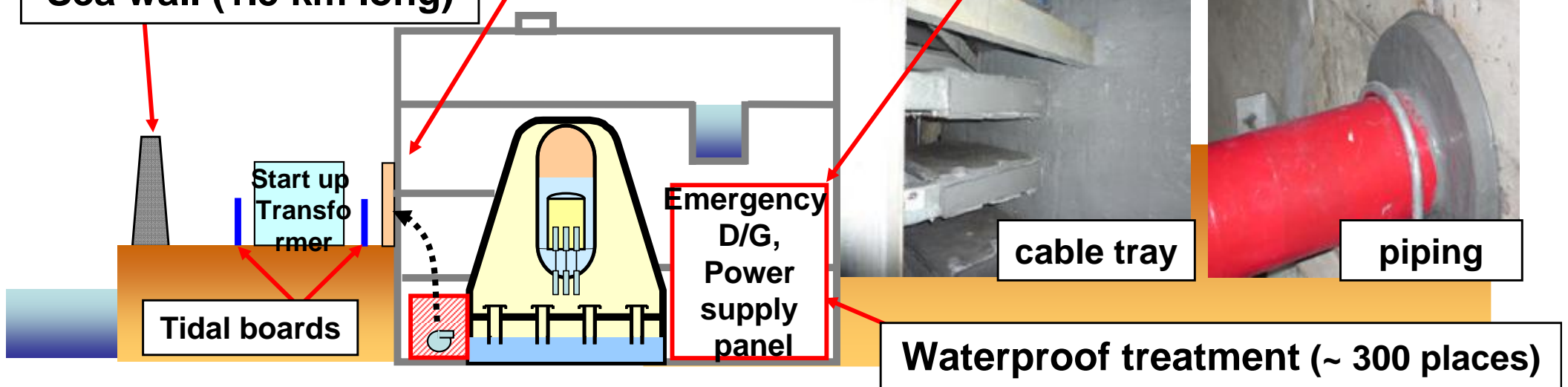
# Safety Enhancement Measures at Kashiwazaki-Kariwa (KK) NPS



Sea wall (1.5 km long)

Tidal walls

Water-tight doors (~60 places)



## Tsunami-induced Accident Prevention Measures

# Safety Enhancement Measures at KK NPS (cont'd)

**High Pressure Alternate Cooling System**



**gas cylinders**



**Fire engines: 8**



**Gas Turbine Generators: 2**

**D/G trucks: 23**



**DC power**



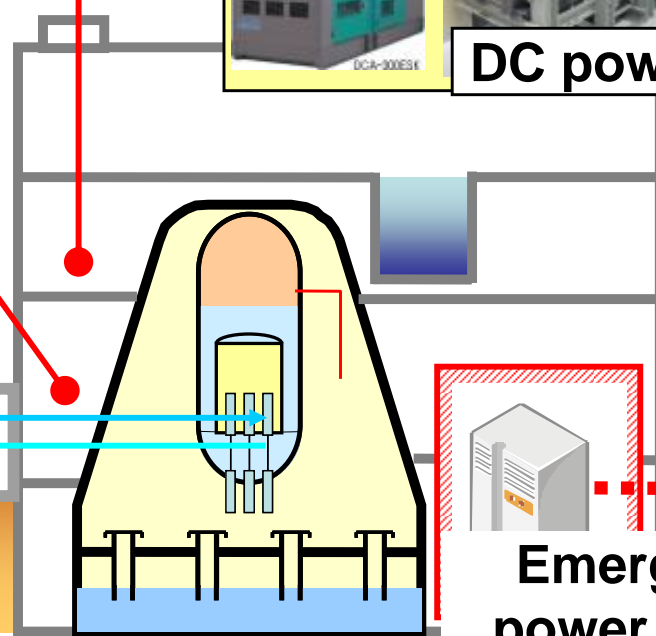
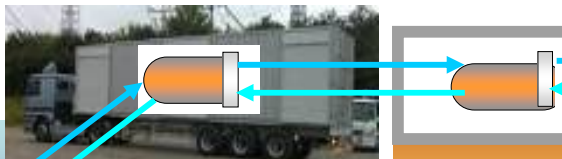
**Emergency power supply**



**Fresh Water Reservoir: 20k ton**



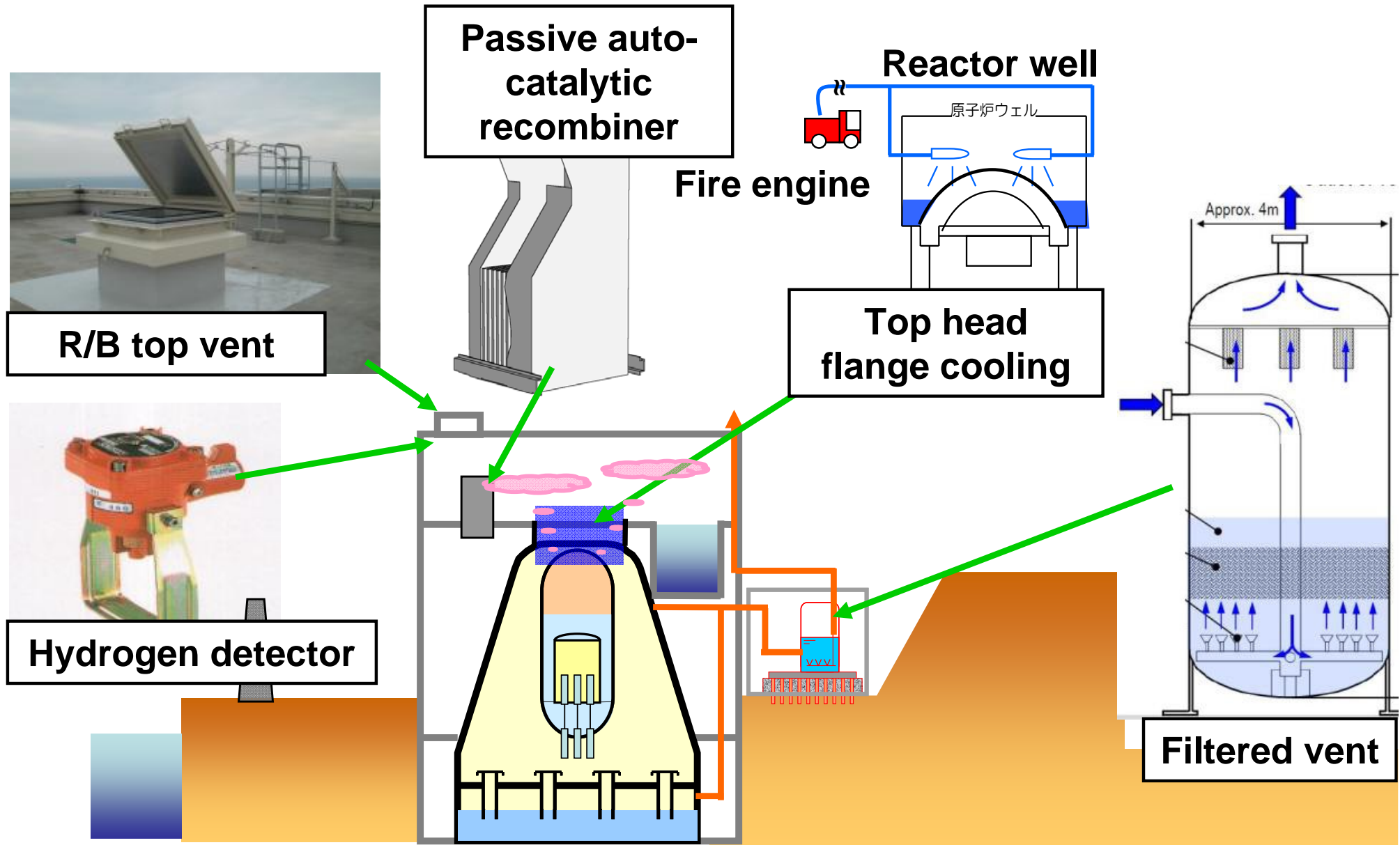
**Alternative heat exchangers: 7**



**Core Damage Prevention Measures**

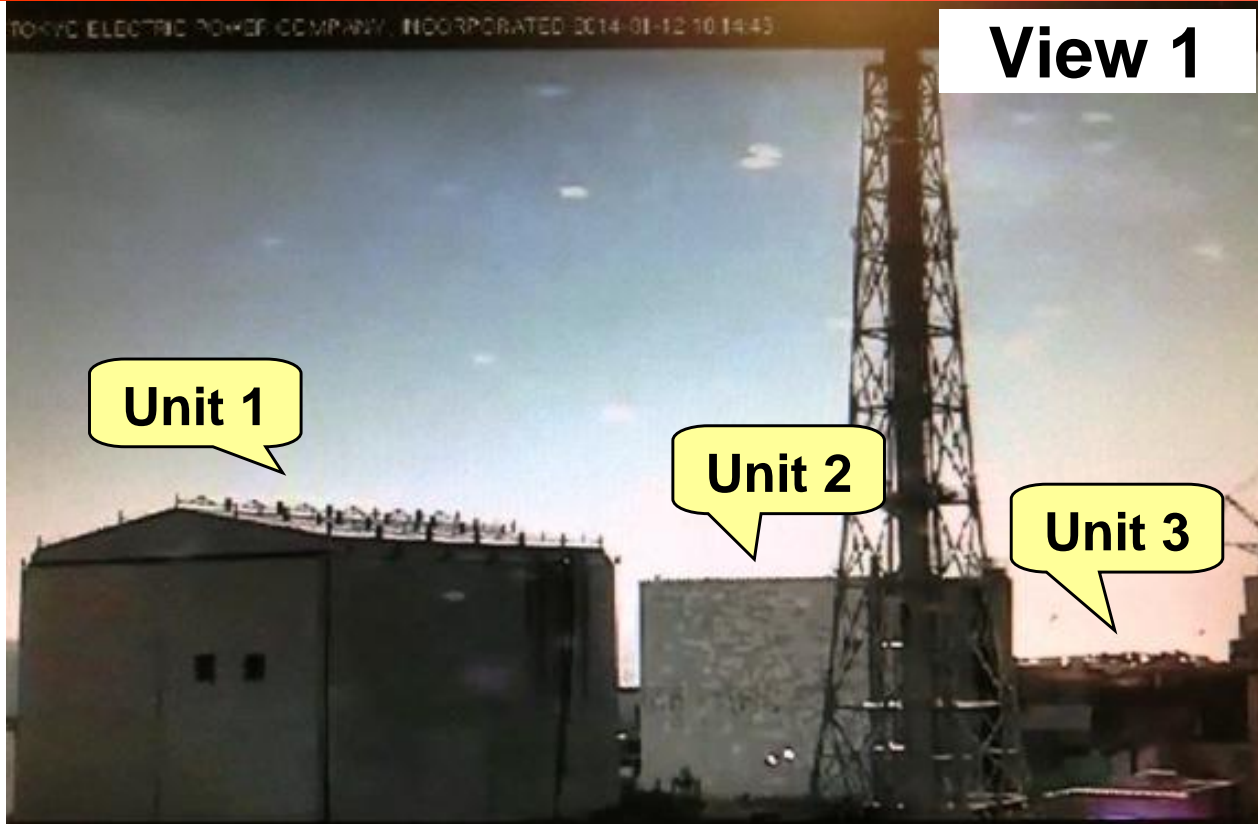


# Safety Enhancement Measures at KK NPS (cont'd)

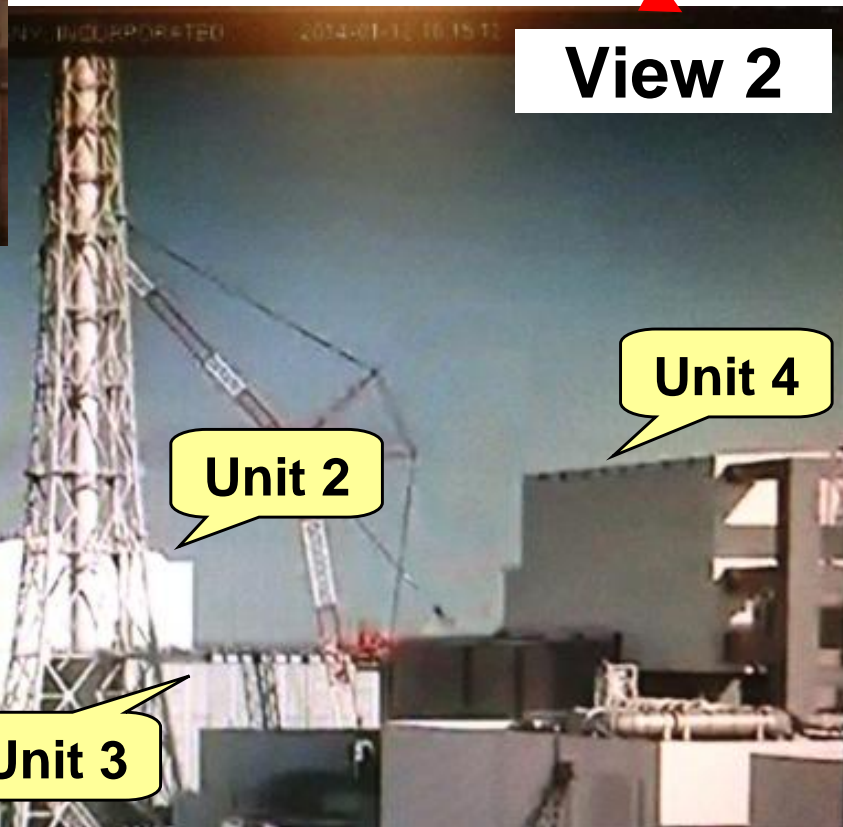
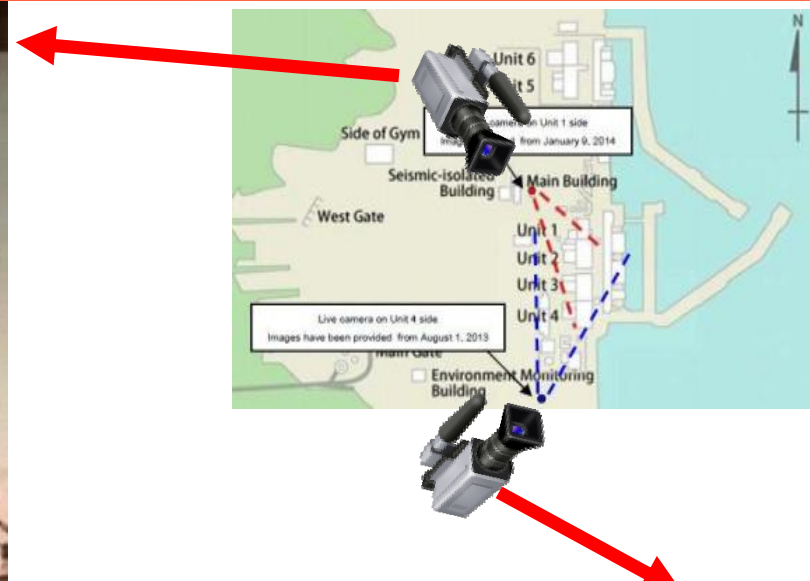


## Post Core Damage Mitigation Measures

# Current Status of Fukushima Daiichi (1F) NPS



View 1



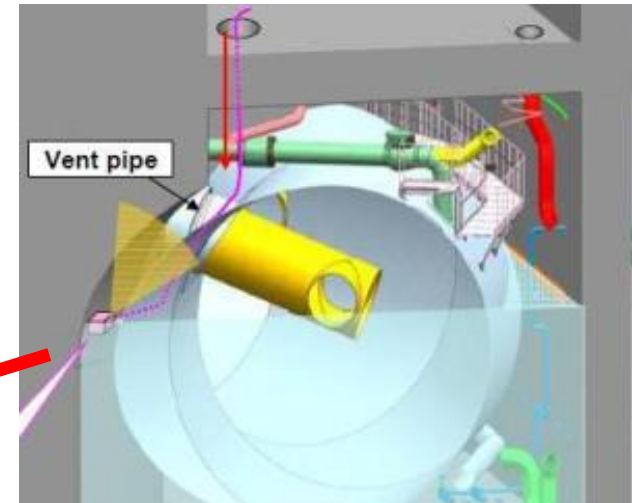
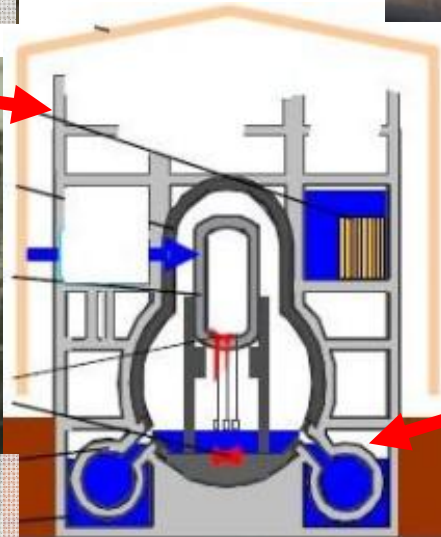
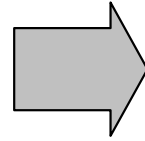
View 2

**Live Camera View  
(as of 1/12/2014)**

<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 Unit 1



Torus Room (11/13/2013)

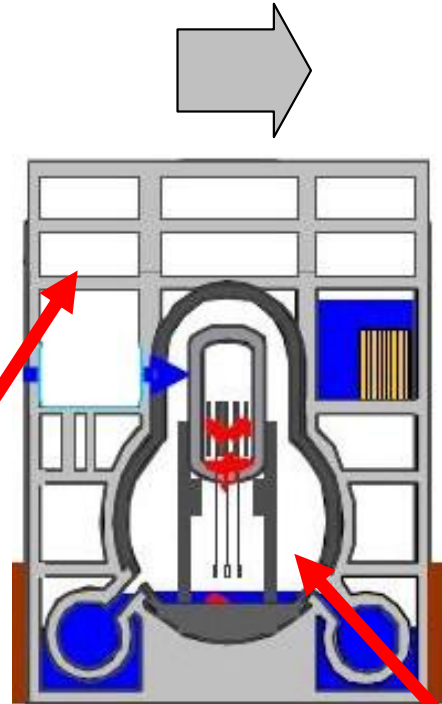
**Reactor building cover to be dismantled to enable rubble removal work to be conducted on refueling floor**



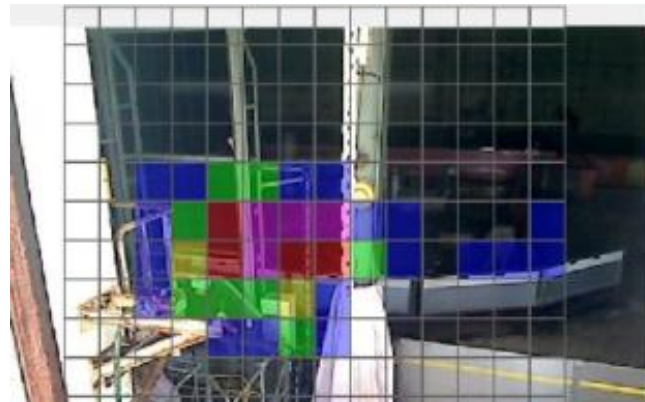
# Progress Made at 1F Unit 2



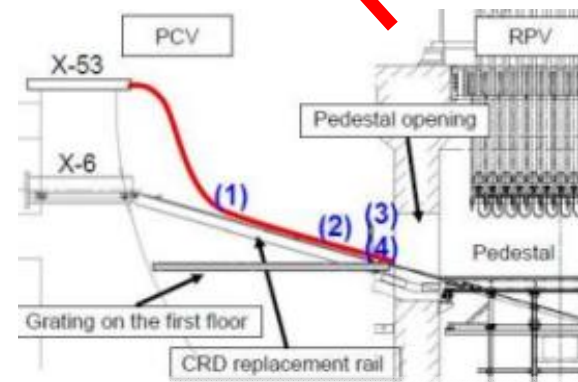
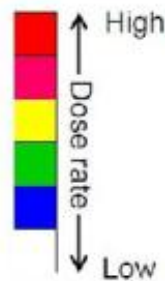
Steam Coming Out From Blow-out Panel (4/10/2011)



Blow-out Panel Closed (3/11/2013)



Gamma Camera Image of Refueling Floor (2/21/2013)



Inside Containment (8/12/2013)

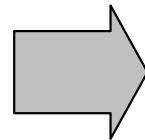


**Attempt to investigate inside reactor pressure vessel by bore scope via TIP guide tube**

# Progress Made at 1F Unit 3



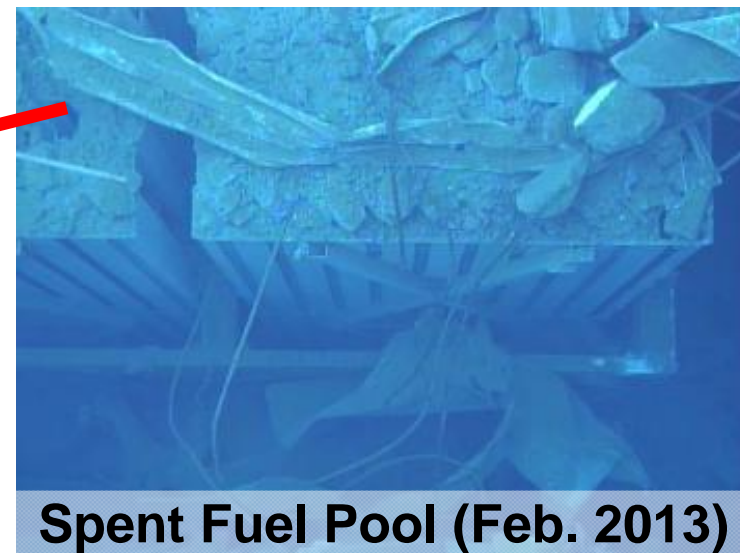
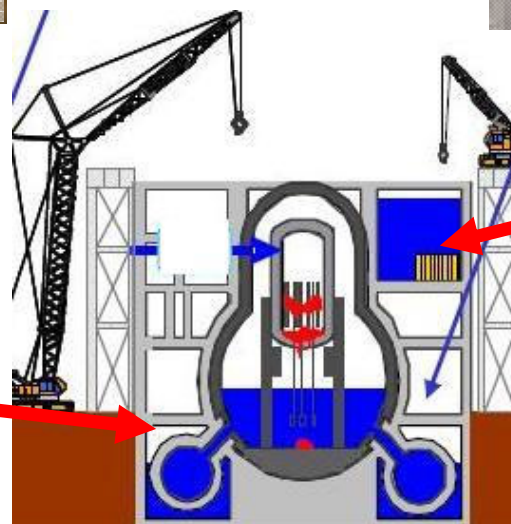
**Crippled Reactor Building (3/15/2011)**



**Large Rubble Removed (10/11/2013)**



**Torus Room (7/11/2012)**



**Spent Fuel Pool (Feb. 2013)**

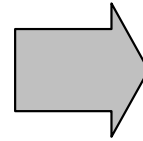
**Preparation work underway to install fuel removal structure**



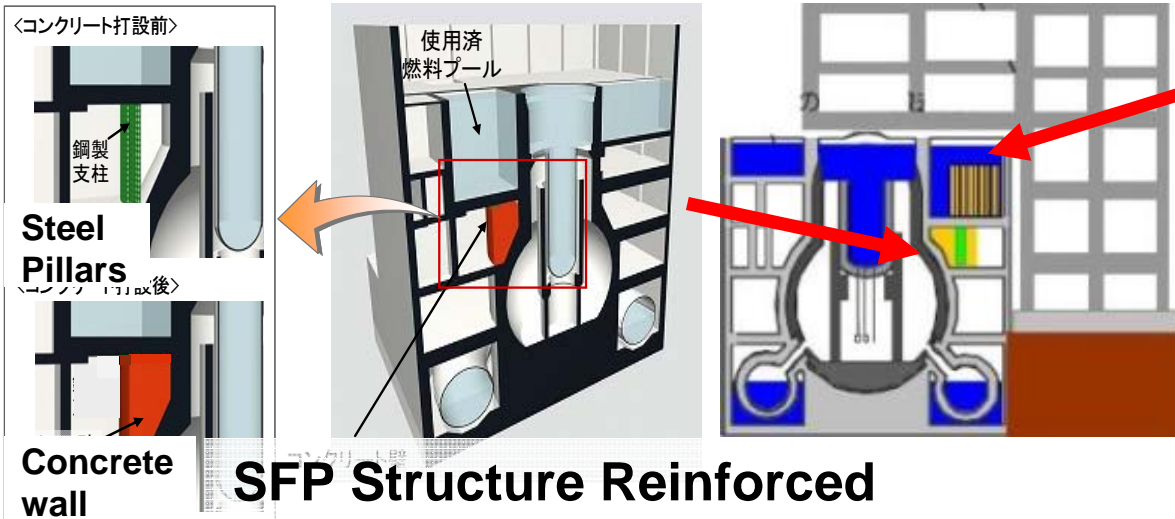
# Progress Made at 1F Unit 4



Water Injection by  
Concrete Pumper (3/22/2011)



Fuel Removal Structure (Nov. 2013)



SFP Structure Reinforced  
(7/30/2011)



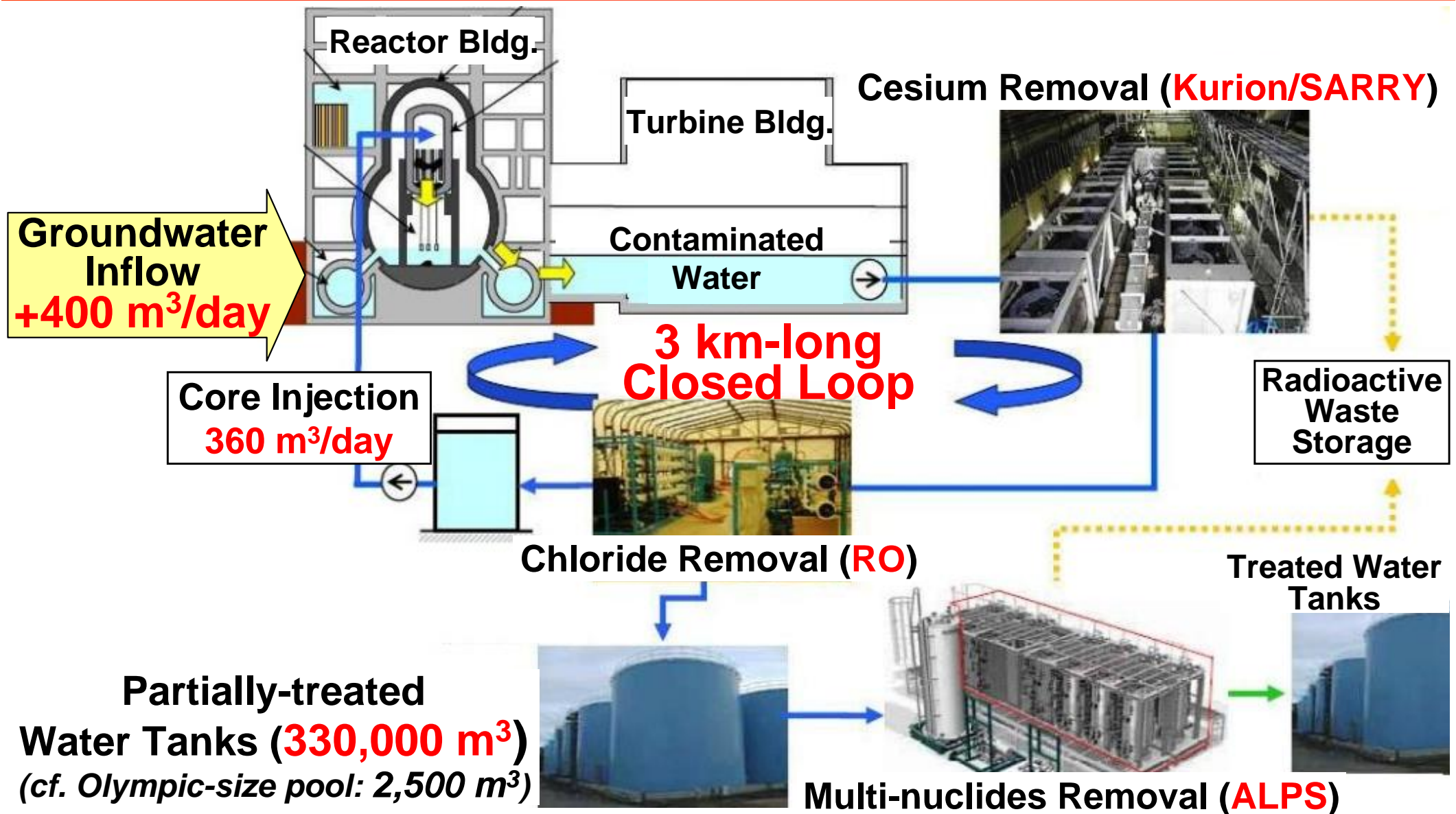
Fuel Removal from SFP (11/18/2013)

**264/1,533 fuel bundles transferred to common pool**

<http://www.tepco.co.jp/en/nu/fukushima-np/removal4u/index-e.html> (as of 2/3/2014)

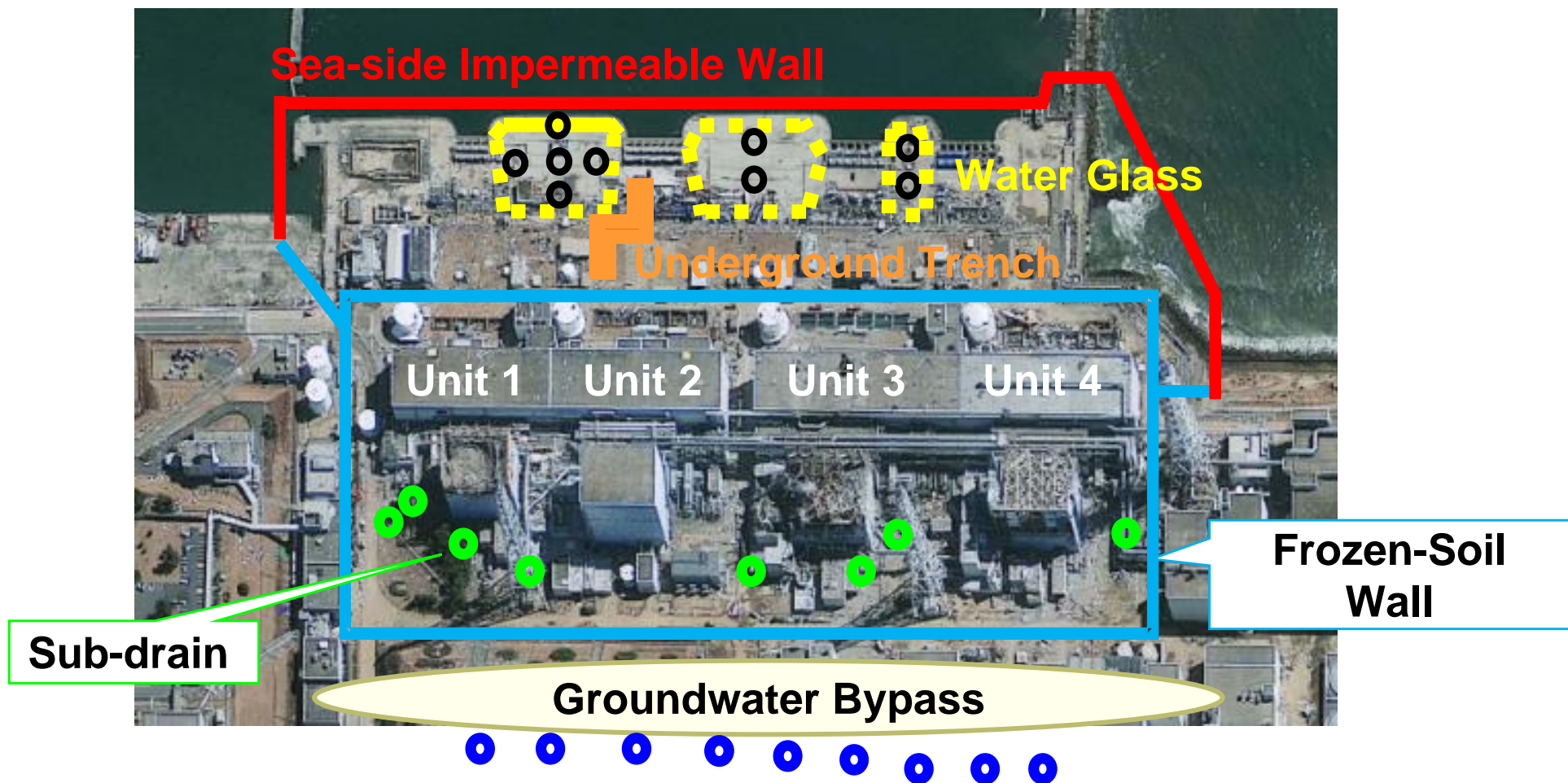


# Circulating-Water Core Cooling System at 1F



- All reactor cores stably cooled
- Increasing water inventory posing challenge

# Contaminated Water Issues at 1F



Contamination detected in groundwater near sea bank;  
Suspected leakage of contamination into sea;

**Immediate and fundamental measures** taken to:

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

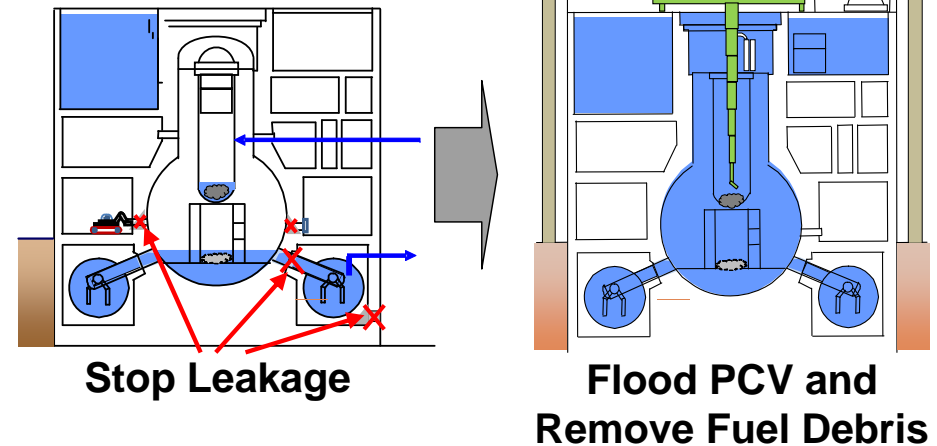
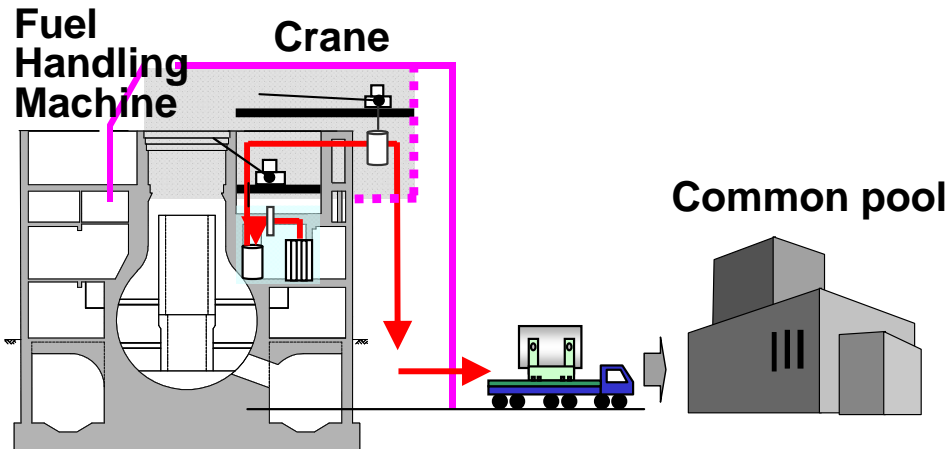
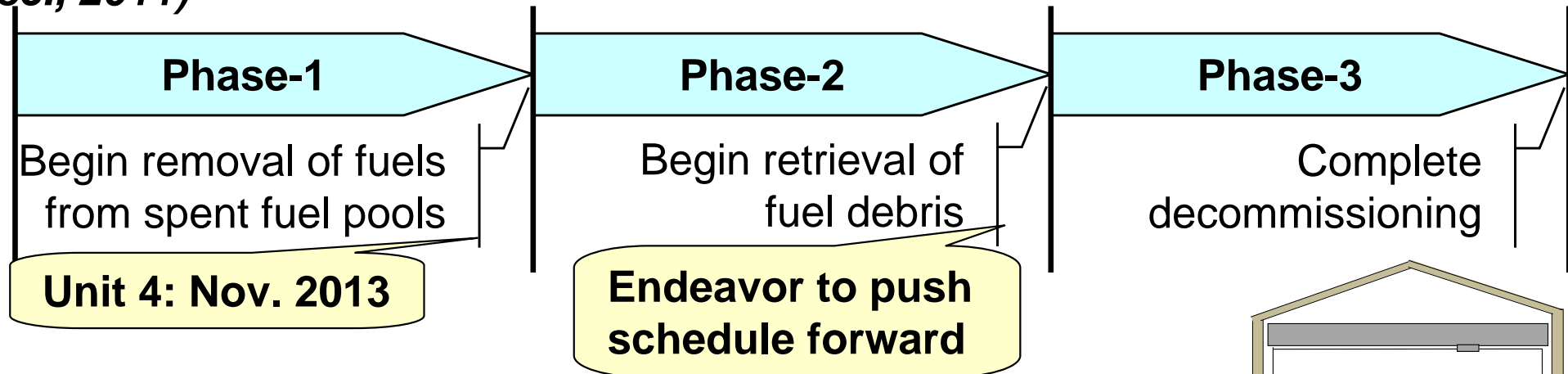
# Decommissioning Roadmap for 1F

**Cold Shutdown  
Condition Achieved  
(Dec., 2011)**

**Within  
2 years**

**Within  
10 years**

**30 to  
40 years**



**Global collaboration vitally important to tackle  
this unprecedented undertaking**

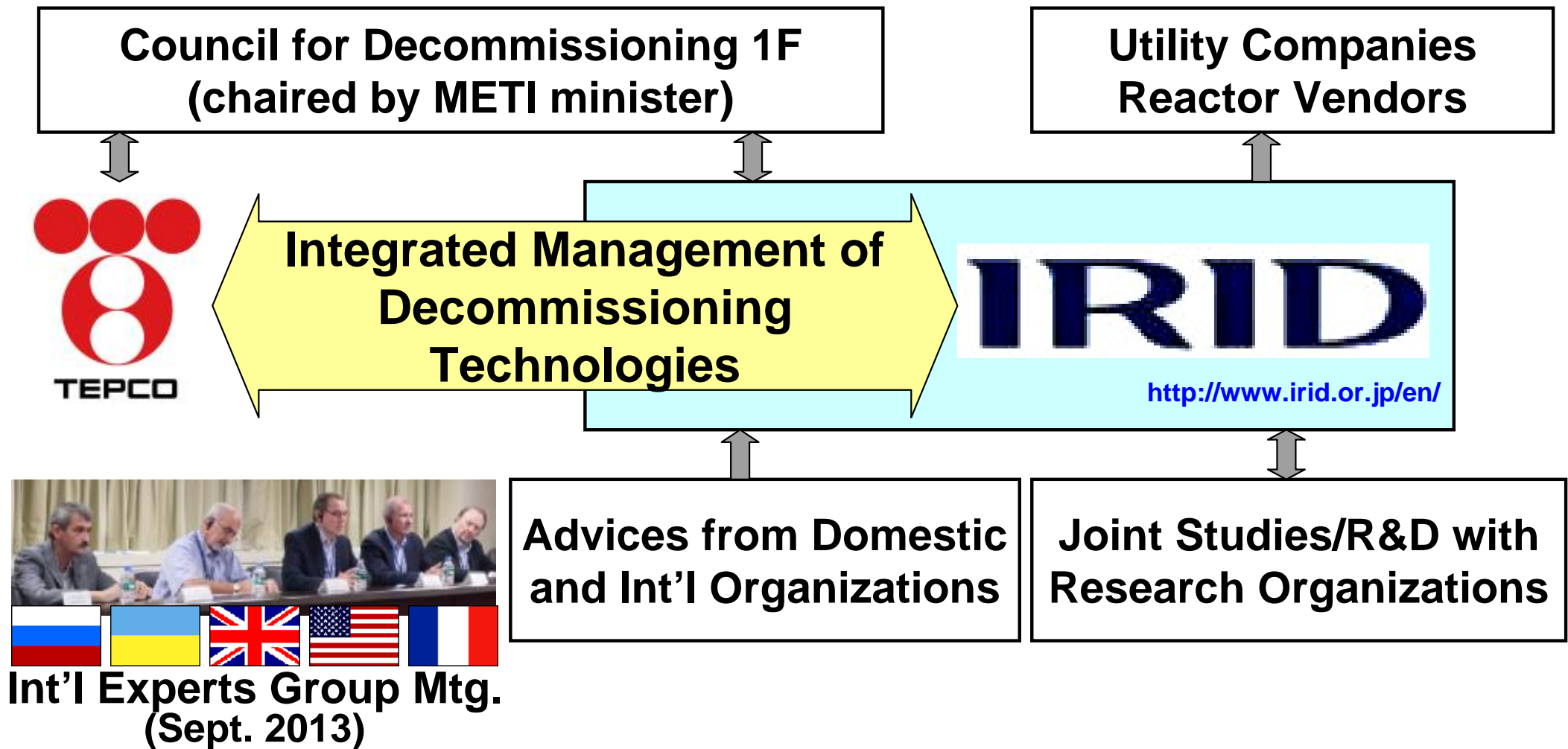


# Global Collaboration: U.S. National Laboratories



- **Feasibility Study Agreement with U.S. Nat'l Labs to identify their expertise applicable to decommissioning at 1F (Sept. 2012-March 2013)**
- **Pursuing further collaboration in following areas:**  
*Groundwater contamination; reactor bldg. water-proofing; radioactive waste disposal; fuel debris recovery/storage; contaminated water treatment*

# Global Collaboration: through IRID



- **International Research Institute for Nuclear Decommissioning (IRID)** established in Aug. 2013
- Soliciting information for technologies in:  
**Contaminated water issues; Fuel debris retrieval**

# Other Activities

- **Compensation for afflicted people:**  
**¥3.3 trillion (approx. \$32 bil.)**  
**(paid out as of Jan. 2014)**
- **Cooperation with gov't in off-site radiation survey, decontamination work, etc.**
- **Assistance in temporary return of evacuees to homes, cleaning homes, etc.**





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

## Nuclear Industry



## Gov't Agencies



## Global Organizations



## Academia



## Professional Organizations, Think Tanks, NPOs, Media



Committed to disseminating lessons learned globally and working together to make nuclear power plants safer  
 → *Weekly update teleconference on Fukushima status*



# References

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<http://www.meti.go.jp/english/earthquake/>
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<http://www.nei.org/Master-Document-Folder/Backgrounders/Reports-And-Studies/Lessons-Learned-from-the-Nuclear-Accident-at-the-F>
- **Electric Power Research Institute (EPRI)**  
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## [International]

- **International Atomic Energy Agency (IAEA)**  
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- **World Association of Nuclear Operators (WANO)**  
<http://www.wano.info/>
- **World Health Organization (WHO)**  
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