Lessons Learnt from Fukushima Daini NPP (2F)
and
Status of Fukushima Daiichi NPP (1F)

June 4, 2012

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TEPCO
TOKYO ELECTRIC POWER COMPANY

Contents

- **Lessons Learnt from 2F**

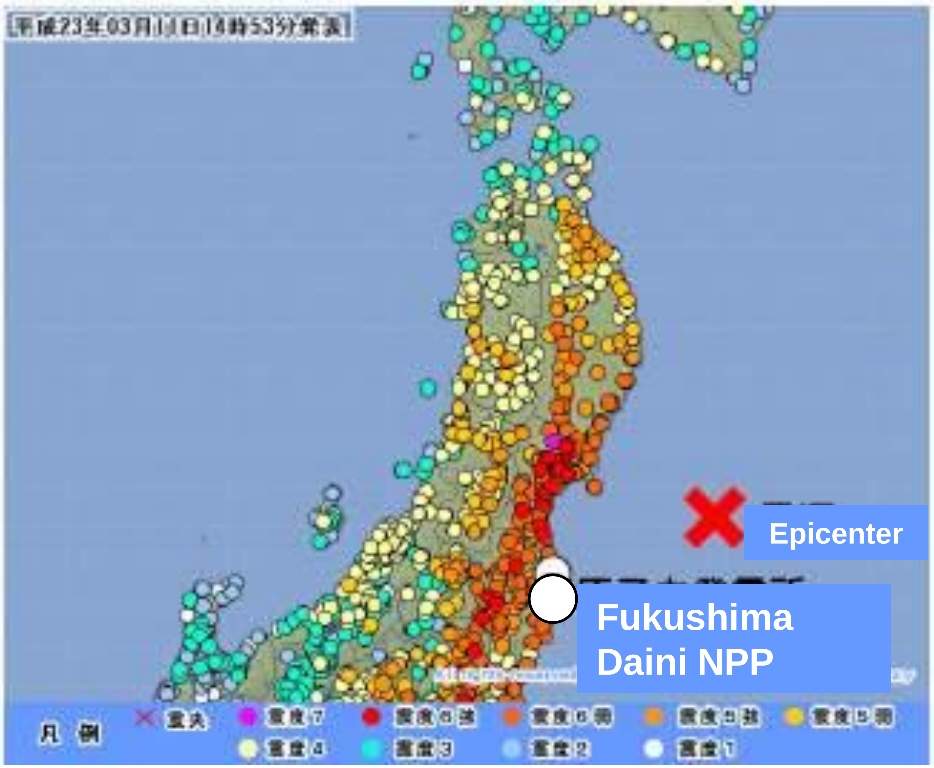
  What we experienced in the event where plants lost ultimate heat sink, but recovered safely from state of emergency using flexible measures.

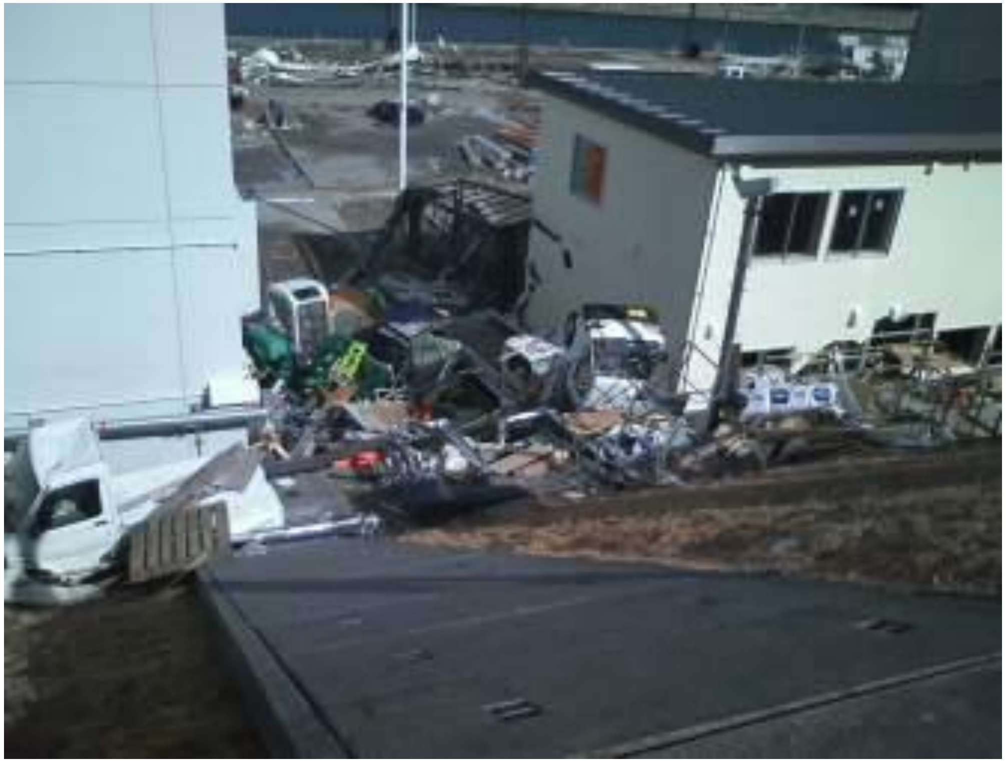
- **Safety Enhancement reflecting lessons learnt from 1F and 2F**

- **Current Status of 1F and Mid-and-Long Term Roadmap toward Decommissioning**

Earthquake and Fukushima Daini NPP (2F)

- 14:46 March 11, 2011
- Magnitude: 9.0
- Hypocenter distance from 2F: 185 km (115 miles)
- All the 4 units were operating at their rated 1100 MWe output.
- Tsunami reached the height of 15 m (50 ft) maximum at the site.





No Damage Caused by the Earthquake

- All units automatically tripped* by acceleration signals.
- Seismic acceleration spectra were mostly within the design values.
- No damage to safety related SSCs was caused by seismic impact.

*Trip set point: 135 gal in horizontal and 100 gal in vertical direction.
The largest acceleration: 277 gal in horizontal and 305 gal in vertical direction.

Reactor refueling floor

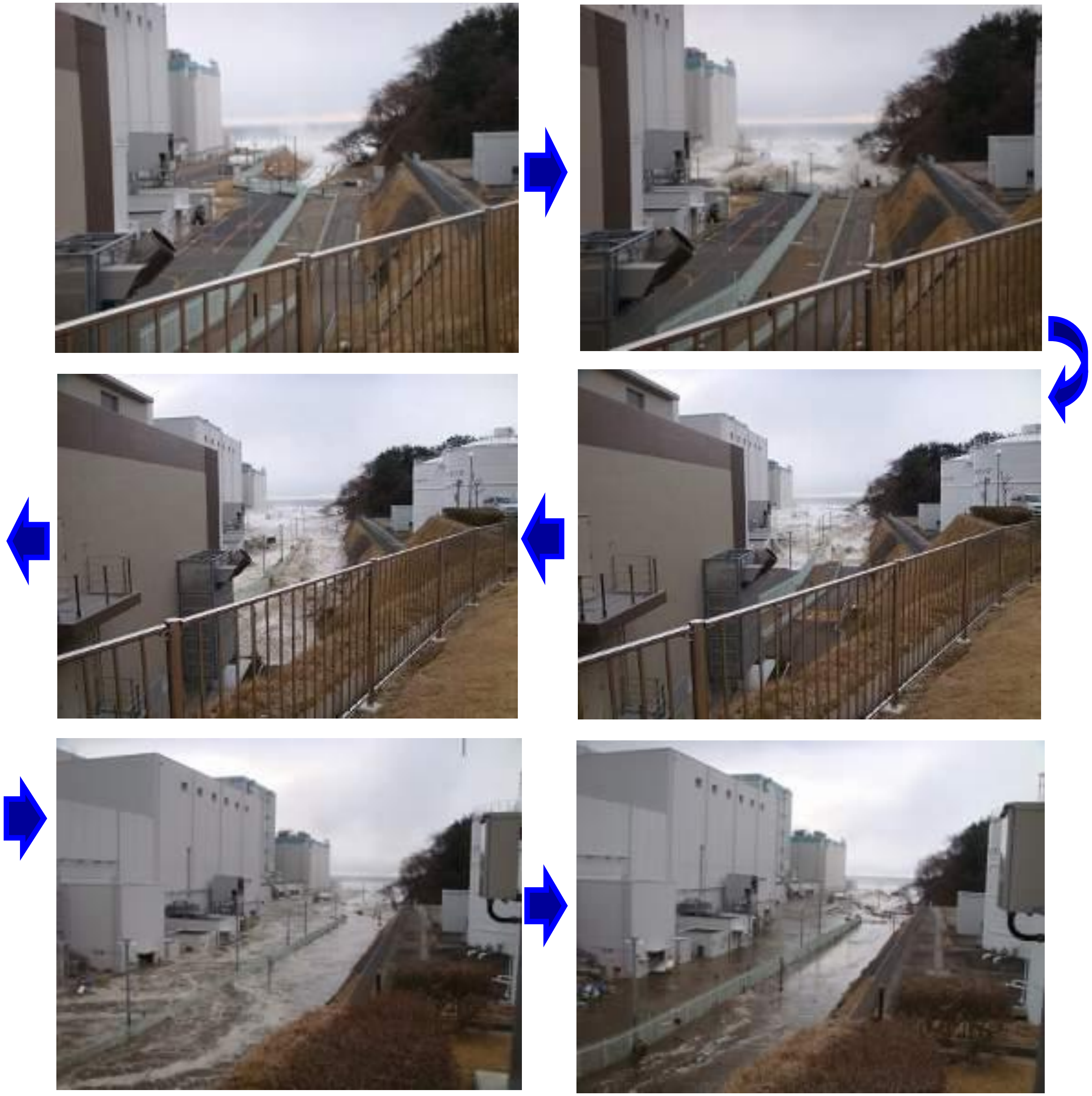
Pump and tank of Stand-by Liquid Control system

RHR heat exchanger

CRD pump

Arrival of Tsunami

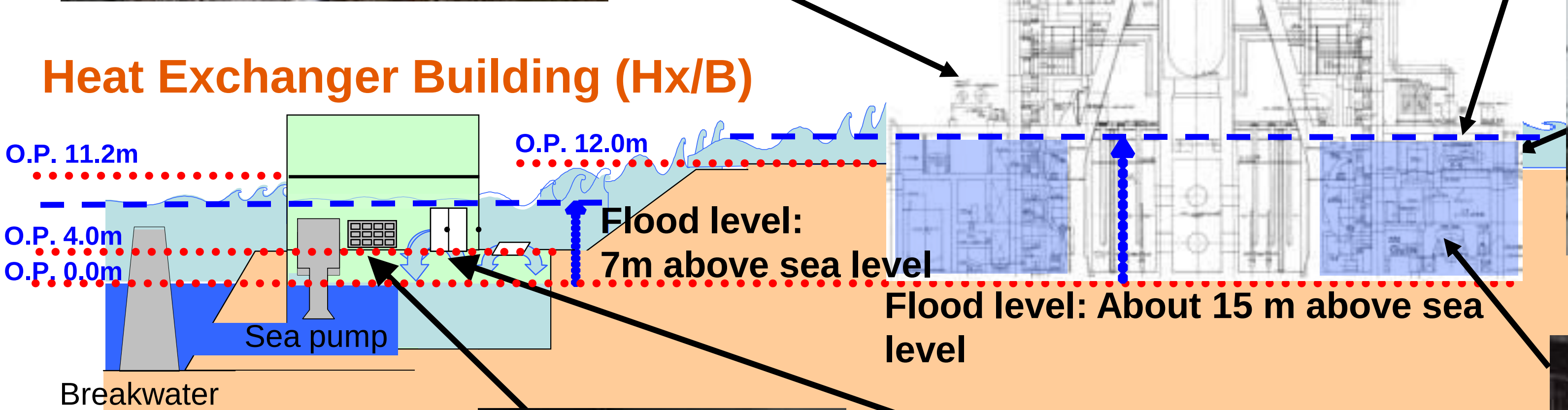
About 15:30, recorded from the upland near site Emergency Response Centre (ERC), towards the east of Unit 1 turbine building.



Cross-Section View of Unit 1 and Flooding

- R/B: Flooding through ventilation louvers
  →Damage in emergency power system
- Hx/B: Damage of watertight hatches
  →Damage in reactor cooling system

EDG air blower



Ventilation louver

Cooling pump

Power cubicles

Equipment hatches

Emergency Diesel Generator (EDG)

System Status after the Tsunami

System		Unit 1	Unit 2	Unit 3	Unit 4
RHR (A) including cooling systems	RHR(A)	Inoperable due to loss of power source and coolong system	Inoperable due to loss of cooling system	Inoperable due to loss of cooling system	Inoperable due to loss of cooling system
	RHRC/ RHRS(A,C)	Inoperable due to submerge of power source and motor	Inoperable due to loss of cooling system	Inoperable due to submerge of power source and motor	Inoperable due to submerge of power source and motor
	EECW(A)	Inoperable due to submerge of power source and motor	Inoperable due to submerge of power source and motor	Inoperable due to submerge of power source and motor	Inoperable due to submerge of power source and motor
LPCS		Inoperable due to loss of power source and coolong system	Inoperable due to loss of cooling system	Inoperable due to loss of cooling system	Inoperable due to loss of cooling system
EDG(A)		Inoperable due to submerge	Inoperable due to loss of cooling system	Inoperable due to loss of cooling system	Inoperable due to loss of cooling system
RHR (B) including cooling systems	RHR(B)	Inoperable due to loss of coolong system	Inoperable due to loss of cooling system	Stand-by	Inoperable due to loss of cooling system
	RHRC/ RHRS(B,D)	Inoperable due to submerge of power source and motor	Inoperable due to submerge of power source	Stand-by	Inoperable due to submerge of power source and motor
	EECW(B)	Inoperable due to submerge of power source and motor	Inoperable due to submerge of power source	Operation	Inoperable due to submerge of power source
RHR(C)		Inoperable due to loss of coolong system	Inoperable due to loss of cooling system	Stand-by	Inoperable due to loss of cooling system
EDG(B)		Inoperable due to submerge	Inoperable due to loss of cooling system	Operation	Inoperable due to loss of cooling system
RWCU		Inoperable due to loss of coolong system	Inoperable due to loss of cooling system	Inoperable due to loss of cooling system	Inoperable due to loss of cooling system
MUWC (alternative water injection)	MUWC(B)	Stand-by	Stand-by	Stand-by	Stand-by
RCIC		Stand-by	Stand-by	Stand-by	Stand-by

🟦 secure (power, pump and motor all working)

🟨 loss of function due to loss of cooling system or power source

🟪 Inoperable

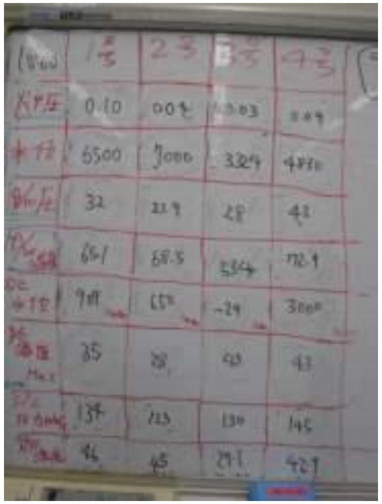
Organizational Response under Emergency

- Site ERC was established under supervision of Site Superintendent.
- Site superintendent gave commands to the members and called in support from the corporate ERC.
- Emergency response units maintained accountability by setting clear goals and reporting/visualizing situation to site ERC on a constant basis.
- Site ERC personnel with operation background were dispatched to MCR.

  This allowed sift operators focus on operation and supervision while maintaining communication between MCR and site ERC through dispatched site ERC personnel.

- Site ERC members had to stay at their posts as there weren’t any backup members.

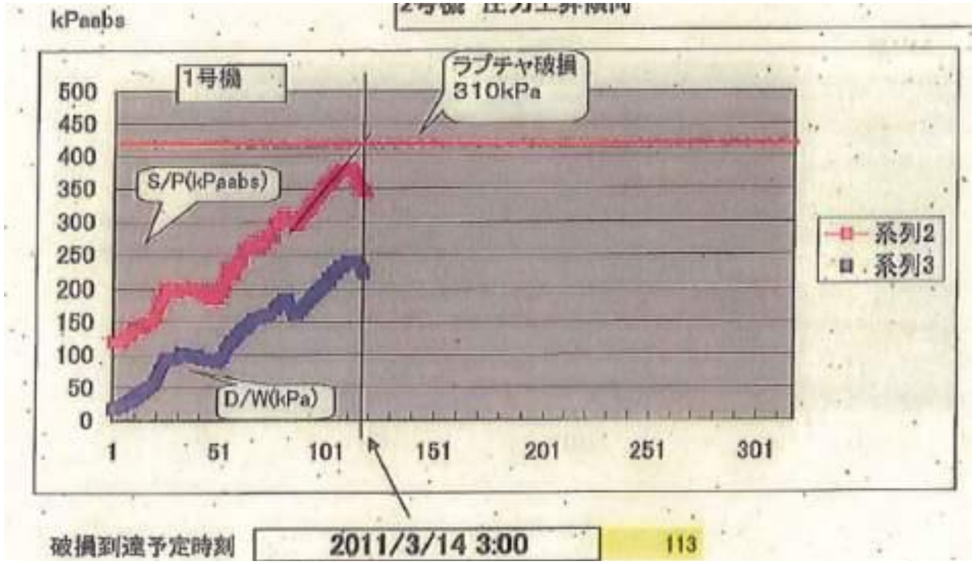
  They did not leave the site for nearly 2 weeks, devoting themselves to emergency response, even in the case where their family members were suffered or evacuated in earthquake and tsunami.



ERC Activities during the Crisis

- Power Outage at site ERC due to the inundation of electrical system for ERC Building.
- In this dark site ERC, loss of ultimate heat sink was confirmed at units 1,2 and 4.

- Plant parameters were analyzed to estimate increases of PCV pressure and temperature.
- Operation and restoration strategies were planned and implemented under the command of site ERC.

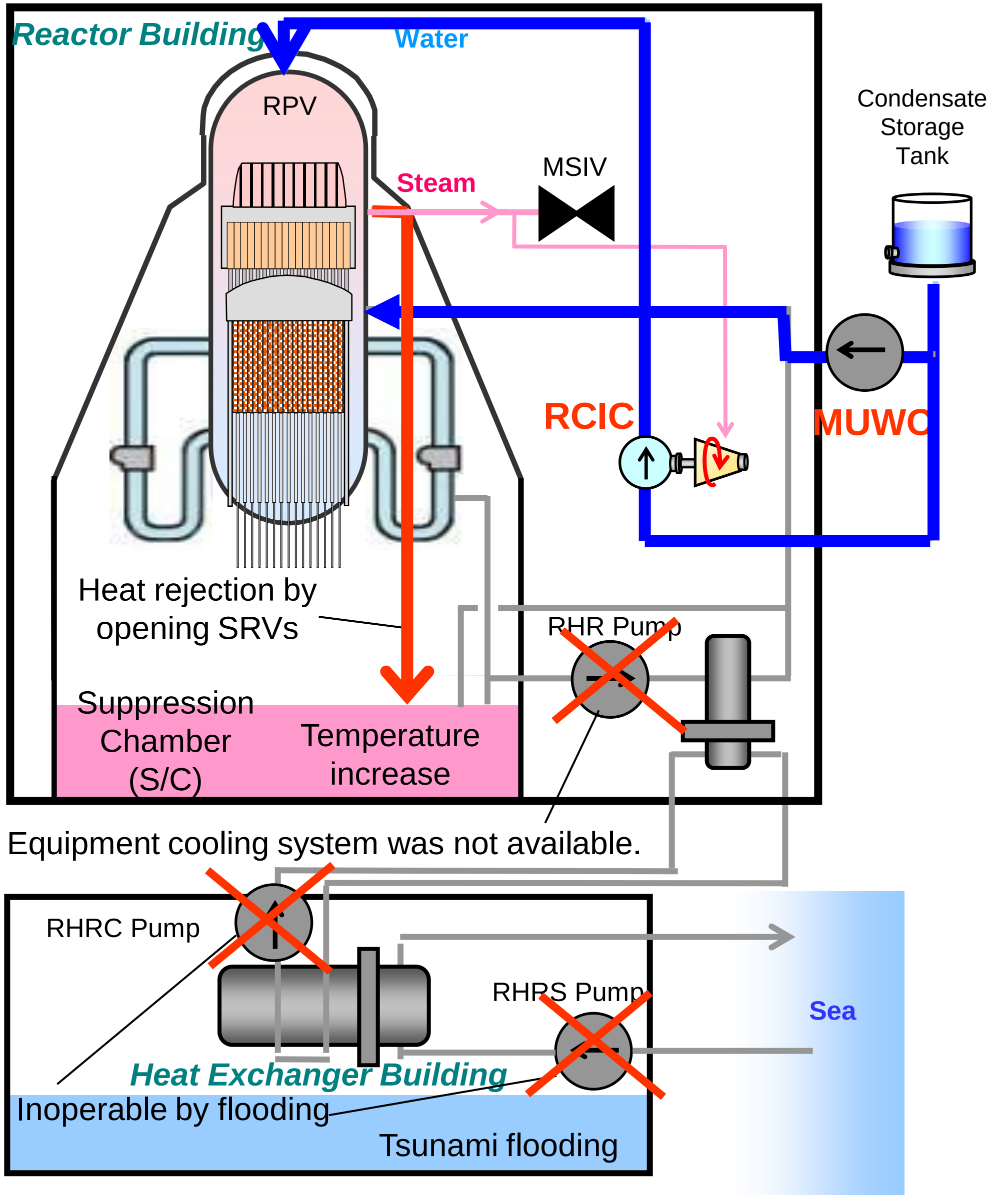


Comparison between estimation and real trend of PCV pressure done at site ERC

Response at Main Control Room and ERC

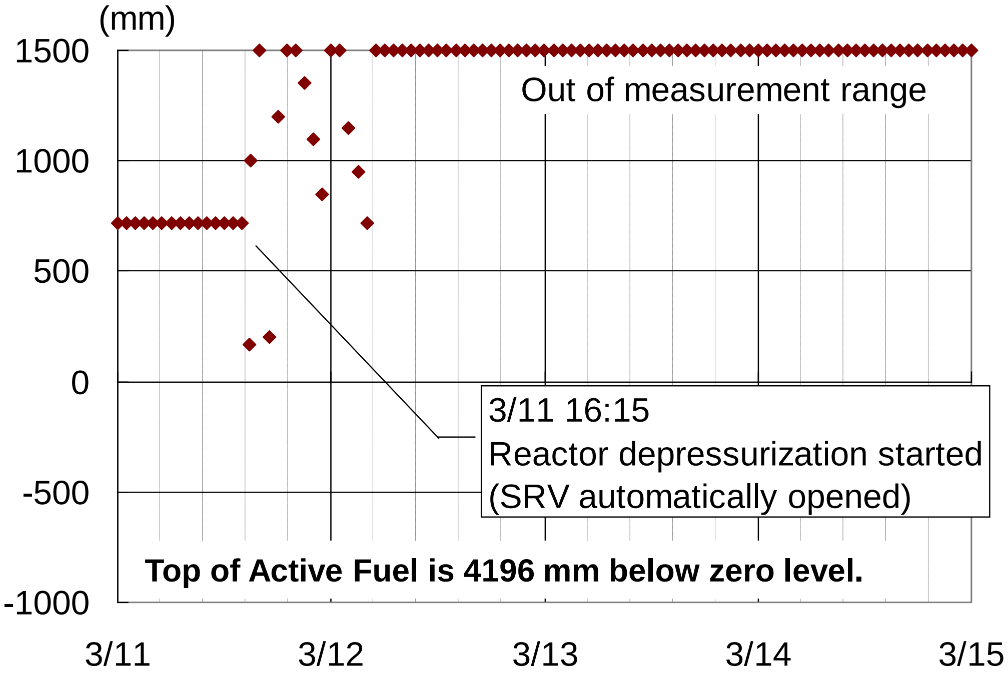
■Operator’s initial response

- MSIVs closed manually, and reactor pressure controlled by SRVs.
- RCIC actuated manually to maintain reactor water level. RCIC repeated automatic trip due to high water level signal and manual restart.
- MUWC actuated for alternative water injection measure introduced for Accident Management, as stated in EOP manual for seamless water injection.
- Reactor depressurized and RCIC stopped due to steam pressure decrease.
- Water level maintained by MUWC.



Successful Reactor Cooling during Transient

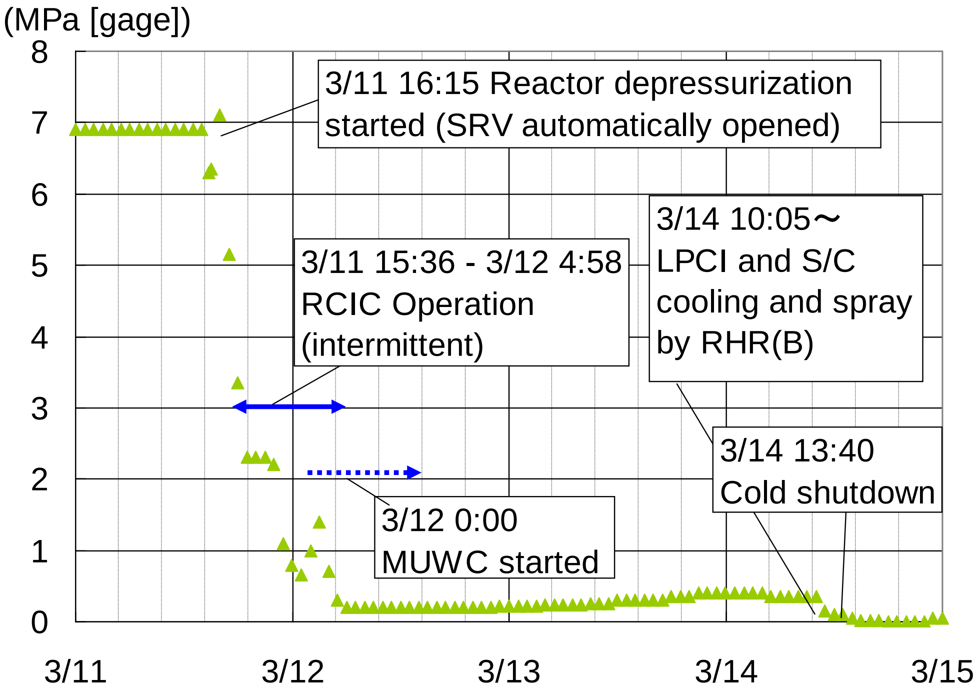
Securing uninterrupted water injection throughout the depressurization process with RCIC at high pressure condition and MUWC at low pressure condition was a critical factor for successful core cooling.



3/11 16:15
Reactor depressurization started
(SRV automatically opened)

Top of Active Fuel is 4196 mm below zero level.

Reactor water level (Unit 1)



3/11 16:15 Reactor depressurization started (SRV automatically opened)

3/11 15:36 - 3/12 4:58
RCIC Operation
(intermittent)

3/14 10:05～
LPCI and S/C cooling and spray by RHR(B)

3/12 0:00
MUWC started

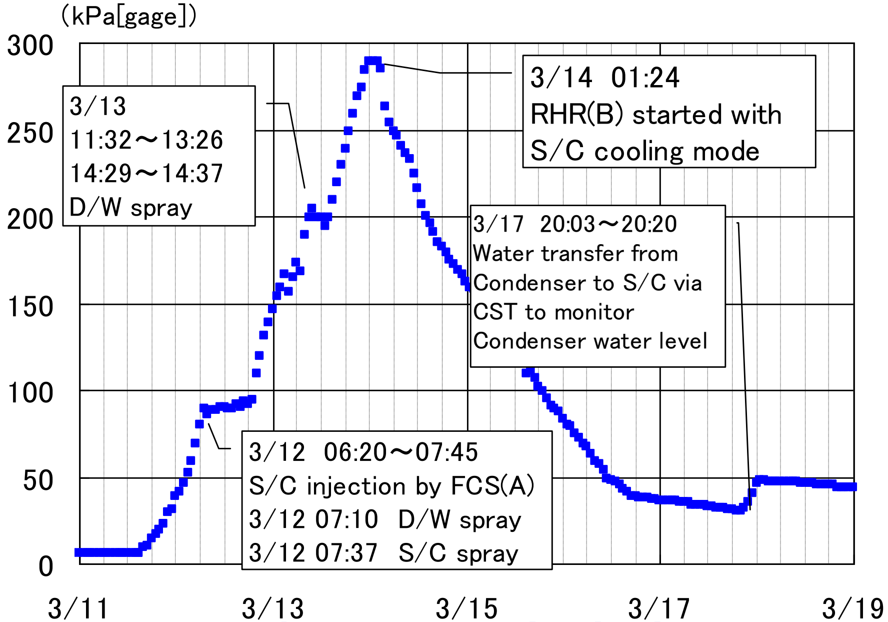
3/14 13:40
Cold shutdown

Reactor pressure (Unit 1)

Efforts to Control Temperature and Pressure in PCV

- Suppression Chamber (S/C) water temperature reached 100ºC (212F).
  → It eventually increased up to about 130ºC (266F).
- Water injected to S/C through Hydrogen Recombiner cooler discharge line in order to mitigate temperature and pressure increases.
- Alternative injection to reactor using MUWC switched to Dry Well (D/W) and S/C sprays.
- S/C temperature decreased after restoration of RHR.

Measures taken by flexibly applying EOP manual effectively extended coping time for restoration without falling into critical situation.



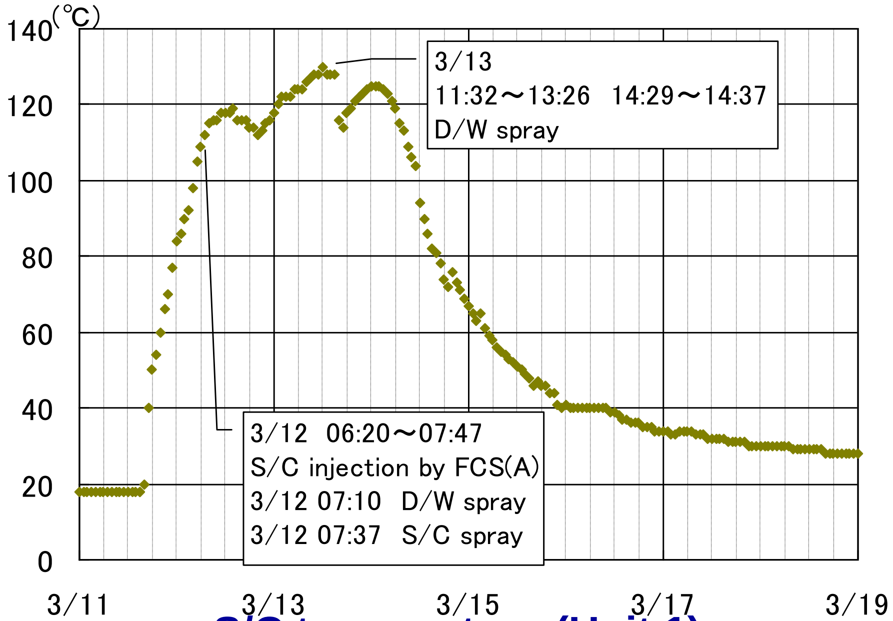
3/13
11:32～13:26
14:29～14:37
D/W spray

3/14 01:24
RHR(B) started with
S/C cooling mode

3/17 20:03～20:20
Water transfer from
Condenser to S/C via
CST to monitor
Condenser water level

3/12 06:20～07:45
S/C injection by FCS(A)
3/12 07:10 D/W spray
3/12 07:37 S/C spray

S/C pressure (Unit 1)



3/13
11:32～13:26 14:29～14:37
D/W spray

3/12 06:20～07:47
S/C injection by FCS(A)
3/12 07:10 D/W spray
3/12 07:37 S/C spray

S/C temperature (Unit 1)

Field Walkdown

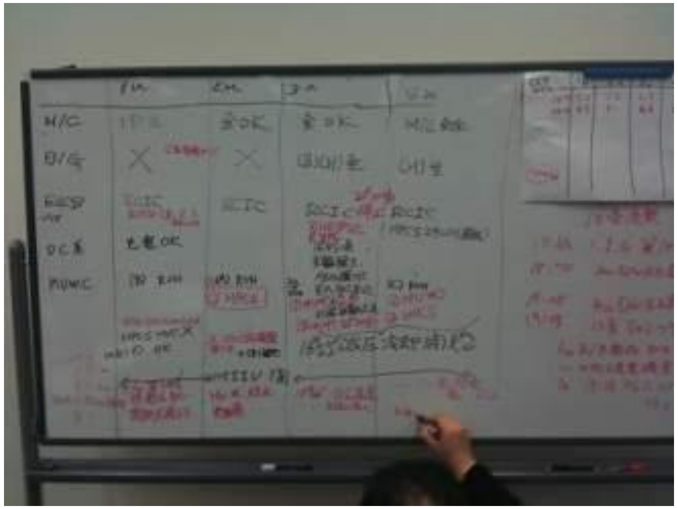
In order to establish a well-prioritized restoration strategy, degree of damage and possibility of short-term restoration must be understood through walkdown.

Challenges in conducting field walkdown

- Under continuous tsunami alerts, walkdown must be done in the field where a lot of debris, openings and flooding areas existed in the dark.
- Preparation for emergency evacuation in case of further tsunami and other safety measures for personnel going out to the field.
- Successful access to facilities near the sea was 6 hours after the tsunami flooding.

Field walkdown after the tsunami

- Plant equipment status checked / component functionality verified.
- Results were summarized and shared at site ERC.
- Site ERC set priorities on recovery of RHR (B) cooling systems by replacing motors and supplying power from survived electrical buses and mobile power vehicles.



Logistics in Emergency Situation

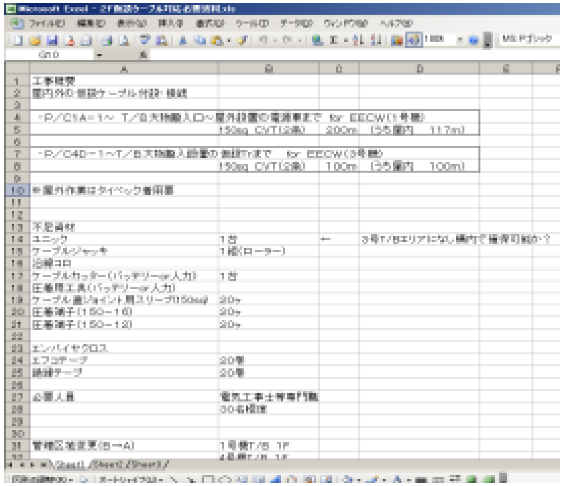
Procurement and transportation of Materials and Equipment

- Emergency procurement of motors, cable, mobile power vehicles, fuel oil and mobile transformers with close cooperation between site ERC and corporate ERC.

Difficulties experienced in logistics

- Motors were transported from Toshiba by a helicopter of Self Defense Force and from Kashiwazaki Kariwa NPP by trucks.
- Securing ground transportation routes and communication were challenges when major highways were severed and public cell phone services were disrupted.

Mobile Power Vehicles



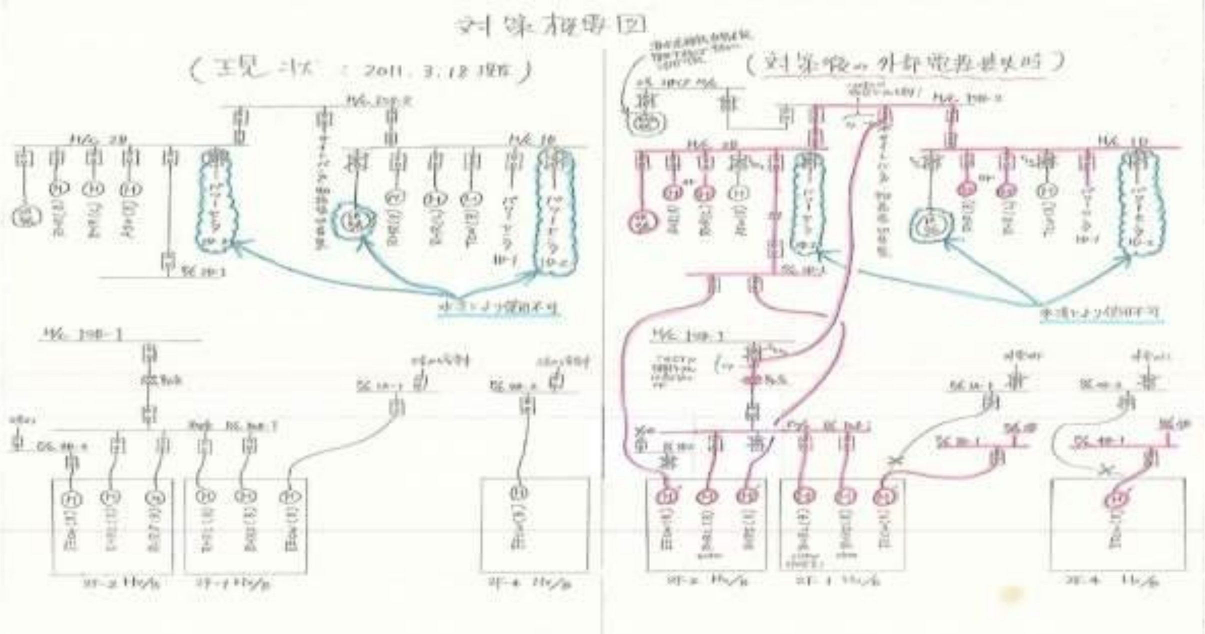
Necessary materials and equipment prioritized and listed

Fuel oil delivery to the site

Emergency Restoration Efforts in the Field

- RHR cooling systems (RHRC, RHRS, EECW) were inspected.
- Motors were replaced for pumps in RHRC and EECW.
- Temporary cable was laid to supply power from survived power cubicles in Rad-Waste Building and Unit 3 Heat Exchanger Building or mobile power vehicles.

Motor replacement



Drawing made at site ERC for temporary cable laying

Recovering Electricity

- Temporary cable of 9 km length was laid by about 200 personnel within a day. *Usually this size of cable laying requires 20 personnel and more than 1 month period.*

- After the pumps for RHR cooling systems were restored and temporary cable was laid, RHR (B) of Unit 1 started up at 1:24 on March 14 and other units followed.

- Finally at 15:42 on March 14 with the start up of Unit 4 RHR, RHR of all four reactors started operation.

- Cold shutdown was achieved at every reactor by 7:15 on March 15.

System Status after Emergency Restoration at Cold Shutdown

System		Unit 1	Unit 2	Unit 3	Unit 4
RHR (A) including cooling systems	RHR(A)	Inoperable due to loss of power source and coolong system	Inoperable due to loss of cooling system	Inoperable due to loss of cooling system	Inoperable due to loss of cooling system
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RHR (B) including cooling systems	RHR(B)	Operation	Operation	Operation	Operation
	RHRC/ RHRS(B,D)	Operation	Operation	Operation	Operation
	EECW(B)	Operation	Operation	Operation	Operation
RHR(C)		Stand-by	Stand-by	Stand-by	Stand-by
EDG(B)		Operable using tie-line from Unit 2	Stand-by	Stand-by	Stand-by
RWCU		Inoperable due to loss of purge line	Inoperable due to loss of purge line	Inoperable due to loss of purge line	Inoperable due to loss of purge line
MUWC (alternative water injection)	MUWC(B)	Stand-by	Stand-by	Stand-by	Stand-by
RCIC		Inoperable for loss of core pressure	Inoperable for loss of core pressure	Inoperable for loss of core pressure	Inoperable for loss of core pressure

🟦 secure (power, pump and motor all working)

🟨 loss of function due to loss of cooling system or power source

🟪 Inoperable

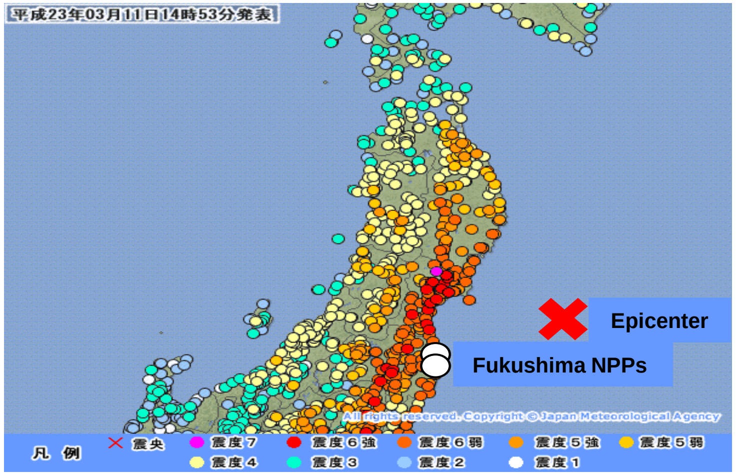
Key Success Factors for 2F Recovery

- **Accident mitigation by applying EOP and AMG**
- **Prioritized restoration strategy based on Field Walkdown**
- **Prompt restoration with success of emergency procurement for materials and equipment**
- **Logistics for long term emergency response**
- **Organizational integrity: Leadership, Communication, Accountability, Professionalism**

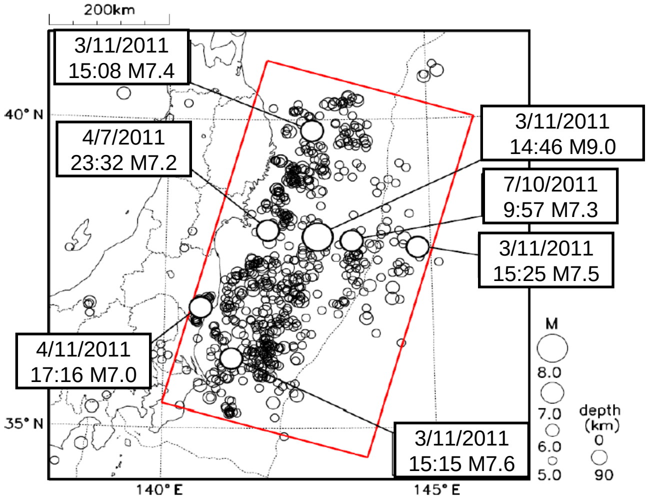
Safety Enhancement reflecting Lessens Learnt (1)

■Prediction and Prevention

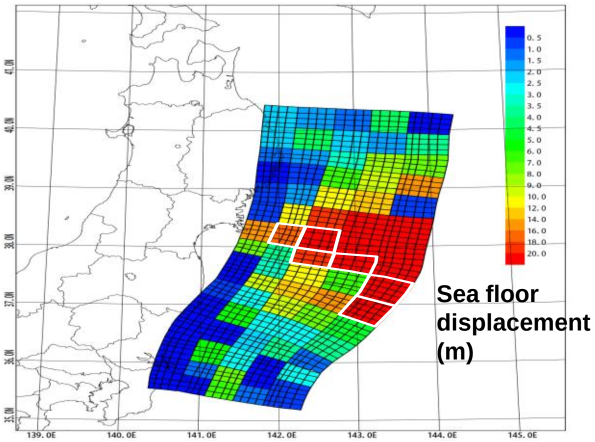
- The earthquake was caused by a coupling movement of several separate seismic regions (Off-shore Miyagi pref., Southern Trench off-shore Sanriku east, Off-shore Fukushima pref., and Off-shore Ibaraki pref.).
- Although Governmental Research Authority as well as TEPCO had evaluated seismic motion and tsunamis in individual regions, coupling of all these regions had not been taken into account.
- Revision of design basis tsunami will consider this mechanism with accumulation of latest scientific knowledge and surveys.



Epicenter and nuclear power plants



Source area of the earthquake



Tsunami wave sources

Safety Enhancement reflecting Lessons Learnt (2)

■Preparedness for Unexpected

- Robustness
  - In the past, prevention of events or even symptoms contributed to improved safety performance of nuclear power plants.
  - More balanced attention paid to mitigation will effectively enhance robust defense-in-depth especially in the case of extreme natural events.
  - Considering emergency response operations, measures to make core injection and cooling functions more secured is important.

- Resilience
  - Measures with more flexibility and mobility should be available to prevent core damage even in the case of beyond design basis events.

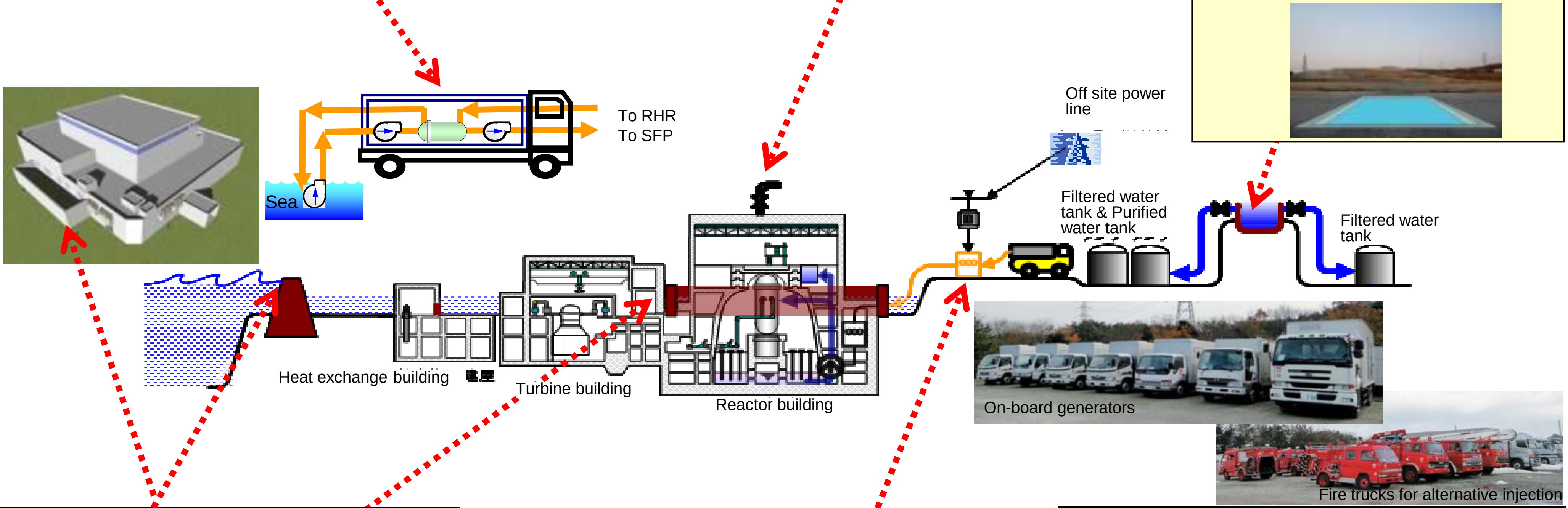
- Minimization of social impact
  - Large area contamination caused extended evacuation of local residents.
  - While placing first priority on preventing core damage, measures will be implemented to mitigate the impact of core damage if it does occur.

Safety Enhancement at Kashiwazaki-Kariwa NPP

Enhancement of heat removal
- On-board heat exchangers and submerged pumps

Prevention of hydrogen accumulation
- Reactor building top vent system

Enhancement of Injection
- Fire trucks
- Submerged pumps
- On-site reservoir



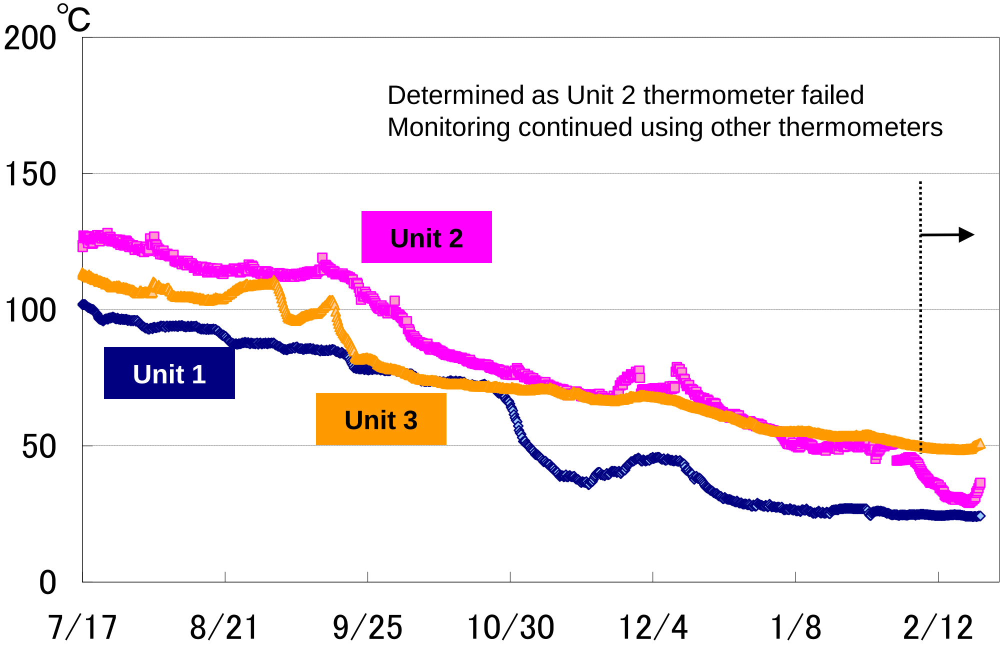
Flood protection
- Embankment
- Wall
- Water-tight doors in Reactor Building

Enhancement of power source
- On- board emergency generators (Gas turbine driven and diesel engine driven)
- Emergency high voltage power cubicle to connect on-board generators with RHR system

Others
- Filter vent system
- Spare gas cylinders for important air-operated valves
- Additional monitoring cars

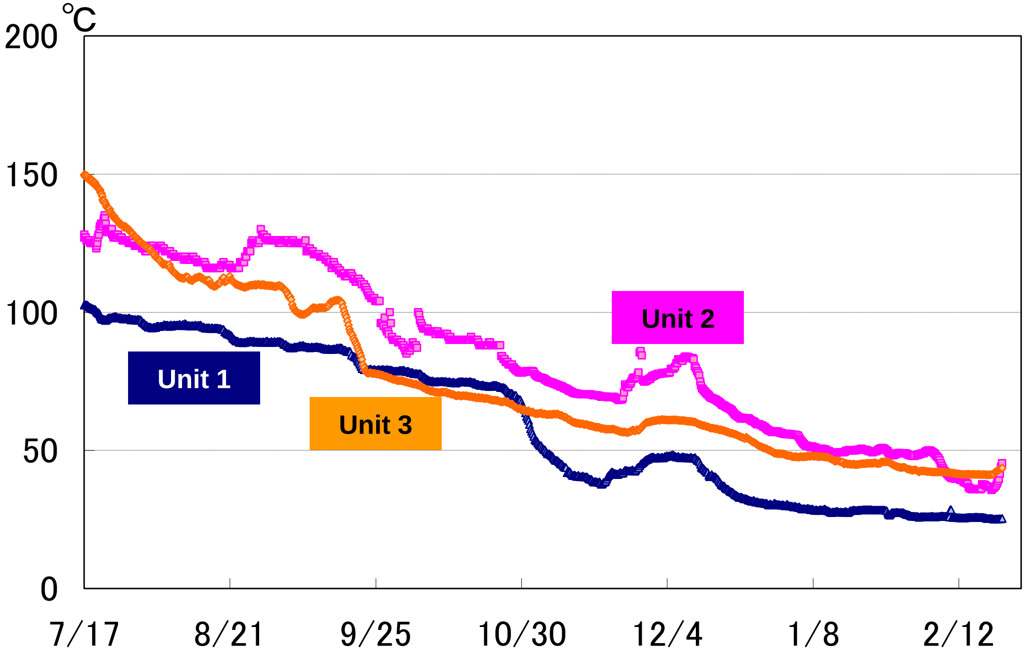
Current Status of Fukushima Daiichi NPP (1F)

- Circulating water cooling continued since June 27, 2011
  - Temperatures at the Reactor bottom and inside the PCV are stable below 100˚C although it is difficult to accurately understand where the damaged fuel is located.
- Release of radioactive materials from containment vessel controlled
  - Release of radioactive materials from the PCV is controlled and radiation dose is significantly reduced by cooling inside of the PCV and controlling steam generation.



Determined as Unit 2 thermometer failed
Monitoring continued using other thermometers

RPV bottom temperature



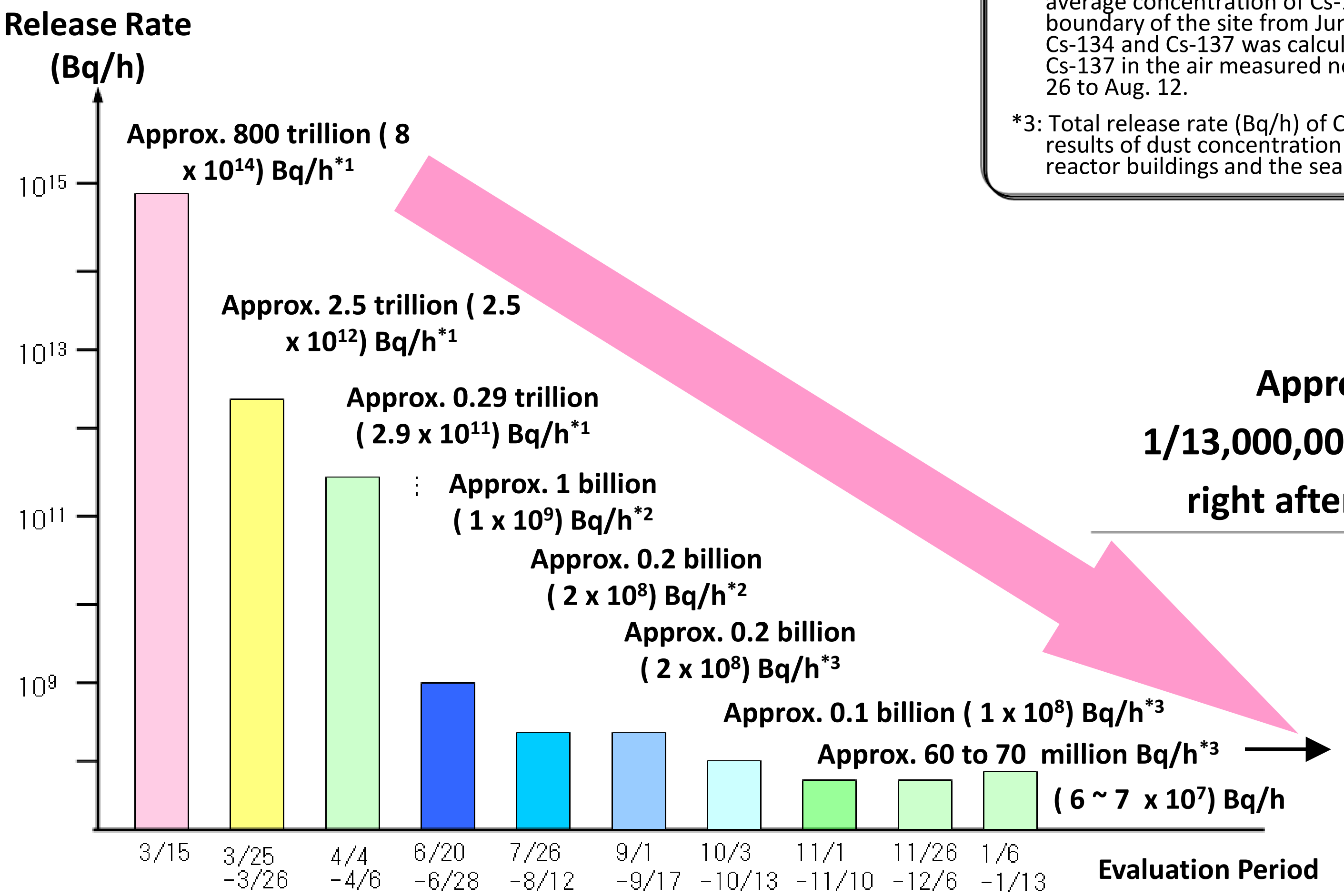
Temperature in PCV

Release Rate of Radioactive Cesium significantly reduced

*1: Total release rate (Bq/h) of Cs-134 and Cs-137 was calculated based on release rate (Bq/h) of Cs-137 as of Mar. 15 mentioned in the report of the 63rd Nuclear Safety Commission of Japan. Total release rates (Bq/h) of Cs-134 and Cs-137 as of Mar. 25 and Apr. 5 were calculated in the same way.

*2: Total release rate (Bq/h) of Cs-134 and Cs-137 was calculated based on average concentration of Cs-137 in the air measured near the west boundary of the site from Jun. 20 to Jun. 28. Total release rate (Bq/h) of Cs-134 and Cs-137 was calculated based on average concentration of Cs-137 in the air measured near the west boundary of the site from Jun. 26 to Aug. 12.

*3: Total release rate (Bq/h) of Cs-134 and Cs-137 was estimated from the results of dust concentration measurement at the upper parts of the reactor buildings and the sea.



Approximately

1/13,000,000 of the amount

right after the accident

Release rate of radioactive Cesium from 1F Unit 1 - 3

Preventing Radioactive Material Dispersion

- Agent sprayed to prevent dispersion of radioactive material.
- Reactor building cover installed on Unit 1.
- Removing rubble and storing/managing them according to radiation level.
- Primary Containment Vessel gas control system to maintain internal pressure of the PCV at around atmospheric level and to manage release.

Reactor building cover installed on 1F Unit 1

Removing rubble from 1F Unit 4

Mid-and-long Term Roadmap of 1F Unit 1 - 4

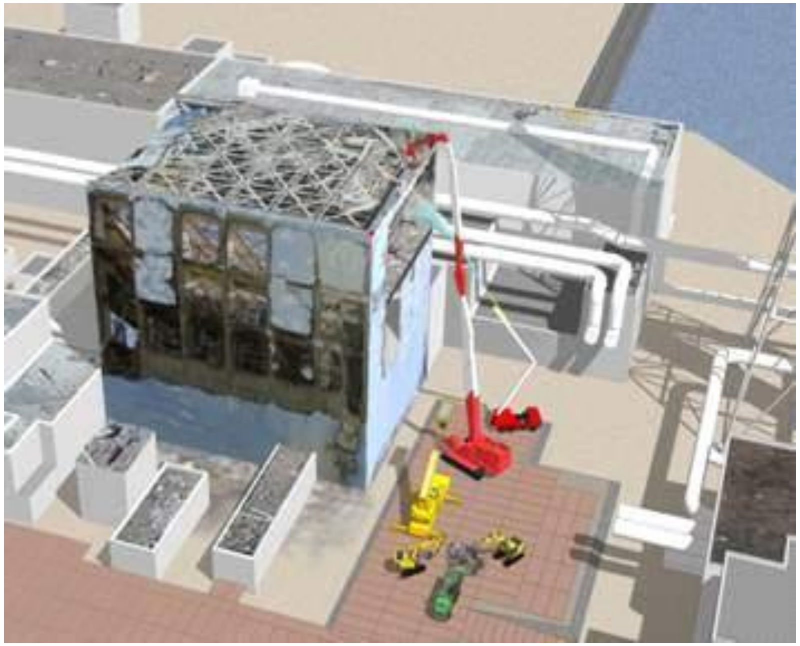
Present （Completion of Step 2 ）

Within 2 Years

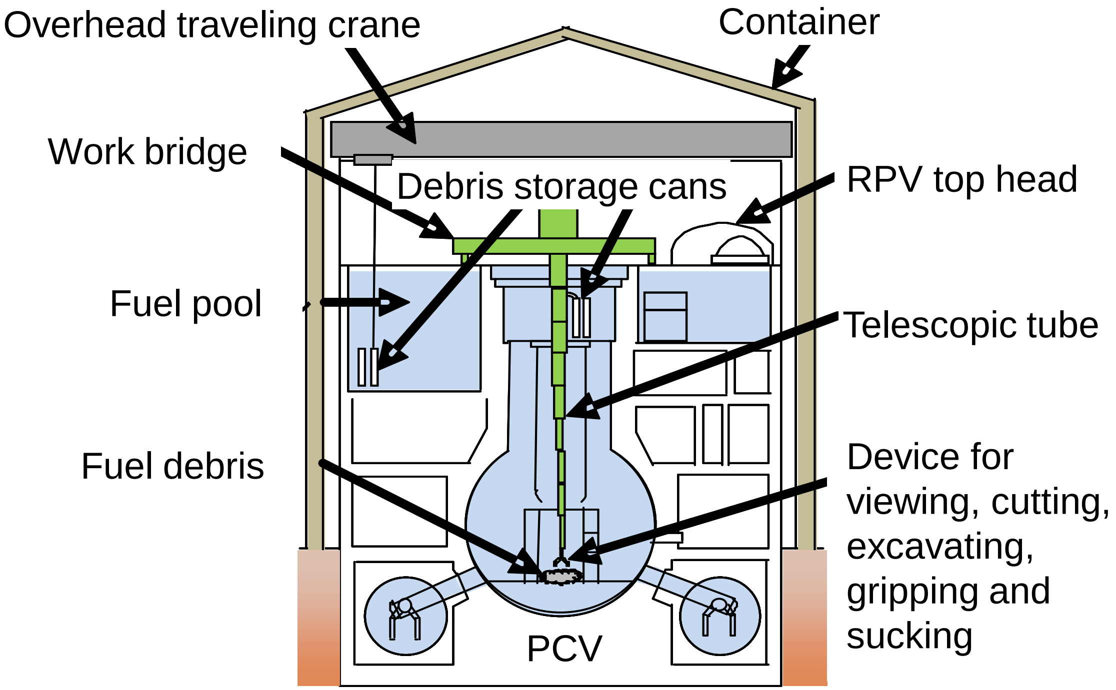
Within 10 Years

After 30-40 Years

Step 1, 2	Phase 1	Phase 2	Phase 3
<Stable conditions achieved > -Condition equivalent to cold shutdown -Significant suppression of emissions	Period to the start of fuel removal from the spent fuel pool	Period to the start of fuel debris removal	Period to the end of decommissioning



Removal of Rubble



Removal of Fuel debris

Sharing Knowledge

Minister of France

ROSATOM

Minister of Ukraine

U.S. Ambassador to Japan

IAEA

NRC

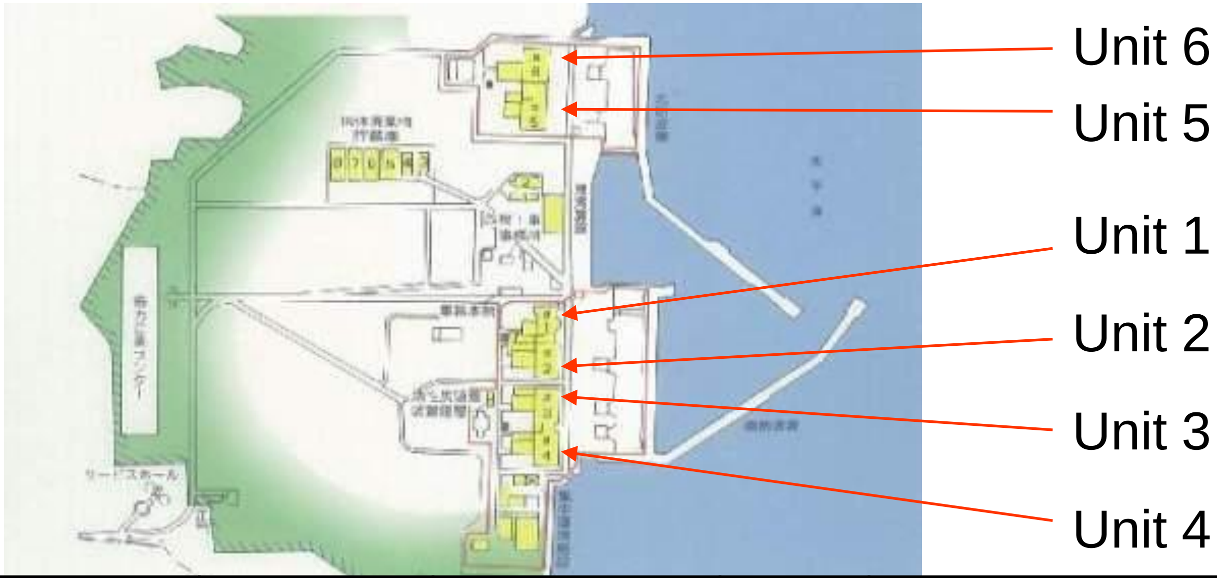
WANO

1F, 2F Information Update

- Internet
  - TEPCO Web Site, updated everyday
    - http://www.tepco.co.jp/en/nu/fukushima-np/index-e.html
  - Japan Nuclear Technology Institute (JANTI) Web Site
    - http://www.gengikyo.jp/english/index.html
- TEPCO Fukushima Nuclear Accident Report
  - Interim Report （December 2011）
    - http://www.tepco.co.jp/en/nu/fukushima-np/index-e.html#anchor02
  - Final Report （June 2012 (scheduled))

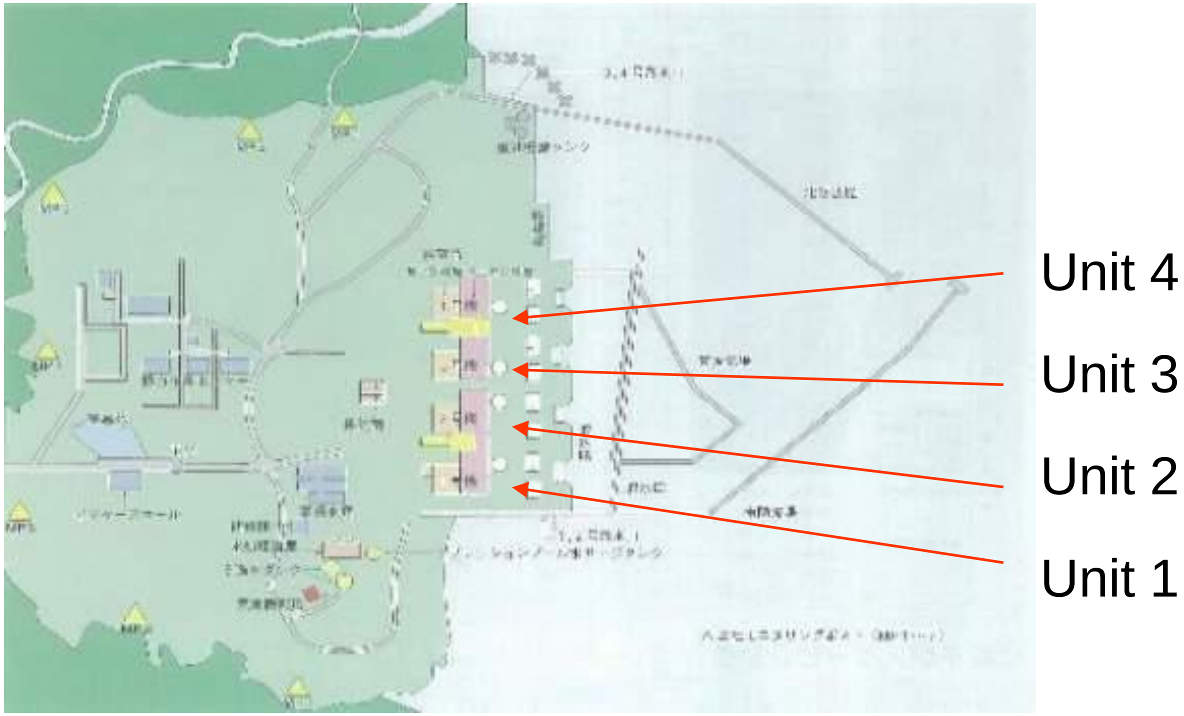
Appendix

Outline of Fukushima Daiichi Nuclear Power Plant (1F)



Location	Unit	In operation since	Plant type	PCV type	Power output (MWe)	Pre-earthquake status
Ohkuma	1	1971.3	BWR-3	Mark- Ⅰ	460	Operating
	2	1974.7	BWR-4	Mark- Ⅰ	784	Operating
	3	1976.3	BWR-4	Mark- Ⅰ	784	Operating
	4	1978.10	BWR-4	Mark- Ⅰ	784	Shutdown for maintenance
Futaba	5	1978.4	BWR-4	Mark- Ⅰ	784	Shutdown for maintenance
	6	1979.10	BWR-5	Mark- Ⅱ	1100	Shutdown for maintenance

Outline of Fukushima Daini Nuclear Power Plant (2F)



Location	Unit	In operation since	Plant type	PCV type	Power output (MWe)	Pre-earthquake status
Naraha	1	1982.4	BWR-5	Mark-Ⅱ	1100	Operating
	2	1984.2	BWR-5	Improved Mark-Ⅱ	1100	Operating
Tomioka	3	1985.6	BWR-5	Improved Mark-Ⅱ	1100	Operating
	4	1987.8	BWR-5	Improved Mark-Ⅱ	1100	Operating

Seismic Acceleration

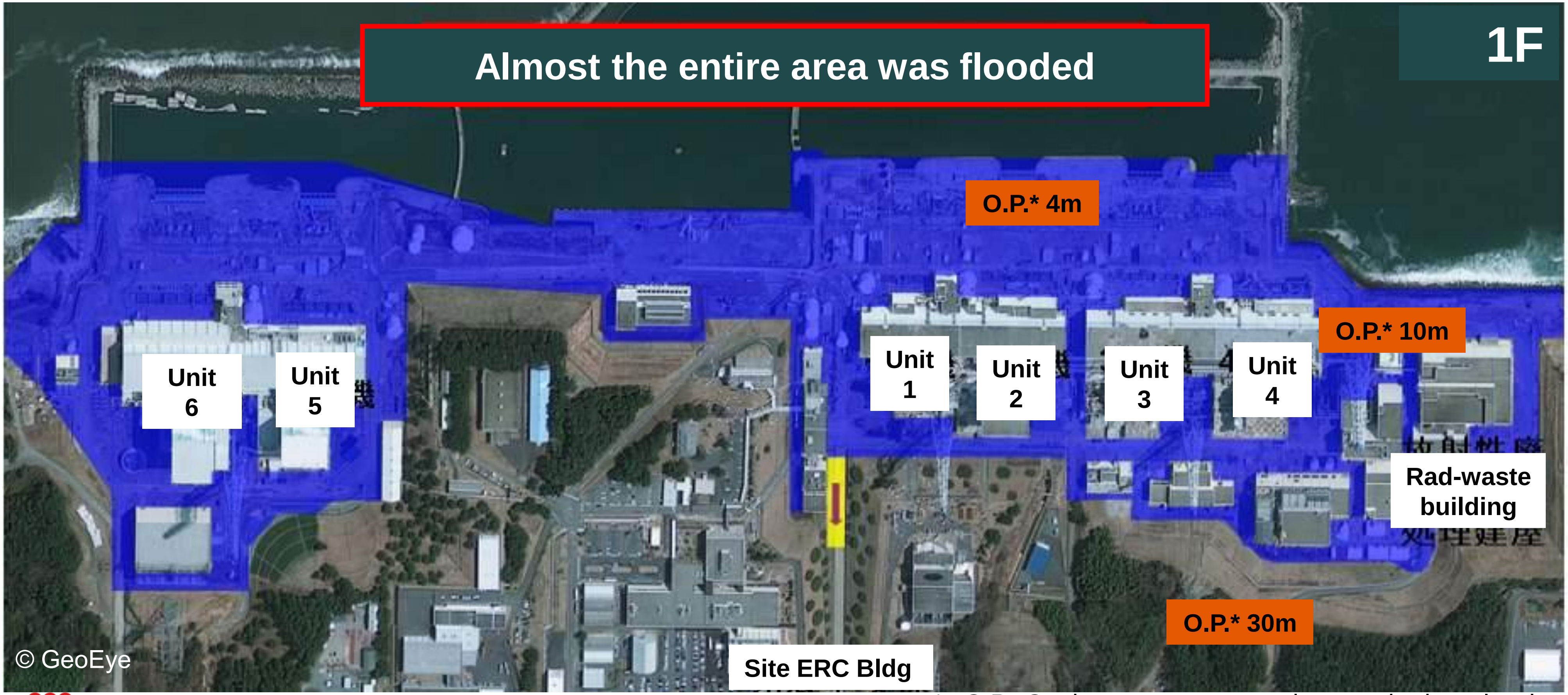
- Most of the observed accelerations were below the design responses except for the values in red.

Observation Point (Base mat of reactor buildings)		Observed Data			Maximum Response Acceleration against Design Basis Earthquake (gal)		
		Maximum Response Acceleration (gal)					
		Horizontal (N-S)	Horizontal (E-W)	Vertical	Horizontal (N-S)	Horizontal (E-W)	Vertical
Fukushima Daiichi (1F)	Unit 1	460*	447*	258*	487	489	412
	Unit 2	348*	**550***	302*	441	438	420
	Unit 3	322*	**507***	231*	449	441	429
	Unit 4	281*	319*	200*	447	445	422
	Unit 5	311*	**548***	256*	452	452	427
	Unit 6	298*	444*	244	445	448	415
Fukushima Daini (2F)	Unit 1	254	230*	305	434	434	512
	Unit 2	243	196*	232*	428	429	504
	Unit 3	277*	216*	208*	428	430	504
	Unit 4	210*	205*	288*	415	415	504

* The records were stopped approximately 130-150 seconds after recording started.

Impact of Earthquake/Tsunami at Fukushima Daiichi NPP (1F)

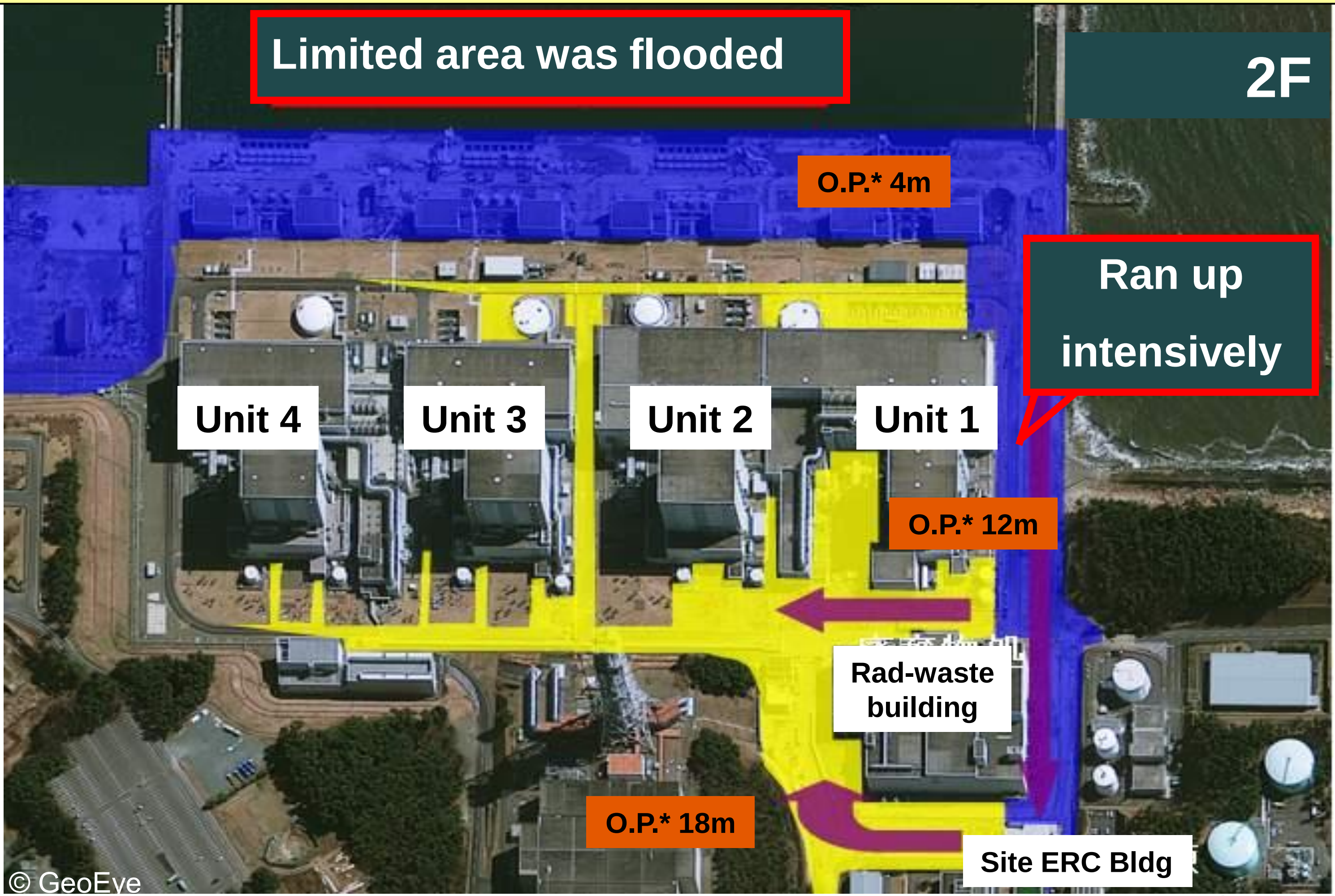
- Observed seismic acceleration exceeded design response at only limited locations.
  - No damage to safety-related equipment due to the earthquake confirmed to date.
- Tsunami severely flooded most of the major buildings.
  - Estimated tsunami height of approx. 13 m (43 ft) was much greater than the design basis of 6.1 m (20 ft).



*: O.P.: Onahama port construction standard sea level.

Impact of Earthquake/Tsunami at Fukushima Daini NPP (2F)

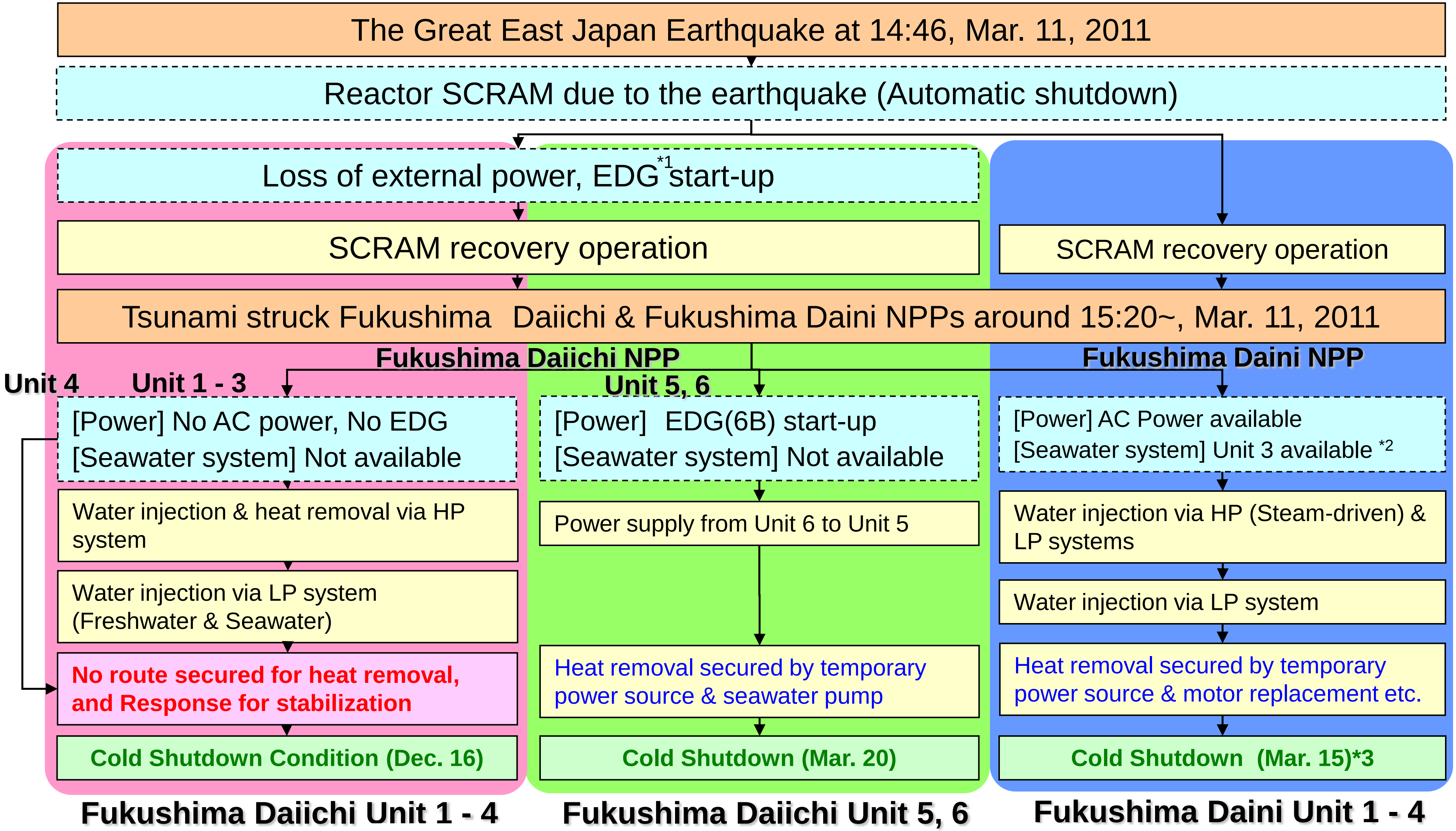
- Observed seismic acceleration was mostly smaller than design response.
- Damage due to tsunami was less extreme compared to 1F.
  - Estimated tsunami height of approx. 9 m was much greater than the design basis of 5.2 m.



*: O.P.: Onahama port construction standard sea level.

Overview of the Fukushima Nuclear Accident

Progress towards Cold Shutdown Status in each Unit (Outline)



The Great East Japan Earthquake at 14:46, Mar. 11, 2011

Reactor SCRAM due to the earthquake (Automatic shutdown)

Loss of external power, EDG[*1] start-up

SCRAM recovery operation

SCRAM recovery operation

Tsunami struck Fukushima Daiichi & Fukushima Daini NPPs around 15:20~, Mar. 11, 2011

Fukushima Daiichi NPP

Fukushima Daini NPP

Unit 4

Unit 1 - 3

[Power] No AC power, No EDG
[Seawater system] Not available

Water injection & heat removal via HP system

Water injection via LP system (Freshwater & Seawater)

No route secured for heat removal, and Response for stabilization

Cold Shutdown Condition (Dec. 16)

Unit 5, 6

[Power] EDG(6B) start-up
[Seawater system] Not available

Power supply from Unit 6 to Unit 5

Heat removal secured by temporary power source & seawater pump

Cold Shutdown (Mar. 20)

[Power] AC Power available
[Seawater system] Unit 3 available[*2]

Water injection via HP (Steam-driven) & LP systems

Water injection via LP system

Heat removal secured by temporary power source & motor replacement etc.

Cold Shutdown (Mar. 15)*3

Fukushima Daiichi Unit 1 - 4

Fukushima Daiichi Unit 5, 6

Fukushima Daini Unit 1 - 4

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*1 EDG : Emergency Diesel Generator

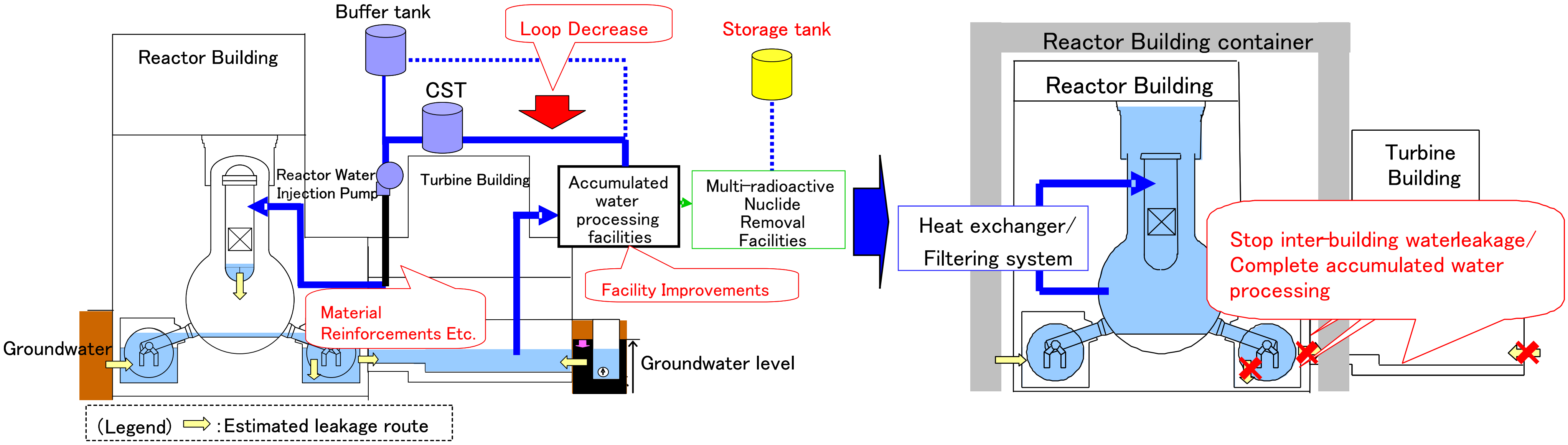
*2 RHR Seawater System

*3 Fukushima-Daini Emergency State was lifted on Dec. 26, 2011

On-going activities at Fukushima Daiichi NPP (1F):

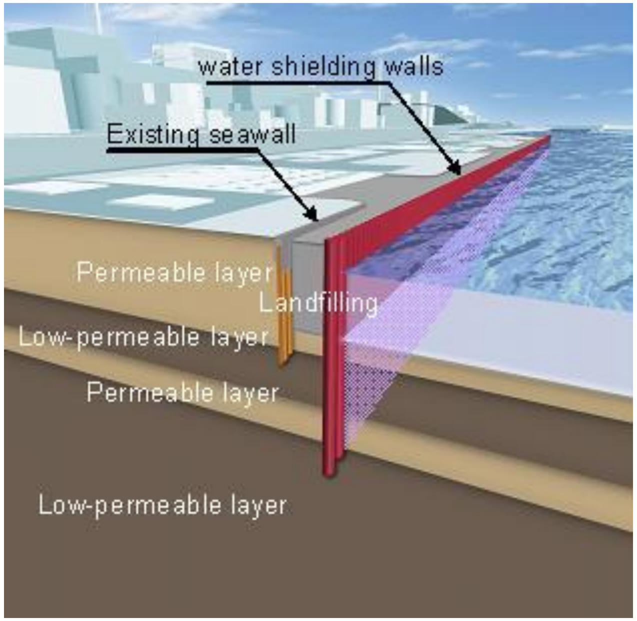
1) Reactor Cooling and Accumulated Water Processing

- In order to stably maintain "a condition equivalent to cold shutdown", circulating water cooling will be continued up to the completion of the fuel debris removal.
- By examining the reliability of the cooling system, improvements will be implemented continuously.
- During Phase 2, processing of accumulated water in the buildings will be finished. In order to achieve more stable cooling, scaling down of the circulation loop is being considered.

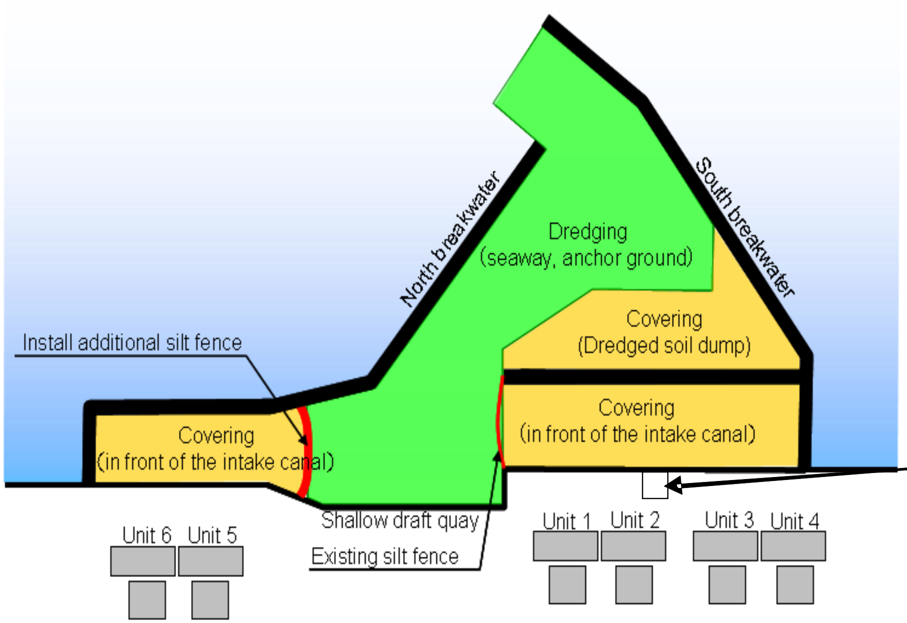


On-going activities at 1F:
2) Mitigation of Sea Water Contamination

- Should underground water be contaminated, water shielding walls will be installed by mid FY2014 in order to prevent underground water from flowing into the ocean.
- Covering and solidifying seabed soil in front of the intake canal will prevent the diffusion of radioactive materials in the soil. By the end of FY2012, continuous operation of the circulating seawater purification facilities will reduce radioactive materials in the seawater inside the site port to the level below the limit for the outside of environment surveillance areas as determined by a notification of the government. Sediments dredged in order to secure a navigable depth for large ships will be covered similarly.
- Afterwards, while maintaining the installed facilities, underground water and sea water etc. will be monitored continuously.



Water shielding walls (Image)



Circulating seawater purification facilities

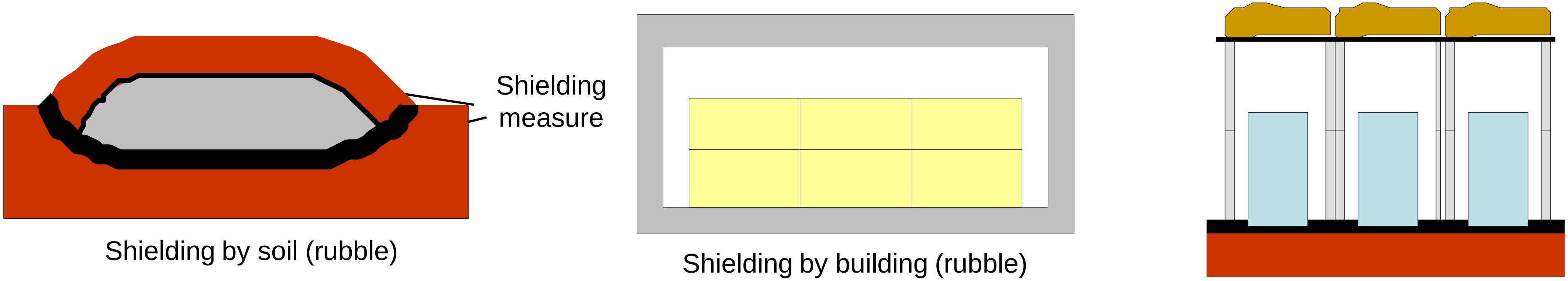
Seabed soil covering in front of water intake

On-going activities at 1F:

3) Radioactive Waste Management and Dose Reduction at the Site

4) Decontamination

- Plan to reduce the effective radiation dose at the site boundaries to below 1 mSv / year by FY2012 as a target date, due to additional emissions from the whole site and radioactive waste stored on the site after the accident (secondary waste materials via water processing and rubble etc.).
- Plan to develop a facility renewal plan by the end of FY2014 that includes the lifetime assessment of the containers for secondary waste from water processing.
- Plan to continue ongoing land and sea environmental monitoring.
- In order to reduce exposure to the public and workers while improving the work environment, step-by-step decontamination measures will be implemented starting from the offices and working areas such as Emergency Response Centre in conjunction with efforts to reduce radiation dosage outside the site.



Shielding by soil (rubble)

Shielding by building (rubble)

Shielding by sandbags etc. (secondary waste from water processing)

Shielding measures (example)