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Overview of the Accident in Fukushima Daiichi Nuclear Power Plants

Naoto Sekimura
University of Tokyo
Japan

August 8, 2011
IAEA
ICTP, Trieste, Italy

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Naoto Sekimura

Vice Dean, School of Engineering, The University of Tokyo
Professor, Department of Nuclear Engineering and Management
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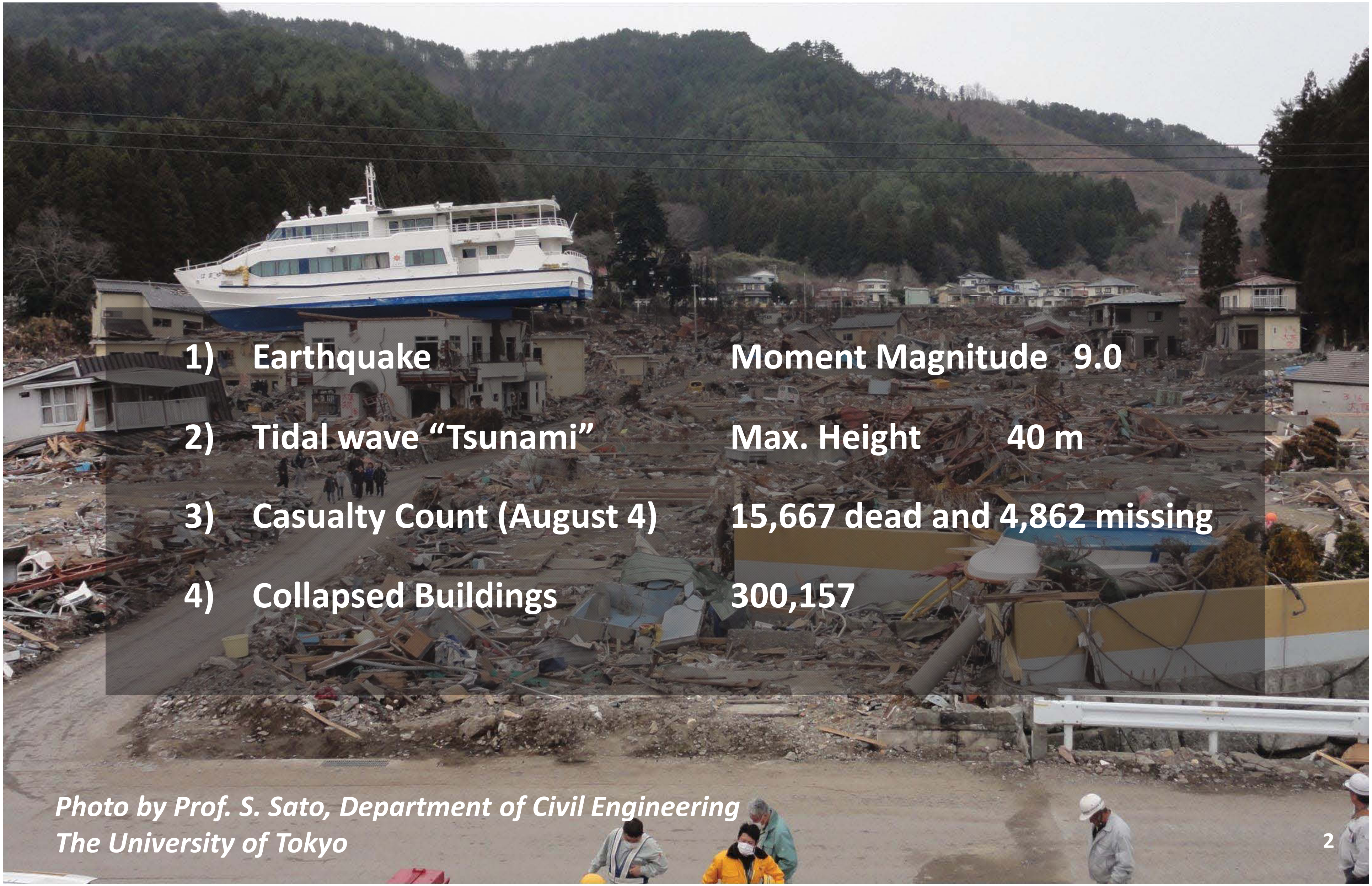
Contents

The information in this presentation is preliminary and needs to be confirmed later.

Earthquake and Tsunami on March 11, 2011



震災の科学技術に対するインパクト
Impact of the Disaster upon Science and Technology

1) 原子力発電所の事故 — 4基同時，レベル7
   Accident of nuclear power plant — 4 plants, Level 7

2) 電力供給不足 — 3950×10^4 kW，計画停電
   Shortage of electric power supply — Rolling blackouts

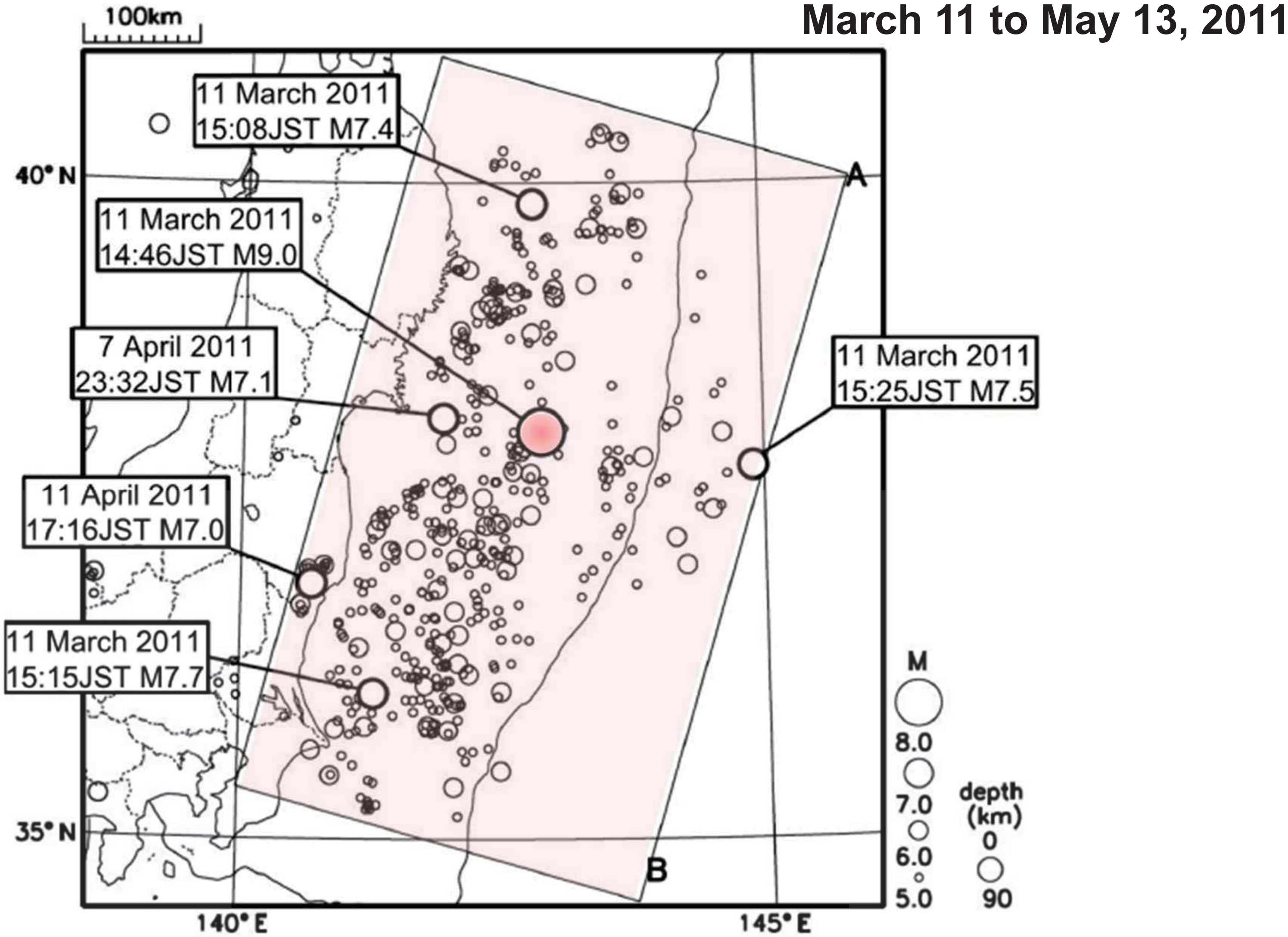
3) 工業生産の低下 — サプライチェーンの断裂
   Diminishing industrial production — Supply-chain disruption

4) 通信網の断裂 — 1週間
   Disruption of communication network — 1 week

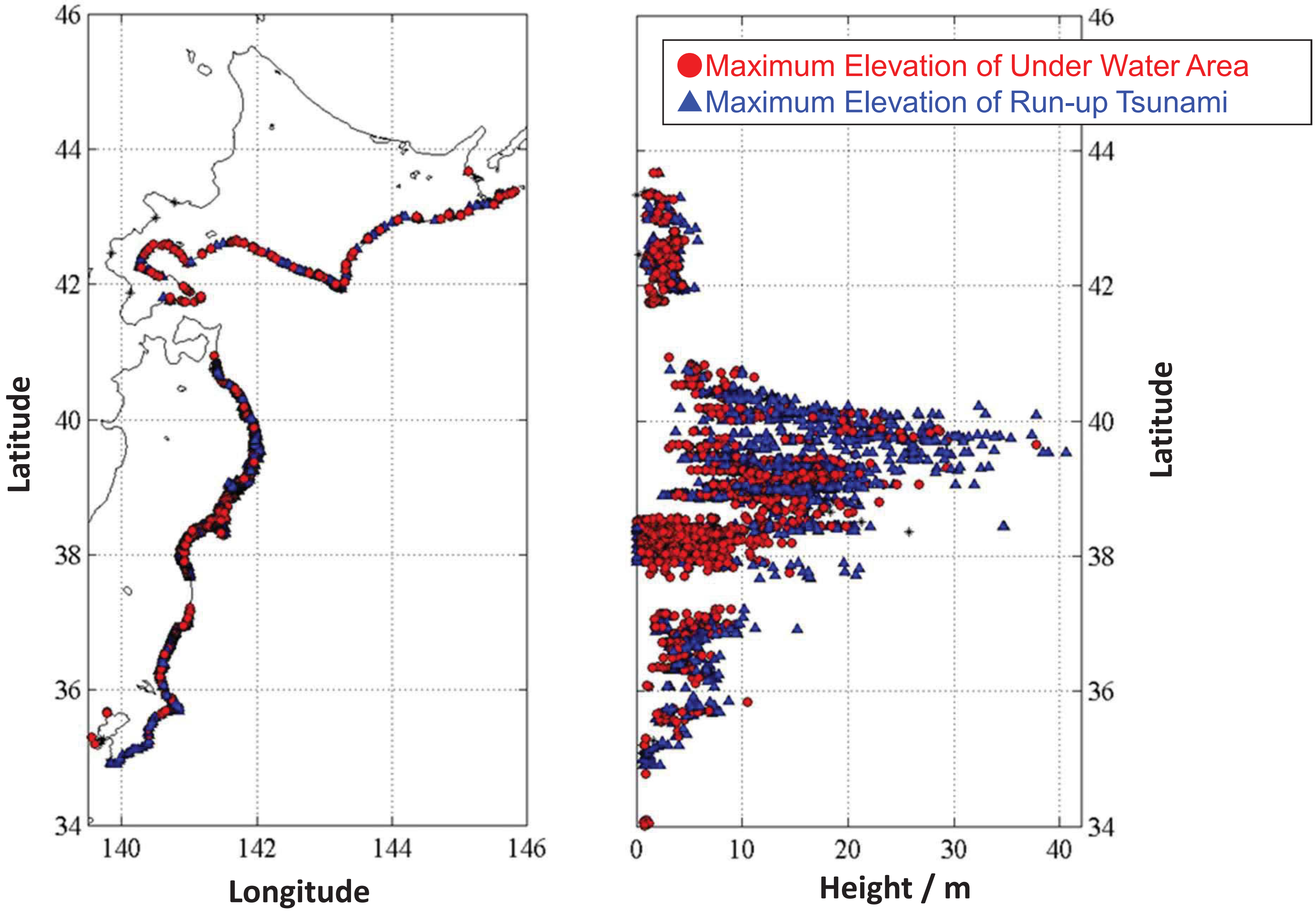
科学技術への信頼低下
Loss of credibility of science and technology ?
工学者・学生の自信喪失
Loss of confidence in engineering scholars and students ?

Prof. T. Kitamori, Dean of School of Engineering, The University of Tokyo

The Main Shock and Aftershock of the Earthquake on March 11, 2011



Tsunami after the Earthquake on March 11, 2011



Compiled by 80 members from 33 organization including The University of Tokyo
http://www.coastal.jp/ttjt/

Automatic Shut-down of Nuclear Reactors by the Earthquake on March 11, 2011

11 reactors were automatically shut-down

- Onagawa Unit 1,2,3
- Fukushima Daiichi Unit 1,2,3
- Fukushima-Daini Unit 1,2,3,4
- Tokai-2

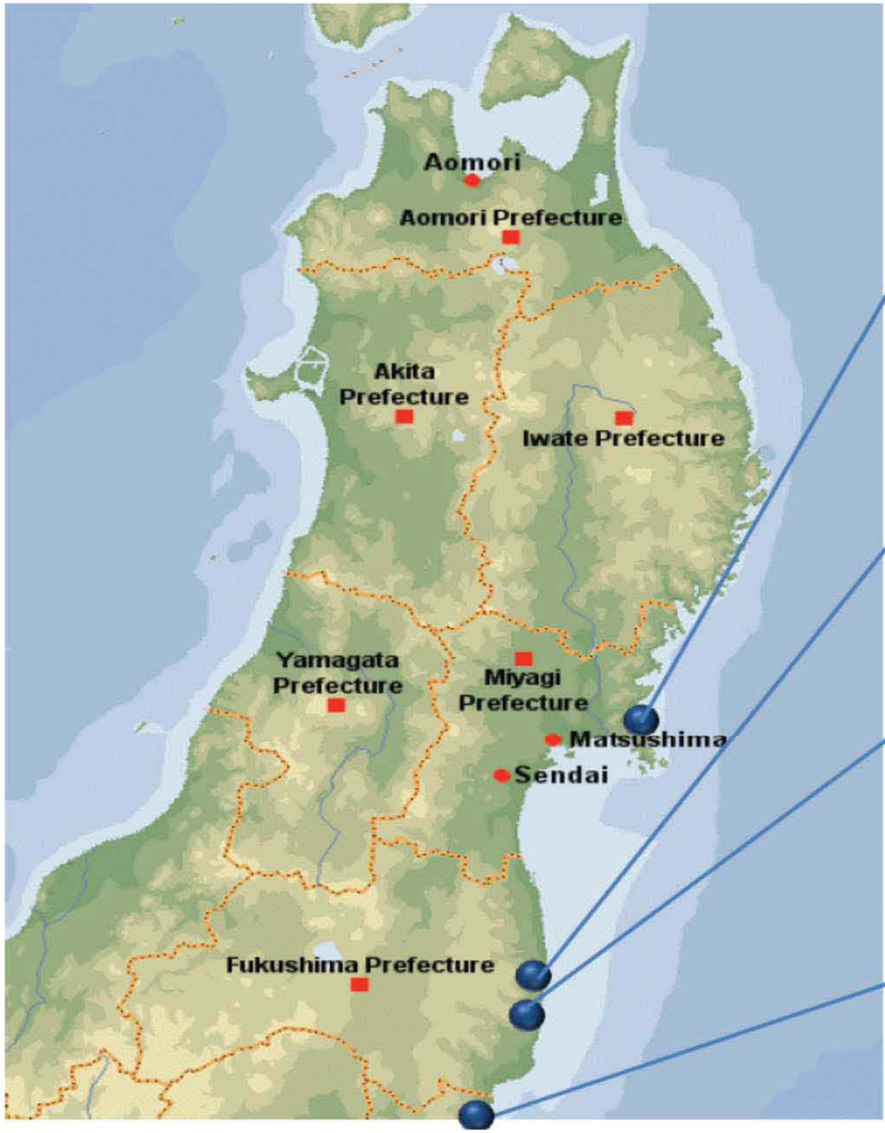
3 reactors were under periodic inspection

- Fukushima Daiichi Unit 4,5,6

- After the automatic shut-down, the Units 1-3 at Onagawa Nuclear Power Station, the Unit 3 at Fukushima Daini Nuclear Power Station, and the Tokai-2 Nuclear Power Station have been cold shut down safely.

- As for the unit 1,2,4 at Fukushima Daini Nuclear Power Station, the operator of the station reported NISA nuclear emergency situation because the temperature of the suppression pools became more than 100 ℃, but afterward the three units have been cold shut down.

Nuclear Power Plants in Eastern Coast of Japan



Onagawa (Tohoku)

Unit1: 524 MW, 1984-
Unit2: 825 MW, 1995-
Unit3: 825 MW, 2002-

*Fukushima Daiichi * (TEPCO)*

Unit1: 460 MW, 1971-
Unit2: 784 MW, 1974-
Unit3: 784 MW, 1976-
Unit4: 784 MW, 1978-
Unit5: 784 MW, 1978-
Unit6: 1,100 MW, 1979-

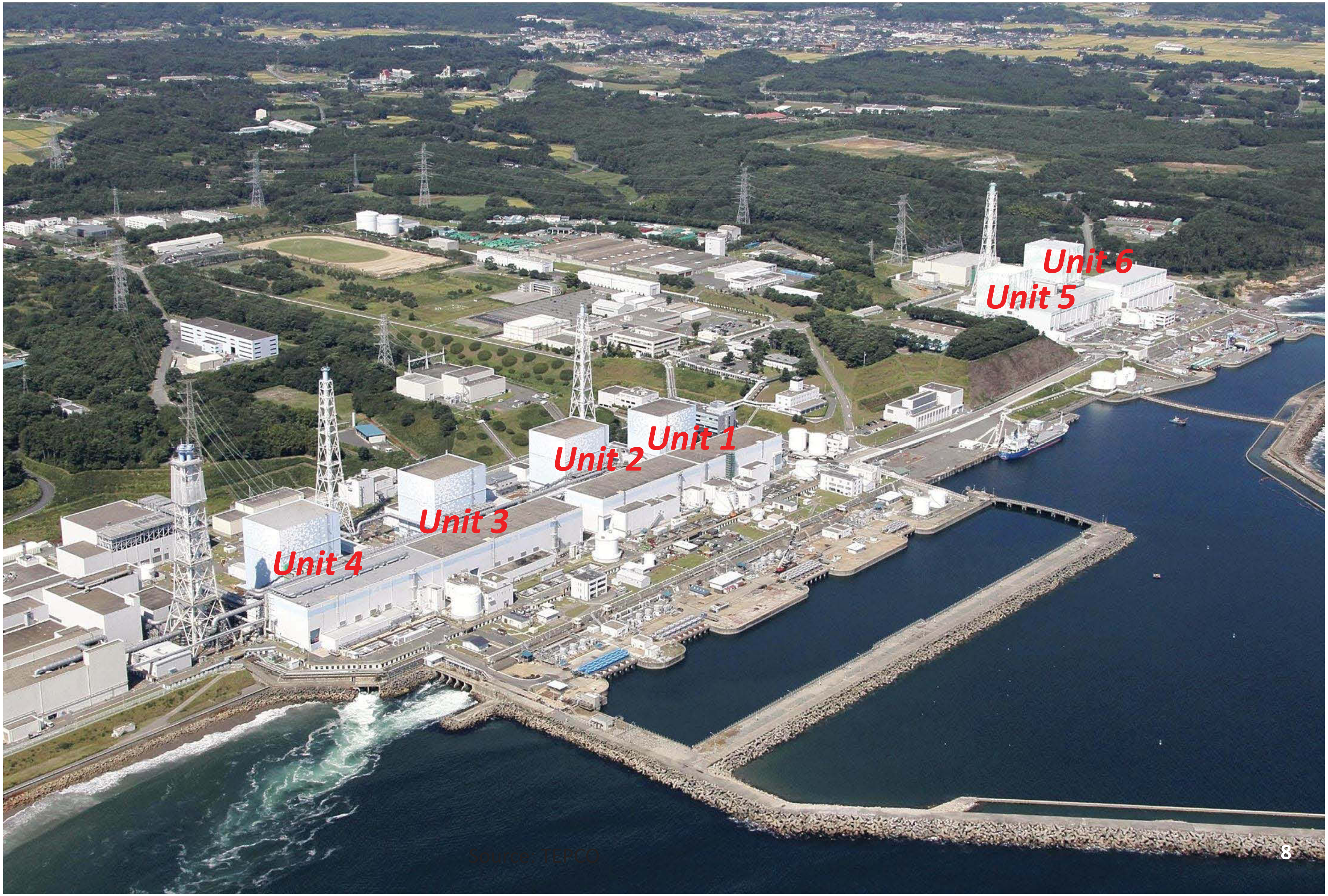
Fukushima Daini (TEPCO)

Unit1: 1,100 MW, 1982-
Unit2: 1,100 MW, 1984-
Unit3: 1,100 MW, 1985-
Unit4: 1,100 MW, 1987-

Tokai-2 (JAPCO) (1,100 MW, 1978-)

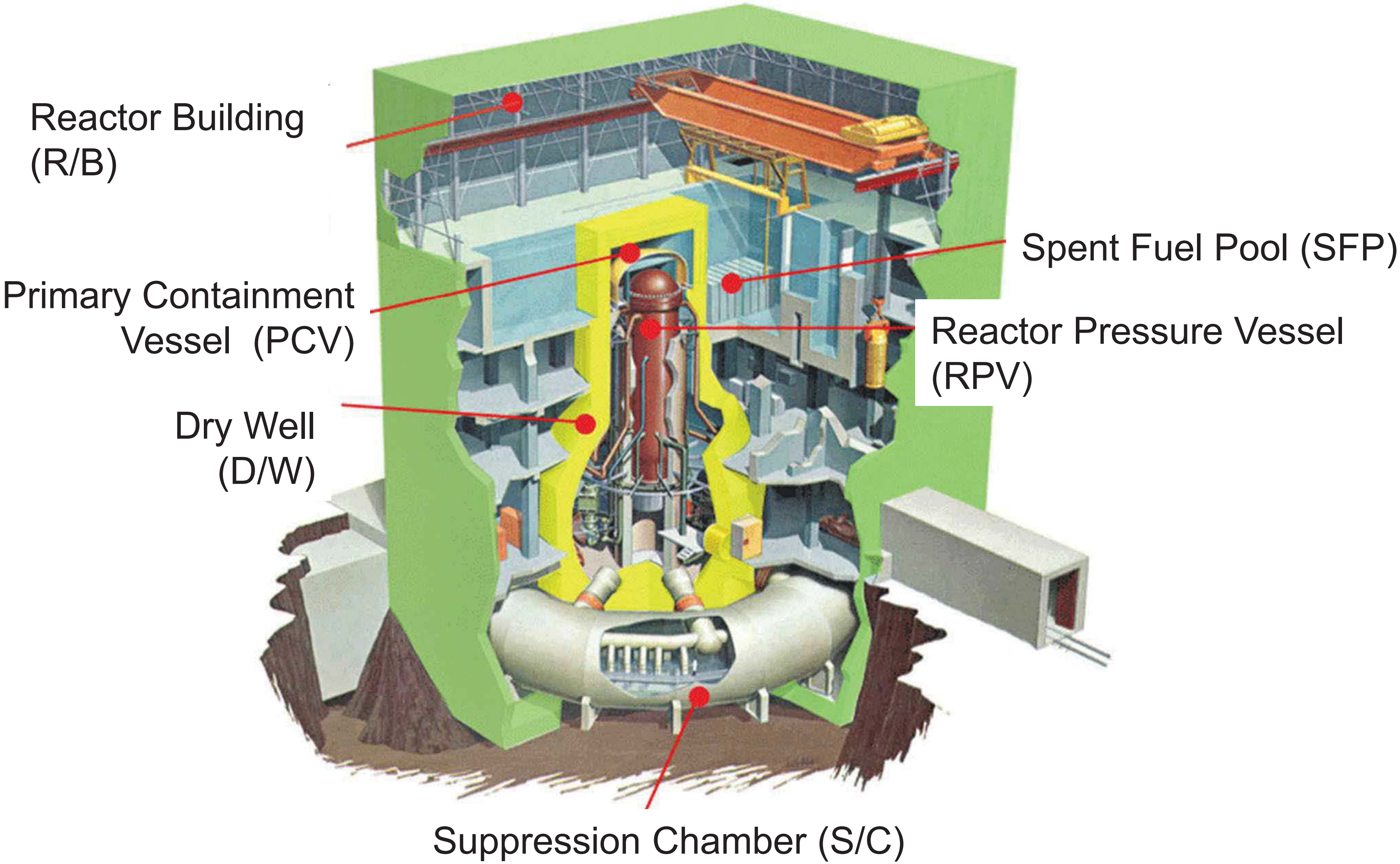
** Fukushima Daiichi locates approximately 230 km north of Tokyo*

Fukushima Daiichi Nuclear Power Plants operated by TEPCO



Source: TEPCO

BWR with Mark-I Type Containment Vessel (Fukushima Daiichi, Units 1,2,3,4 and 5)



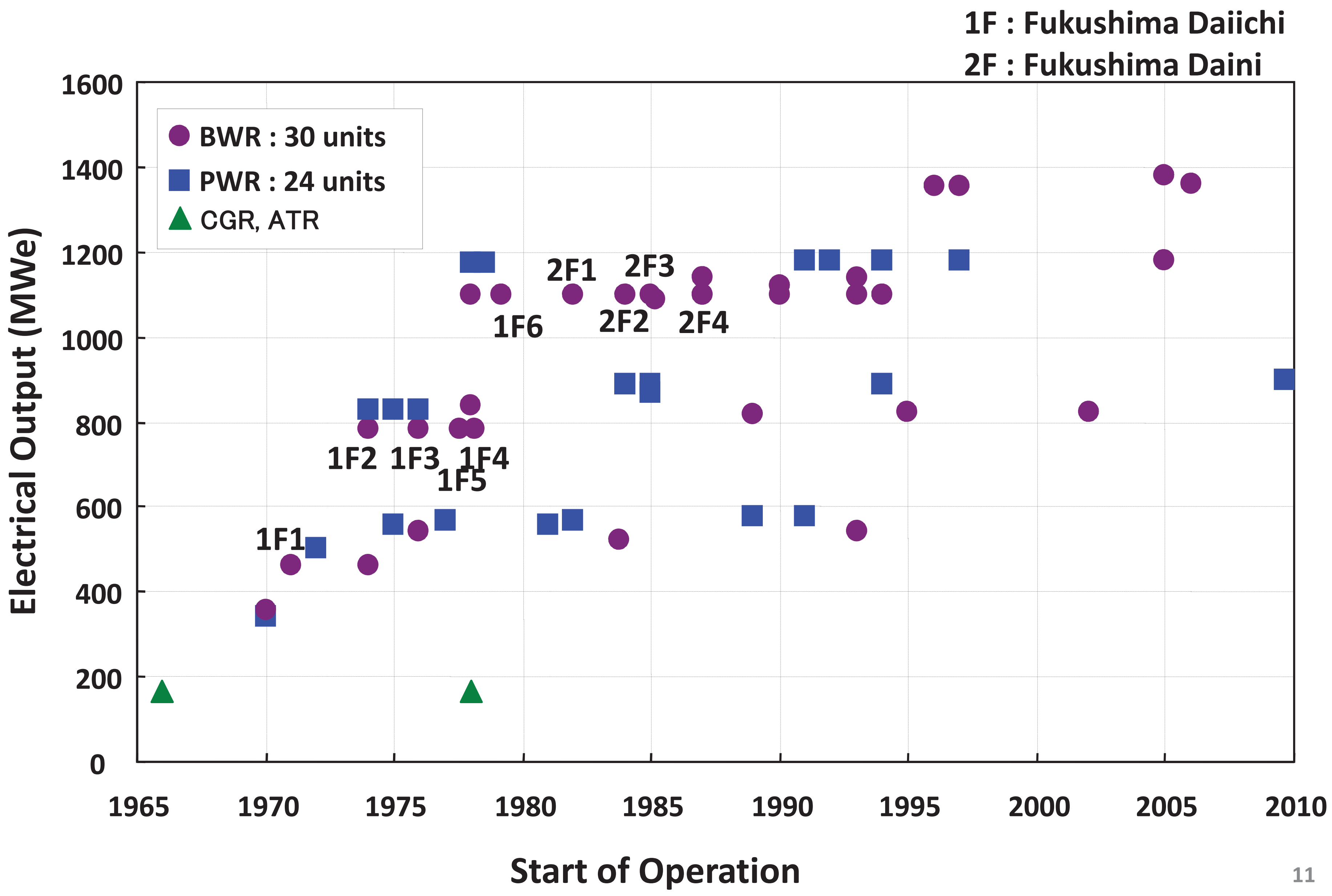
Summary of Fukushima Daiichi NPP

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
	BWR-3	BWR-4	BWR-4	BWR-4	BWR-4	BWR-5
PCV Model	Mark-I	Mark-I	Mark-I	Mark-I	Mark-I	Mark-II
Electric Output	460MWe	784MWe	784MWe	784MWe	784MWe	1100MWe
RPV Operation Pressure	6.89MPa	6.93MPa	6.93MPa	6.93MPa	6.93MPa	6.93MPa
RPV Max. Design Pressure	8.24MPa	8.24MPa	8.24MPa	8.24MPa	8. 62MPa	8.62MPa
RPV Max. Operation Temp.	300℃	300℃	300℃	300℃	302℃	302℃
PCV Max. Design Pressure	384kPa	384kPa	384kPa	384kPa	384kPa	279kPa
PCV Max. Pressure *	427kPa	427kPa	427kPa	427kPa	427kPa	310kPa
PCV Max. Temp	140℃	140℃	140℃	140℃	138℃	171℃:D/W 105℃:S/C
Commercial Operation	1971.3.26	1974.7.18	1976.3.27	1978.10.12	1978.4.18	1979.10.24
Emergency DG	2	2 **	2	2 **	2	3 **
Electric Grid	275kV×4				500kV×2	
Plant Status on Mar. 11	In Operation	In Operation	In Operation	Long Outage for Shroud Replacement	Refueling Outage	Refueling Outage

* Typical operating pressure of PCV is about 5 kPa.

** One Emergency DG is Air-Cooled

Nuclear Power Plants in Japan



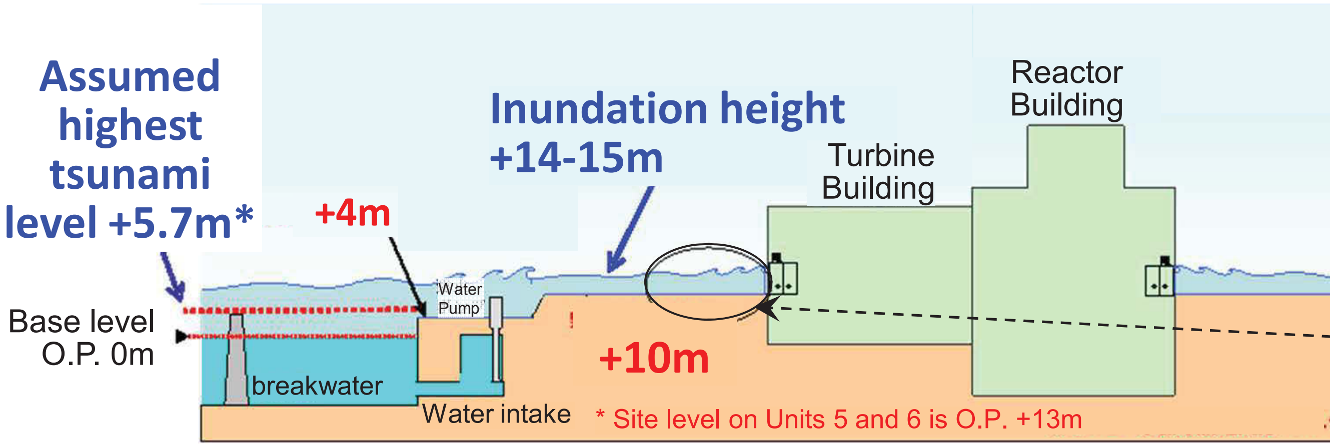
Recorded Intensity of Ground Motion and Basic Earthquake Ground Motion

		Observed Maximum Response Acceleration * (Gal)			Max Response Acceleration against Basic Earthquake Ground Motion (Gal), Ss		
		Horizontal (N-S)	Horizontal (E-W)	Vertical	Horizontal (N-S)	Horizontal (E-W)	Vertical
Fukushima Daiichi	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	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

* At the lowest basement of reactor building

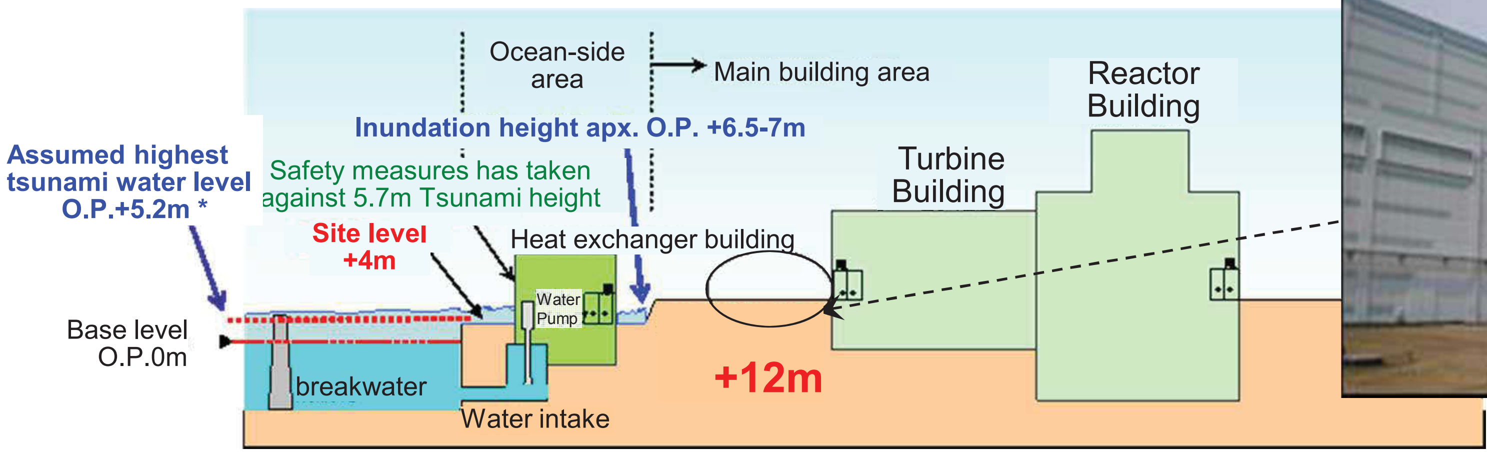
Tsunami

Fukushima Daiichi

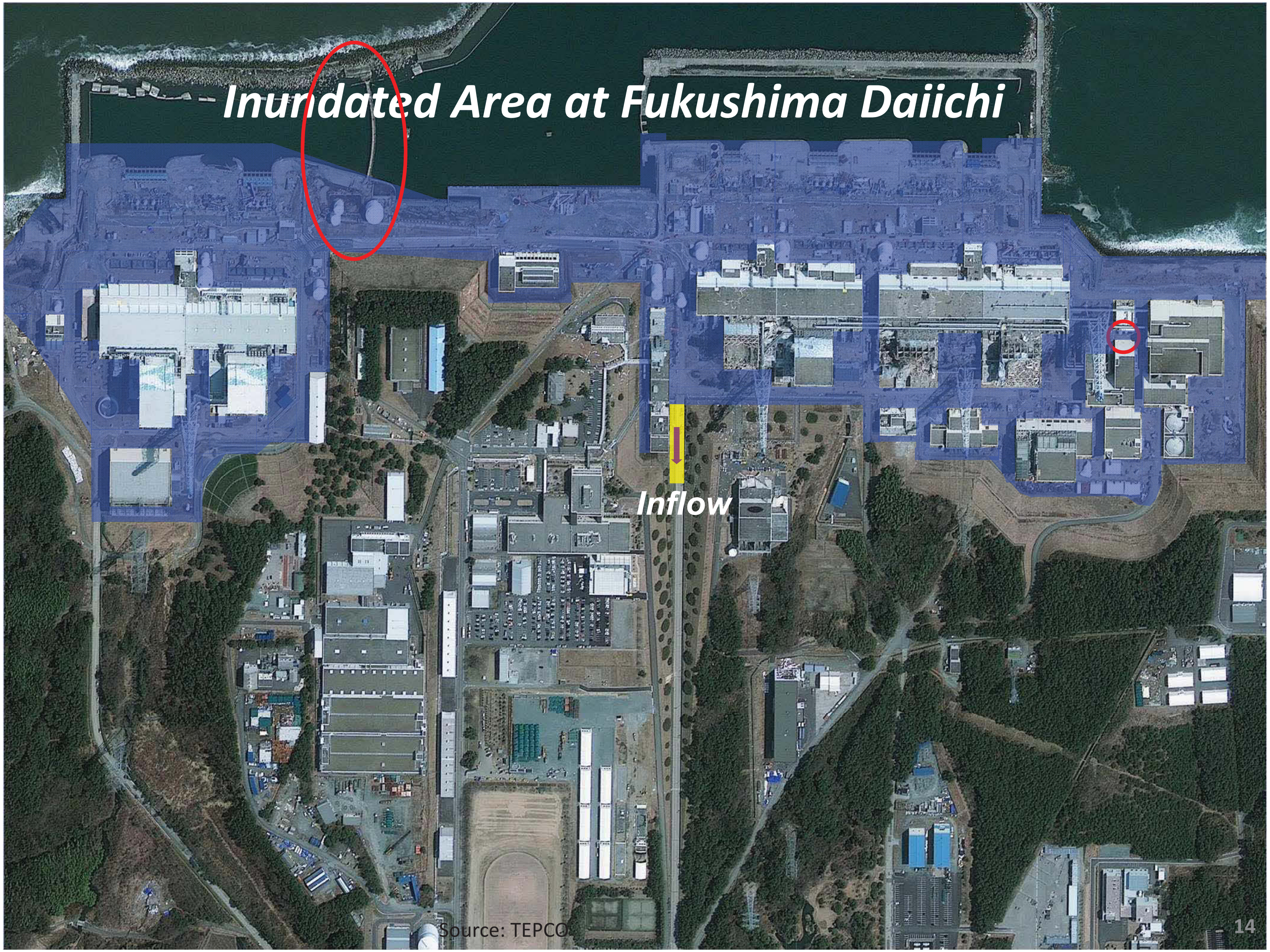


** Based on 2002 guidelines for NPPs issued by the Nuclear Civil Engineering Committee of JSCE*

Fukushima Daini



O.P.: Onahama bay construction base level


Inundated Area at Fukushima Daiichi
Inflow
Source: TEPCO
14

Tsunami on March 11, 2011

Source: TEPCO

Tsunami on March 11, 2011

15:42:40

15:42:46

15:43:26

15:43:36

15:43:54

15:44:18

15:44:44

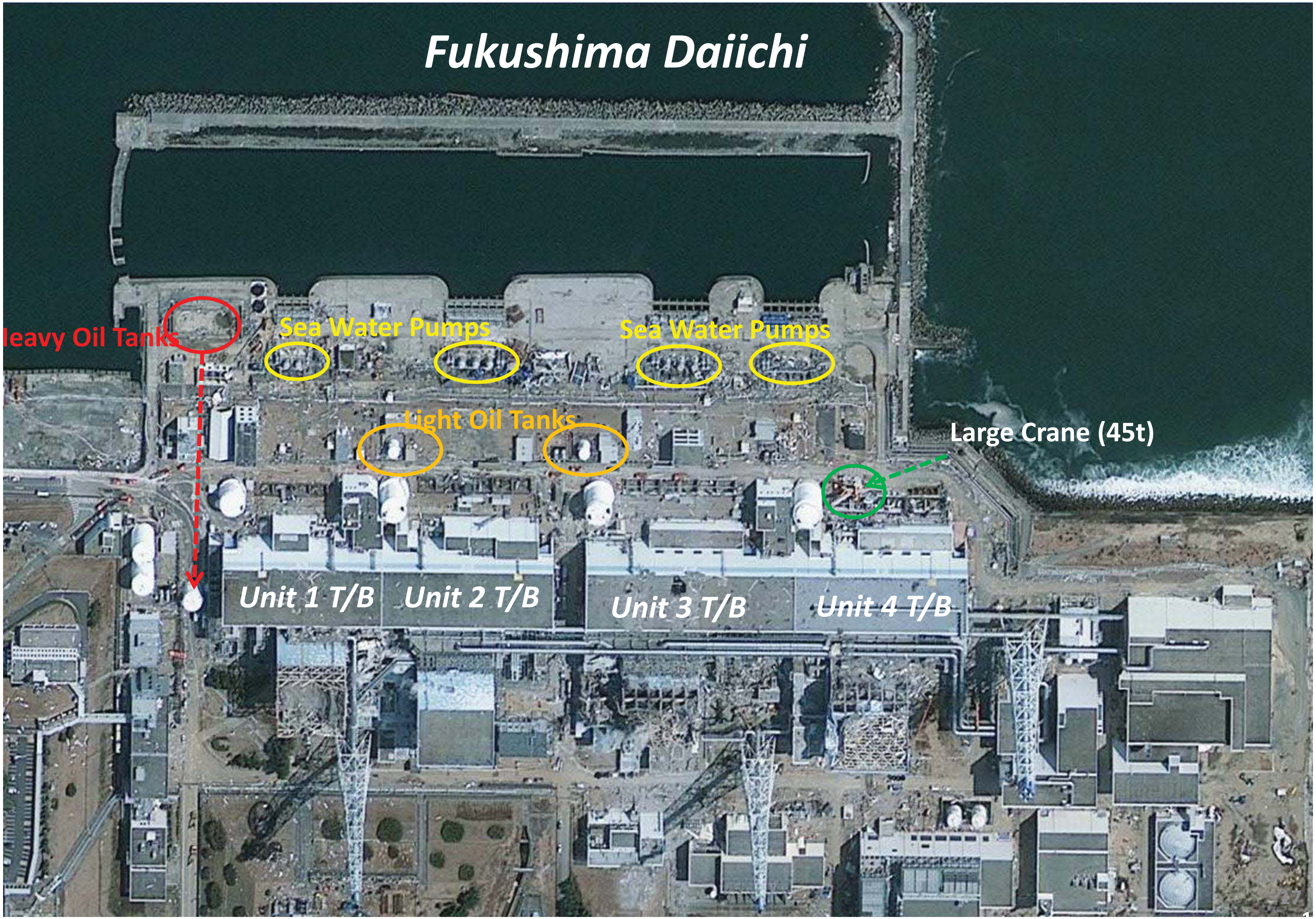
15:44:58

15:46:10

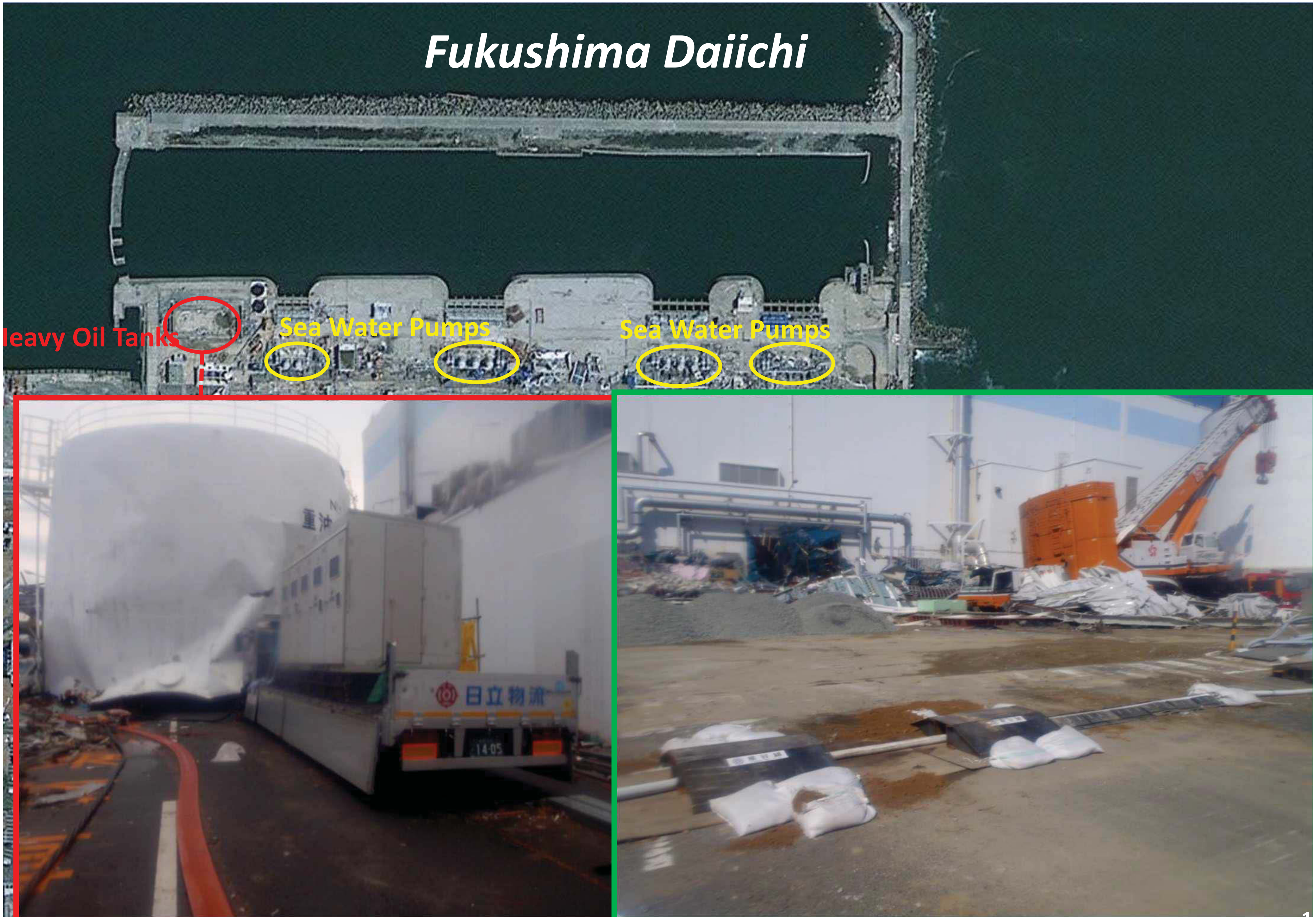
Tsunami height in Fukushima Daiichi was about 15 m.

Source: TEPCO

Tsunami on March 11, 2011



Tsunami on March 11, 2011



Station Black-Out in Units 1-4

- Loss of Off-Site Power Supply and EDG -

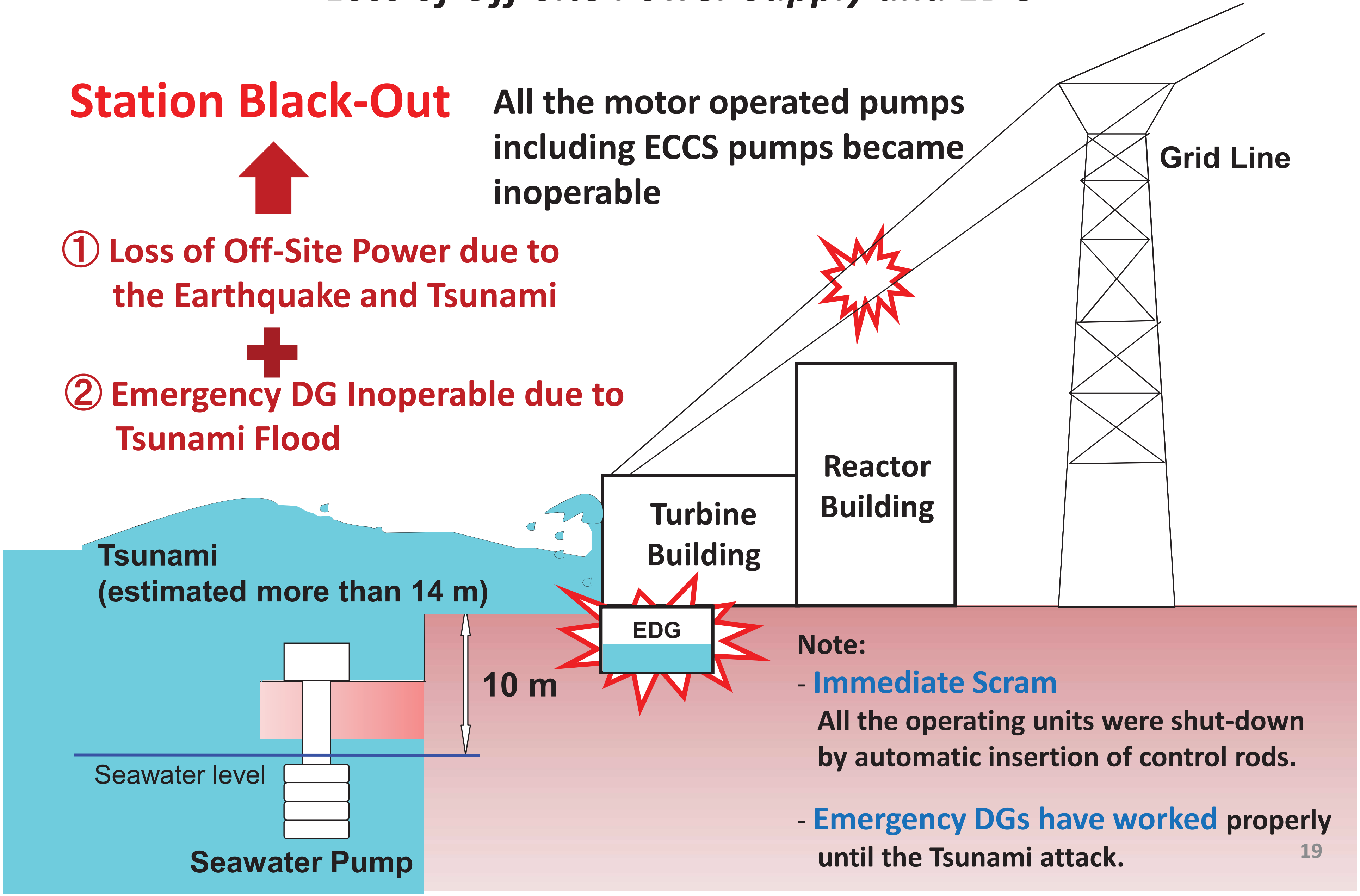
Station Black-Out

All the motor operated pumps including ECCS pumps became inoperable

① Loss of Off-Site Power due to the Earthquake and Tsunami

➕

② Emergency DG Inoperable due to Tsunami Flood



Note:

- **Immediate Scram**
  All the operating units were shut-down by automatic insertion of control rods.

- **Emergency DGs have worked** properly until the Tsunami attack.

Loss of Off-site Power Supply and EDG in Units 1-4

Loss of the external power supply

Okuma 1L,2L : Breakers were broken due to the earthquake

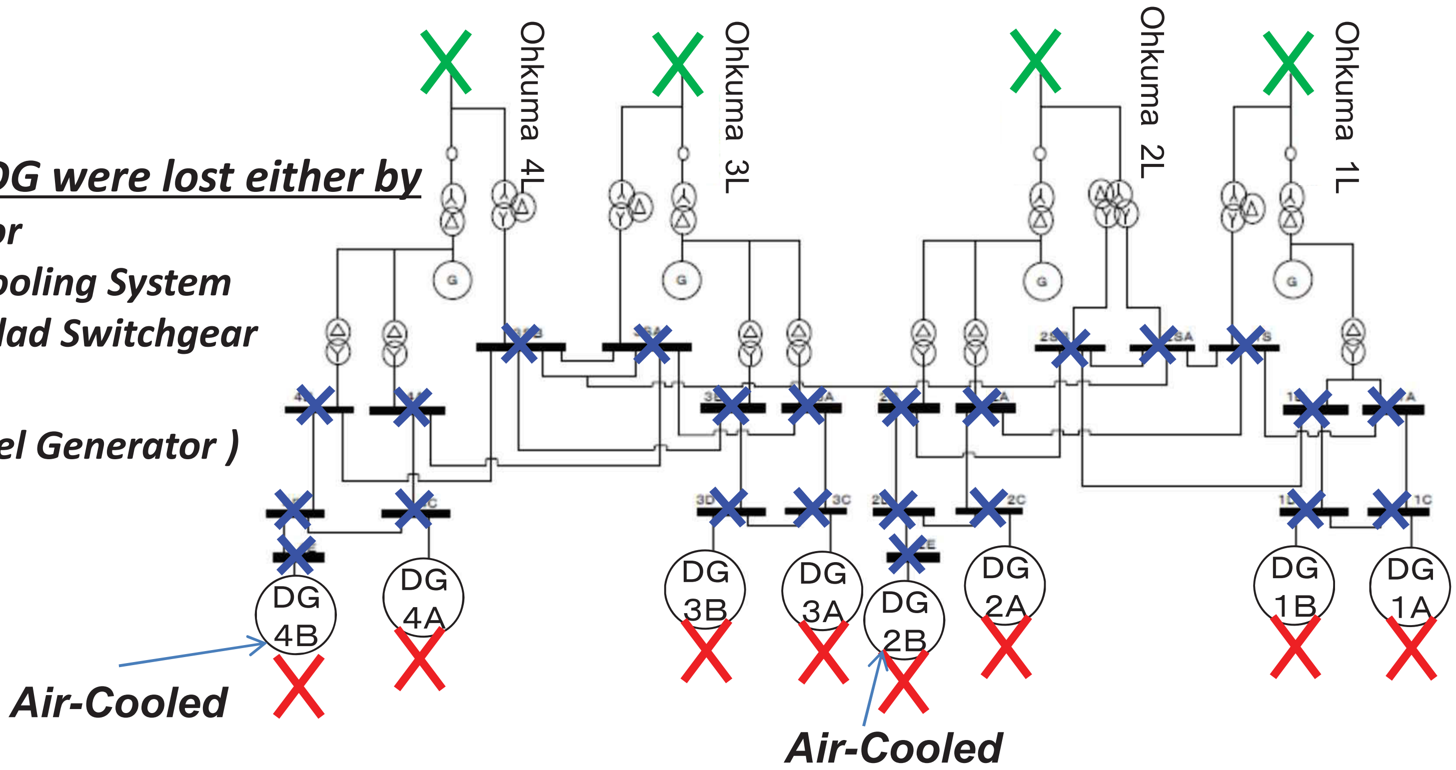
Okuma 3L : Under modification

Okuma 4L : The failure cause is being investigated

Functions of all the EDG were lost either by

1) Damage in Generator
2) Loss of Sea-Water Cooling System
3) Damage at Metal-Clad Switchgear

(EDG : Emergency Diesel Generator)

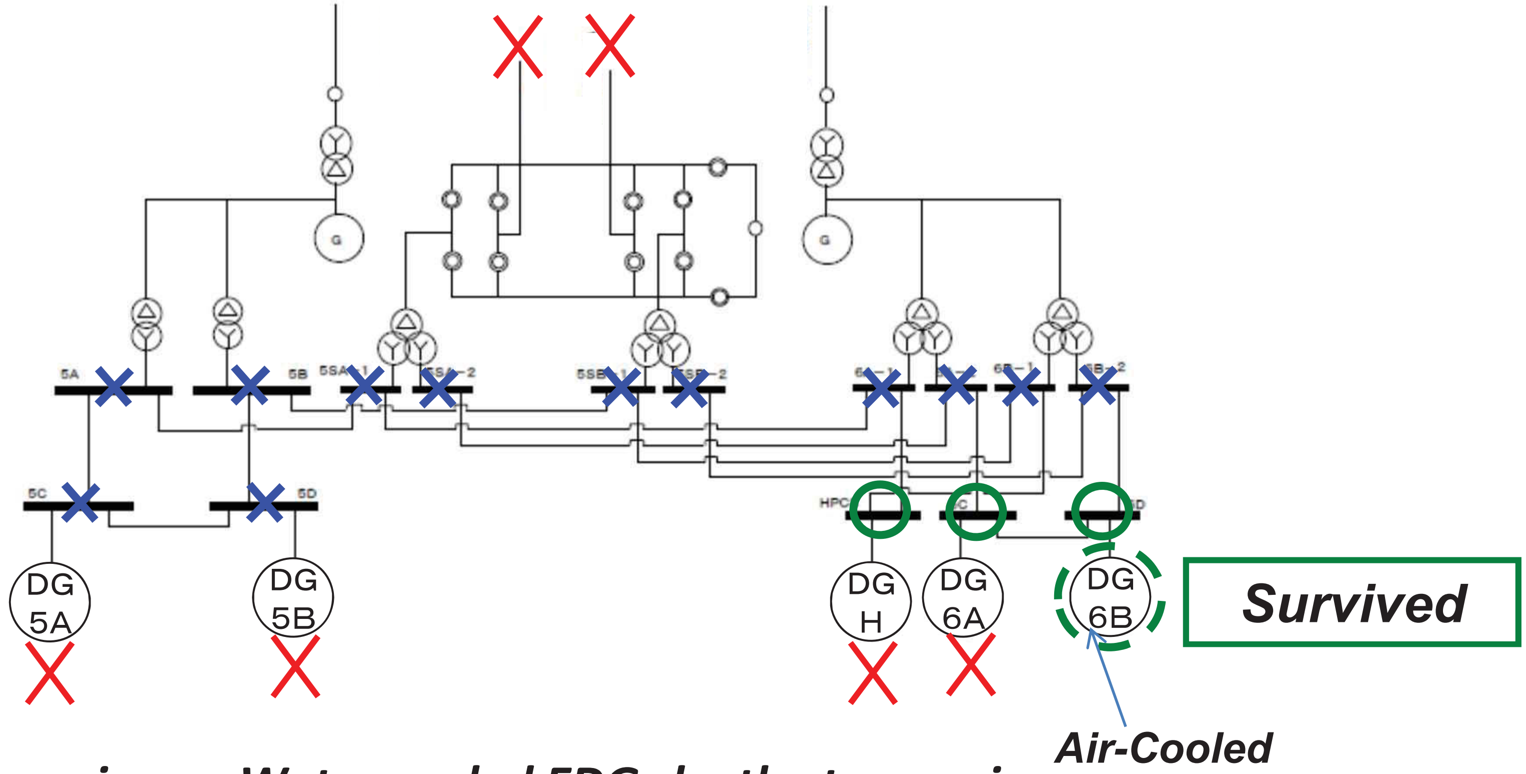


Recovery of Off-site Power Supply

Unit 2 on March 20, Unit 1,3,4 on March 22

One Air-Cooled DG (DG6B) survived in Units 5 & 6

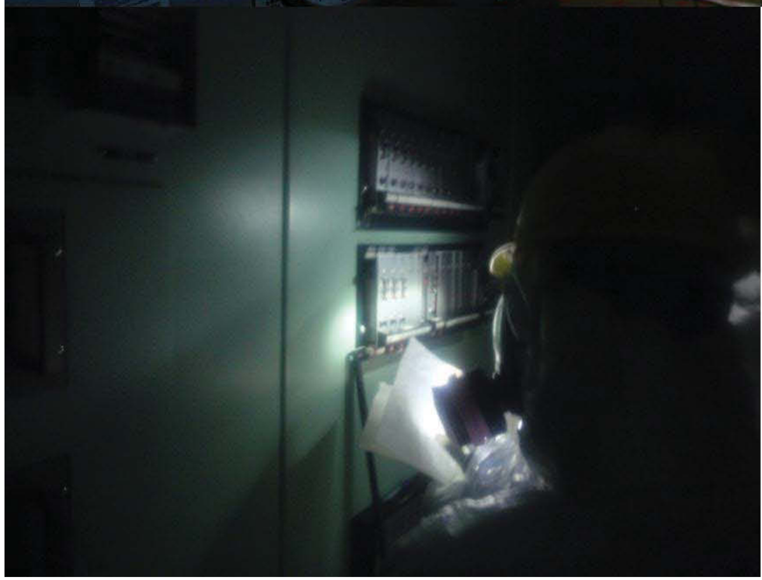
Pylons damage by the earthquake caused loss of off-site power supply



Damage in sea-Water cooled EDGs by the tsunami

Recovery of Off-site Power Supply on March 20-21

Photographs from One of the Fukushima 50



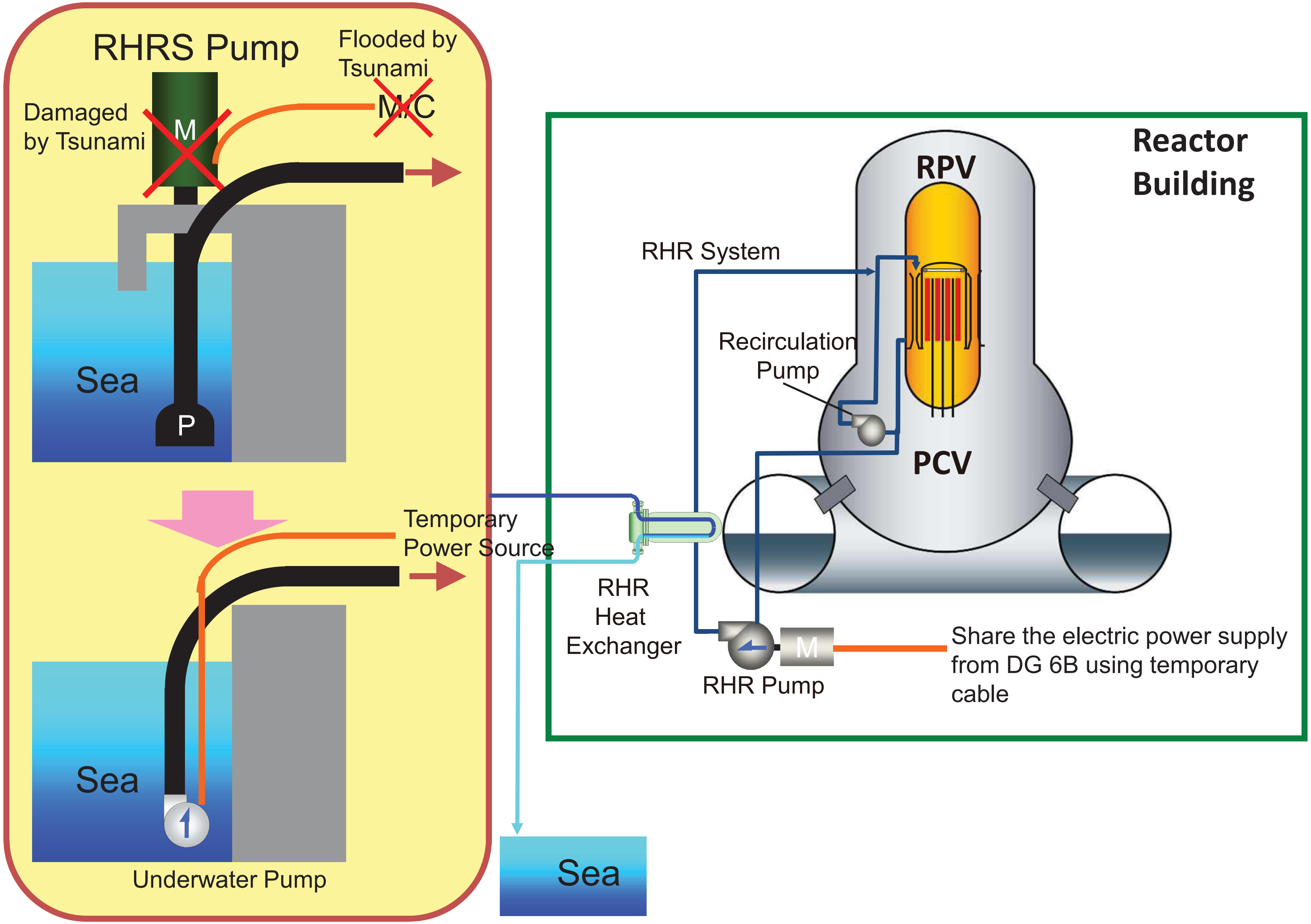
Source: TEPCO

- **After the Tsunami,**
  - **No lighting available**
  - **What they can get are flashlights, batteries (some are removed from automobiles), fire trucks and some compressors**
  - **Very difficult to measure the major safety parameters like water level, reactor pressure, CV pressure**

Summary : Differences of Units 1-4, Fukushima Daiichi

- ***Fukushima Daiichi Units 5 & 6***
  - **Elevation of the ground is 13 m. (Units 1 - 4 : 10m)**
  - **One air cooled EDG of Unit 6 which is located on the ground level was survived.**
  - **Metal Clad Switchgears were not lost.**
  - **Temporary sea water pump installed after the earthquake was operable, making use of power for RHR and others from survived EDG.**
- ***Fukushima Daini NPPs***
  - **External power was not lost.**
  - **RHR function of Unit 3 was survived.**
  - **Motors of sea water pumps for Unit 1,2 and 4 were replaced by March 14, followed by re-activation of core cooling function.**
- ***Onagawa NPPs***
  - **Elevation of the plants was 14.8m which is higher than Tsunami height.**
- ***Tokai-2***
  - **Although off-site power was lost until May 13, 2 out of 3 EDGs were not lost thanks to the recently installed barrage to one of 2 seawater pump area to protect pumps from tsunami.**

Alternative RHRS pump for Unit 5



Radioactive Materials and Decay Power in Units 1, 2 and 3

Source Term just after the Shutdown

Unit 1 Fuel

I-131 : 1.9×10^{18} Bq

Cs-137 : 2.0×10^{17} Bq

Unit 2

I-131 : 2.7×10^{18} Bq

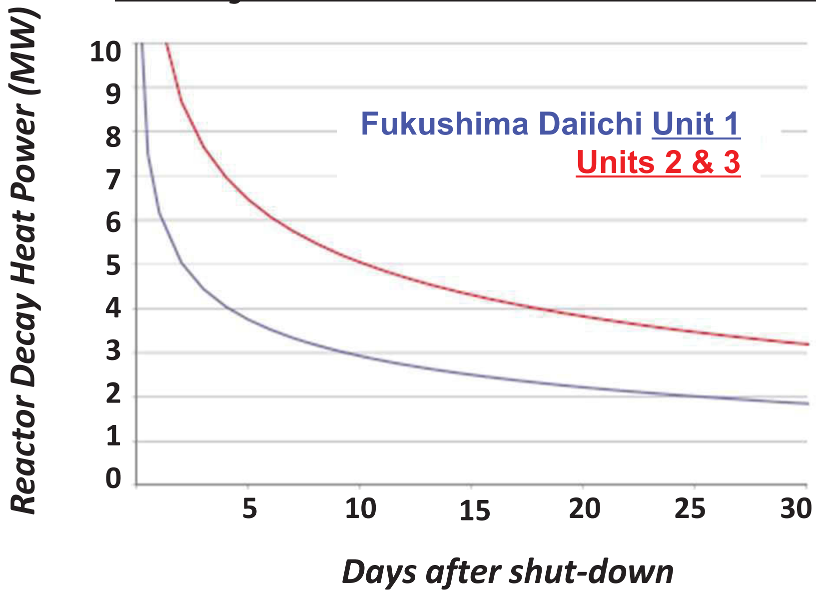
Cs-137 : 2.4×10^{17} Bq

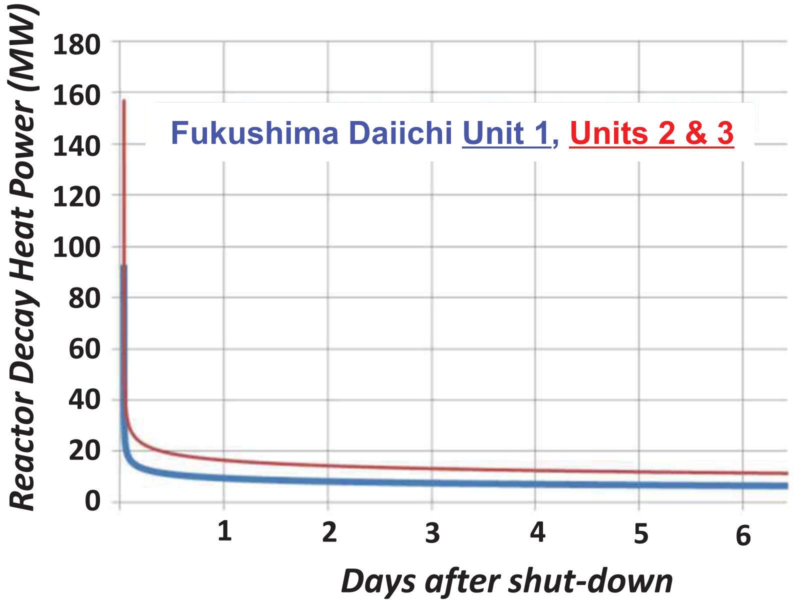
Unit 3

I-131 : 2.7×10^{18} Bq

Cs-137 : 2.4×10^{17} Bq

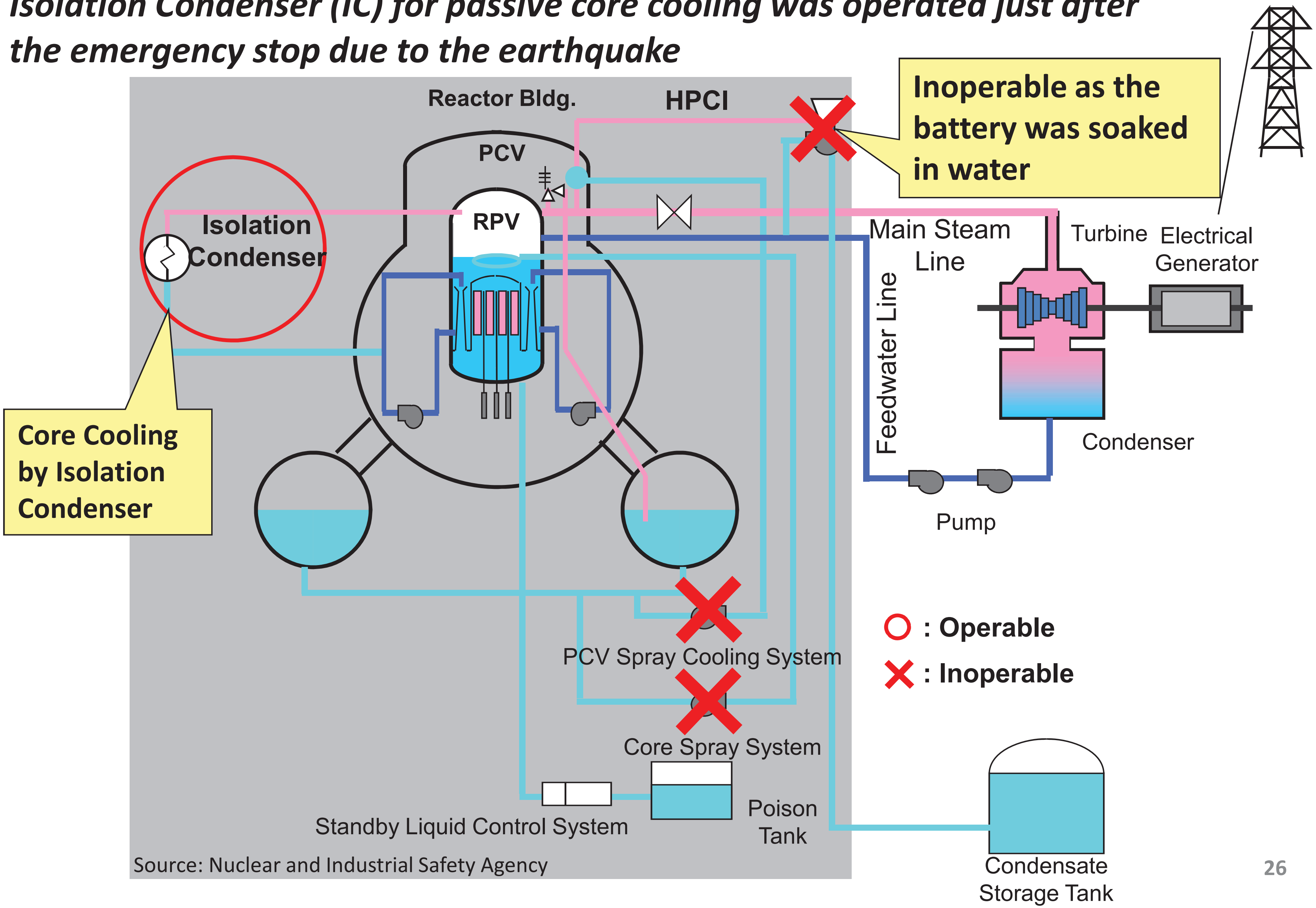
Decay Heat after the Shutdown





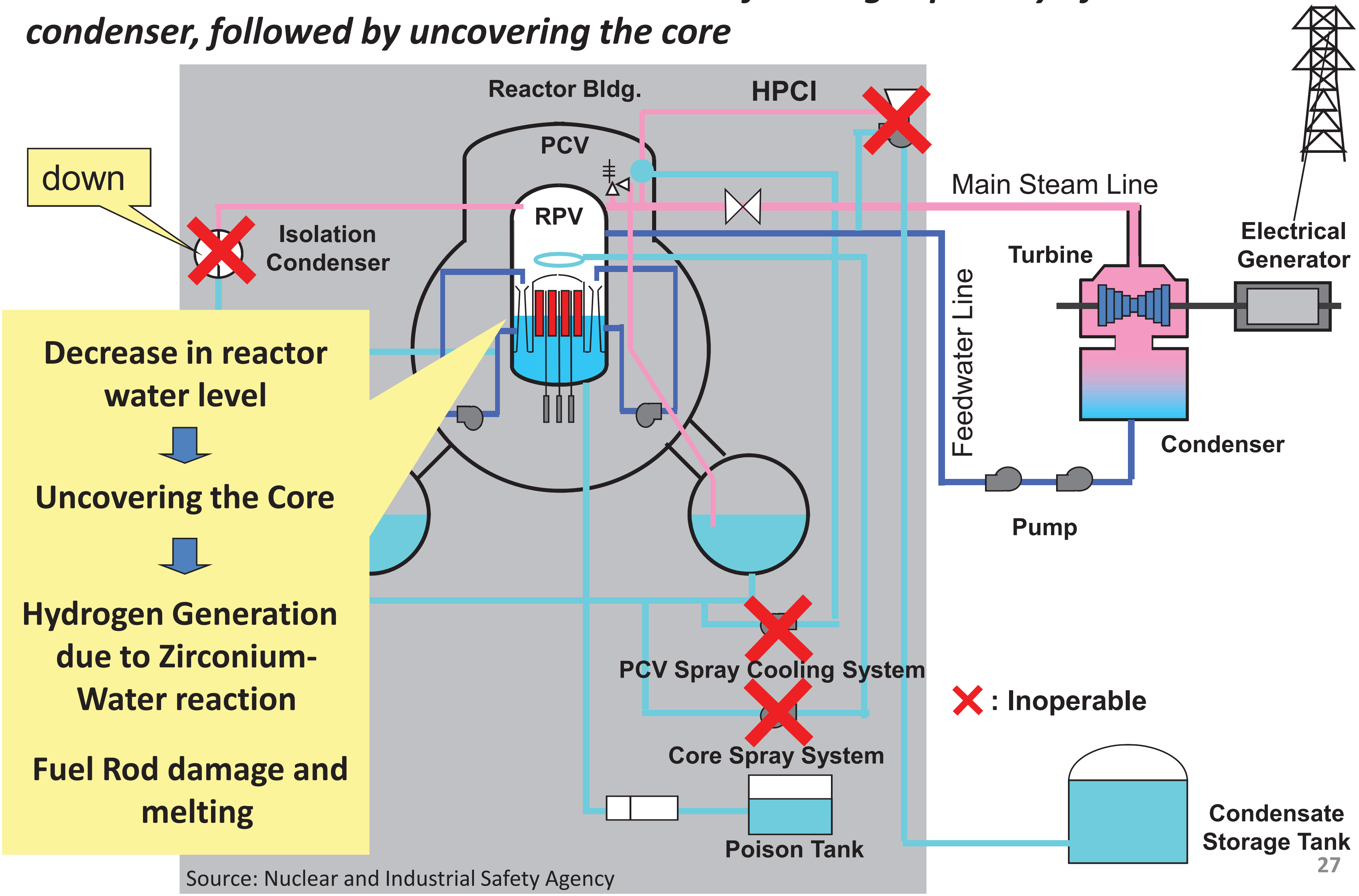
Unit 1 : Cooling by Isolation Condenser

Isolation Condenser (IC) for passive core cooling was operated just after the emergency stop due to the earthquake



Unit 1 : Loss of Cooling

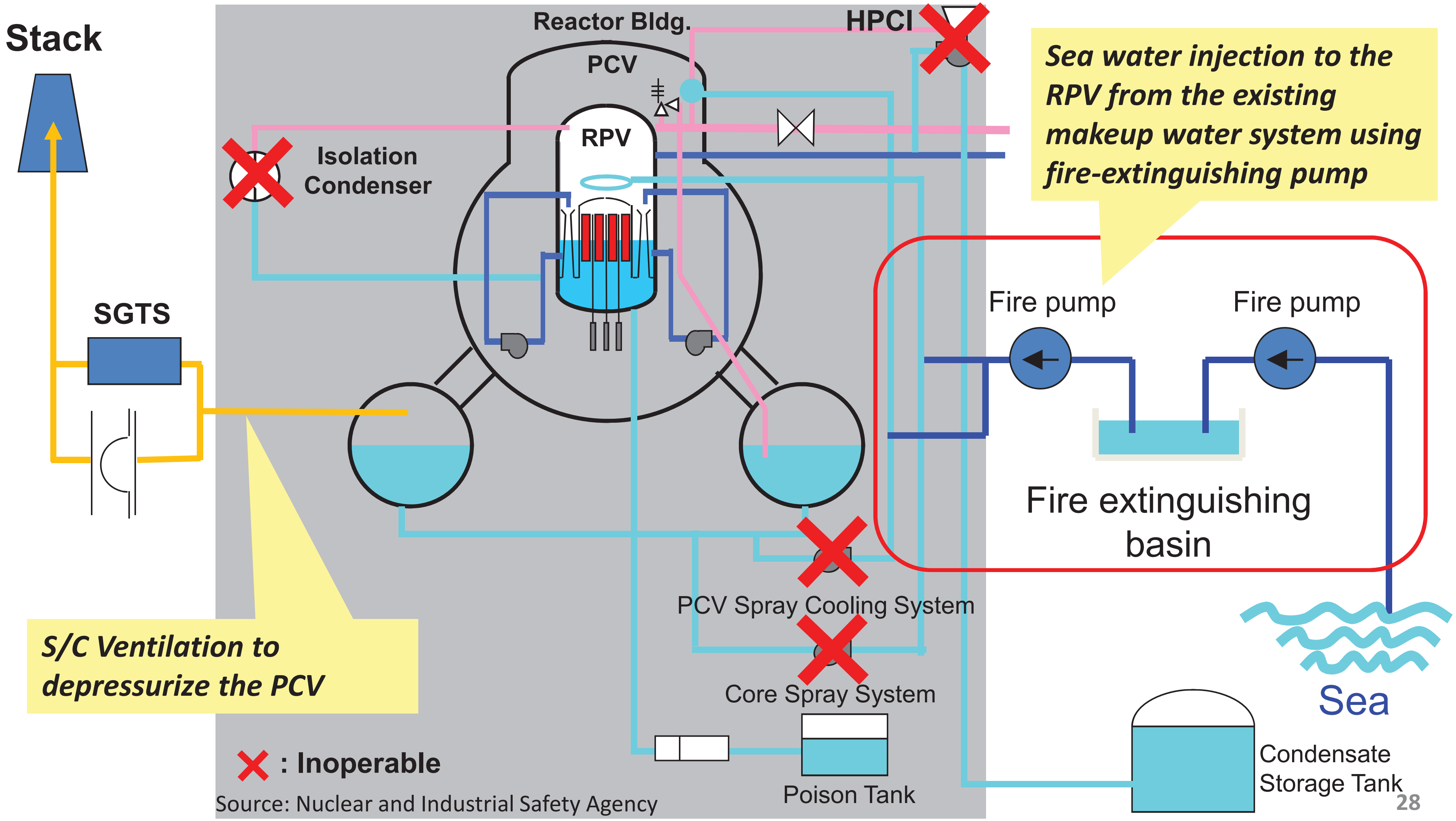
Decrease in reactor water level due to loss of cooling capability of Isolation condenser, followed by uncovering the core



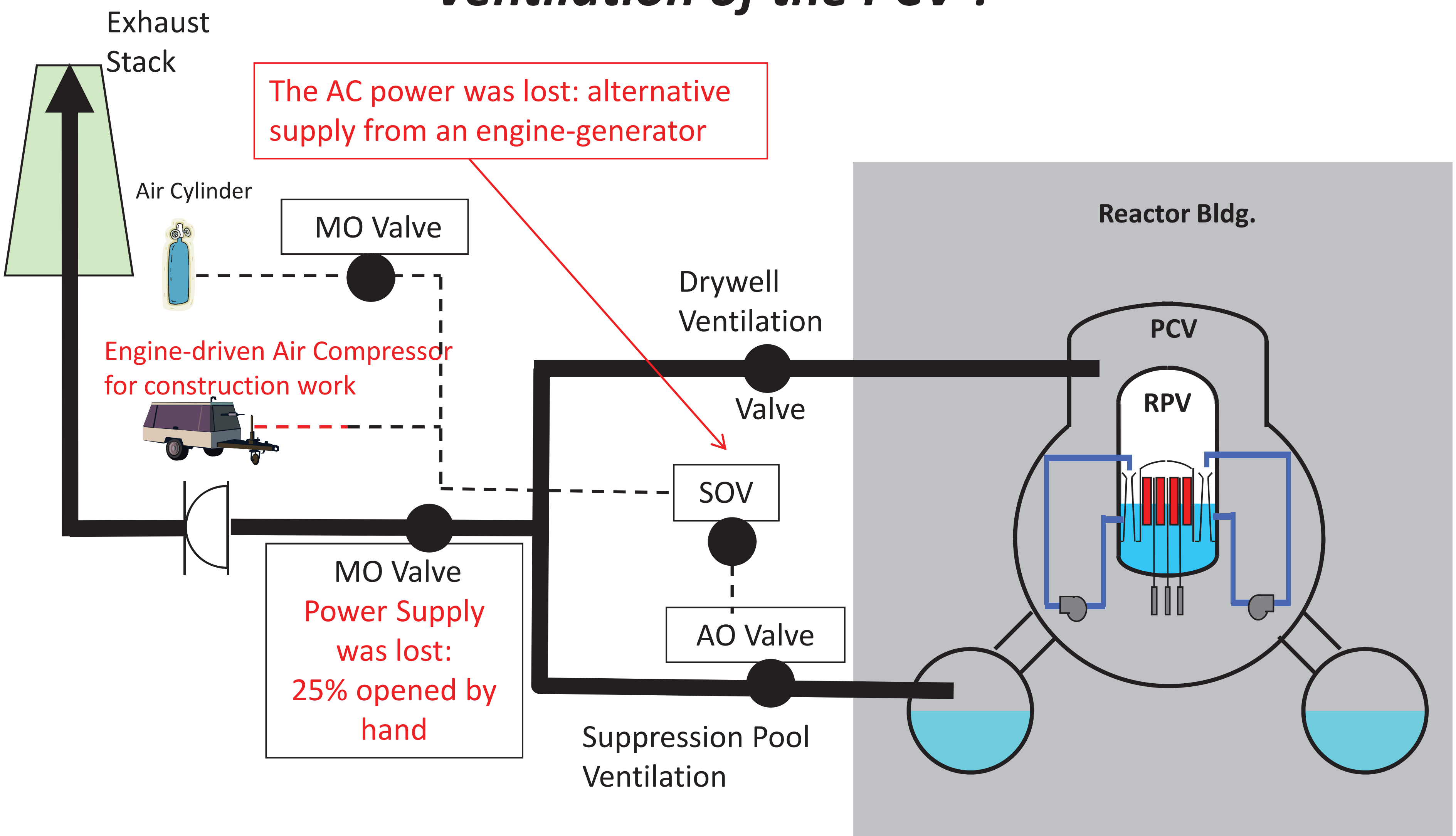
Source: Nuclear and Industrial Safety Agency

Unit 1 : PCV Ventilation and Cooling by Sea Water Injection

- ***S/C Ventilation to depressurize the PCV***
- ***Sea water injection using fire water pump***



Ventilation of the PCV ?

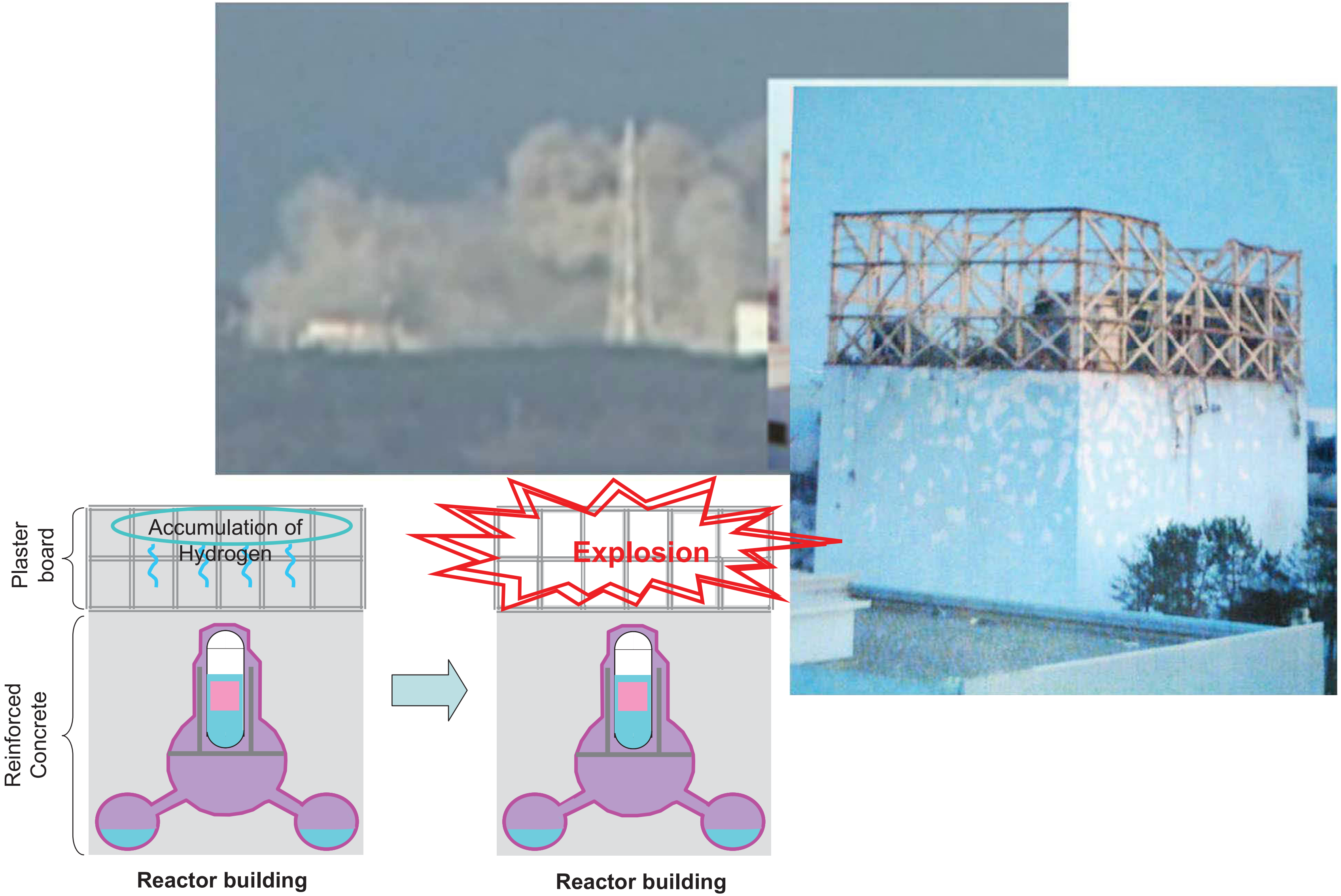


- *It was extremely difficult to achieve the ventilation line without supply of the electricity and instrumentation air.*
- *High radiation dose in the Reactor Building also impeded the work.*

Unit 1 : Equipments for Water Injection and PCV Ventilation

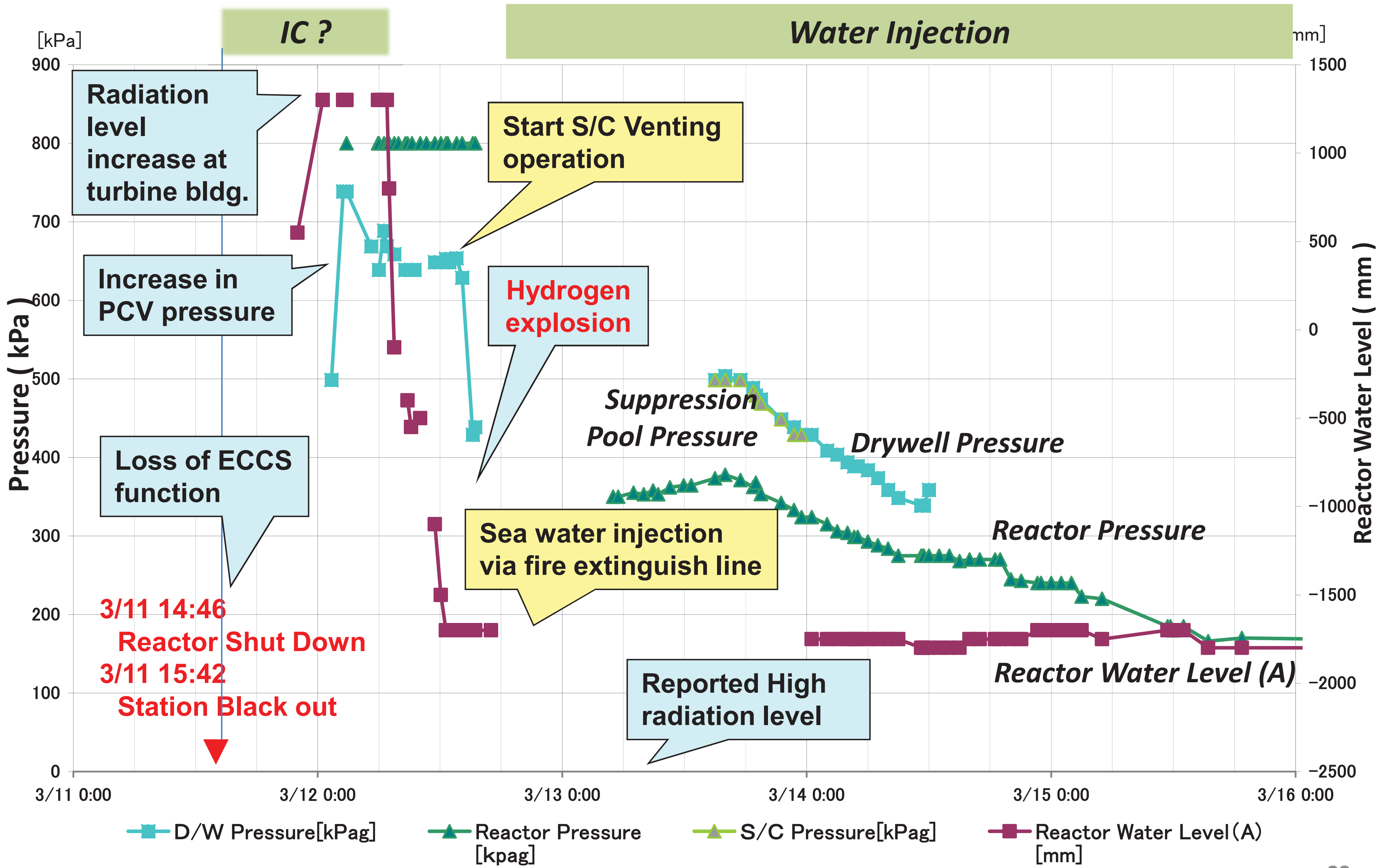
Equipment Name		*Status*	*Damage Status*	*Applied Operations*	Status of Fukushima Daini
Water Injection Equipment	**High Pressure Coolant Injection system (HPCI)**	×	Loss of power (oil pump)	—	○ Timely water injection is possible using the MUWC
	Condensate and Feed Water System (FDW)	×	Water injection not possible due to isolation signal	—	
	Core Spray System (CS)	×	Power and sea water system loss	—	
	Shut down Cooling system (SHC)	×	Power and sea water system loss	—	
	Make Up Water Condensate (MUWC)	×	Loss of power, motor water damage	—	
	Fire Protection System (FP)	×	D/D FP* startup not possible	Fire engine used	
PCV Ventilation Equipment	**S/C vent valve** Valve number: AO-1601-72	×	AC power loss/low air pressure	Temporary power supply Temporary air compressor	○ Valves can be operated when necessary
	S/C vent bypass valve Valve number: AO-1601-90	×	AC power loss/low air pressure		
	D/W vent valve Valve number: AO-1601-1	×	AC power loss/low air pressure		
	D/W vent bypass valve Valve number: AO-1601-83	×	AC power loss/low air pressure		
	PCV vent valve Valve number: MO-1601-210	×	Power loss	Manual operation	

Hydrogen Explosion in the Operation Floor in Unit 1
- March 12, 15:36 -



Water Level in RPV, Pressure in RPV and PCV (D/W & S/C)

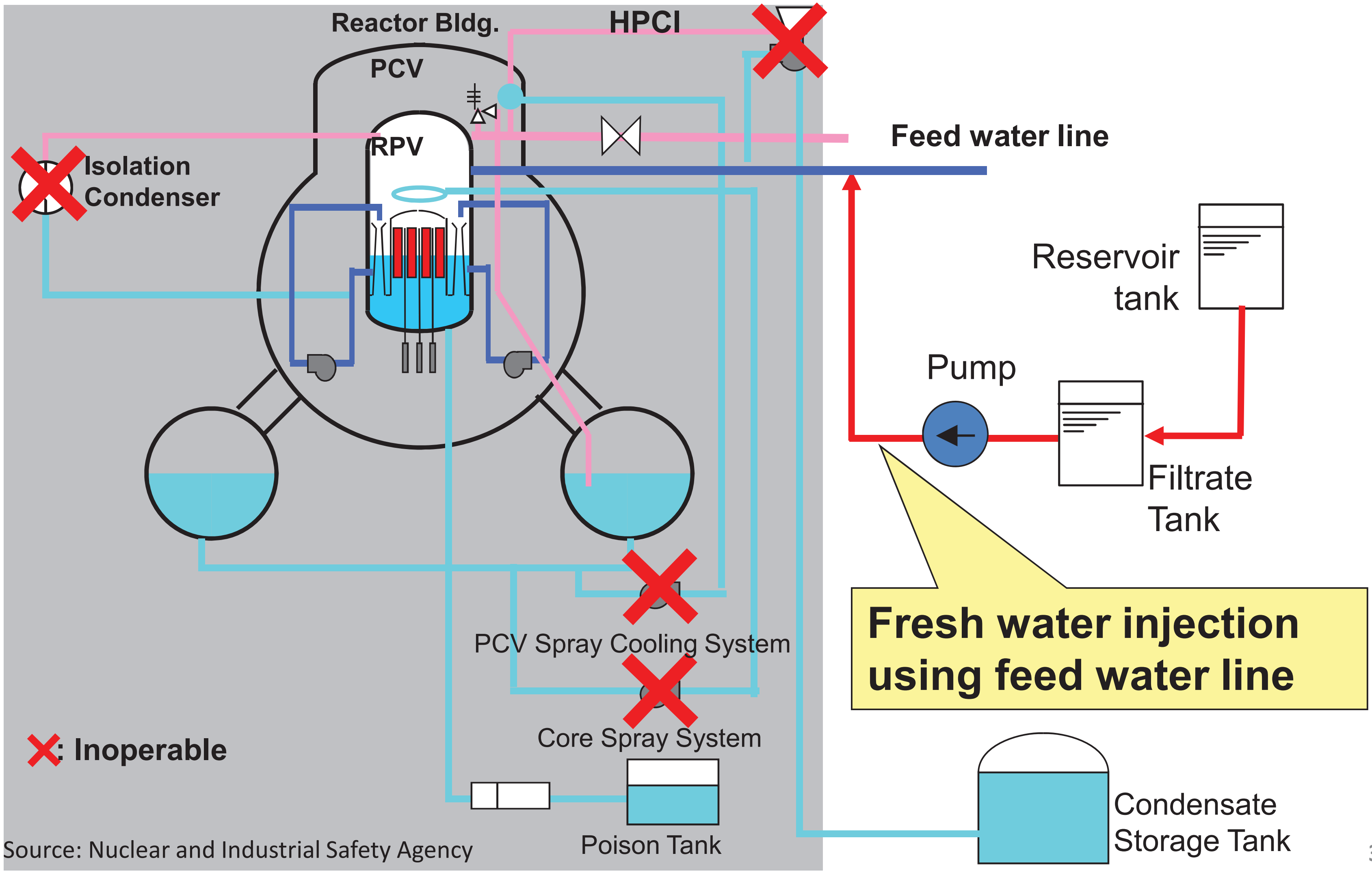
From March 11 to 16 in Unit 1



Source: Side event material on the "Fukushima Daiichi Accident and Initial Safety Measures Worldwide" in IAEA.

Unit 1 : Cooling

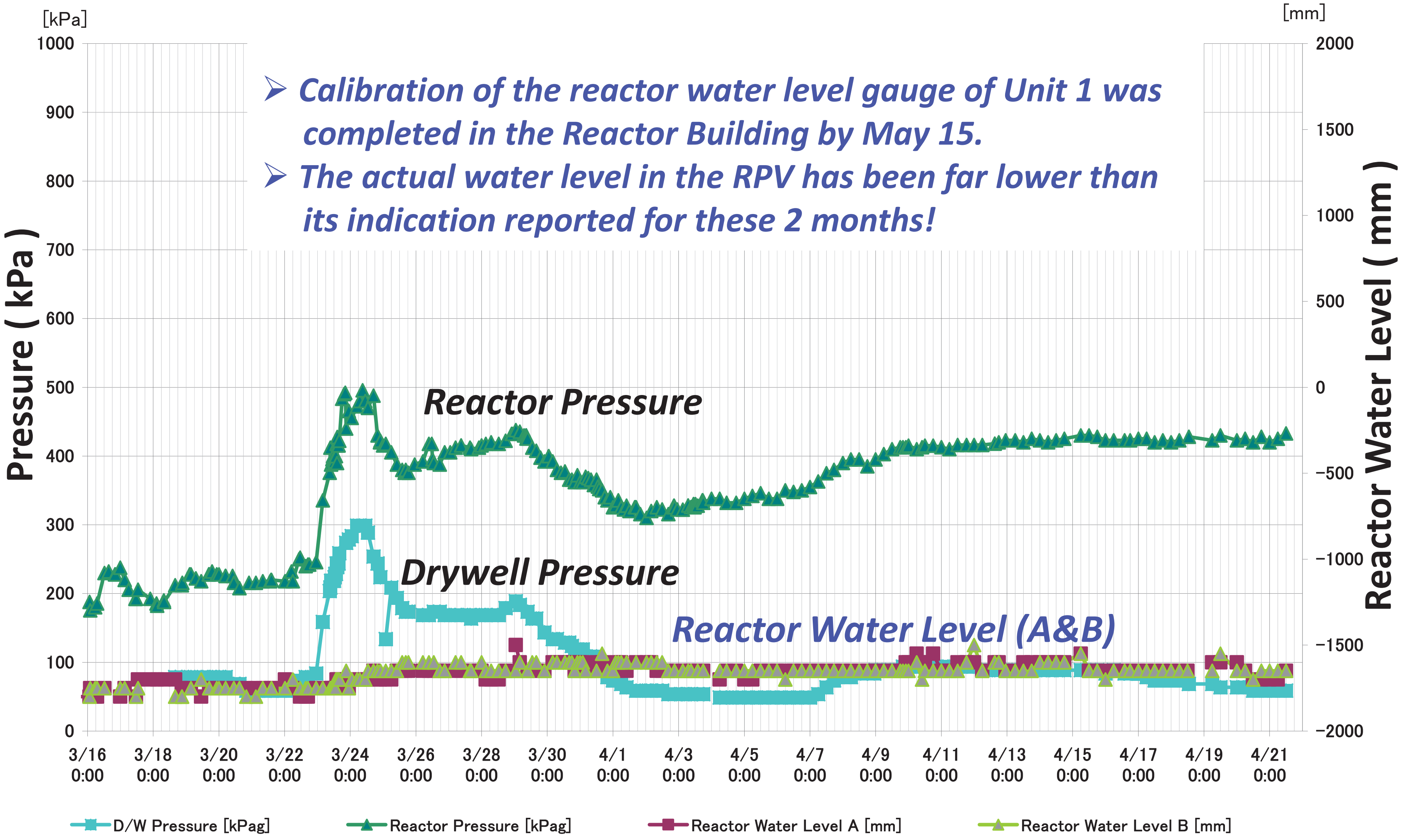
Switched to fresh water injection on March 25th



Source: Nuclear and Industrial Safety Agency

Reported Water Level in RPV, Pressure in RPV and PCV (D/W)

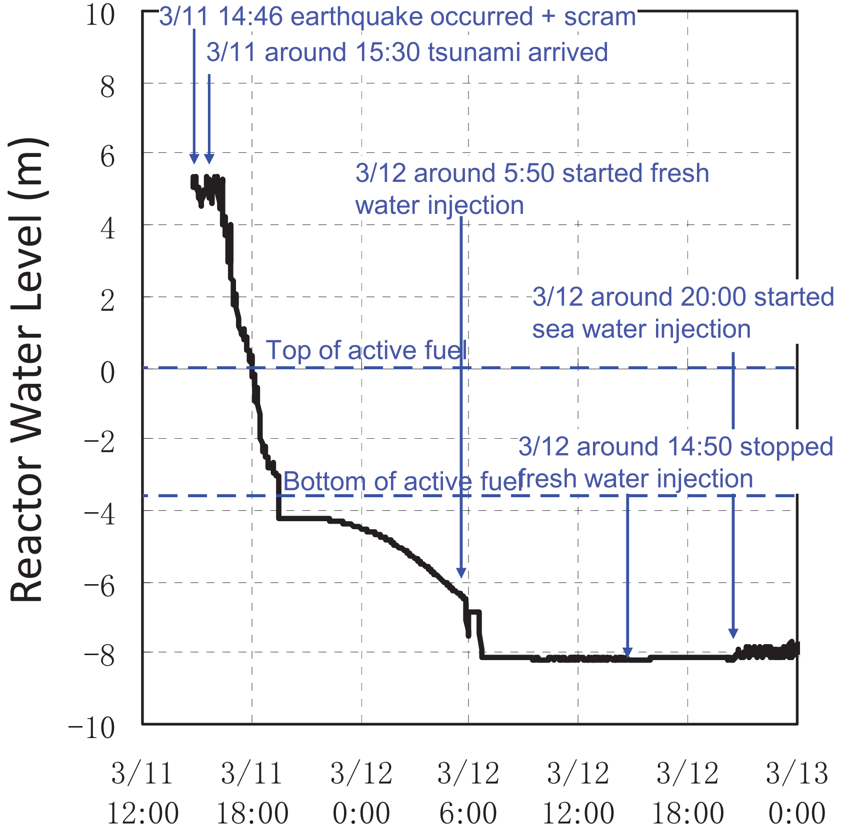
From March 16 to Apr. 21 in Unit 1

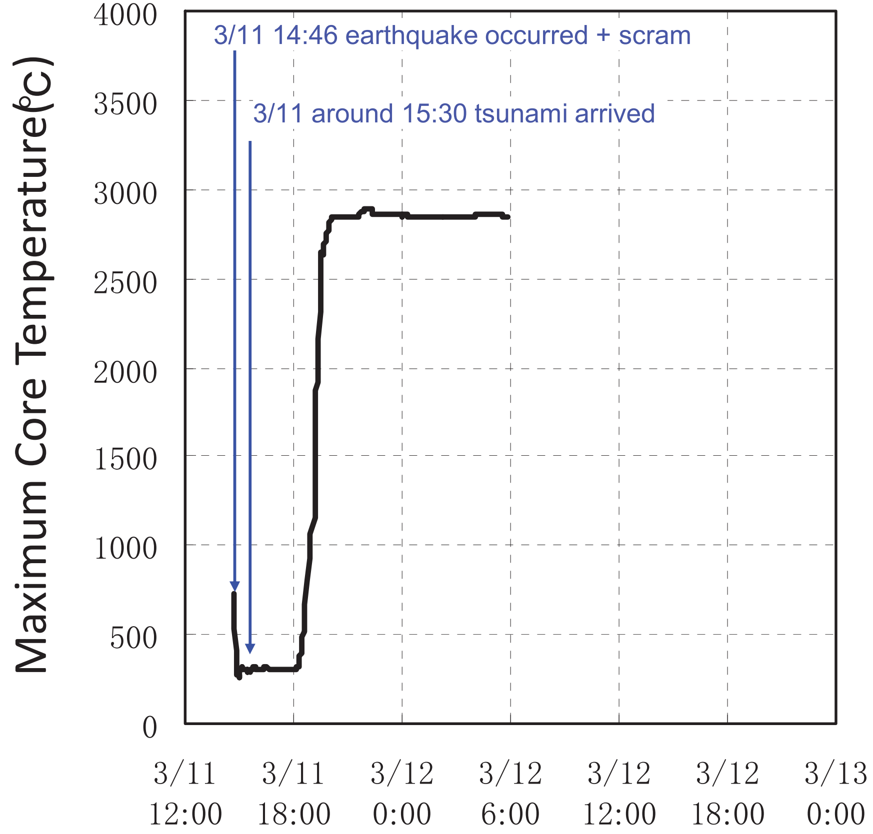


Source: NISA & TEPCO's press release.

Reactor Water Level and Core Temperature in Unit 1
- Simulation Trial by the MAAP code -

Assuming that IC lost its function by the Tsunami



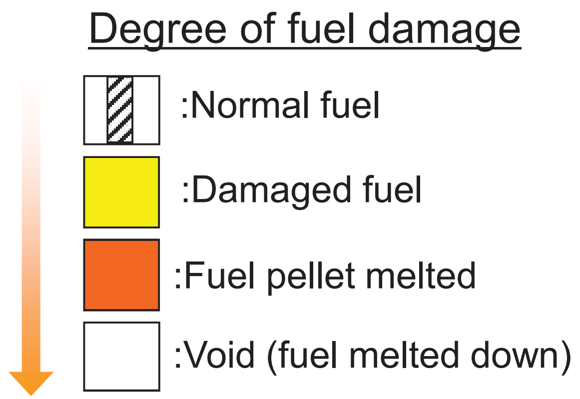


- reached top of active fuel in 3 hours (around 18:00) after the scram
- reached bottom of active fuel in 4 and a half hours (around 19:30) after the scram

The core temperature started increasing when the reactor water level became lower than top of active fuel, then reached the core melting temperature.

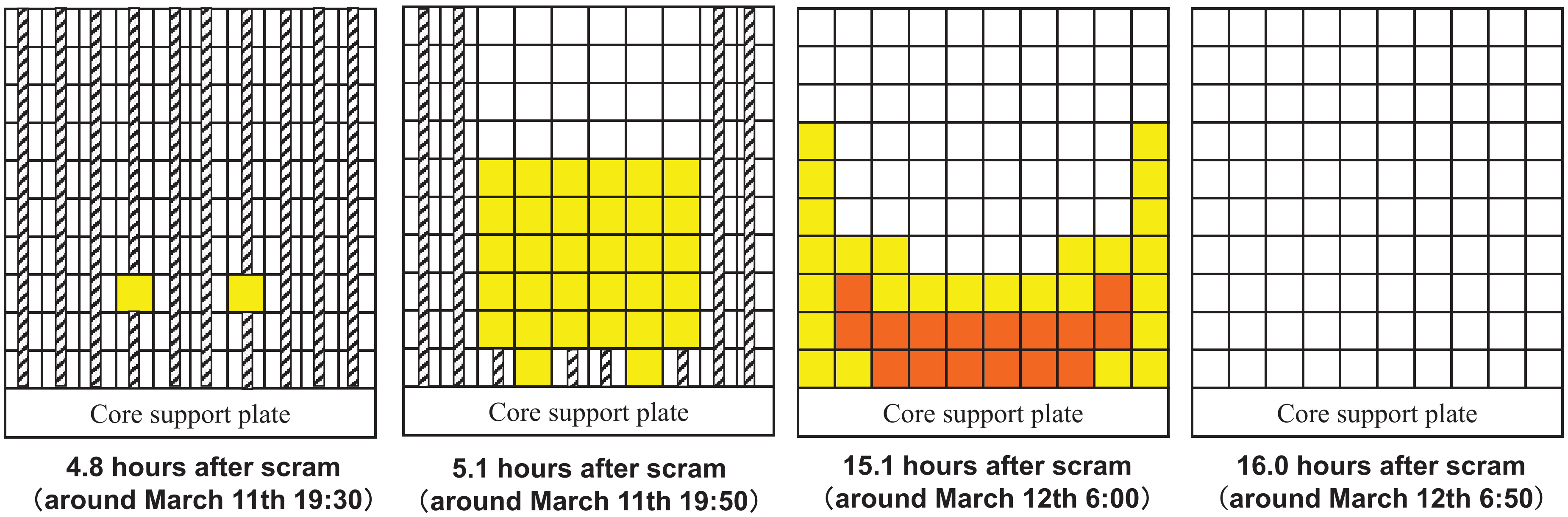
Source: TEPCO

Transition of Core Status in Unit 1
- Simulation Trial Results by the MAAP code -



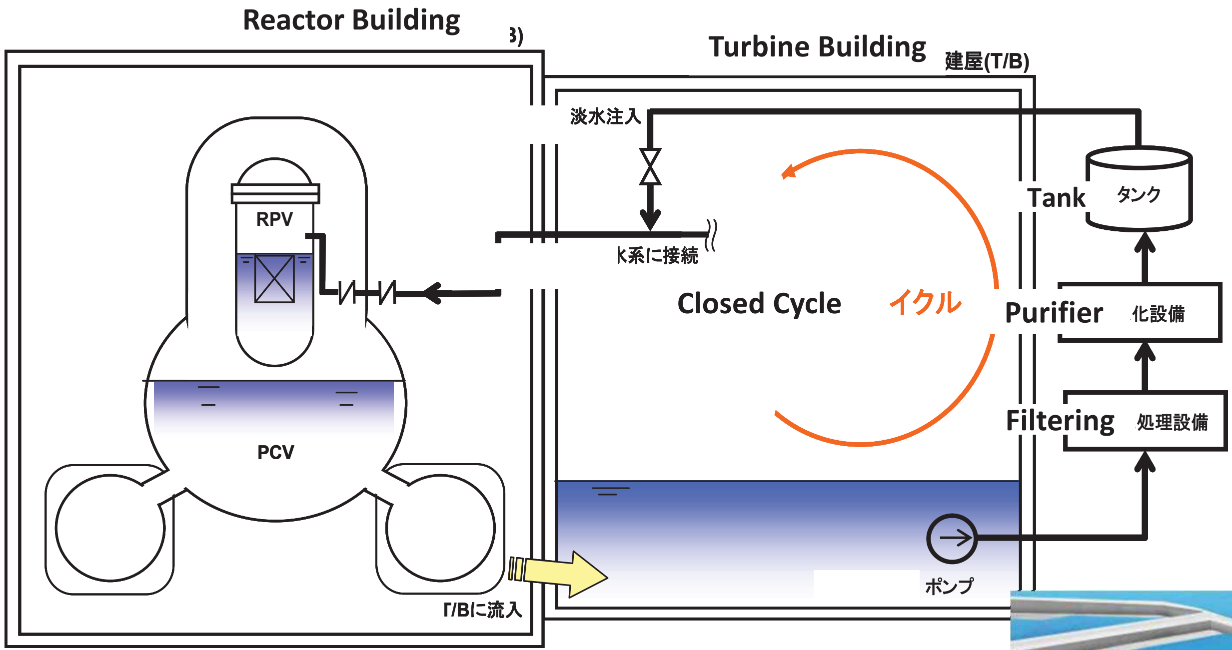
- ***Melting starts from the central part of the core.***
- ***In 16 hours after scram, most part of the core fell down to the RPV bottom.***
- ***Although RPV is damaged in this provisional analysis, the actual damage of RPV is considered to be limited according to the temperatures presently measured around the RPV.***

Source: TEPCO



Comparison of simulation results and their sensitivity on input parameters from other severe accident analysis codes like MELCOR and THALES should also be made.

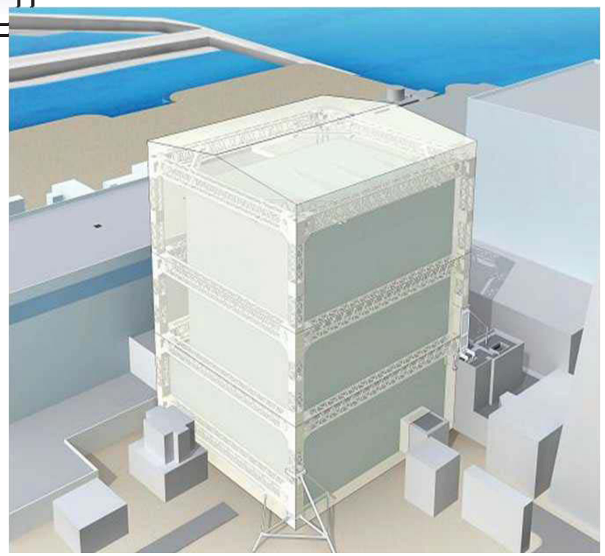
System outline of water reuse as reactor coolant by processing accumulated water



Nitrogen Injection to PCV to avoid hydrogen explosion

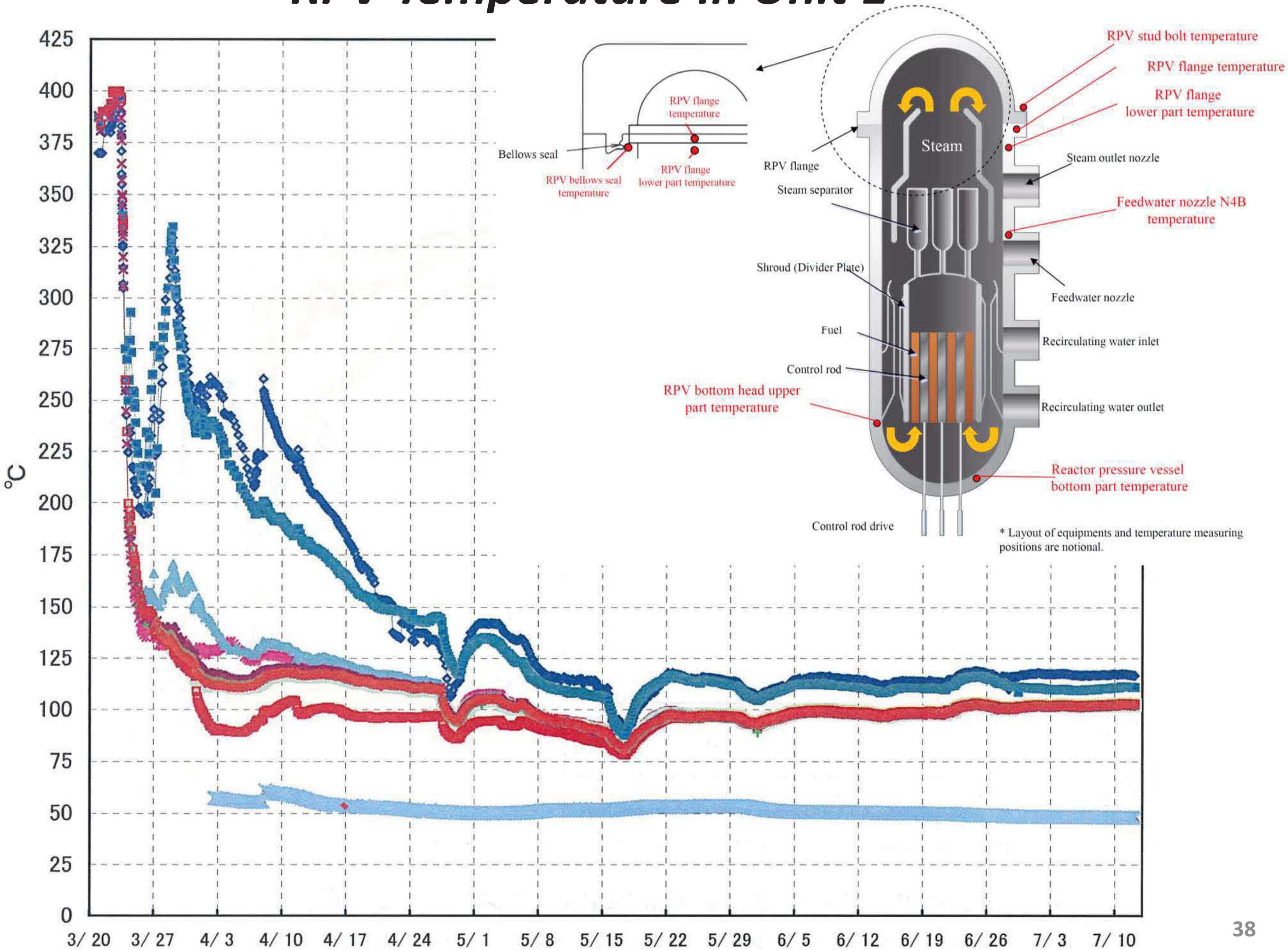
Reactor Building Cover for Unit 1

47m(NS), 42m(EW), 54m(Height)



Source: TEPCO

RPV Temperature in Unit 1



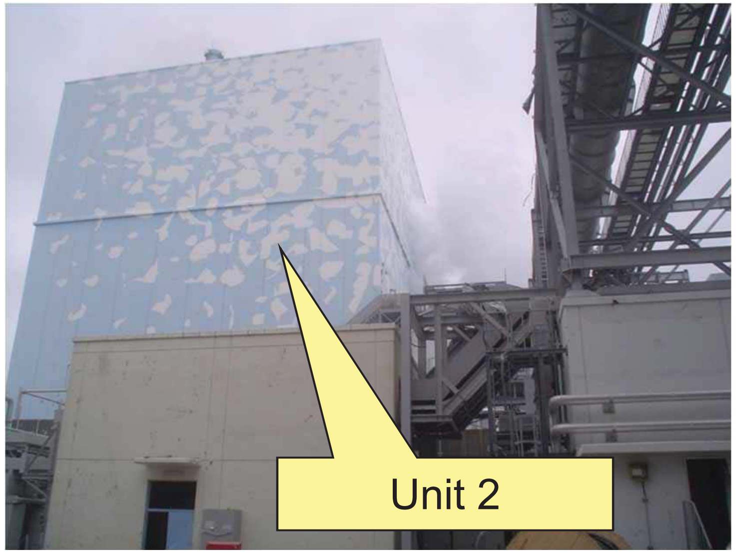
Short-term Actions for Termination of Accident and Emergency

- **Stable Cooling to Cold Shut-down**
  - Flooding the containment to a certain level & installation of heat exchanger to remove heat
  - SFP cooling system
- **Minimize Airborne and Liquid Effluent**
  - Recycling of water, storage of contaminated water, …
  - Cover for reactor building, site soil, ground water, …
- **Dose and Contamination Maps**

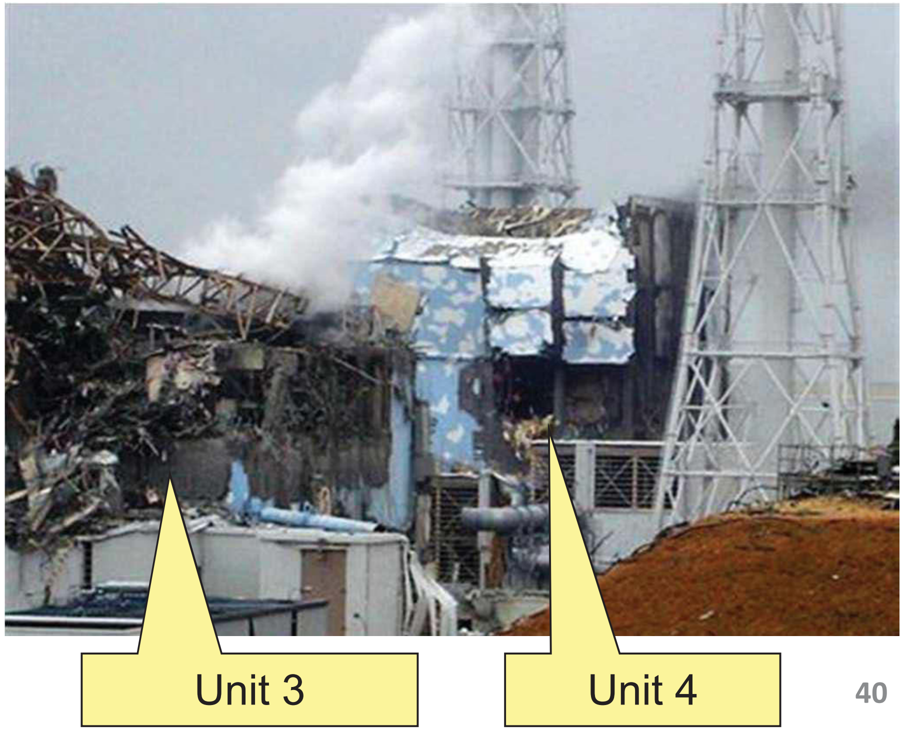
Unit 3

Unit 2

Hydrogen explosion at Unit 3 on March 14

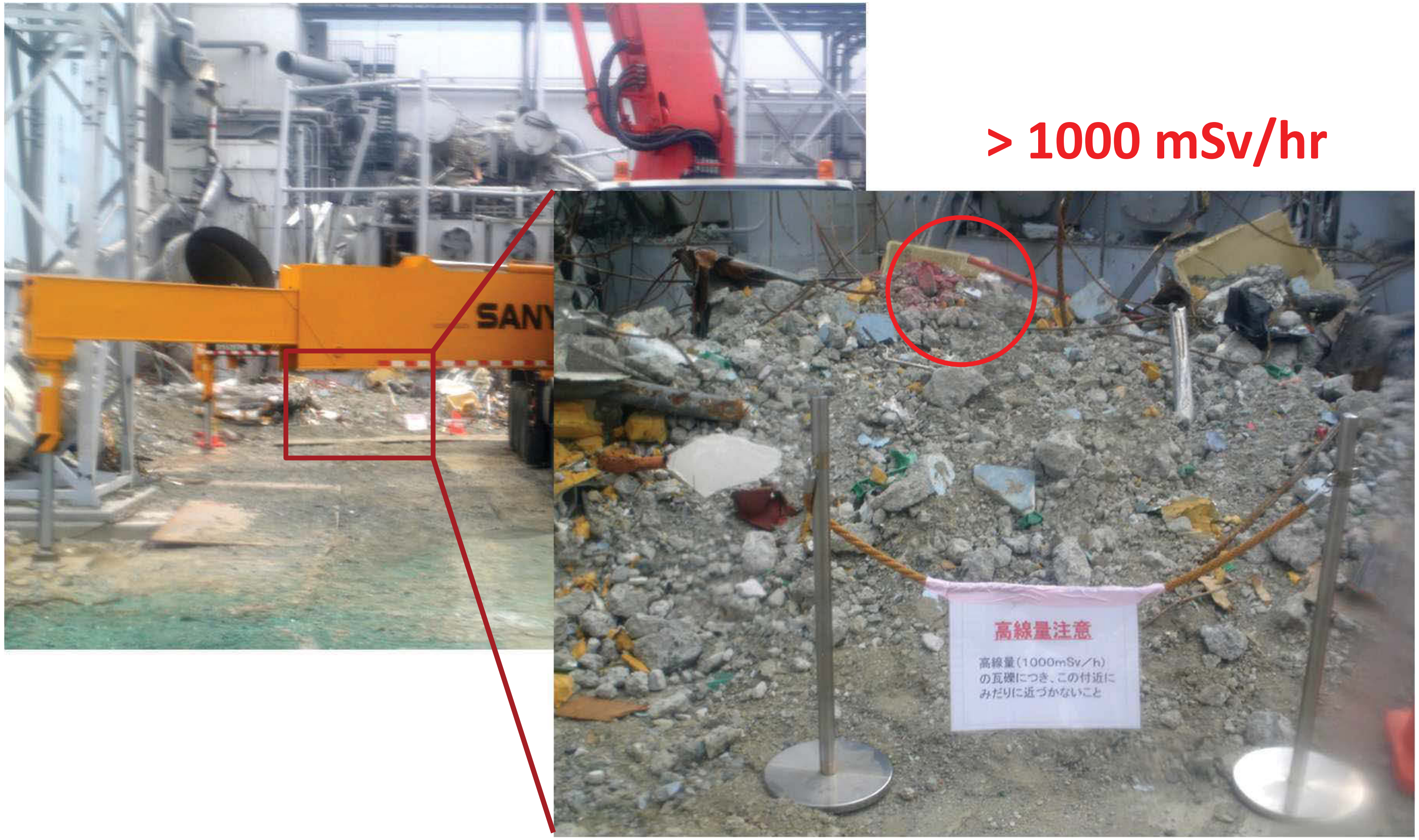


Explosion sound at Unit 2 on March 15



Source: TEPCO

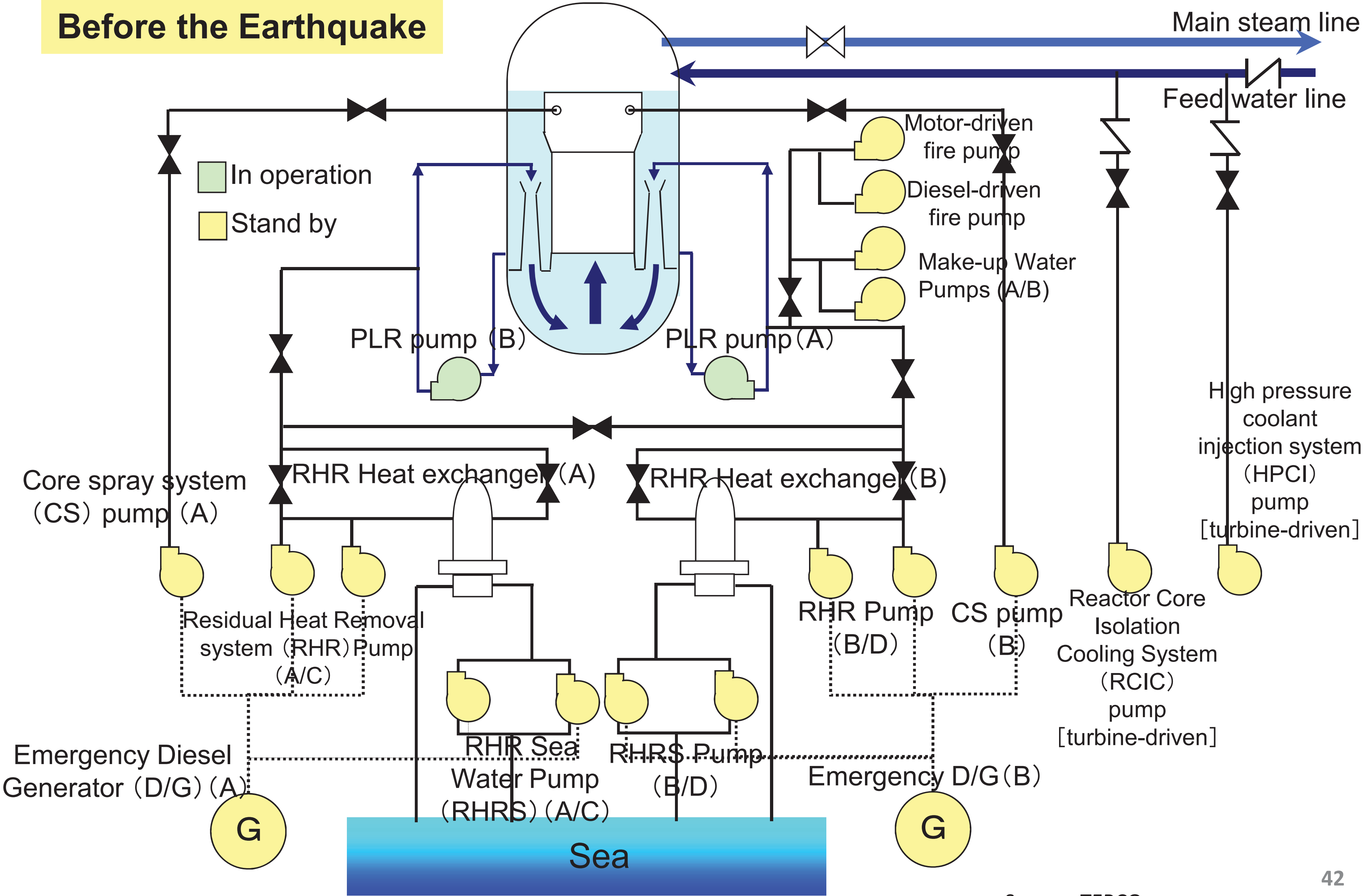
Highly Radioactive Debris near Unit 3



Source: TEPCO

Unit 3 Outline of Water Injection Systems

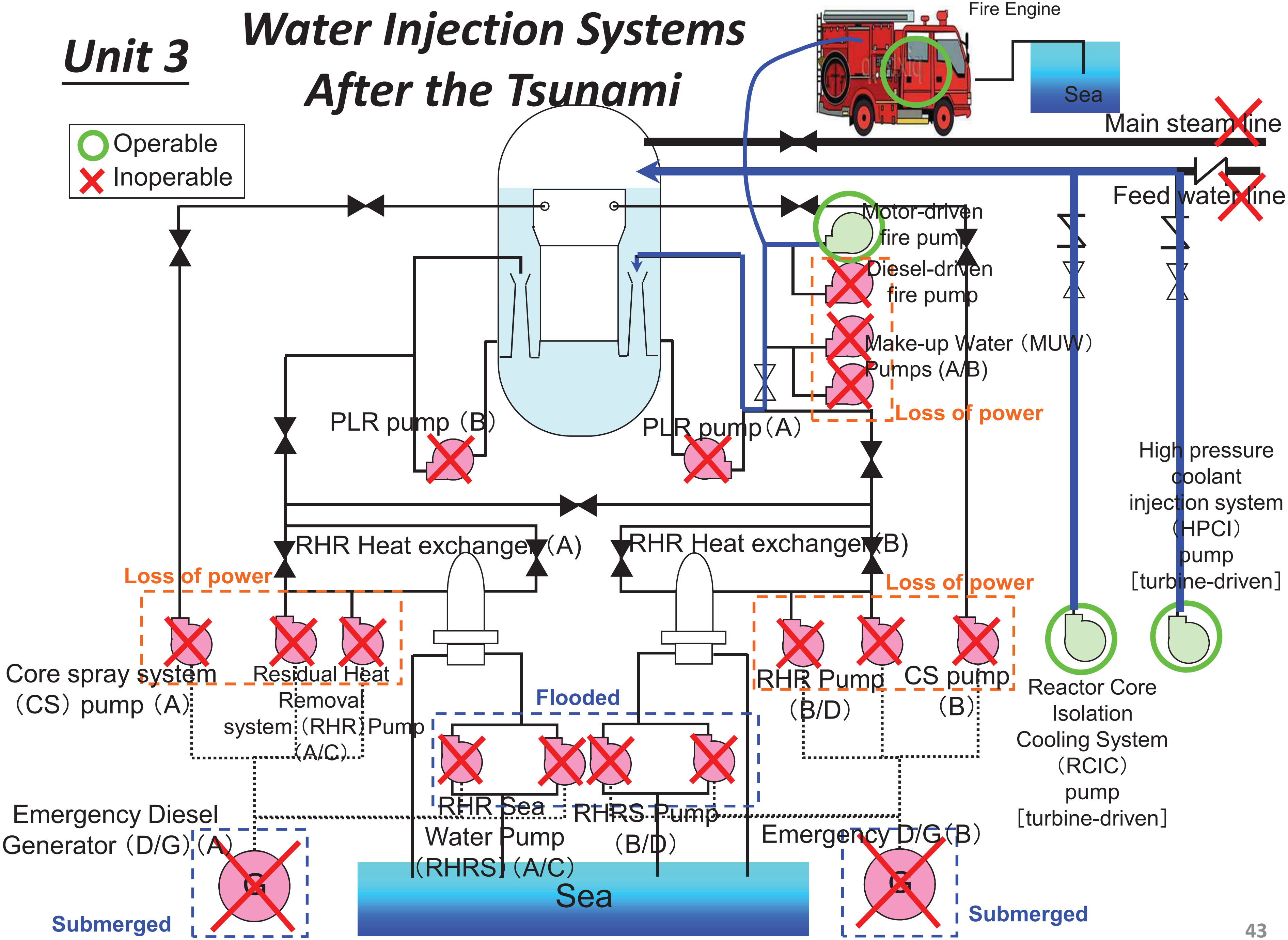
Before the Earthquake



Source: TEPCO

Unit 3

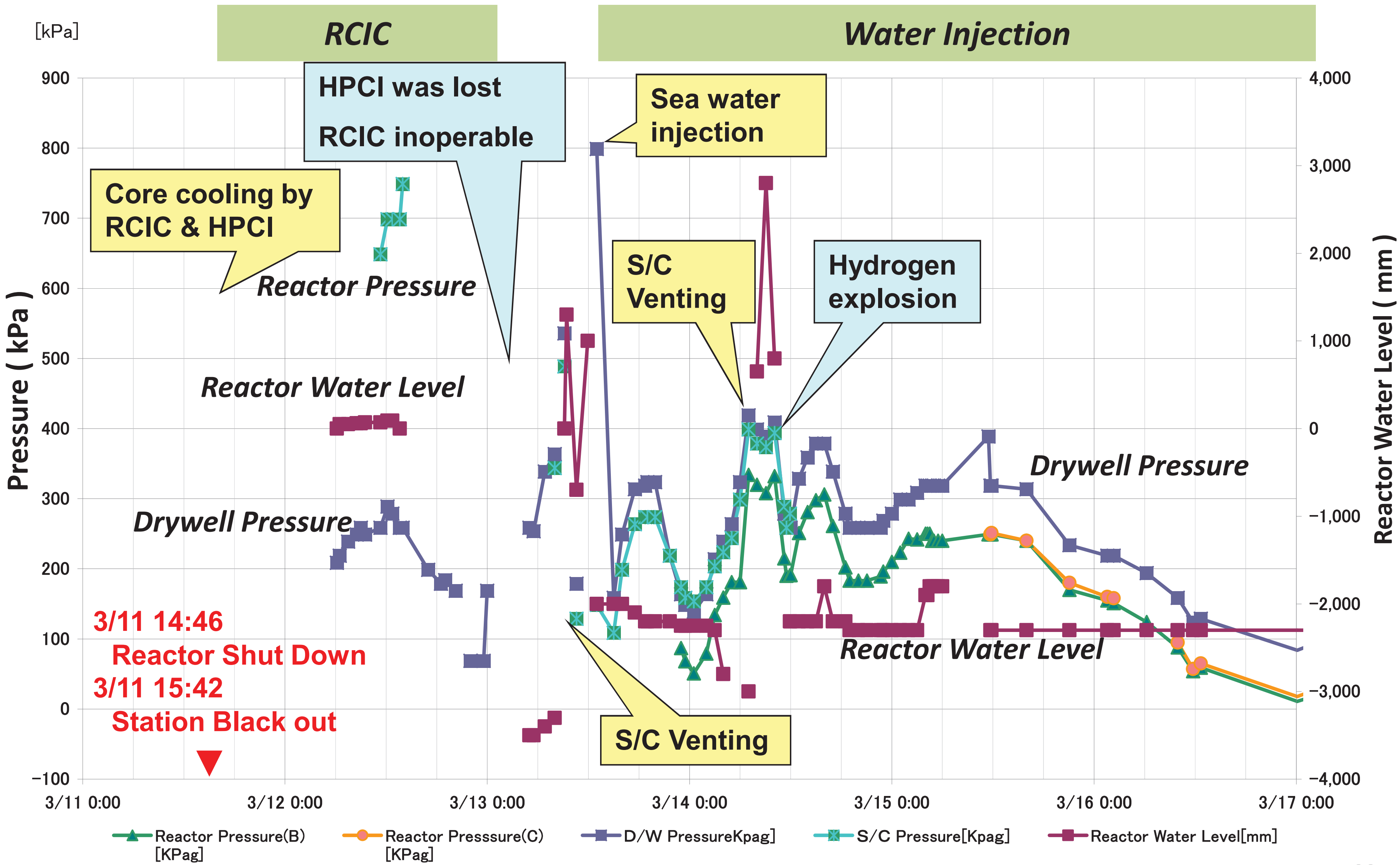
Water Injection Systems After the Tsunami



Source: TEPCO

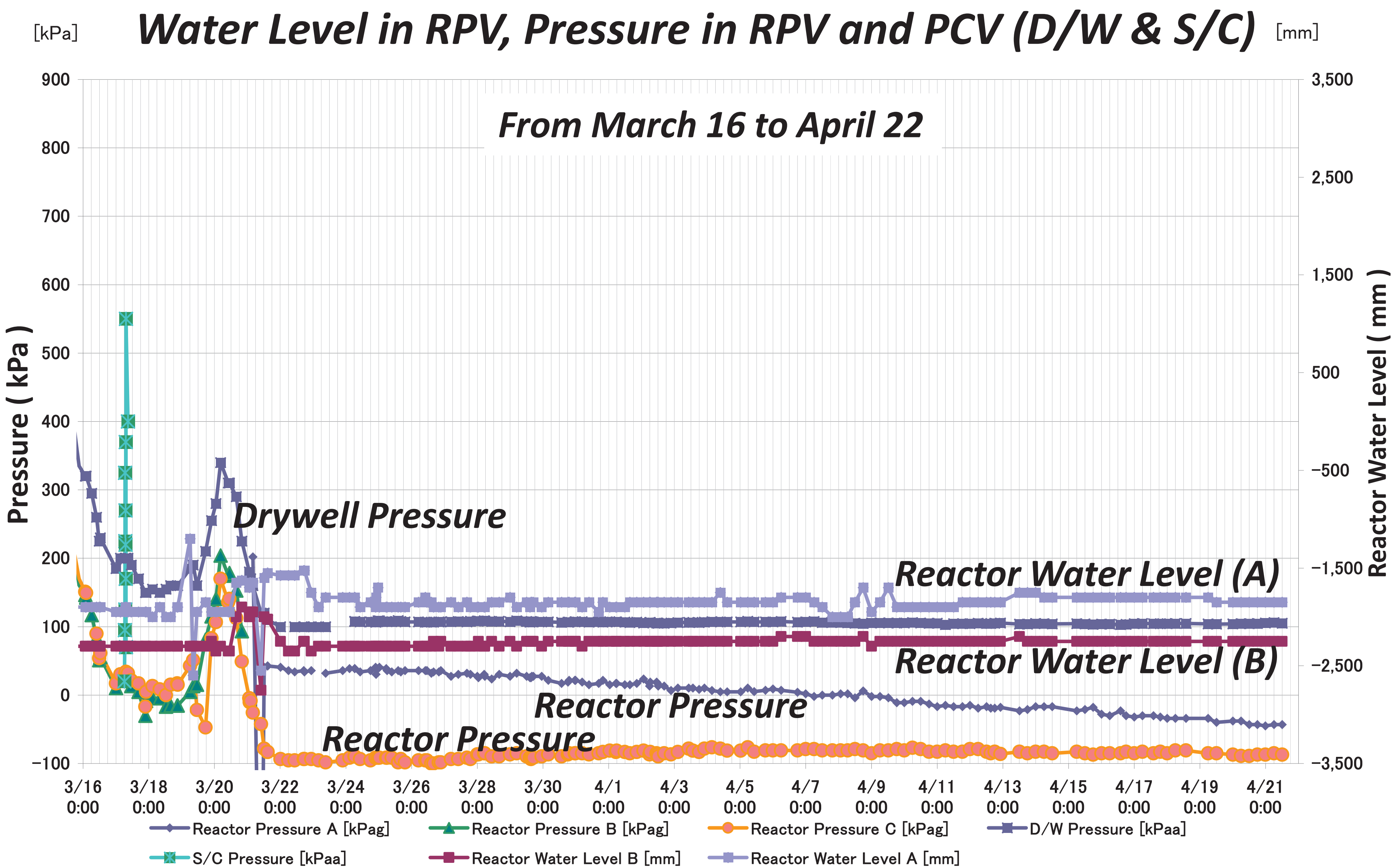
Unit 3 Water Level in RPV, Pressure in RPV and PCV

From March 11 to 17



Source: Side event material on the “Fukushima Daiichi Accident and Initial Safety Measures Worldwide” in IAEA.

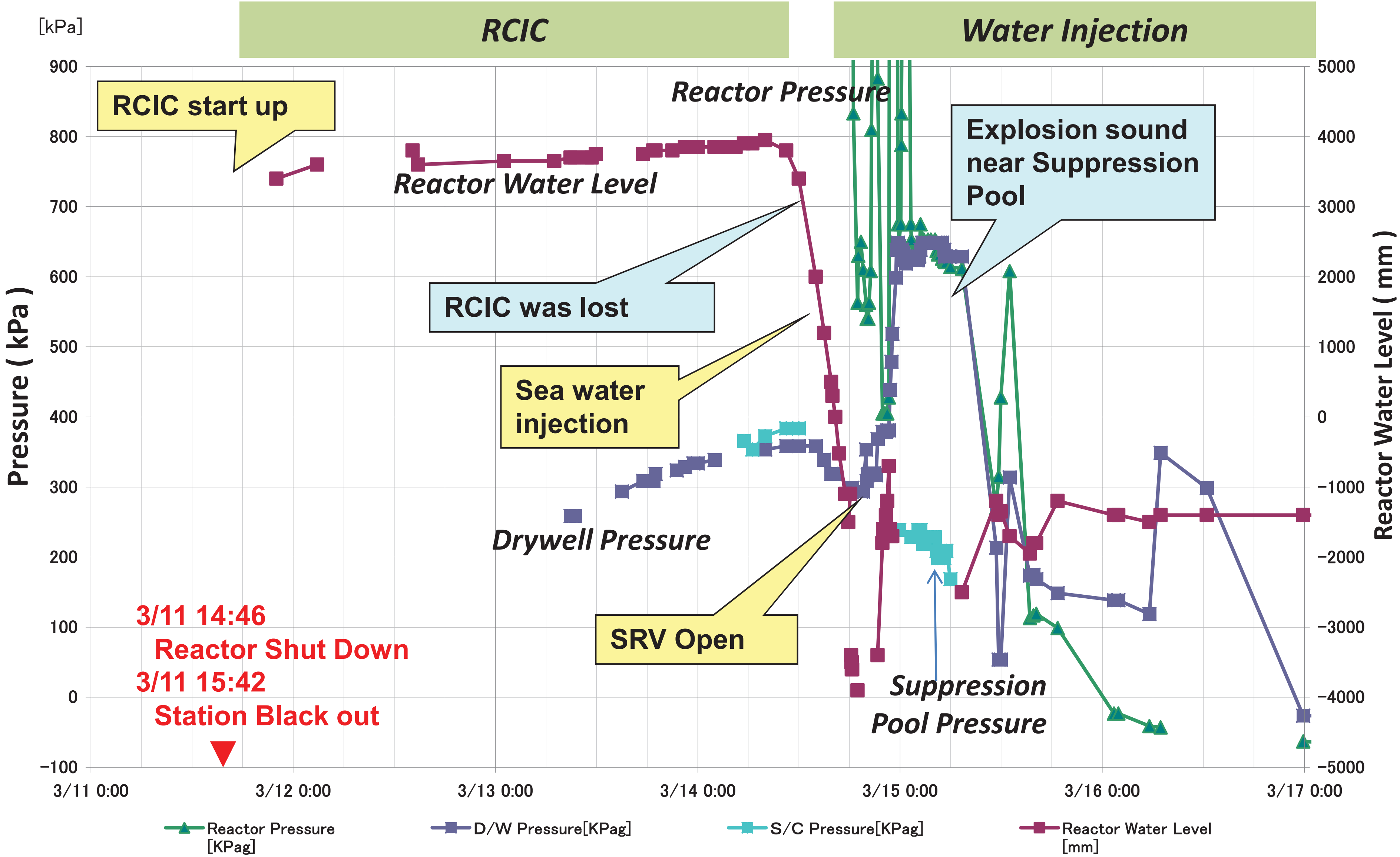
Unit 3



Source: NISA & TEPCO's press release

Unit 2 Water Level in RPV, Pressure in RPV and PCV (D/W & S/C)

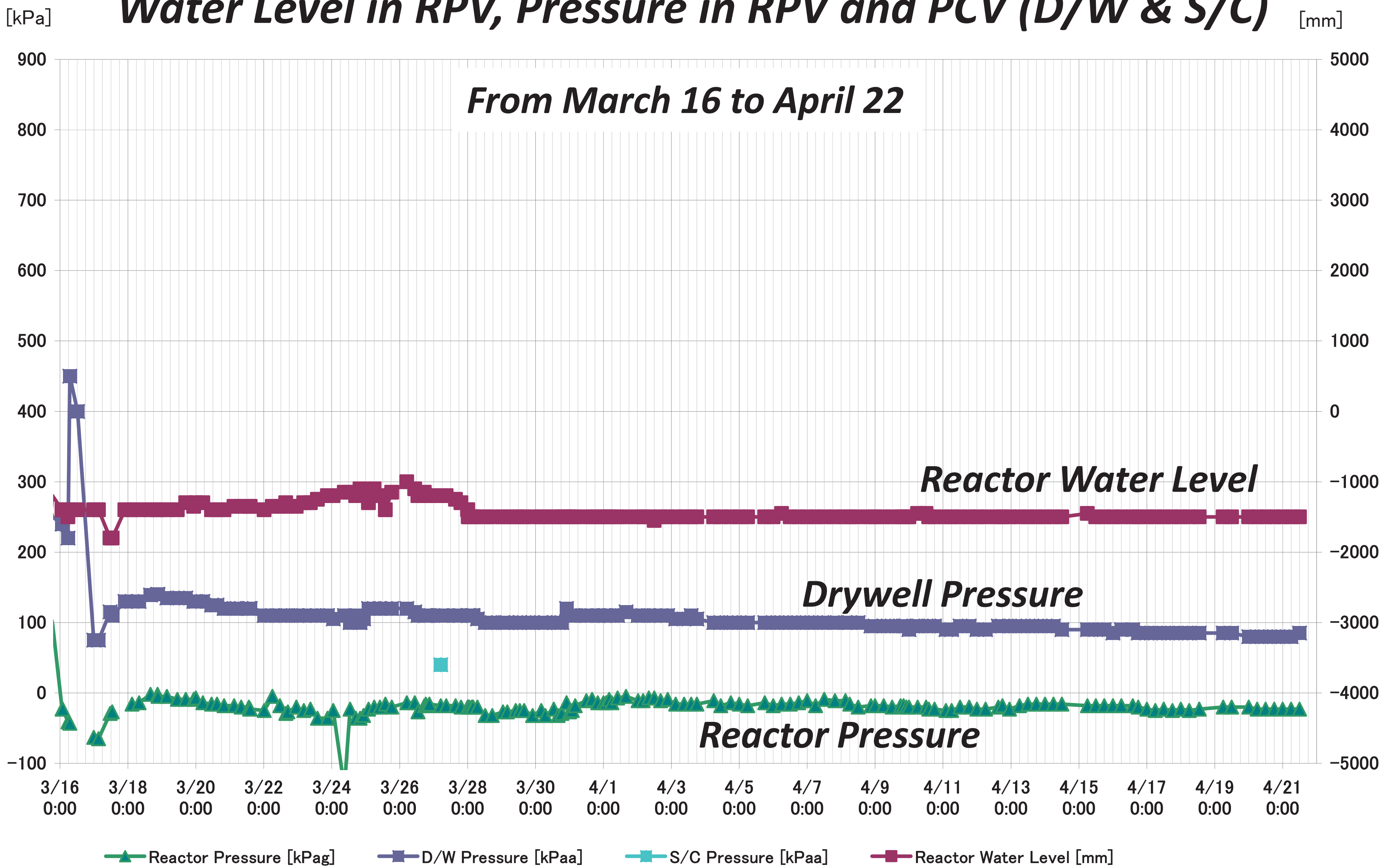
From March 11 to 17



Source: Side event material on the "Fukushima Daiichi Accident and Initial Safety Measures Worldwide" in IAEA.

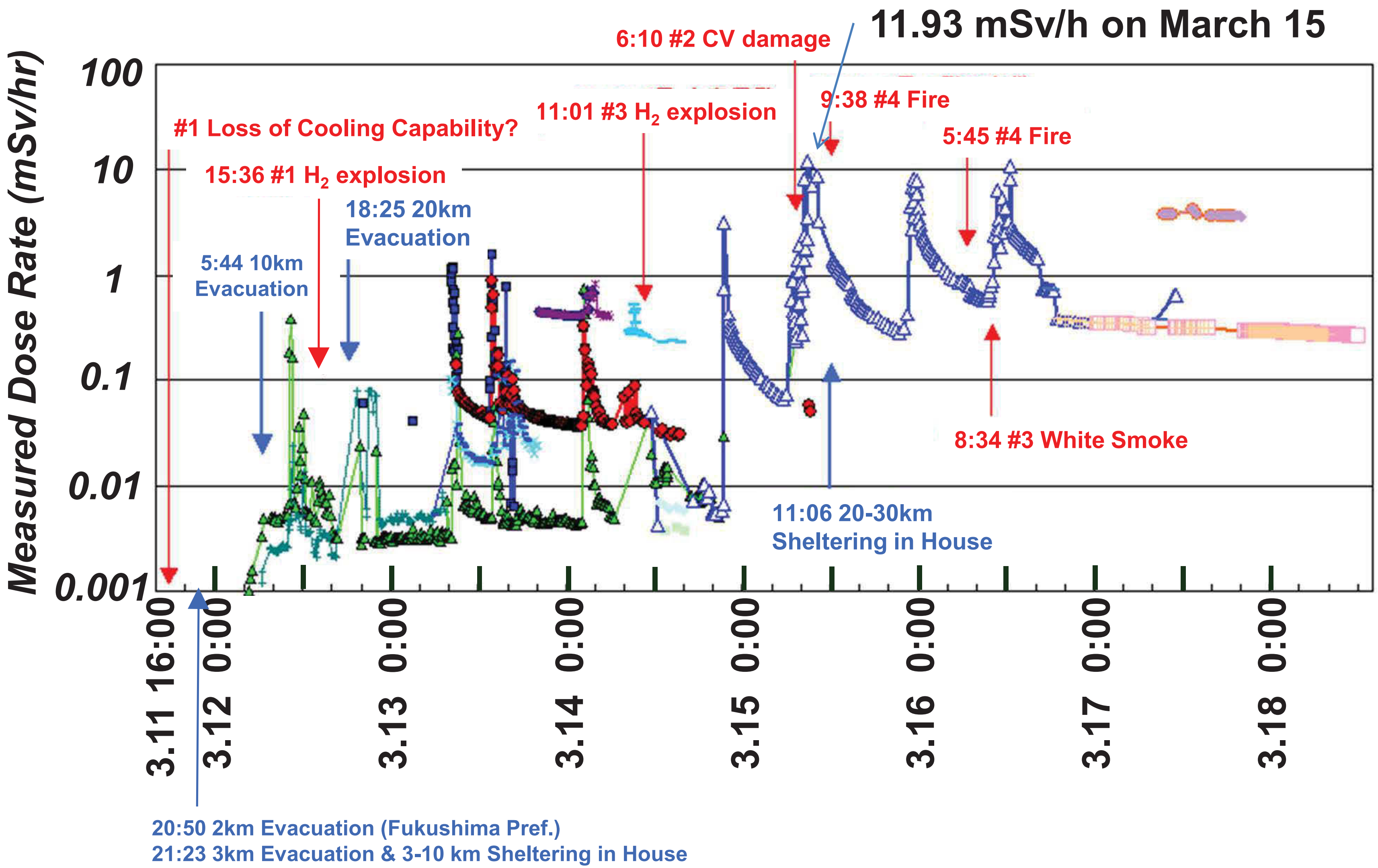
Unit 2

Water Level in RPV, Pressure in RPV and PCV (D/W & S/C)

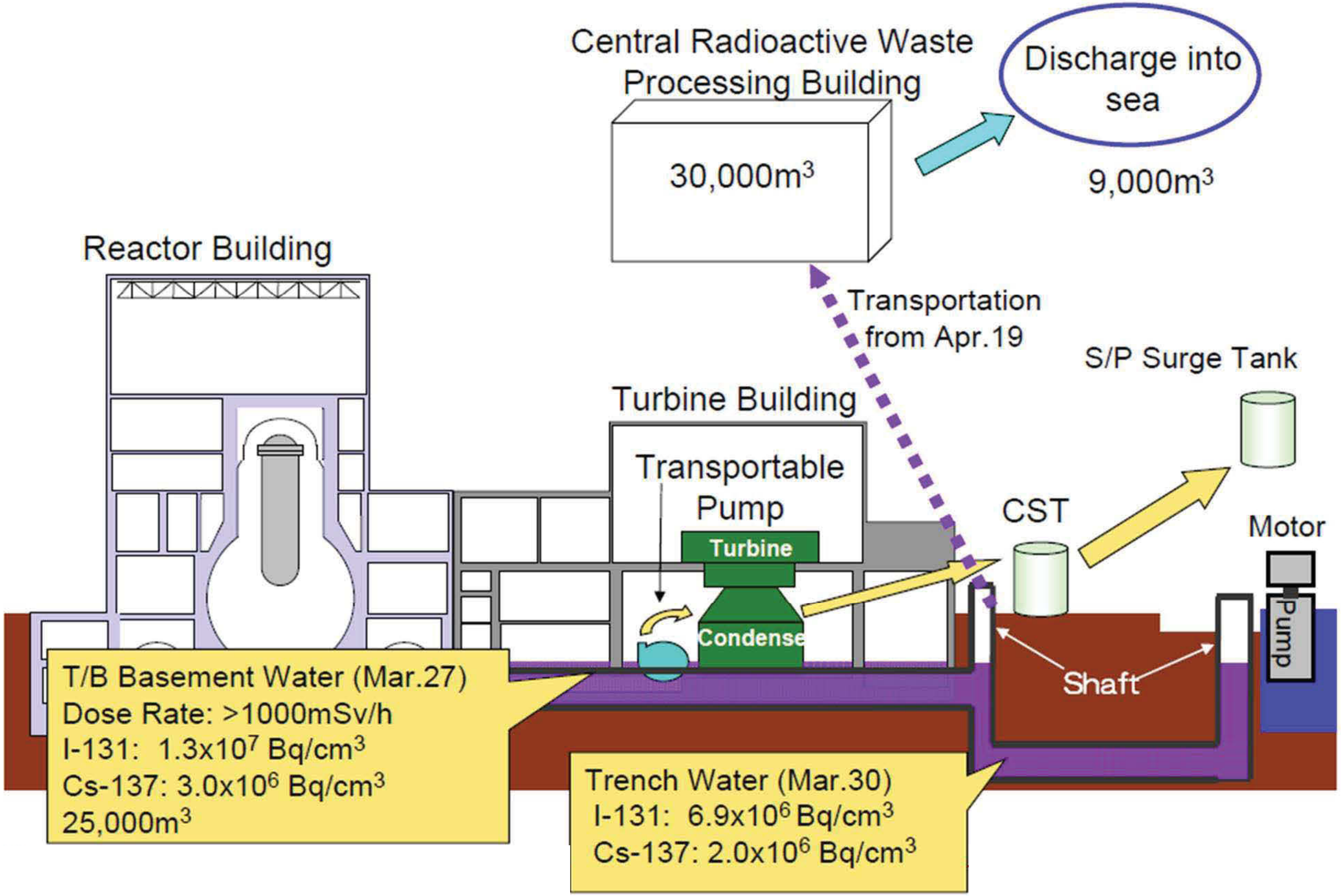


Source: NISA & TEPCO's press release.

On-site Radiation Monitoring in Fukushima Daiichi Site From March 11 to 18



Measures against Water Puddles at Fukushima Daiichi



Source: TEPCO

Leakage of Highly Radioactive Water from Unit 2

Leakage of radioactive water to the ocean between Apr. 1 to 6 from the pit of Unit 2

Amount of Released Water : 520 m^3

Concentration of Radioactive Materials

I-131 : $5.4x10^4$ Bq/cm^3
Cs-134 : $1.8x10^4$ Bq/cm^3
Cs-137 : $1.8x10^4$ Bq/cm^3

Total Released Radioactivity

I-131 : $2.8x10^{15}$ Bq
Cs-134 : $9.4x10^{14}$ Bq
Cs-137 : $9.4x10^{14}$ Bq

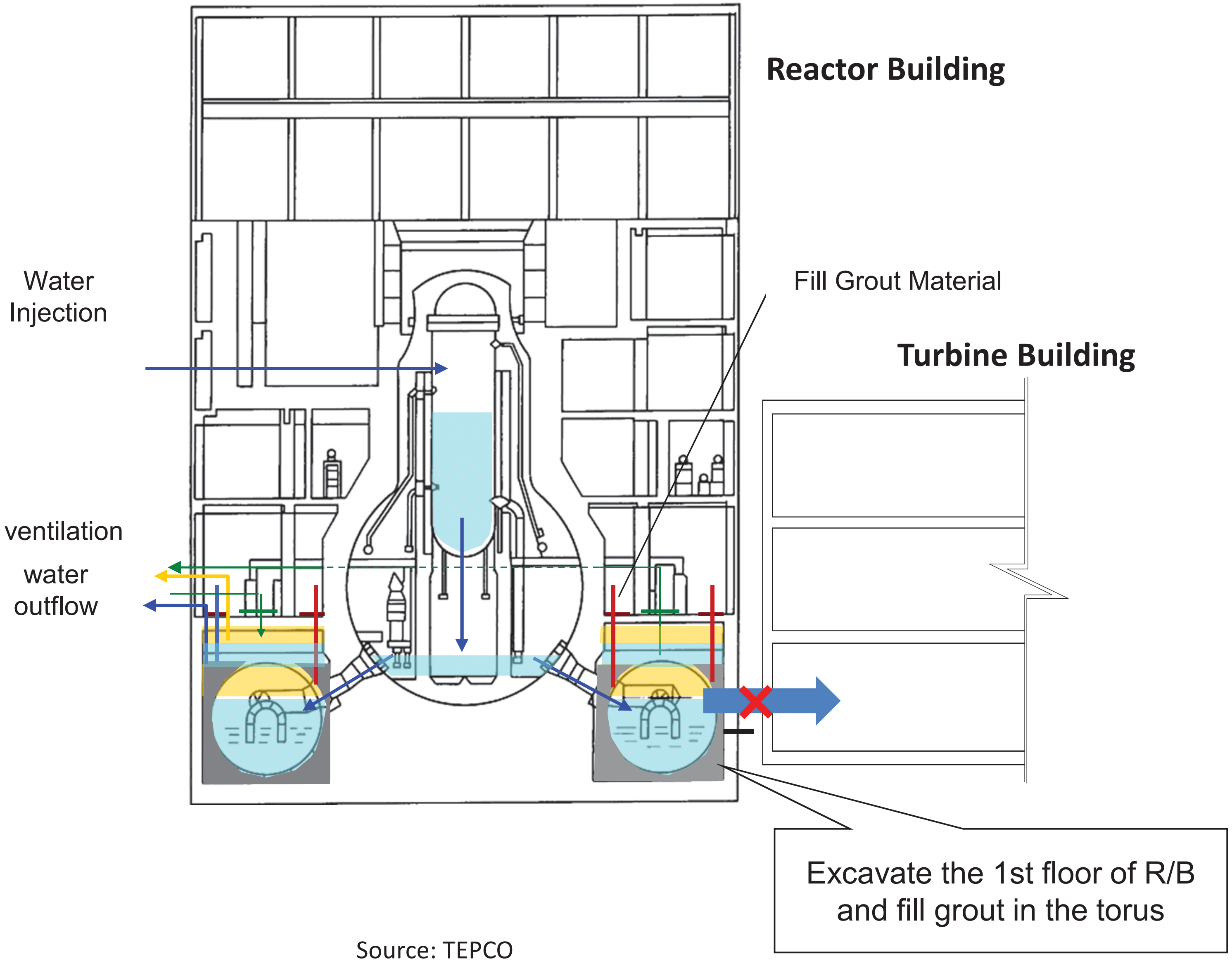
Source: TEPCO

Countermeasures

-Drilled a hole into the pit and injected water glass (sodium silicate) into the pit.

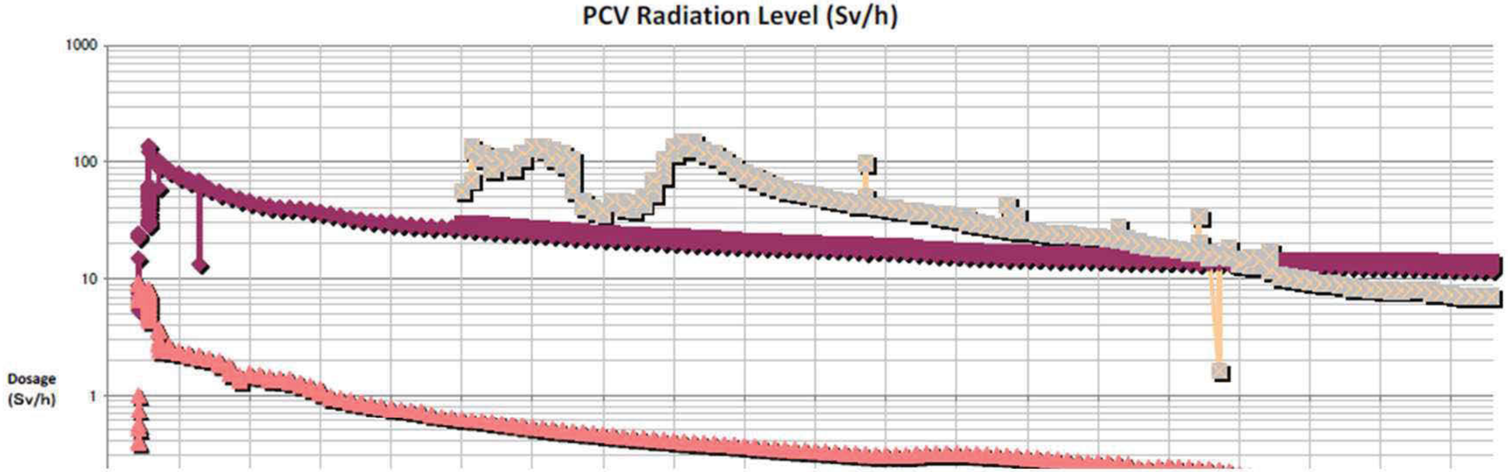
-By April 6, the outflow was confirmed to stop.

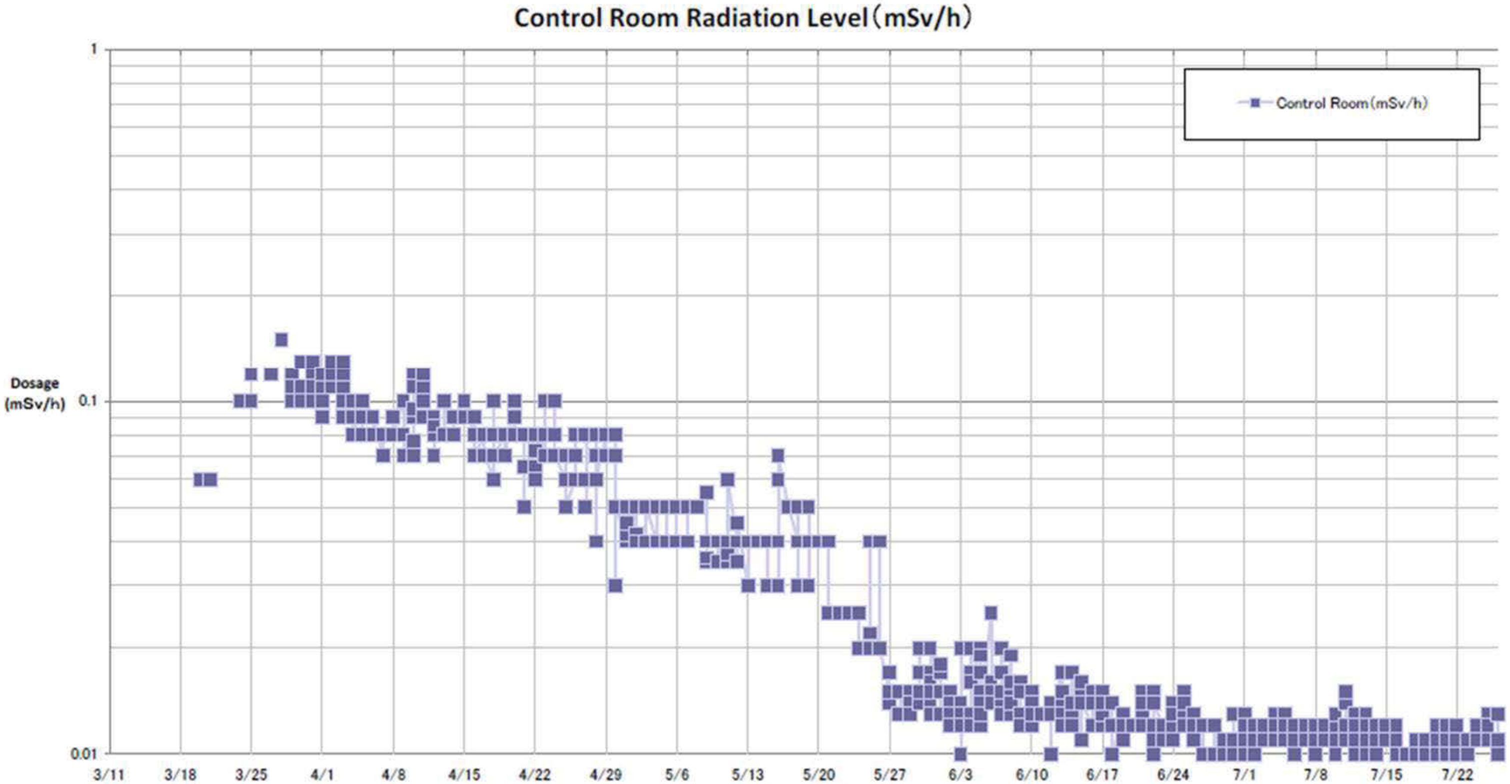
Countermeasure to Seal the Damaged Location in the PCV of the Unit 2



Source: TEPCO

Radiation Levels in the PCV and Control Room of the Unit 2



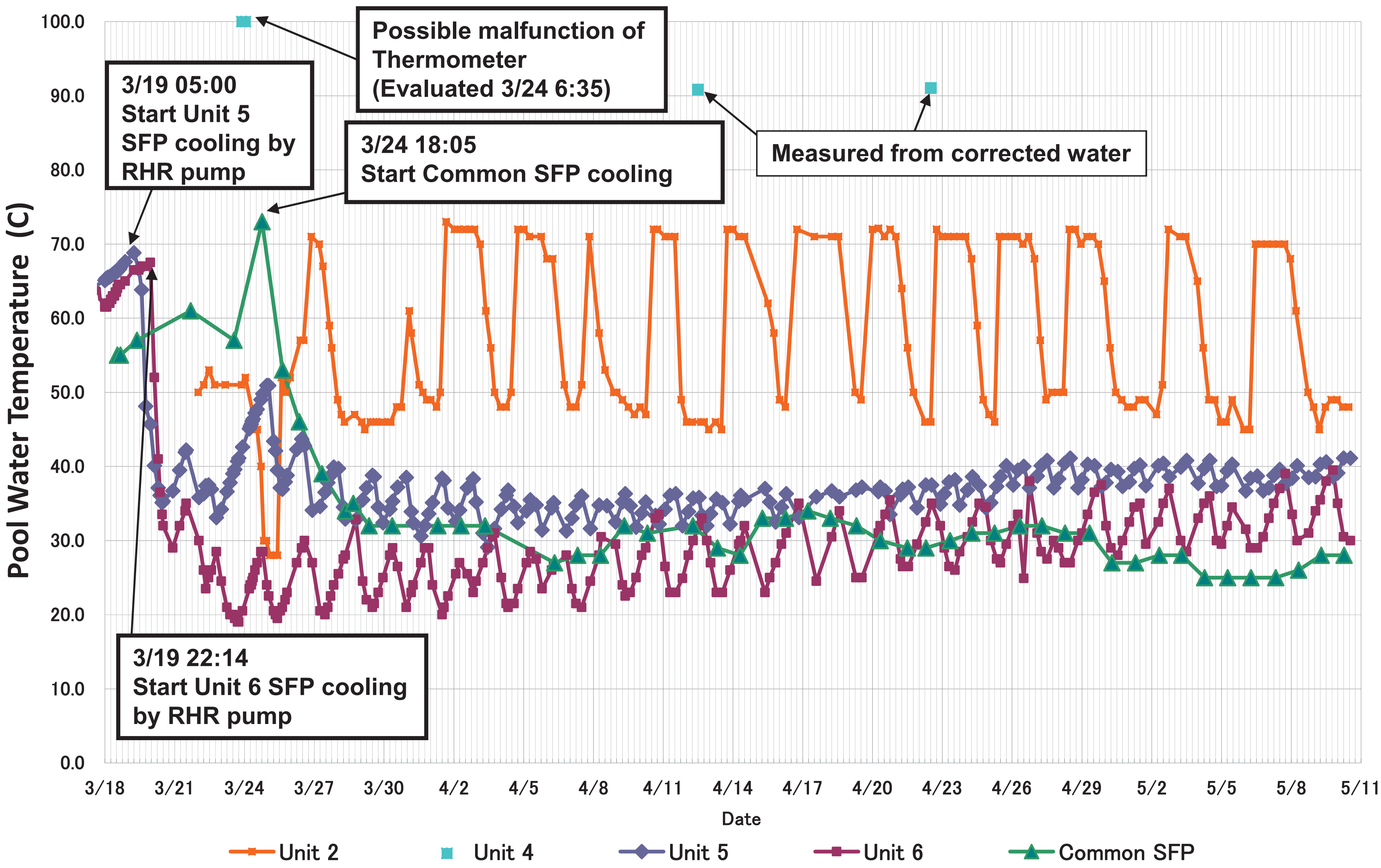


Fuel Assemblies in Reactor Core and Spent Fuel Pool

Unit	*1*	*2*	*3*	*4*	*5*	*6*
Number of Fuel Assembly in the Core	400	548	548*	-	548	764
Number of Spent Fuel Assembly in the SFP	292	587	514	1,331	946	876
Number of New Fuel Assembly in the SFP	100	28	52	204	48	64
Water Volume (m^3)	1,020	1,425	1,425	1,425	1,425	1,497
Heat Generation in Spent Fuel Pool (MW)	0.07	0.47	0.23	2.3	0.08	0.07

** including 32 MOX Fuel Assembly*

Temperature History of Spent Fuel Pools

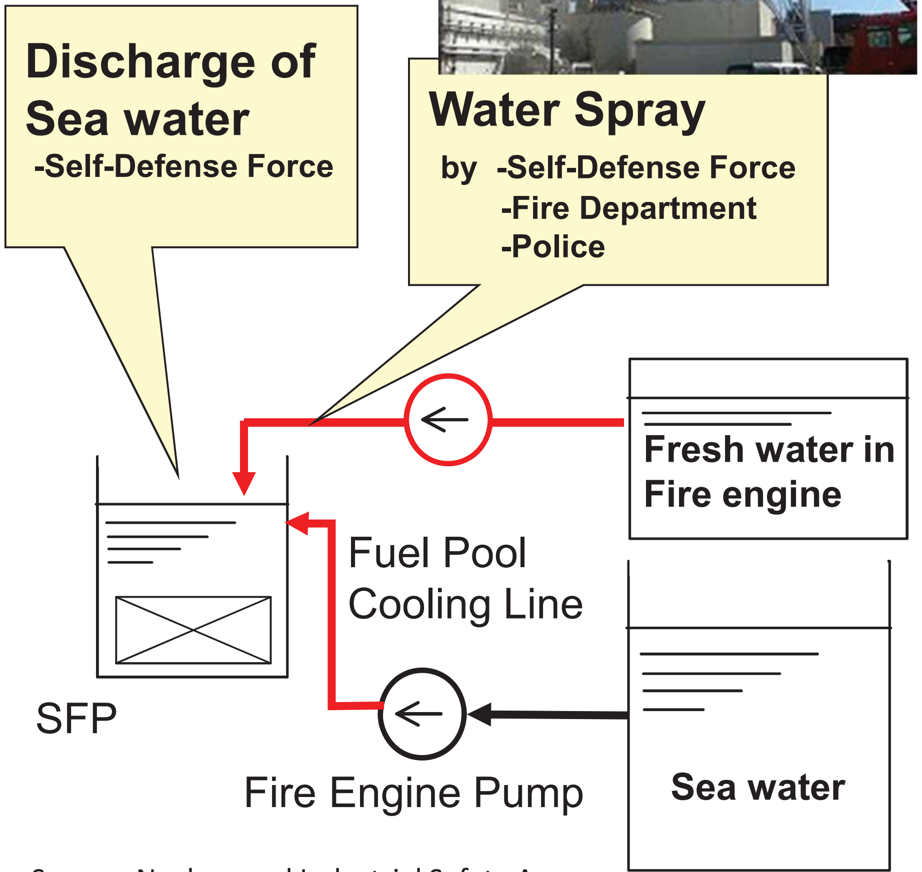


Source: NISA & TEPCO's press release

Unit 3 : Spent Fuel Pool Cooling

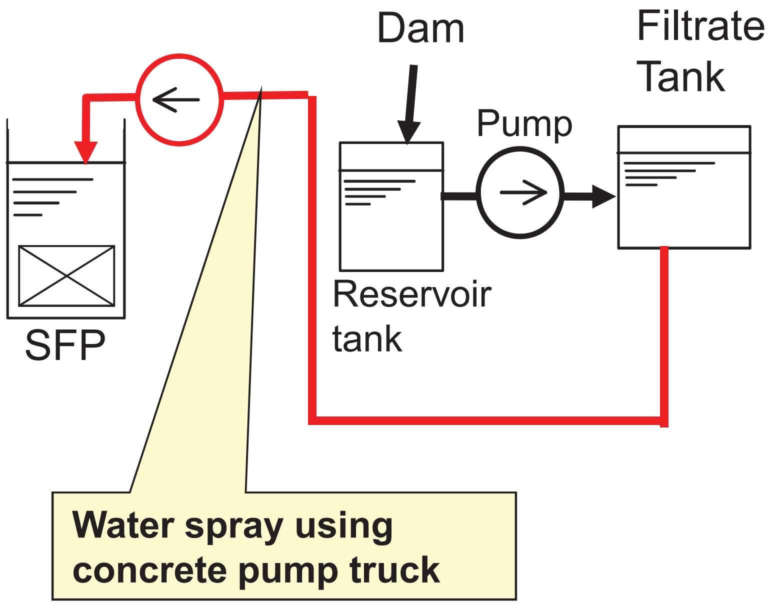
【1st Stage】Sea water injection

asahi.com



Source: Nuclear and Industrial Safety Agency

【2nd Stage】Fresh water injection



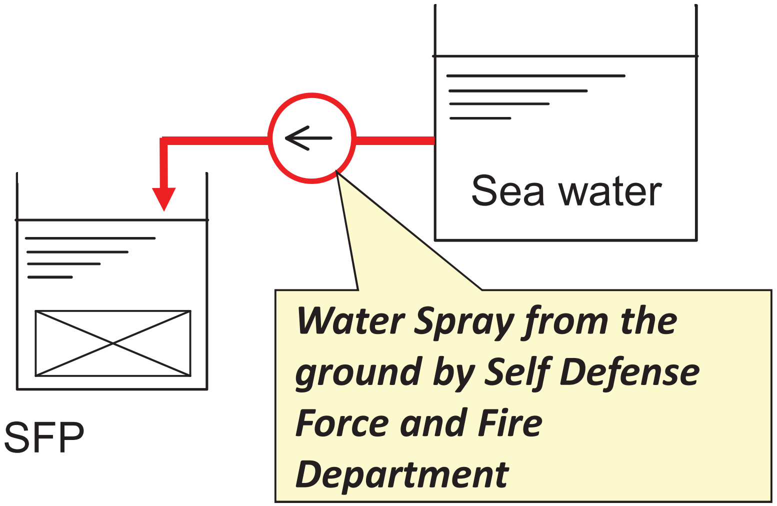
【3rd Stage】Cyclic Cooling

Cyclic cooling started on June 30, by alternative cooling system and filtering system.

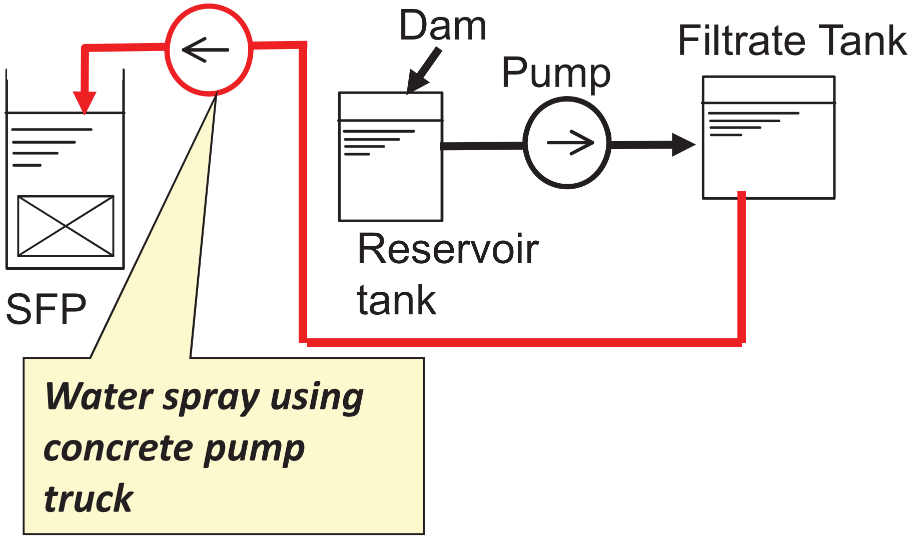
Current temperature of the SFP : 34℃

Unit 4 : Spent Fuel Pool Cooling

【1st Stage】Sea Water Injection



【2nd Stage】Fresh Water Injection



- Reactor building damage on March 15

Source: Nuclear and Industrial Safety Agency

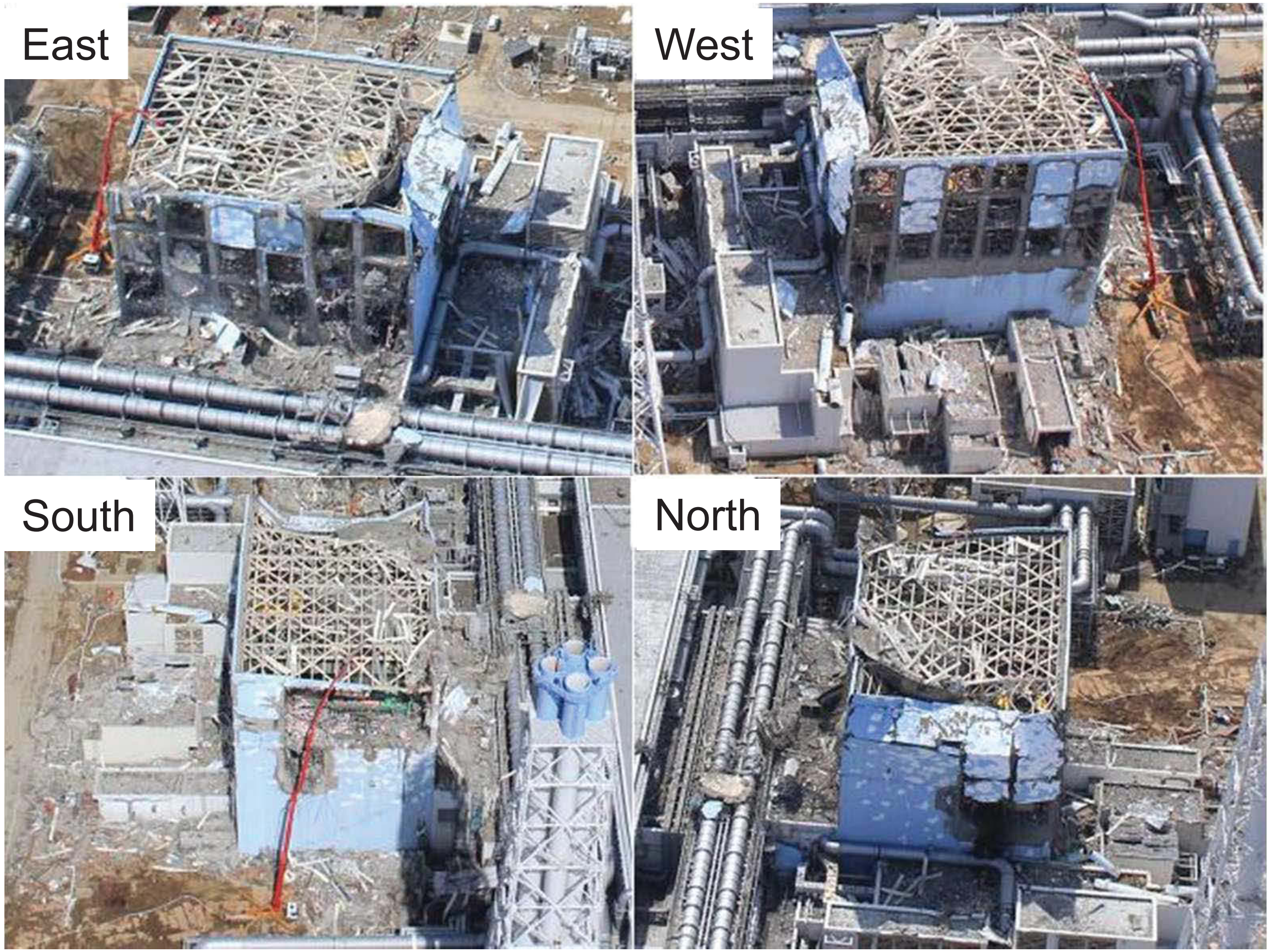
【3rd Stage】Cyclic Cooling

Cyclic cooking started on July 31, by alternative cooling system and filtering system.

86℃ → 82-84℃
after 7 hours of operation of the system

Hydrogen Explosion in Unit 4 ?

Possible mechanisms ; (1) Zr-H_2O reaction in the SFP, (2) H_2 from Unit 3,
(3) Decomposition of H_2O into H_2 and O_2 under radiation



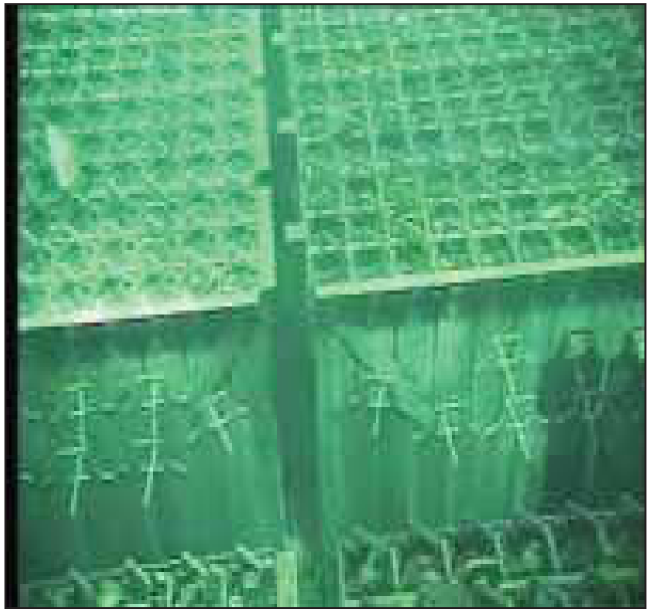
Unit 4 : Spent Fuel Pool

- ***No significant damage was identified by underwater camera inspection***
- ***Water sampling on April 12 also shows relatively low radioactivity in SFP water***

Analysis result of water in the SFP of Unit 4
(Date of Collection April 12 and 28)

Detected Nuclides	*Density (Bq/cm^3) on April 12*	*Density (Bq/cm^3) on April 28*
Cesium 134	88	-
Cesium 137	93	55
Iodine 131	220	27

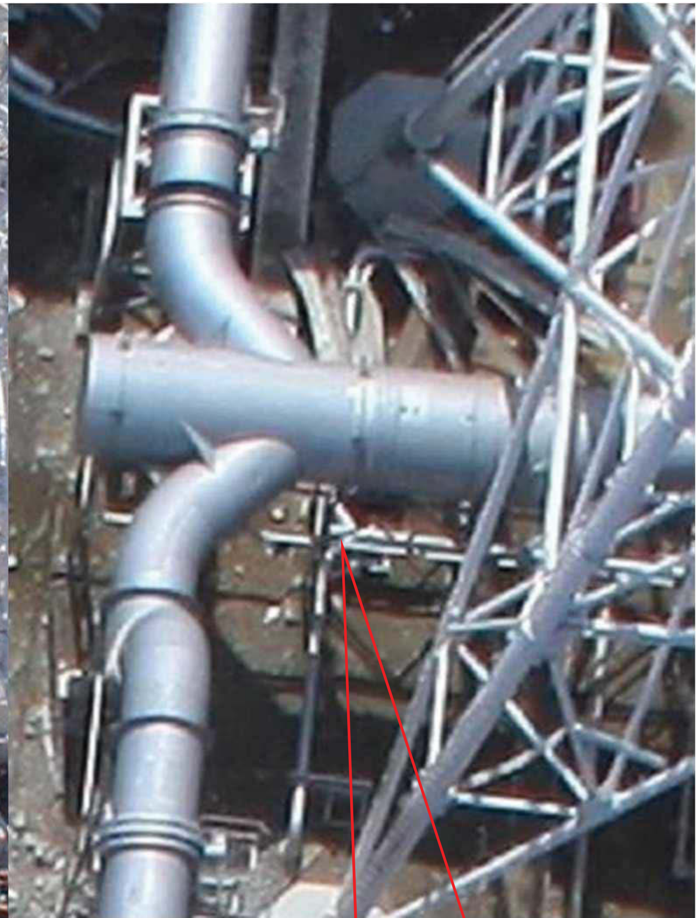
Source: TEPCO

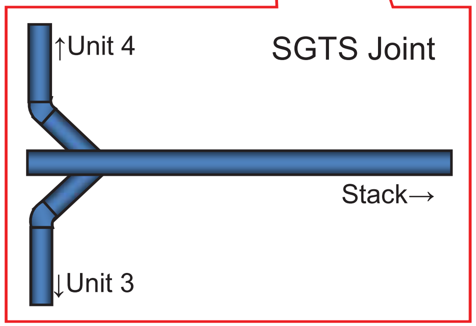


Source: TEPCO

Zr-H_2O reaction in the SFP at high temperature

Stand-by Gas Treatment Systems for Units 3 and 4

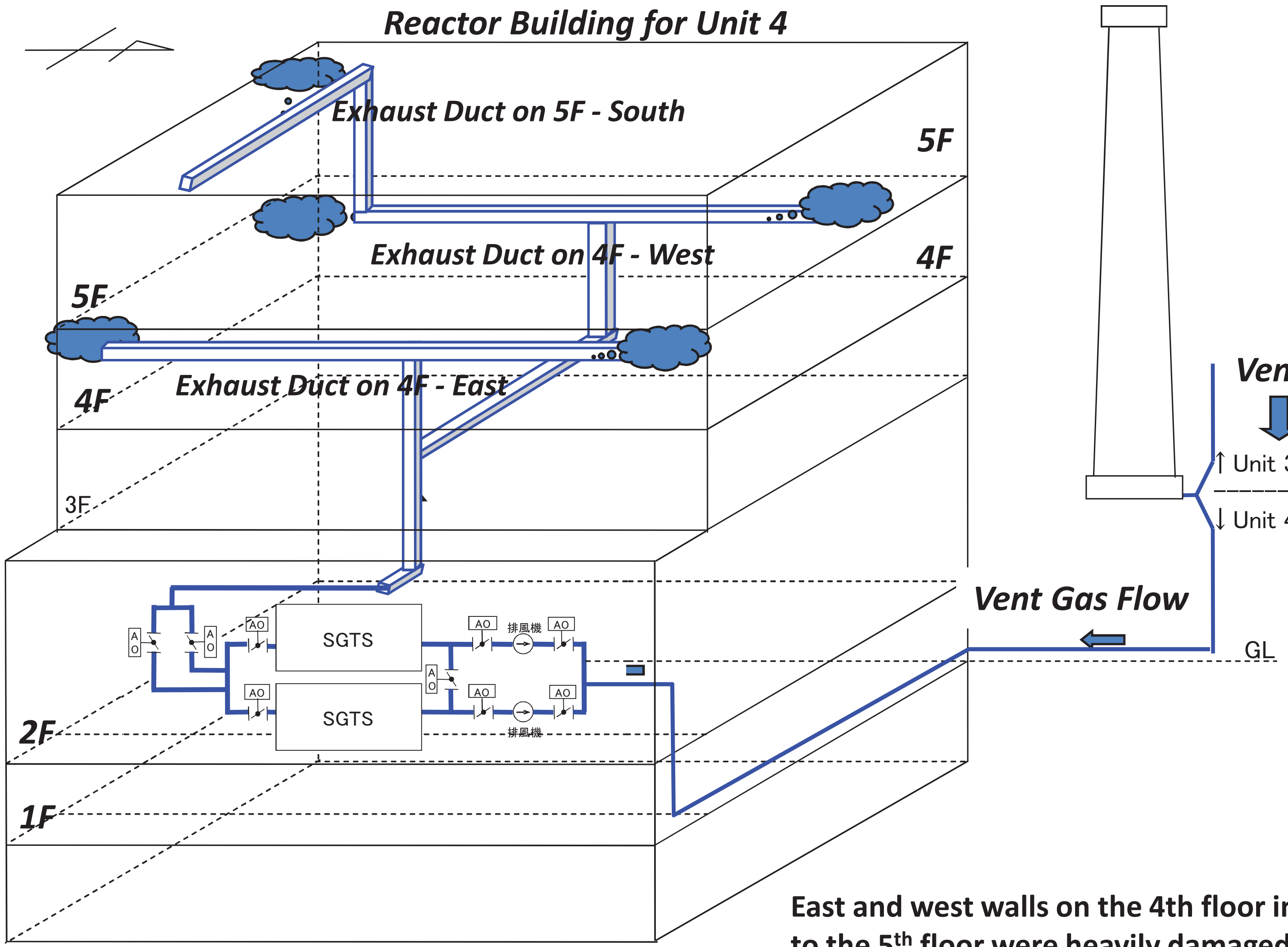




Pipes of stand-by gas treatment systems for Units 3 and 4 are connected.

Source: TEPCO

Possible Mechanism of Hydrogen Explosion in Unit 4



East and west walls on the 4th floor in addition to the 5th floor were heavily damaged.

Source: TEPCO

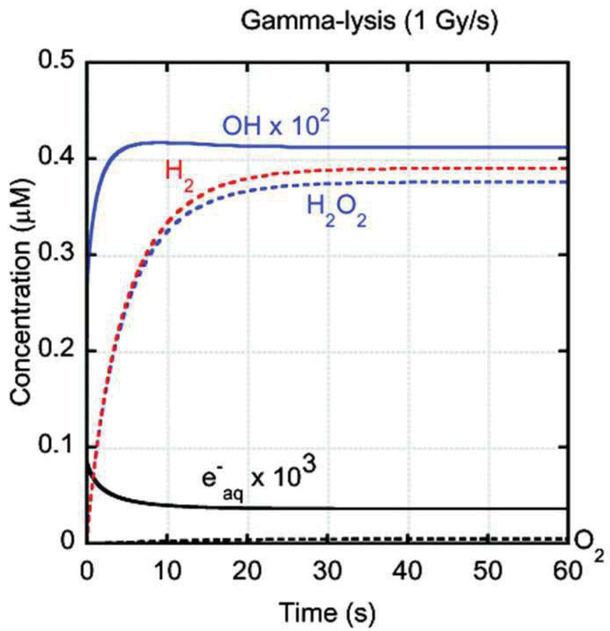
Experiments on High Concentration of Hydrogen Gas under Radiation at Boiling Temperature

G-values	$-H_2O$	e^-_{aq}	OH	H	H_2O_2	H_2	HO_2
Gamma-ray	4.1	2.7	2.8	0.56	0.68	0.45	~0.01
Alpha-ray	2.65	0.06	0.24	0.21	0.985	1.3	0.22

May 16, 2011

Prof. Katsumura Group

The University of Tokyo and JAEA

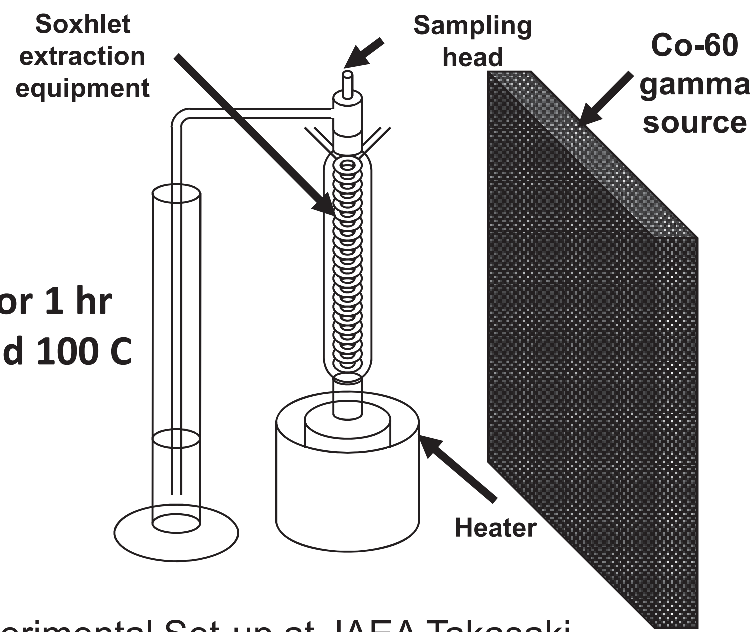


Typical BWR condition simulation of radiation chemistry reactions considering the reaction between H_2 and OH, resulting in steady state concentration of H_2.

New Finding by H_2 production under irradiation;

- ***Effective transfer of H_2 into gas phase at 100 C***
- ***High concentration of H_2 through condensation of H_2O at lower temperature region***

6.8 kGy/h for 1 hr at 80, 97 and 100 C



Experimental Set-up at JAEA Takasaki

INES Rating
International Nuclear and Radiological Event Scale

INES Level	People and Environment	Radiological Barriers and Control	Defence-in-Depth
Major Accident Level 7	• Major release of radioactive material with widespread health and environmental effects requiring implementation of planned and extended countermeasures.		
Serious Accident Level 6	• Significant release of radioactive material likely to require implementation of planned countermeasures.		
Accident with Wider Consequences Level 5	• Limited release of radioactive material likely to require implementation of some planned countermeasures. • Several deaths from radiation.	• Severe damage to reactor core. • Release of large quantities of radioactive material within an installation with a high probability of significant public exposure. This could arise from a major criticality accident or fire.	
Accident with Local Consequences Level 4	• Minor release of radioactive material unlikely to result in implementation of planned countermeasures other than local food controls. • At least one death from radiation.	• Fuel melt or damage to fuel resulting in more than 0.1% release of core inventory. • Release of significant quantities of radioactive material within an installation with a high probability of significant public exposure.	
Serious Incident Level 3	• Exposure in excess of ten times the statutory annual limit for workers. • Non-lethal deterministic health effect (e.g., burns) from radiation.	• Exposure rates of more than 1 Sv/h in an operating area. • Severe contamination in an area not expected by design, with a low probability of significant public exposure.	• Near accident at a nuclear power plant with no safety provisions remaining. • Lost or stolen highly radioactive sealed source. • Misdelivered highly radioactive sealed source without adequate procedures in place to handle it.
Incident Level 2	• Exposure of a member of the public in excess of 10 mSv. • Exposure of a worker in excess of the statutory annual limits.	• Radiation levels in an operating area of more than 50 mSv/h. • Significant contamination within the facility into an area not expected by design.	• Significant failures in safety provisions but with no actual consequences. • Found highly radioactive sealed orphan source, device or transport package with safety provisions intact. • Inadequate packaging of a highly radioactive sealed source.
Anomaly Level 1			• Overexposure of a member of the public in excess of statutory annual limits. • Minor problems with safety components with significant defence-in-depth remaining. • Low activity lost or stolen radioactive source, device or transport package.
NO SAFETY SIGNIFICANCE (*Below Scale/Level 0*)			

INES Rating
International Nuclear and Radiological Event Scale

- ***NISA issued provisional INES ratings , based on "What is known" at the time.***
- ***At first, following units were rated as Level 3 based on "Defense in Depth" criteria about 10 hours later from the earthquake.***
  - Fukushima Daiichi Units 1, 2 and 3, Fukushima Daini Units 1, 2 and 4
- ***In the evening on March 12, the rating of Fukushima Daiichi Unit 1 was re-evaluated to Level 4 base on the "Radiological Barriers and Control" criteria.***
- ***On March 18, Fukushima Daiichi Units 1, 2 and 3 were re-rated to Level 5 based on "Radiological Barriers and Control" criteria because the fuel damage was highly possible. Fukushima Daiichi Unit 4 was evaluated to Level 3 based on the "Defense in Depth" criteria.***
- ***On April 12, Fukushima Daiichi NPPs was revised Level 7 based on the "People and Environment" criteria, as a result of discharged estimation.***
- ***Official rating will be done after cause and countermeasures are identified.***

INES Rating

	Level	Examples
Accident	7 Major Accident	**Chernobyl NPS Accident/Former Soviet Union (1986)** **Fukushima Dai-ichi NPS Accident/Japan（2011）**
Accident	6 Serious Accident	
Accident	5 Accident with Wide Consequences	Windscale/UK: Fire/UK（1957） Three Miles Island NPS Accident/USA（1979）
Accident	4 Accident with Local Consequences	Tokai Village JCO/Japan: Criticality Accident（1999） Saint-Laurent NPS Accident/France（1980）
Abnormal Incident	3 Serious Incident	Vandellos NPS/Spain: fire(1989)
Abnormal Incident	2 Incident	No2 unit, Mihama NPS: rupture of the steam generator pipe (1991)
Abnormal Incident	1 Anomaly	Monju (FBR):sodium leak /Japan（1995） No2 unit, Tsuruga NPS /Japan: leakage of the primary coolant(1999) No3 unit, Mihama NPS /Japan: damage to the secondary loop (2004)
Under Scale	0 No Safety Significance	（No safety significant incident）
Under Scale	Out of subject	（No safety related incident)

Amount of Released Radioactive Material

	Estimated release from Fukushima Daiichi		(Reference) Release from Chernobyl
	by NISA	by Nuclear Safety Commission	
Iodine 131 (a)	130 thousands T Bq ($1.3X10^{17}$Bq)	150 thousands T Bq ($1.5X10^{17}$Bq)	1,800 thousands T Bq ($1.8X10^{18}$Bq)
Cesium 137	6 thousands T Bq ($6.0X10^{15}$Bq)	12 thousands T Bq ($1.2X10^{16}$Bq)	85 thousands T Bq ($8.5X10^{16}$Bq)
Iodine value conversion (b)	240 thousands T Bq ($2.4X10^{17}$Bq)	480 thousands T Bq ($4.8X10^{17}$Bq)	3,400 thousands T Bq ($3.4X10^{18}$Bq)
(a) + (b)	**370 thousands T Bq ($3.7X10^{17}$Bq)**	**630 thousands T Bq ($6.3X10^{17}$Bq)**	**5,200 thousands T Bq ($5.2X10^{18}$Bq)**

INES level 7 equivalent : over 10 thousands Tera Becquerel (T Bq) (over 10^{16}Bq)

Source: Nuclear and Industrial Safety Agency

Difference between Chernobyl and Fukushima

① Responses aftermath of the accident

- Chernobyl : Left untouched, because it was impossible to enter the premises due to radioactive contamination.
- Fukushima: Recovery work is under way towards settlement of the accident.

② Situations of radioactive exposure

- Chernobyl : 28 deaths due to acute radioactive exposure.
- Fukushima : No deaths.

③ Situations of the accidents

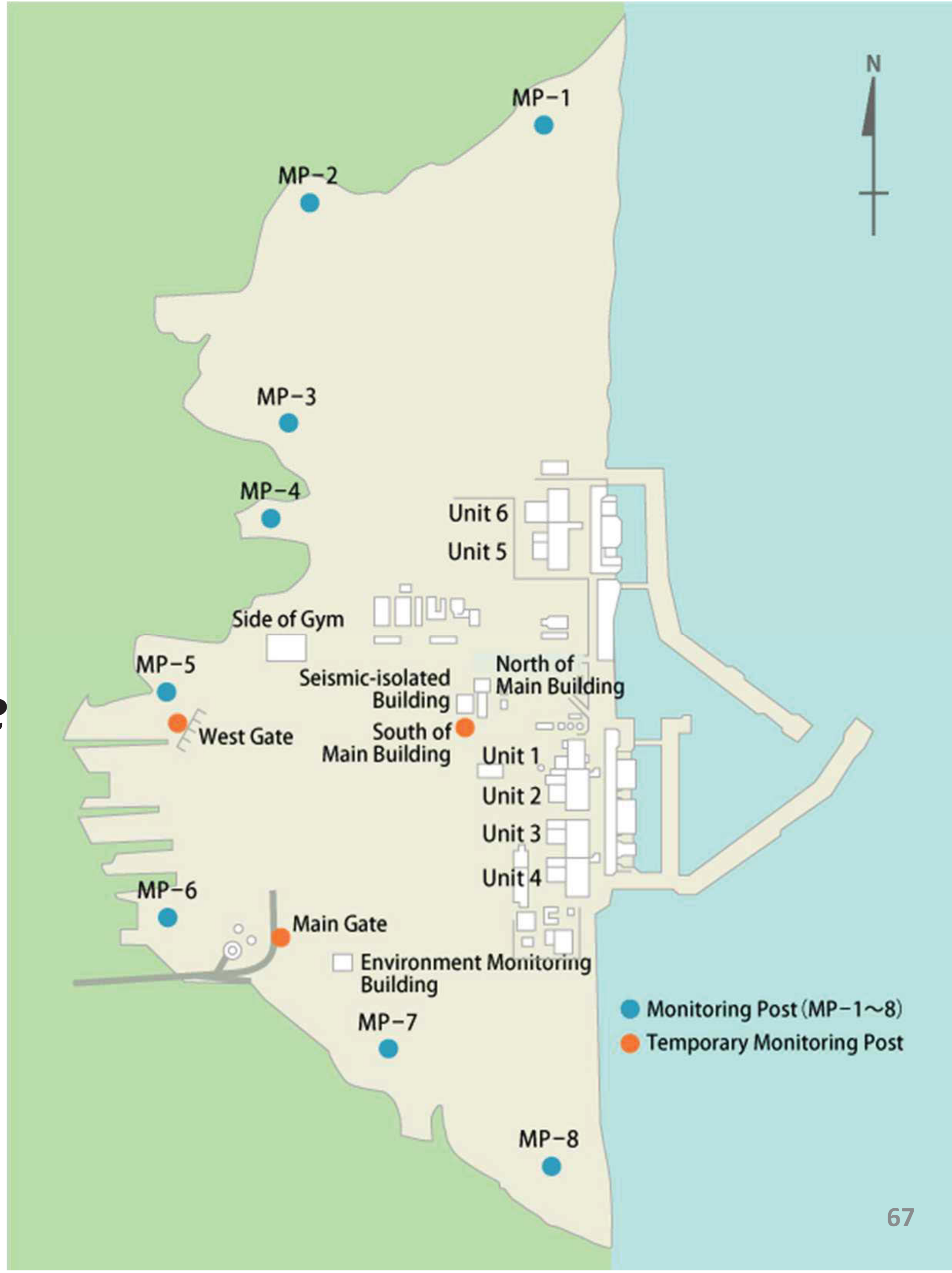
- Chernobyl : Reactor (with no container) exploded and large-scale fire occurred.
- Fukushima: hydrogen explosion occurred but no large-scale explosion or continuous fires.

④ Radioactivity levels

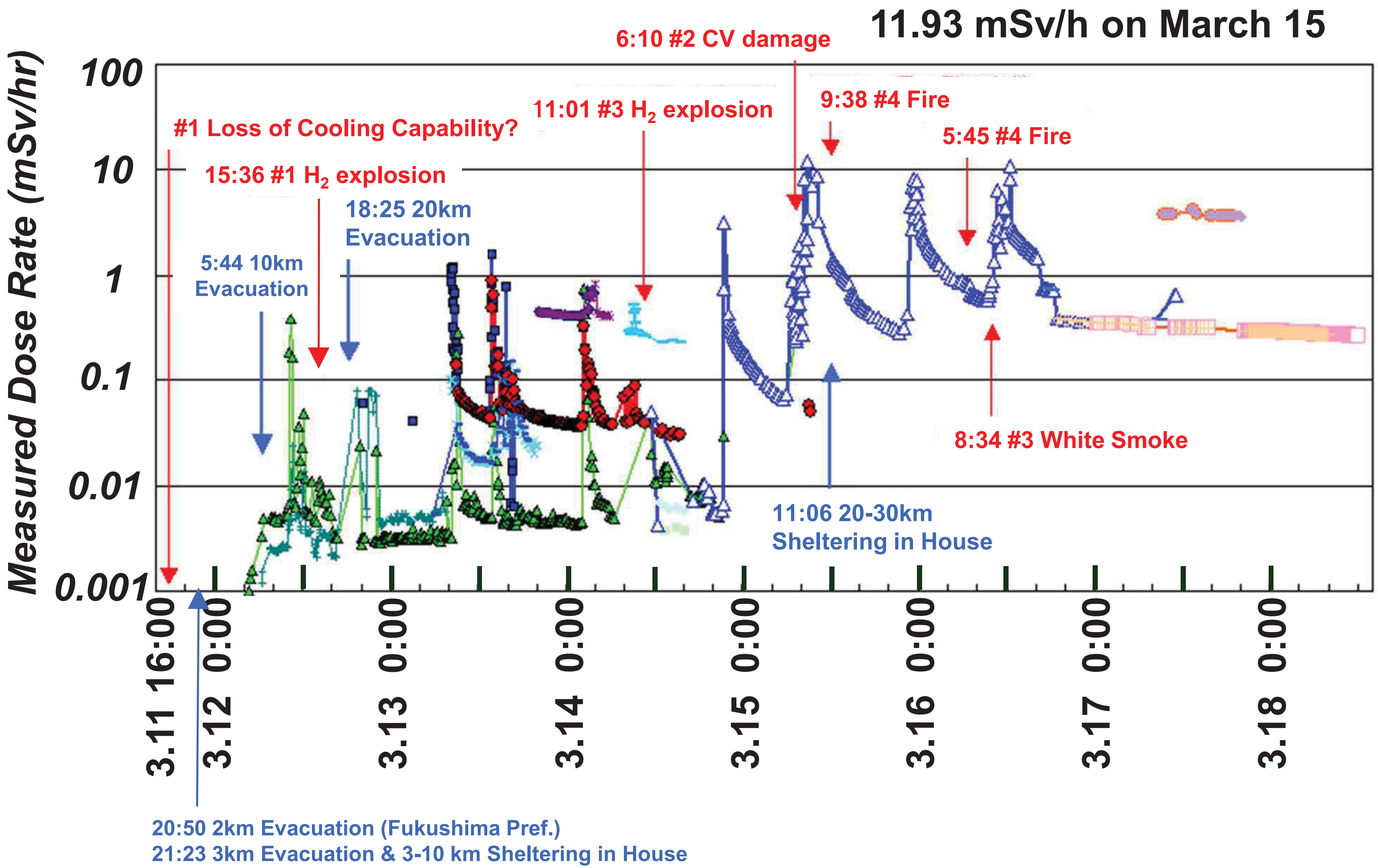
- Amount of radiation released from Fukushima NPS is about one tenth that of Chernobyl.

Monitoring Posts

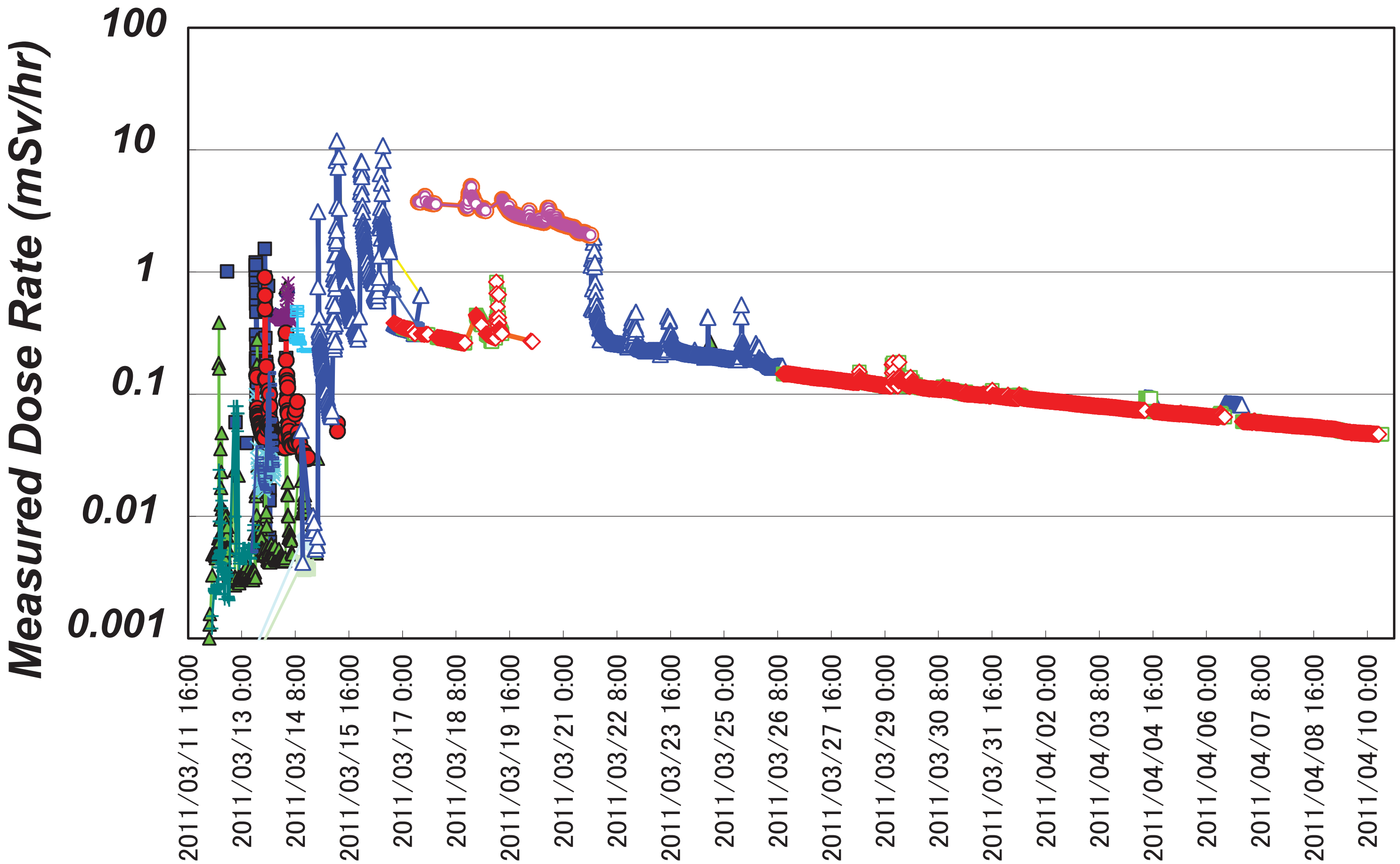
in the Fukushima Daiichi Nuclear Power Plants Site



On-site Radiation Monitoring in Fukushima Daiichi Site From March 11 to 18

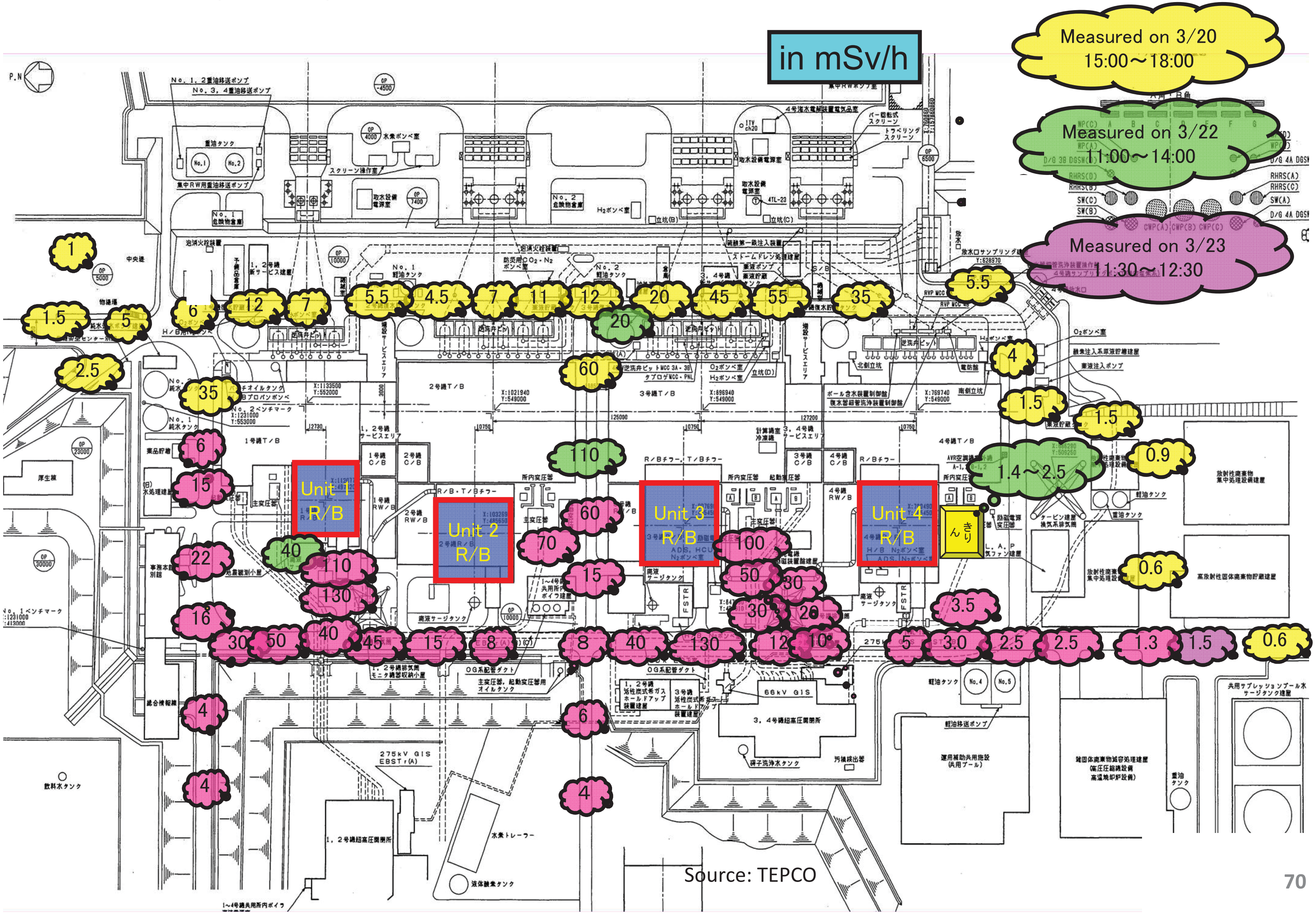


On-site Radiation Monitoring in Fukushima Daiichi Site From March 11 to April 10



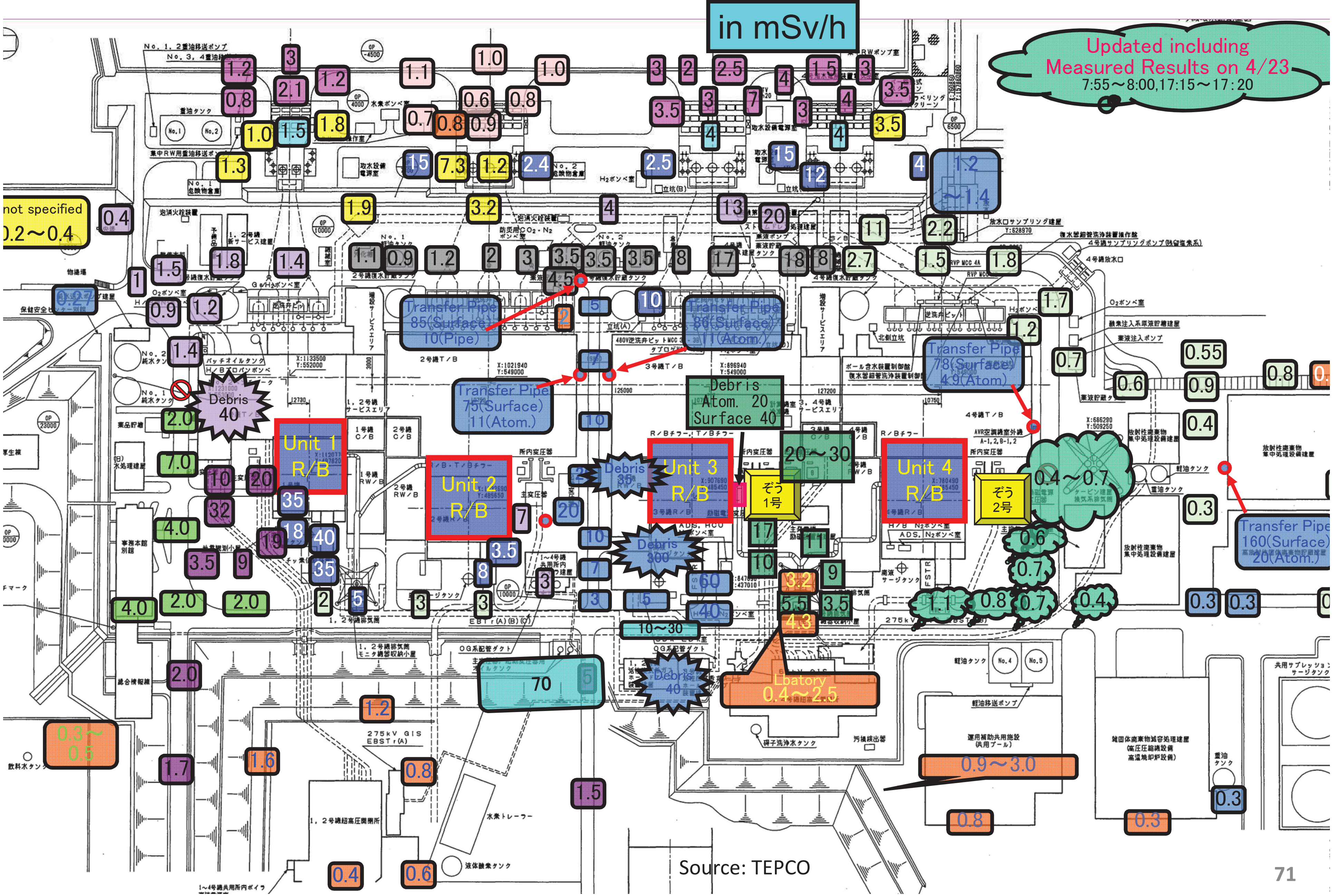
Source: NISA & TEPCO's press release

Survey Map in Fukushima Daiichi Site March 23, 2011



Source: TEPCO

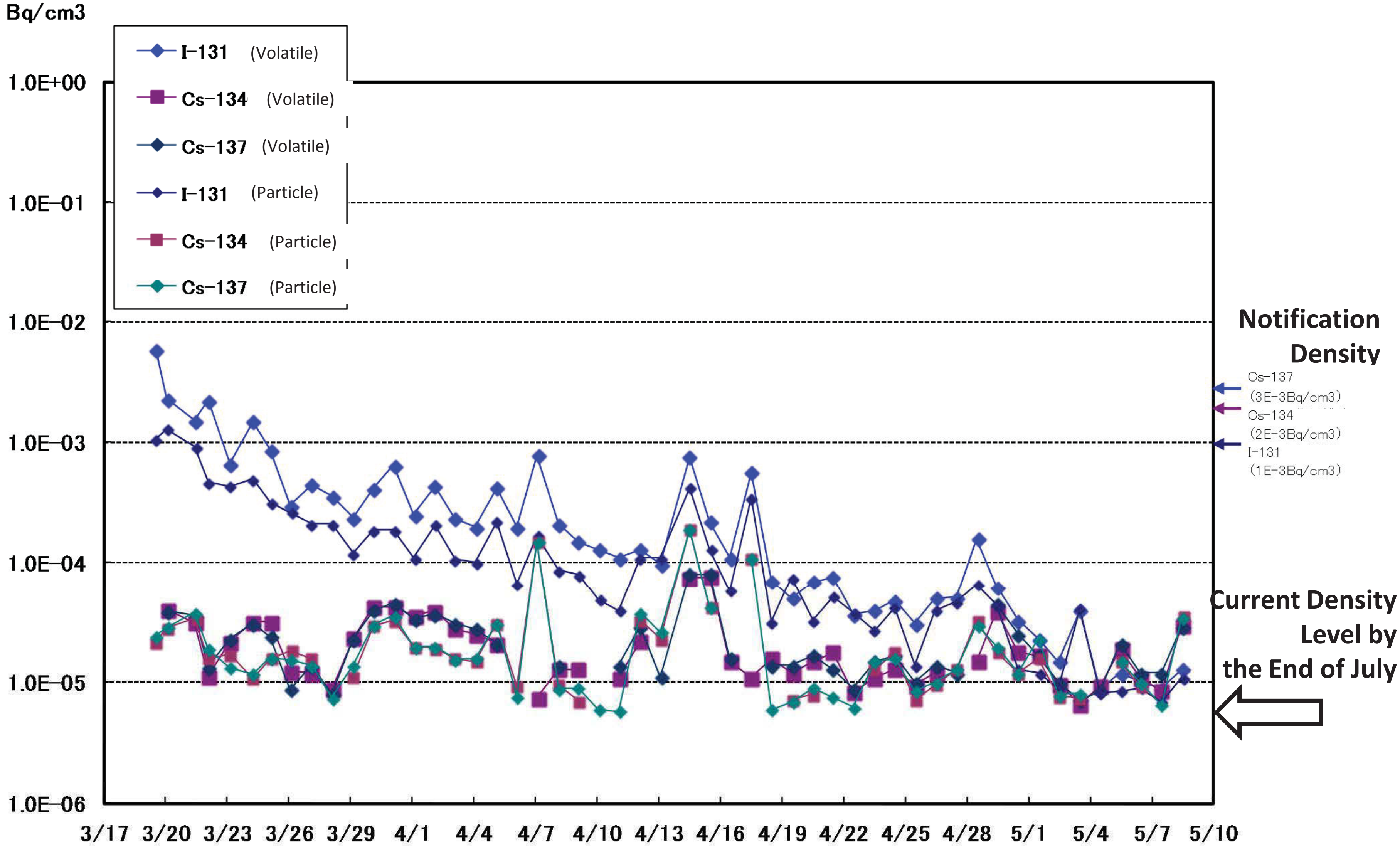
Survey Map in Fukushima Daiichi Site April 23, 2011



Source: TEPCO

On-Site Monitoring of Radioactive Materials

Radioactive materials in the air measured by TEPCO



Source: TEPCO

Integrated Dose of External Exposure

SPEEDI code

Adult

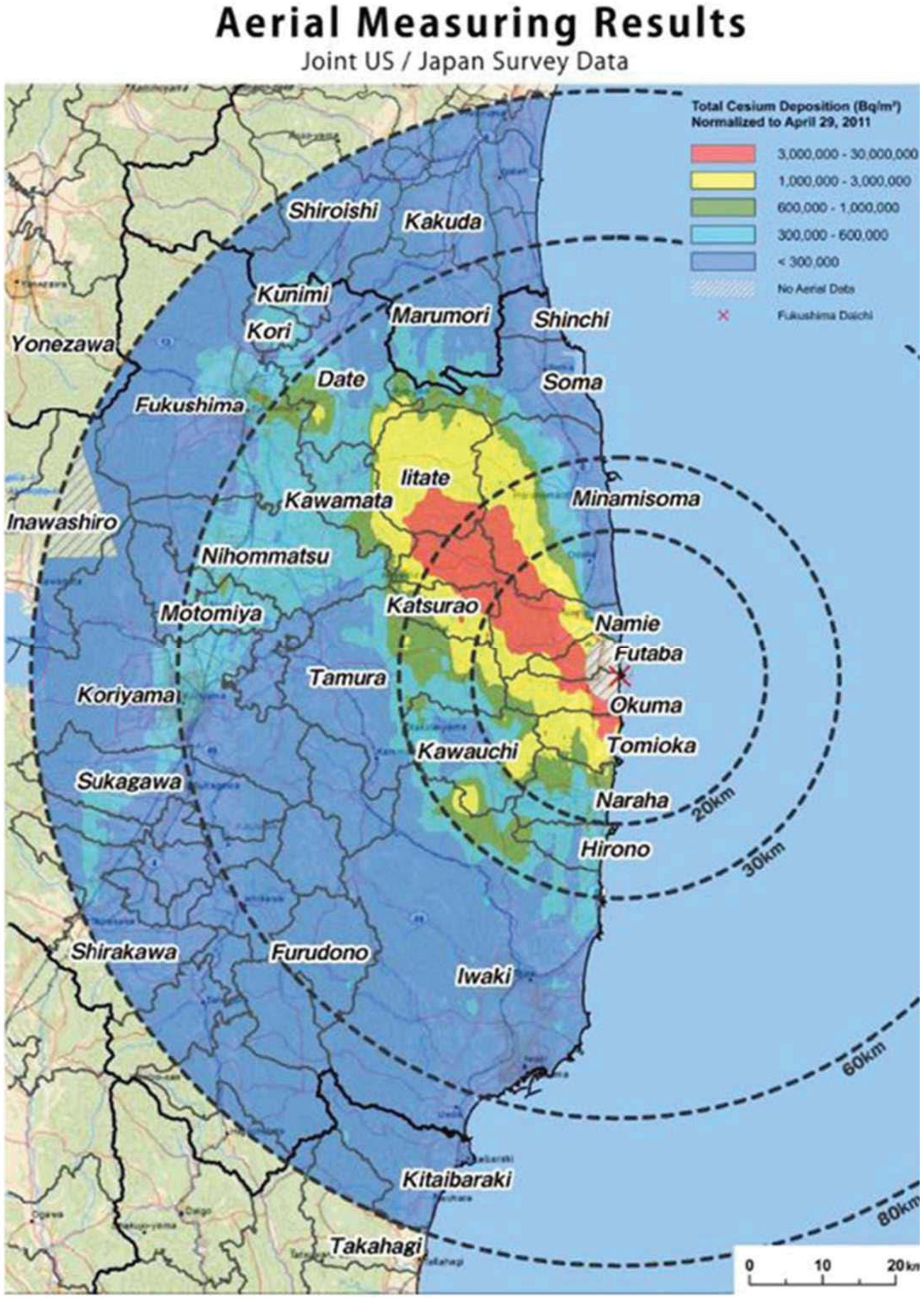
from March 12
to April 24, 2011

Effective Dose in mSv

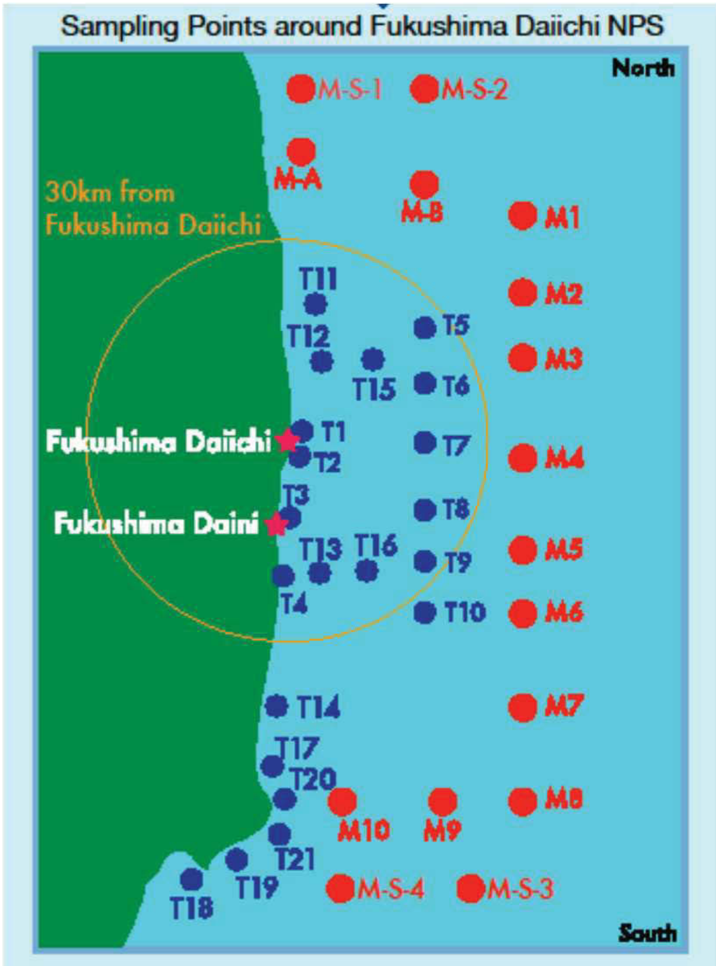
1= 100
2= 50
3= 10
4= 5
5= 1

Cesium Deposition

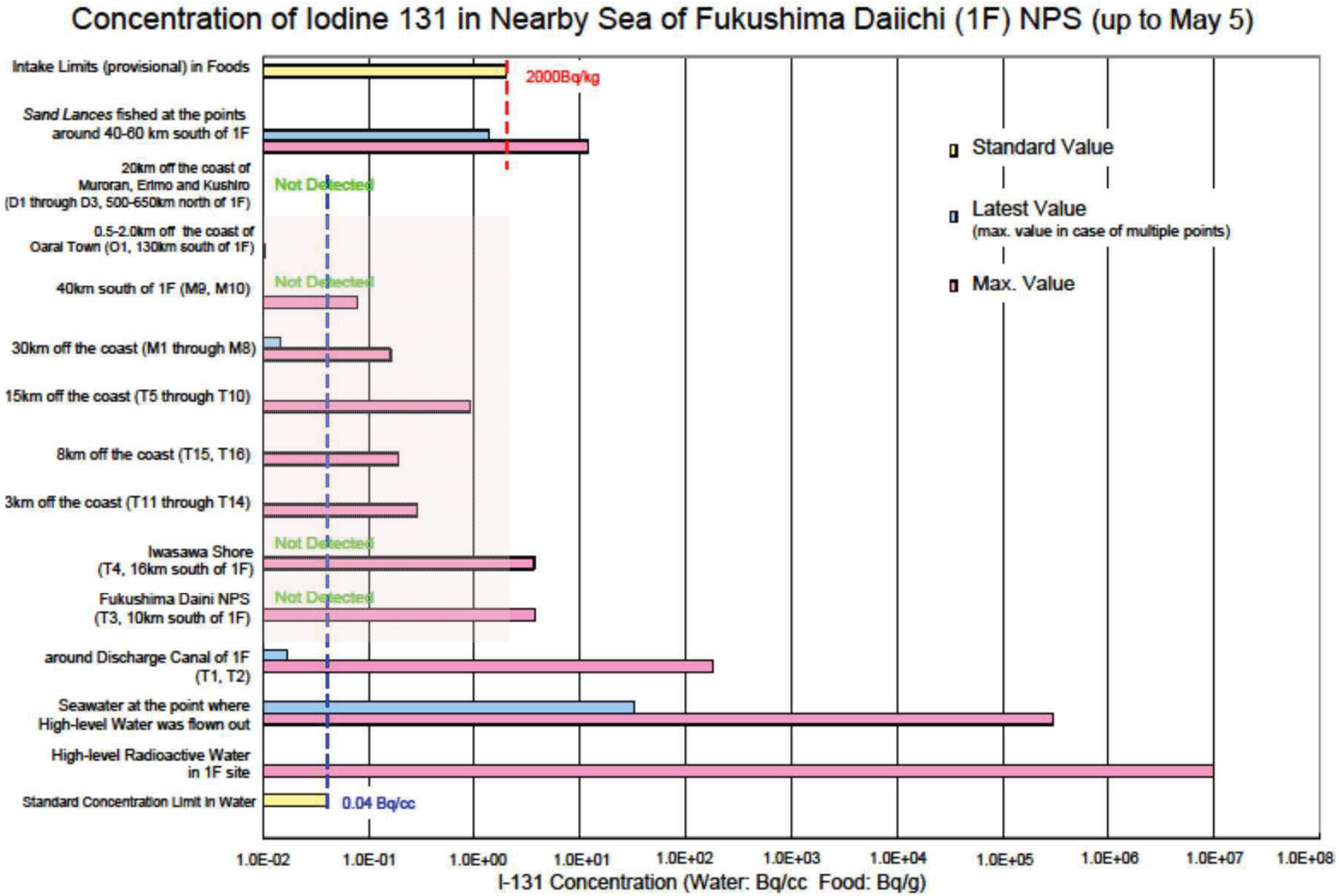
April 29, 2011

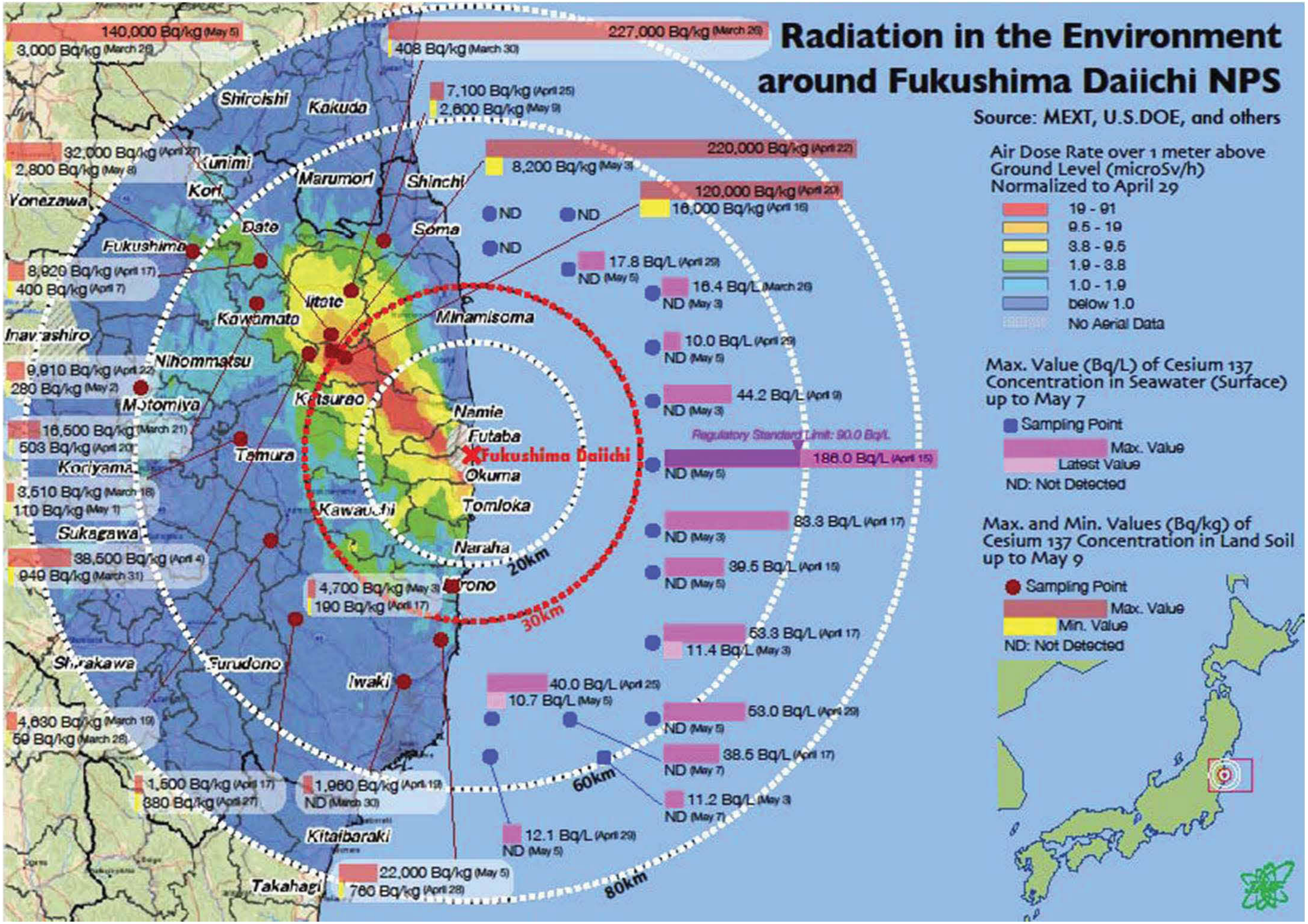


Monitoring of Radioactive Materials in Near-by Sea of Fukushima Daiichi NPPs



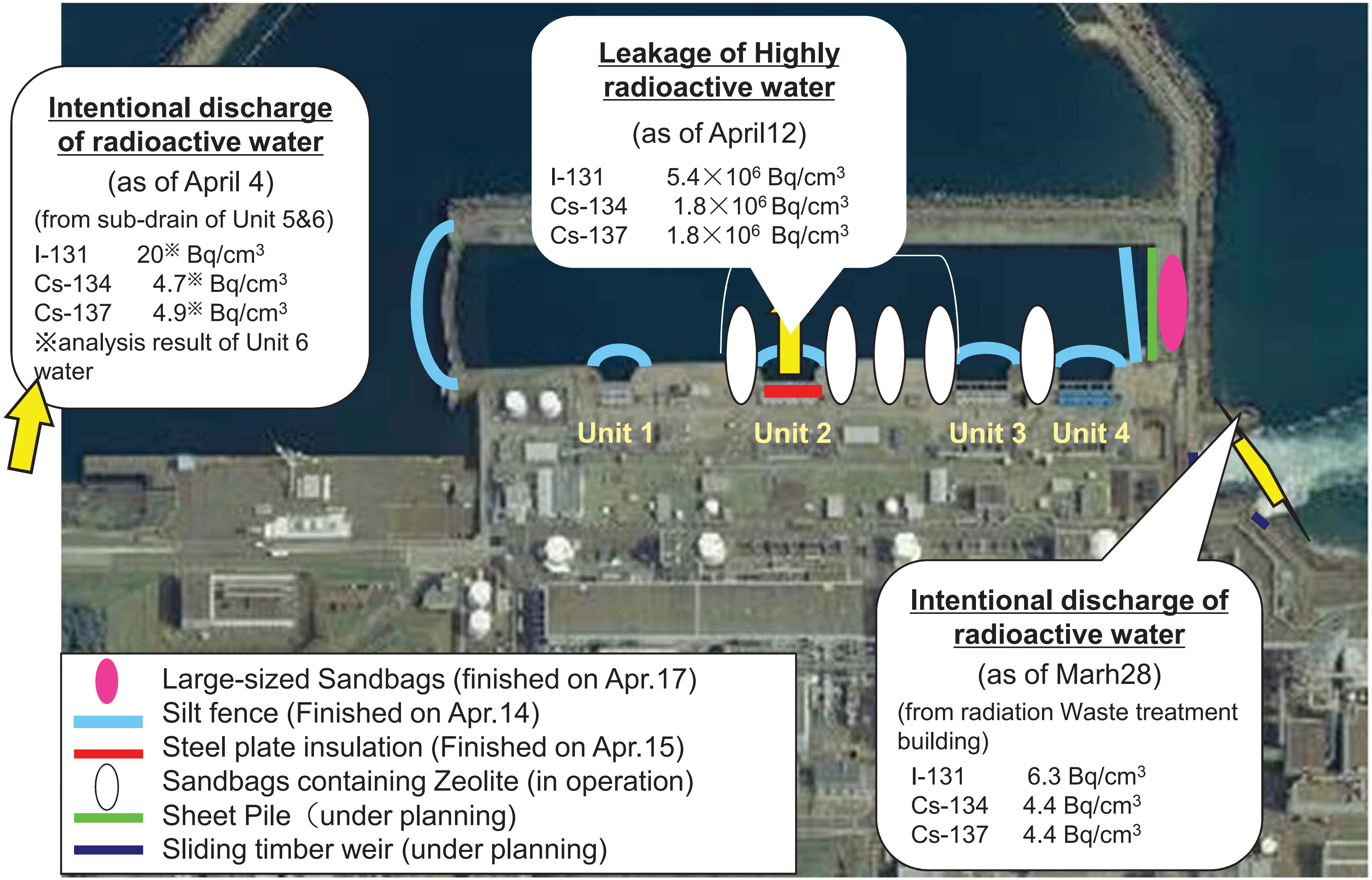
Monitoring of Iodine 131 in Near-by Sea of Fukushima Daiichi NPPs



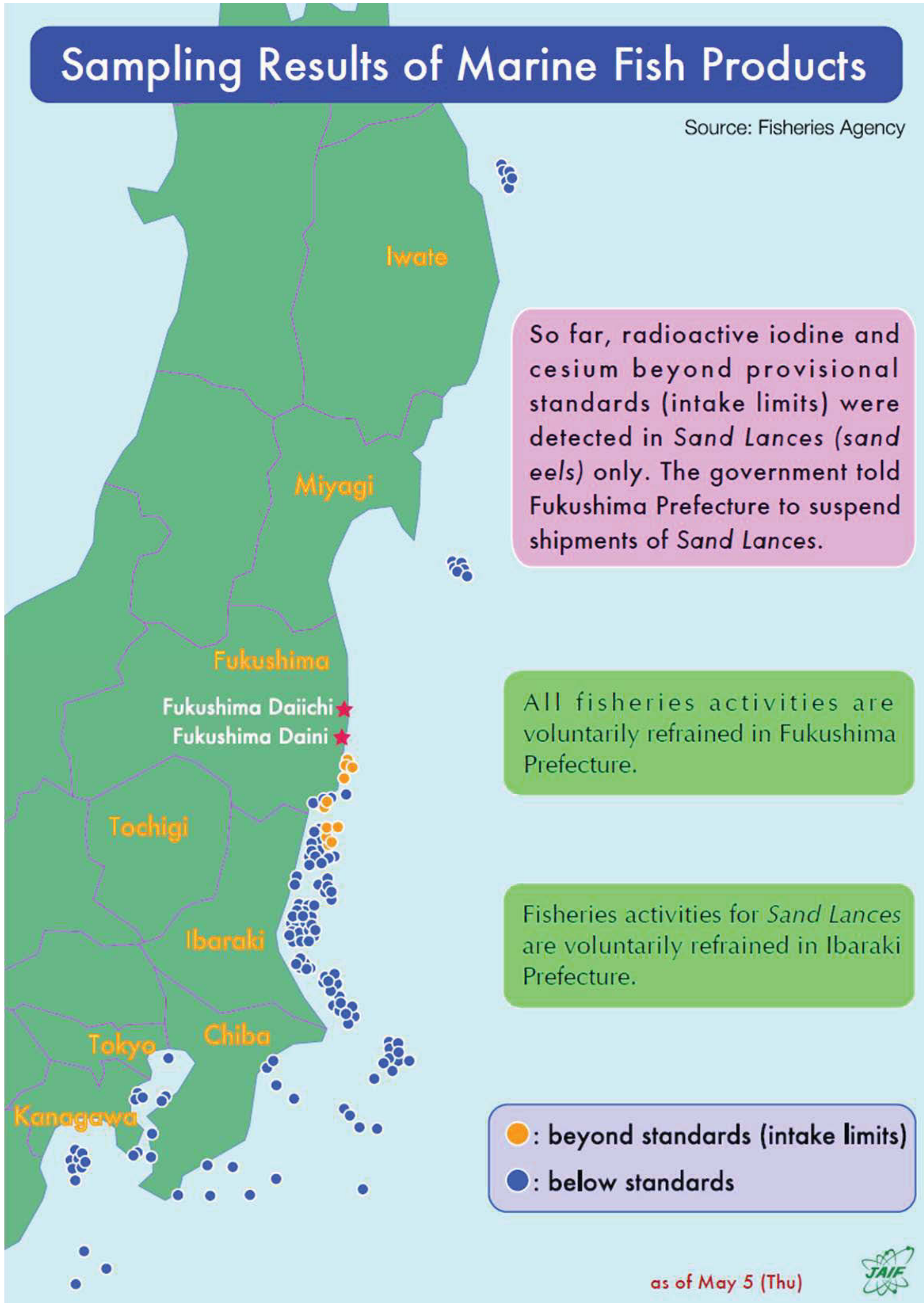


Radiation in the Environment around Fukushima Daiichi NPS
Source: MEXT, U.S.DOE, and others
Air Dose Rate over 1 meter above Ground Level (microSv/h) Normalized to April 29
19 - 91
9.5 - 19
3.8 - 9.5
1.9 - 3.8
1.0 - 1.9
below 1.0
No Aerial Data
Max. Value (Bq/L) of Cesium 137 Concentration in Seawater (Surface) up to May 7
Sampling Point
Max. Value
Latest Value
ND: Not Detected
Max. and Min. Values (Bq/kg) of Cesium 137 Concentration in Land Soil up to May 9
Sampling Point
Max. Value
Min. Value
ND: Not Detected
140,000 Bq/kg (May 5)
3,000 Bq/kg (March 26)
227,000 Bq/kg (March 26)
408 Bq/kg (March 30)
7,100 Bq/kg (April 25)
2,600 Bq/kg (May 9)
32,000 Bq/kg (April 27)
2,800 Bq/kg (May 8)
220,000 Bq/kg (April 22)
8,200 Bq/kg (May 3)
120,000 Bq/kg (April 20)
16,000 Bq/kg (April 16)
8,920 Bq/kg (April 17)
400 Bq/kg (April 7)
9,910 Bq/kg (April 22)
280 Bq/kg (May 2)
16,500 Bq/kg (March 21)
503 Bq/kg (April 20)
3,510 Bq/kg (March 18)
110 Bq/kg (May 1)
38,500 Bq/kg (April 4)
949 Bq/kg (March 31)
4,700 Bq/kg (May 3)
190 Bq/kg (April 17)
4,630 Bq/kg (March 19)
59 Bq/kg (March 28)
1,500 Bq/kg (April 17)
380 Bq/kg (April 27)
1,960 Bq/kg (April 19)
ND (March 30)
22,000 Bq/kg (May 5)
760 Bq/kg (April 28)
ND
ND
ND
17.8 Bq/L (April 29)
ND (May 5)
16.4 Bq/L (March 26)
ND (May 3)
10.0 Bq/L (April 29)
ND (May 5)
44.2 Bq/L (April 9)
ND (May 3)
Regulatory Standard Limit: 90.0 Bq/L
186.0 Bq/L (April 15)
ND (May 5)
83.3 Bq/L (April 17)
ND (May 3)
39.5 Bq/L (April 15)
ND (May 5)
53.3 Bq/L (April 17)
11.4 Bq/L (May 3)
40.0 Bq/L (April 25)
10.7 Bq/L (May 5)
53.0 Bq/L (April 29)
ND (May 5)
38.5 Bq/L (April 17)
ND (May 7)
11.2 Bq/L (May 3)
ND (May 7)
12.1 Bq/L (April 29)
ND (May 5)
Shiroishi
Kakuda
Kunimi
Marumori
Shinchi
Kori
Yonezawa
Date
Soma
Fukushima
Iitate
Kawamato
Minamisoma
Inawashiro
Nihommatsu
Motomiya
Katsurao
Namie
Futaba
Fukushima Daiichi
Okuma
Tamura
Koriyama
Tomioka
Kawauchi
Sukagawa
Naraha
Hirono
20km
30km
60km
80km
Shirakawa
Furudono
Iwaki
Kitaibaraki
Takahagi

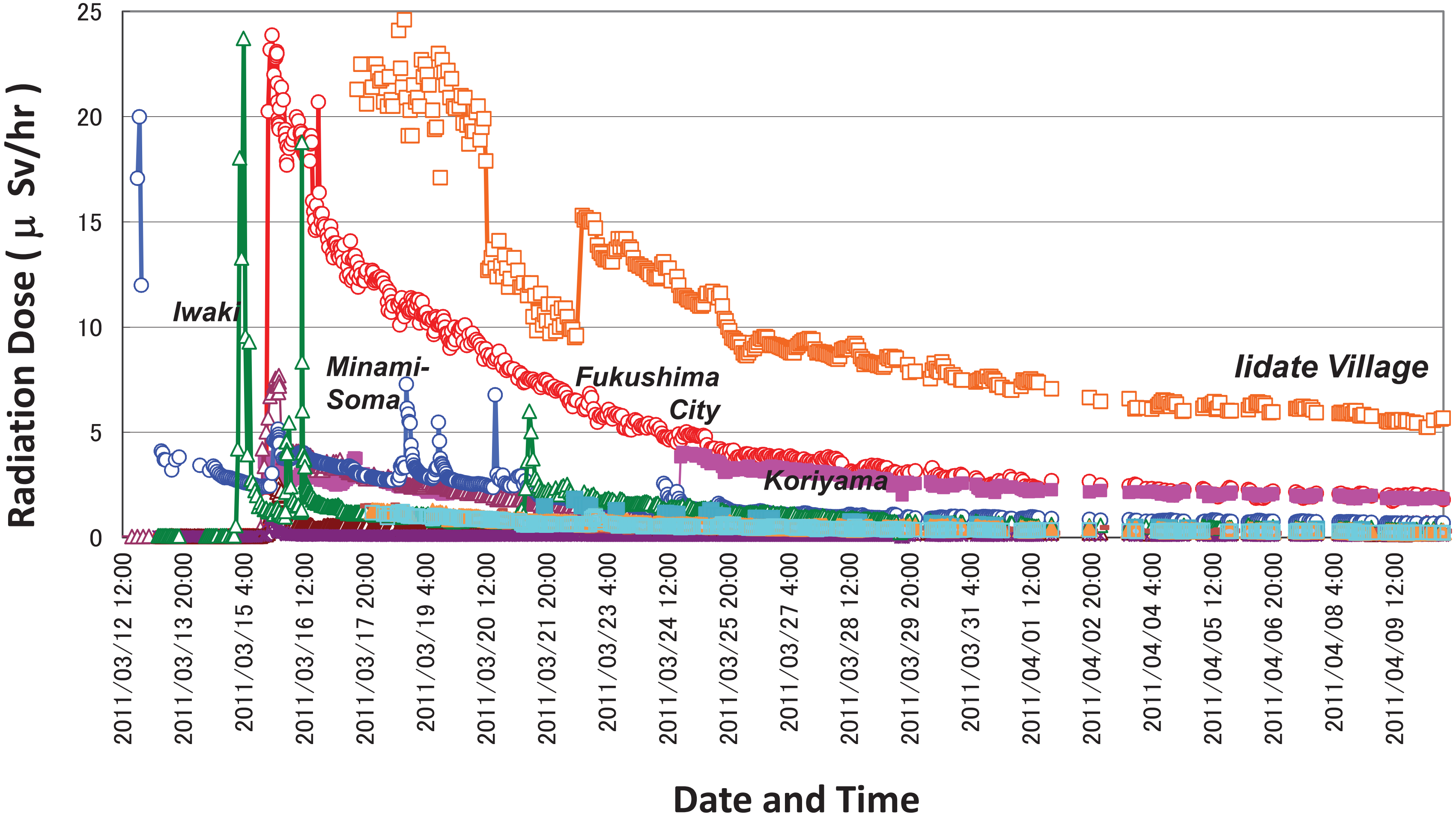
Measures to prevent the spread of radioactive water



Source: TEPCO

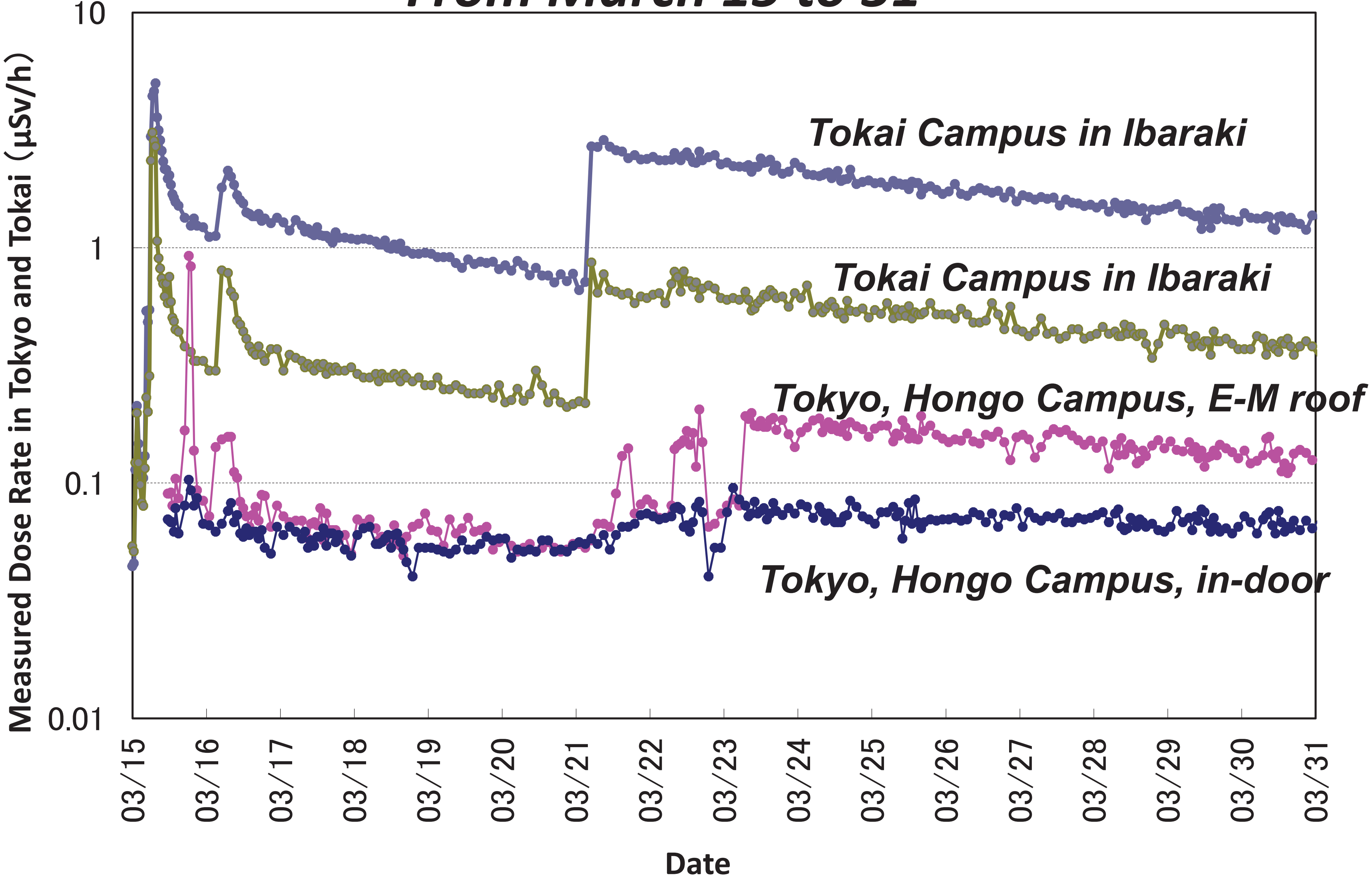

Sampling Results of Marine Fish Products
Source: Fisheries Agency
Iwate
Miyagi
Fukushima
Fukushima Daiichi
Fukushima Daini
Tochigi
Ibaraki
Chiba
Tokyo
Kanagawa
So far, radioactive iodine and cesium beyond provisional standards (intake limits) were detected in *Sand Lances (sand eels)* only. The government told Fukushima Prefecture to suspend shipments of *Sand Lances*.
All fisheries activities are voluntarily refrained in Fukushima Prefecture.
Fisheries activities for *Sand Lances* are voluntarily refrained in Ibaraki Prefecture.
: beyond standards (intake limits)
: below standards
as of May 5 (Thu)
JAIF

Monitoring Radiation Dose in Fukushima Prefecture



Source: MEXT press release

Radiation Monitoring at The University of Tokyo From March 15 to 31

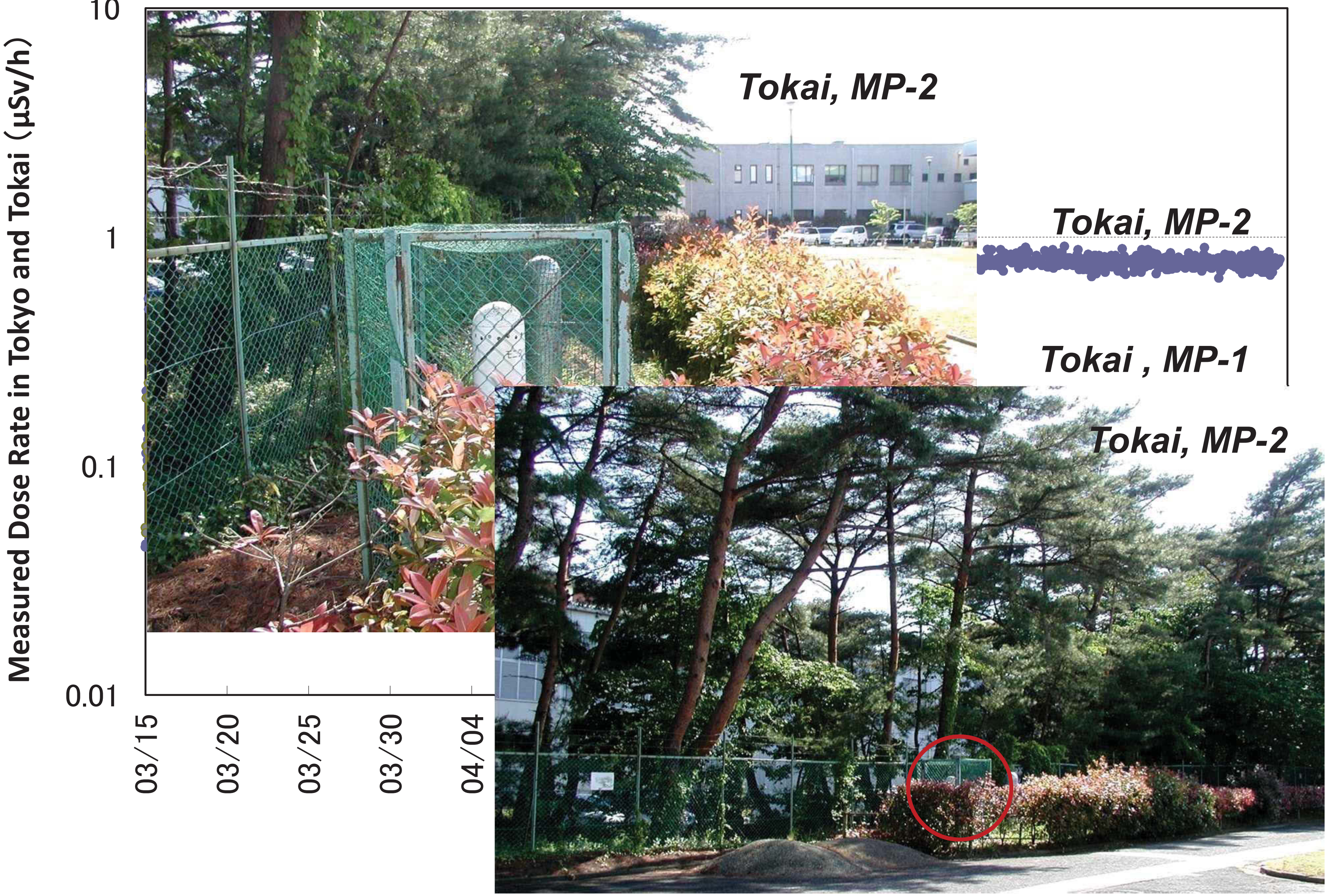


Distance from Fukushima Daiichi NPPs

Ibaraki, Tokai Campus : 110 km

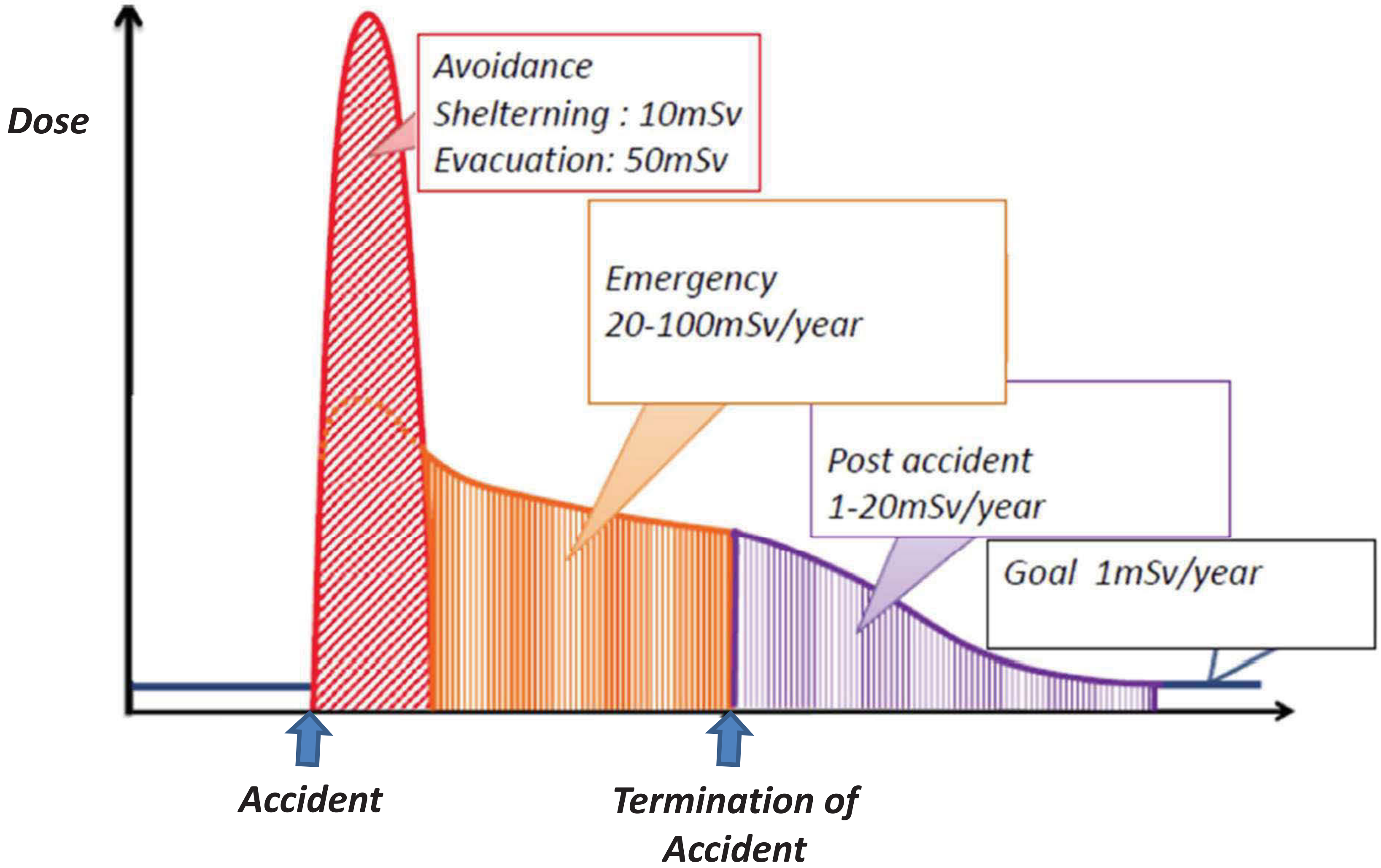
Tokyo, Hongo Campus : 230 km

Radiation Monitoring at The University of Tokyo
From March 15 to May 24

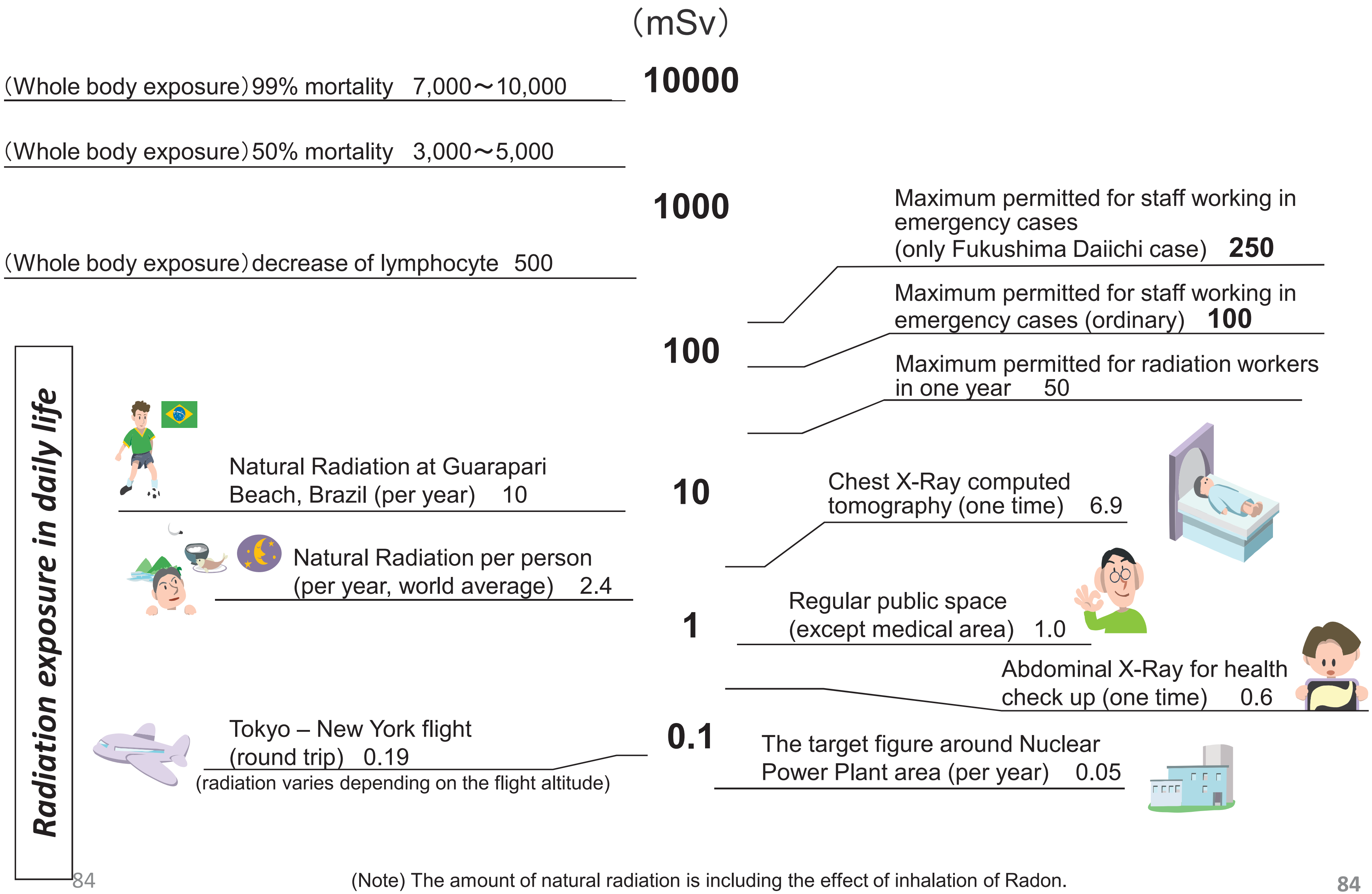


Emergency Dose and Goals to Terminate the Accident

Nuclear Safety Commission on April, 12

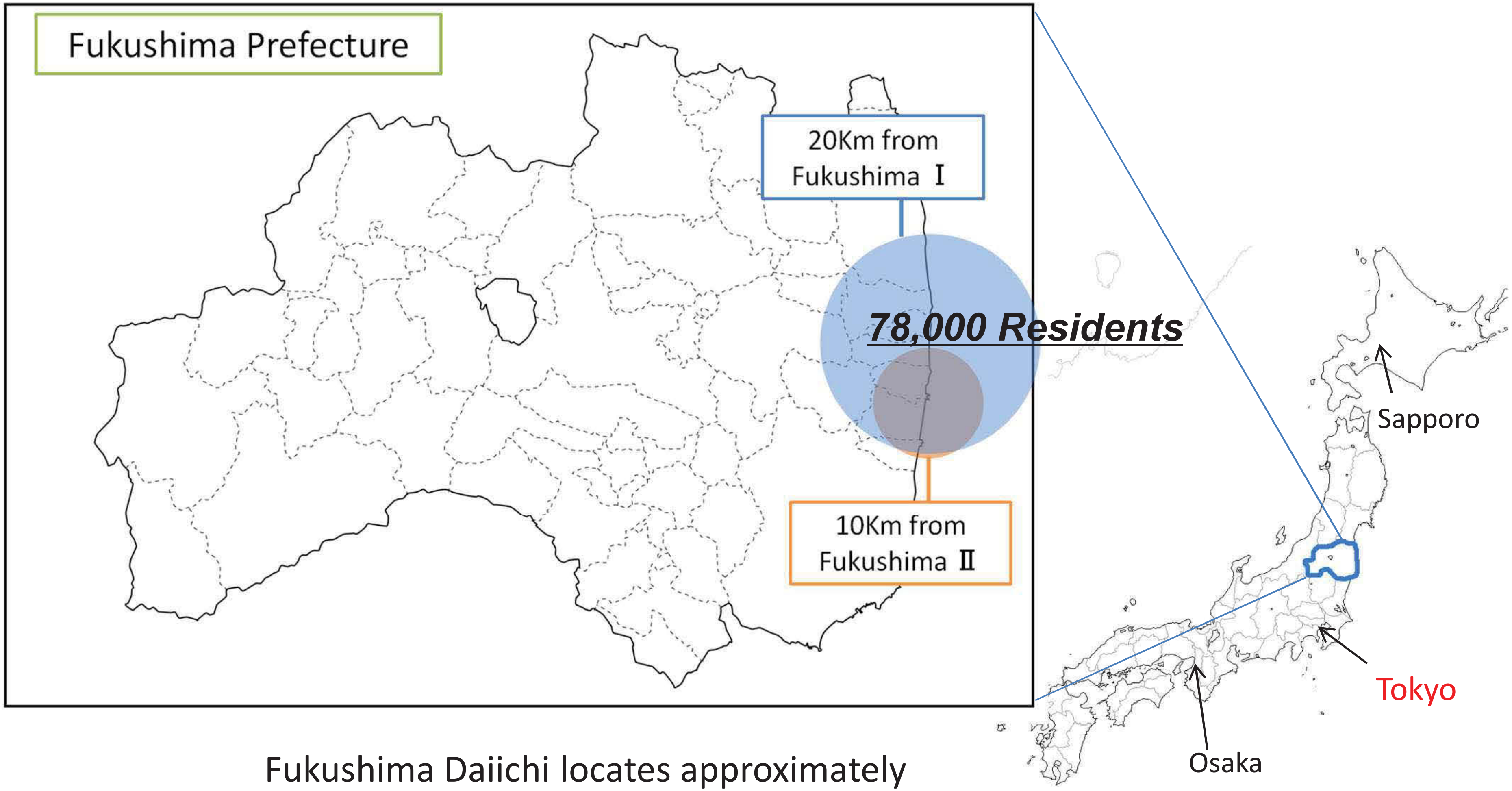


Relationship between Health and Radiation Dose in mSv



(Note) The amount of natural radiation is including the effect of inhalation of Radon.
(source) UNSCEAR 2000 Report, "Sources and Effects of Ionizing Radiation" etc.

Evacuation of Residents



Fukushima Daiichi locates approximately
- 230 km from Tokyo
- 580 km from Osaka
- 600 km from Sapporo

Evacuation of Residents

➤The government took measures such as taking shelters or evacuation as follows based on the reports from Fukushima Daiichi & Daini.

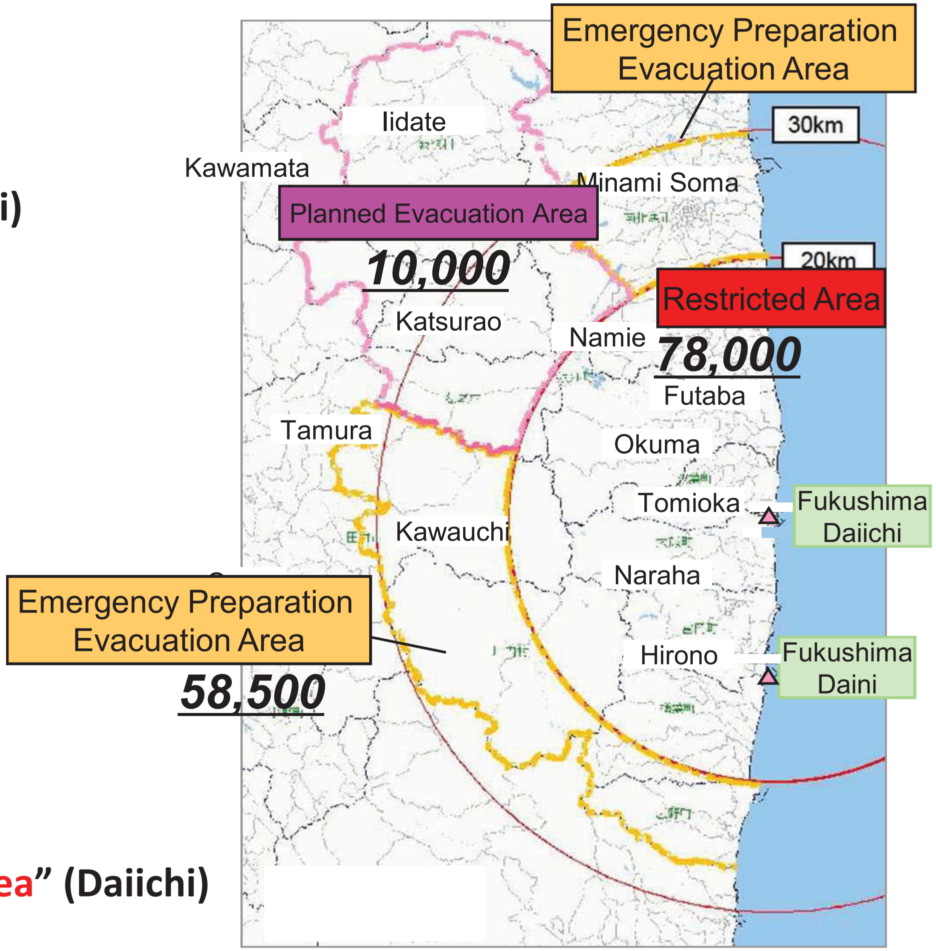
Fri, 11 March
14:46 The Earthquake
19:03 Emergency Declaration by the Gov't (Daiichi)
21:23 3 km radius evacuation (Daiichi)
10 km radius taking shelter (Daiichi)

Sat, 12 March
5:44 10 km radius evacuation (Daiichi)
7:45 3 km radius evacuation (Daini)
10 km radius taking shelter (Daini)
17:39 10 km radius evacuation (Daini)
18:25 20 km radius evacuation (Daiichi)

Tue, 15 March
11:00 20-30 km radius taking shelter (Daiichi)

Thu, 21 April
11:00 20 km radius is designated as "Restricted Area" (Daiichi)

Fri, 22 April
9:44 20-30 km radius taking shelter has been lifted (Daiichi)
Establishment of "Planned Evacuation Area" and "Emergency Preparation Area"



Source: NISA website

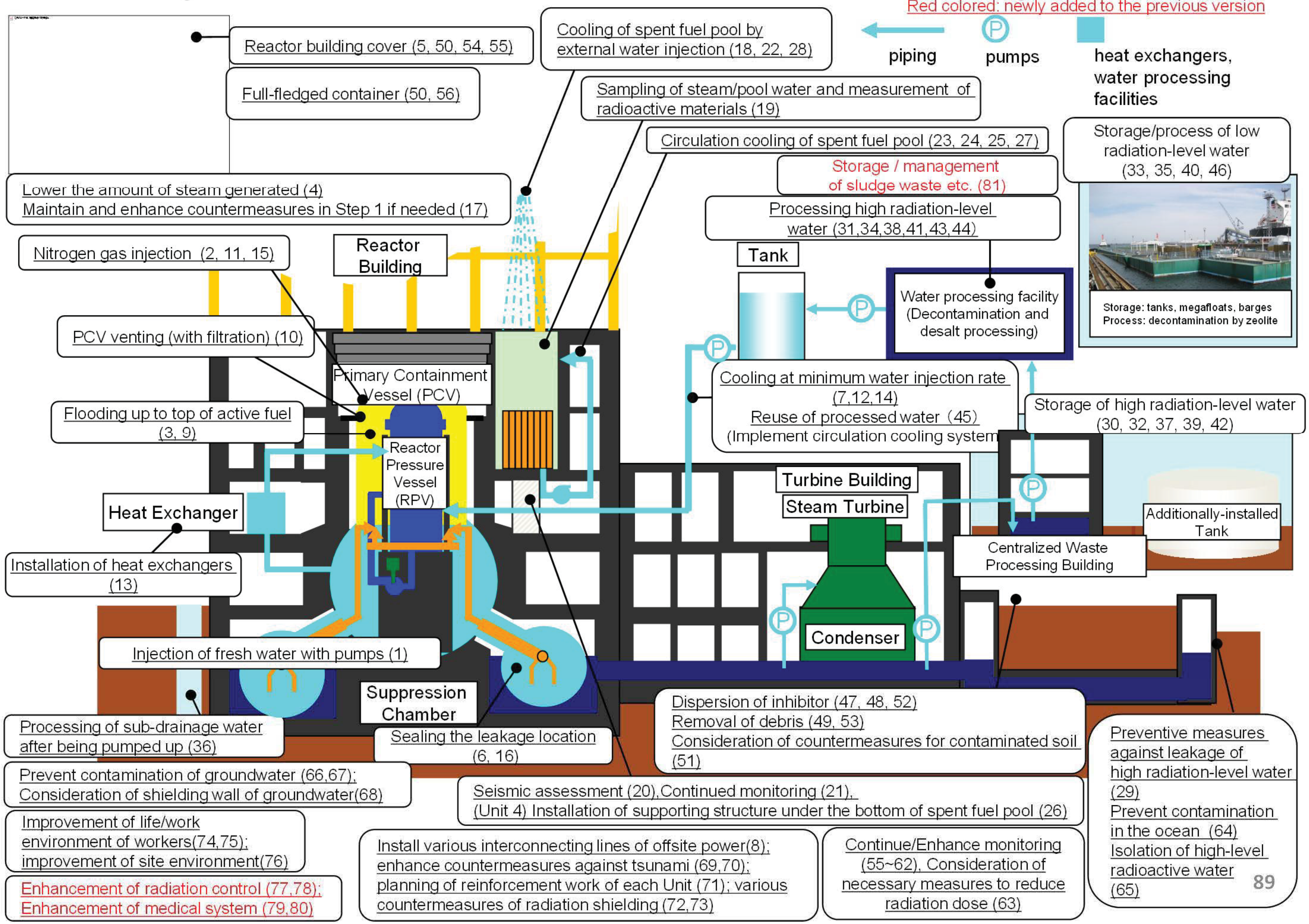
TEPCO's Roadmap on April 17

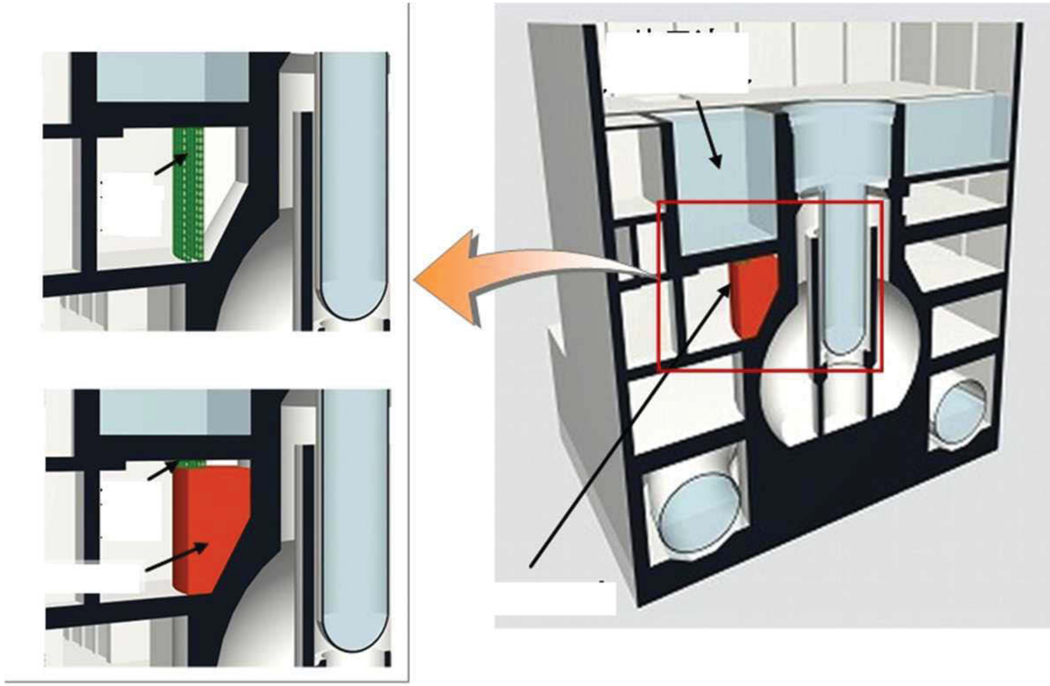
	Step 1 (About 3 Months)	Step 2 (Minimum about 6 to 9 Months)
Target	Steady Reduction of Radiation Dose	Controlling Radiation Release and Significant Reduction of Radiation Dose
Reactors	Stable Cooling (Water Filling over the Fuel)	Achieving the State of Cold Shutdown
Spent Fuel Pools	Stable Cooling	Keeping the Sufficient Water Level for More Stable Cooling (Remote Operation)
Radioactive Contaminated Water	Prevention of Outflow to the out of the Site	Processing and Decreasing the Contaminated Water
Radioactive Contaminated Atmosphere/Soil	Prevention of Spread	Covering Up the Entire Reactor Building

TEPCO's Roadmap on April 17

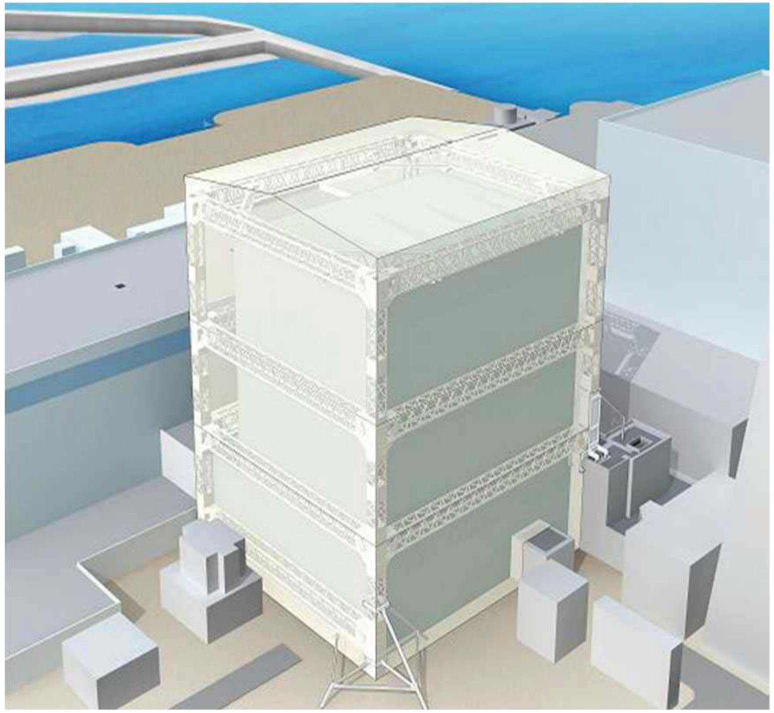
		Current Status	STEP1(3 month)	STEP2(6~9 month)	Mid-term Issues
I. Cooling	(1) Reactors	Injecting fresh water	Nitrogen gas injection Examination and implementation of heat exchange function, etc Stable cooling Flooding up to top of active fuel	Cold shutdown condition	Prevention of breakage of structural materials , etc.
	(2) Spent Fuel Pools	Injecting fresh water	Restore coolant circulation system, etc Stable cooling	Examination and implementation of heat exchange function, etc More stable cooling	Removal of fuels
II. Mitigation	(3) Accumulated Water	Storing water with radiation, etc	Installation of storage / processing facilities, etc Secure storage place	Decontamination / Desalt processing (reuse), etc Decrease contaminated water	Installation of full-fledged water treatment facilities
	(4) Atmosphere / Soil		Dispersion of inhibitor, Installing reactor building cover, etc		Solidification of contaminated soil, etc
III. Monitoring, etc	(5) Measurement, Reduction, etc	Monitoring of radiation	Expand/enhance monitoring, etc	Sufficiently reduce radiation dose in evacuation area	Continue monitoring environmental safety

Major Countermeasures in the Power Station as of June 17

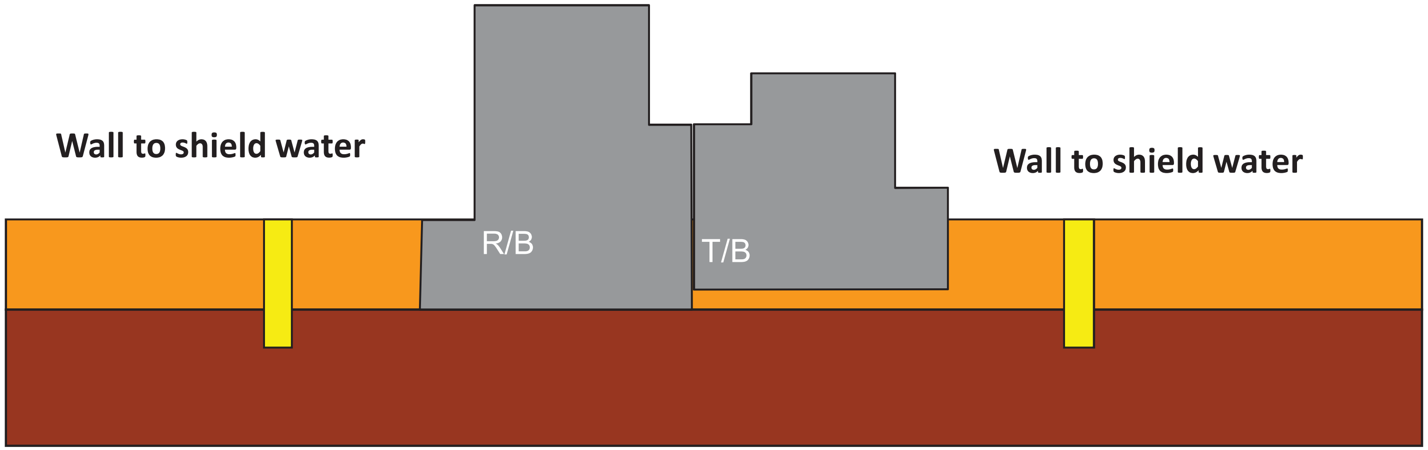




Installing Supporting Structure for SFP in Unit 4
Completed by July 30



Install of Reactor Building Cover for Unit 1

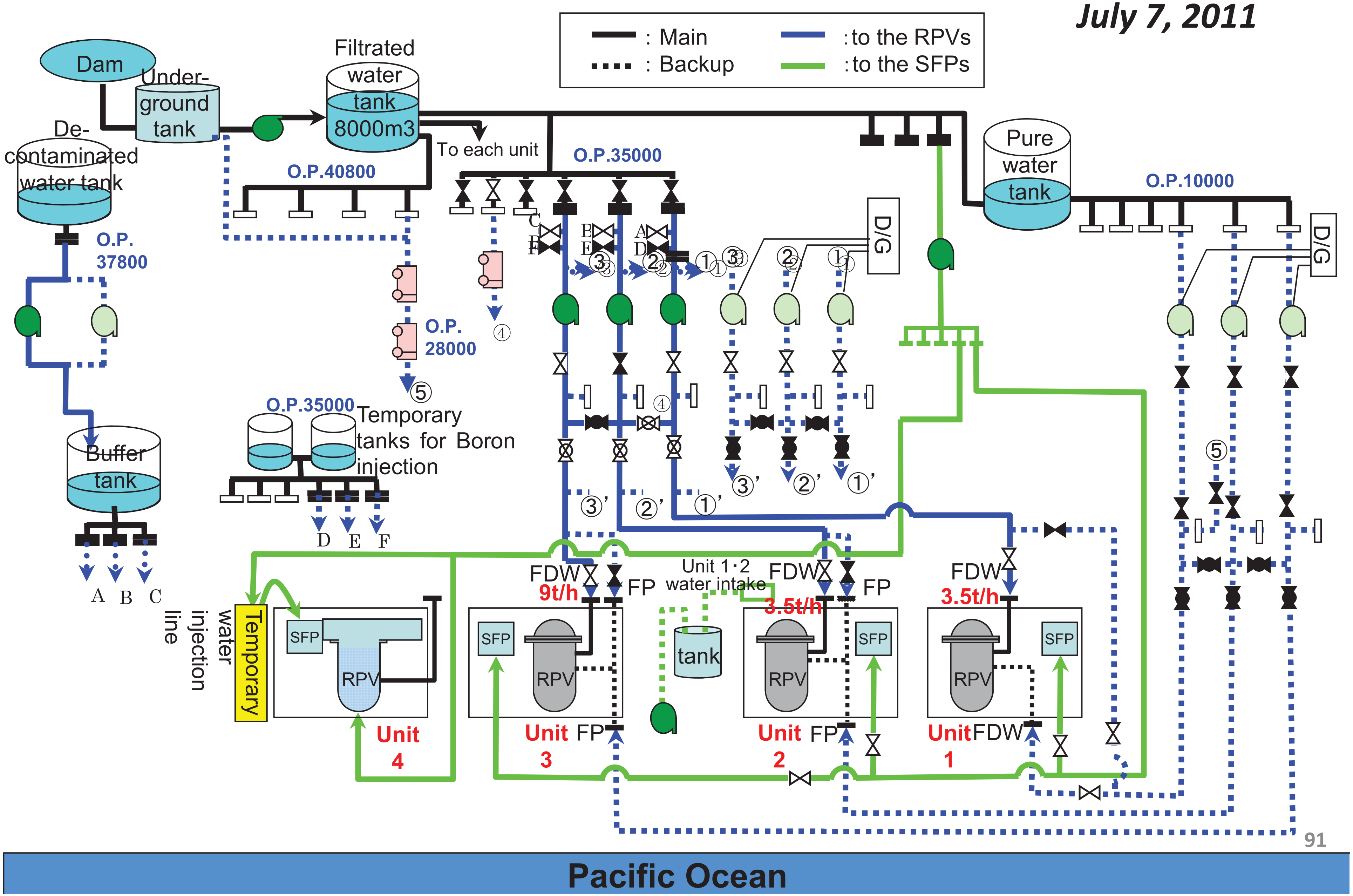


Measure to shield groundwater

Source: TEPCO

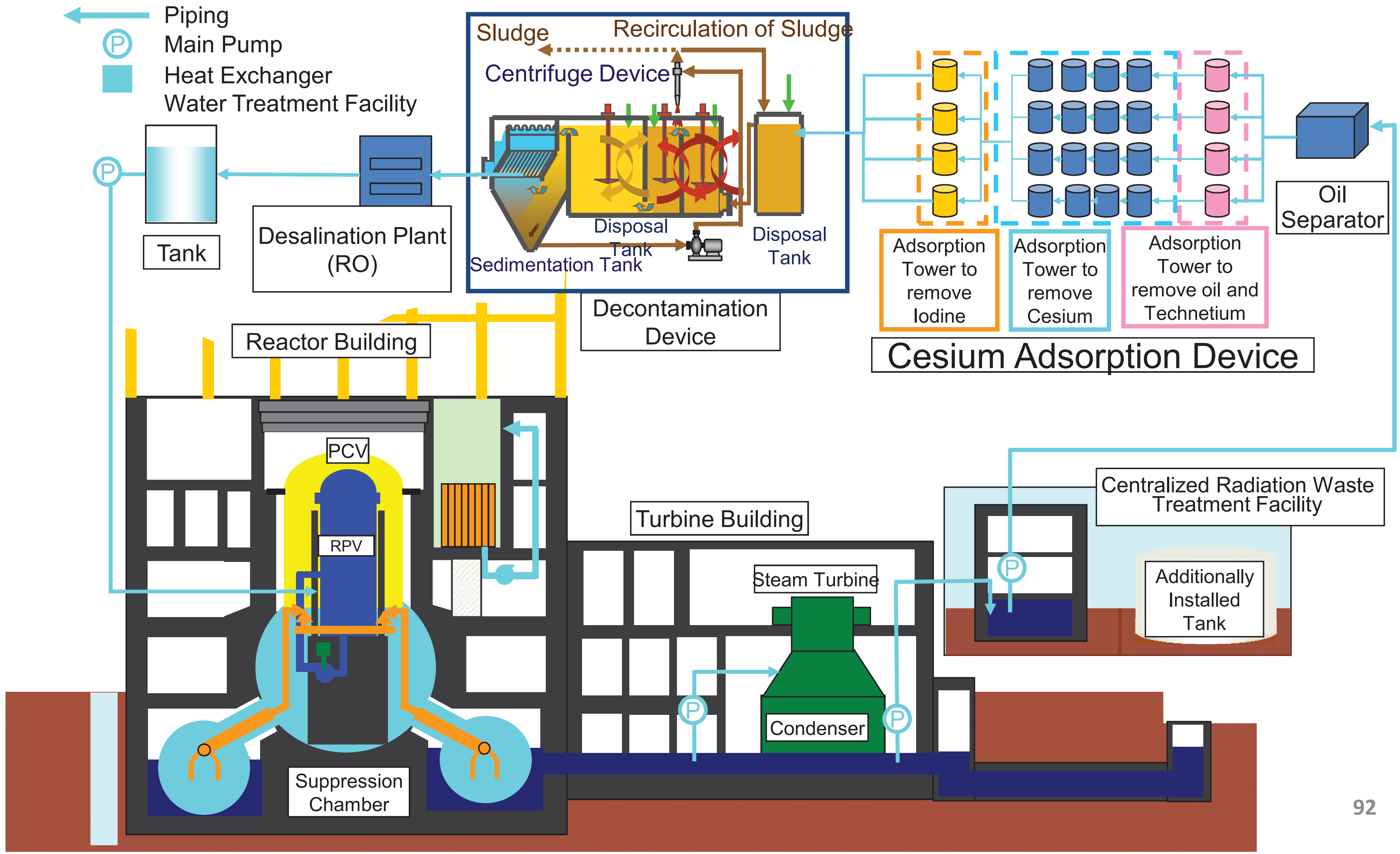
Current Water Supply System for Cooling

July 7, 2011



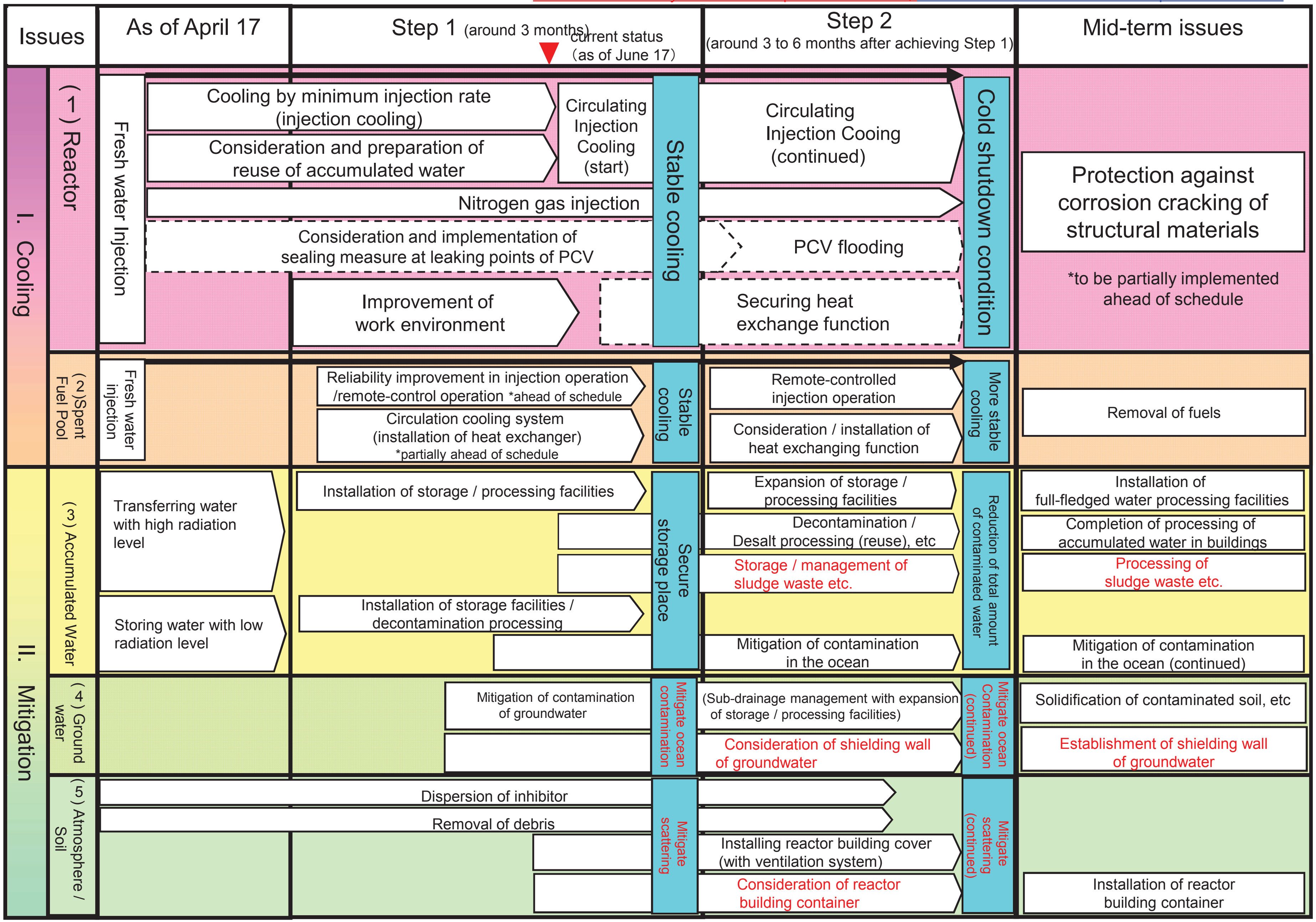
Circulating Water Cooling with the Treatment System for Highly Contaminated Water

Since June 27



Current Status of Roadmap as of June 17

Red colored: newly added to the previous version, Blue colored: modified from the previous version



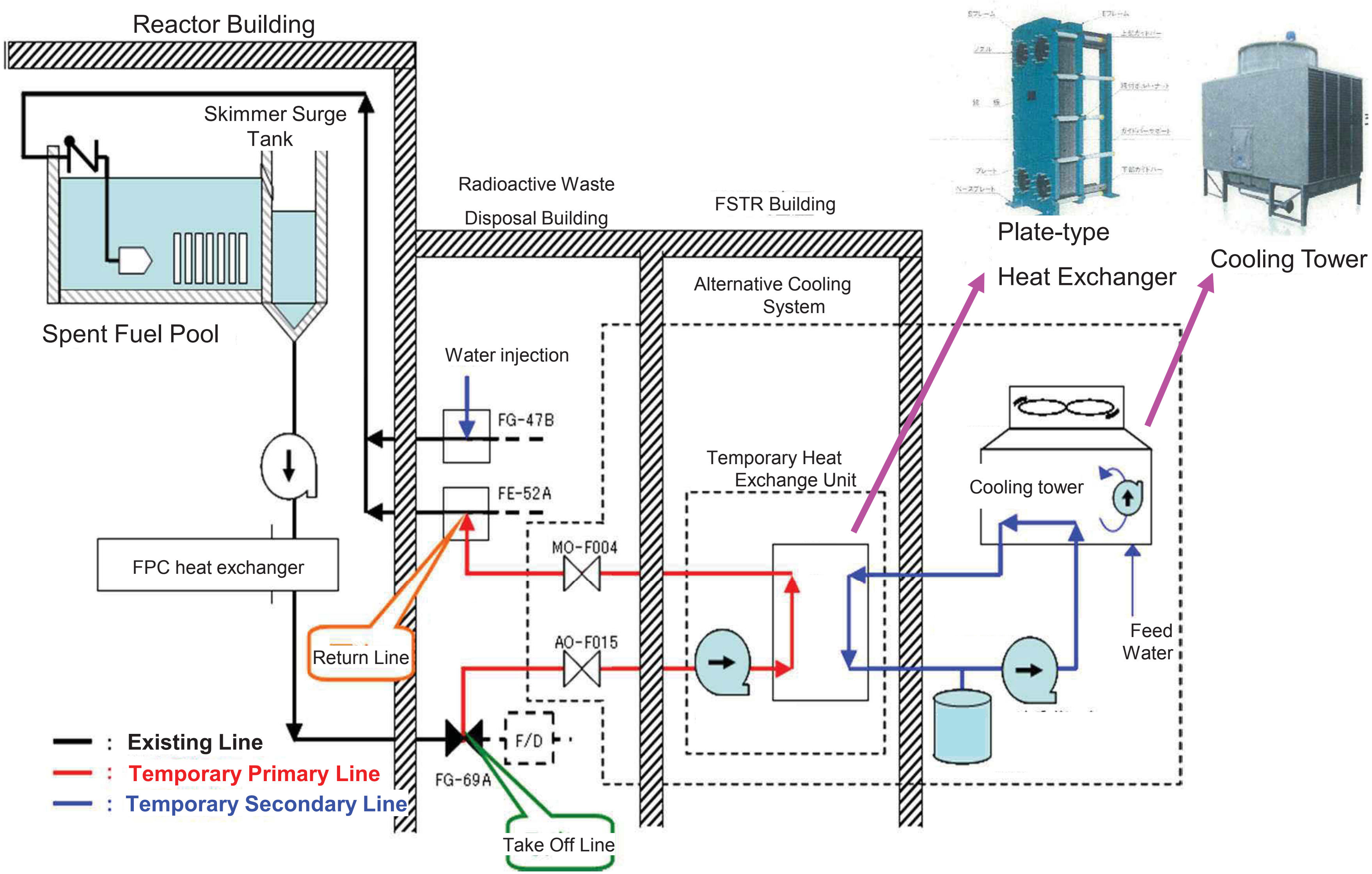
Current Status of Roadmap as of June 17

Red colored: newly added to the previous version, Blue colored: modified from the previous version

Issues		As of April 17	Step 1 (around 3 months) ▼ current status (as of June 17)	Step 2 (around 3 to 6 months after achieving Step 1)	Mid-term issues
III. Monitoring/ Decontamination	(6) Measurement, Reduction and Announcement	Expand/ enhance monitoring of radiation dose in and out of the power station and inform of results fast and accurately		Sufficiently reduce radiation dose in Evacuation Order / Deliberate Evacuation Preparation Area/ Evacuation Preparation Area	Continue monitoring and informing environmental safety
IV. Countermeasures against aftershocks, etc	(7) Tsunami, Reinforcement, etc	Enhancement of countermeasures against aftershocks and tsunami, preparation for various countermeasures for radiation shielding	(Unit 4 spent fuel pool) Installation of supporting structure Mitigate disasters	Consideration / implementation of reinforcement work of each Unit Mitigate disasters (continued)	Reinforcement work of each Unit
V. Environment improvement	(8) Life/work environment		Improvement of workers' life / work environment Enhancement of environment improvement	Enhancement of environment Improvement (continued)	Improvement of workers' life / work environment (continued)
	(9) Radiation control / Medical care		Enhancement of Healthcare	Improvement of radiation control / medical system Enhancement of Healthcare (continued)	Improvement of radiation control / medical system (continued)

Installation of Heat Exchangers for Spent Fuel Pools

➢ In Unit 3, temporary heat exchanger and cooling tower have been installed after Unit 2, and began circulating cooling of SFP, securing stable cooling from July 1st. Similar measures will be taken for Units 1 and 4 accordingly.



To Prevent Diffusion of Radioactive Materials

- Sprayed dust inhibitor agents to reduce spreading of powder dust containing radioactive materials on the ground. (Have been spraying intermittently since April 1st. Have been spraying at full-scale since April 26 Have been spraying on the buildings since May 27).
- Took following measures in order to prevent radioactive contaminated water from running off into the sea.
  - ✓ Injected coagulants from the holes near the shaft and confirmed the outflow stopped. (at 5:38 am, April 6)
  - ✓ Installed a rubber plate and jig to enhance water sealing.
  - ✓ Installed large sandbags and silt fences around the breakwater at the site.
  - ✓ Installed circulation type seawater purification system at screen area

Coagulant injection to stop outflow

Circulation type seawater purification system installation

Spraying dust inhibitor agents to the buildings and site

Silt fence installation

Introduction of Remote Controlling Machine and Robots

Outdoor debris removal
(May 6)

Opening an air lock
(April 18)

Name	Packbot	Talon
Appearance		
Operation	Surveys indoors or outdoors	Surveys indoors or outdoors

Name	Backhoe	Crawler Dump	Bobcat	Brokk90
Appearance				
Work	Outdoor debris removal	Moving debris	Outdoor debris removal	Outdoor or indoor debris removal

Radiation Control for Workers

Radiation Dose from External and Internal Exposure for Workers in Fukushima Daiichi Nuclear Power Station

3,695 Workers (working from March) and 3,388 Workers (from April) * have been inspected by July 29, 2011

Radiation Dose (External + Internal)	: Number of Workers
100mSv～150mSv	: 86
150mSv～200mSv	: 14
200mSv～250mSv	: 2
250mSv～	: 6 (309mSv～ 678mSv)

Measures to control dose

- **Information sharing** : Each group of emergency response organization share the information that they have with each other and confirm judgments or directions from several points of view.
- **Logistic enhancement** : Deploy necessary materials such as masks or potassium iodine so that workers can use immediately in case abnormal status of nuclear plants are predicted.
- **Eating restriction** : Establish eating/resting time and location. Eating shall be prohibited not only in main control rooms of Units 1~4 in Fukushima Daiichi but also in statutory radiation controlled area (per surface contamination and radioactive density in the air), etc.

* out of total workers 3,747(from March) + 3,776 (from April)

Improvement of Working Environment

- Setting up of rest stations for workers in each area as well as implementing countermeasures to prevent heat stroke during the summer such as installing water coolers and providing use of "cooling vests".
- Improving the living environment of Fukushima Daini gymnasium, where the workers are residing.
- We will continuously make every effort to improve the living/working environment.

Inside the rest place in former Emergency Response Room

Bunk beds in gymnasium at Fukushima Daini

Refrigerant for neck (water cooling type)

Drinking water at rest place in former Emergency Response Room

Shower room in gymnasium at Fukushima Daini

Refrigerant for neck (freezing type)

Conclusion : Preliminary Lessons Learned

The importance of <u>Defense in Depth</u> has been recognized with this accident

(1) Appropriate DBAs

Appropriate consideration for natural hazards by design
<u>- Design basis tsunami height 5.7m against 15m of actual tsunami height</u>

(2) Robustness and diversity in responding to beyond DBAs such as station black-out for long-duration, loss of ultimate heat sink

① Appropriate design philosophy to sustain safety function against common cause failures brought by natural hazards

- ***<u>All the emergency DGs, except 1 air-cooled DG, were water-cooled and all were located in the basement of T/Bs</u>***
- ***<u>All the sea-water pumps were located slightly above the design tsunami height and they were with no protection against water</u>*.**

② Appropriate AM measures for both prevention and mitigation of SAs

- ***<u>No AMs for SFP cooling and Hydrogen gas control in the R/Bs</u>***
- ***<u>No AMs training under severe conditions for multi-units under continuous aftershocks</u>***

Conclusion : Preliminary Lessons Learned

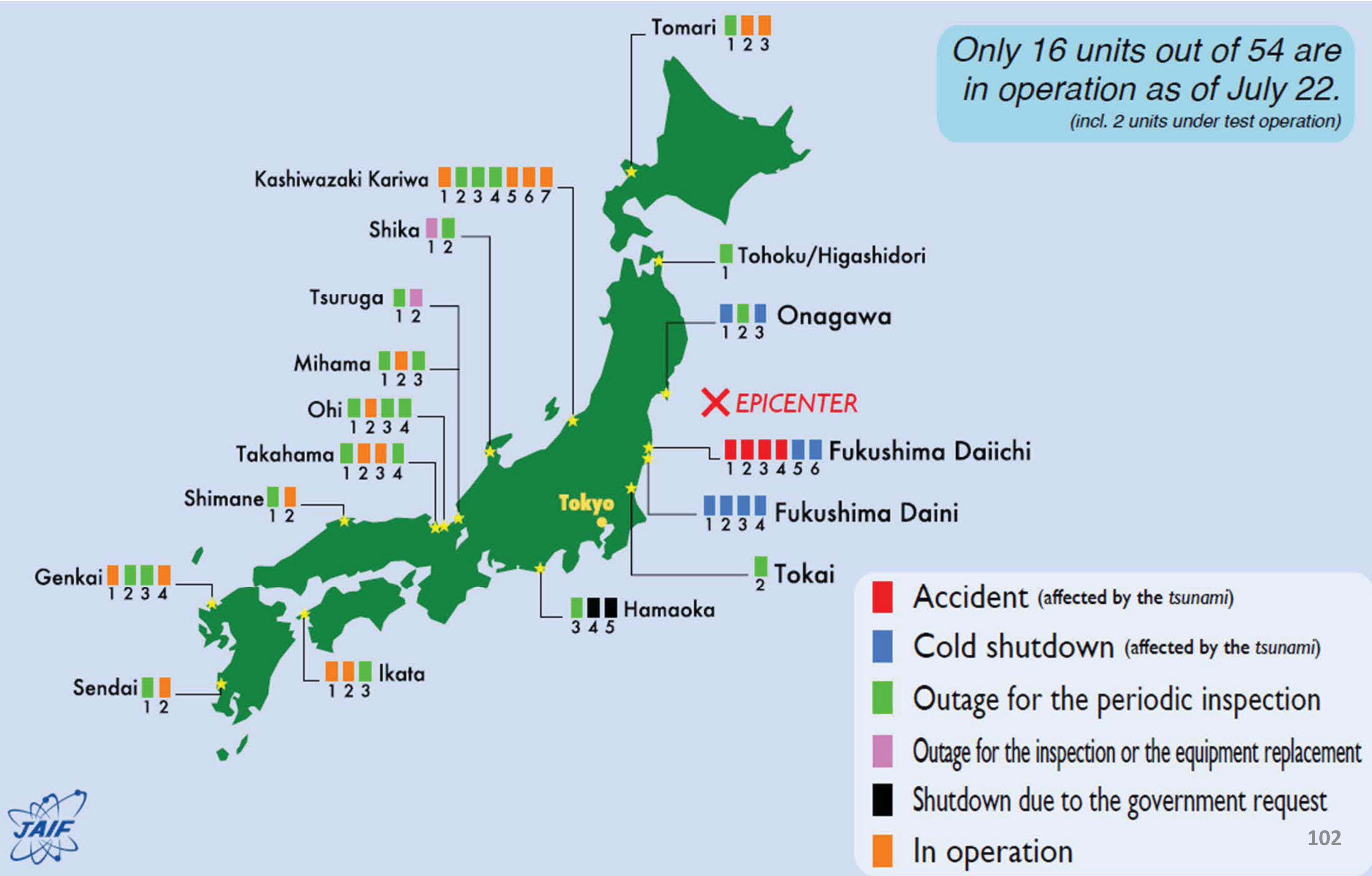
(3) Difficult situations for post severe accident recovery

- ***Warning for aftershocks and subsequent Tsunami***
- ***High radiation in the working area***
- ***Massive radioactive debris within the site***

(4) Emergency Preparedness and responses

- ***Evacuation zones***
- ***Function of off-site center***
- ***Communication***
- ***Radiation monitoring***

Status of Nuclear Power Plants in Japan



IAEA Expert Mission To Japan

- IAEA expert mission visited Japan from May 24th to June 1st, 2011 for a preliminary investigation of the nuclear accident.

Mission Report—Preliminary Summary (Excerpt)

- The Japanese Government, nuclear regulators and operators have been extremely open in sharing information and answering the many questions of the mission to assist the world in learning lessons to improve nuclear safety.
- The response on the site by dedicated, determined and expert staff, under extremely arduous conditions has been exemplary and resulted in the best approach to securing safety given the exceptional circumstances.
- The Japanese Government's longer term response to protect the public, including evacuation, has been impressive and extremely well organized. A suitable and timely follow-up programme on public and worker exposures and health monitoring would be beneficial.

Source：NISA web site

IAEA
Original English

For Further Reading and Discussion

IAEA
International Atomic Energy Agency

MISSION REPORT

THE GREAT EAST JAPAN EARTHQUAKE EXPERT MISSION

IAEA INTERNATIONAL FACT FINDING EXPERT MISSION OF THE FUKUSHIMA DAI-ICHI NPP ACCIDENT FOLLOWING THE GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

Tokyo, Fukushima Dai-ichi NPP, Fukushima Dai-ni NPP and Tokai Dai-ni NPP, Japan

24 May – 2 June 2011

The IAEA Mission urges the international nuclear community to consider the following 15 conclusions and 16 lessons in order to take advantage of the unique opportunity created by the Fukushima accident to seek to learn and improve worldwide nuclear safety.

- **Conclusion 1: The IAEA Fundamental Safety Principles provide a robust basis in relation to the circumstances of the Fukushima accident and cover all the areas of lessons learned from the accident.**

- **Conclusion 2: Given the extreme circumstances of this accident, the local management of the accident has been conducted in the best way possible and following Fundamental Principle 3.**

- **Conclusion 3: There were insufficient defense-in-depth provisions for tsunami hazards. In particular:**
  - **although tsunami hazards were considered both in the site evaluation and the design of the Fukushima Dai-ichi NPP as described during the meetings and the expected tsunami height was increased to 5.7 m (without changing the licensing documents) after 2002, the tsunami hazard was underestimated;**
  - **thus, considering that in reality a 'dry site' was not provided for these operating NPPs, the additional protective measures taken as result of the evaluation conducted after 2002 were not sufficient to cope with the high tsunami run up values and all associated hazardous phenomena (hydrodynamic forces and dynamic impact of large debris with high energy);**
  - **moreover, those additional protective measures were not reviewed and approved by the regulatory authority;**
  - **because failures of structures, systems and components (SSCs) when subjected to floods are generally not incremental, the plants were not able to withstand the consequences of tsunami heights greater than those estimated leading to cliff edge effects; and**
  - **severe accident management provisions were not adequate to cope with multiple plant failures.**

- Conclusion 4: For the Tokai Dai-ni and Fukushima Dai-ni NPPs, in the short term, the safety of the plant should be evaluated and secured for the present state of the plant and site (caused by the earthquake and tsunami) and the changed hazard environment.
- In particular, if an external event Probabilistic Safety Assessment (PSA) model is already available, this would be an effective tool in performing the assessment.
- Short term immediate measures at Fukushima Dai-ichi NPP need to be planned and implemented for the present state of the plant before a stable safe state of all the units is reached. Until that time the high priority measures against external hazards need to be identified using simple methods in order to have a timely plan.
- As preventive measures will be important but limited, both on-site and off-site mitigation measures need to be included in the plan. Once a stable safe state is achieved a long term plan needs to be prepared that may include physical improvements to SSCs as well as on-site and off-site emergency measures.

- Conclusion 5: An updating of regulatory requirements and guidelines should be performed reflecting the experience and data obtained during the Great East Japan Earthquake and Tsunami, fulfilling the requirements and using also the criteria and methods recommended by the relevant IAEA Safety Standards for comprehensively coping with earthquakes and tsunamis and external flooding and, in general, all correlated external events. The national regulatory documents need to include database requirements compatible with those required by IAEA Safety Standards.
- The methods for hazard estimation and the protection of the plant need to be compatible with advances in research and development in related fields.

- Conclusion 6: Japan has a well organized emergency preparedness and response system as demonstrated by the handling of the Fukushima accident.
- Nevertheless, complicated structures and organizations can result in delays in urgent decision making.

- Conclusion 7: Dedicated and devoted officials and workers, and a well organized and flexible system made it possible to reach an effective response even in unexpected situations and prevented a larger impact of the accident on the health of the general public and facility workers.

- Conclusion 8: A suitable follow up programme on public exposures and health monitoring would be beneficial.

- Conclusion 9: There appears to have been effective control of radiation exposures on the affected sites despite the severe disruption by the events.

- Conclusion 10: The IAEA Safety Requirements and Guides should be reviewed to ensure that the particular requirements in design and severe accident management for multi-plant sites are adequately covered.

- Conclusion 11: There is a need to consider the periodic alignment of national regulations and guidance to internationally established standards and guidance for inclusion in particular of new lessons learned from global experiences of the impact of external hazards.

- **Conclusion 12: The Safety Review Services available with the IAEA's International Seismic Safety Centre (ISSC) would be useful in assisting Japan's development in the following areas:**
  - **External event hazard assessment;**
  - **Walkdowns for plants that will start up following a shutdown; and**
  - **Pre-earthquake preparedness.**

- **Conclusion 13: A follow-up mission including Emergency Preparedness Review (EPREV) should look in detail at lessons to be learned from the emergency response on and off the site.**

- **Conclusion 14: A follow-up mission should be conducted to seek lessons from the effective approach used to provide large scale radiation protection in response to the Fukushima accident.**

- **Conclusion 15: A follow-up mission to the 2007 Integrated Regulatory Review Service (IRRS) should be conducted in light of the lessons to be learned from the Fukushima accident and the above conclusions to assist in any further development of the Japanese nuclear regulatory system.**

Lessons in the IAEA Expert Mission Report

- **Lesson 1: There is a need to ensure that in considering external natural hazards:**
  - **the siting and design of nuclear plants should include sufficient protection against infrequent and complex combinations of external events and these should be considered in the plant safety analysis – specifically those that can cause site flooding and which may have longer term impacts;**
  - **plant layout should be based on maintaining a 'dry site concept', where practicable, as a defence-in-depth measure against site flooding as well as physical separation and diversity of critical safety systems;**
  - **common cause failure should be particularly considered for multiple unit sites and multiple sites, and for independent unit recovery options, utilizing all on-site resources should be provided;**
  - **any changes in external hazards or understanding of them should be periodically reviewed for their impact on the current plant configuration; and**
  - **an active tsunami warning system should be established with the provision for immediate operator action.**

- **Lesson 2: For severe situations, such as total loss of off-site power or loss of all heat sinks or the engineering safety systems, simple alternative sources for these functions including any necessary equipment (such as mobile power, compressed air and water supplies) should be provided for severe accident management.**

- **Lesson 3: Such provisions as are identified in Lesson 2 should be located at a safe place and the plant operators should be trained to use them. This may involve centralized stores and means to rapidly transfer them to the affected site(s).**

- **Lesson 4: Nuclear sites should have adequate on-site seismically robust, suitably shielded, ventilated and well equipped buildings to house the Emergency Response Centres, with similar capabilities to those provided at Fukushima Dai-ni and Dai-ichi, which are also secure against other external hazards such as flooding. They will require sufficient provisions and must be sized to maintain the welfare and radiological protection of workers needed to manage the accident.**

- **Lesson 5: Emergency Response Centres should have available as far as practicable essential safety related parameters based on hardened instrumentation and lines such as coolant levels, containment status, pressure, etc., and have sufficient secure communication lines to control rooms and other places on-site and off-site.**

- **Lesson 6: Severe Accident Management Guidelines and associated procedures should take account of the potential unavailability of instruments, lighting, power and abnormal conditions including plant state and high radiation fields.**

- **Lesson 7: External events have a potential of affecting several plants and several units at the plants at the same time. This requires a sufficiently large resource in terms of trained experienced people, equipment, supplies and external support. An adequate pool of experienced personnel who can deal with each type of unit and can be called upon to support the affected sites should be ensured.**

- **Lesson 8: The risk and implications of hydrogen explosions should be revisited and necessary mitigating systems should be implemented.**

- **Lesson 9: Particularly in relation to preventing loss of safety functionality, the robustness of defence-in-depth against common cause failure should be based on providing adequate diversity (as well as redundancy and physical separation) for essential safety functions.**

- <u>Lesson 10</u>: **Greater consideration should be given to providing hardened systems, communications and sources of monitoring equipment for providing essential information for on-site and off-site responses, especially for severe accidents.**

- <u>Lesson 11</u>: **The use of IAEA Safety Requirements (such as GS-R-2) and related guides on threat categorization, event classification and countermeasures, as well as Operational Intervention Levels, could make the off-site emergency preparedness and response even more effective in particular circumstances.**

- <u>Lesson 12</u>: **The use of long term sheltering is not an effective approach and has been abandoned and concepts of 'deliberate evacuation' and 'evacuation-prepared area' were introduced for effective long term countermeasures using guidelines of the ICRP and IAEA.**

- <u>Lessons 13</u>: **The international nuclear community should take advantage of the data and information generated from the Fukushima accident to improve and refine the existing methods and models to determine the source term involved in a nuclear accident and refine emergency planning arrangements.**

- <u>Lesson 14</u>: **Large scale radiation protection for workers on sites under severe accident conditions can be effective if appropriately organized and with well led and suitable trained staff.**

- <u>Lesson 15</u>: **Exercises and drills for on-site workers and external responders in order to establish effective on-site radiological protection in severe accident conditions would benefit from taking account of the experiences at Fukushima.**

- <u>Lesson 16</u>: **Nuclear regulatory systems should ensure that regulatory independence and clarity of roles are preserved in all circumstances in line with IAEA Safety Standards.**