東京大学
THE UNIVERSITY OF TOKYO

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2nd International Workshop on
Radiation Effects in Nuclear Technology

Overview of the Accident in Fukushima Daiichi Nuclear Power Plant

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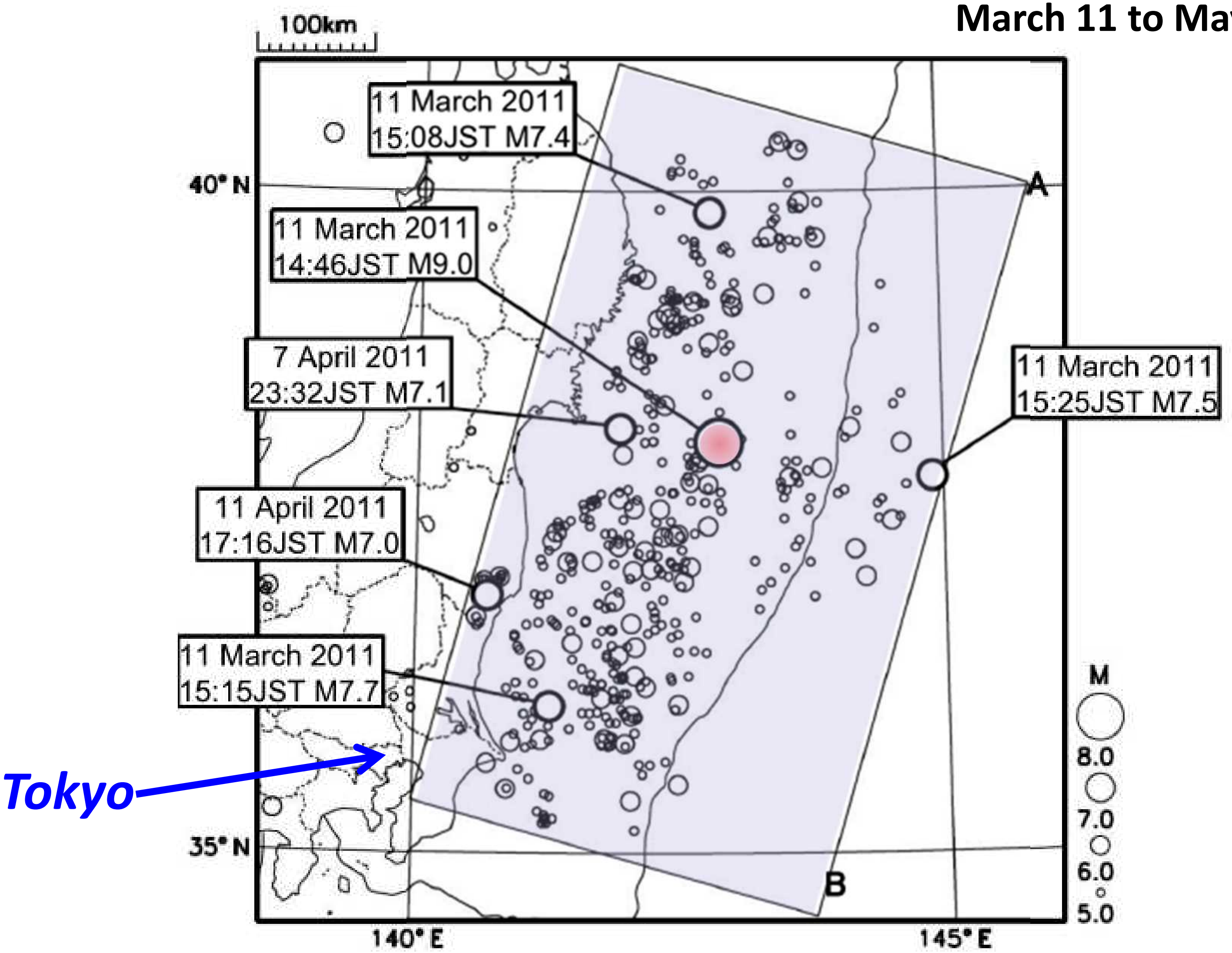
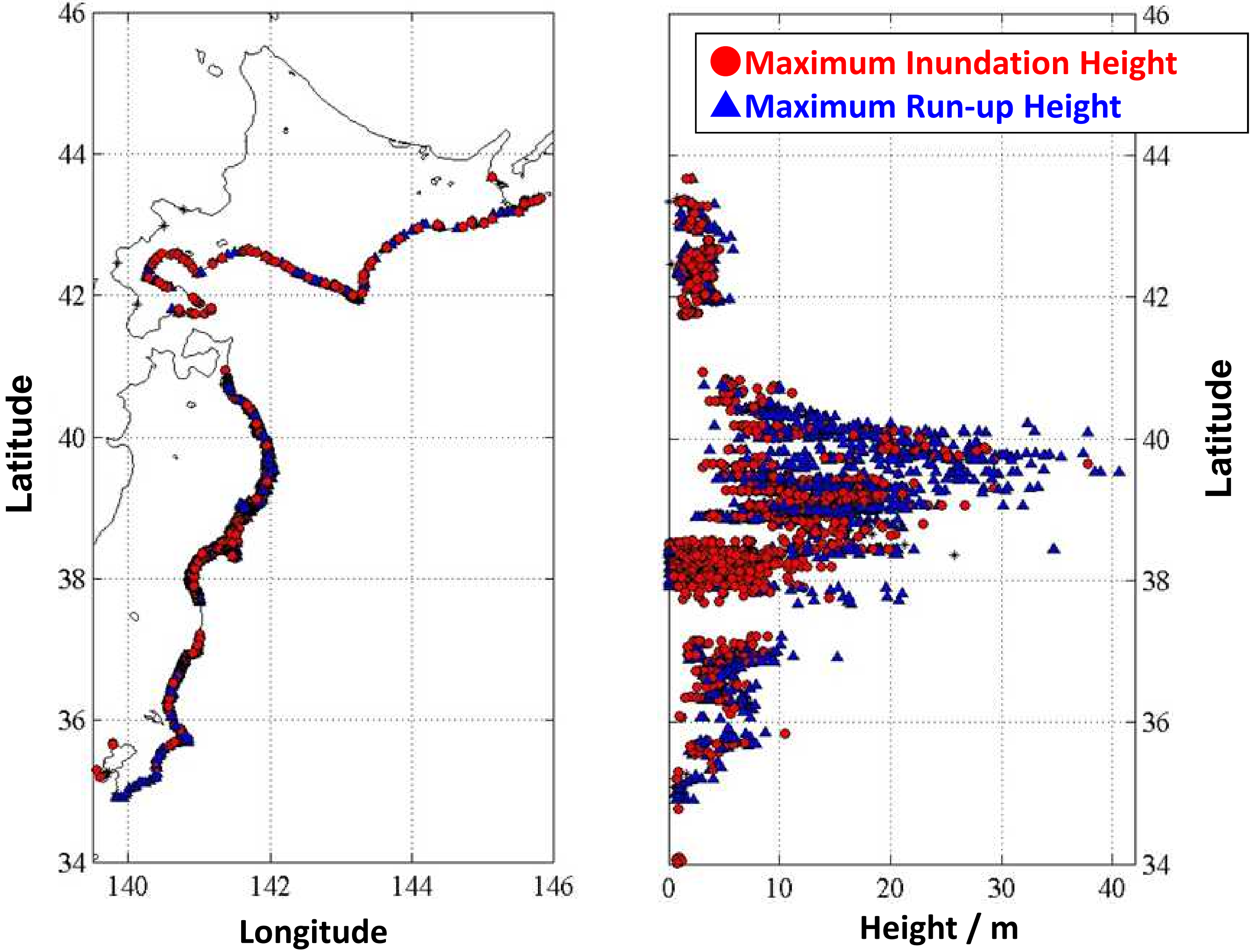
The Main Shock and Aftershock
of the Earthquake on March 11, 2011

March 11 to May 13, 2011



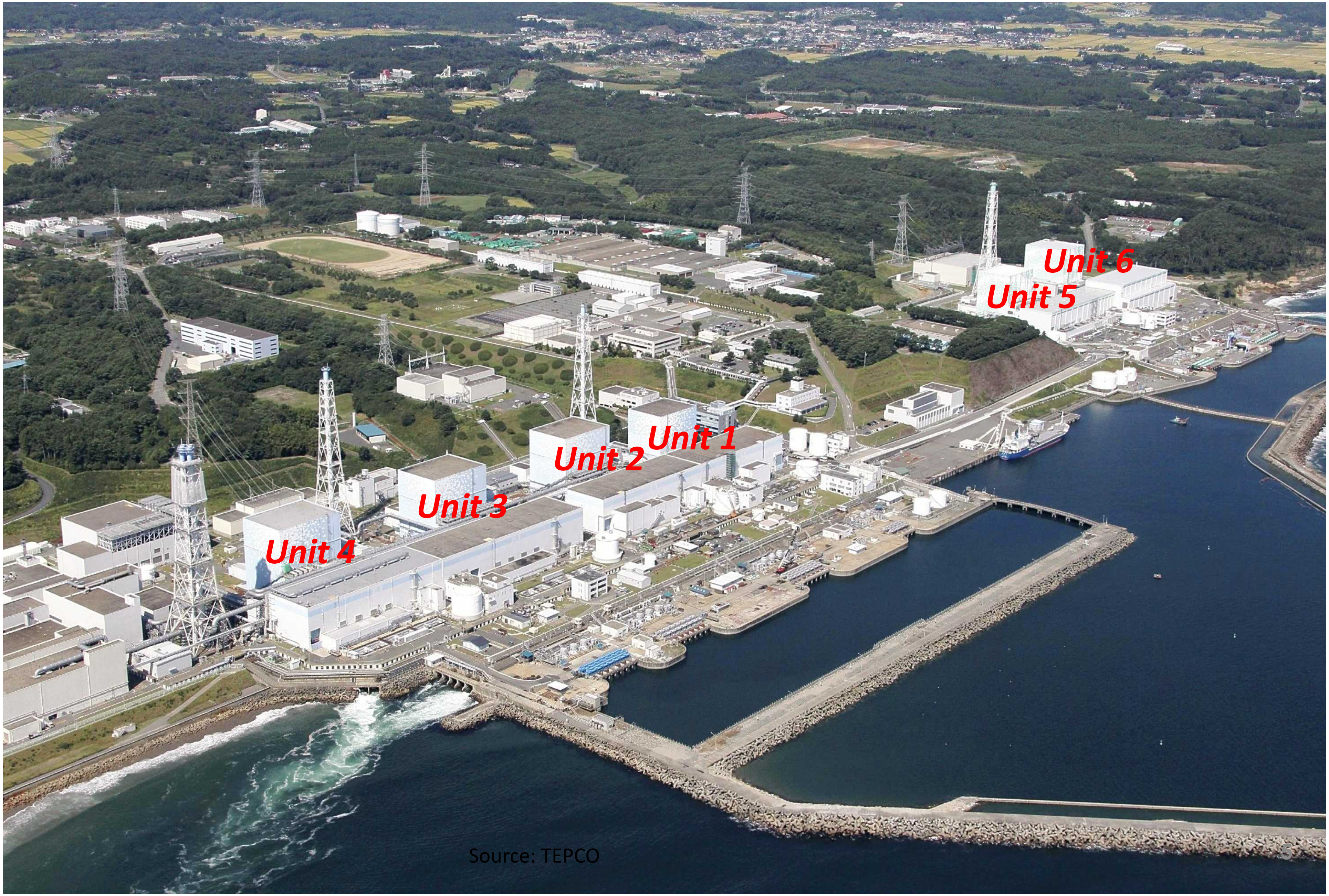
Earthquake Research Institute, The University of Tokyo

Tsunami after the Earthquake on March 11, 2011

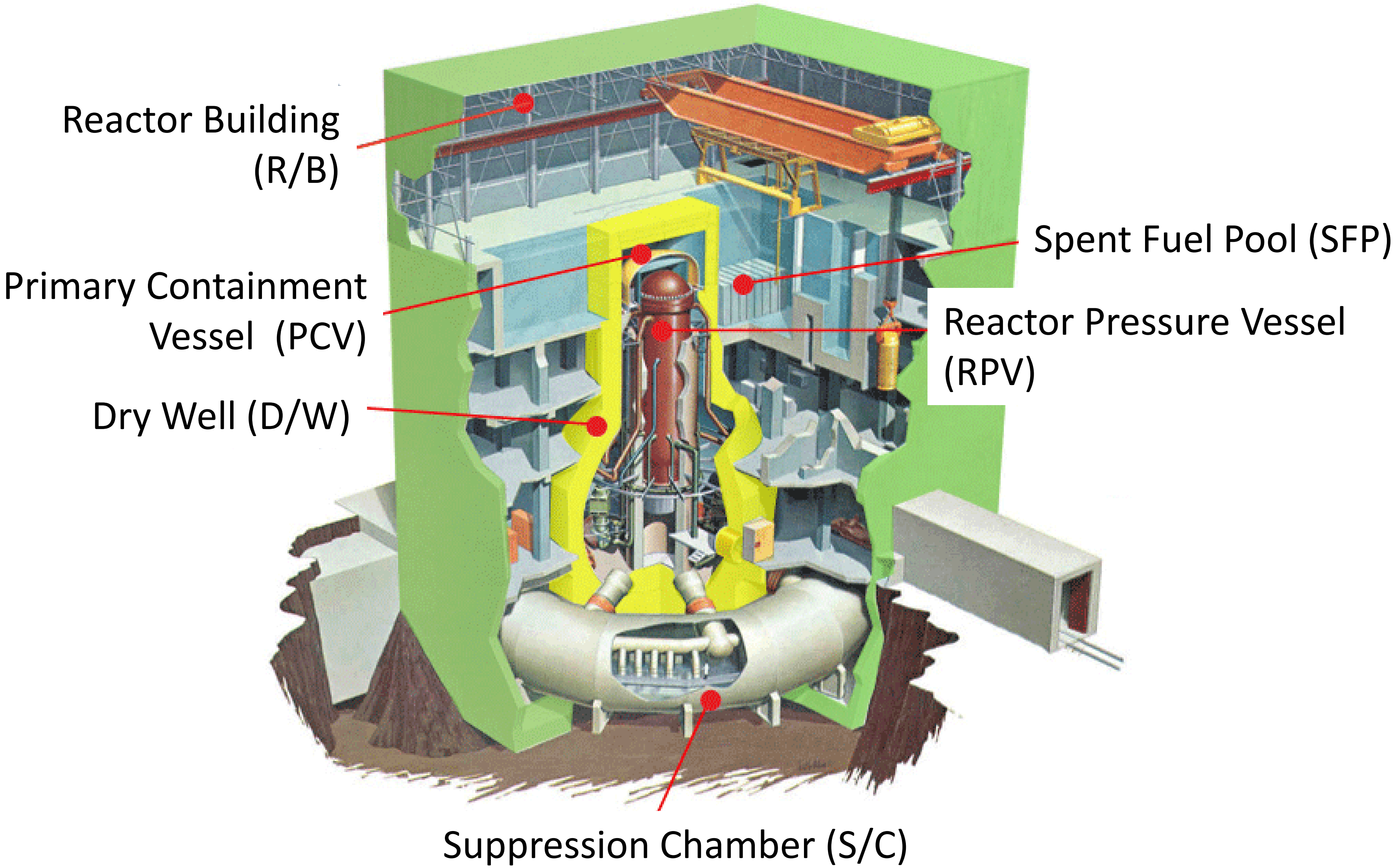


Compiled by 80 members from 33 organization including The University of Tokyo
http://www.coastal.jp/ttjt/

Fukushima Daiichi Nuclear Power Plants operated by TEPCO



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



Summary of Fukushima Daiichi Nuclear Power Plants

	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

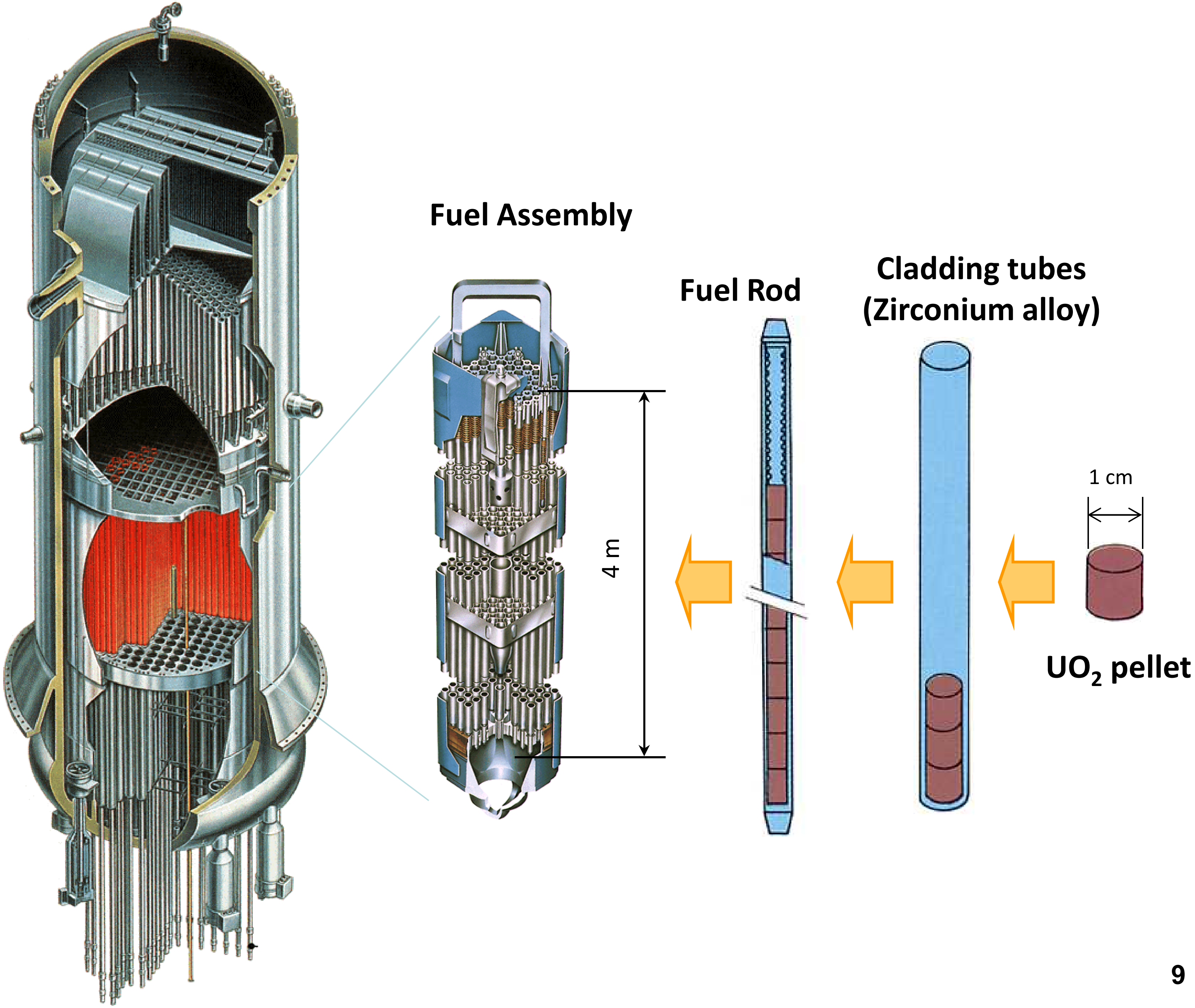
* Typical operating pressure of PCV is about 5 kPa.

** One Emergency DG is Air-Cooled

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

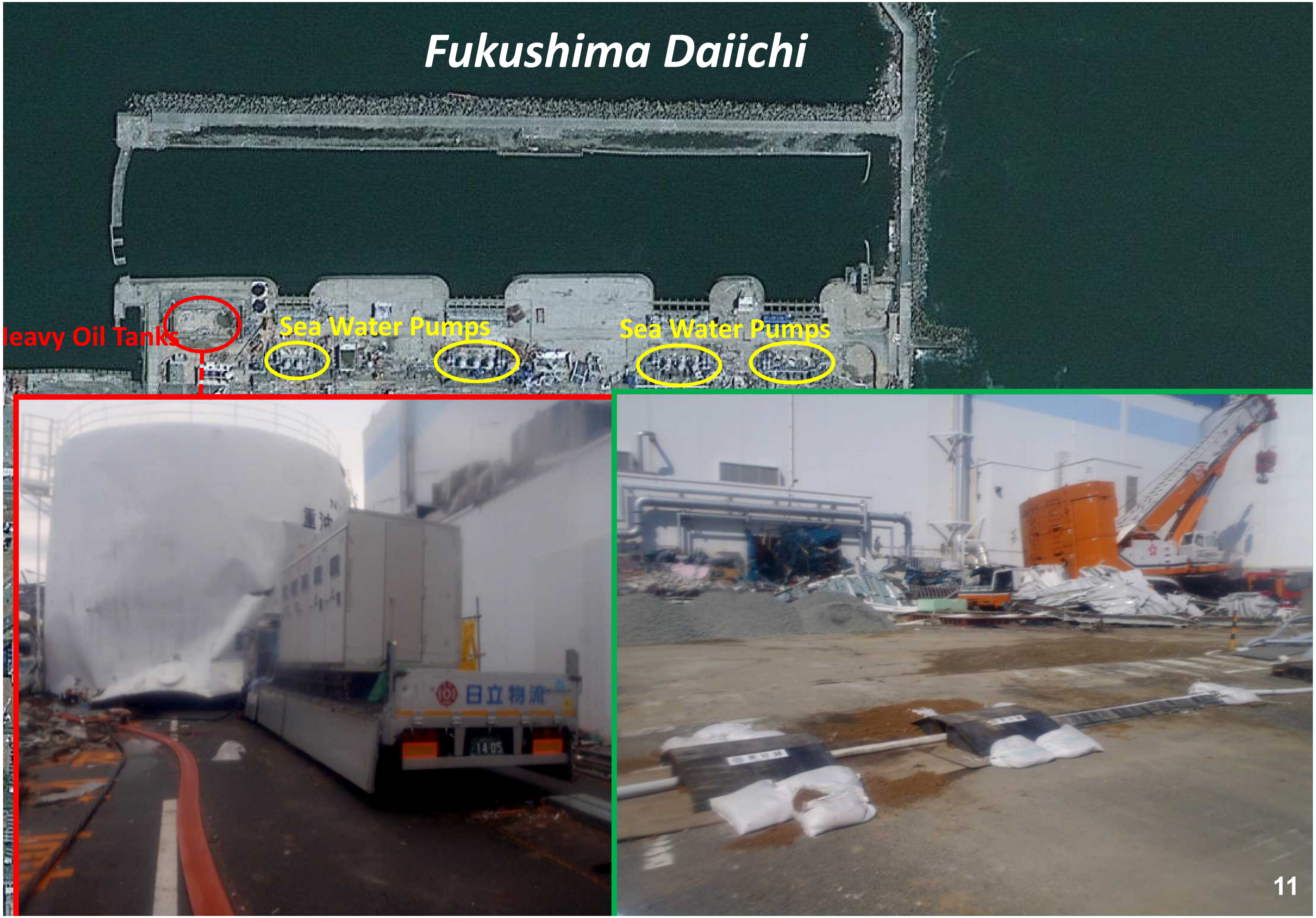
** including 32 MOX Fuel Assembly*


Fuel Assembly
4 m
Fuel Rod
Cladding tubes
(Zirconium alloy)
1 cm
UO_2 pellet

Tsunami on March 11, 2011

Source: TEPCO

Tsunami on March 11, 2011



Tsunami, 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

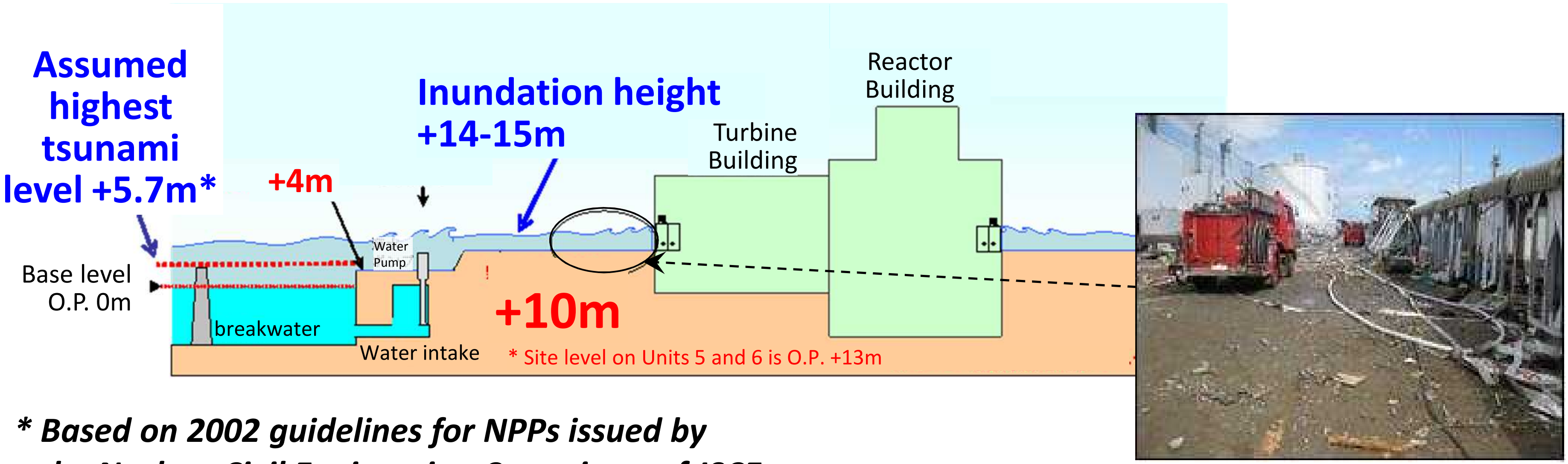
15:46:10

Inundation height of the Tsunami in Fukushima Daiichi was about 15 m.

Source: TEPCO

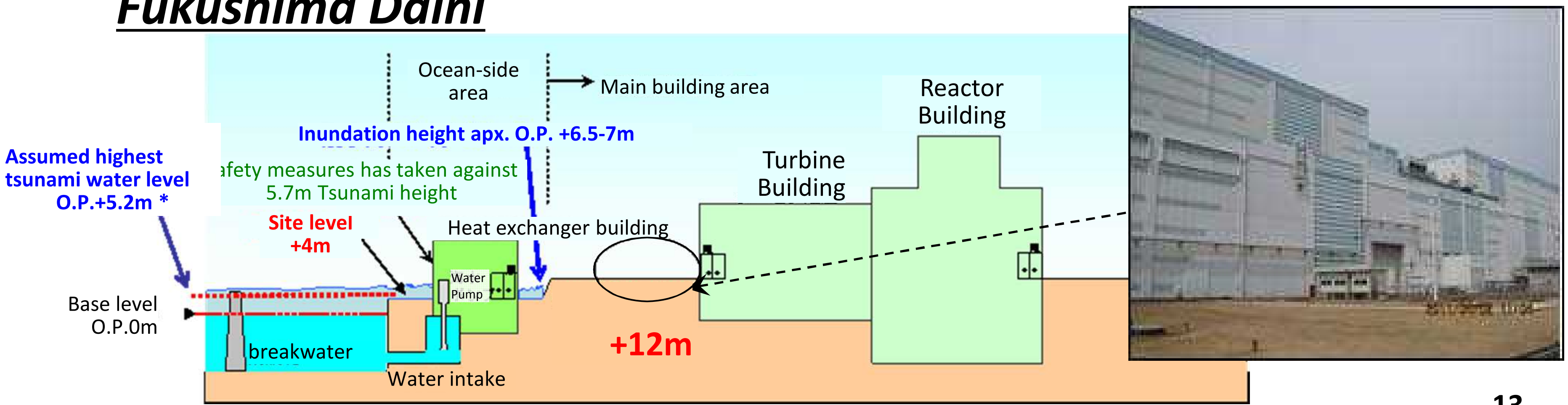
Tsunami

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

Station Black-Out in Fukushima Daiichi Units 1-4

- Loss of Off-Site Power Supply and Emergency Diesel Generators -

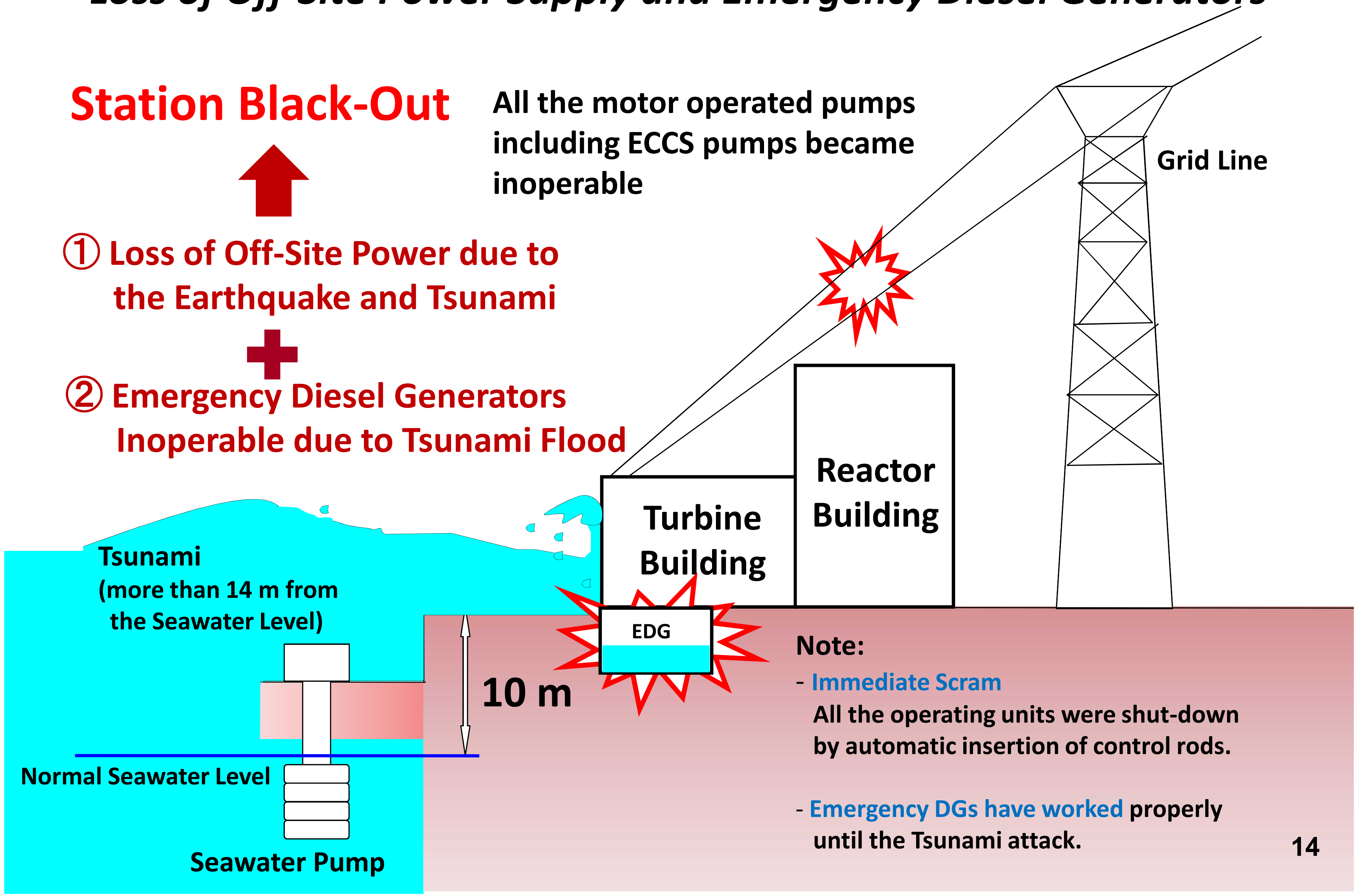
Station Black-Out

All the motor operated pumps including ECCS pumps became inoperable

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

+

② Emergency Diesel Generators 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

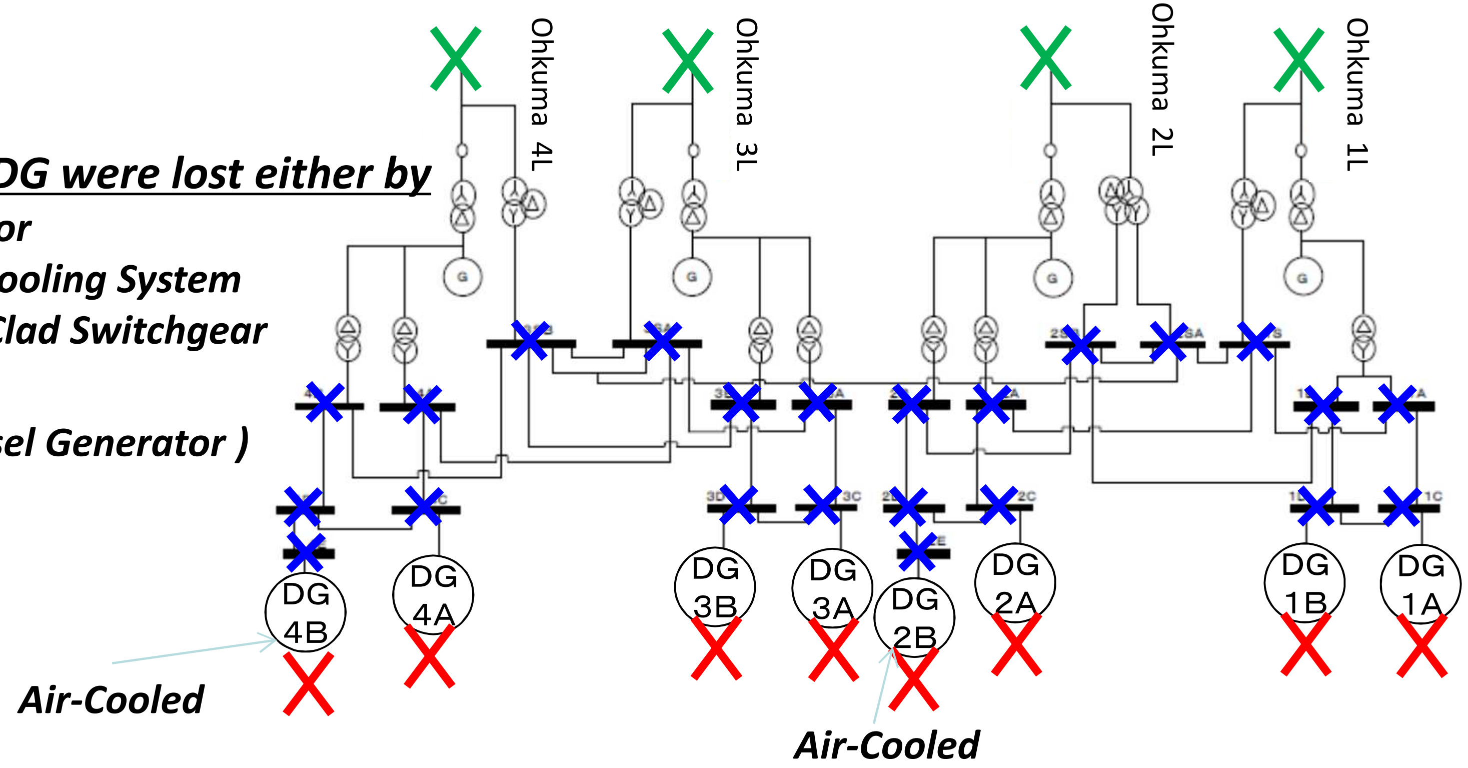
Okuma 1L,2L : Breakers were broken due to the earthquake

Okuma 3L : Under modification

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)

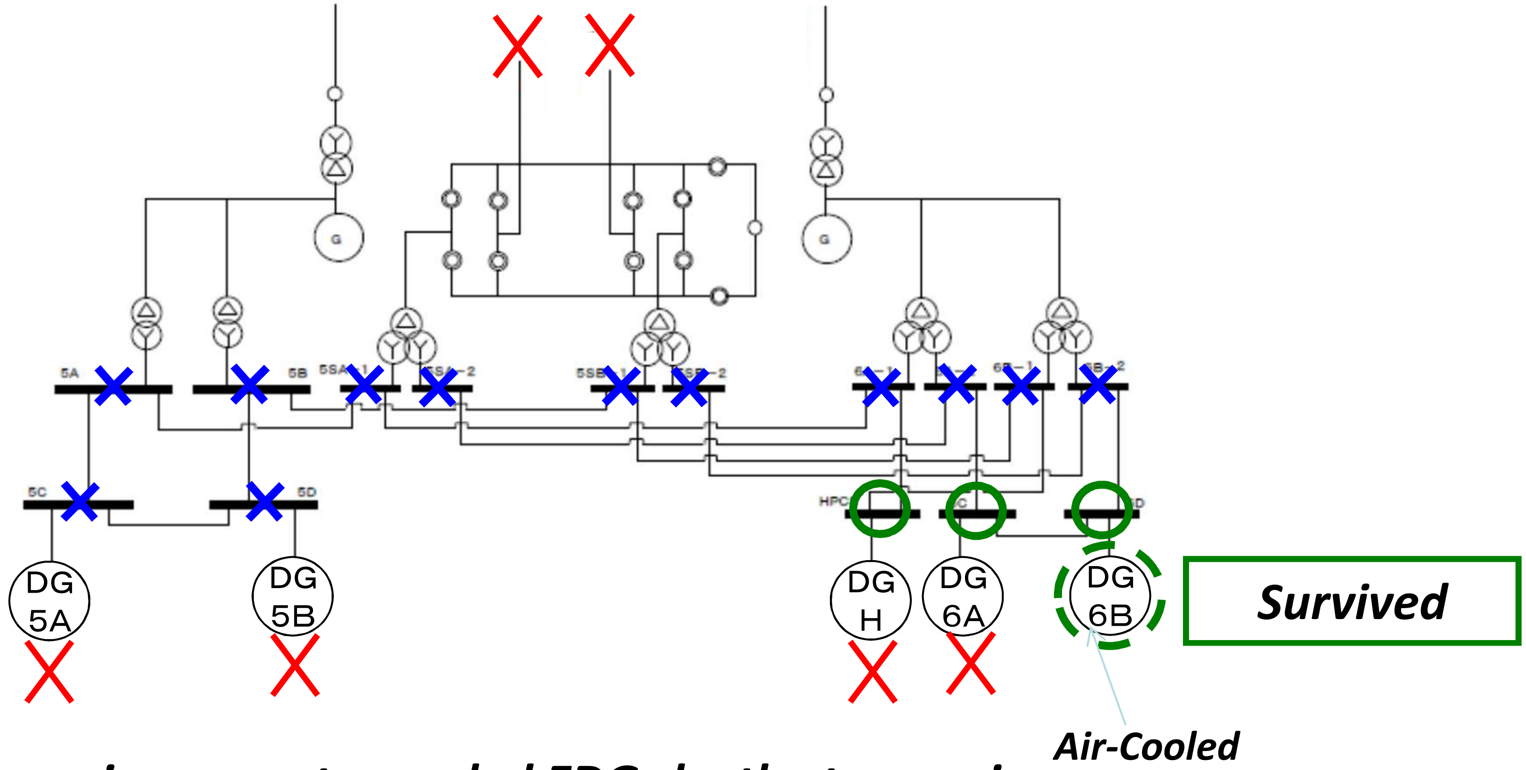


Recovery of Off-site Power Supply

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**

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

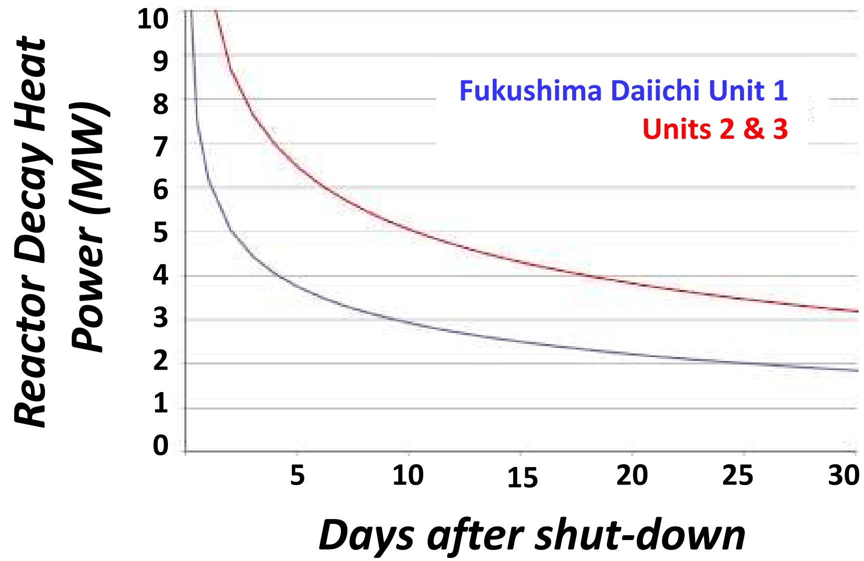
Unit 3

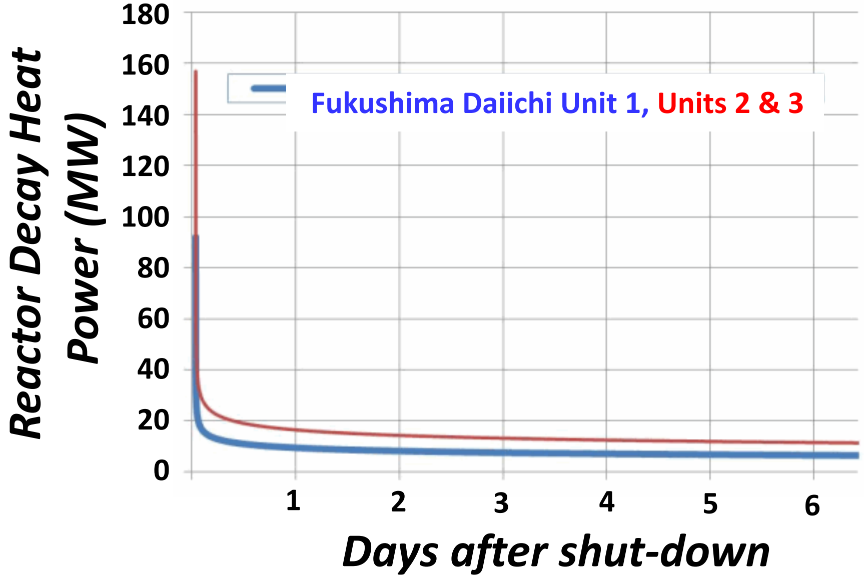
- I-131 : 2.7×10^{18} Bq
- Cs-137 : 2.4×10^{17} Bq

Example of Release Rate assumed in a SA code

Ba group	2.60E-04
Ce group	4.00E-06
Cs group	5.80E-02
I group	6.70E-02
La group	8.40E-07
Ru group	5.40E-10
Te group	3.00E-02
Xe group	9.60E-01

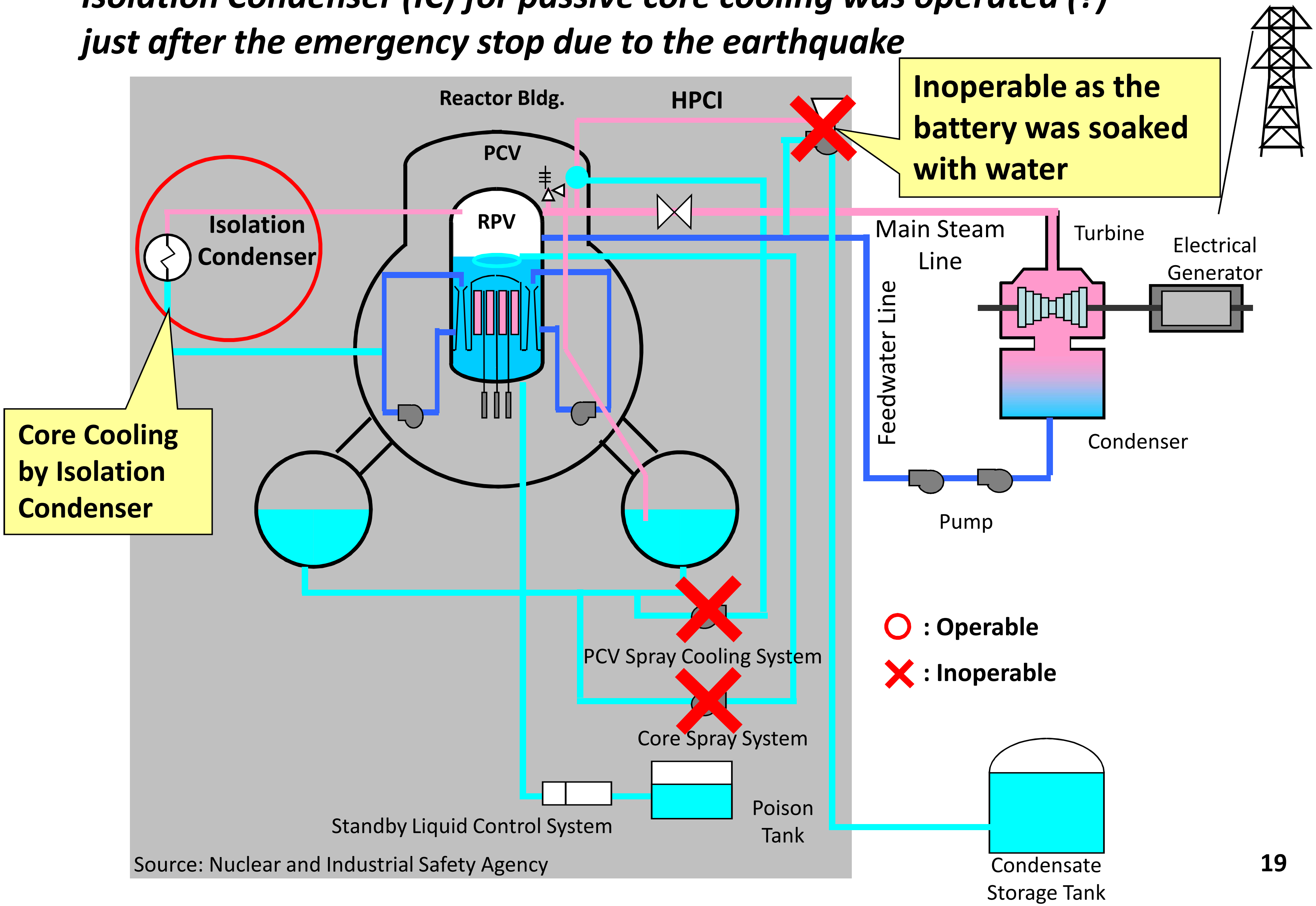
Decay Heat after the Shutdown





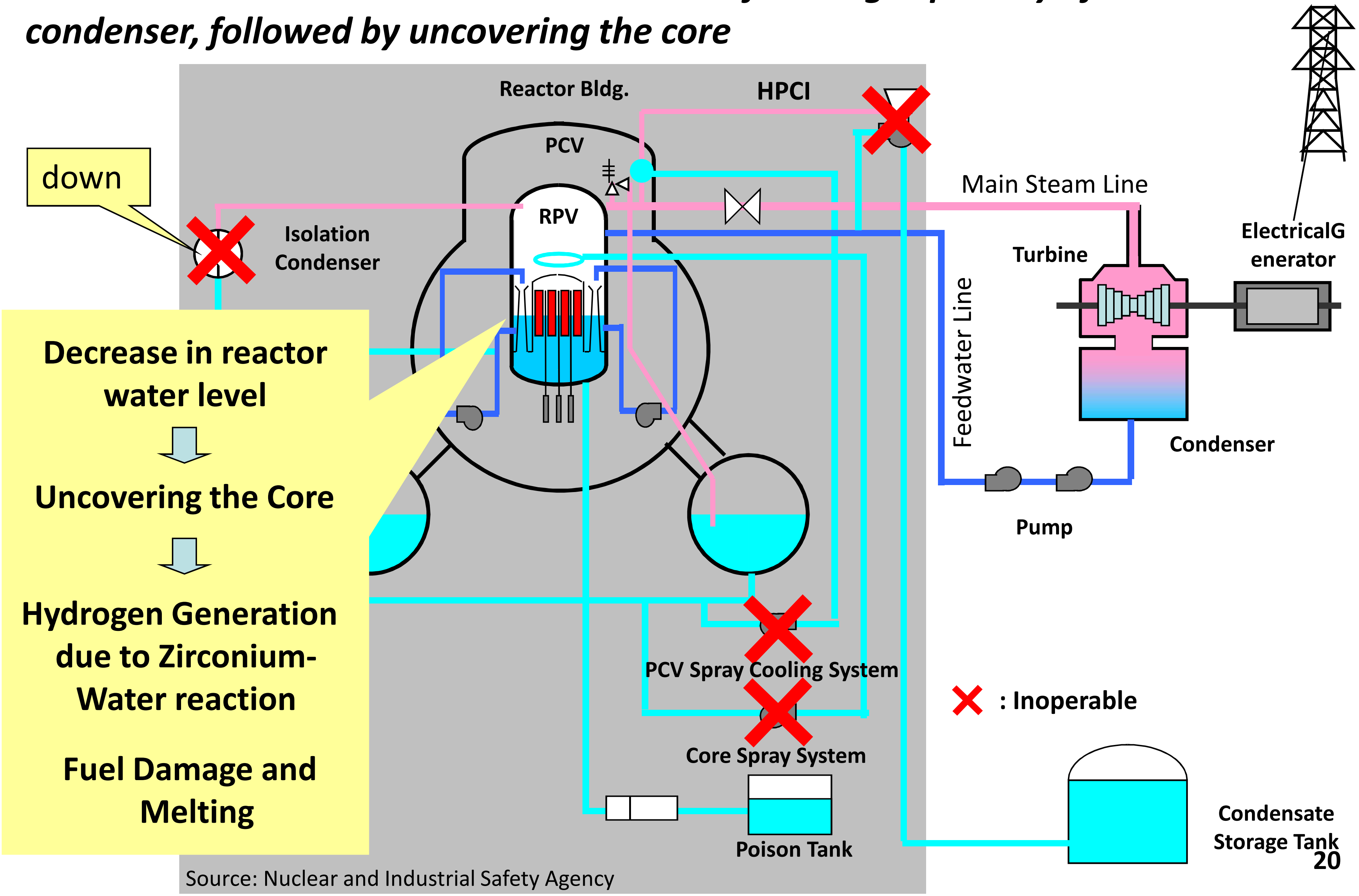
Unit 1 : Cooling by Isolation Condenser

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



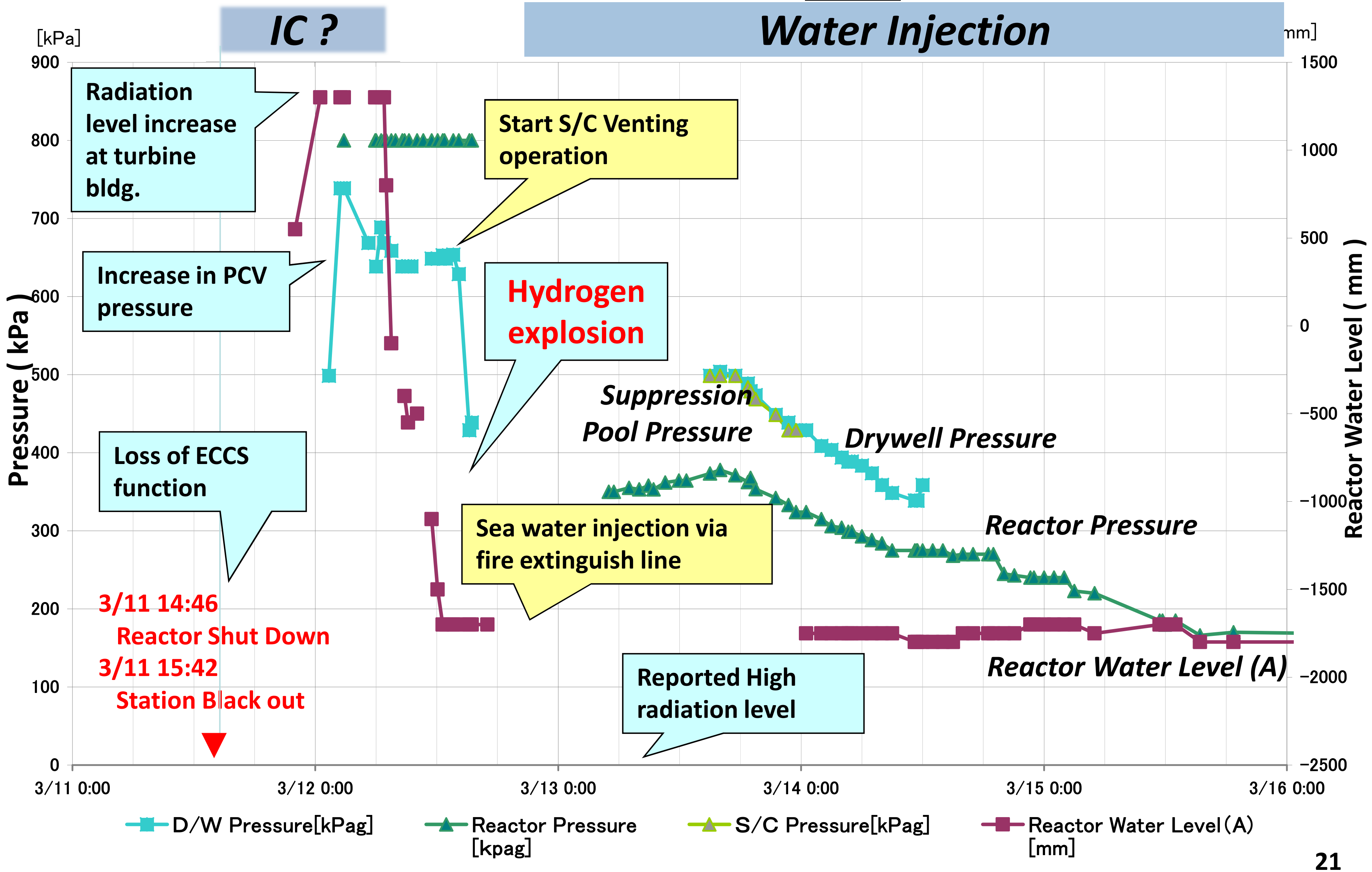
Unit 1 : Loss of Cooling

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



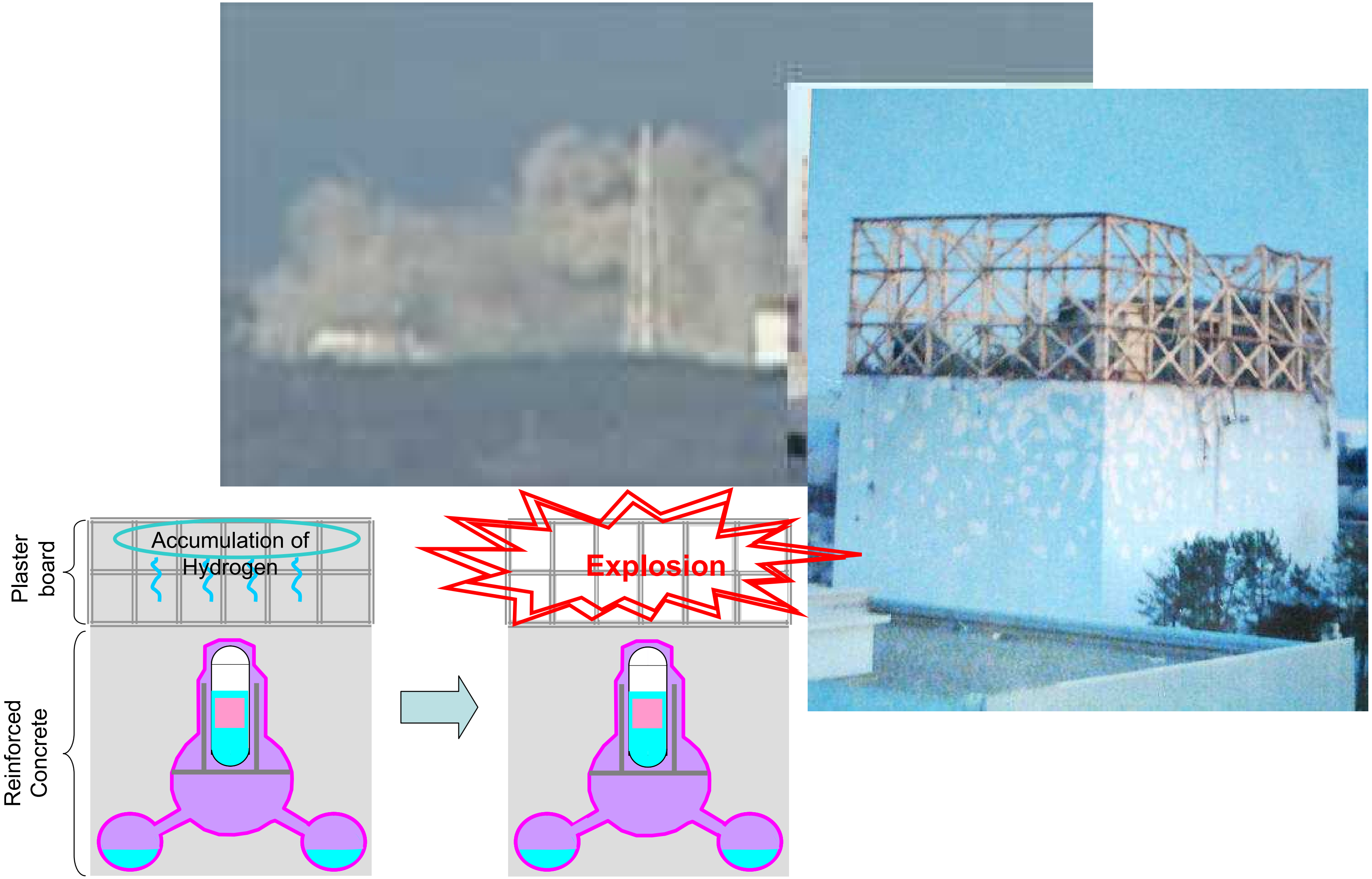
Water Level in RPV, Pressure in RPV and PCV (D/W & S/C)

From March 11 to 16 in Unit 1



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

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



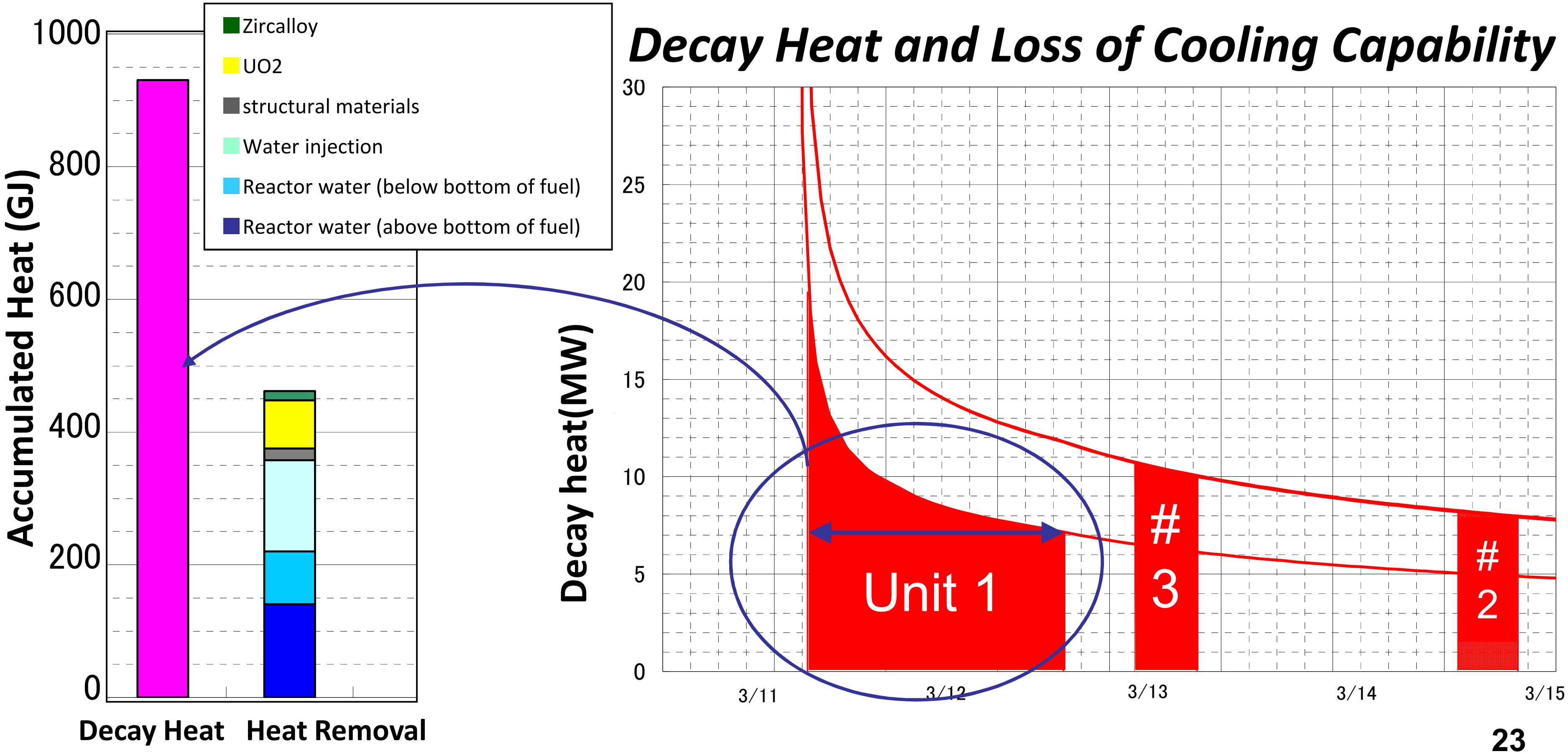
Reactor building

Reactor building

Balance between Decay Heat and Heat Removal in Unit 1

Decay Heat ≫ Heat Removal

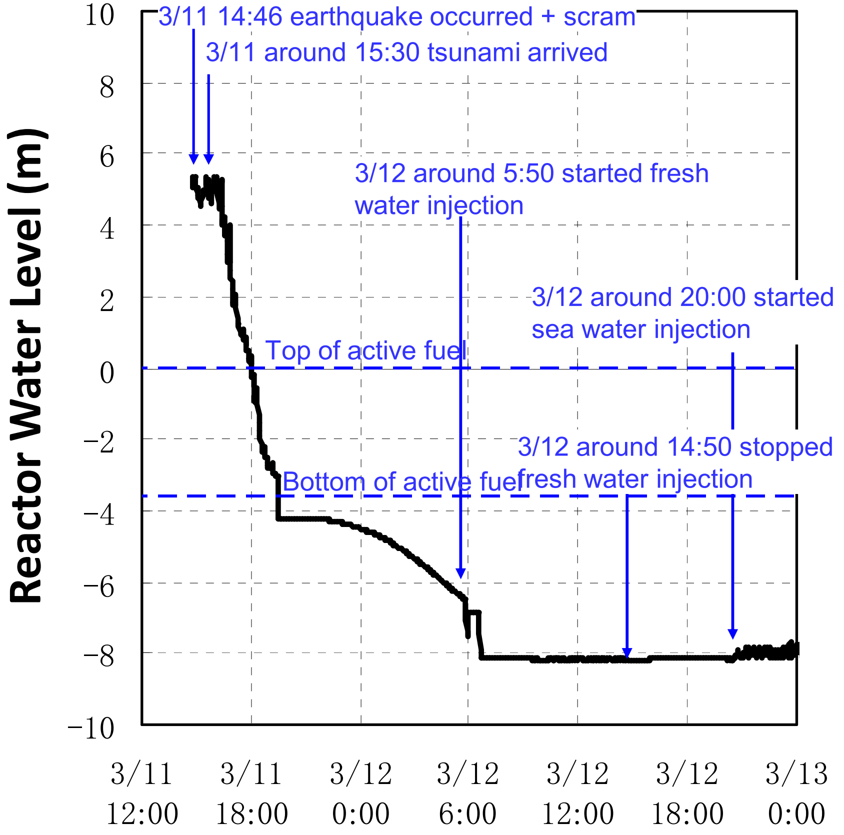
- **Total decay heat before sea water injection greatly exceeds the amount of heat which reactor water and structural materials could absorb.**
- **All molten core moved to RPV bottom and they damaged RPV and run down to PCV.**

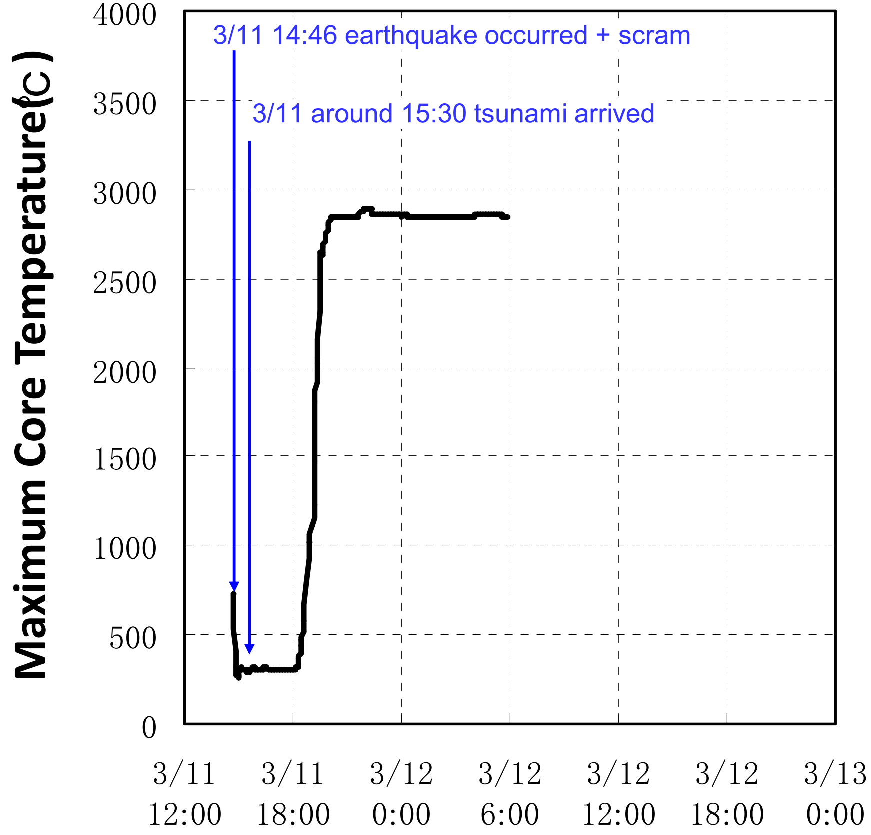


Source: TEPCO

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

Assuming that IC lost its function by the Tsunami





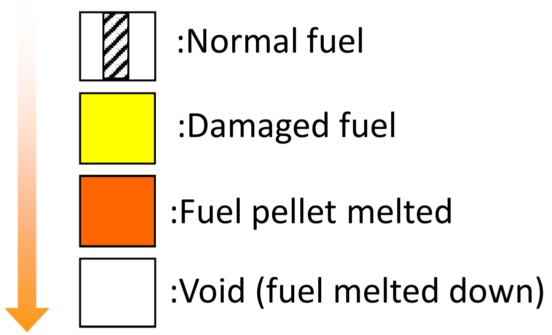
- reached top of active fuel in 3 hours (around 18:00) after the scram
- reached bottom of active fuel in 4 and a half hours (around 19:30) after the scram

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

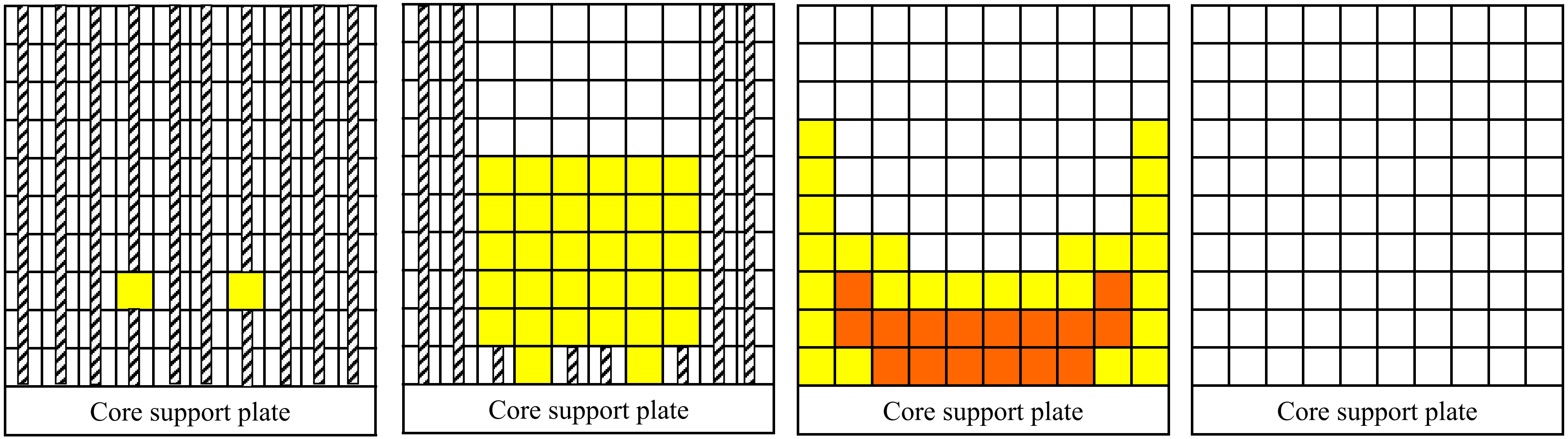
Transition of Core Status in Unit 1
- Simulation Trial Results by the MAAP code -

Degree of fuel damage



- 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

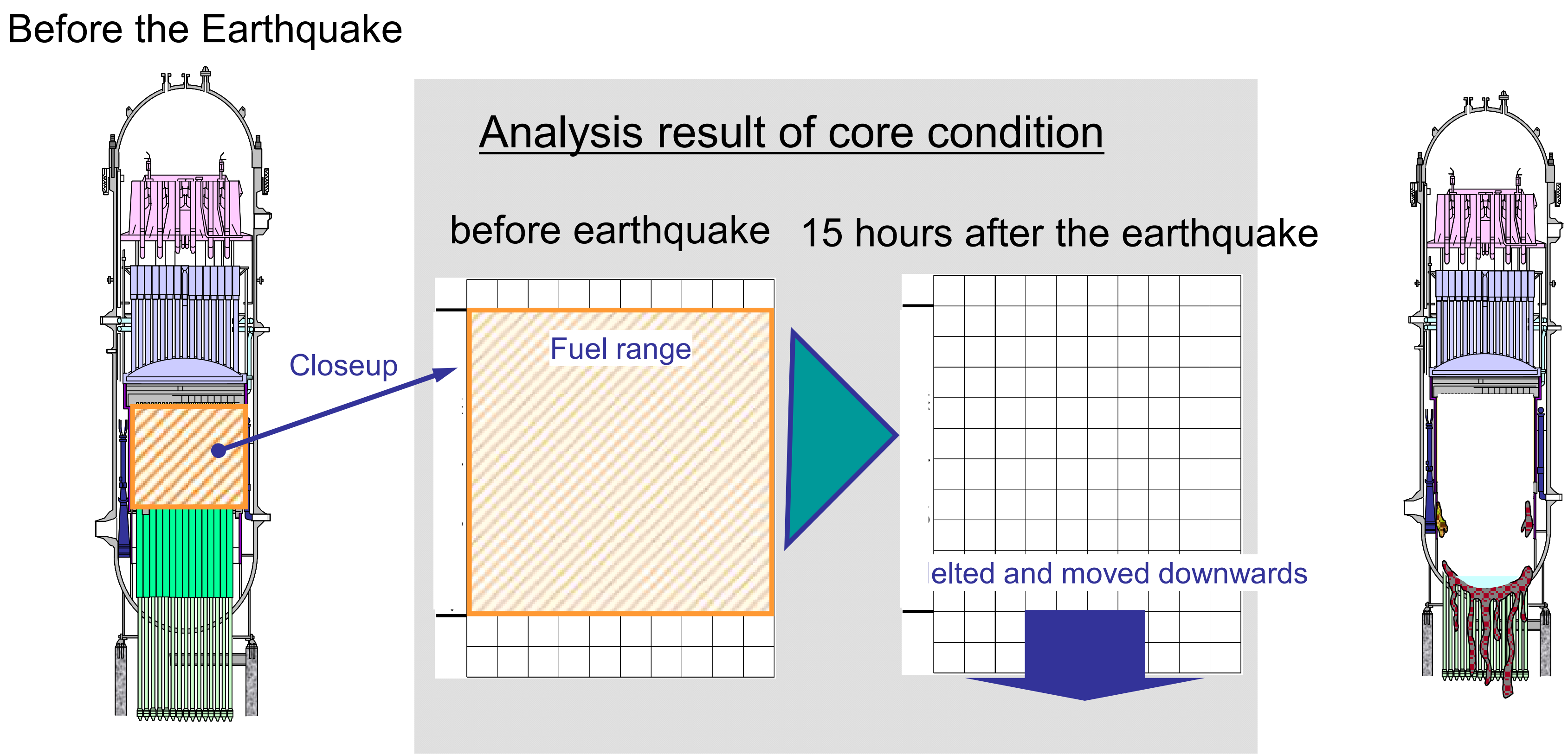


4.8 hours after scram (around March 11th 19:30) | **5.1 hours after scram (around March 11th 19:50)** | **15.1 hours after scram (around March 12th 6:00)** | **16.0 hours after scram (around March 12th 6:50)**

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

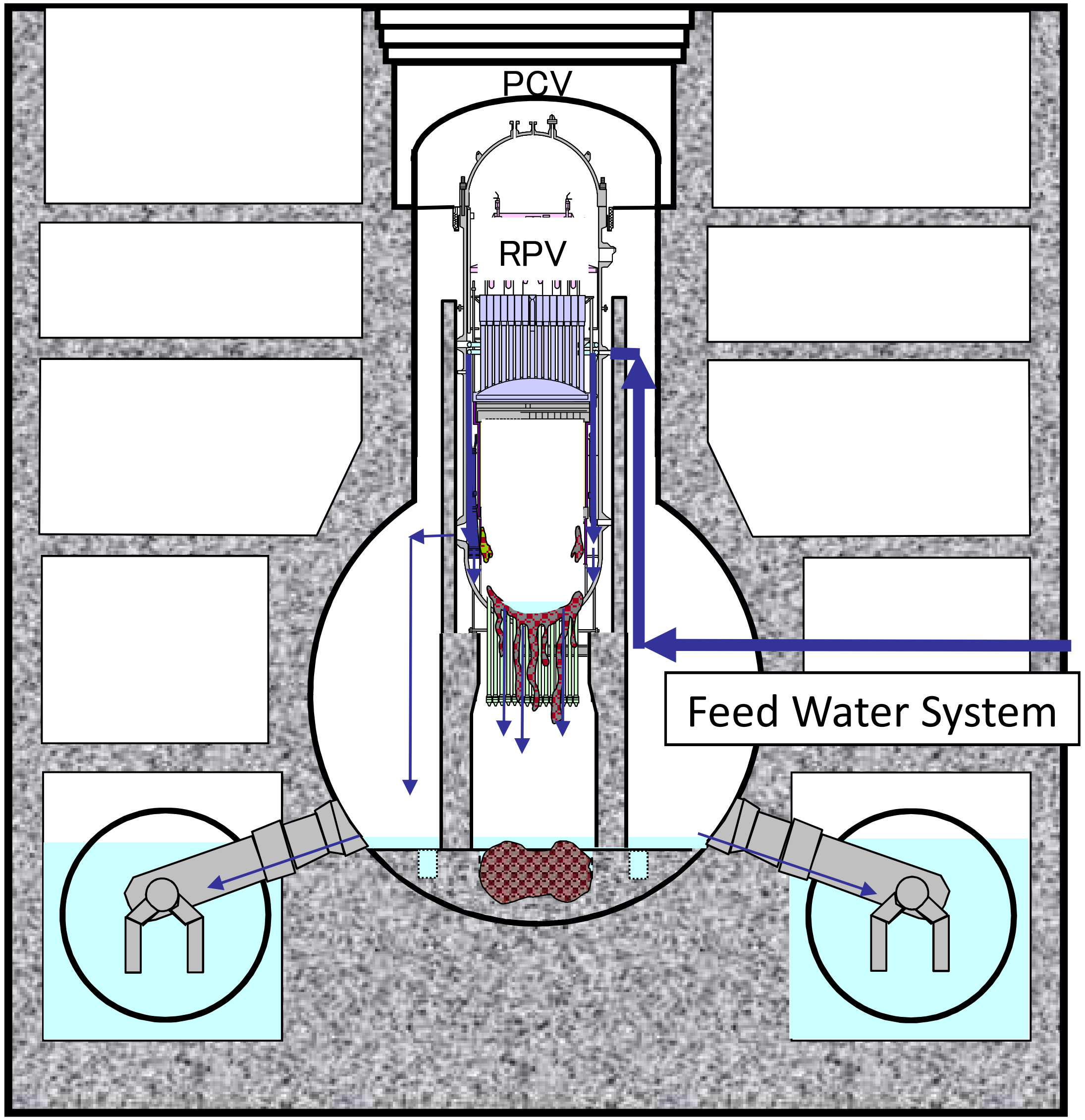
Summary of Simulation Results by the MAAP code in Unit 1

- All the fuels were melted and moved downwards from fuel range.
- **RPV is likely to be damaged by molten core.**



Source: TEPCO

Summary of Damage in Unit 1



Source: TEPCO

- MAAP code analysis indicates;

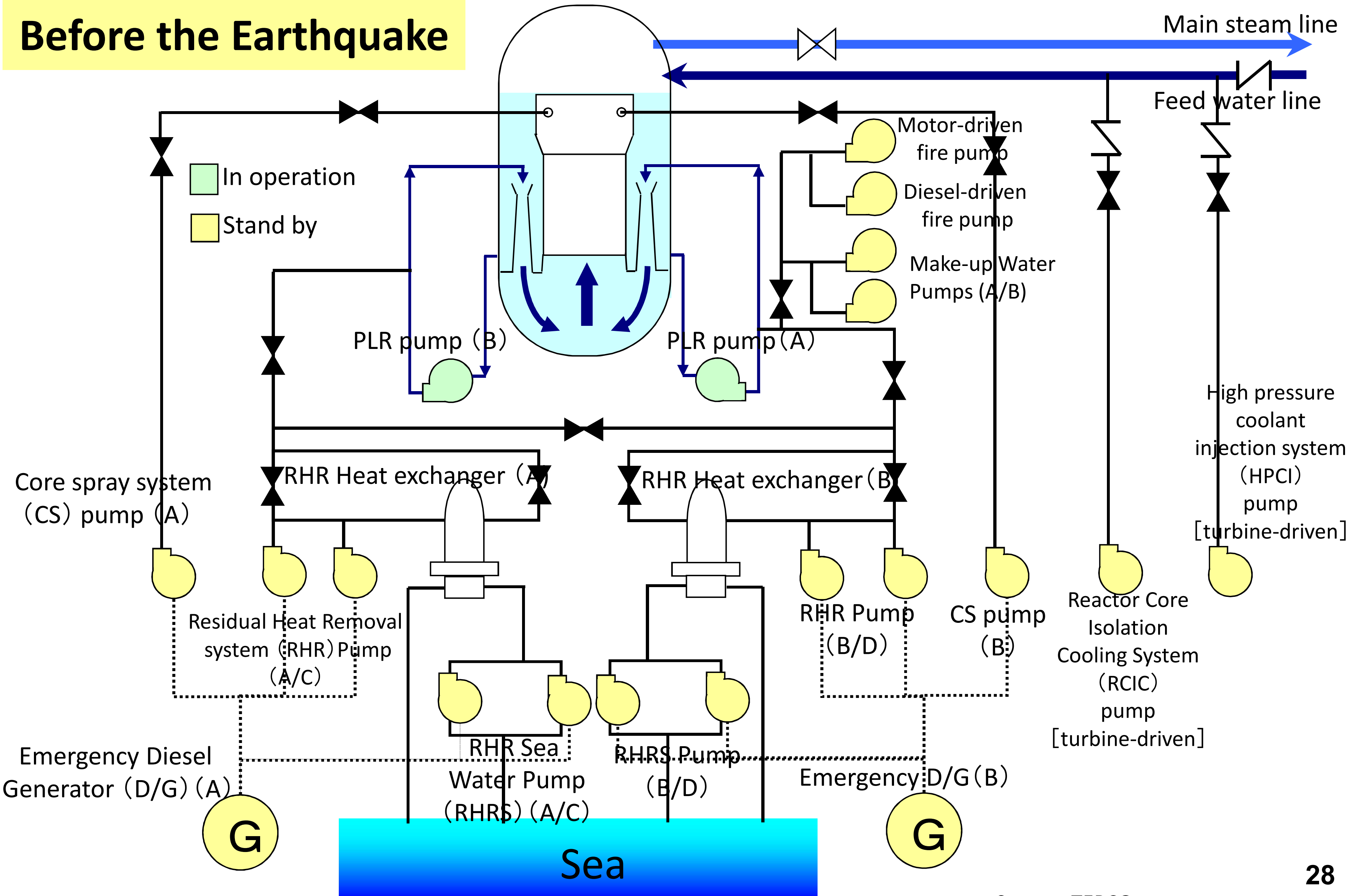
<u>All fuel rods were melted and relocated to the RPV bottom.</u>
<u>A considerable quantity of fuel dropped to the PCV bottom.</u>

【Presumption by the record of reactor water level indicator】
【Presumption by the heat balance between decay heat and heat removal】
【Presumption by radioactive concentration of PCV gas】
【Presumption by the radiation dose in RCW】
【Evaluation of current state by temperature reading 】 etc.

- Currently water is injected to the RPV via the feed water piping. Temperature of the RPV bottom and the PCV is stable at less than 100 C .
- **Almost all fuel dropped to the PCV bottom, is in contact with water, and is cooled.**

Unit 3 *Outline of Water Injection Systems*

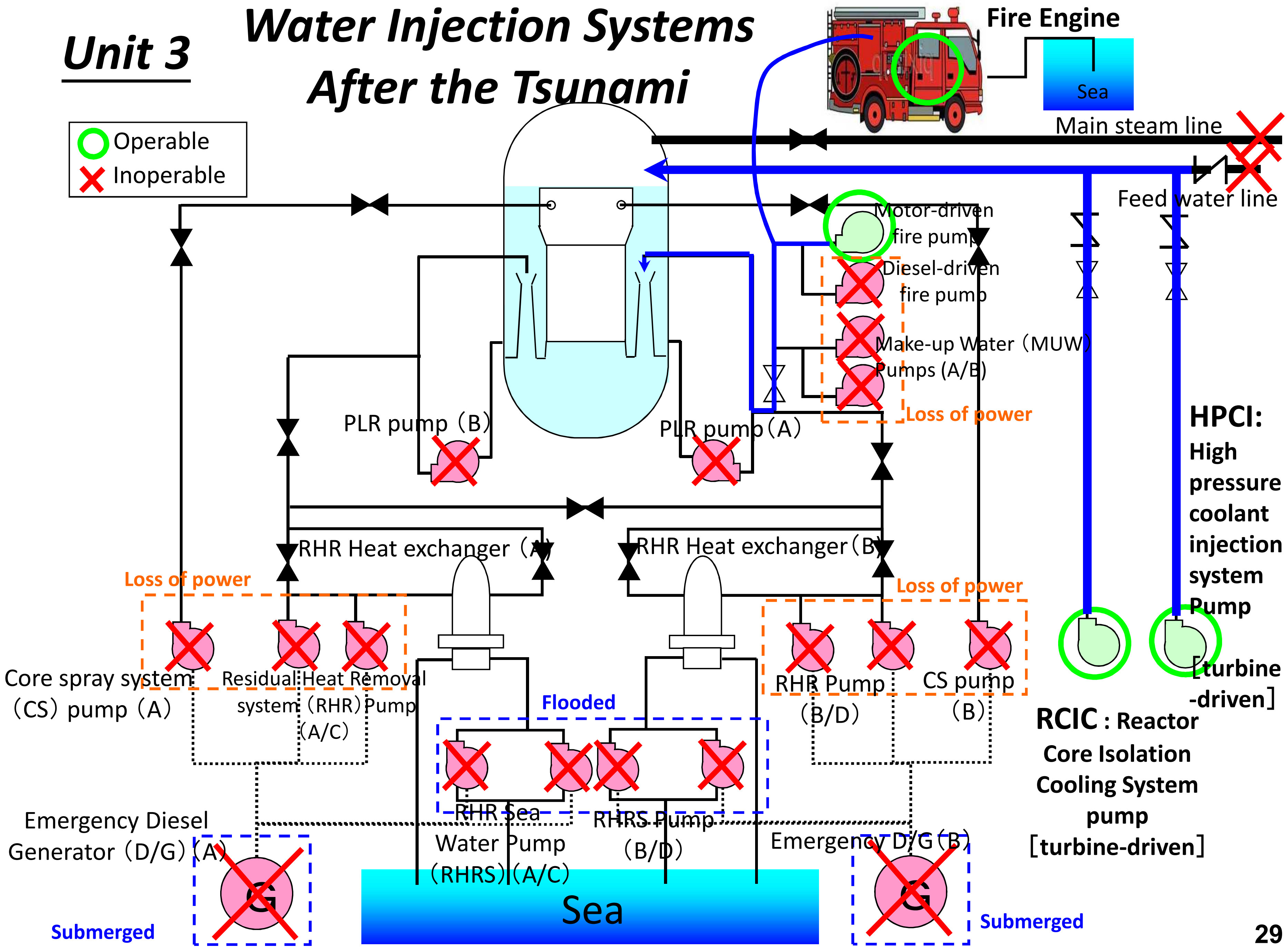
Before the Earthquake



Source: TEPCO

Unit 3

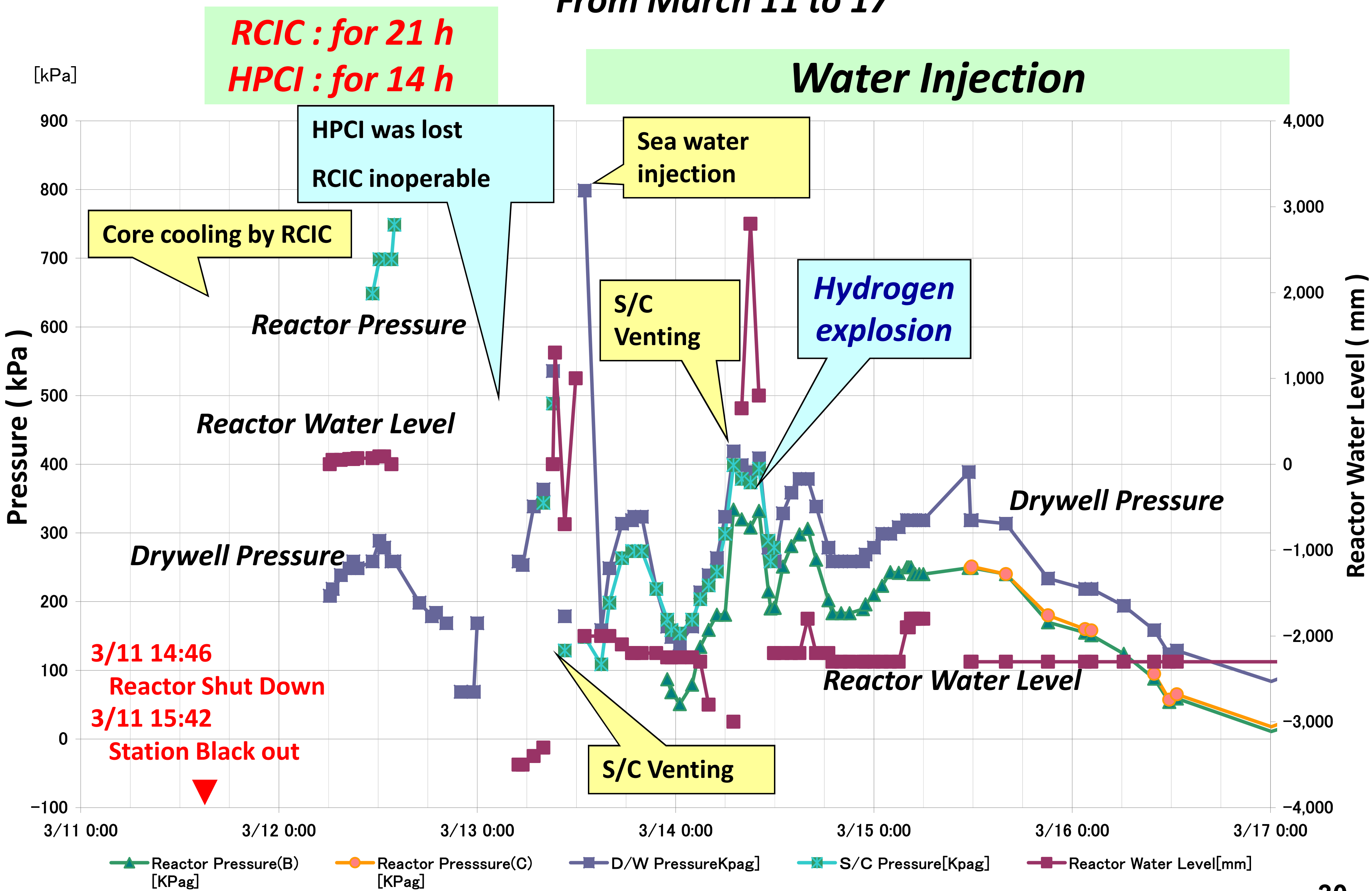
Water Injection Systems After the Tsunami



Source: TEPCO

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

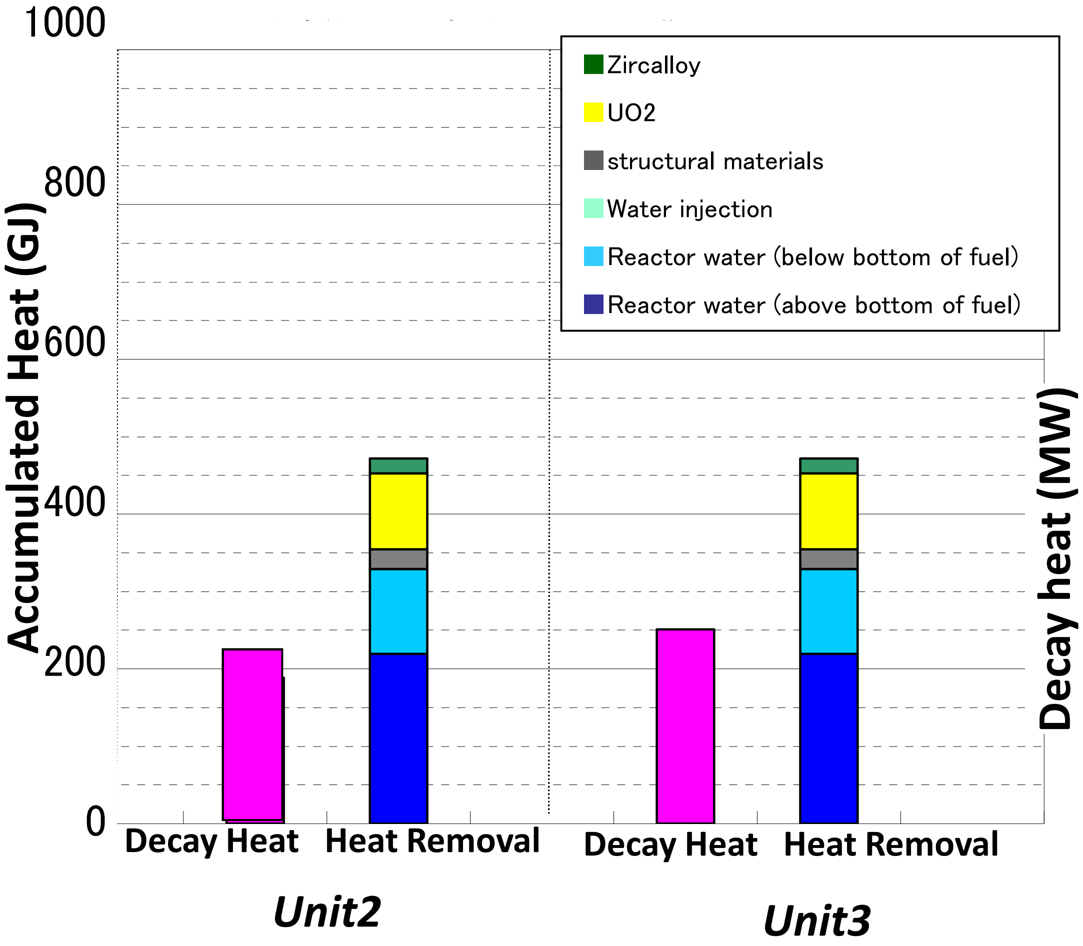
From March 11 to 17



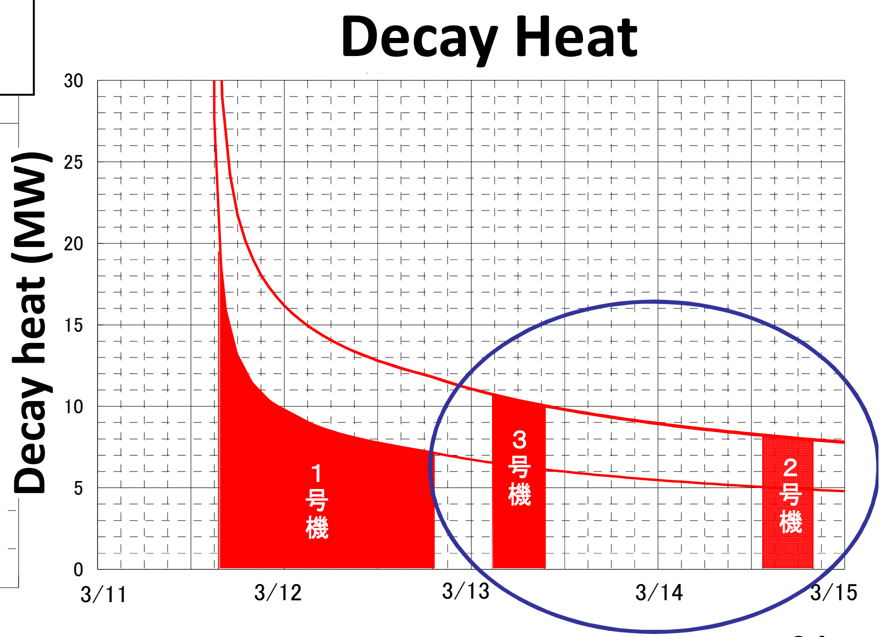
Source: Side event material on the "Fukushima Daiichi Accident and Initial Safety Measures Worldwide" in IAEA.

Balance between Decay Heat and Heat Removal in Units 2 & 3

- **Decay heat generated in the period where water injection was interrupted exceeded the heat removal amount which reactor water and structural materials could absorb.**
- **It is assumed that certain amount of fuel possibly melted and moved downwards, which also lead damage RPV.**



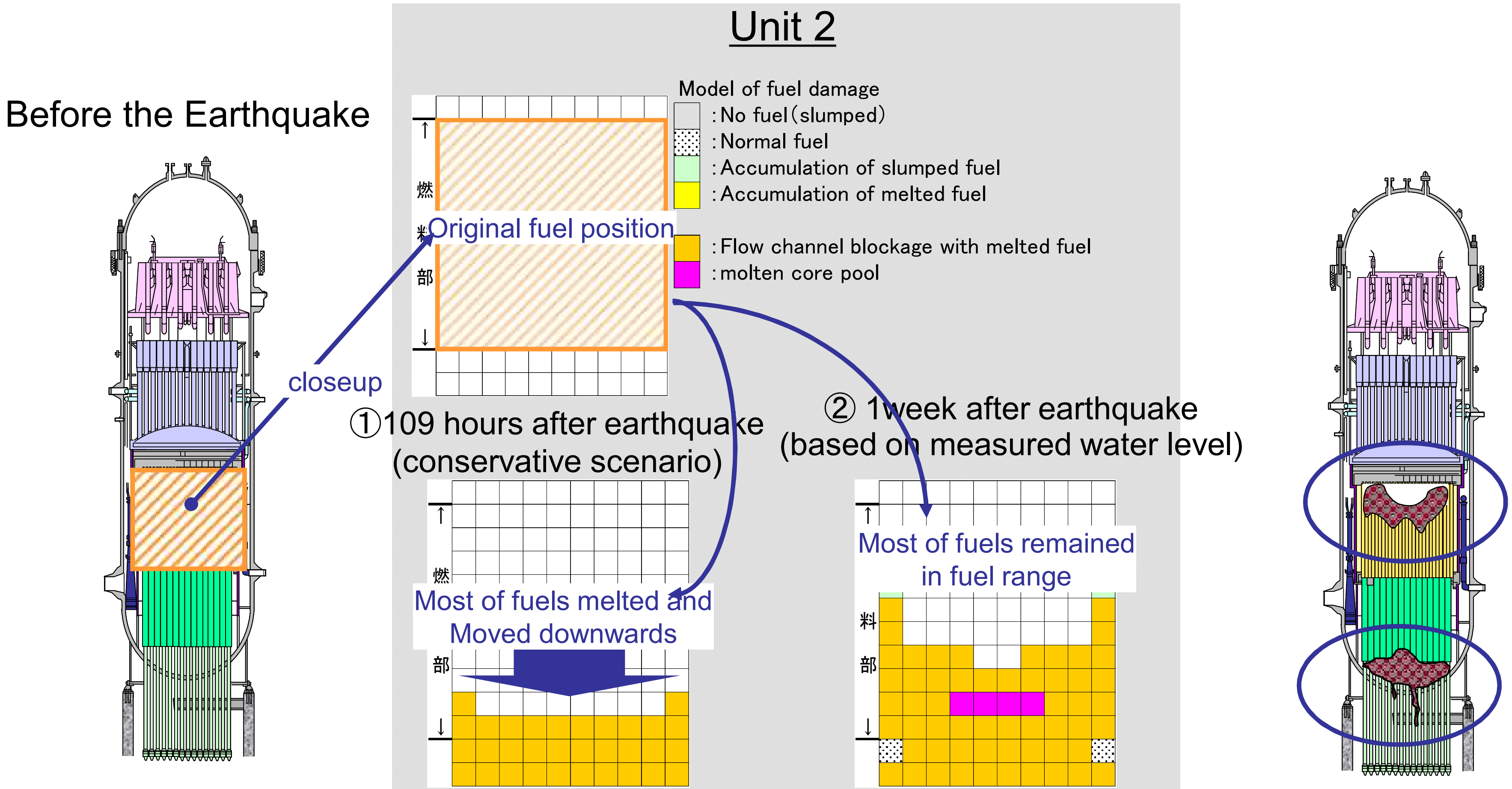
In units 2 & 3, the period where water injection was interrupted was shorter than unit1



Source: TEPCO

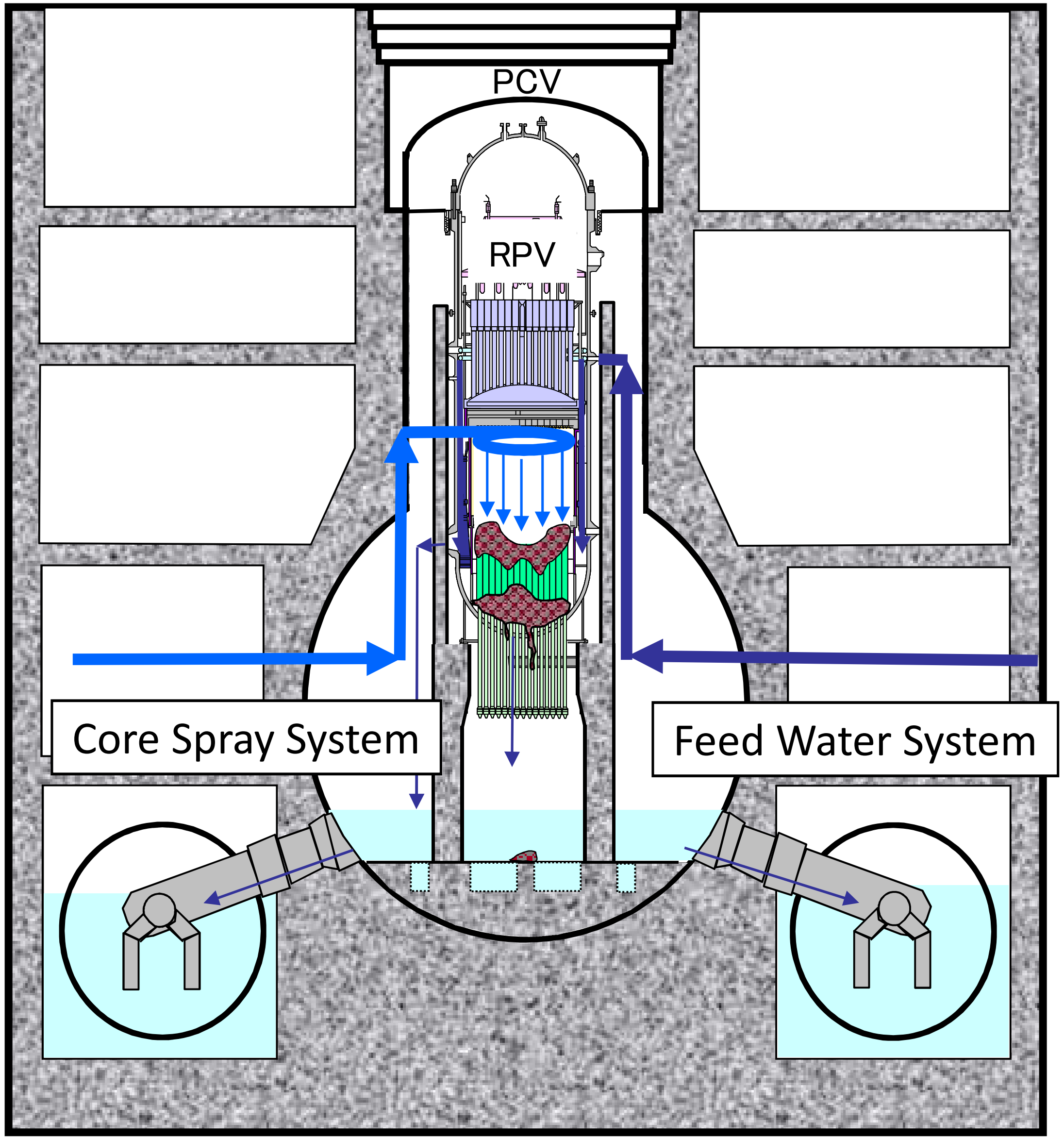
Summary of Simulation Results by the MAAP code in Units 2 and 3

- Most of fuels melted and moved to RPV bottom <u>in the conservative scenario</u> which assume smaller amount of water injection considering uncertainty of reactor water level indicator.
- Although some fuels were damaged, most of fuels remained in fuel range <u>in the scenario based on measured water level with indicator</u>.



Source: TEPCO

Summary in Units 2 and 3



Source: TEPCO

- **<u>Although fuel was damaged and melted, some fuel remains at the core. And some fuel dropped to the RPV plenum or to the pedestal in the PCV.</u>**

  【Record of water level】

  【Heat balance based on the amount of water injection】

  【Evaluation by temperature in the RPV and the PCV】 etc.

- Currently water is injected to the RPV via the feed water piping and core spray piping. Temperature at the each part of the PCV is stable at 100℃ or less. Therefore, the fuel at each location is in contact with water, and is cooled.

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
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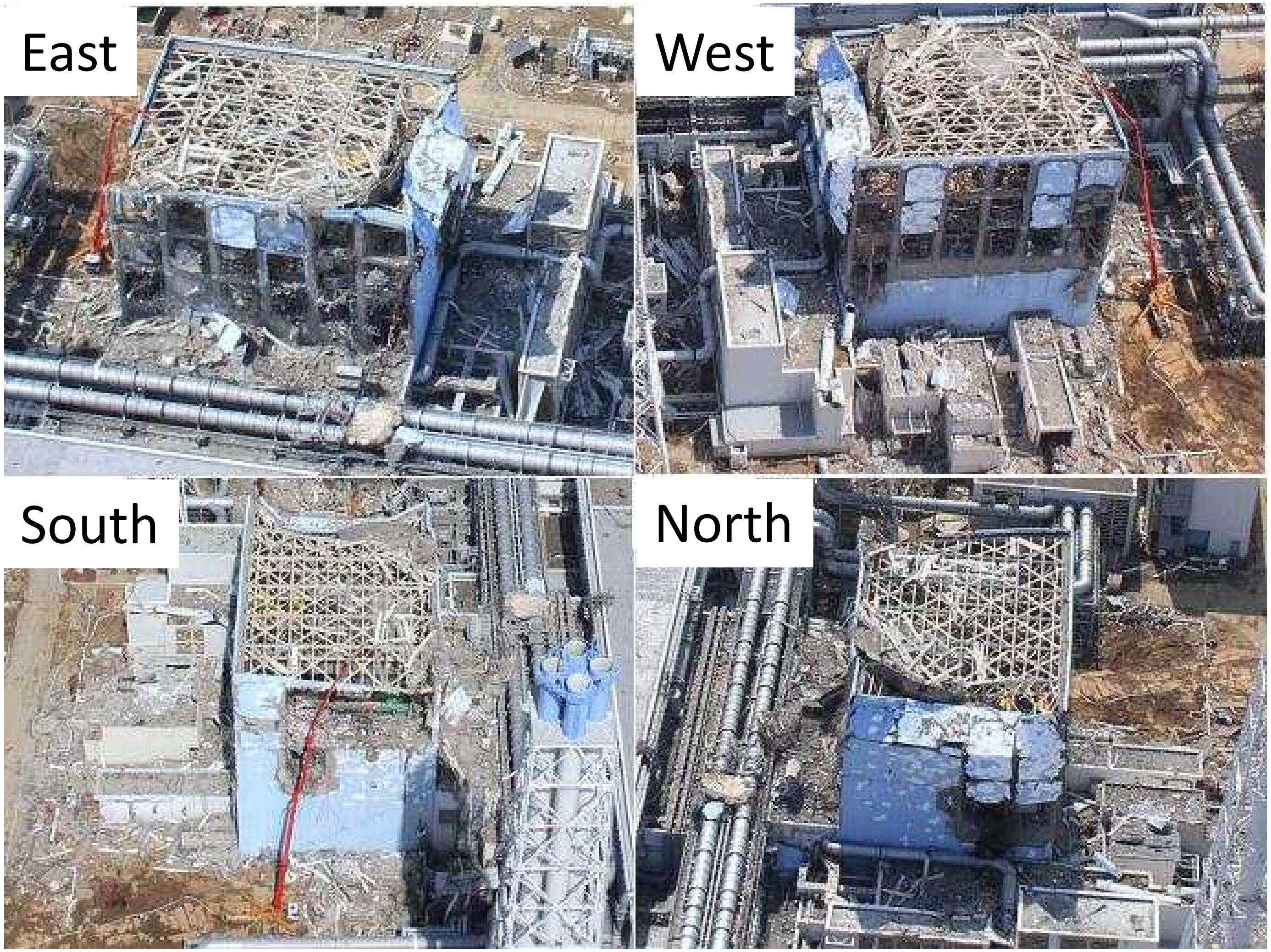
Heat Generation in Spent Fuel Pool (MW)	0.07	0.47	0.23	2.3	0.08	0.07

** including 32 MOX Fuel Assembly*

Hydrogen Explosion in Unit 4 on March 15

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 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

(1) Zr-H_2O reaction in the SFP at high temperature

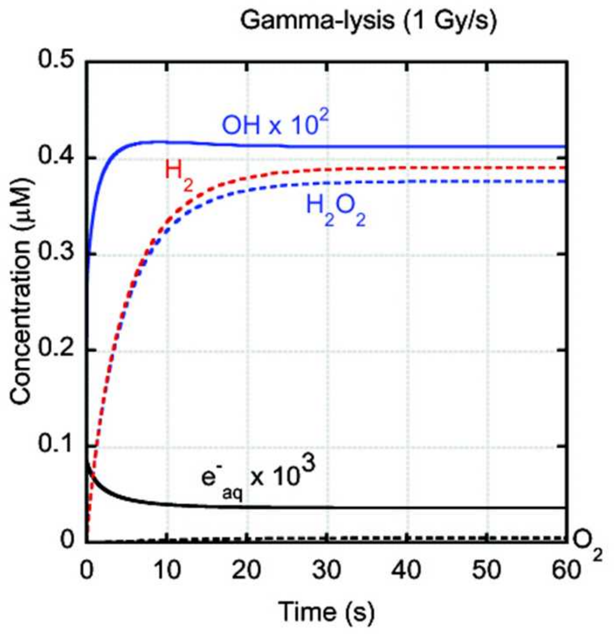
High Concentration of Hydrogen Gas Production in Water at Boiling Temperature under Radiation

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

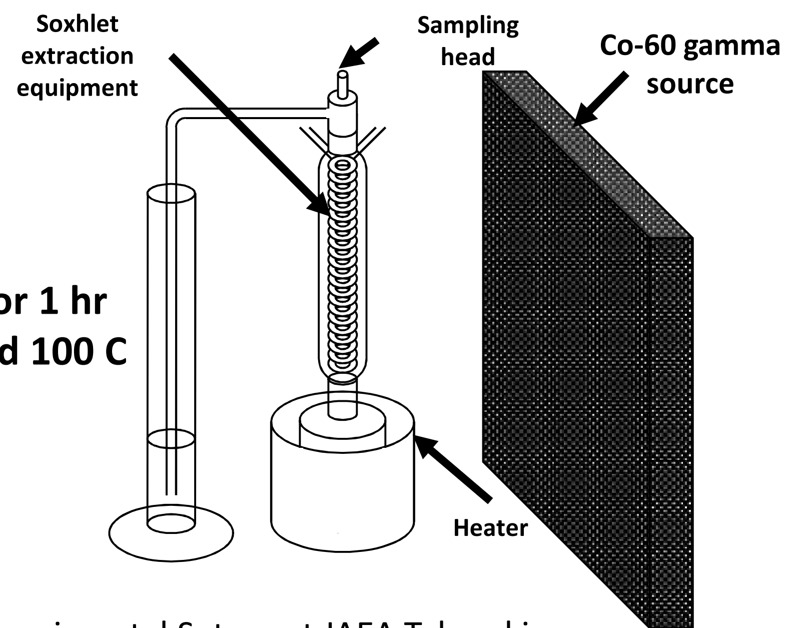


Typical BWR condition simulation of radiation chemistry reactions considering the reaction between H_2 and OH, resulting in steady state concentration of H_2.

New Finding by H_2 production under irradiation;

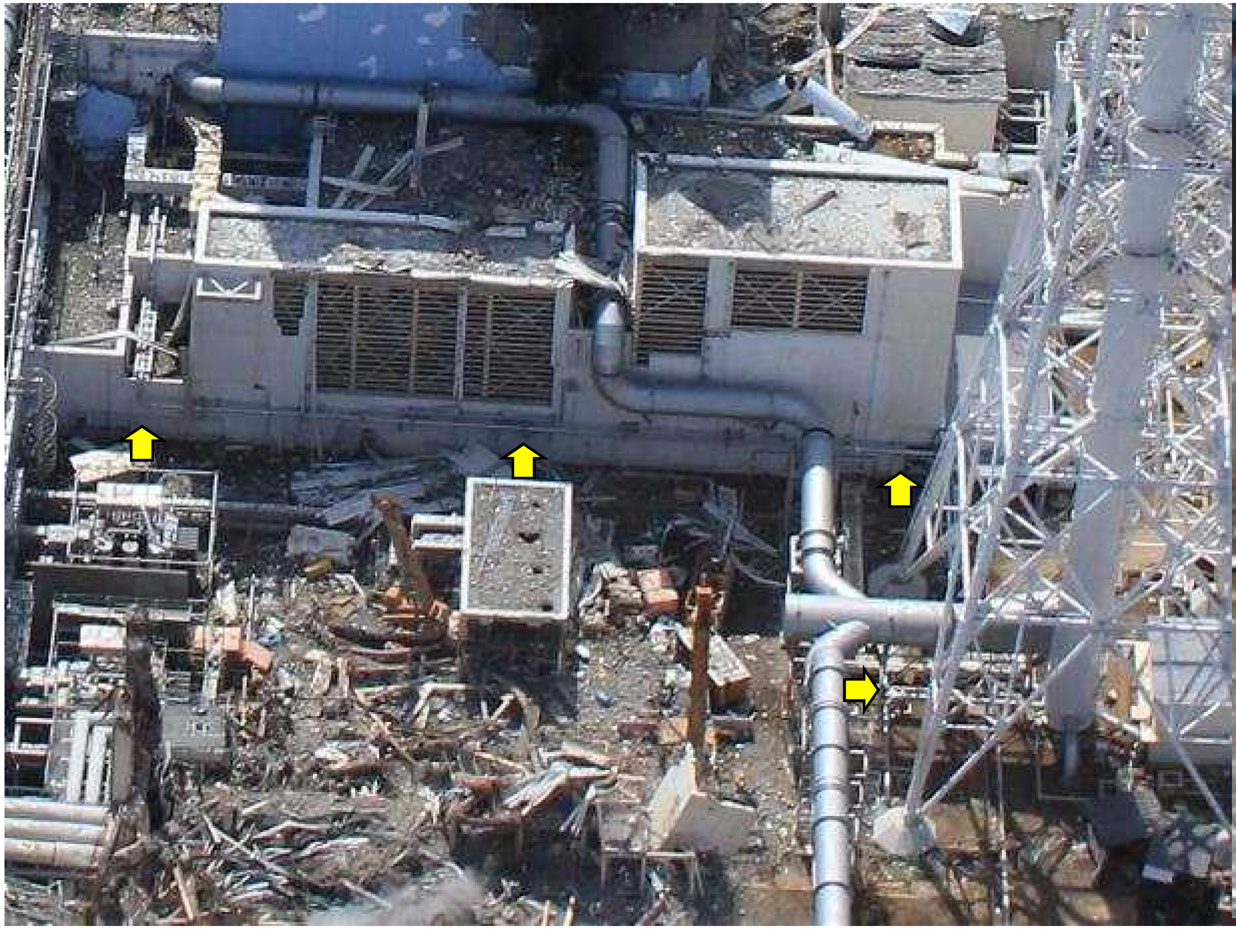
- ***Effective transfer of H_2 into gas phase at 100 C***
- ***High concentration of H_2 through condensation of H_2O at lower temperature region***

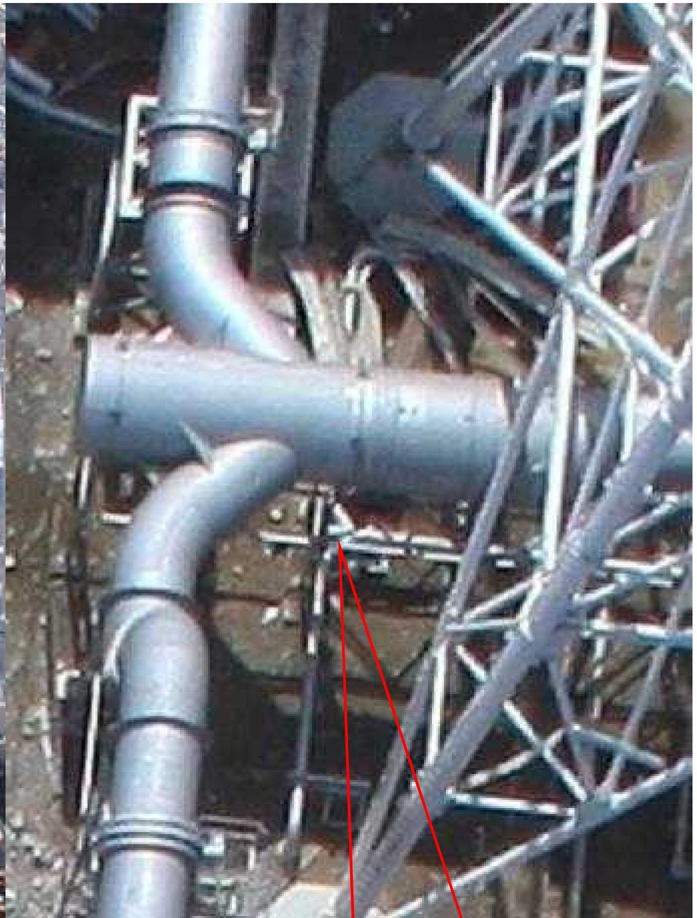
6.8 kGy/h for 1 hr at 80, 97 and 100 C

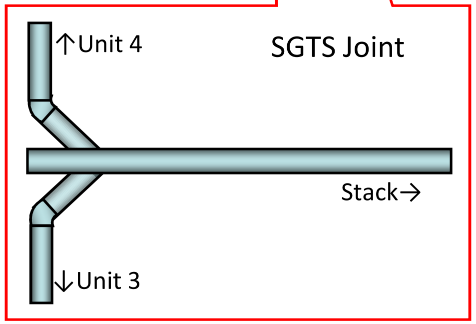


Experimental Set-up at JAEA Takasaki

Stand-by Gas Treatment Systems for Units 3 and 4



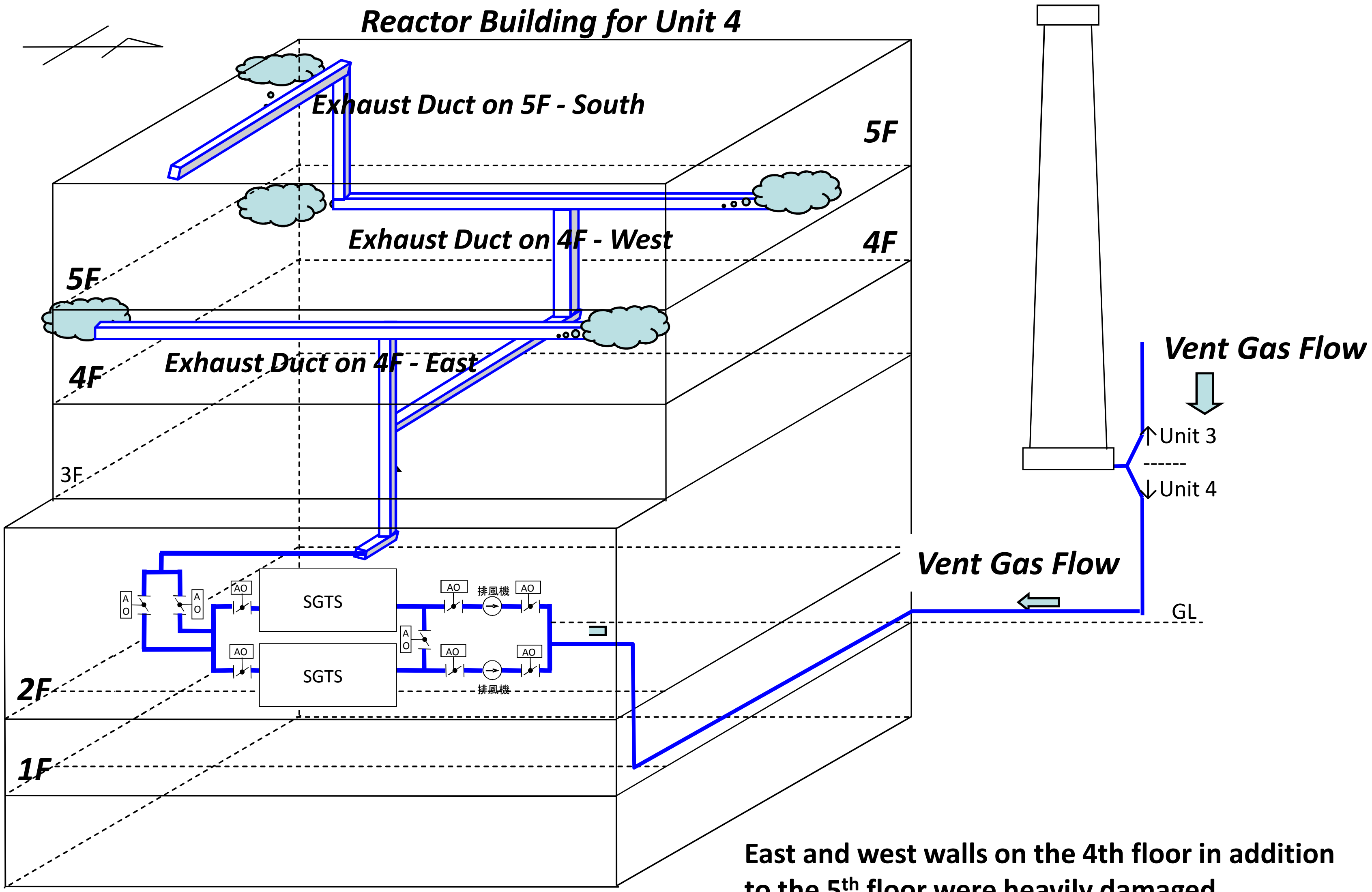




Pipes of stand-by gas treatment systems for Units 3 and 4 are connected.

Source: TEPCO

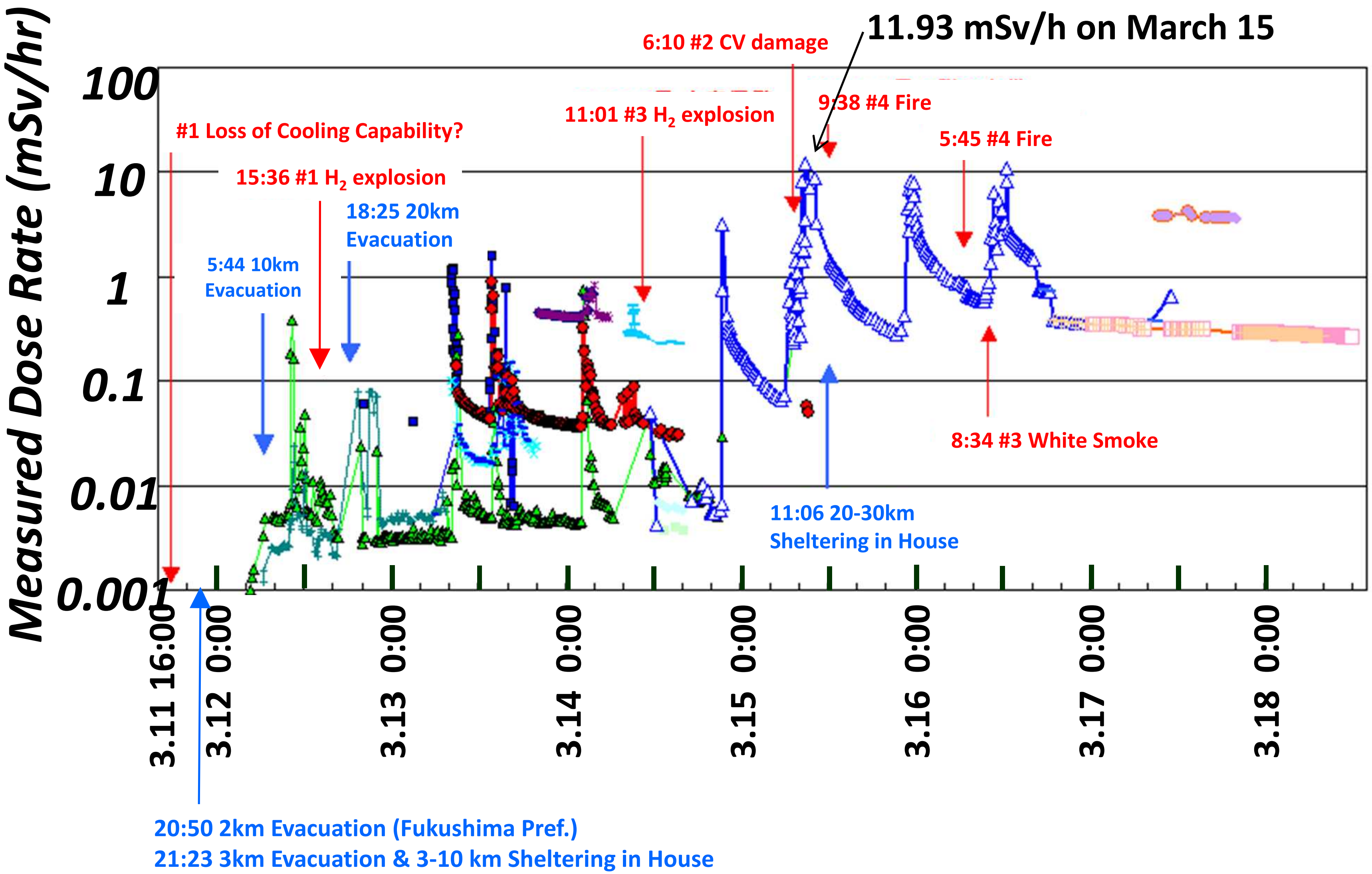
Possible Mechanism of Hydrogen Explosion in Unit 4



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

Source: TEPCO

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



International Nuclear Event Scale (INES)

Level	Off-site Impact	On-site Impact	Defense-in-depth Degradation
7	Major release		
6	Significant release		
5	Limited release	Severe damage	
4	Minor release	Significant damage / Fatal exposure of worker	
3	Very small release	Severe spread of contamination / health effects to worker	Near accident
2		Significant spread of contamination / overexposure of worker	Significant failure
1			Beyond Operation limit
0			

Out of scale

Amount of Released Radioactive Material to determine INES Rating

INES level 7 : > 10^{16}Bq equivalent

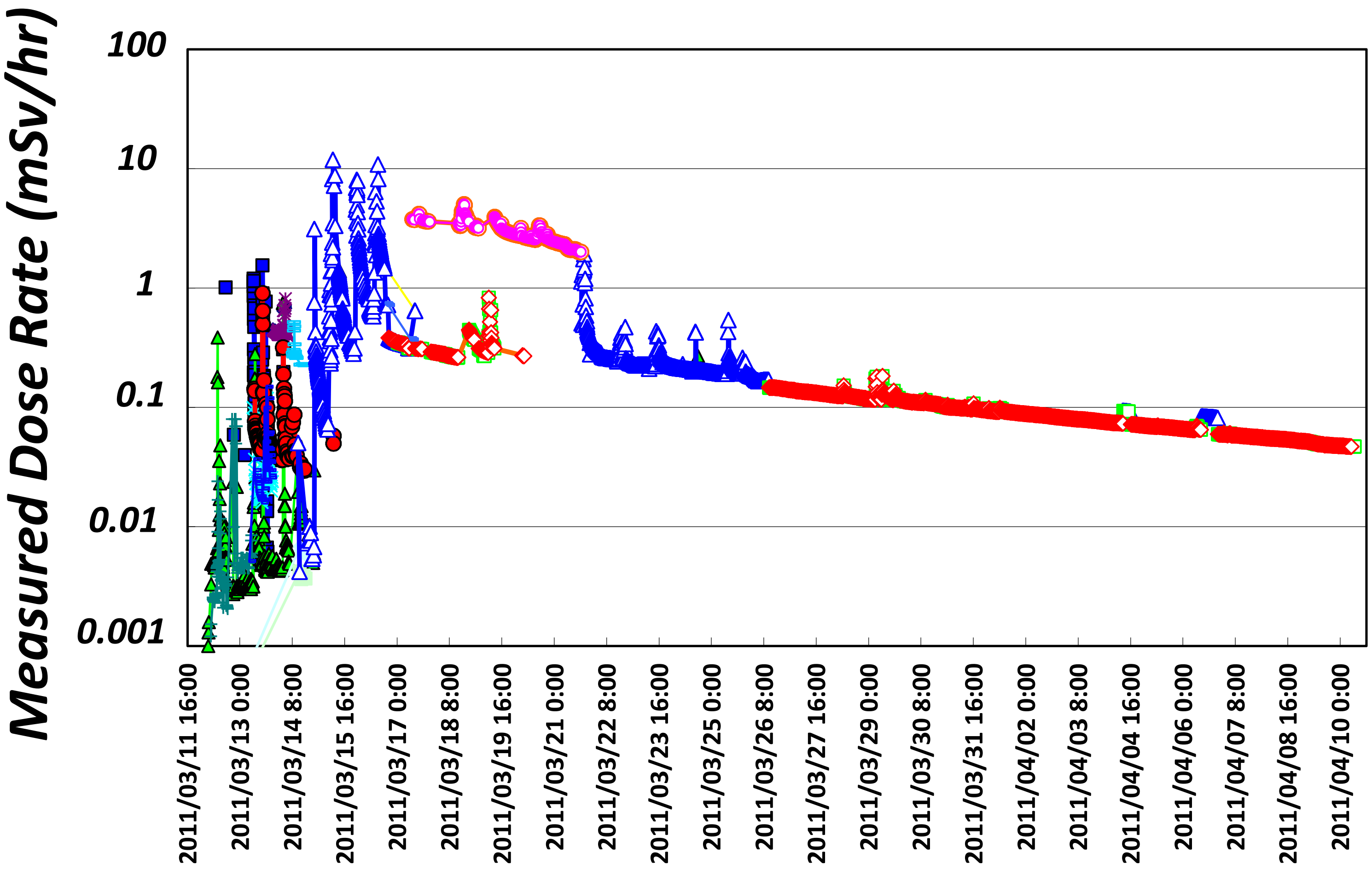
	Estimated release from Fukushima Daiichi		(Reference) Release from Chernobyl
	by NISA	by Nuclear Safety Commission	
Iodine 131 (a)	130 thousands T Bq ($1.3X10^{17}$Bq)	150 thousands T Bq ($1.5X10^{17}$Bq)	1,800 thousands T Bq ($1.8X10^{18}$Bq)
Cesium 137	6 thousands T Bq ($6.0X10^{15}$Bq)	[illegible]	…sands T Bq (…$X10^{16}$Bq)
Iodine value conversion (b)	240 thousands T Bq ($2.4X10^{17}$Bq)	[illegible]	…usands T Bq (…$X10^{18}$Bq)
(a) + (b)	**370 thousands T Bq ($3.7X10^{17}$Bq)**	[illegible]	**…usands T Bq (…$X10^{18}$Bq)**

Example of Release Rate assumed in a SA code

Ba group	2.60E-04
Ce group	4.00E-06
Cs group	5.80E-02
I group	6.70E-02
La group	8.40E-07
Ru group	5.40E-10
Te group	3.00E-02
Xe group	9.60E-01

INES Manual (2008) co-sponsored by IAE…

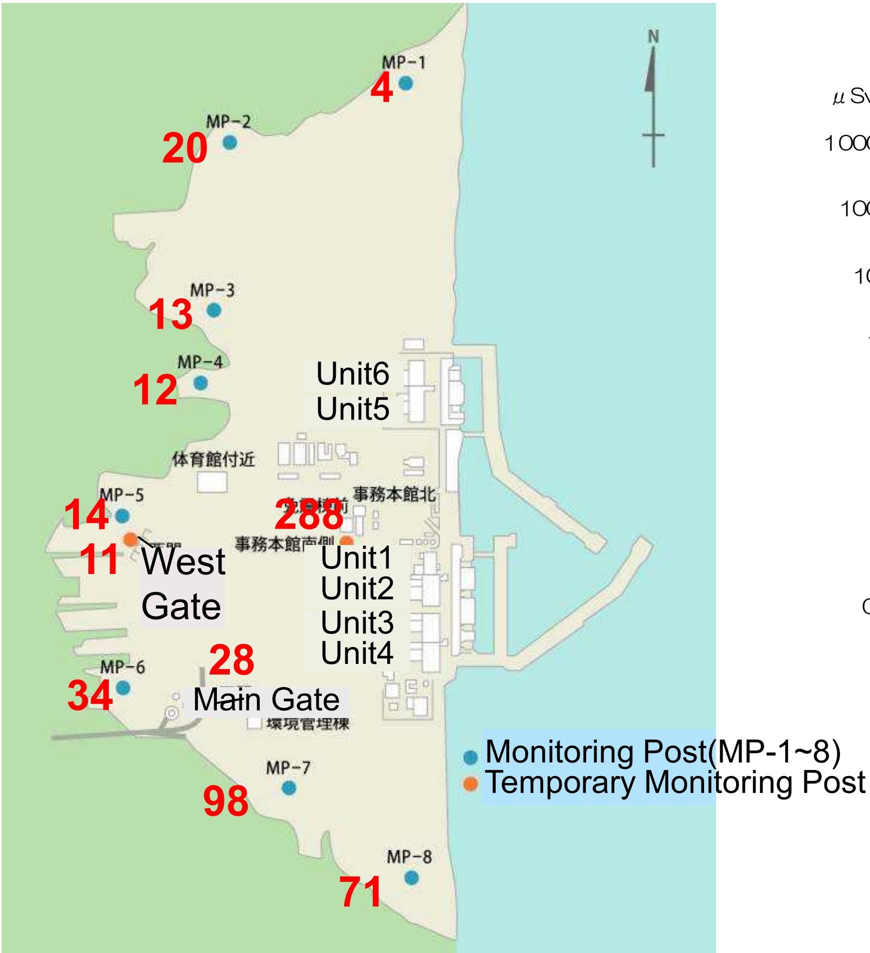
On-site Radiation Monitoring in Fukushima Daiichi Site From March 11 to April 10

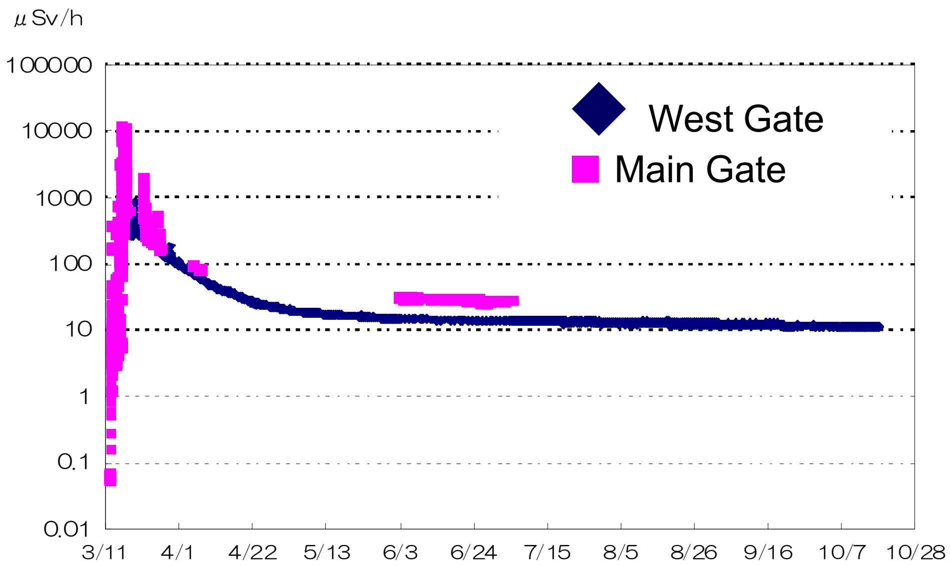


Source: NISA & TEPCO's press release

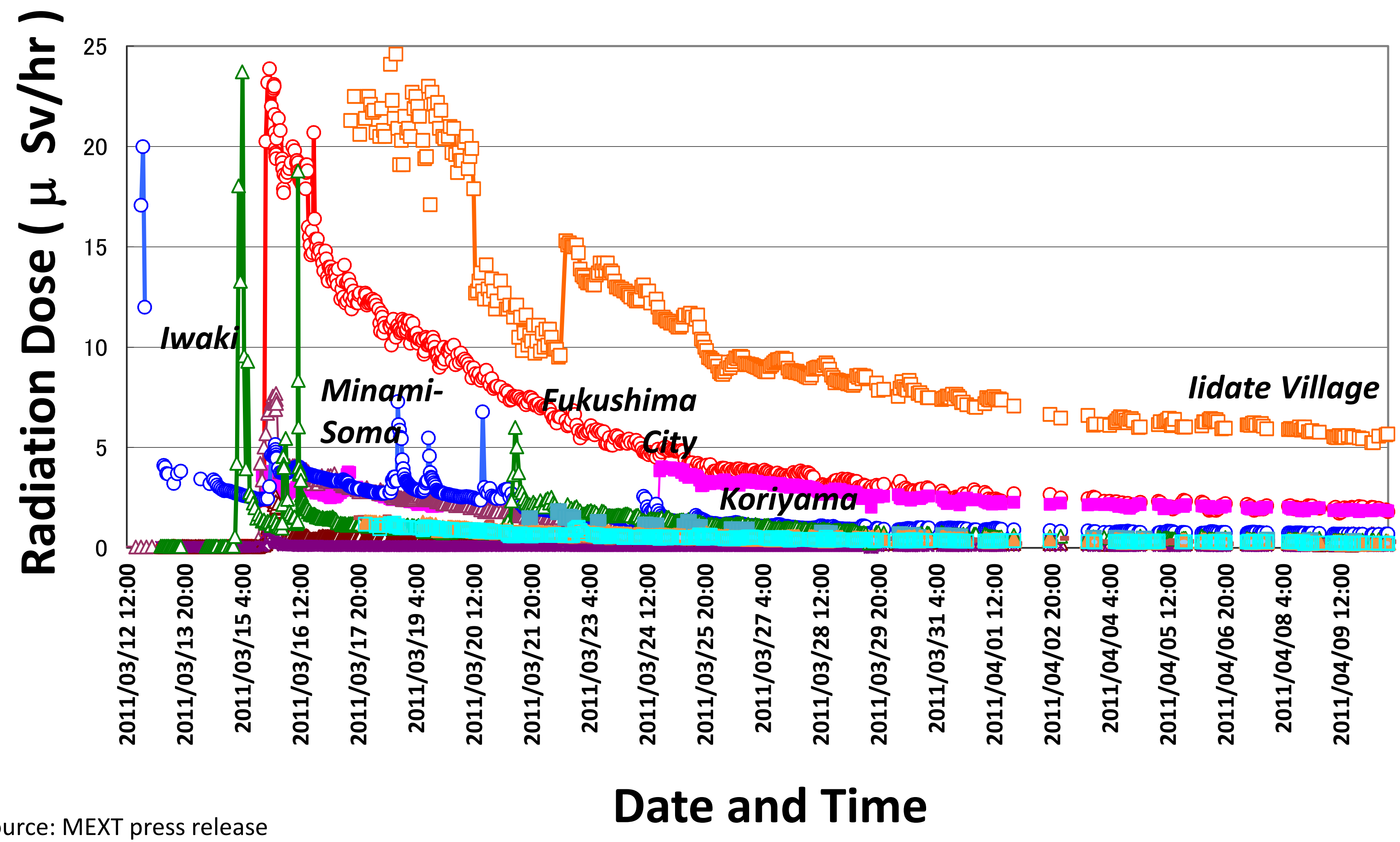
On-site Radiation Monitoring in Fukushima Daiichi Site From March 11 to October 17

dose rate measured at on-site monitoring posts



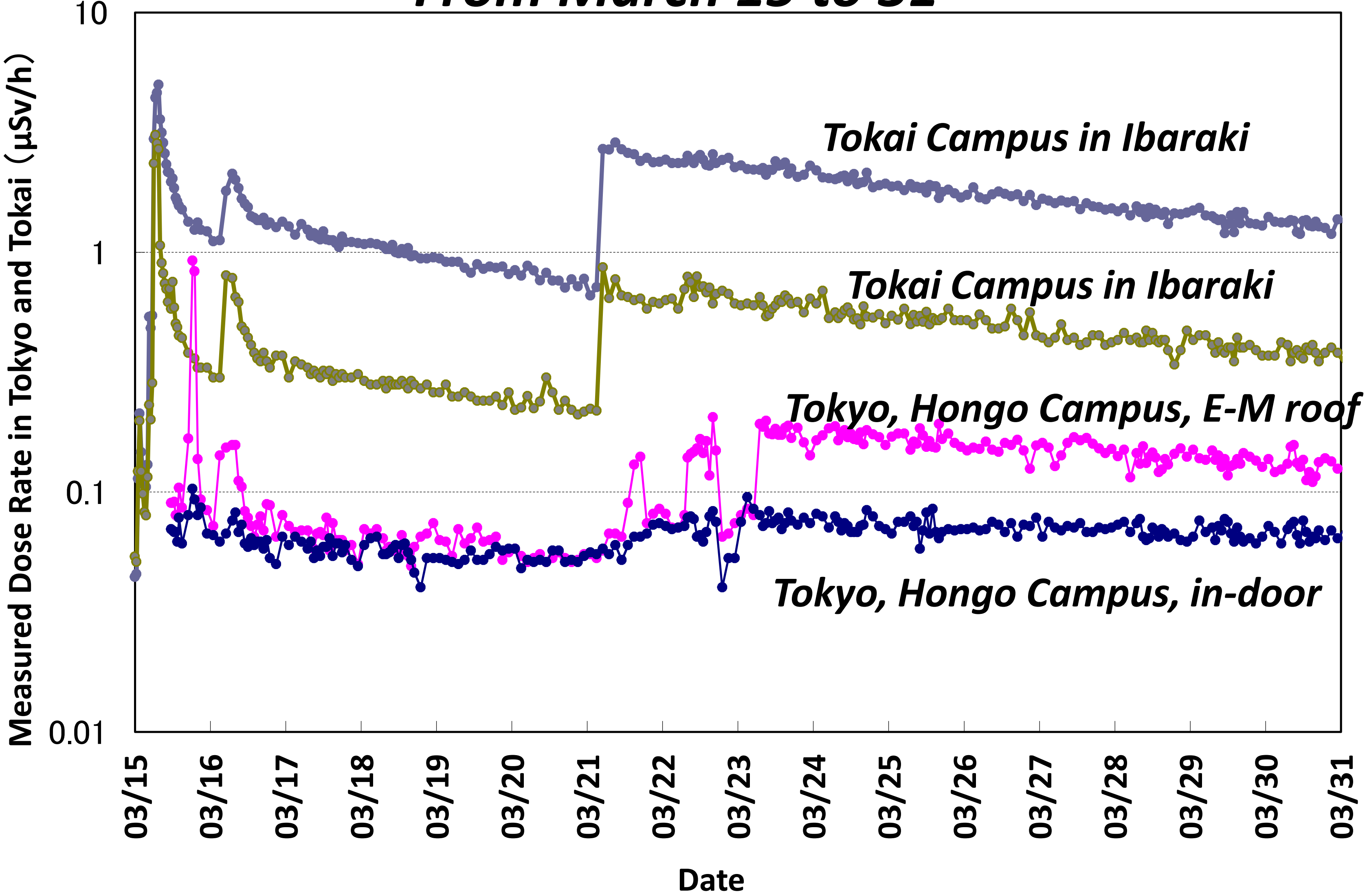


Monitoring Radiation Dose in Fukushima Prefecture



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

Integrated Dose by External Exposure

SPEEDI code

Adult

from March 12 to April 24, 2011

Effective Dose in mSv

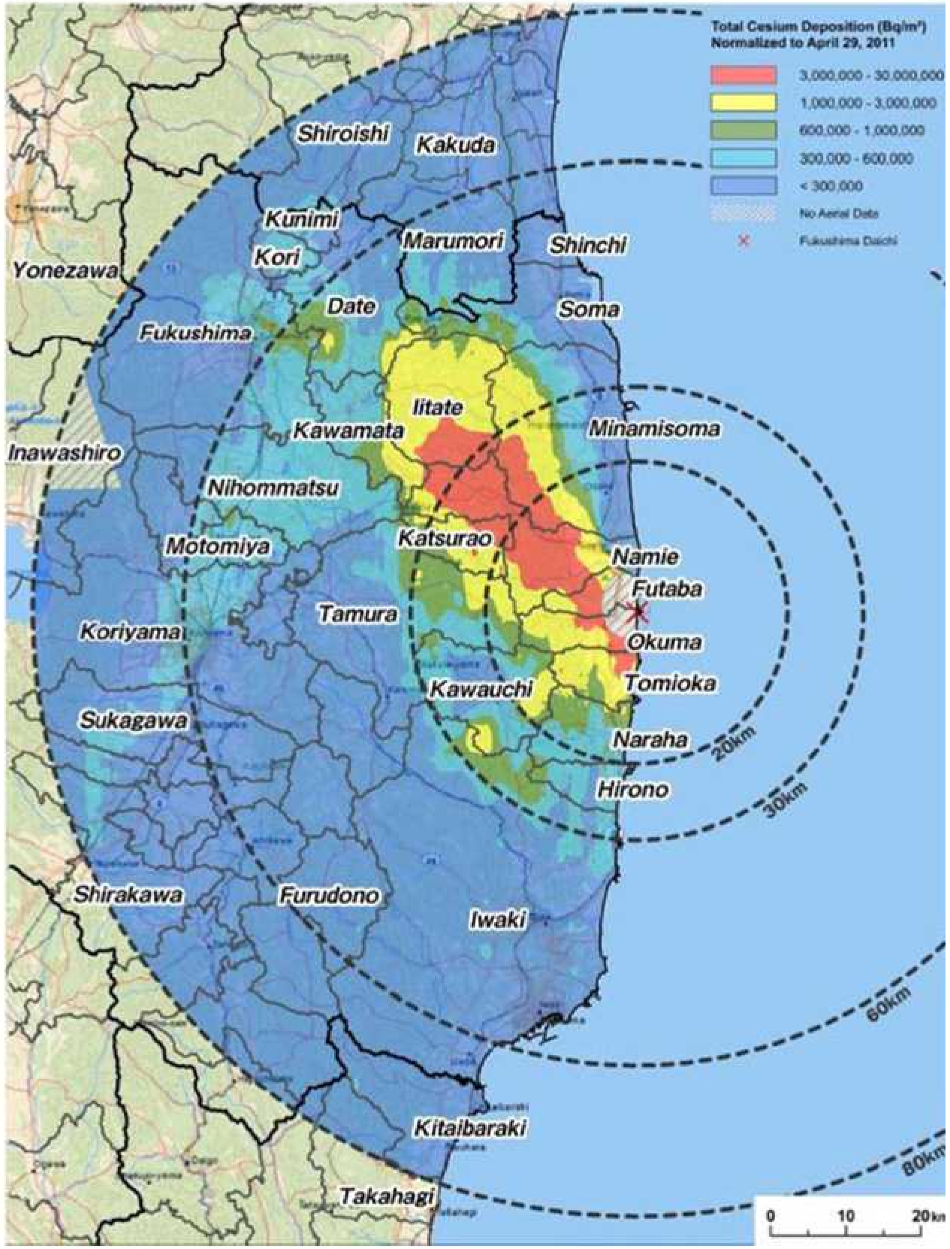
1	100
2	50
3	10
4	5
5	1

Cesium Deposition

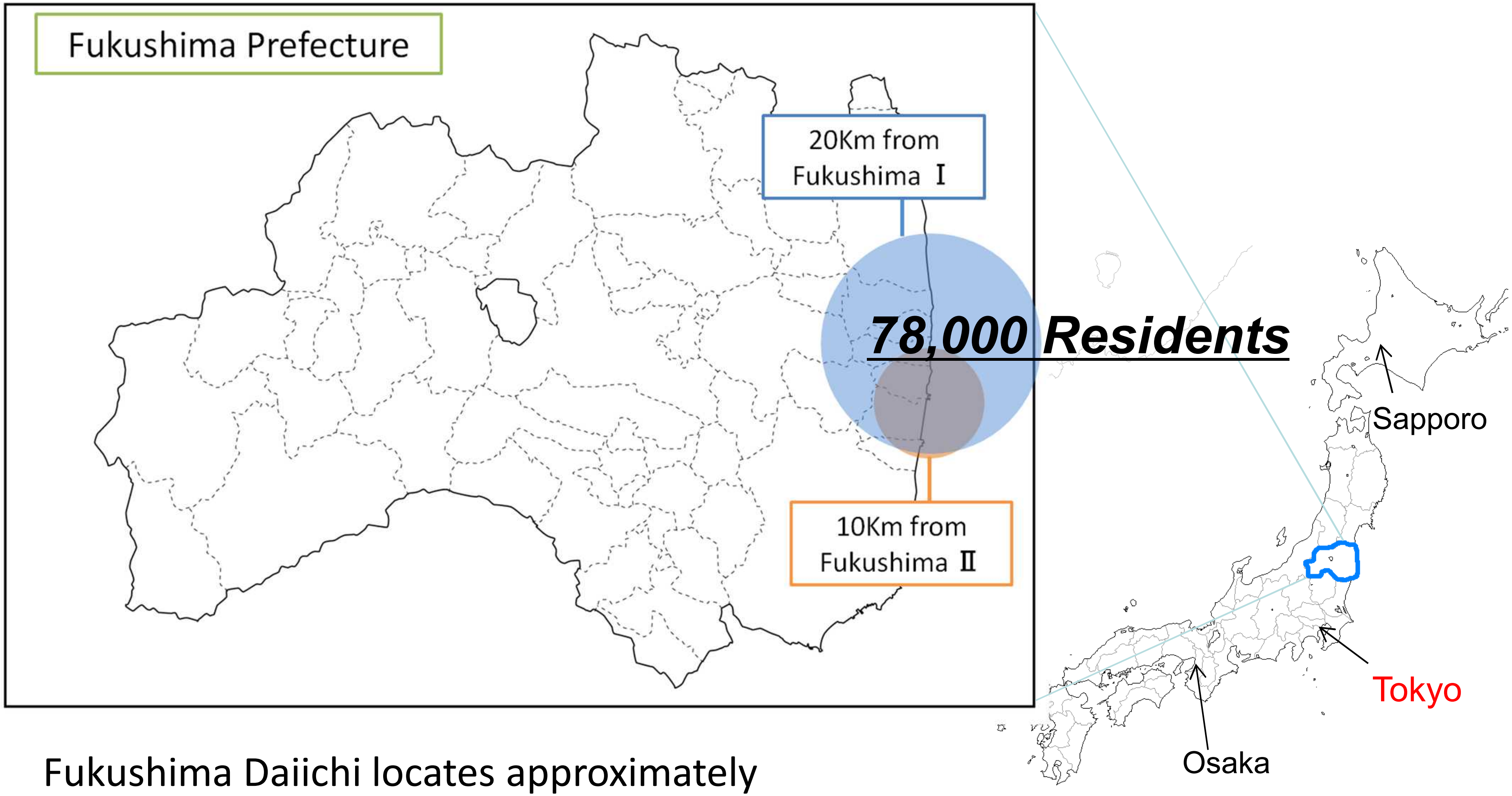
April 29, 2011

Aerial Measuring Results

Joint US / Japan Survey Data



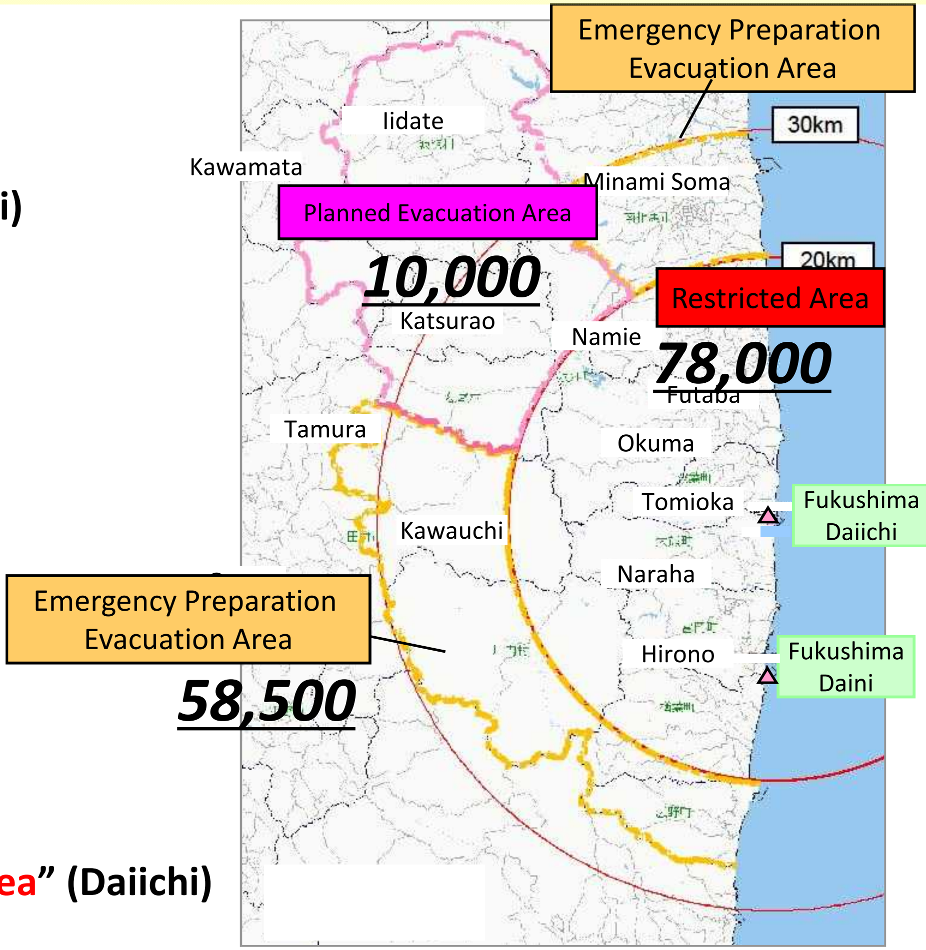
Evacuation of Residents



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.



Source: NISA website

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"

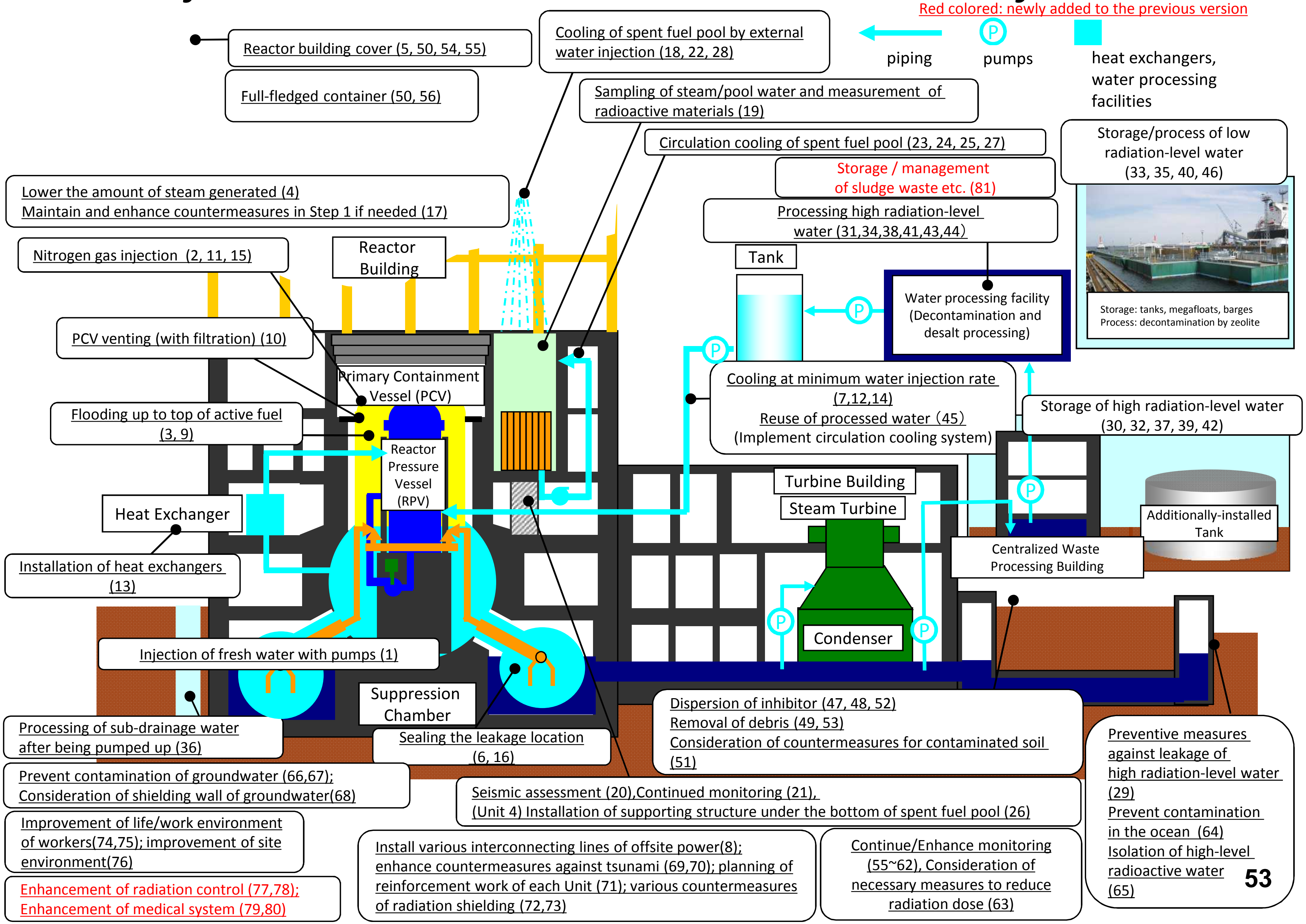
Short-term Issues

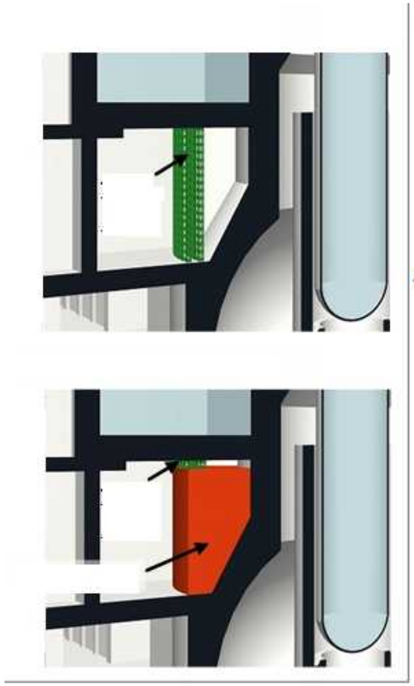
- ***Core cooling*** **:** *Stable Cooling to Cold Shut-down by Dec. 16 ?*
  - Continuous and stable core cooling
  - Understanding of core condition
- ***Mitigation***
  - Consideration of full-fledged processing facilities
  - Safe storage of secondary wastes
  - Prevention of contamination of groundwater
- ***Monitoring / Decontamination***
  - Clear understanding of contamination and release rate
  - Dose reduction and decontamination
- ***Environmental improvement***
  - Dose control for workers

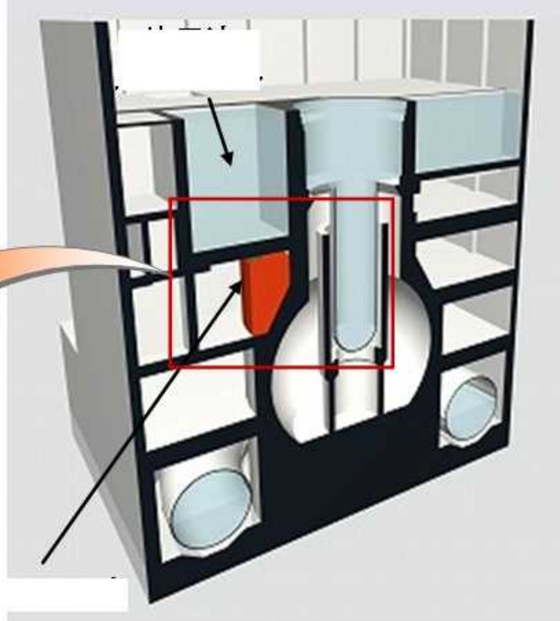
TEPCO’s Roadmap on April 17

	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

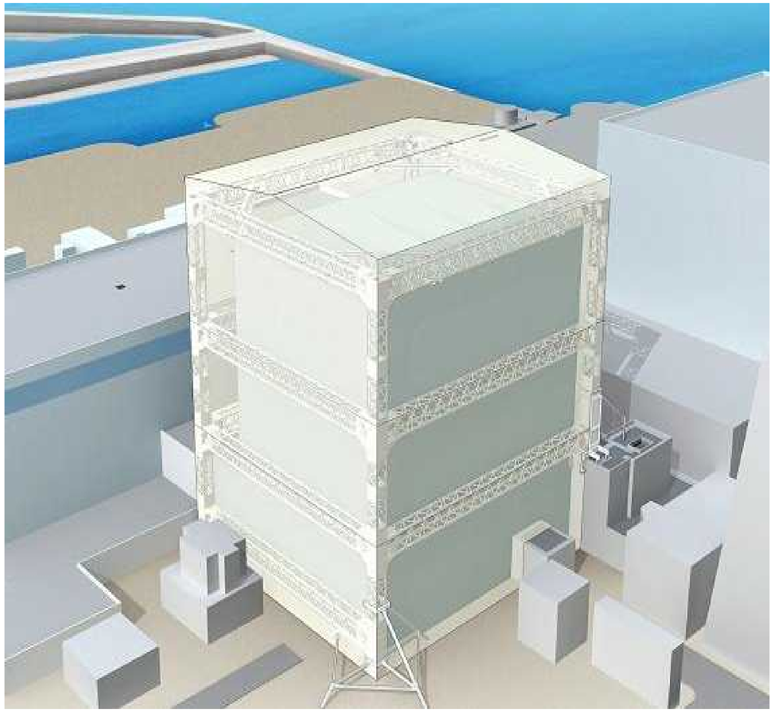
Major Countermeasures in the Power Station as of June 17



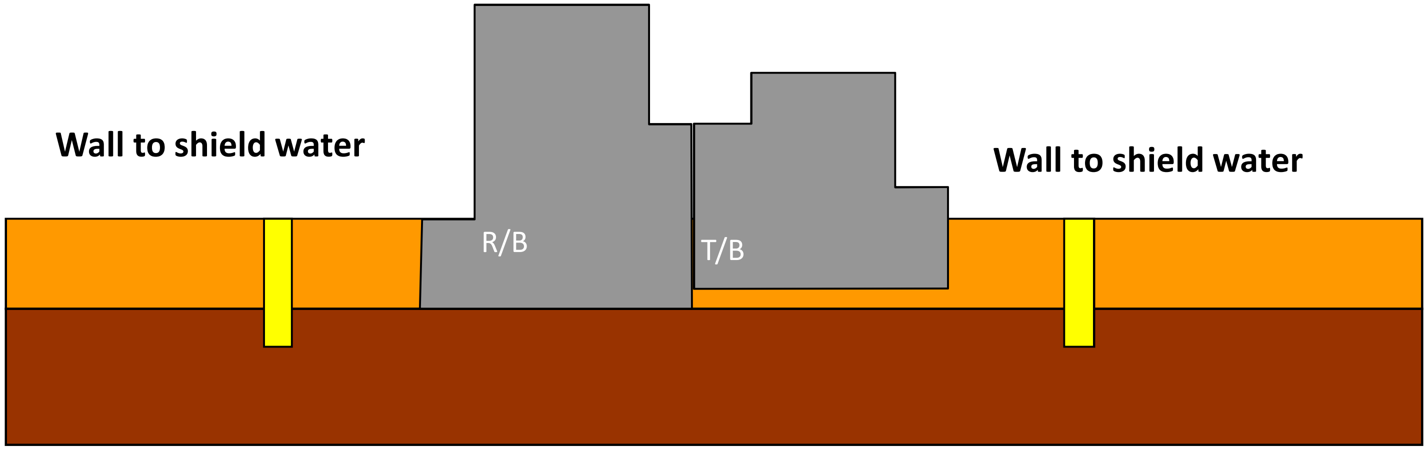




Installing Supporting Structure for SFP in Unit 4 Completed by July 30



Install of Reactor Building Cover for Unit 1



Measure to shield groundwater

Source: TEPCO

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)

Long-term Issues

- ***Long-term storage and disposal of radioactive wastes***
  - Interim storage of core debris and radioactive wastes
  - Final disposal of radioactive wastes

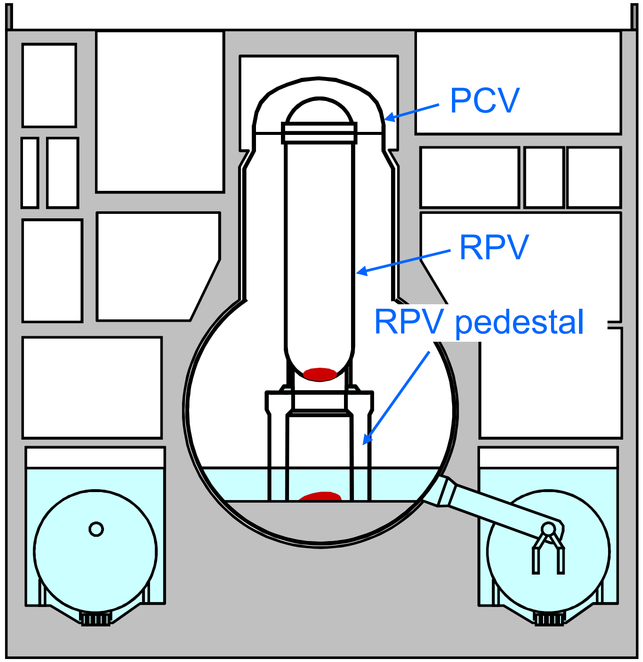
- ***Defueling***
  - Defueling from SFPs
    1) Preservation of integrity of the SFP structures until completion of defueling activities
    2) Construction of Fuel / Cask handling equipments

  - Defueling from RPV/PCVs
    1) Understanding of core condition
    2) Stopping RPV/ PCV water leakage for reflooding

- ***Decontamination***
  - Contaminated soil and off-site radiological mitigation
  - Interim storage of primary and secondary wastes generated from decontamination work

- ***Decommissioning***
  - Handling of severely damaged and radiated core materials
  - Completion of water processing

Materials Issues to be Evaluated



- **Evaluation of RPV/PCV materials**
  - **- Corrosion Evaluation**

    Proper assumption of progression of corrosion

  - **- Mechanical Property Evaluation**

    Elevated temperature history exceeding design basis was observed during the accident

    → Change in mechanical property should be evaluated for seismic analysis

- **RPV Pedestal**

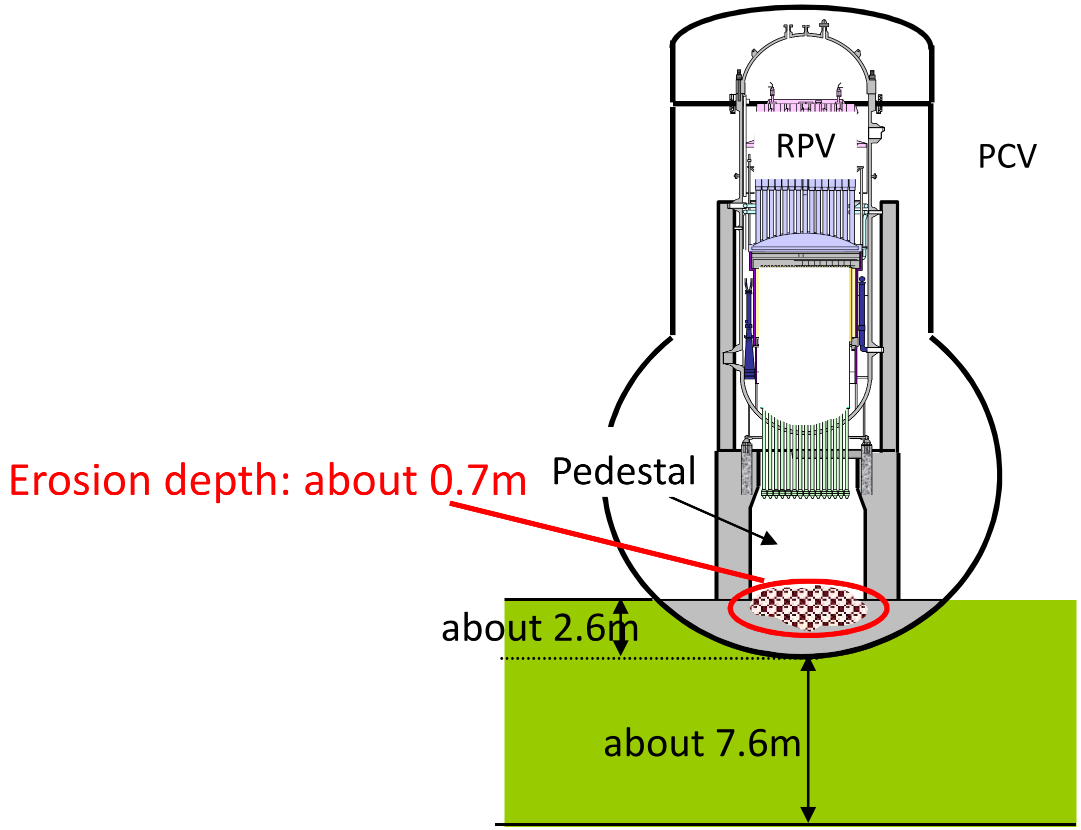
  Evaluation of stability of RC (Reinforced Concrete) structure of RPV pedestal after the high temperature history and immersion to the sea water

- **Development of Corrosion Mitigation Techniques such as:**

  - Reduction of O_2 and Cl^-
  - Cathodic Protection
  - Inhibitors

Erosion of Concrete in RCV in Unit 1

- Possibly the melted fuel eroded concrete at the PCV bottom. The erosion depth analysis was carried out by MAAP code. **On realistic conditions, the result of the erosion depth analysis became about 0.7m.**
- **The gas emitted by the disassembly of concrete is not detected, indicating no further erosion of concrete by the melted fuel.**

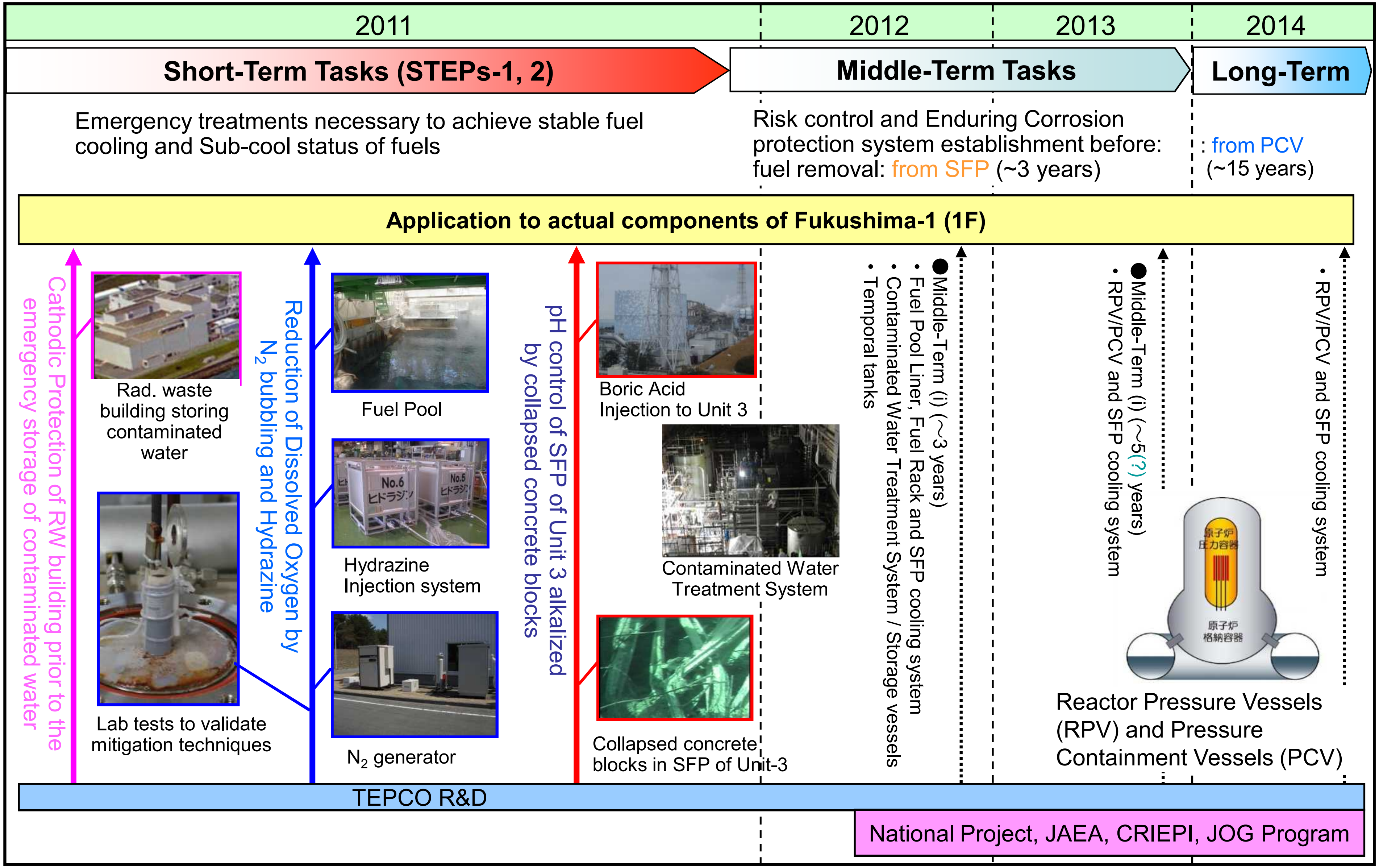


Source: TEPCO

Analysis Condition

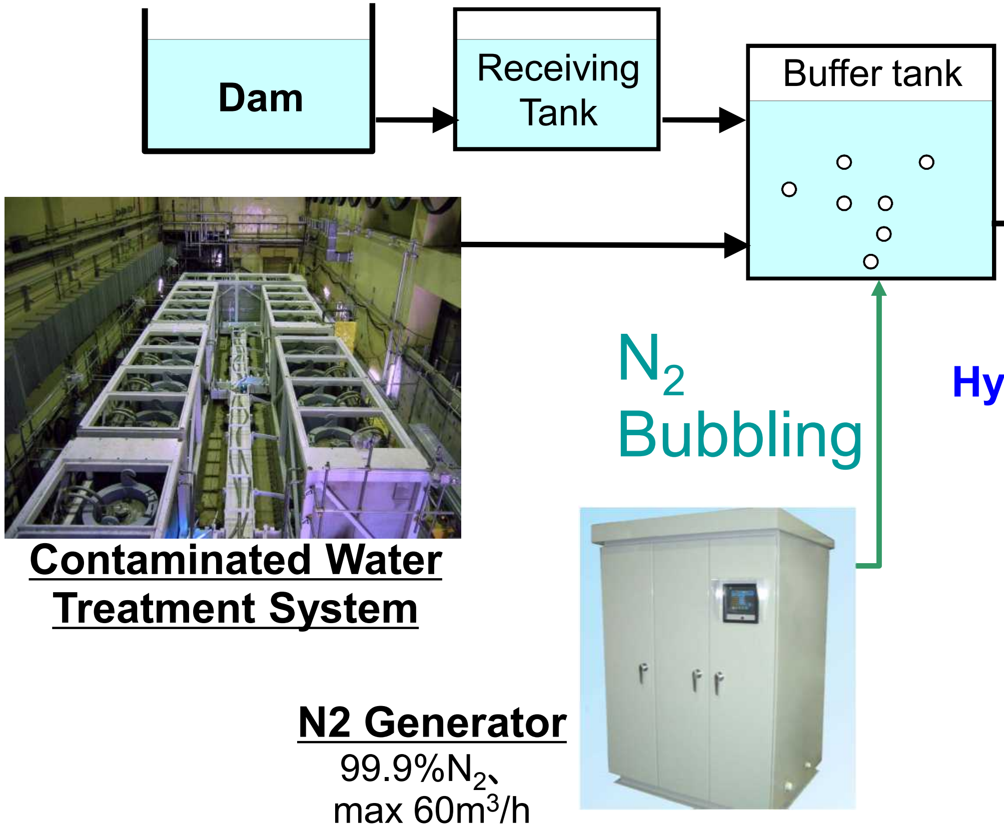
- Deposition Condition
  - The fuel which dropped inside the pedestal spread also to the drywell floor through the slit.
  - A certain amount of fuel flowed also into the equipment / floor drain sump pit in the pedestal.
- Decay Heat
  - Decay heat due to the volatile fission products was not added up for the erosion depth analysis. (When erosion of concrete started, the volatile fission products had already been emitted.)

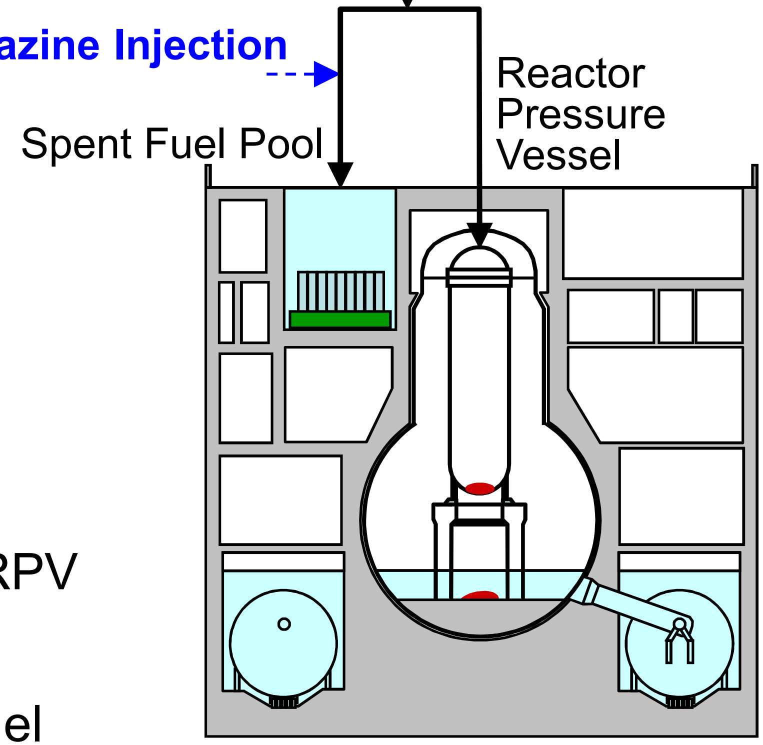
Current Schedule of Corrosion Management



Source: TEPCO

Reduction of Dissolved Oxygen (Nitrogen Bubbling)





- N_2 bubbling was applied to the coolant of RPV and SFP to reduce the Dissolved O_2
- Hydrazine injection is also applied to the fuel pool of Units 2~4

Source: TEPCO

Reduction of Dissolved Oxygen (Hydrazine Injection)

- **Hydrazine (N_2H_4)：**
  - Common deoxidant for general boilers including fossil power plants
  - Also used as deoxidant in PWRs

- **Deoxygenation reaction by hydrazine:**

$$N_2H_4 + O_2 \rightarrow N_2 + H_2O$$

Reaction products (N_2, H_2O) have no negative effect on corrosion

However, hydrogen is produced by thermal decomposition reaction in >350ºC range

$$2N_2H_4 \rightarrow 2NH_3 + N_2 + H_2$$

- **Hydrazine injection is applied to fuel pools where temperature is now well controlled.**
- **Application to RPV/PCV will be considered when the fuel cooling will be stable enough not to exceed H_2-generation temperature.**

Desalting from Spent Fuel Pools

- **Objective:**

  To reduce Cl^- concentration to < 10 ppm in order to prevent localized corrosion of fuel pool liner made of 304 stainless steel

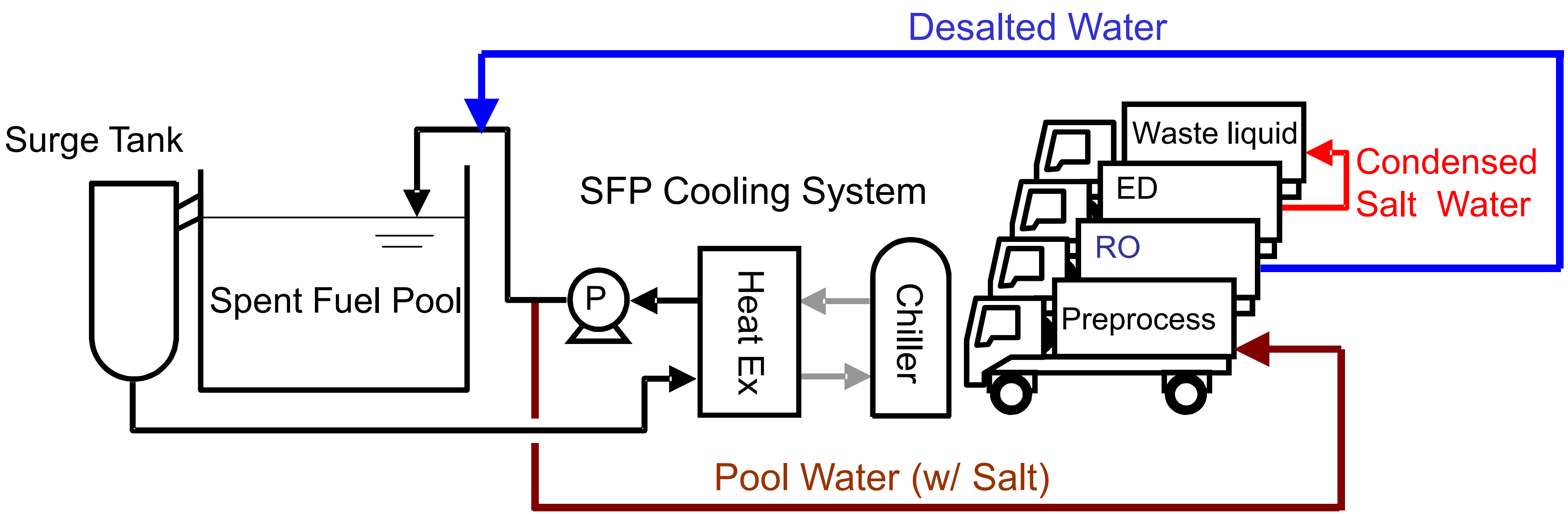
- **System Composition:**

  (1) Pre-processing: Removal of oil and radioactive materials to protect RO

  (2) Reverse Osmosis membrane (RO): Transferring salt to waste liquid

  (3) Electrodialytic Treatment (ED): Condensing waste liquid

  → Desalted water: 94%, Waste liquid: 6%



Source: TEPCO

System application to SFP of Unit-4

Desalting System is mounted on trucks and will be transferred to Units 2 and 3 in series

Source: TEPCO

Stability Assessment of RPV/PCV

- **Function as the boundary of radioactive material has been lost, however, it is still crucial until the fuel removal to:**

  - Secure seismic stability
  - Prevent drastic increase in leak rate of coolant

  ⬇

  Minimizing corrosion of structural materials is the key issue

- **Different characteristics from SFP evaluation**
  - Lower corrosion rate compare to localized corrosion of stainless steels

    More extensive consideration can be (and needed to be) performed

  - Garnering information is far more difficult due to radiation-related impediments

    Coordination and cooperation with another projects and institutes are important

Source: TEPCO

Preliminary Lessons Learned

The importance of Defense in Depth has been recognized with this accident

(1) Appropriate Design Basis Accidents (DBAs)

Appropriate consideration for natural hazards by design

- Design basis tsunami height 5.7m against 15m of actual tsunami height

(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

- All the emergency DGs, except 1 air-cooled DG, were water-cooled and all were located in the basement of T/Bs

- All the sea-water pumps were located slightly above the design tsunami height and they were with no protection against water.

② Appropriate Accident Management (AM) measures for both prevention and mitigation of Severe Accidents

- No AMs for SFP cooling and Hydrogen gas control in the R/Bs

- No AMs training under severe conditions for multi-units under continuous aftershocks

Defense-in-depth for Systems Safety

1	Prevention of Abnormal Operation and Failures	Conservative Design, High Quality in Construction and Operation
2	Control of Abnormal Operation and Detection of Failures	Control, Limiting and Protection Systems, and other Surveillance Features
3	Control of Accidents within the Design Basis	Engineering Safety Features and Accident Procedures
4	Control of Severe Plant Conditions including Prevention of Accident Progression and Mitigation of the Severe Accident Consequences	Complementary Measures and Accident Management
5	Mitigation of Radiological Consequences of Significant Releases of Radioactive Materials	Off-site Emergency Response

Preliminary Lessons Learned (continued)

(3) Difficult Situations for Post Severe Accident Recovery

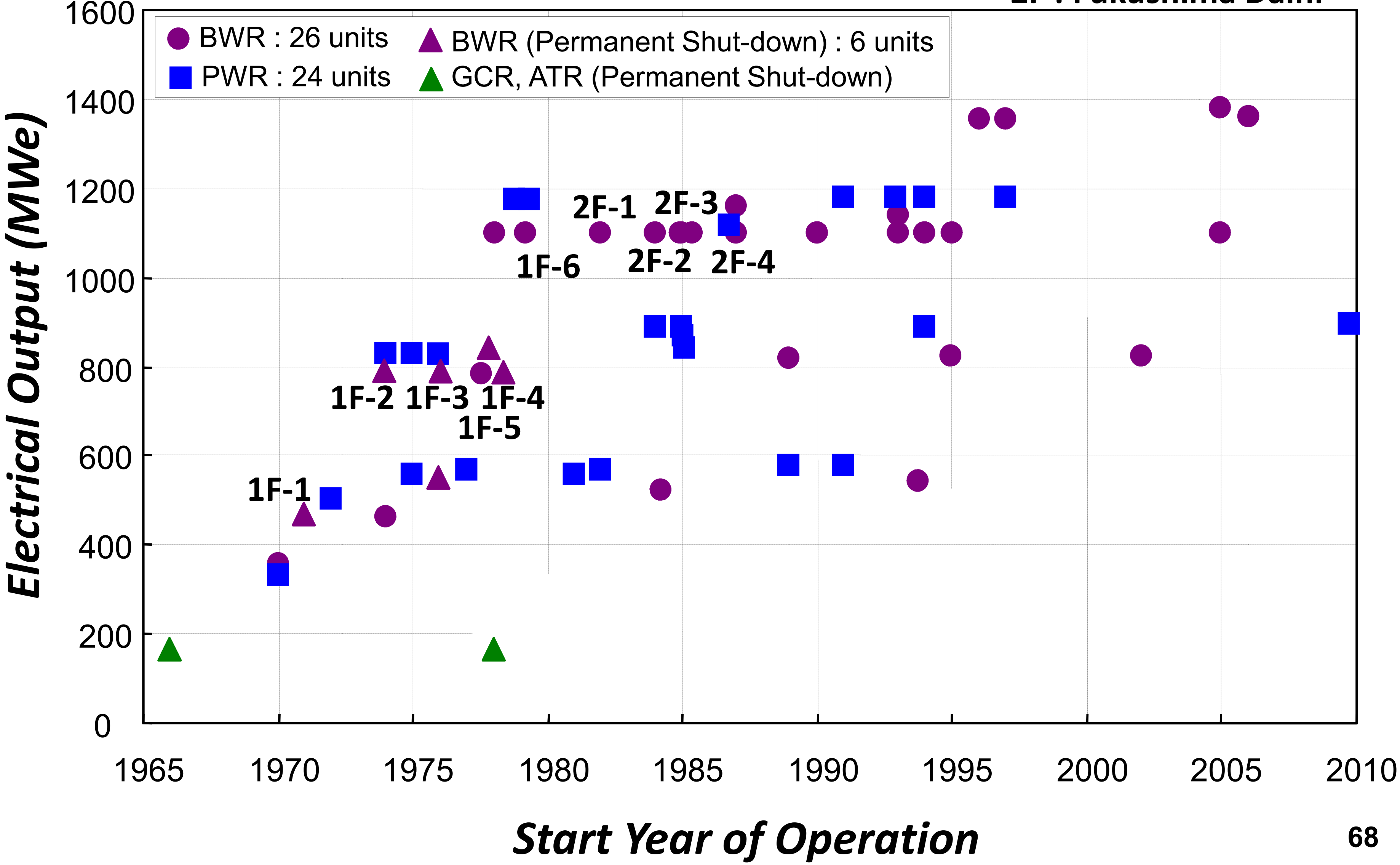
- *Warning for aftershocks and subsequent Tsunami*
- *High radiation in the working area*
- *Massive radioactive debris within the site*

(4) Emergency Preparedness and Responses

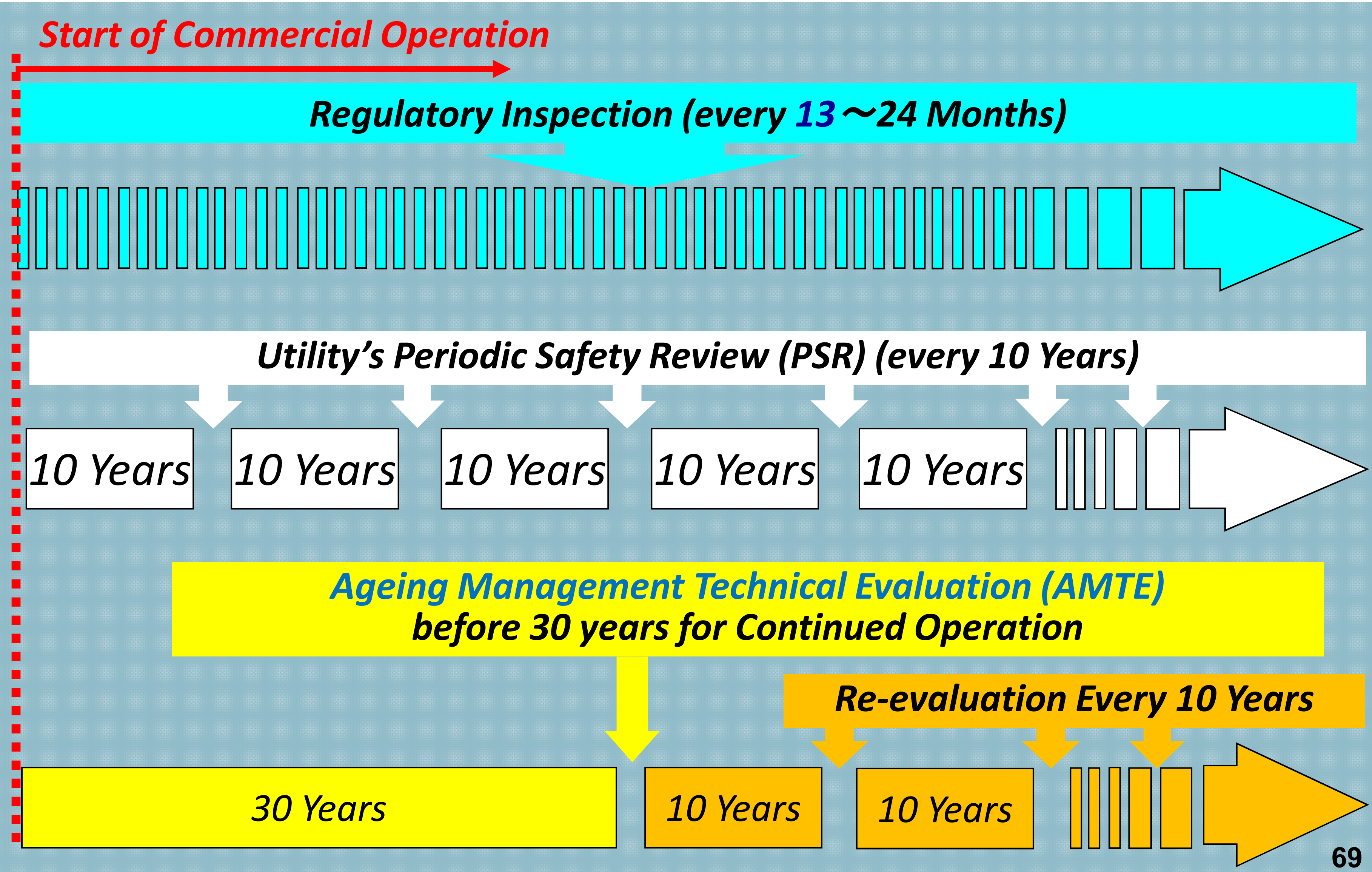
- *Evacuation zones*
- *Function of off-site center*
- *Communication*
- *Radiation monitoring*

Nuclear Power Plants in Japan

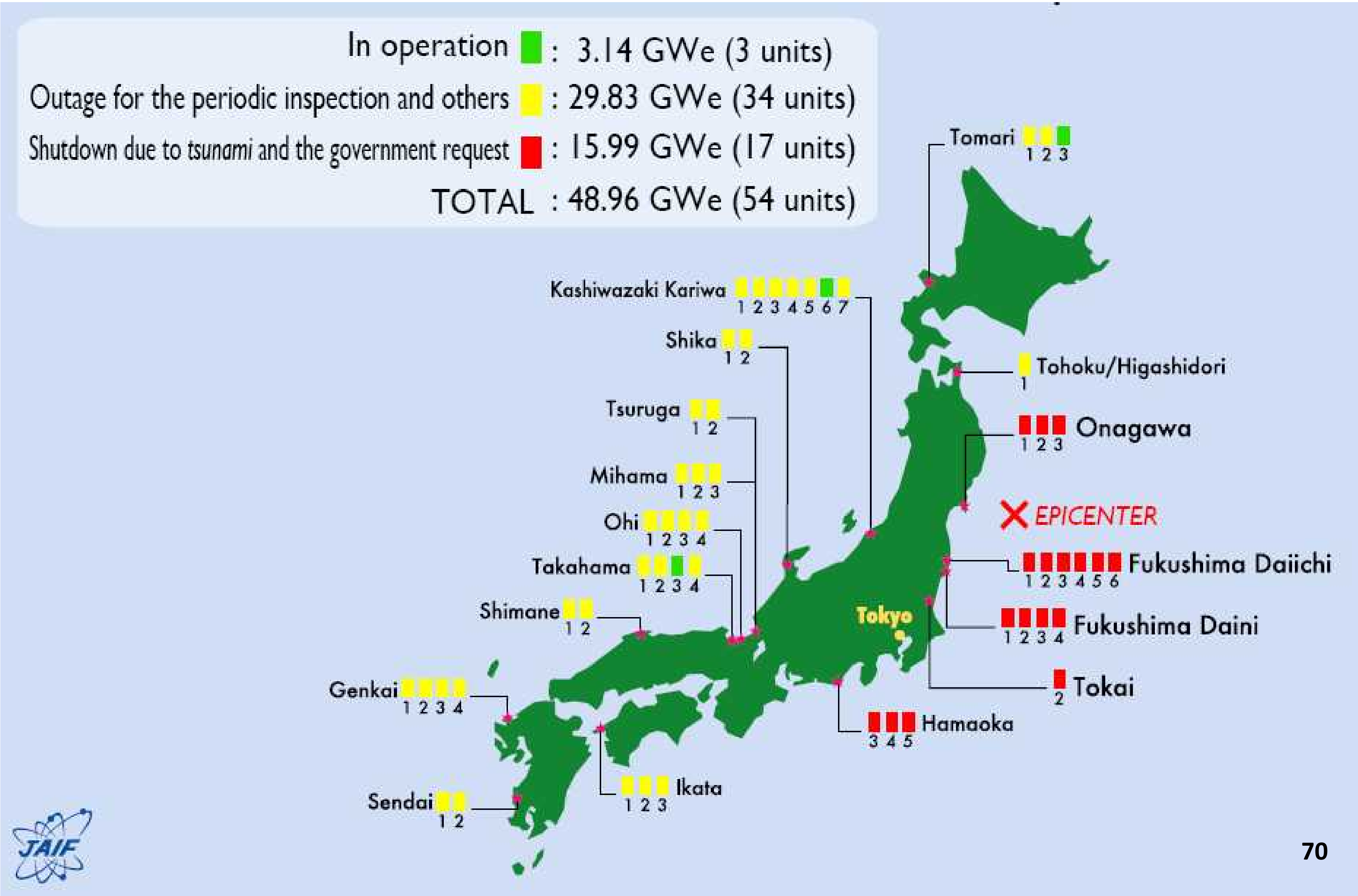
1F : Fukushima Daiichi
2F : Fukushima Daini



Regulatory Systems for Inspection, Periodic Safety Review and Ageing Management Technical Evaluation

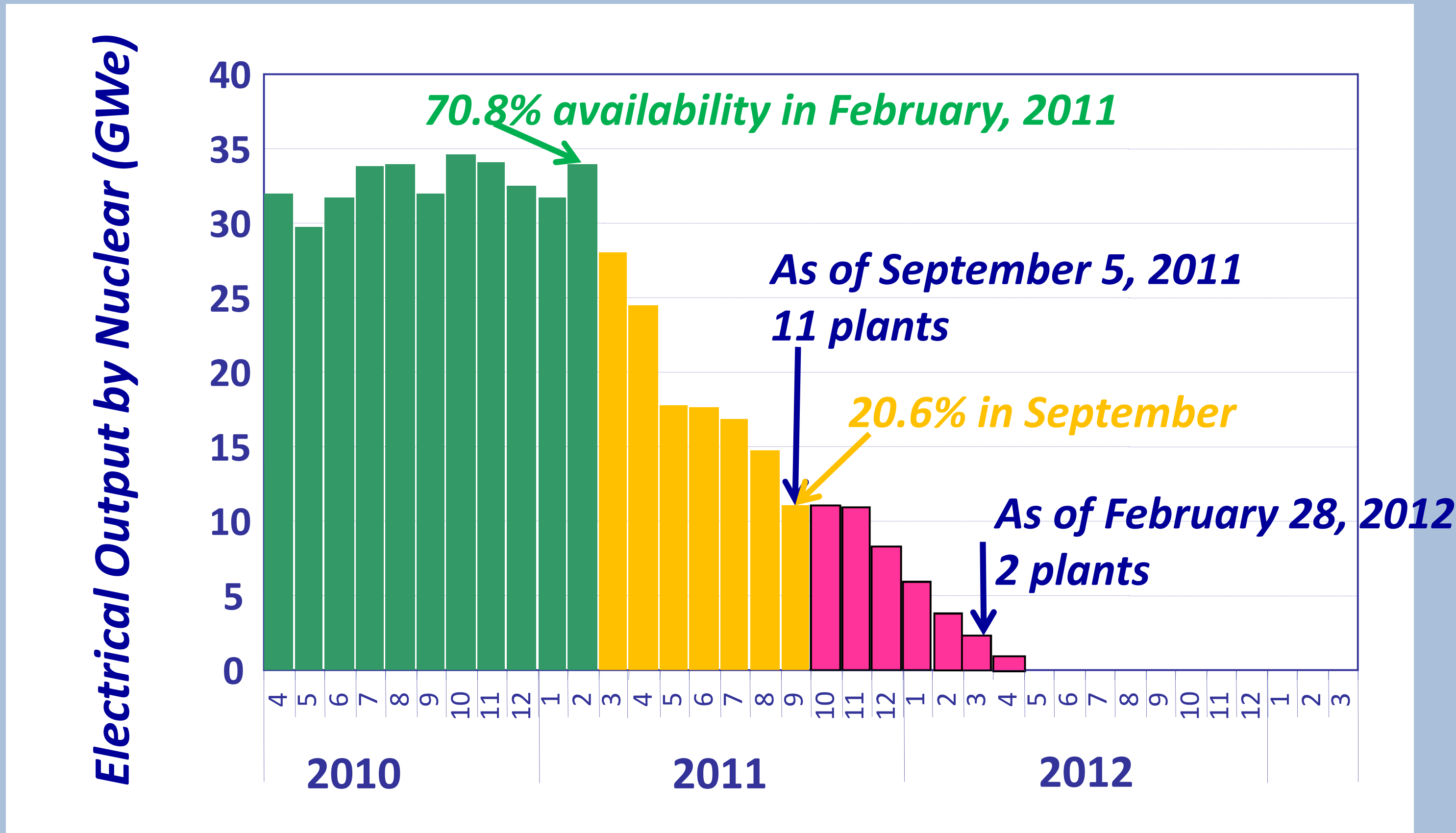


Current Status of Nuclear Power Plants in Japan



Status of Nuclear Power Plants in Japan

No Restart from Regular Outage after March 11



Thank you very much.