Fukushima Daiichi Accident: Why it happened, What happened and the Challenge of nuclear safety in Japan

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HEU-TAMU Summer School on Nuclear Reactor System Engineering

Introduction of lecturer

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- Area of Interest: Nuclear Safety and Simulation
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My presentation today is based on the following papers

- **MIYATA Koichi and NISHINO Shoichiro**：Evaluation of plant behavior during the accident at Fukushima Daiichi Nuclear Power Station, **International Journal of Nuclear Safety and Simulation, Vol.3, No.4,2012, pp.243-254 .**
- **International Workshop on Functional Modeling Method, November 23-24, 2012, Lingby, Denmark .**

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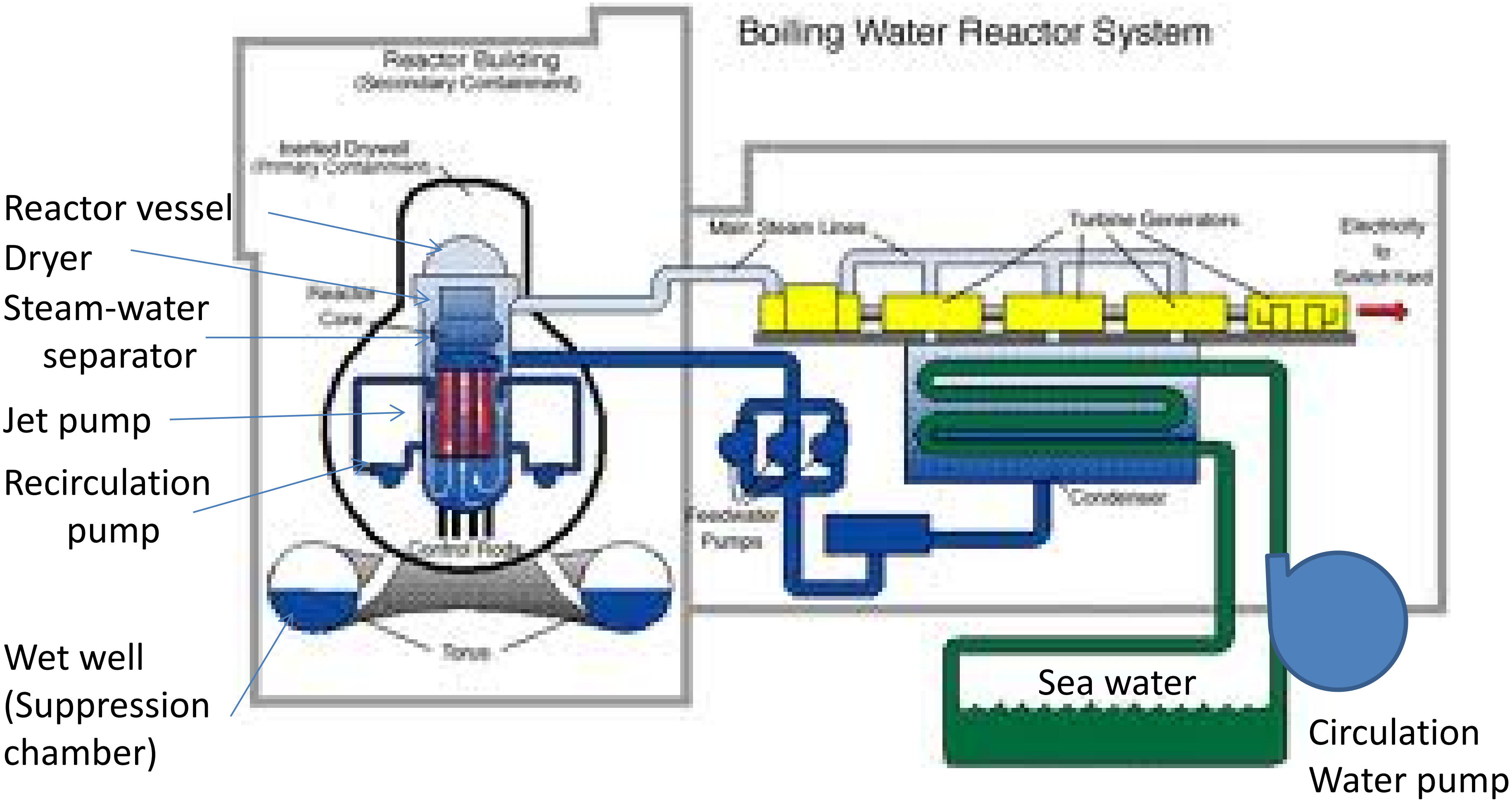
1.Introduction

1.1 Boiling Water Reactor

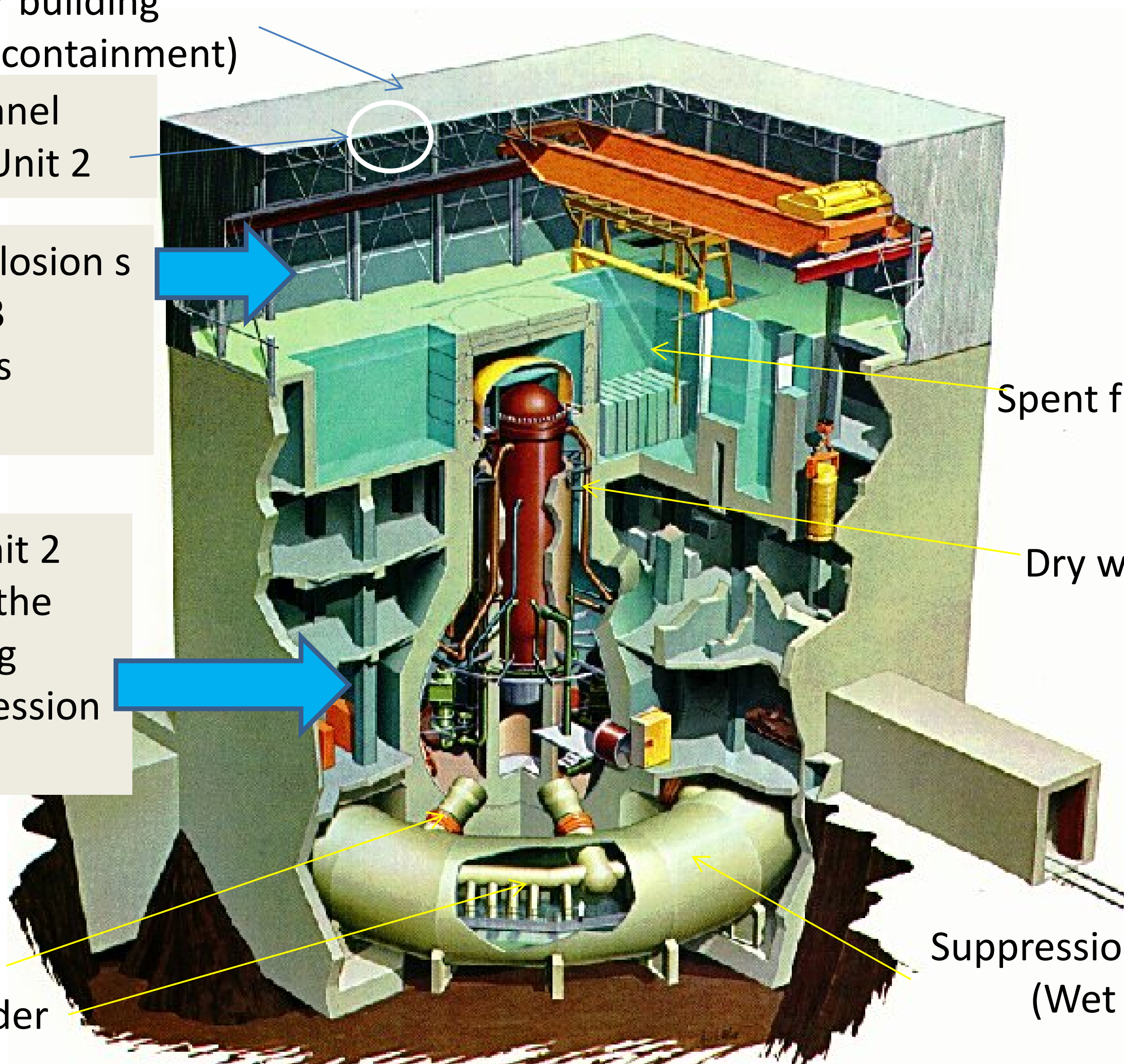
1.2 Fukushima Daiichi and Daini NPS

1.3 Plate Tectonics of Earth

1.1 Boiling Water Reactor



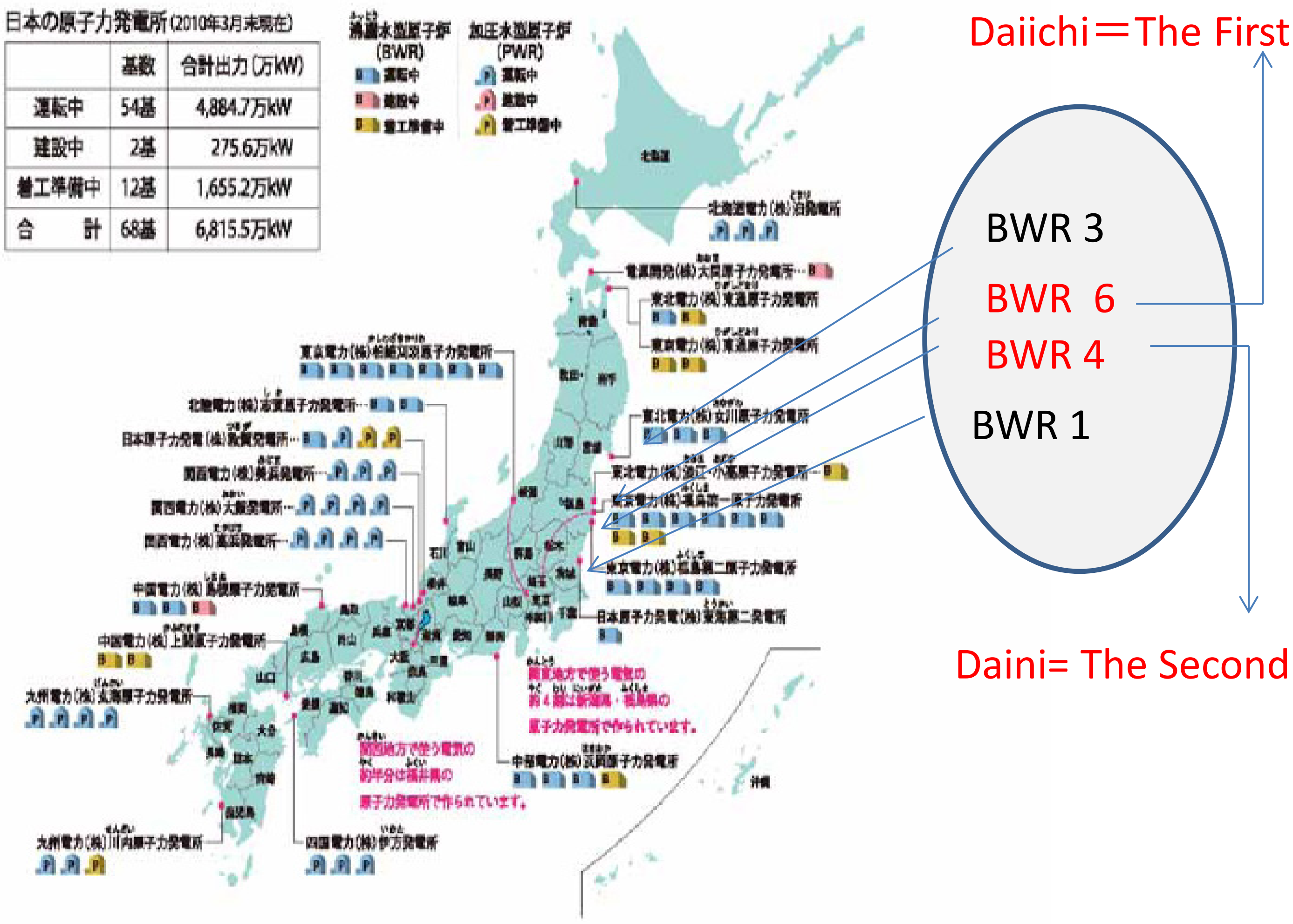
Mark 1 Containment



Nuclear Power Stations in Japan
(As of March, 2010)

日本の原子力発電所(2010年3月末現在)

	基数	合計出力(万kW)
運転中	54基	4,884.7万kW
建設中	2基	275.6万kW
着工準備中	12基	1,655.2万kW
合　計	68基	6,815.5万kW



出所：チャレンジ！原子力ワールド

1.2 Fukushima Daiichi NPS

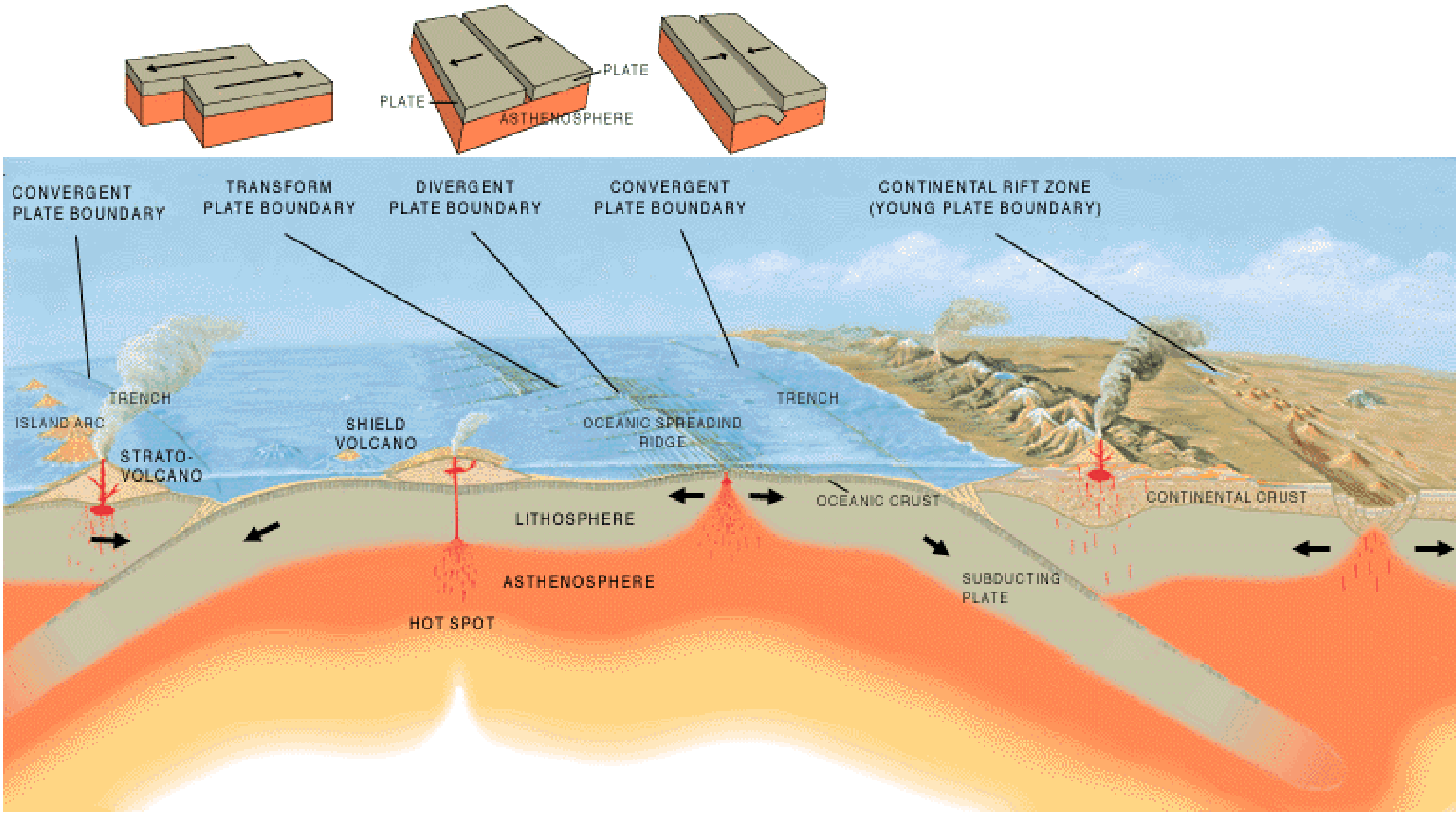
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Electric power (Mwe)	460	784	784	784	784	1100
Commercial operation	1971	1974	1976	1978	1978	1979
Reactor type	BWR-3	BWR-4	BWR--4	BWR-4	BWR--4	BWR-5
Containment type	MARK I	MARK I	MARK I	MARK I	MARK I	MARK II
Isolation cooling system	IC	RCIC	RCIC	RCIC	RCIC	RCIC
State at earthquake	On power	On power	On power	Shutdown	Shutdown	Shutdown

1.2 Fukushima Daini NPS

	Unit 1	Unit 2	Unit 3	Unit 4
Electric power (Mwe)	1100	1100	1100	1100
Commercial operation	1982	1984	1985	1987
Reactor type	BWR-5	BWR-5	BWR-5	BWR-5
Containment type	MARK II	MARK II-Mod	MARK II-Mod	MARK II-Mod
Isolation cooling system	RCIC	RCIC	RCIC	RCIC
State at earthquake	On power	On power	On power	On power

Fukushima Daiichi NPS before Accident

1.3 Plate tectonics of earth



Deep-Sea Drill Ship used in Ocean Drilling Program

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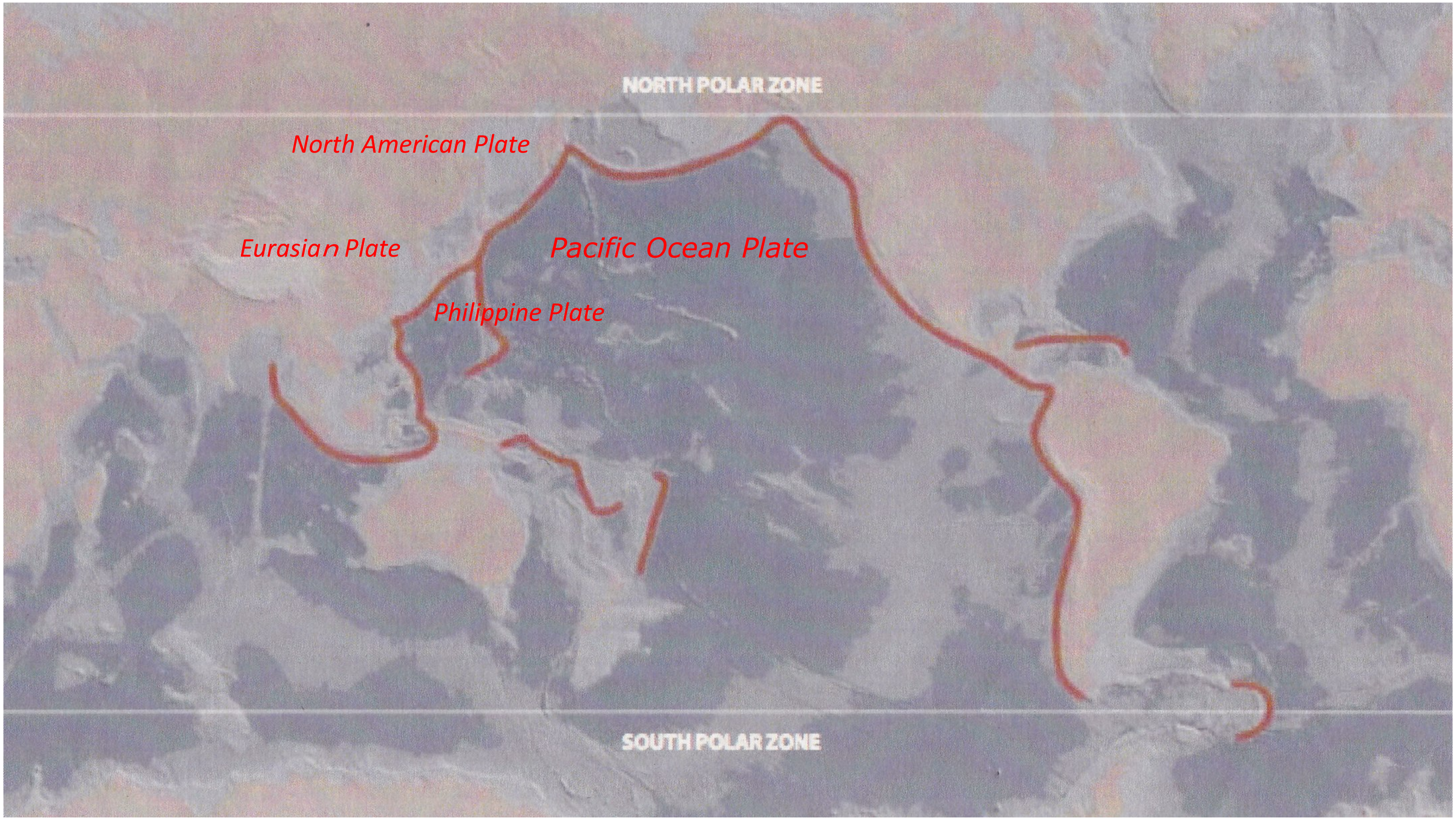
Plate tectonics of earth



2. Impact of earthquake and tsunami

2.1Great East Japan Earthquake

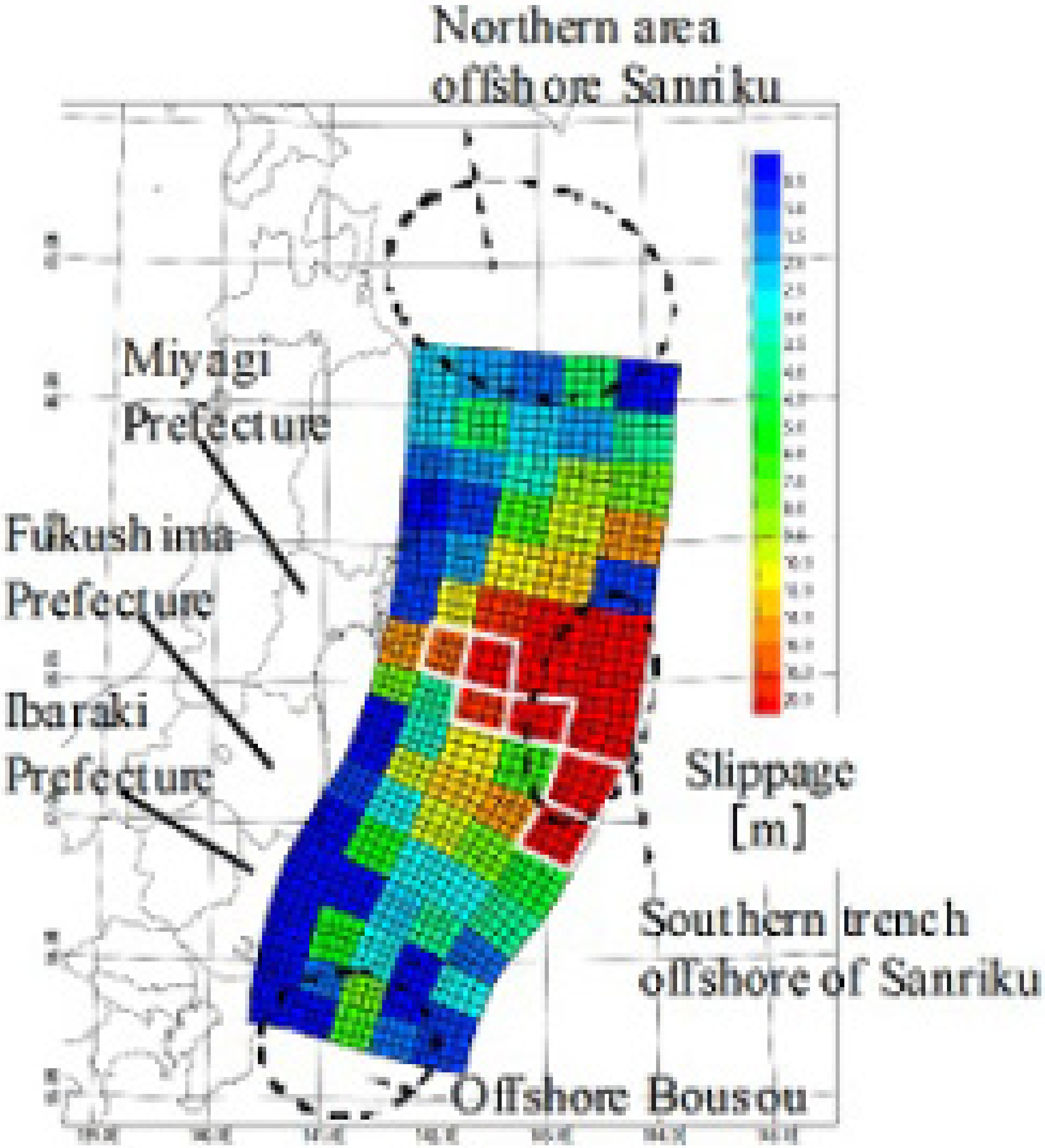
2.2Impact of the earthquake on the power station

2.3Direct damage to the Fukushima Daiichi NPS from the Tsunami

2.4Direct damage to the Fukushima Daini NPS from the Tsunami

2.1 Great East Japan Earthquake

- The main shock of the Great East Japan Earthquake that occurred at 14:46 on March 11, 2011, was a devastating earthquake of magnitude 9.0 (the fourth largest ever recorded in the world)
- The earthquake caused massive slippage in the southern trench offshore of Sanriku and to a lesser extent in the northern area offshore of Sanriku and in the trench offshore of Bousou.
- The earthquake was caused by the movement of several seismic source regions offshore of: Sanriku, Miyagi Prefecture, Fukushima Prefecture and Ibaraki Prefecture


Northern area
offshore Sanriku
Miyagi
Prefecture
Fukushima
Prefecture
Ibaraki
Prefecture
Slippage
[m]
Southern trench
offshore of Sanriku
Offshore Bousou

2.1 Great East Japan Earthquake

- The focal area of the earthquake stretched from offshore of Iwate Prefecture to offshore of Ibaraki Prefecture, approximately 500 kilometers in length and about 200 km in width, with a maximum slip of more than 50 meters.
- Past seismic ground motion and tsunamis caused by individual source regions had been assessed.

- TEPCO, as well as the Headquarters for Earthquake Research Promotion (the Japanese government's earthquake investigation and research institution) had not expected that earthquakes would occur with the concurrent movement of all of the above regions.

2.1 Great East Japan Earthquake

- The observed seismic motions at the Fukushima Daiichi NPS's R/B base mat partially exceeded the maximum acceleration used as the design basis seismic ground motion, Ss, the guideline for seismic safety assessment, however, it was largely below the design limits.

- On the other hand, the March 11 tsunami greatly exceeded the design basis, with the height evaluated as approximately 13 meters
- The tsunami height was more than twice the height resulting from evaluation based on the assessment method applied by the Japan Society of Civil Engineers (Onahama Peil - local construction datum level - O.P. +5.4 ~ 6.1 m).

2.2 Impact of the earthquake on the power station

- Although off-site power was lost due to the seismic motion, the emergency diesel generators (EDGs) started successfully and supplied emergency power to the NPS.
- Also high pressure injection systems including the isolation condenser (IC) and the reactor core isolation cooling (RCIC) were in operation as expected without any abnormalities.
- Judging from the plant parameters, it was believed that there were no abnormalities with the integrity of reactor coolant system boundaries or associated equipment.

2.2Impact of the earthquake on the power station

- Seismic resistance of the main facilities that is important for reactor safety was assessed using earthquake response analysis based on observed earthquake data
- It was confirmed that all calculated values were below the evaluation criteria

Seismic Analysis Results （Unit Mpa）

Equipment		Unit 1		Unit 2		Unit 3	
		Calculated Value	Assement critical value	Calculated Value	Assement critical value	Calculated Value	Assement critical value
Reactor core support structure		103	196	122	300	100	300
Reactor pressure vessel		93	222	29	222	50	222
Main steam system piping		269	374	208	360	151	378
Reactor containment vessel		98	411	87	278	158	278
Shutdown cooling system	pump	8	127				
	piping	228	414				
RHR	pump			45	185	42	185
	piping			87	315	269	363
Other*		105	310			113	335

*Other listed equipment subject to assessment:

(Unit 1) Isolation condenser system pipes

(Unit 3) High pressure coolant injection system (HPCI) steam pipes

2.2Impact of the earthquake on the power station

- Furthermore, Fukushima Daiichi Units 1 to 6 were visually inspected to the greatest extent possible.
- Within the scope of those checks, items important to safety and even facilities of low seismic class were almost completely unaffected by the earthquake.
- From the results of these investigations, it is presumed that the earthquake itself did not affect the nuclear power plant's safe operation.

2.2Impact of the earthquake on the power station

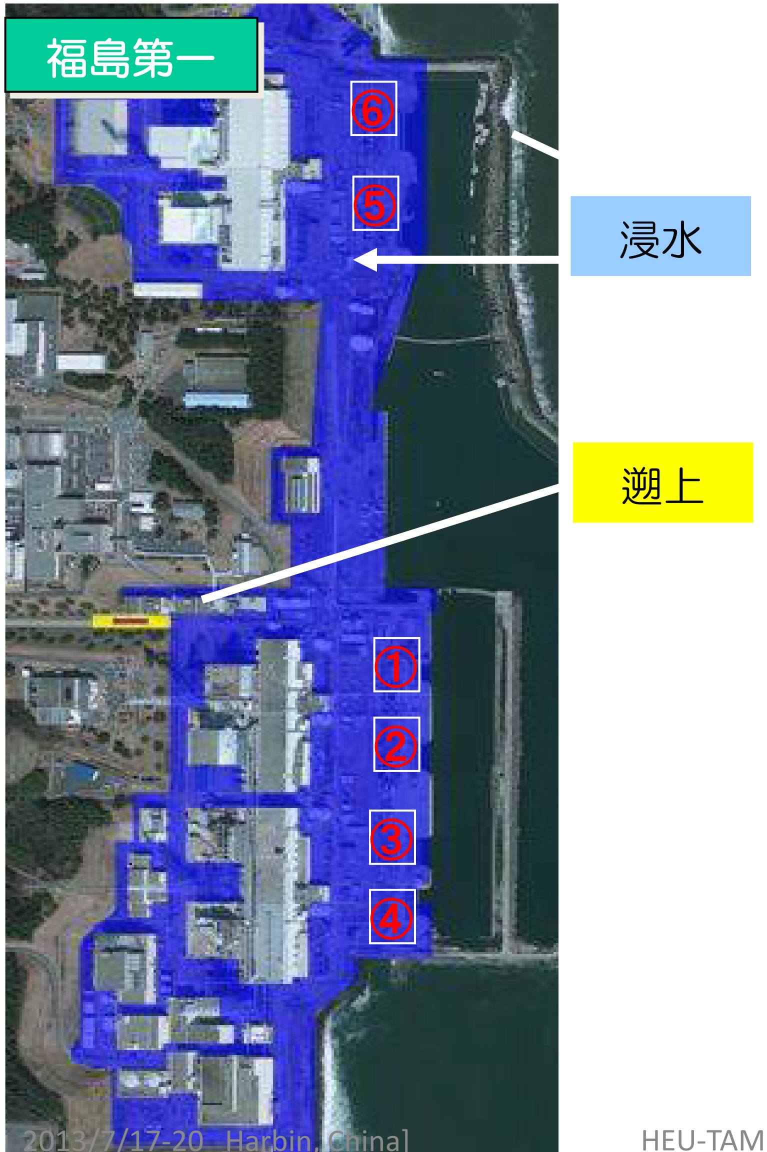
- Meanwhile, at Fukushima Daini NPS, the emergency cooling system pumps automatically started up after reactor scram and also operated with no abnormalities until the tsunami hit.
- The plants achieved cold shutdown safely with no core damage. Subsequent facility inspections found no damage to the functional performance of safety-critical equipment except for damage by the tsunami.
- Thus, it is considered that the earthquake had no impact on the functions of safety-critical systems.

2.3Direct damage to the Fukushima Daiichi NPS from the Tsunami

- About one hour after the earthquake, big tsunami arrived the plant site.
- At Fukushima Daiichi NPS, the tsunami run-up reached the ground level of major buildings (O.P.+10 m on Units 1 to 4, while O.P.+13 m on the Units 5 & 6.
- The flooded areas covered the entire area of major building.
- The flood height on Units 1 to 4 was approximately O.P. +11.5 m to 15.5 m, and flood depth approximately 1.5 to 5.5 m.
- On the side of Units 5 and 6, the flood height was approximately O.P. +13 m to +14.5 m, and flood depth approximately 1.5 m or less.

Submergence of Fukushima NPPs by tsunami

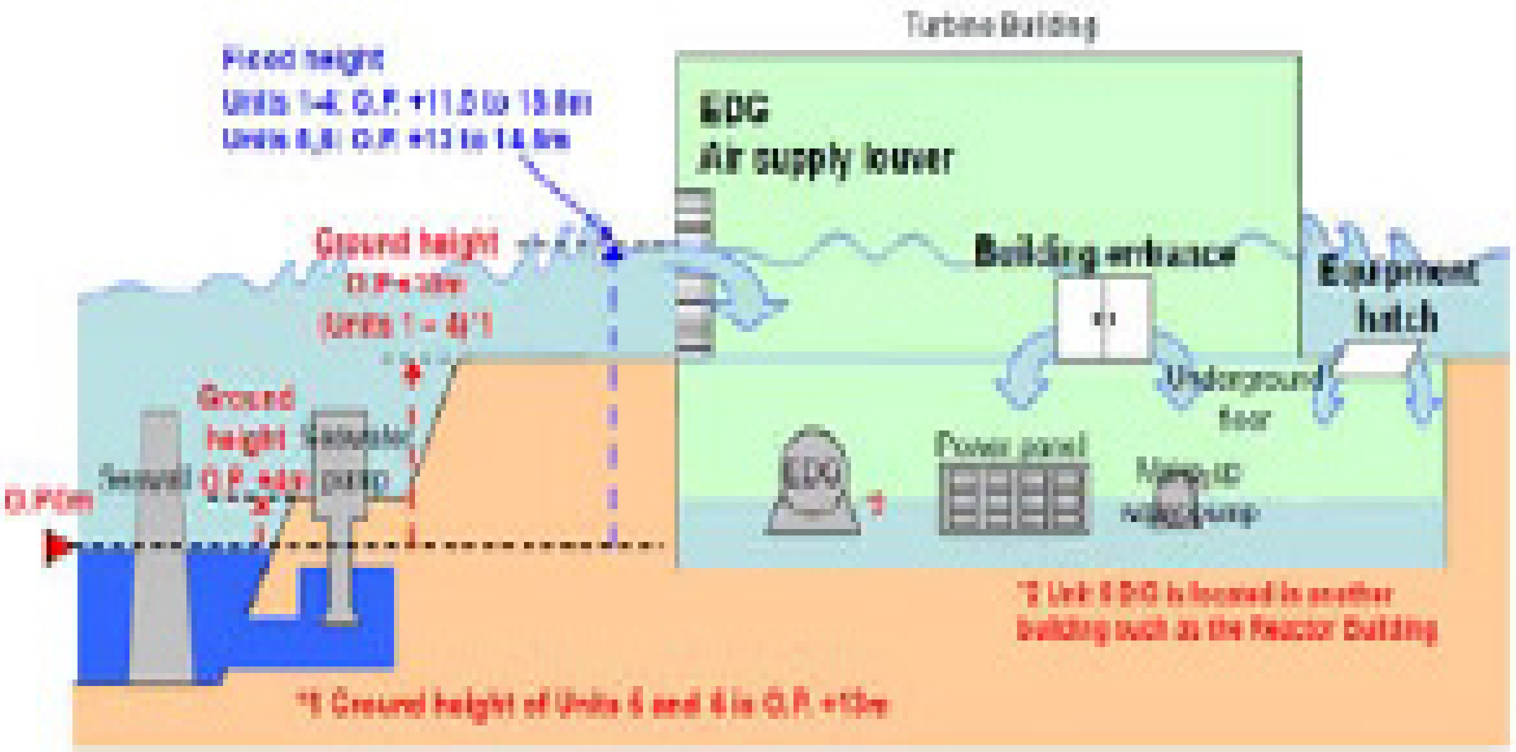
Fukushima Daiichi NPS



2.3Direct damage to the Fukushima Daiichi NPS from the Tsunami

- Flooding by the tsunami induced damage to building entranceways, EDG intake louvers and aboveground equipment hatches.
- Sea water also entered into the EDG room and power panel room located on the underground floor.
- Since the tsunami was far higher than the ground level of the emergency seawater system pumps (O.P. +4 m), the tsunami caused these pumps (installed outdoors) to be submerged, resulting in loss of safety system function.

Path of inundation into major buildings (Fukushima Daiichi NPS).



2.3Direct damage to the Fukushima Daiichi NPS from the Tsunami

- Subsequently many power panels were inundated and all EDGs in operation were shut down except for Unit 6.
- This caused the loss of all AC power (station black out (SBO)) and resulted in the loss of all cooling functions using AC power.
- Furthermore, due to flooding of the cooling system seawater pumps, the heat removal function of transferring decay heat from the reactor to seawater was lost.
- In addition, Units 1 and 2 lost DC power concurrently with the tsunami's impact.
- On the other hand, DC power at Unit 3 withstood the tsunami and the core cooling systems were able to deliver water to the reactor core, but subsequently these core cooling systems did not work due to the depletion of DC power.

2.3Direct damage to the Fukushima Daiichi NPS from the Tsunami

- Subsequently many power panels were inundated and all EDGs in operation were shut down except for Unit 6.
- This caused the loss of all AC power (station black out (SBO)) and resulted in the loss of all cooling functions using AC power.
- Due to flooding of cooling system seawater pumps, heat removal of transferring decay heat from reactor to seawater was lost.
- In addition, Units 1 and 2 lost DC power concurrently with the tsunami's impact.
- On the other hand, DC power at Unit 3 withstood the tsunami and the core cooling systems were able to deliver water to the reactor core, but subsequently these core cooling systems stopped - mostly due to the depletion of DC power.

2.3Direct damage to the Fukushima Daiichi NPS from the Tsunami

- As for Fukushima Daiichi Units 5 and 6, since one of Unit 6's EDGs was functioning and feeding its electric power to Unit 5, water could be injected into the core for both Units 5 and 6.
- The heat removal function was thereby restored and cold shutdown of these units was achieved.

2.3Direct damage to the Fukushima Daiichi NPS from the Tsunami

- Furthermore, because of a total station blackout, there were limited communications measures and lighting in the main control rooms (MCRs).
- Out in the yard, tsunami-induced debris and residual water, as well as the risk of being hit by another tsunami, made working conditions even more difficult.

Power Source Damage in Fukushima Daiichi NPS

	1F-1	1F-2	1F-3	1F-4	1F-5	1F-6
Off-site power source	×				×	
EDG	×	△	×	△	△	○
Emergency high-voltage power panel (M/C)	×	×	×	×	×	○
Normal high-voltage power panel (M/C)	×	×	×	×	×	×
Emergency low-voltage power panel (P/C)	×	△	×	△	×	○
Normal low-voltage power panel (P/C)	×	△	×	△	△	×
DC power source	×	×	○→△	×	○	○
Seawater pump	×	×	×	×	×	×

○: Operable

△: EDG main unit not damaged by water, but inoperable due to M/C and related equipment being submerged

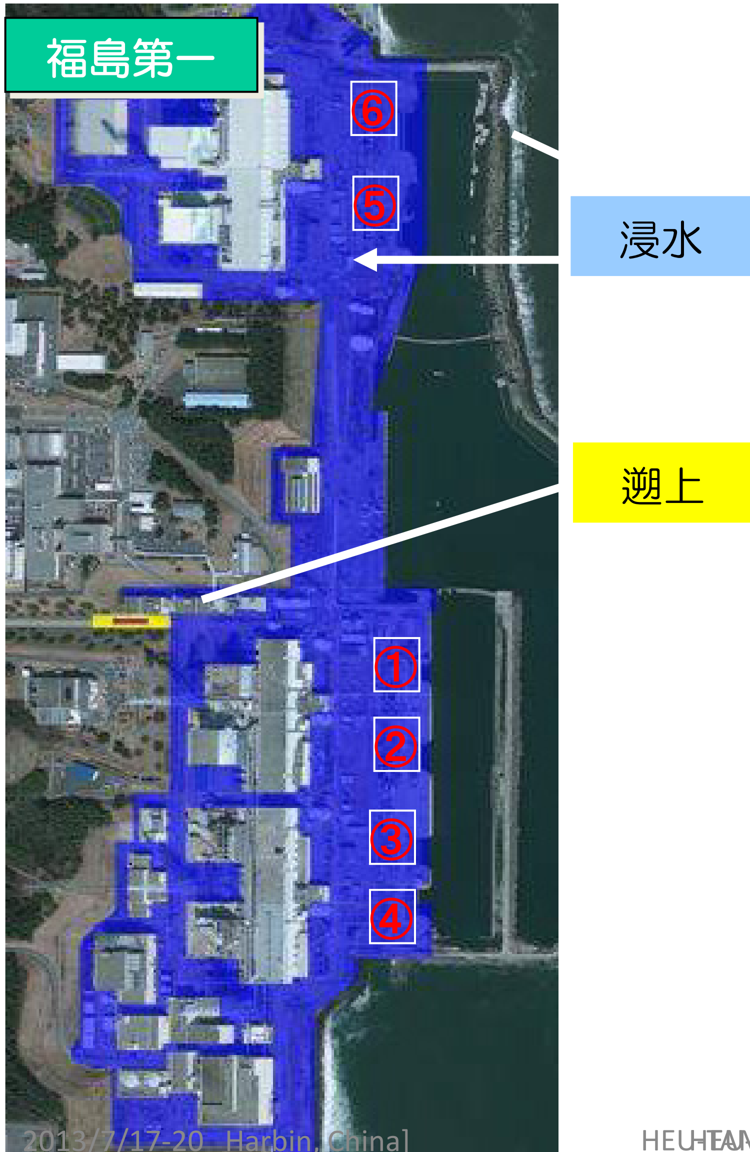
×: Inoperable

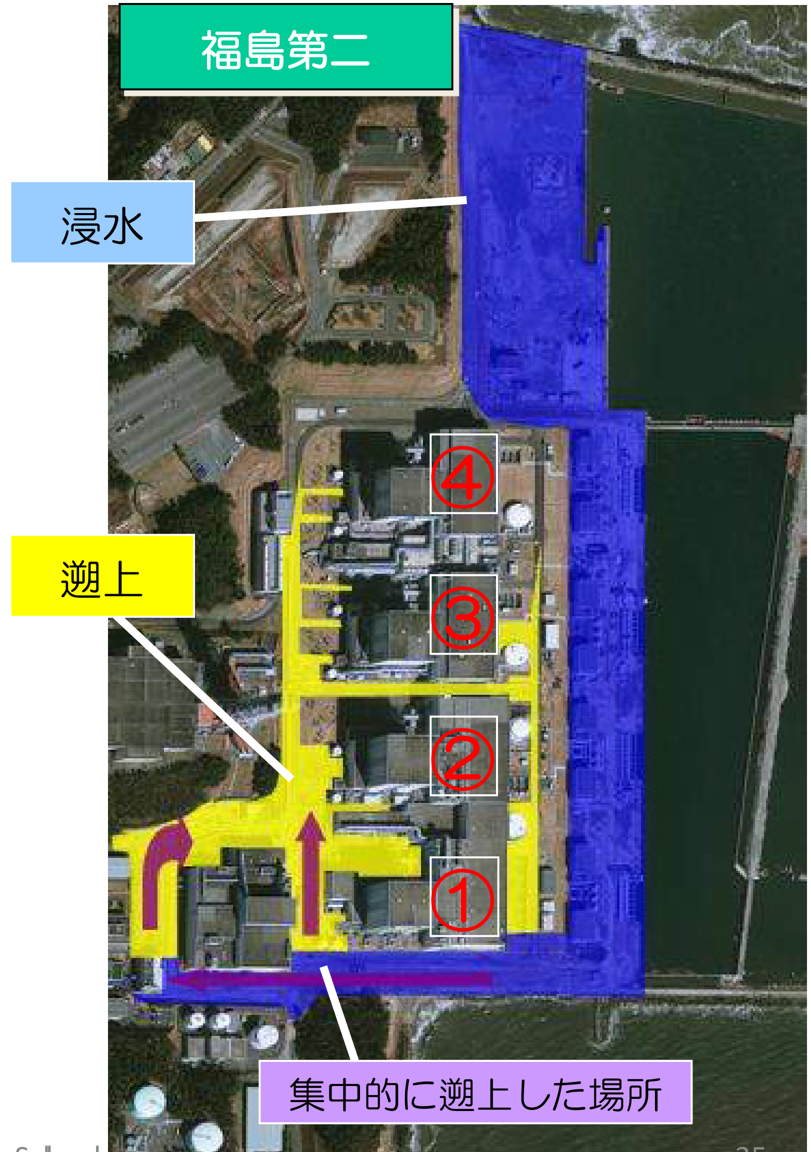
2.4Direct damage to the Fukushima Daini NPS from the Tsunami

- At Fukushima Daini NPS, although the entire seaside area of O.P. +4 m was flooded (flood height approximately O.P. +7 m), there were no watermarks of the tsunami run-up breaching the slope to the O.P. +12 m major buildings area.
- Since the damage was less than that of Fukushima Daiichi NPS, the accident response were entirely different

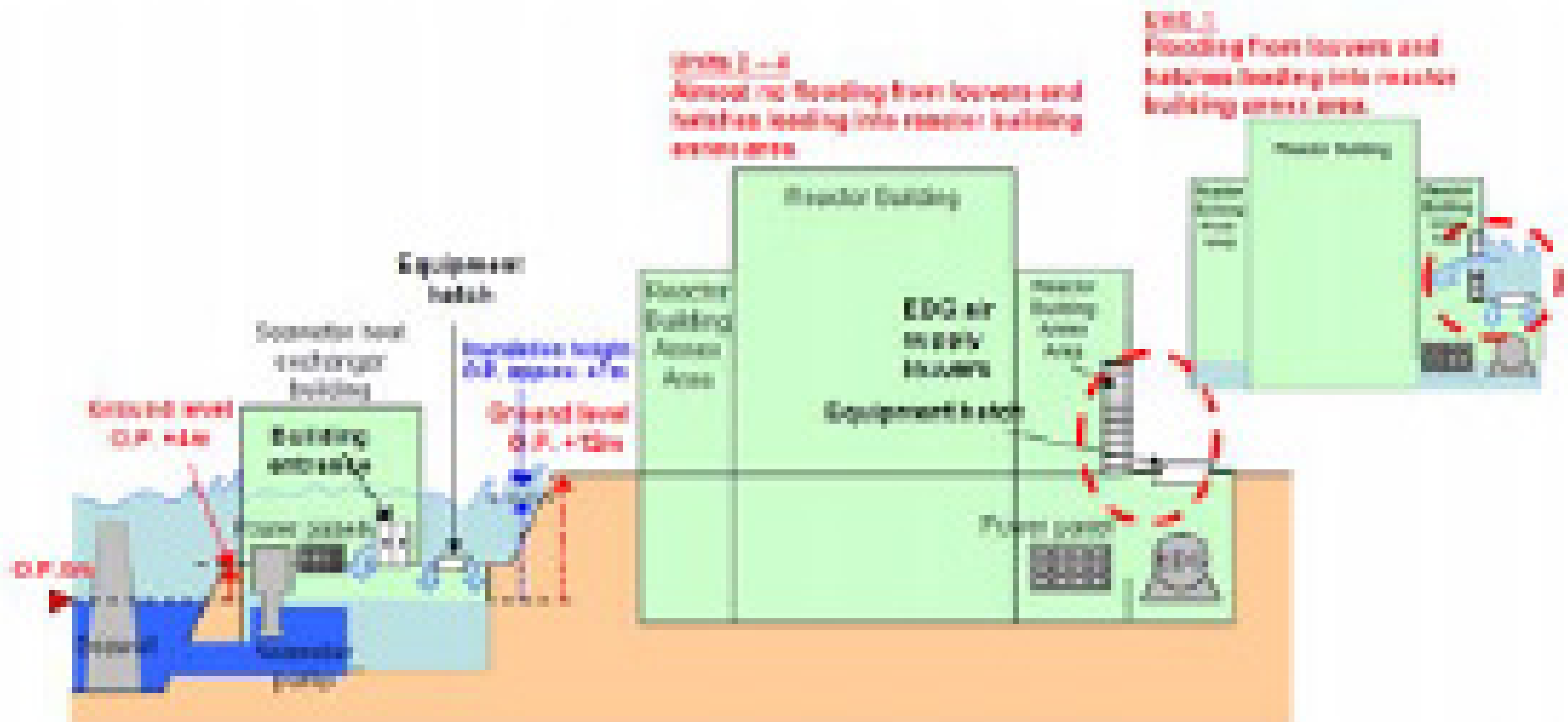
Submergence of Fukushima NPPs by tsunami

Fukushima Daini NPS





Path of inundation into major buildings (Fukushima Daini NPS).



2.4Direct damage to the Fukushima Daini NPS from the Tsunami

- At Fukushima Daini NPS, the tsunami caused the loss of emergency seawater system pump facilities at Units 1, 2 and 4.
- This prevented residual heat from being removed to the sea.
- However, since off-site power remained available for all units, it was possible to use alternate low pressure water injection systems such as the Make-up Water Condensate System (MUWC). MCRs' monitoring and operating functions were also maintained.

Power Source Damage at Fukushima Daini NPS

	2F-1	2F-2	2F-3	2F-4
Off-site power source	○			
EDG	×	△	○	○
Emergency high-voltage power panel (M/C)	△	○	○	○
Normal high-voltage power panel (M/C)	○	○	○	○
Emergency low-voltage power panel (P/C)	△	△	△	△
Normal low-voltage power panel (P/C)	○	○	○	○
DC power source	△	○	○	○
Seawater pump	×	×	△	×

○: Operable

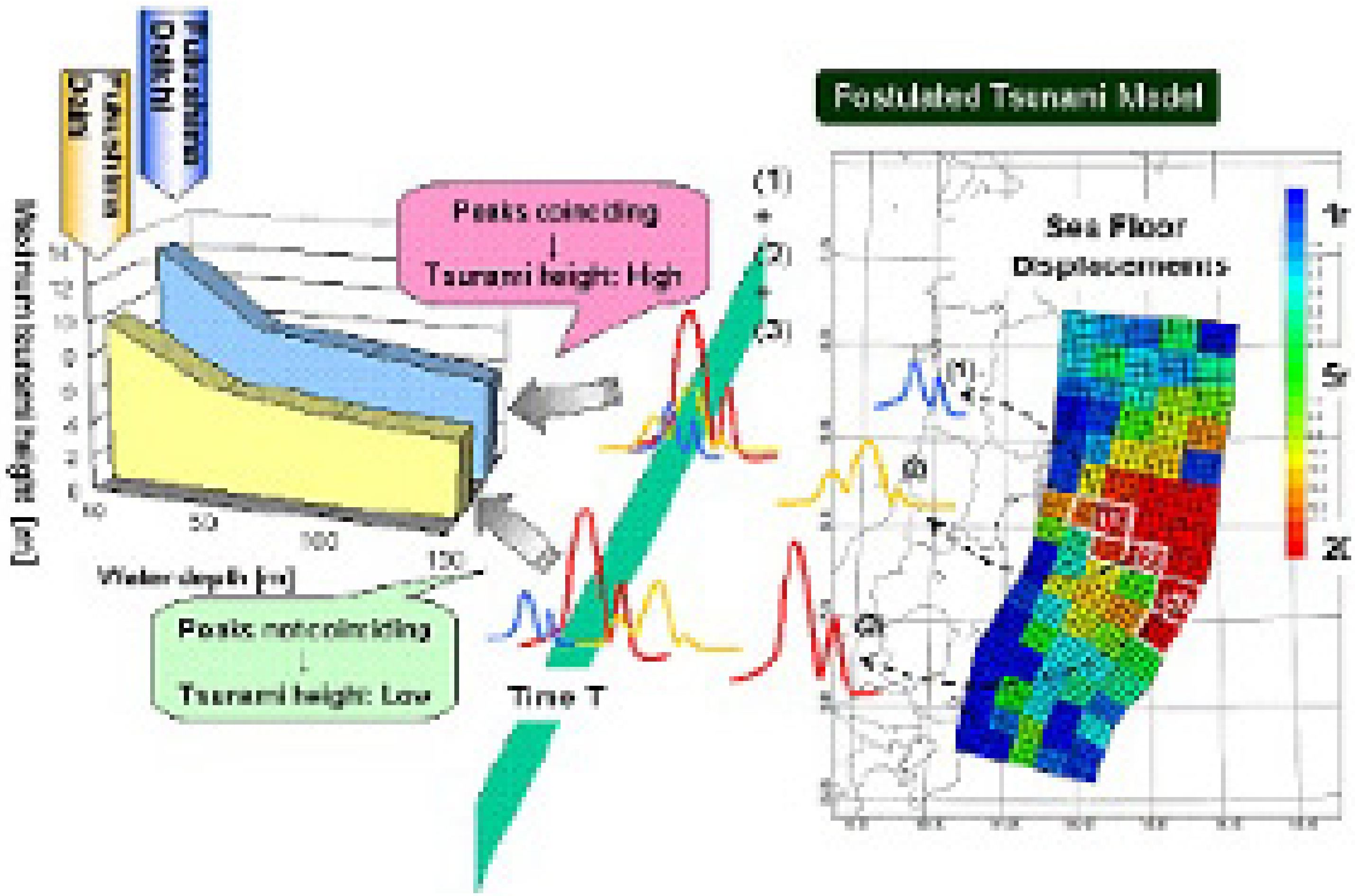
△: EDG main unit not damaged by water, but inoperable due to M/C and related equipment being submerged

×: Inoperable

Why difference in Daiichi and Daini NPSs?

- Analysis has shown that the difference in the tsunami heights at Fukushima Daiichi NPS and Fukushima Daini NPS was caused by the degree of superposition of tsunami waves occurring in different epicentral areas.

The superposition analysis results of tsunami (image).



3. Fukushima Daiichi accident

- 3.1 Three rules of thumb
- 3.2 Severe accident phenomena
- 3.3 Various severe accident codes
- 3.4 Summary of Fukushima accident
- 3.5 TEPCO's analysis of Fukushima Daiichi Accident

Three Rules of Thumb for Nuclear Reactor Safety

- STOP
- COOL
- CONTAIN

Reactor was stopped, however decay heat

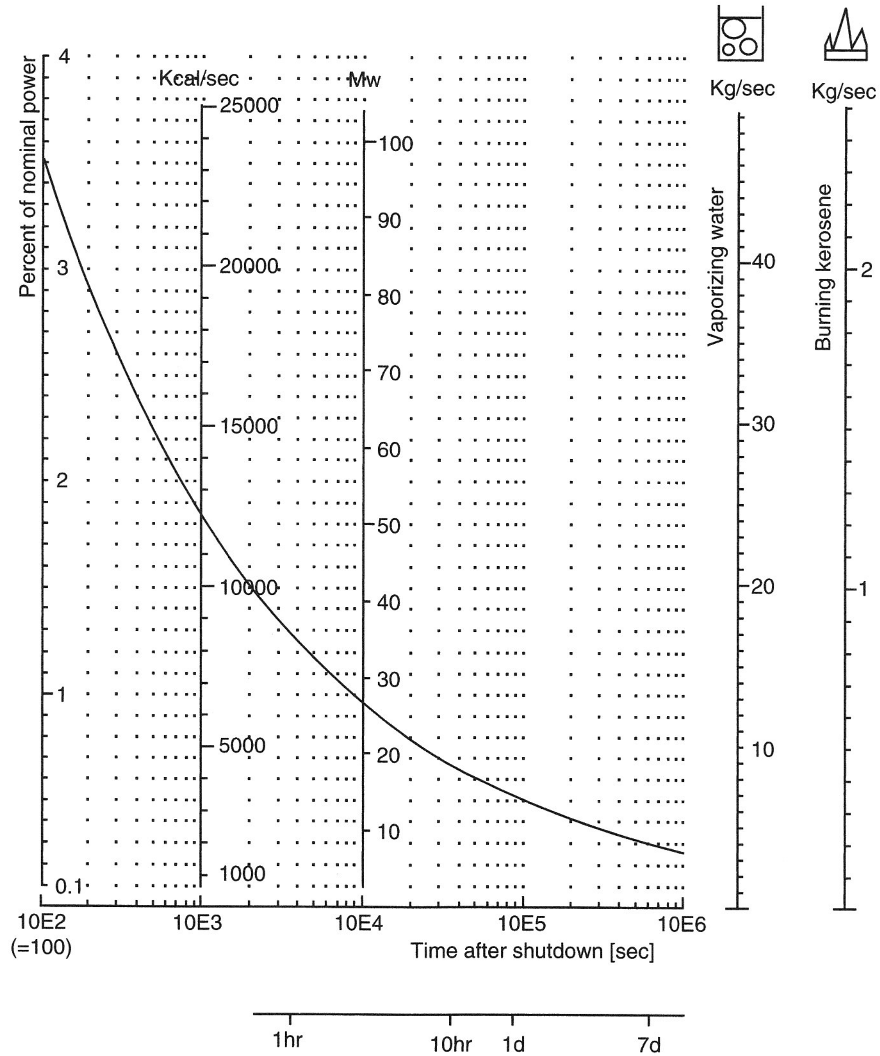


Figure 3-2. Decay power for a 2775 MWt reactor (±10% over best estimate).

Emergency Core Cooling System (ECCS) and Containment

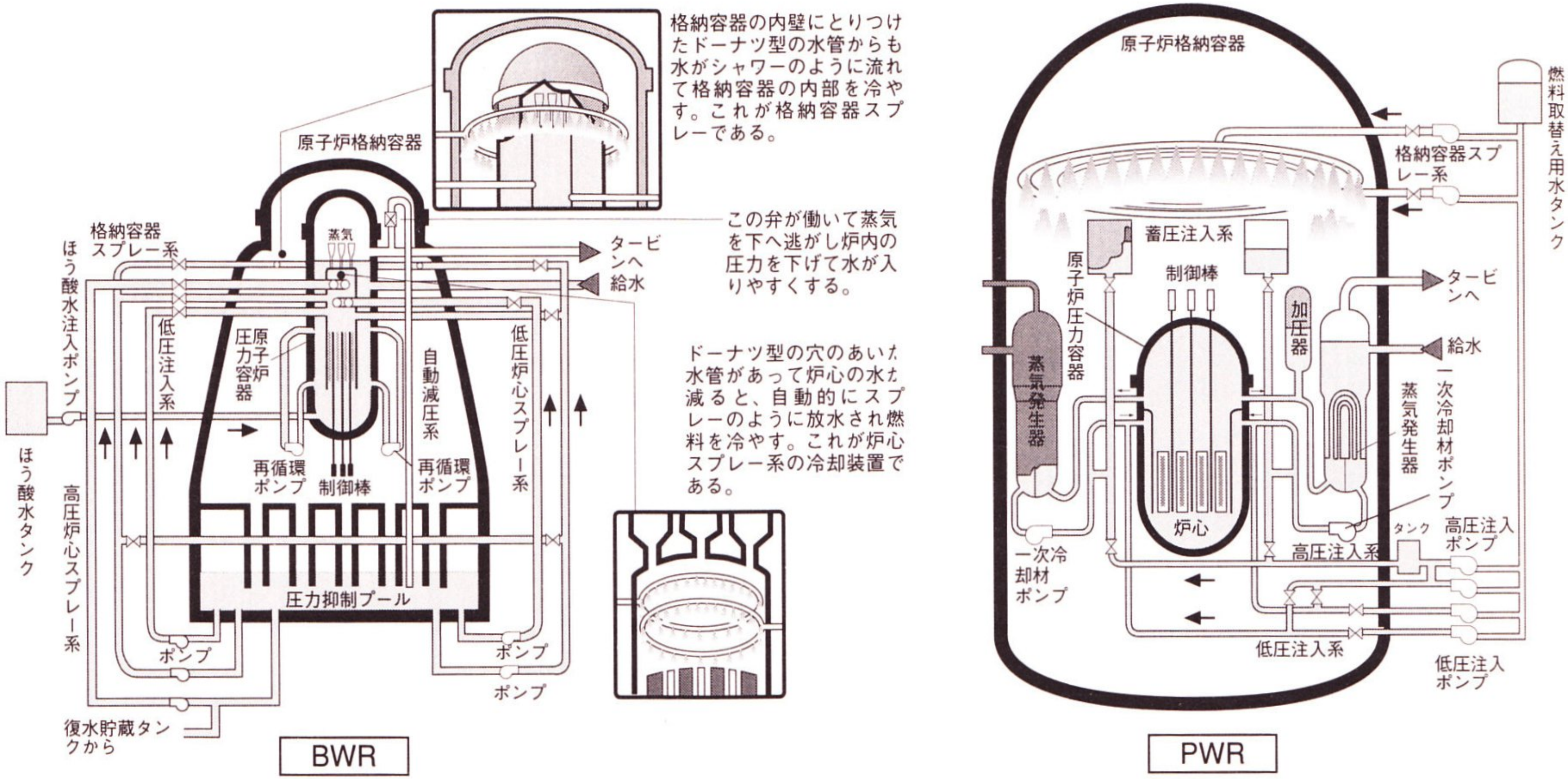


図6−23　軽水炉における非常用炉心冷却装置（ECCS）

THE REACTOR COULD BE STOPPED EVEN IN SUCH BIG EARTHQUAKE

BUT COOL AND CONTAIN WERE LOST BY TSUNAMI WHICH CAME CA ONE HOUR AFTER THE EARTHQUAKE

3.1 Severe accident phenomena

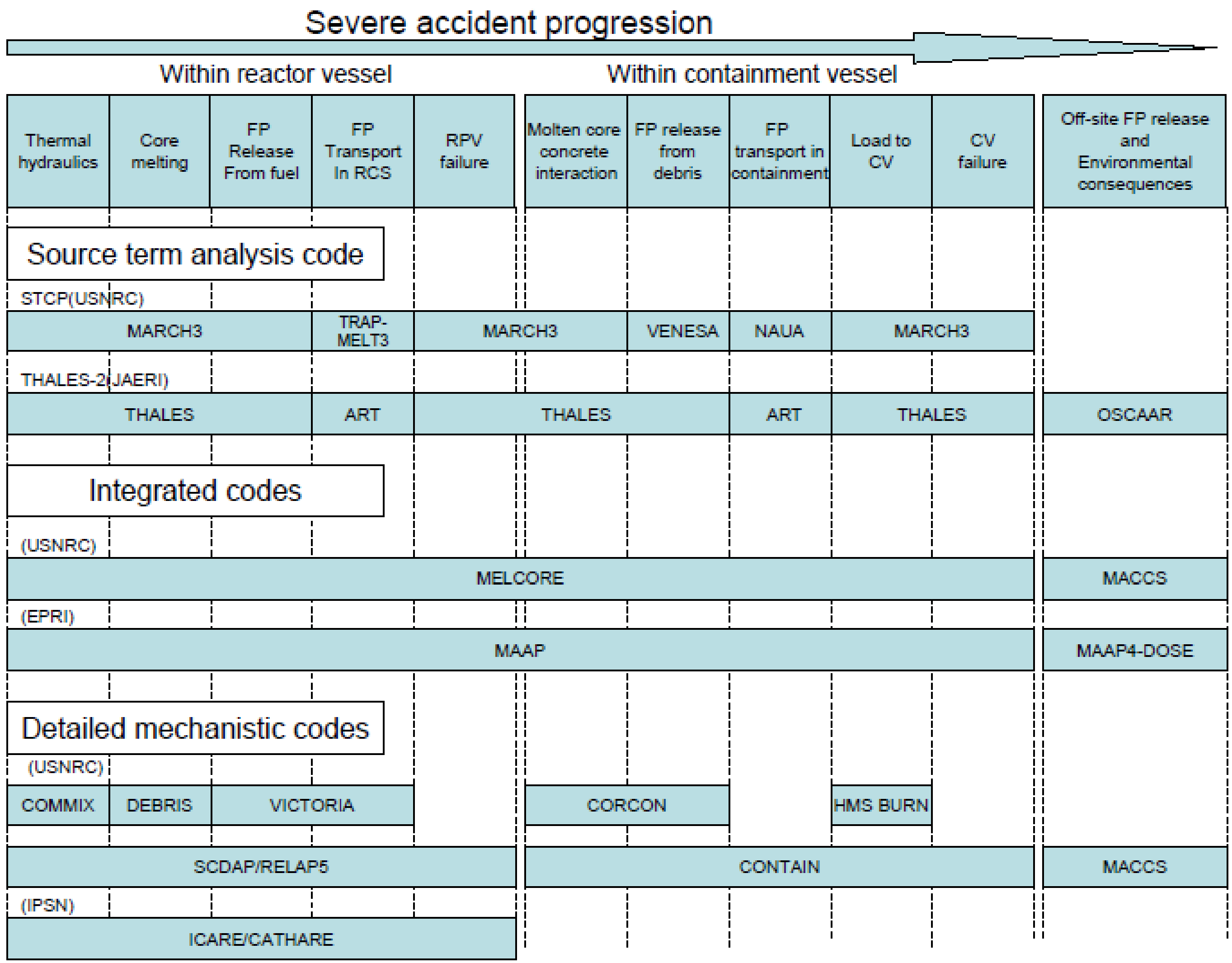
Severe accident phenomena	Transient over-power	LOCA
Fuel behavior mainly related to failure to stop the nuclear reaction	Fuel swelling Fuel failure and melting Pellet-clad interaction Fuel relocation/slumping	
Coolant behavior mainly related to failure to cool the reactor		DNB Two-phase flow Natural circulation Blowdown-refill-quench-reflood CCFL
Various violent interaction behavior mainly related to failure to contain radiological release by the ruptures of reactor vessel and containment vessel	FCI Zr-water reaction Hydrogen explosion Steam explosion Corium-concrete reaction Direct containment heating	

Zr-water reaction

$$Zr + 2H_2O \rightarrow ZrO_2 + 2H_2$$

- Embrittlement of Zircalloy by absorption of Oxigen
- Hydrogen generation leads to hydrogen explosion

3.2 Various severe accident codes



3.3 Summary of Fukushima accident

- All operating units succeeded in automatic shutdown just after earthquake.
- Offsite power was lost in Fukushima Daiichi by stumbling of tall tower of electric transmission as well as switchyard by earthquake,

  while this was maintained in Fukushima Daini.
- Sea water pumps in all plants were damaged (loss of heat sink)
- Any other power sources were almost lost in Fukushima Daiichi ‘s Units 1 -4 after tsunami inundation.(loss of all AC+DC power).

3.3 Summary of Fukushim accident

- This combination of (loss of all AC+DC power)+(loss of heat sink) brought about fatal severe core meltdown accidents in Fukushima Daiichi Units 1, 2, and 3 to discharge large amount of radioactive gas out of the plant site.
- The Unit 4 was in maintenance shutdown with all spent fuel out of reactor core put in the spent fuel pool.
- But the R/B of Unit 4 was destroyed by hydrogen explosion. The coolability of this spent fuel was also big concern at the time.

3.4 TEPCO's analysis of Fukushima Daiichi Accident

- The plant behavior during the accident and the hydrogen explosions in the R/Bs was analyzed by MAAP for the Fukushima Daiichi NPS Units 1 to 4 .
- MAAP is Modular Accident Analysis Program (MAAP) developed by EPRI. It contains fully-integrated modular models for primary system thermodynamics, core heat-up, degradation, melting, fission product release and so on.

3.4 TEPCO's analysis of Fukushima Daiichi Accident

- The post-analysis of Fukushima Daiichi severe accident is not like the experimental analysis in big laboratory.
- At the time of accident, almost all instruments (water level, pressure, temperature) were either out of scale, failed or lost , and displays , data log and illuminations in MCR were all unavailable. (Very scant data to validate the analysis).
- It is impossible to gather data from damaged plants for the long time because high radioactivity prevents to conduct such human activity.

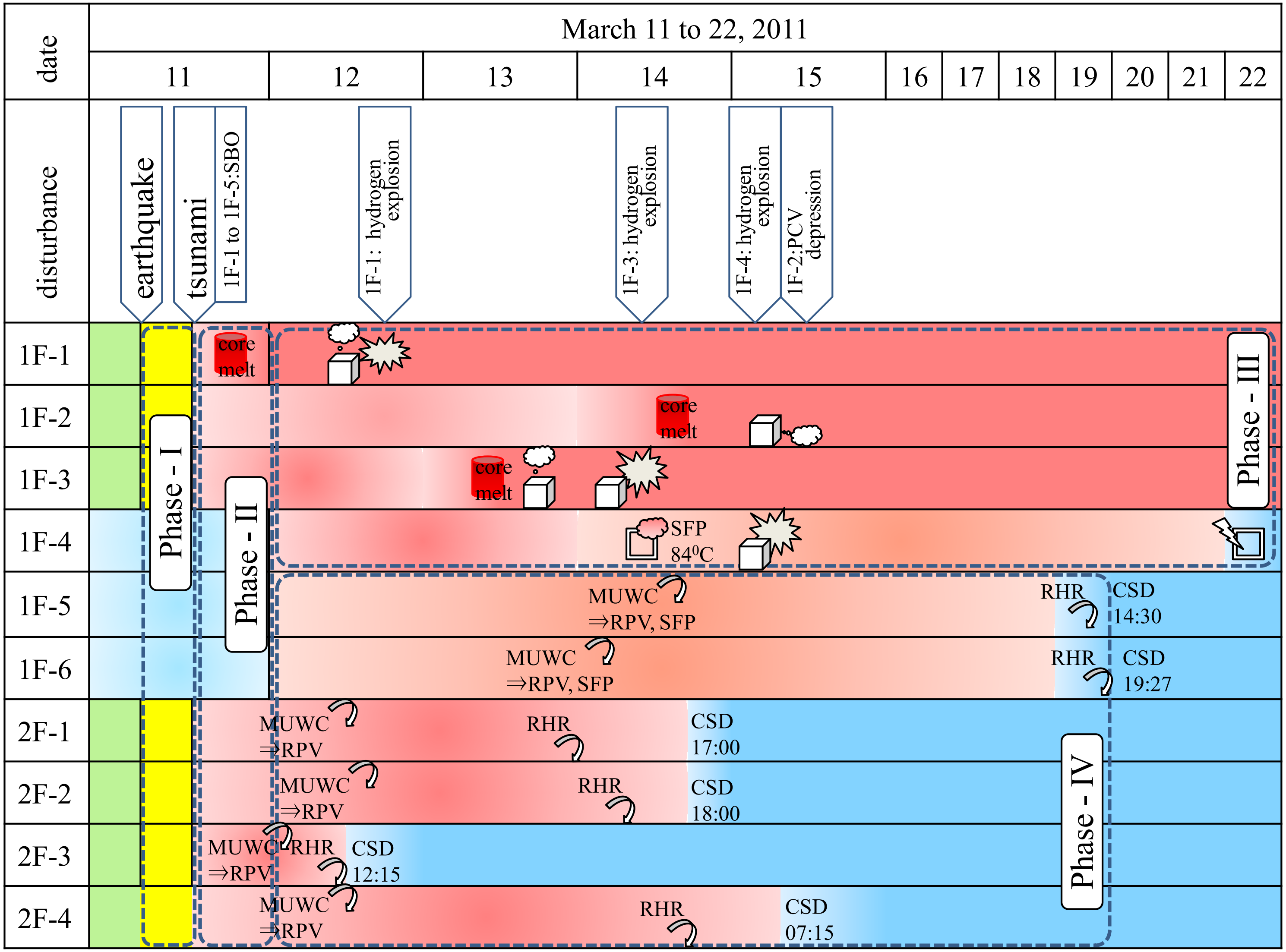
3.4 TEPCO's analysis of Fukushima Daiichi Accident

- Then what was the purpose of MAAP analysis by TEPCO?
- To conjecture most plausible trends of each unit by making full use of available sensor data including radiation monitor, observed accident phenomena (explosion, steam blow-out, fire, etc), human actions to recover the plant (Valve operation, Containment vent, water charging by fire engine, recovery of electric panels, etc)

3.4 TEPCO's analysis of Fukushima Daiichi Accident

- To estimate time histories of major process parameters (pressure, water level, etc) of the damaged plant, time of core melt, reactor vessel melt-through, place of hydrogen explosion, amount of concrete melt-through, reason of explosion in Unit 4 R/B, etc.
- For details of Units 1, 2, 3, and 4, please refer the paper by Miyata of TEPCO, in IJNS.

3.4 TEPCO's analysis of Fukushima Daiichi Accident



SBO: Station blackout

NUWC: Makeup water condensate system

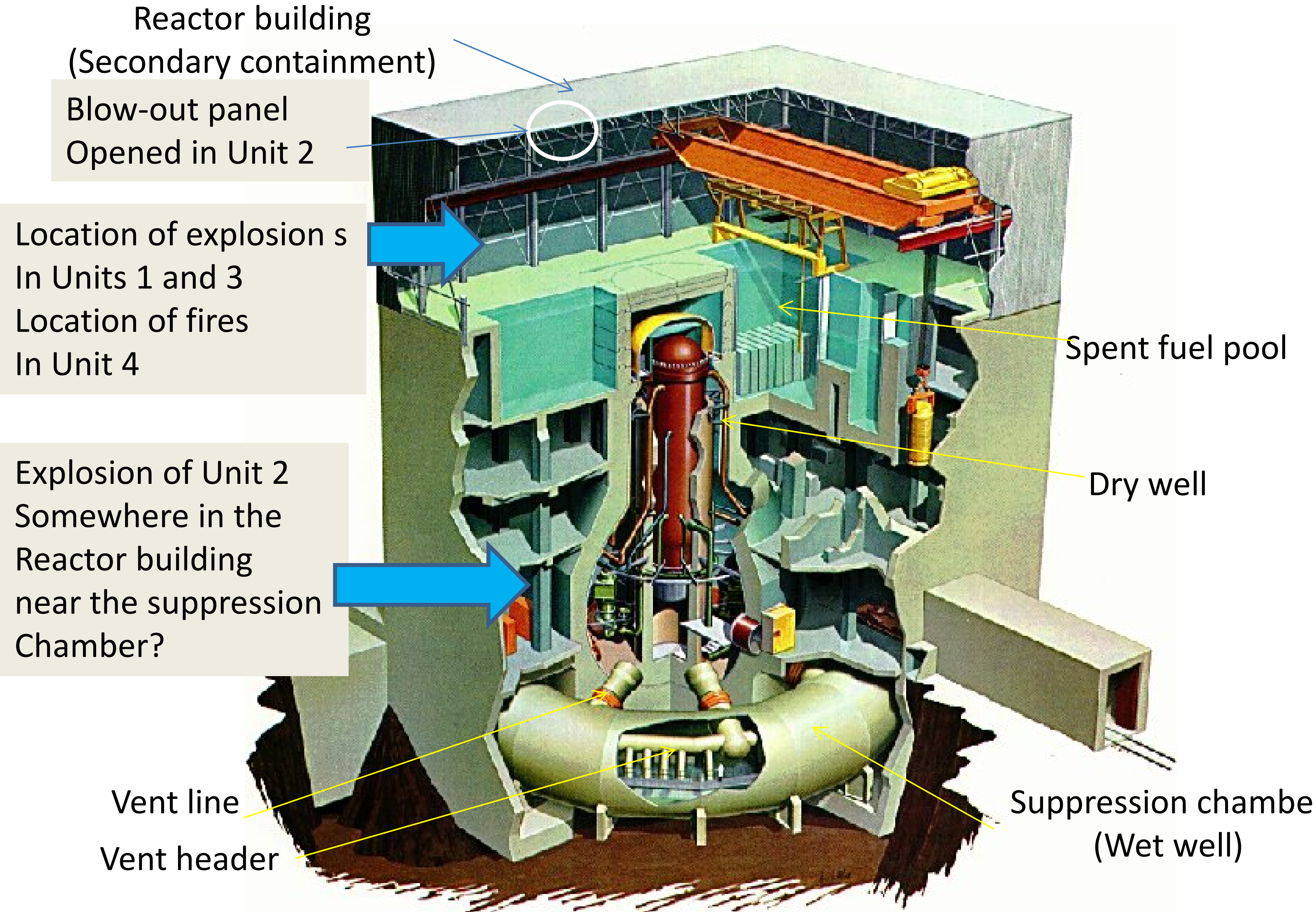
RPV: Reactor pressure vessel

RHR: Residual Heat removal system

CSD: Cold Shutdown state

SFP: Spent Fuel pool

Mark 1 Containment

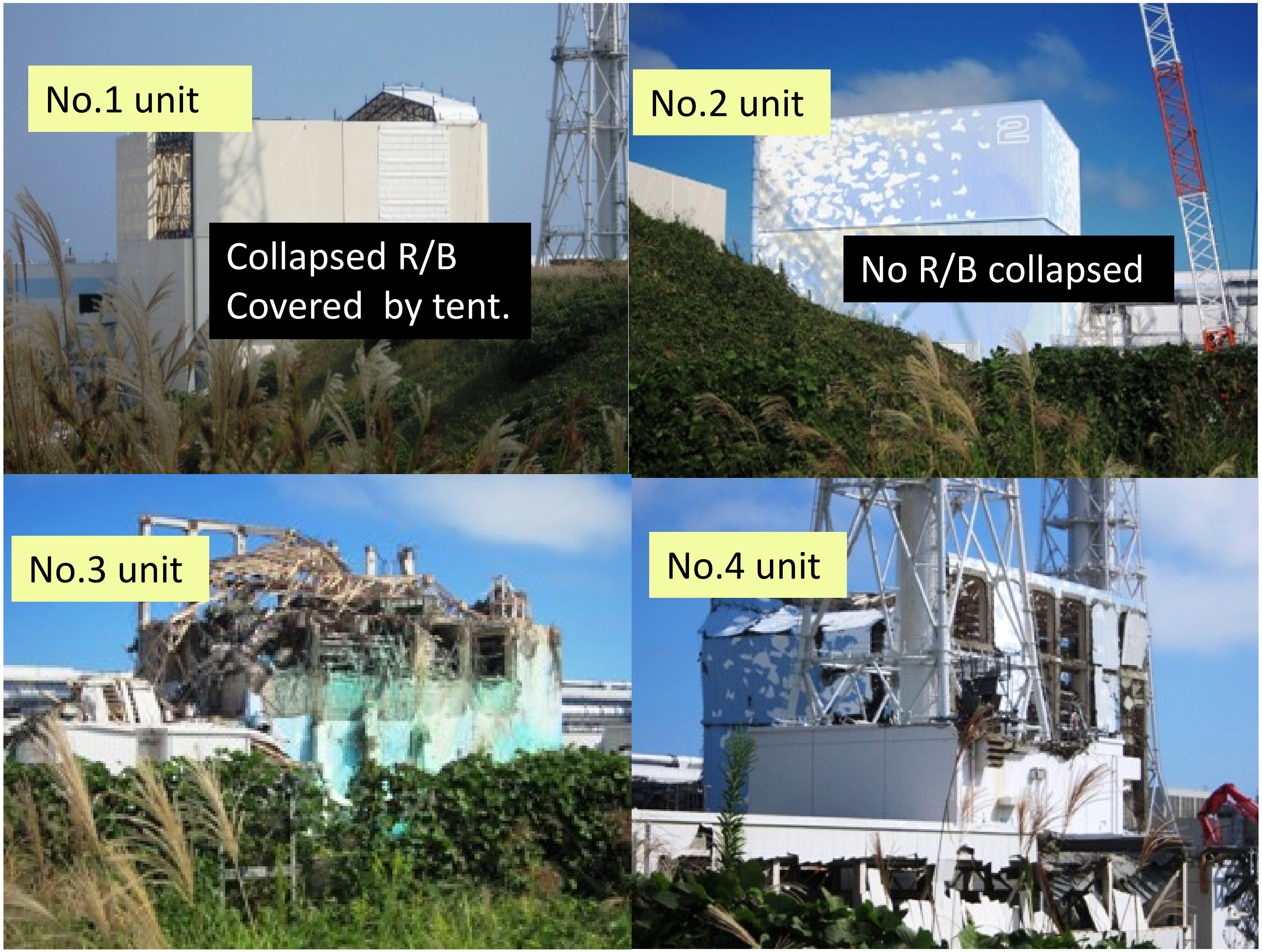


Appearance of Unit 1 R/B after explosion.

Appearance of Unit 3 R/B after explosion.

Appearance of Unit 4 R/B after explosion.

Appearance of damaged units of Fukushima Daiichi NPS (Around October 2011)



Contents (Second part)

4.Atmospheric release of radioactive materials

5.TEPCO learned lessons from Fukushima accident and countermeasures

6. Lessens for nuclear disaster preparedness

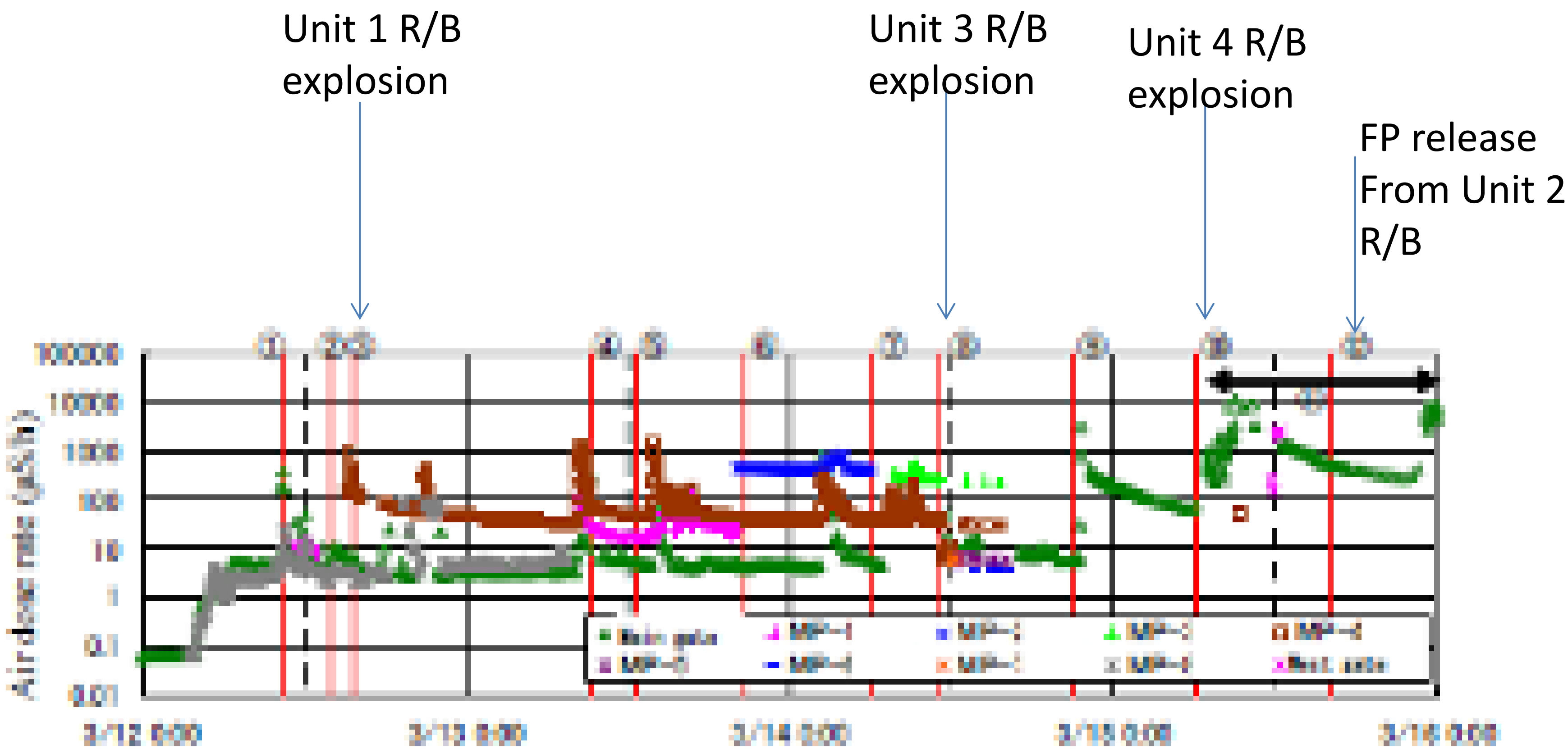
Nuclear disaster preparedness in Japan before Fukushima Daiichi accident/Change of the meaning of risk communication/Preparing for nuclear emergency and post-accident management

4.Atmospheric release of radioactive materials

4.1 Major events when radioactive materials were released into the atmosphere

4.2 Causes of high level contamination areas to the northwest of Fukushima Daiichi NPS

4.1 Major events when radioactive materials were released into the atmosphere



Monitoring data.

Evaluation of the release of radioactive materials into the atmosphere

No.	Date/time	Unit	Event	Amount released (PBq)			
				Noble gases	I-131	Cs-134	Cs-137
①	March 12 after 10:00	1	Unknown*	3	0.5	0.01	0.008
②	March 12 after 14:00	1	S/C vent	4	0.7	0.01	0.01
③	March 12 15:36	1	Building explosion	10	3	0.05	0.04
④	March 13 after 09:00	3	S/C vent	1	0.3	0.005	0.003
⑤	March 13 after 12:00	3	S/C vent	0~0.04	0~0.009	0~0.0002	0~0.0001
⑥	March 13 after 20:00	3	S/C vent	0~0.003	0~0.001	0~0.00002	0~0.00002
⑦	March 14 after 06:00	3	S/C vent	0~0.003	0~0.001	0~0.00002	0~0.00002
⑧	March 14 11:01	3	Building explosion	1	0.7	0.01	0.009
⑨	March 14 after 21:00	2	Unknown*	60	40	0.9	0.6
⑩	March 15 06:12	4	Building explosion	--	--	--	--
⑪	March 15 after 07:00	2	Release from building	100	100	2	2
⑫	March 15 after 16:00	3	S/C vent	0~0.003	0~0.001	0~0.00002	0~0.00002
Total (including amount released which does not identify events)				Approx.500	Approx.500	Approx.10	Approx.10

*Both S/C vent or release from building can be considered, but event can not be specified.

4.1 Major events when radioactive materials were released into the atmosphere

- The release of particulate radioactive materials at the time of vent was limited due to the scrubbing effect in the suppression pool and the amounts released were smaller in comparison to that from the R/B of Unit 2. TEPCO considers that the vent operation had minor impact on the total contamination load.
- Judging from the monitoring data at the time of the explosions of Units 1, 3 and 4 R/Bs, the amounts of release were quite small compared to that from Unit 2 R/B, and TEPCO does not consider hydrogen explosion to be a major cause of the total contamination.

4.1 Major events when radioactive materials were released into the atmosphere

- As shown in the previous monitoring data, dose rates taken on March 15 show a rapid increase from several hundred to tens of thousands μSv/h near the main gate over several hours after 07:00 and then a decrease to approximately 1,000μSv/h at noon on the same day.
- The dose rate measured at 23:00 increased to close to 10,000μSv/h again. Considering the wind patterns on the day, TEPCO believes that a large amount of radioactive materials were released continuously throughout this time period.

4.1 Major events when radioactive materials were released into the atmosphere

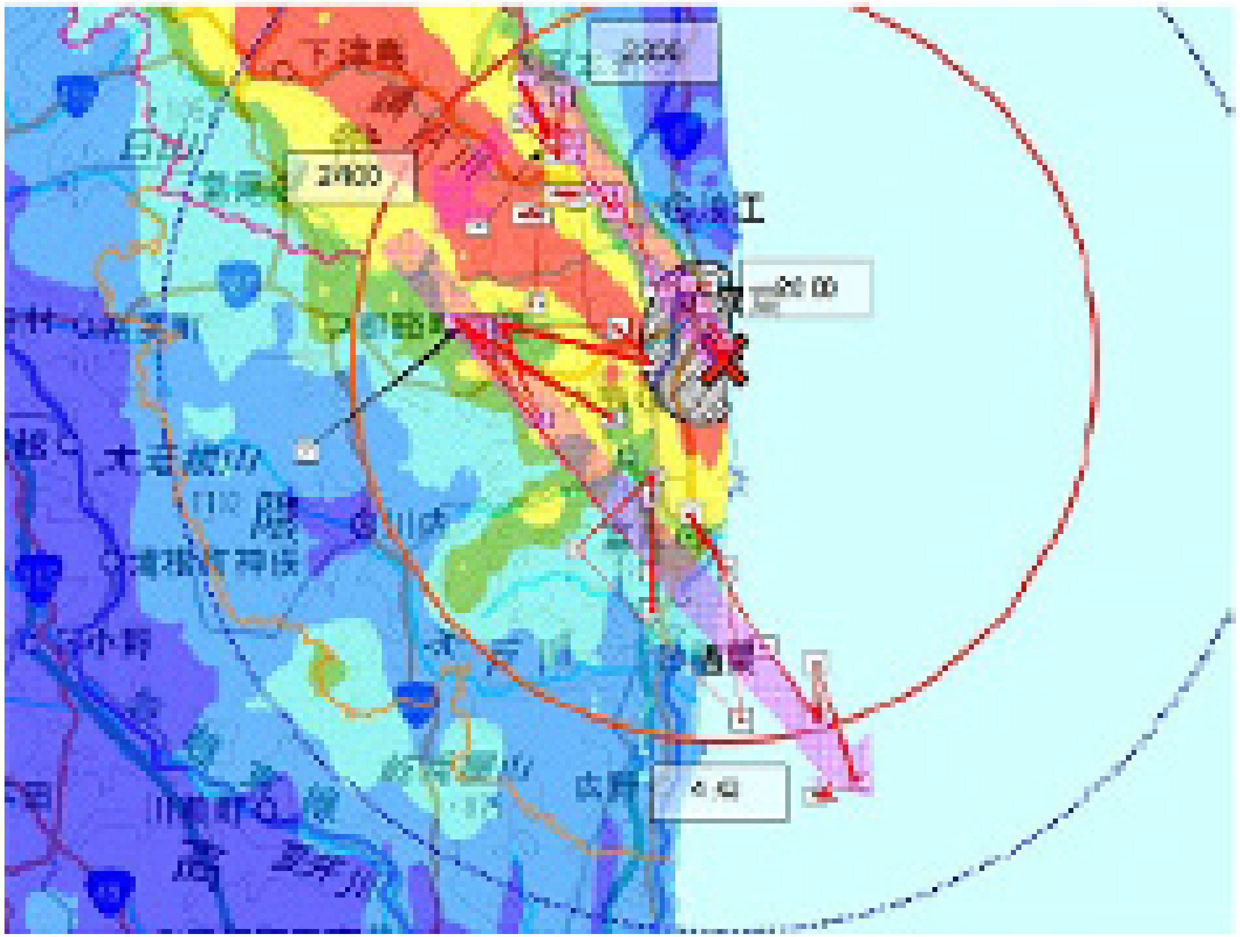
- Since Unit 2 PCV pressure decreased substantially between 07:00 and 11:00 on the same day , and white smoke was seen coming from Unit 2 R/B (the next figure)
- It is highly likely that Unit 2 was the source of the release.

Fukuichi live camera (around 19:00 on March 15).

4.2 Causes of high level contamination areas to the northwest of Fukushima Daiichi NPSre

- Radioactive release from the R/B of Unit 2 on March 15 in conjunction with winds to the north-northwest (the next figure) and rain fall (the second next figure) had a major impact on the environmental contamination.
- The reason for this amount of release is that the emissions from Unit 2 bypassed the suppression pool and there was therefore no scrubbing effect. (According to TEPCO's estimation, major FP release path is through failed flange seal of PCV head.)
- The reason why no hydrogen explosion in Unit2 R/B was that the blow-out panel was already blown-out by the time of Unit 1 R/B explosion.
- As a matter of fact, FPs released on March 15 reached as far as 40 km from Fukushima Daiichi NPS. This far-reaching FP release let citizen in evacuation be thrown into heavy confusion at the time.

Path of plume released from Unit 2 after 20:00 on March 15.



Rain clouds radar map in Fukushima Prefecture at 23:00 on March 15.

5.TEPCO learned lessons from Fukushima accident and countermeasures

- 5.1 Learned lessons
- 5.2 Countermeasures

5.1 Learned lessons

- During the earthquake, all reactors automatically scrammed and off-site power was lost. Considering the success of EDGs start-up and plant parameter trends, it is judged that no significant damage occurred due to the earthquake directly.
- However, a 13m high tsunami exceeded far beyond the design basis when it struck the power station. This historically gigantic tsunami damaged almost all power panels leading to the loss of all power supply.
- Because of prolonged loss of AC / DC power and ultimate heat sink, all efforts to cool down the reactor core proved ineffective. This led to core melt resulting in a hydrogen explosion.

5.1 Learned lessons

- Since the Fukushima accident was far beyond design basis accident (DBA), even the systems and components prepared for accident management, such as water injection to reactors and/or PCV, instruments, illumination, and PCV venting all lost their functions.
- The aftermath of the tsunami and explosions resulted in rubble being scattered throughout the yard. This seriously hindered the workers' recovery efforts.

5.2 Countermeasures

- TEPCO believes it is essential as countermeasures from a safety perspective to consider the response capability to resolve the accident even on the premise that the function of nearly all equipment in the power station is lost.
- Therefore, countermeasures after Fukushima accident from both hardware and software perspectives are being considered .

Hardware countermeasures

Buildings / Water-intakes :	**Tide wall, Reinforced water plates / Watertight-doors**
Water injection / Cooling	Enhanced water-tightness for pumps, Fire-engines Precut cables / Connecting terminal
Depressurization	N_2 cylinders, Batteries for opening valves
Power supply	Mobile power supply, Spare portable batteries, Enhanced water-tightness
Hydrogen accumulation prevention	"Top venting" of R/B, Opening BOP
Infrastructure	Off-site power, Rubble removal, Communication system, Lighting, Radiation protection.
Mid-to-long term items	Reliable / Filtered venting, Post-accident instrumentation, Improvement in reliability of high-pressure injection system

Software countermeasures

- Organization, Command and control, Roles and responsibilities, Resources
- Information sharing / Plant status recognition
- Transportation of resources
- Access control
- Radiological protection
- Public relations / Conveying information
- Cooperation with government

6. Japanese earned lessens for nuclear disaster preparedness

6.1 Nuclear disaster preparedness in Japan before Fukushima Daiichi accident

6.2 Change of the meaning of risk communication

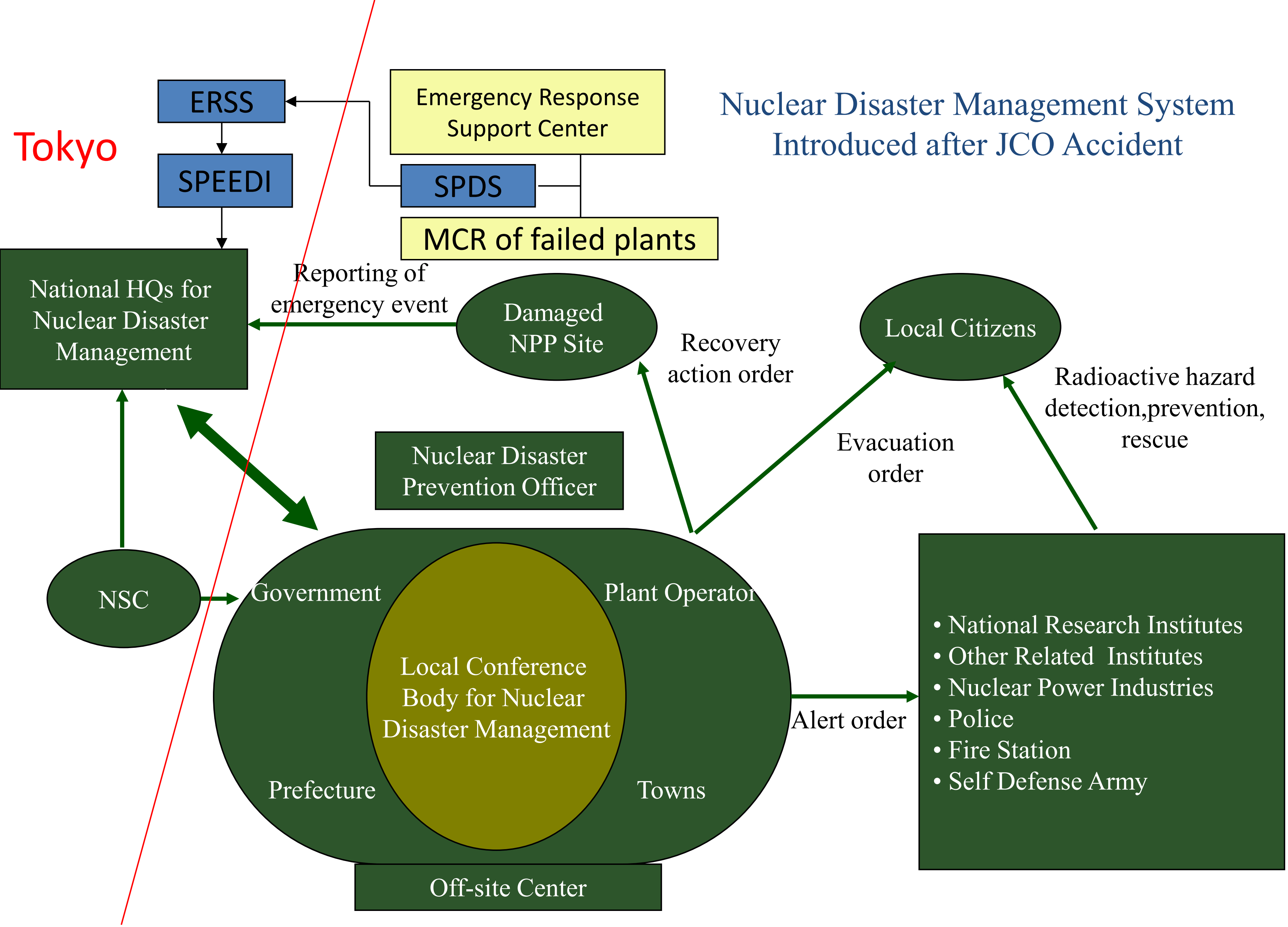
6.3 Preparing for nuclear emergency and post-accident management

6.1 Preparedness for nuclear disaster in Japan before Fukushima Daiichi accident

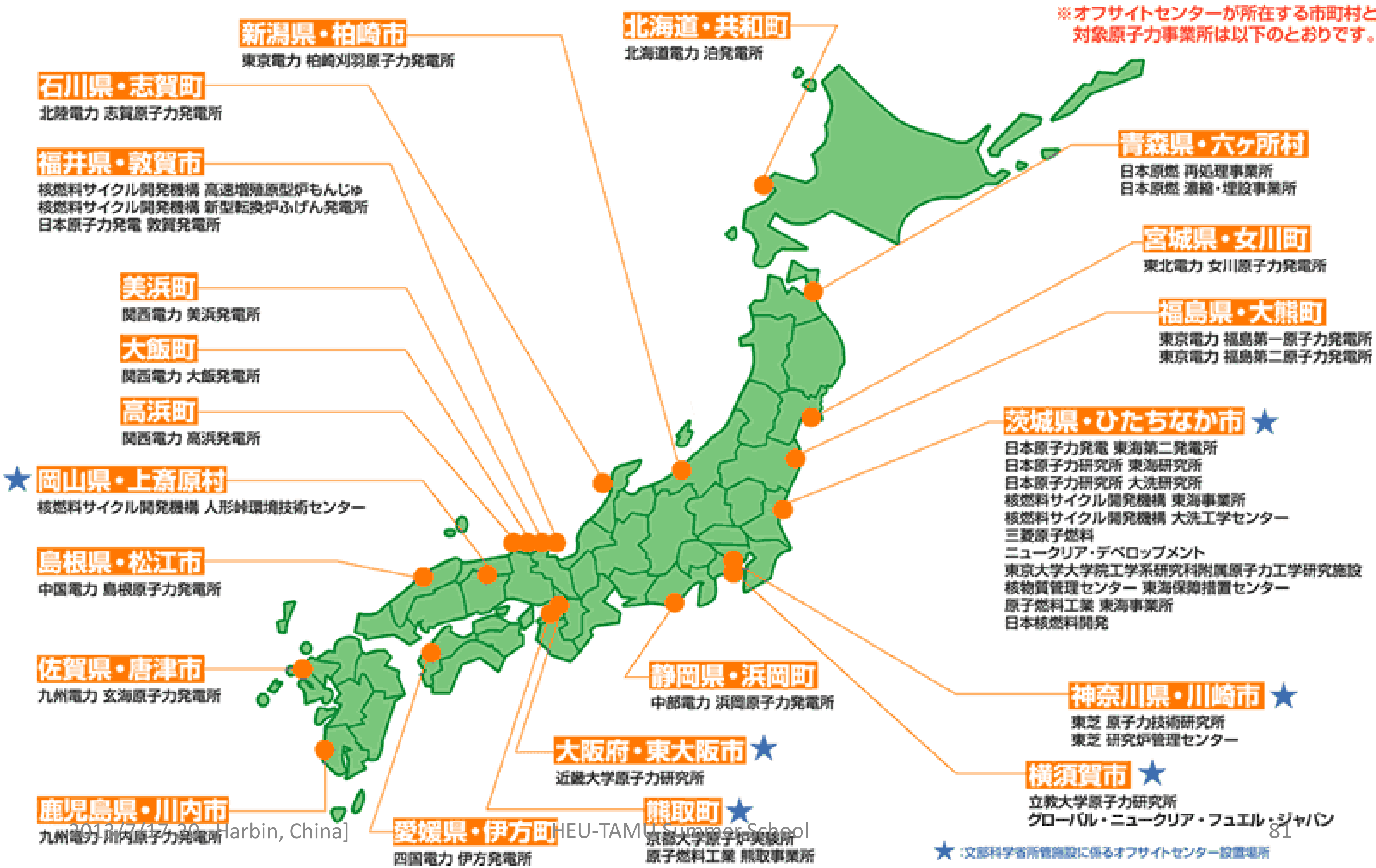
Prepared in Japan in 2000 just after JCO accident *, but it does not work as it planned

*JCO accident = "Nuclear Re-Crilticality" accident occurred in an experimental facility of a nuclear fuel re-conversion company for producing high enriched UO2 for Experimental fast reactor Joyo in Tokai mura. Three workers were heavily neutron irradiated and the two were eventually died in hospital.
At this accident, the town mayor ordered citizen in Tokai-mura to evacuate or stay in the building to avoid possible neutron exposure from the facility.
After then, Nuclear Disaster Prevention Act was firstly enacted in Japanese Diet, but the enhancement of severe accident countermeasures had been left to nuclear industries (No national regulation were applied for severe accident management in nuclear power plant.)

Nuclear Disaster Management System Introduced after JCO Accident



Locations of Off-Site Centers in Japan



Off-site center in Ohi-cho

Helicopter to monitor airborne radioactivity

Anti-radioactive robot for nuclear disaster

Scenery of public evacuation training

6.2 Change of the meaning of risk communication

Before Fukushima

- Persuade people not to worry about nuclear (Myth of nuclear safety)

After Fukushima

- Make people understand risk of nuclear severe accident

Three types of nuclear risk communication to the public

Ordinary days (Before accident)	**-Let public know emergency response plan be well established** **-Public enlightenment and train to let people familiar with the content of the plan**
During accident	-Public broadcasting and use of various communication channels to warn the residents and inform what to do -When necessary, conduct evacuation plan in order to mitigate radioactive hazard to the public -When necessary, conduct medical care to the people to be in concern
After accident	-Let evacuated people to live healthy life in refugee place -Recover the contaminated land and environment for the residents to return their home eventually

Direct effect of Fukushima to be reflected in Disaster prevention plan

1

- Severe accident measures against earthquake, tsunami, air plane attack, terrorist attack, etc, should be included in the safety design of nuclear power.

2

- EPZ expanded from 10 km to 30 km.

3

- Mission of emergency response center should be strengthened with its intactness to external hazard. ?
- Off-site center should be located well apart from plant site and its intactness should be strengthened as to the building structure and telecommunication capabilities. ?

What should be considered for better risk management if nuclear disaster occur-Some lessens from Fukushima

- A single big event would accompany with other big events (i.e. earthquake +tsunami) to become bigger nuclear disaster !
- Core damage of nuclear reactor is very fast to discharge FPs to the neighboring environment. Radioactive materials will dissipate very broadly in short time. So no waste of time to respond promptly.
- People cannot see the radioactive material discharged from nuclear facility by their sensing ability, and the radioactive hazard has multi-faceted effect. (Direct dose and indirect dose ; External dose and internal dose.)

6.3 Preparing for nuclear emergency and post-accident management

How the world nuclear academies* see Fukushima Daiichi accidents

- By Fukushima Daiichi accident, a large amount of radioactive materials were widely discharged into surrounding environment
- The direct cause of the accident was an extremely rare natural event far beyond human prediction
- However, this class of accident can even be fully prevented in future, by the current LWR technologies.
- Further research and development are needed essentially for the adequate provision of equipments and organizational training

*ASME, ANS, INPO, Carnegie Institution for Science, etc.

Enhanced five defense levels of nuclear safety

Defense level	Objective	Essential means
Level 1	Prevention of abnormal operations and of malfunctions	Conservative design and high quality of construction and operation
Level 2	Control of abnormal operation and detection of malfunction	Control, limitation and protection systems and other surveillance characteristics
Level 3	Control of accidents included In the design basis	Engineered safety systems and accident procedures
Level 4	Control of the severe accident conditions of the plant, Including the prevention of accident and mitigation of consequences	Additional measures and accident management
Level 5	Mitigation of the radiological consequences of significant releases of radioactive products	External site emergency plan

Complete change of nuclear regulation in Japan after Fukushima Daiichi accident

- Former national nuclear regulation bodies (nuclear safety commission and nuclear and industrial safety agency were abolished, and nuclear regulatory agency started from September last year.)
- Nuclear Disaster Prevention Act was completely revised in June this year.
- New nuclear regulatory guide was just issued in July 18.

THANK YOU VERY MUCH FOR YOUR ATTENTION.