East Japan Earthquake on March 11, 2011 and Emergency Response at Fukushima Daini Nuclear Power Plant

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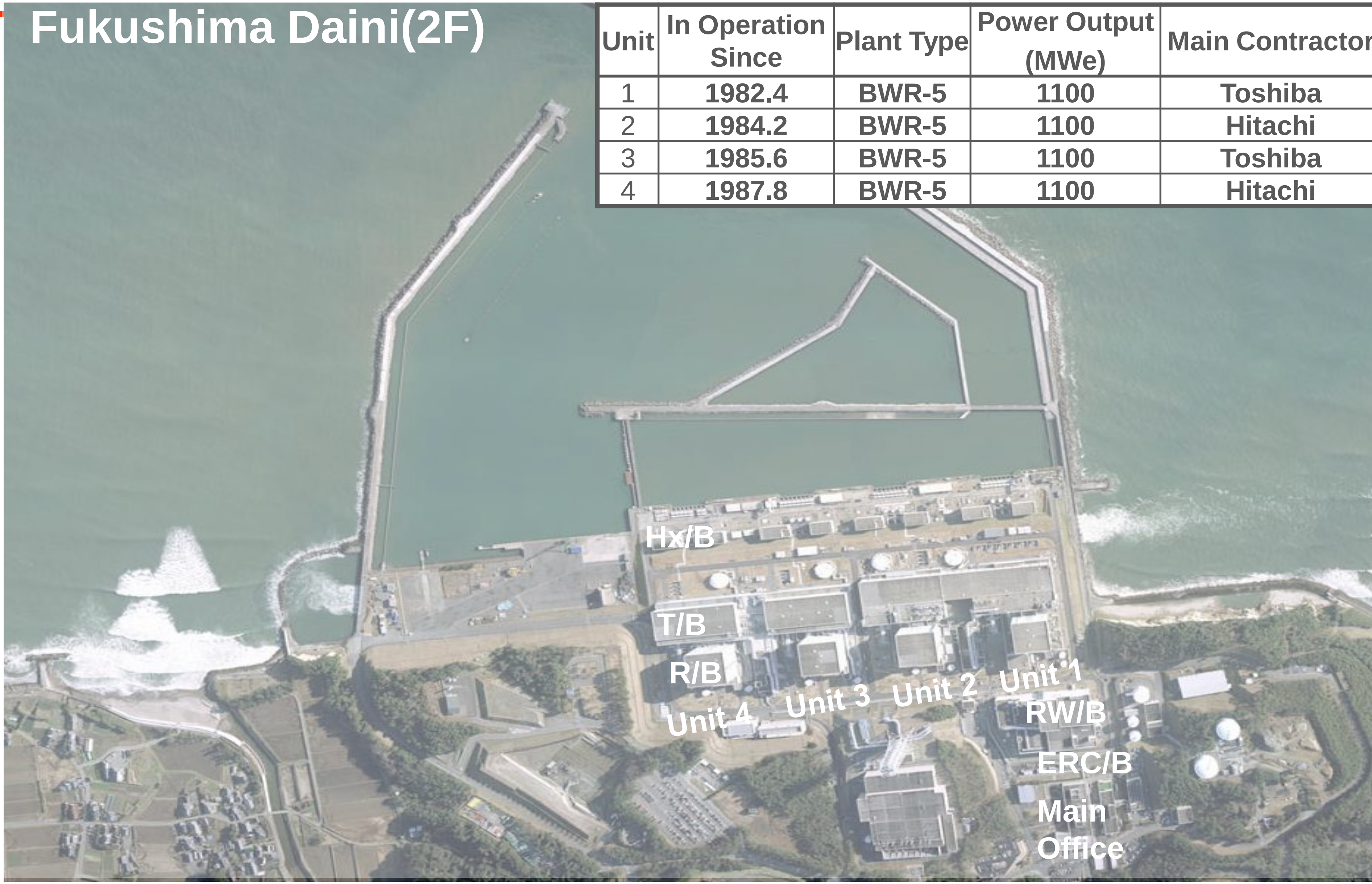
Overview of Fukushima Daini Nuclear Power Station

Unit	In Operation Since	Plant Type	Power Output (MWe)	Main Contractor
1	1982.4	BWR-5	1100	Toshiba
2	1984.2	BWR-5	1100	Hitachi
3	1985.6	BWR-5	1100	Toshiba
4	1987.8	BWR-5	1100	Hitachi



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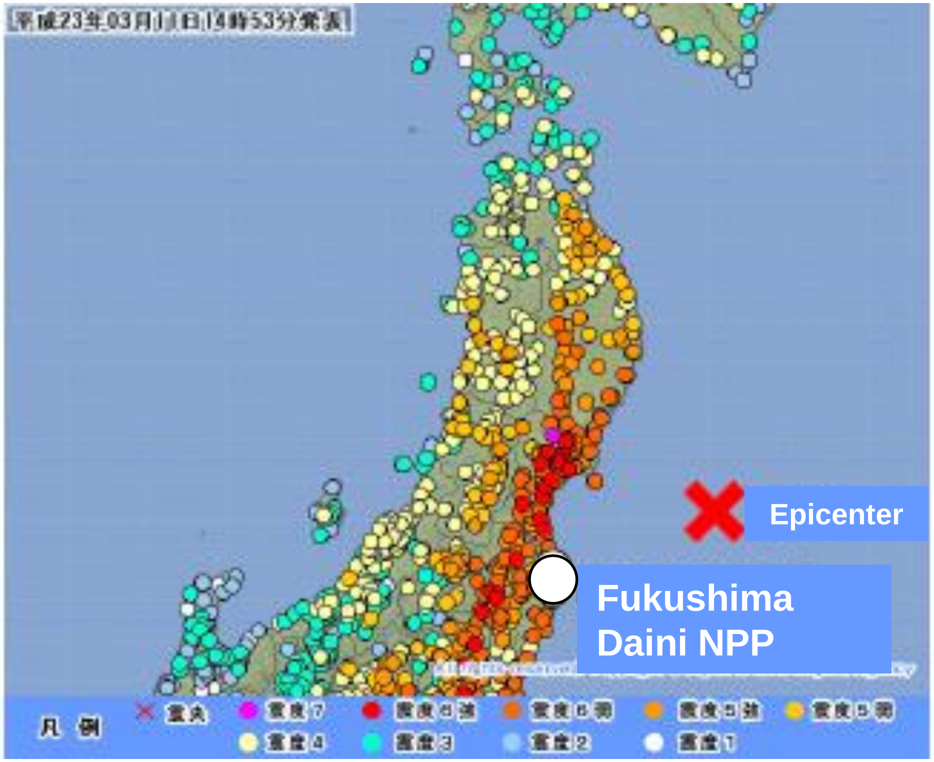
East Japan Earthquake

- 14:46 March 11, 2011
- Magnitude: 9.0
- Hypocenter distance from Fukushima Daini: 185 km (115 miles)
- One of the largest tsunamis in Japanese history
- At Fukushima Daini NPP the tsunami reached the height of 15 m (50 ft) maximum.



All the four units of Fukushima Daini Nuclear Power Plant were operating at their rated power before the earthquake.

All units automatically tripped* by acceleration signals.

(*Trip set point: 135 gal for horizontal acceleration, 100 gal for vertical acceleration)

No damage to safety related SSCs was caused by seismic impact.

The largest acceleration: 277 gal in horizontal and 305 gal in vertical direction.
Seismic acceleration spectra were mostly within the design values.

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Tsunami run up in Fukushima Daini NPS

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Site Emergency Response Center (ERC) at 16:05 on Match 11, 2011

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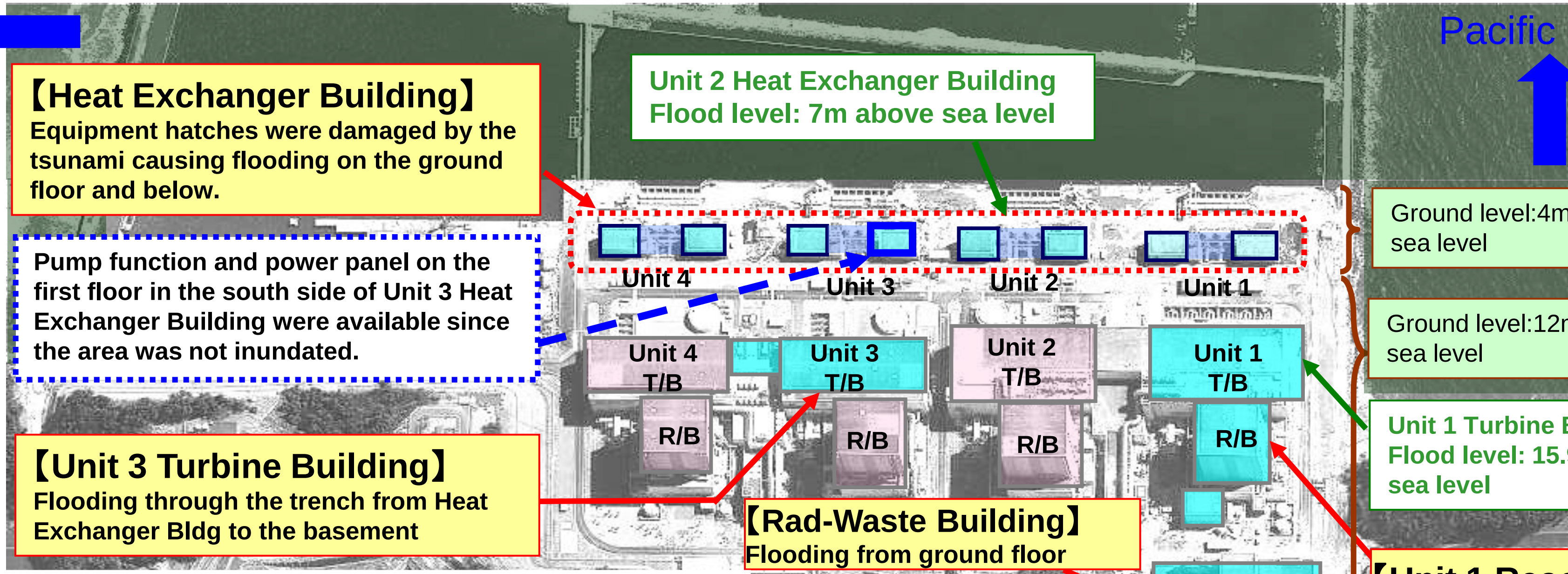
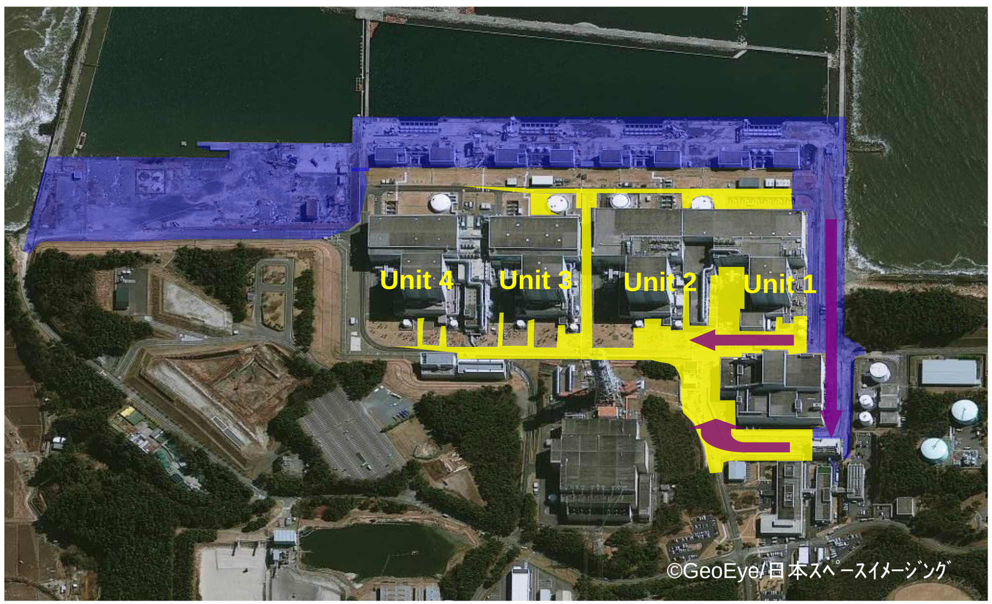
Flooding Caused by the Tsunami(1)





【Reactor Building】

Unit 2～4 Not Flooded

【Turbine Building】

Unit 2 and Unit 4 Not Flooded

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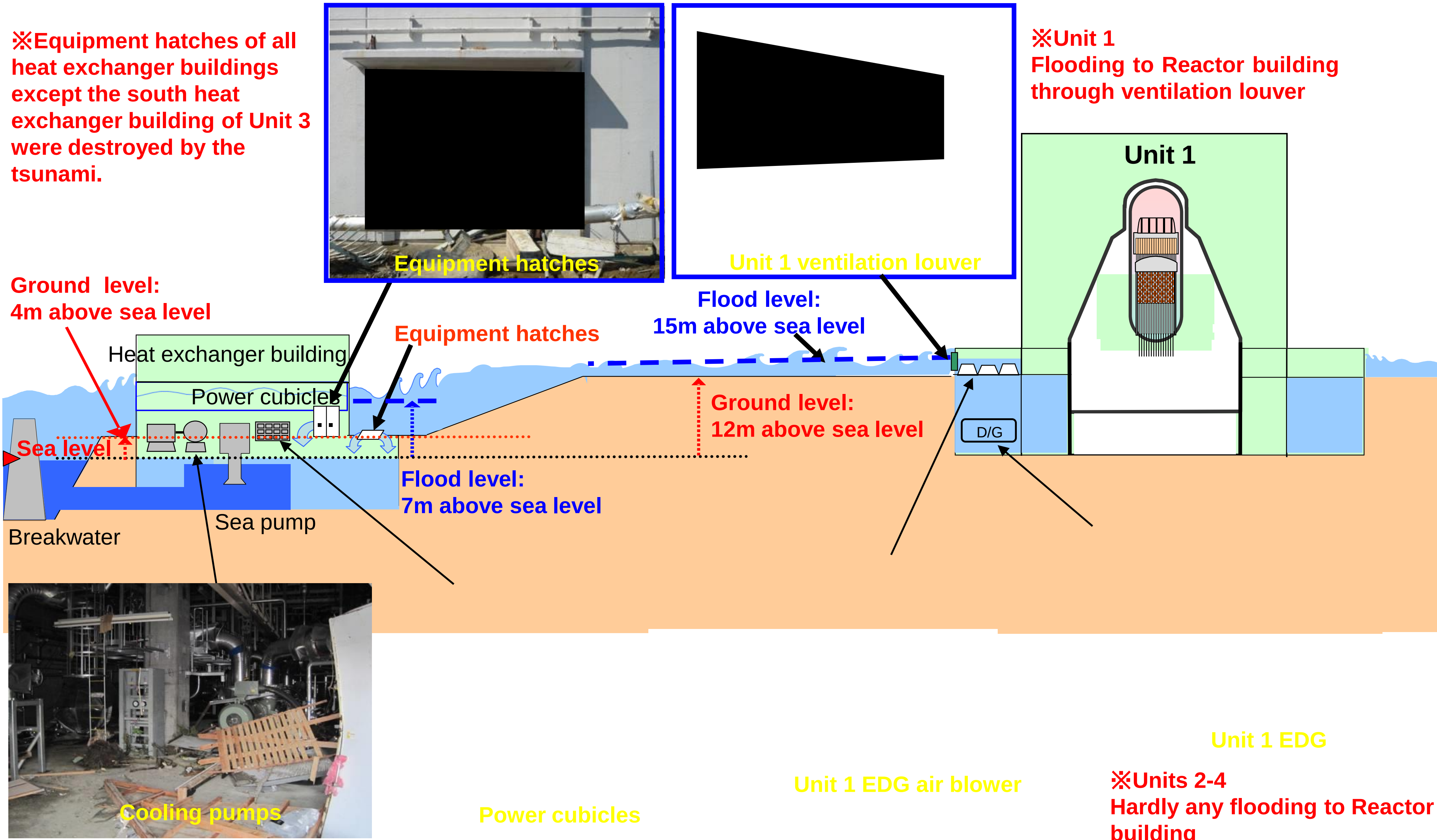
Flooding Caused by the Tsunami(2)



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System Status after the Tsunami

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

secure (power, pump and motor all working)

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

Inoperable

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System Status after the Tsunami

	unit 1		unit 2		unit 3		unit 4	
	equipment	status	equipment	status	equipment	status	equipment	status
M/C Emergency	M/C 1C	inoperable due to submerge	M/C 2C	operation	M/C 3C	operation	M/C 4C	operation
	M/C 1D	operation	M/C 2D	operation	M/C 3D	operation	M/C 4D	operation
	M/C 1H	inoperable due to submerge	M/C 2H	operation	M/C 3H	operation	M/C 4H	operation
P/C Emergency	P/C 1C−1	inoperable due to submerge	P/C 2C−1	operation	P/C 3C−1	operation	P/C 4C−1	operation
	P/C 1C−2	inoperable due to submerge	P/C 2C−2	inoperable due to submerge	P/C 3C−2	inoperable due to submerge	P/C 4C−2	inoperable due to submerge
	P/C 1D−1	operation	P/C 2D−1	operation	P/C 3D−1	operation	P/C 4D−1	operation
	P/C 1D−2	inoperable due to submerge	P/C 2D−2	inoperable due to submerge	P/C 3D−2	operation	P/C 4D−2	inoperable due to submerge

areas in red: inoperable areas in blue: operable

- P/Cs in the **blue boxes** are in the heat exchanger buildings on the sea side.
- All power sources of the cooling systems were lost except for **P/C 3D−2**.

Organizational Response under Emergency

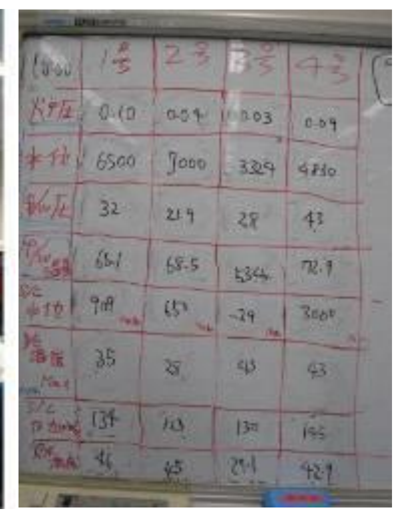
- Emergency response units maintained accountability by setting clear goals and reporting/visualizing situation to ERC on a constant basis.

- ERC personnel with operation background were dispatched to MCR.

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

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

  They did not leave the site to meet their families until April, devoting themselves to restoration activities, even in the case where their family were suffered or evacuated by the earthquake and the tsunami.



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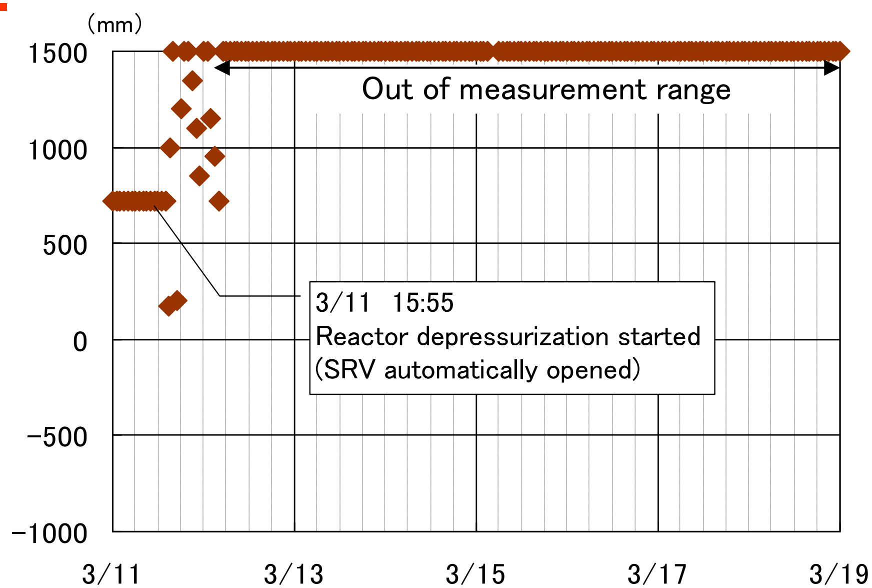
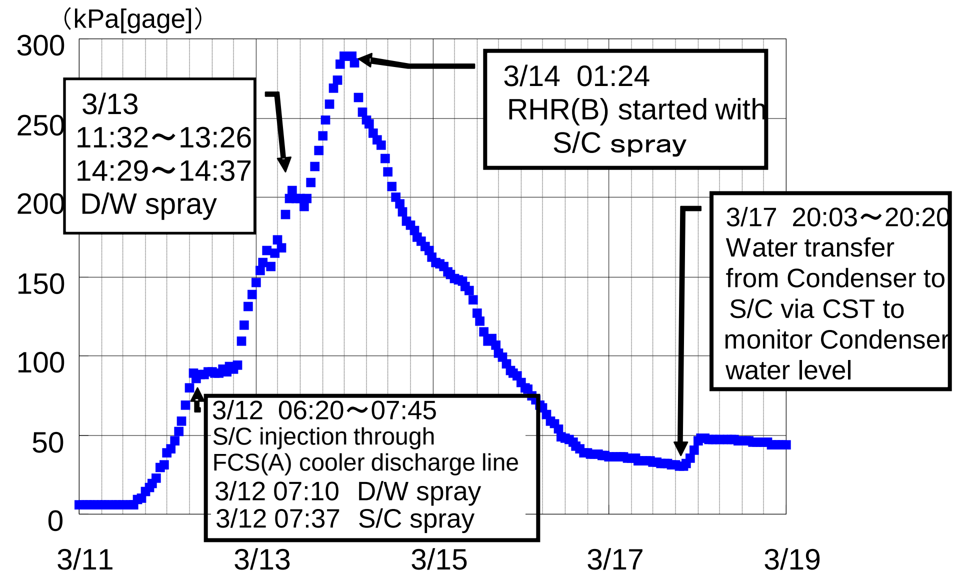
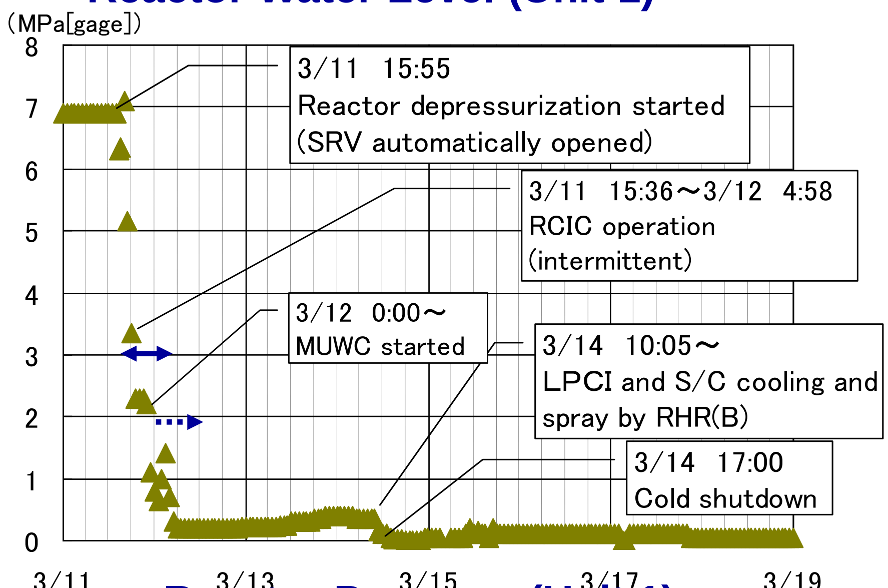
Efforts to mitigate accident progress



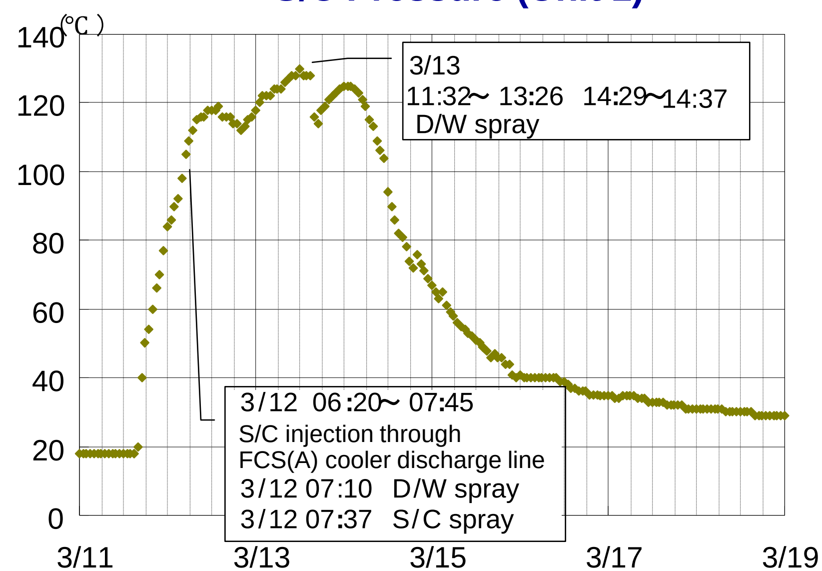
Reactor Water Level (Unit 1)



S/C Pressure (Unit 1)



Reactor Pressure (Unit 1)



S/C Temperature (Unit 1)

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Recovery Actions toward Cold Shutdown

Walkdown to identify damage of equipment (Midnight, March 11)

- Under continuous tsunami alerts, walkdown must be done in the field where a lot of debris, openings and flooding areas existed in the dark.
- Consideration was given for short-term restoration. Site ERC set priorities on recovery of RHR (B) cooling systems by replacing motors and supplying power from survived electrical buses and mobile power vehicles.

Emergency procurement of materials and equipment (March 12)

- Emergency procurement of motors, cable, mobile power vehicles, fuel oil and mobile transformers with close cooperation between site ERC and corporate ERC.
- Motors were transported from Toshiba by a cargo plane of SDF and from Kashiwazaki Kariwa NPP by trucks.

Equipment and power restoration work in the field (March 13)

- Pumps of RHR cooling systems (RHRC, RHRS, EECW) were inspected and failed motors were replaced.
- Temporary cable was laid to supply power from survived power cubicles in Rad-Waste Building and Unit 3 Heat Exchanger Building or mobile power vehicles.
- Temporary cable of 9 km length was laid by about 200 personnel within a day.
  Usually this size of cable laying requires 20 personnel and more than 1 month period.

Reactor cooling started with restored RHR pumps (March 14)

Various efforts made us achieve cold shutdown at all units at 7:15 on March 15th, 2011.

Procurement of Power Supply Vehicles

Replacement of a motor

Temp. Cable Laying

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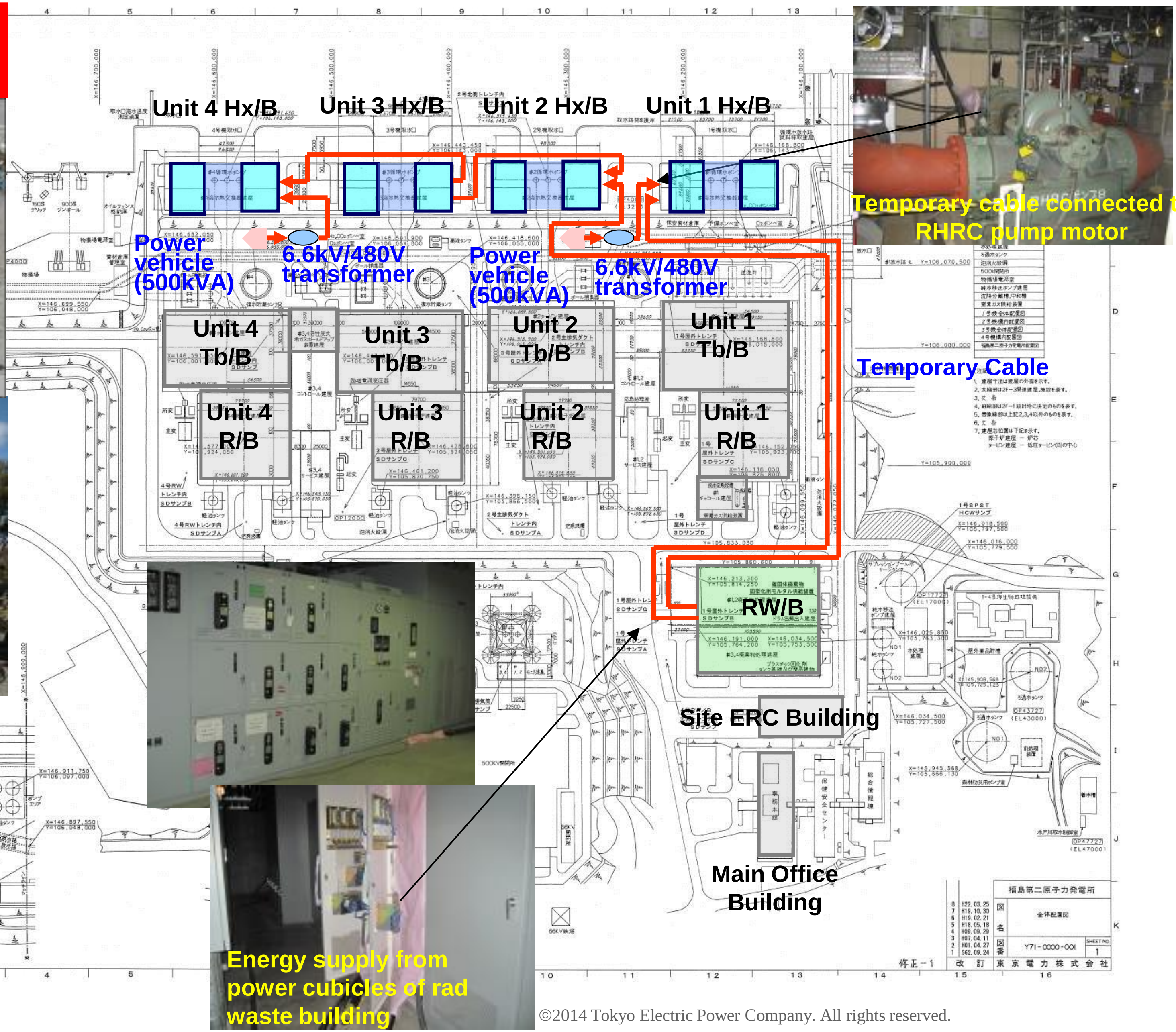
Temporary Cable for Emergency Power Supply

Temporary cable of 9 km length was laid by about 200 personnel within a day.



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Countermeasures reflecting the lessons learned from our restoration activities after the tsunami and the accident in Fukushima Daiichi

Lessons learned from Fukushima Daini

Lesson	Countermeasures
Procurement of motors and cables for laying temporary cable in order to secure emergency power supply.	･ Diversification of power supply ･Staging spare motors, cables etc. ･Deployment of power vehicles and GTG vehicles ･Installing new terminals for connecting power vehicles to reduce time for cable laying
Difficulties in removing debris and transporting equipment.	･Enhancing emergency response capability by acquiring necessary skills for shutdown, cooling, and containment ･Making routes and space available for emergency response by operating heavy machines by ourselves

Lessons learned from Fukushima Daiichi

Lesson	Countermeasures
Station Black Out	･Deployment of power vehicles and GTG vehicles for prompt power supply ･Training site personnel for restoring power
Loss of cooling and water injecting functions	･Stand by fire engines on the highland as flexible water injection measure ･Training site personnel for water injection to the reactor and spent fuel pool

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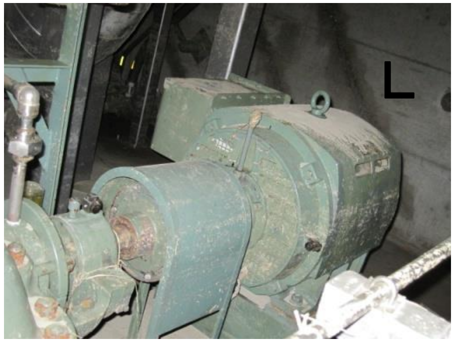
Enhancement on Direct Management

After the accident, while ensuring equipment and materials, reinforcing electric power source (deployment of mobile power vehicles, air-cooled gas turbine generators) and ensuring water injection measures (fire engines) as emergency countermeasures, trainings have been conducted so that TEPCO personnel can make an initial response for themselves in case the situation similar to 3.11 occurs.

Based on lessons-learned derived from experiences on 3.11, four teams were established, and each team is currently conducting trainings for direct management according to plans.

Team	Persons	Countermeasures against risks
Motor Replacement Team	3 or 4 sub-team per team (7 or 8 per sub-team)	To transport spare cooling pump motors and replace ones which become inoperable due to submergence in water for them
Pump Recovery Team		To overhaul submerged pumps, replace bearings, reassemble them and make them operable.
Cable Connecting Team		To lay cables to supply power to replaced motors and conduct operations on them
Debris Removal Team		To remove debris on the road and recover the road with gravel and steel plates to conduct works shown above

- Each team conducts trainings once or twice per month.
- In addition to four teams shown above, a project team(8 persons) has been established to implement progress/skill management and hold review meeting.



Water damage on motors induced by tsunami

Water damage on pumps induced by tsunami

Laying temporary cables

Debris near the seaside road

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For Further Enhancement of Safety

Robustness

- **Improve robustness to decrease risks for common mode failure against external events**

Resilience

- **Improve capability of flexible and efficient response to Beyond Design Basis Events**

It is not important that:

“cars which never have flat tires should be manufactured”.

What matters to us is that:

“even if we have a flat tire, spare tires and tools are there ready, and the personnel have the skills to use them in order to replace the flat tire themselves”.

Safety Goals to minimize social impact

- **Filtered venting system to mitigate large scale land contamination**

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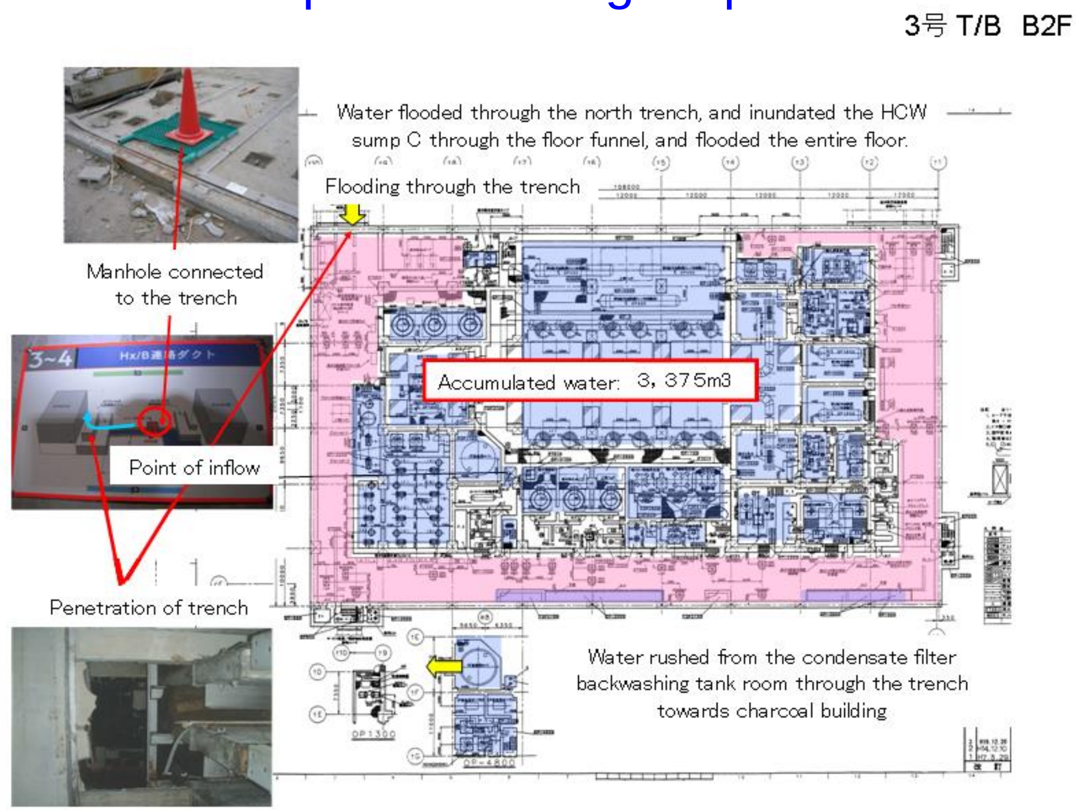
To share our Lessons with global peers

Summarizing our perceptions: Fukuni no Kiseki (Triumph/Trajectory of Fukushima Daini)
- We summarized about 360 lessons we have learned through achievement of cold shutdown. (Sept.24, 2012)

-Accepting experts and exchanging information from foreign and domestic nuclear organizations.

Example of flooding map



By sharing these lessons to other nuclear power plants and society, we can make a social contribution and improve the reliability of nuclear plants all over the world.

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Personnel Mental Health Care (1)

- Habitation before the accident （Number of personnel: 721）
  - Approximately 80% personnel were living in the neighboring municipalities within 20 kilometers from Fukushima Daiichi Nuclear Power Plant.
  - More than half numbers of personnel were hometowners.
  - Collapsed houses (total collapse and half collapse): 23
  - Personnel facing the death of relatives: 8

- While workers working at the sites are also disaster victims, they are regarded as the person who caused damage at the temporally housing and local communities they live. This fact made them mentally unstable.

- All the members were informed that stabilizing all plants by March 23rd, 2011 was top priority.
  - 3/11 ～ On duty around the clock
  - 3/16 ～ On duty/stand-by around the clock
  - 3/24 ～ 3 days-on/ 1 day-off (Night duty) + Holiday
  - End of June ～ 3 days-on/ 1 day-off (Night duty) + Holiday
5 days-on/ 2 day-off (Night duty) + Holiday

- Though communication means had been tried to be prepared so that all members could get in touch with their families, they were ready 7 to 10 days after initiating to try.

- Few members were injured and exposed to radiation at the site.

- There was the medical care team at the site. However, there were not experts familiar with mental health care there.

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Personnel Mental Health Care (2)

- Mental Health Care
  - In the middle of April, 2011, members both at Fukushima Daiichi and at Daini reported psychological stress, and medical specialist heard what they are like.
  - In May and June, 2011, questionnaires were conducted for members working both at Fukushima Daiichi and at Daini.
  - Due to the earthquake and Tsunami, medical specialist interviewed members who lost family and colleagues, experienced impending death, lost household furniture, were discriminated/defamed and witnessed hydrogen explosion.
  - Long-term mental support has been conducted by medical experts familiar with stress induced by disaster from National Defense Medical College.
  - After the accident, the results from conducting mental health care were reported.

    （Prof. Shigemura from National Defense Medical College,

    Prof. Tanigawa from Ehime University etc.）
    - August 15th, 2012 issue of US medical magazine JAMA

      (The Journal of the American Medical Association)
    - Mental distress of members working at Fukushima Daiichi and Dain
    - Presentations were delivered both at The Japanese Society of Psychiatry and Neurology and at Japanese Society for Traumatic Stress Studies.

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What was important in human and organizational aspects

1. **Ensure common understanding of plant conditions through sharing of essential parameters among the members of emergency organizations.**

   Also ensure that critical decisions and information are shared among the members.

   - Key plant parameters and system and component status were continuously monitored and visualized in the ERC. Core cooling condition was especially important.
   - Briefings for emergency personnel in the ERC on plant status to provide near future outlook. Communicated to members the estimated time needed to stabilize the plant and/or whether the situation was getting better or worse.
   - Leaders should pay attention to both what is known and what is not known.
   - Communication means between the ERC and the MCR should be ensured.
   - Common understanding of critical decisions and plant parameters among the members of emergency organizations should be ensured in order that site personnel can work as one.
   - ERC leader should manage conflicts, fears and anxieties of response staff, including those who have been dispatched to the Fukushima Daini site and those unfamiliar with the nuclear field.
   - ERC leader decided to sit in a location where he could easily obtain information related to decision-making and see the face of each sub-leader in the ERC.

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TEPCO

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What was important in human and organizational aspects

2. TEPCO personnel should be able to perform emergency response actions regarding “shut down”, “cooling” and “contain”.

- Most of the restoration work was done by TEPCO personnel because there was so much uncertainty in manpower.

  (In actuality, maintenance contractors could not come to the site.)
- Removal of debris was essential to secure access paths. Transporting and installing motors and connecting cables were hard work.
- Basic knowledge of radiation protection and contamination prevention measures were insufficient for security, transportation and administrative staff.
- ERC personnel should have the following skills.
  - Work required for “shut down”, “cooling” and “contain”
  - Use of heavy machinery for rubble removal and heavy weight transportation
  - Determining whether equipment is available or unavailable after earthquake/tsunami
- Necessary equipment and tools should be ready on site.
  - Bulldozers, large buses, cranes
  - Mobile lifters for transporting large-scale equipment
  - Cable end handling tools etc.

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What was important in human and organizational aspects

3. Difficulties in logistics caused physical and psychological impacts.

- Lack of materials caused by the unexpected prolongation of recovery activities.
- Problems from impassable roads, traffic control and disconnected cellular phones.
- Since transportation services were unavailable, materials and equipment were transported by TEPCO personnel, including water trucks.
- Mobile power vehicles required fuelling every 3 hours, in dark, dangerous conditions, even after the explosion at Fukushima Daiichi.

4. Strategy for staffing site and corporate emergency response organizations quickly in the initial stages of a multi-unit accident.

- This event occurred on a Friday afternoon. Approximately 500 members responded to the accident, including 250 emergency response personnel. In the MCR, almost all of the operators, including those who were off-duty, arrived, and nearly every one of them remained at the site for recovery activities until the end of March.
- It is important to identify how people are to assemble in the event of a tsunami, including at night and weekends, considering the risks of transportation and impassable roads, in order to respond in the early stages of an accident.
- By reflecting lessons learned and ensuring emergency response capability 24 hours a day and 365 days a year, the staffing strategy for ERO was improved.

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5. Emotional concerns must be taken care of.

- Emergency response personnel continued to work in a tense atmosphere for a long period, even while some of their family members were suffering due to the disaster.
- Over 100 personnel in Fukushima Daini were diagnosed with Post-Traumatic Stress Disorder. ※
- Since May 2011, periodic examination has been conducted by professionals from the National Defense Medical College to minimize stress-related illnesses.

※Jun Shigemura, Takeshi Tanigawa, Isao Saito, Soichiro Nomura (2012), Psychological distress in workers at the Fukushima nuclear power plants, *The Journal of the American Medical Association*

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Thoughts on Leadership (overall)

- What matters is to work as a team: Team and members should be motivated and inspired.
- The leader is the only person who can oversee the team in its entirety: Situation awareness is crucial.
- Information management should be centralized.
- The aim of decision-making should be to achieve goals. Safety of personnel should be given top priority, but personnel should be prepared to engage in high risk work if this becomes necessary.
- What should be done, which task should come first and how things will work should be clearly indicated to the team to enable them to perform tasks efficiently with limited time and manpower.

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Thoughts on Leadership (command and control)

- Leader takes full responsibility for command and control.
- Specific instructions should be delivered clearly to each sub-leader.
- Leader should express in words both understanding of and gratitude for reports from members.
- As soon as members seek direction, leader should quickly respond to them.
- Critical decision-making and changes in policy should be conducted after receiving unanimous approval for them.
- Leader should reprimand members if they did not perform their tasks as instructed, and console them if the task they were instructed to perform did not go to plan.

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Thoughts on Leadership (information sharing)

- Plant-related information
- Concerns
- What is happening
- How much longer efforts need to be made and whether the situation is getting better or worse
- Areas considered dangerous from a personal safety perspective
- Sharing plant conditions with local communities

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