Addenda to the update of the Fukushima Daiichi Nuclear Power Station accident (March 11 through May 31, 2011)

IJNS Editor

Abstract: These addenda provide the figures and tables for helping readers to understand the article titled "the update of the Fukushima Daiichi Nuclear Power Station (NPS) accident" by SHIBUTANI Yu. These figures and tables are mainly referred from "Report of the Japanese Government to the IAEA Ministerial Conference on Nuclear Safety- The Accident at TEPCO's Fukushima Nuclear Power Stations - June 2011 Nuclear Emergency Response Headquarters Government of Japan"
(http://www.kantei.go.jp/foreign/kan/topics/201106/iaea_houkokusho_e.html)
Keyword: Fukushima Daiichi NPS; earthquake; tsunami; level 7 nuclear accident

1. Location of Fukushima Daiichi NPS and the general features

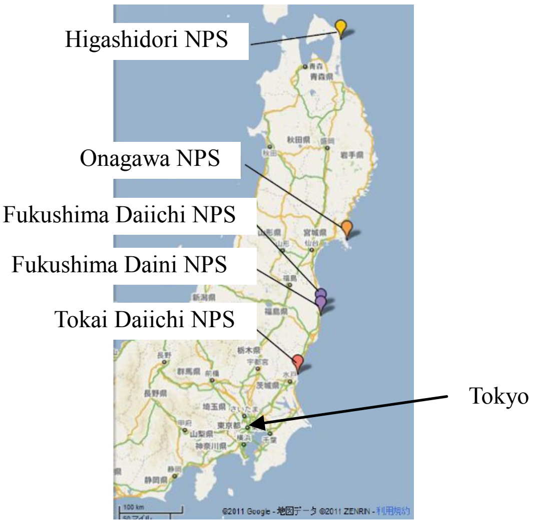


Fig.1 Location of Fukushima Daiichi and other NPSs on the northeast coast of Japan. Modified by IJNS editor

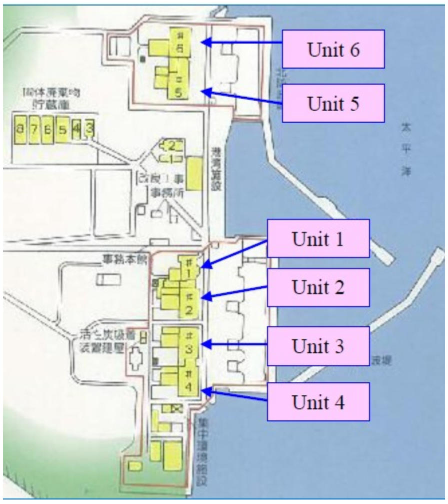


Fig. 2 Plant layout of Fukushima Daiichi NPS.

Table 1 General features of six units in Fukushima Daiichi NPS and the state of operation at the time of the earthquake

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Electric output (MWe)	460	784	784	784	784	1100
Commissioning	1971/3	1974/7	1976/3	1978/10	1978/4	1979/10
Reactor model	BWR3	BWR4			BWR5	
Primary Containment Vessel	Mark-1					Mark-2
State of plant	In operation	In operation	In operation	Periodic inspection	Periodic inspection	Periodic inspection
Number of fuel assemblies in the core (including MOX)	400	548	548 (32)	All fuel assemblies shipped to spent fuel pool; disconnected on 2010/11/29; pool gate closed; reactor well filled with water	548; disconnected on 2011/1/2; RPV pressure tests under way; RPV head put in place	764; disconnected on 2010/8/13 RPV head put in place
Number of fuel assemblies in the spent fuel pool (including new fuel / MOX)	392 (100 / -)	615 (28 / -)	566 (52 / 0)	1,535 (204 / -)	994 (48 / -)	940 (64 / -)

Received date: July 3, 2011

2. Tsunami hazard

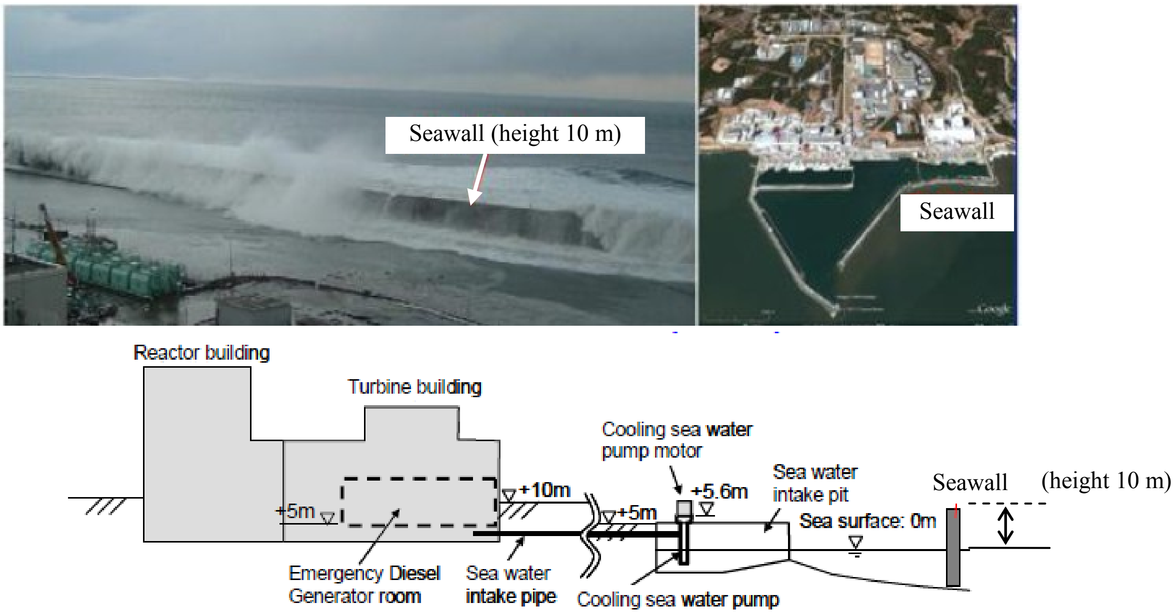


Fig.3 Snap shot of the tsunami just getting over seawall (top left), birds eye view of seawall layout (top right), and cross-sectional layout of Fukushima Daiichi NPS. Modified by IJNS editor

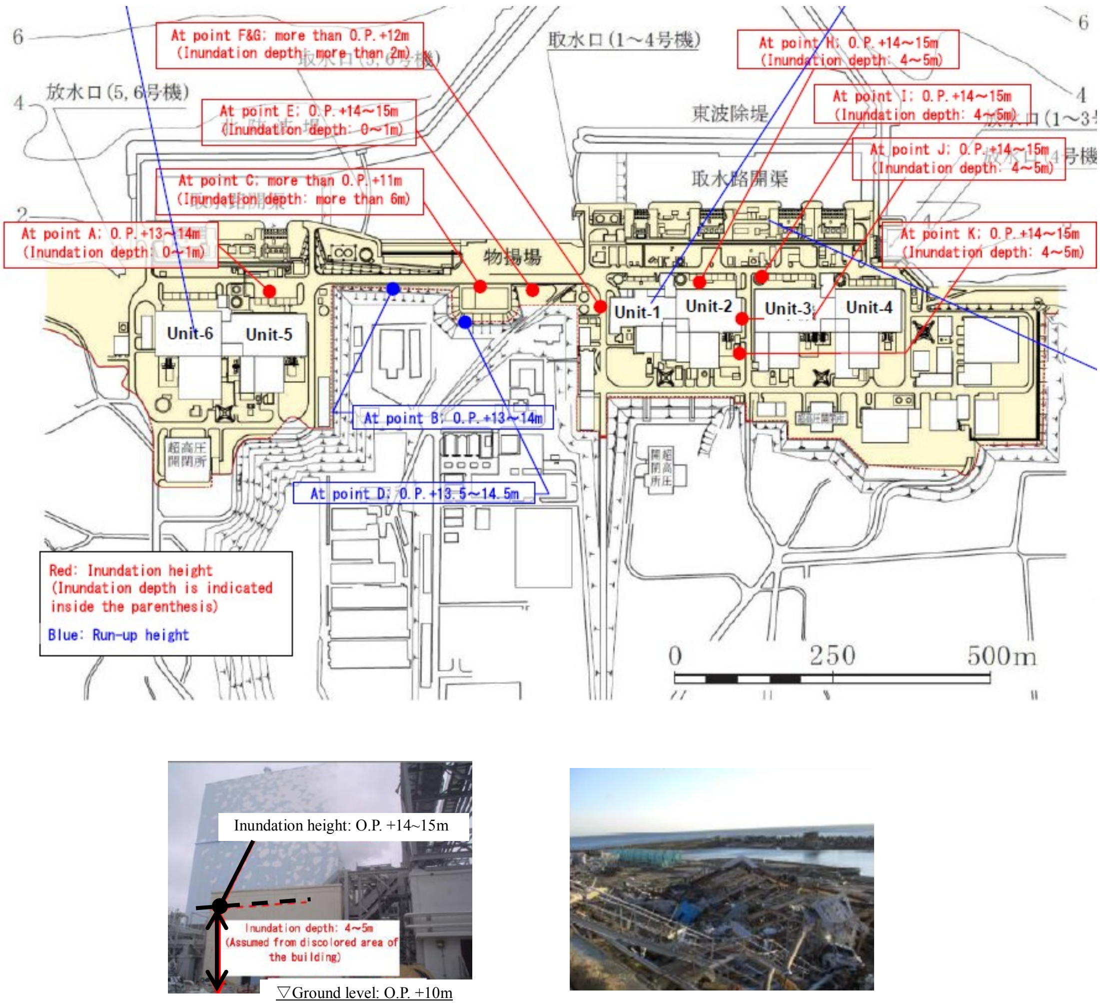


Fig.4 Inundation area (yellow part) of Fukushima Daiichi NPS due to the tsunami (top). Photos showing inundation height (bottom left), and wrecked intake pump area (bottom left). Modified by IJNS editor

3. Response of the official organizations for nuclear emergency

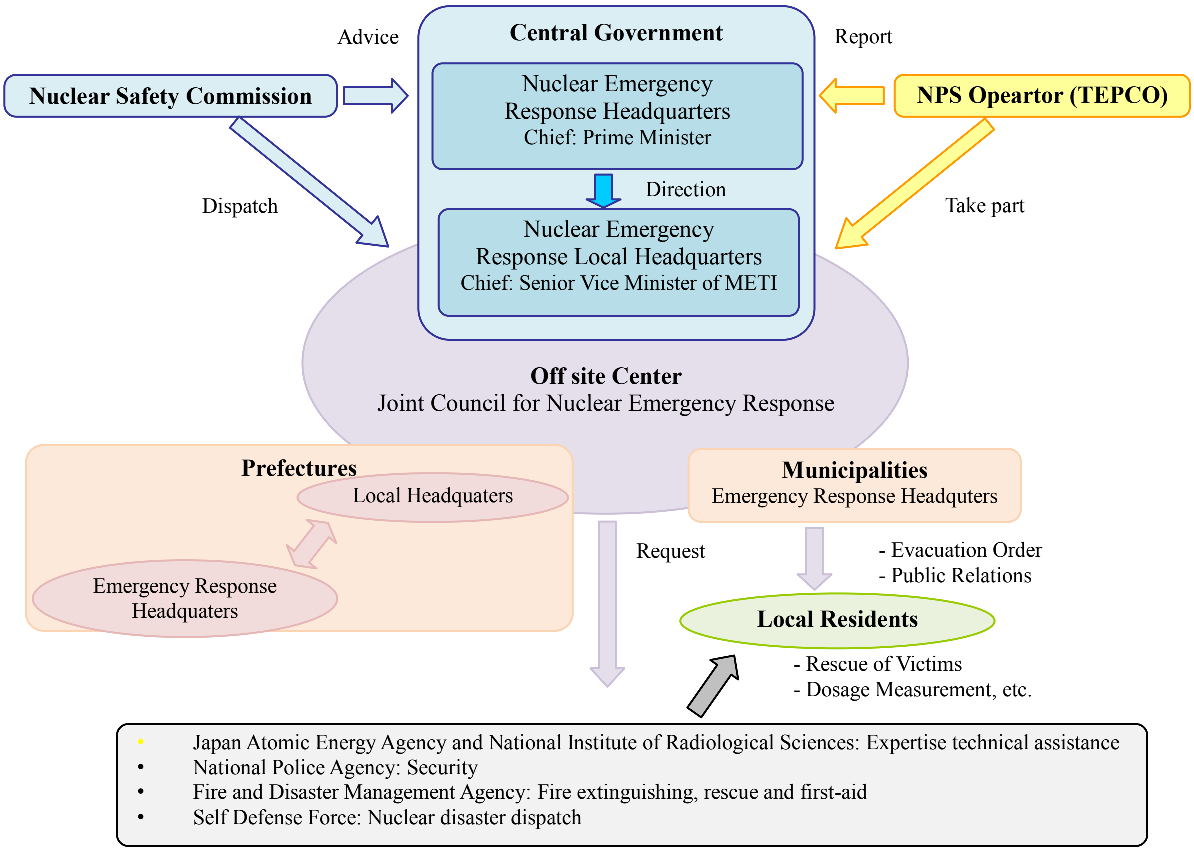


Fig.5 Formal relation of various organizations involving nuclear emergency response described in Japan's Act on Special Measures Concerning Nuclear Emergency Preparedness.

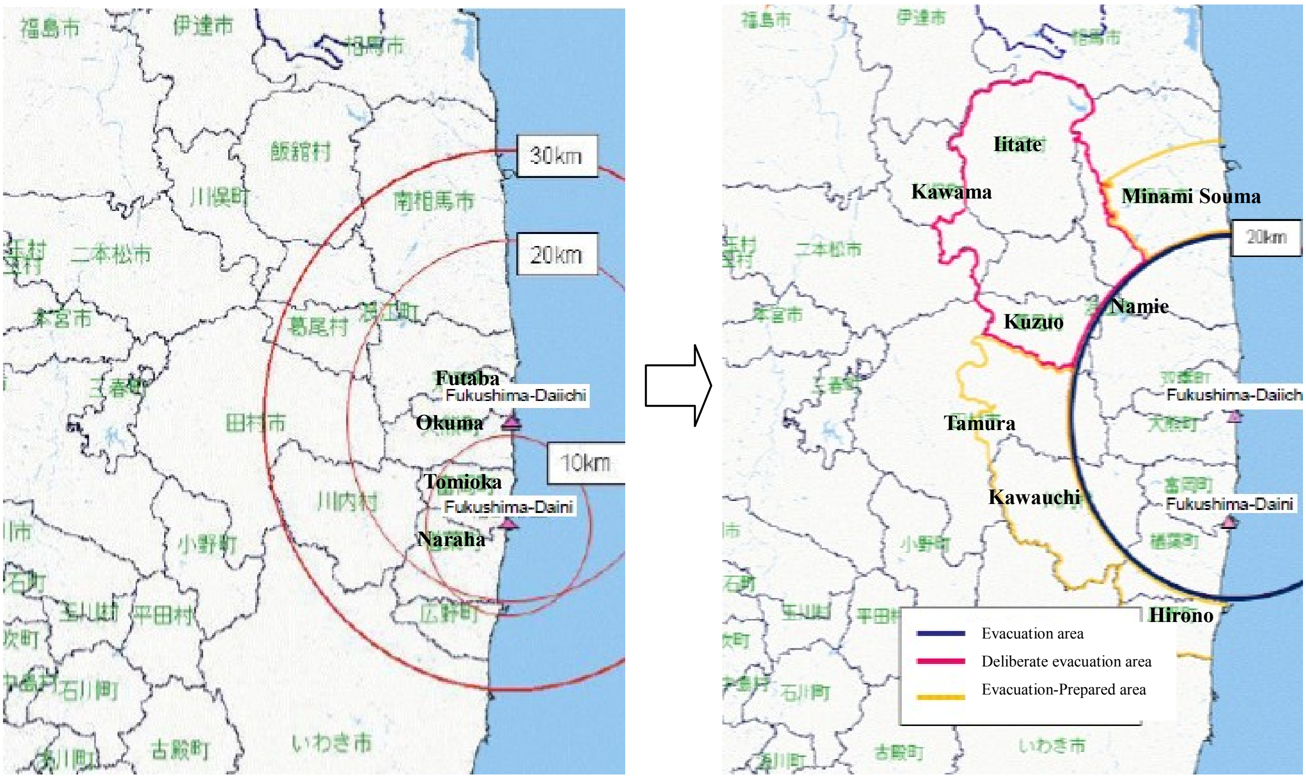
Table 2 Time record of actual establishment of various organizations to cope with Fukushima Daiichi accident.

Date	Time	Establishment
March 11	15:42	The Ministry of Economy, Trade and Industry (METI) in charge of safety regulation of nuclear power plants received a report from a nuclear operator pursuant to the Act on Special Measures Concerning Nuclear Emergency Preparedness (Total loss of AC power during operation) and established the Nuclear Emergency Preparedness Headquarters and the On-site Headquarters.
	16:00	The Nuclear Safety Commission of Japan (NSC Japan) held an extraordinary meeting and decided to organize an Emergency Technical Advisory Body.
	16:36	In response to the report as of 15:42 pursuant to the provisions of Article 10 of the Act on Special Measures Concerning Nuclear Emergency Preparedness, the Deputy Chief Cabinet Secretary for Crisis Management established Emergency Response Office for the nuclear accident at Prime Minister's Office.
	19:03	The Prime Minister declared the nuclear emergency and established the Nuclear Emergency Response Headquarters at TEPCO's headquarters in Tokyo, and the Local Nuclear Emergency Response Headquarters at Fukushima prefecture.
	in parallel	Other ministries and agencies established organizations to respond to the emergency.

Note: The Nuclear and Industrial Safety Agency (NISA) is an independent agency under the supervision of METI. The role of NISA is in charge of supervising the operation and maintenance of nuclear power plants and nuclear fuel cycle facilities.

Table 3 Time record of instructions to the local residents
Issued by the Director General of the Nuclear Emergency Response Headquarters
and the Governor of Fukushima Prefecture

Date	Time	Instructions
March 11	20:50	Instruction of evacuation to the residents and others of Okuma Town and Futaba Town within 2 km radius from the NPS. (by the Governor of Fukushima Prefecture)
	21:23	Instruction of evacuation to the residents living within a radius of 3 km from the NPS was issued. Instruction of stay in-house to the residents living within a radius of 3 to 10 km from the NPS was issued.
March 12	05:44	Instruction of evacuation to the residents living within a radius of 10 km from the NPS was issued.
	18:25	Instruction of evacuation to the residents living within a radius of 20 km from the NPS was issued.
March 15	11:00	Instruction of stay in-house to the residents living within a radius of 20 to 30 km from the NPS was issued.
April 21	11:00	Instruction to designate the evacuation area as the restricted area in accordance with the Basic Law on Natural Disasters was issued.
April 22	09:44	The stay in-house instructions were lifted and the Deliberate Evacuation Area and Evacuation-Prepared Area in Case of Emergency were established. (see Fig. 6)



(Before April 21) (After April 22)

Fig.6 Establishment of restricted area on April 21.

The Restricted Area is intended to limit access to the area in order to prevent residents and others from radiological risk by entering the evacuation area. The evacuation area (within 20 km from Fukushima Daiichi and 10 km from Fukushima Daini) and the stay in-house area instructed before April 21 (left). The stay in-house area was lifted, and the evacuation area (black line; within 20 km from Fukushima Daiichi), the deliberate evacuation area (red line) and evacuation-prepared area (yellow line) in case of emergency were established after April 22 (right)
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4. INES scale

Table 4 Time record of provisional evaluations of INES scale

Date	Provisional evaluation
March 11	Level 3 was issued as provisional evaluation, based on the decision by NISA that the emergency core cooling system for water injection had become unusable.
March 12	Level 4 was issued as provisional evaluation, based on the decision by NISA that approximately more than 0.1% of the radioactive materials in the reactor core inventory had been emitted.
March 18	Level 5 was issued as provisional evaluation, based on the decision by NISA that the several percentages of the radioactive materials in the core inventory were released.
April 12	Level 7 was announced as provisional evaluation, based on the estimation by NISA was 370,000TBq of radioactivity in iodine equivalent, in addition to the calculated estimate 630,000TBq by NSC.

Table 5 Examples of nuclear facility accident

	People and the Environment	**Radiological Barriers and Control**	**Defense-in-Depth**
Major Accident **Level 7**	Chernobyl, Former Soviet Union, 1986 Widespread health and environmental effects. External release of a significant fraction of reactor core inventory.		
Serious Accident **Level 6**	Kyshtym, Russia, 1957 Significant release of radioactive material to the environment from explosion of storage tank of high radioactive waste.		
Accident with Wider Consequences **Level 5**	Windscale Pile, UK, 1957 Release of radioactive material to the environment following a fire of a reactor core.	Three Mile Island, USA, 1979 Severe damage in the reactor core.	
Accident with Local Consequences **Level 4**	Tokaimura, Japan, 1999 Fatal neutron exposures of workers by a criticality event occurred at a reconversion facility.	Saint Laurent des Eaux, France, 1980 Melting of one channel of fuel in the reactor with no release outside the site.	
Serious Incident **Level 3**	No example available	Sellafield, UK, 2005 Release of large quantity of radioactive material, contained within a reprocessing installation.	Vandellos, Spain, 1989 Near accident caused by fire resulting in loss of safety systems at the nuclear power station
Incident **Level 2**	Atucha, Argentina, 2005 Overexposure of a worker exceeding the annual limit at a power reactor.	Cadarache, France, 1993 Spread of contamination in an area not expected by design.	Forsmark, Sweden, 2006 Degraded safety functions by common cause failure in the emergency power supply system at nuclear power plant.
Anomaly **Level 1**			Breach of operating limits at a nuclear facility.
No safety significance Below scale **Level zero**			

Note: The International Nuclear and Radiological Event Scale (INES) is to classify nuclear and radiological accidents and incidents by considering the following three areas of impact:
People and the Environment considers the radiation doses to people close to the location of the event and the widespread, unplanned release of radioactive material from an installation.
Radiological Barriers and Control covers events without any direct impact on people or the environment and only applies inside major facilities. It covers unplanned high radiation levels and spread of significant quantities of radioactive materials confined within the installation.
Defense-in-Depth also covers events without any direct impact on people or the environment, but for which the range of countermeasures put in place to prevent accidents did not function as intended.
Reference: IAEA Publication, [on-line] http://www.iaea.org/Publications/Factsheets/English/ines.pdf

5. How the plant responded but affected by the tsunami

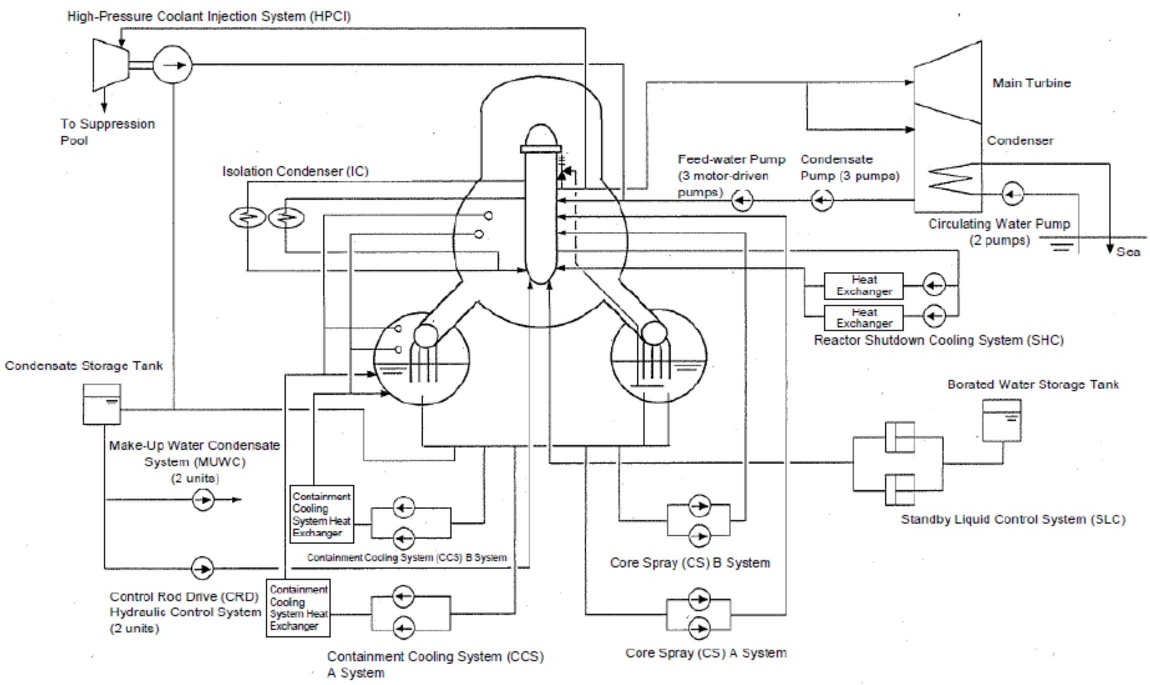


Fig.7 Normal configuration of Emergency Core Cooling System of the Fukushima Daiichi NPS (Unit 1).

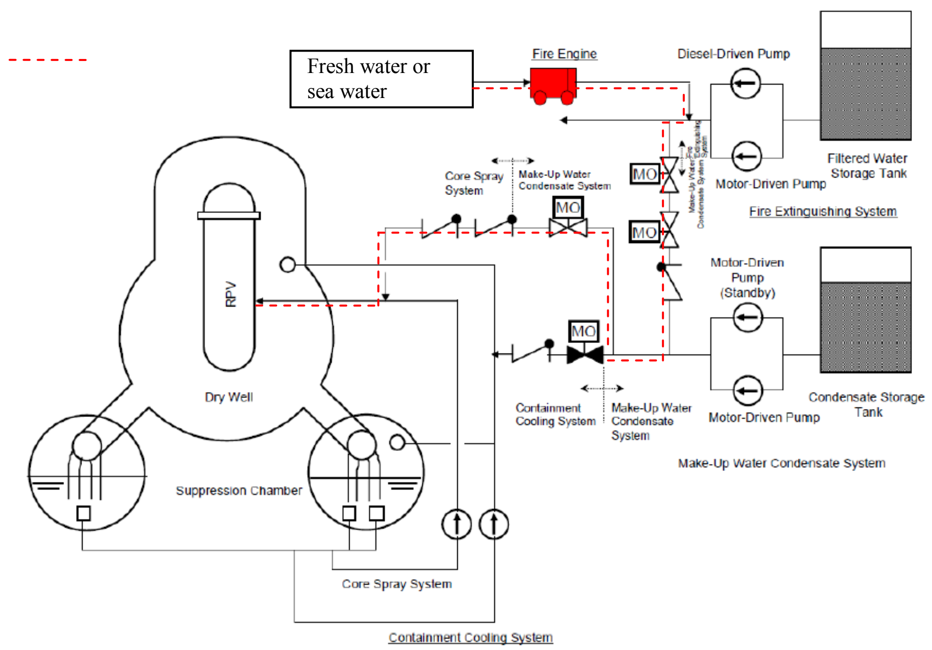
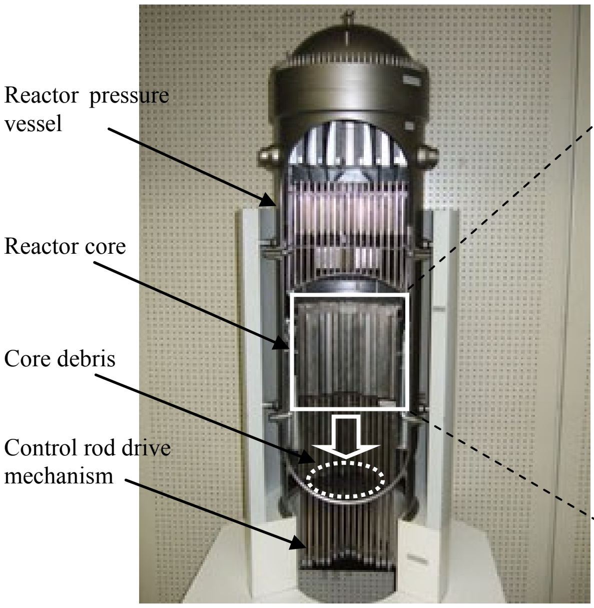
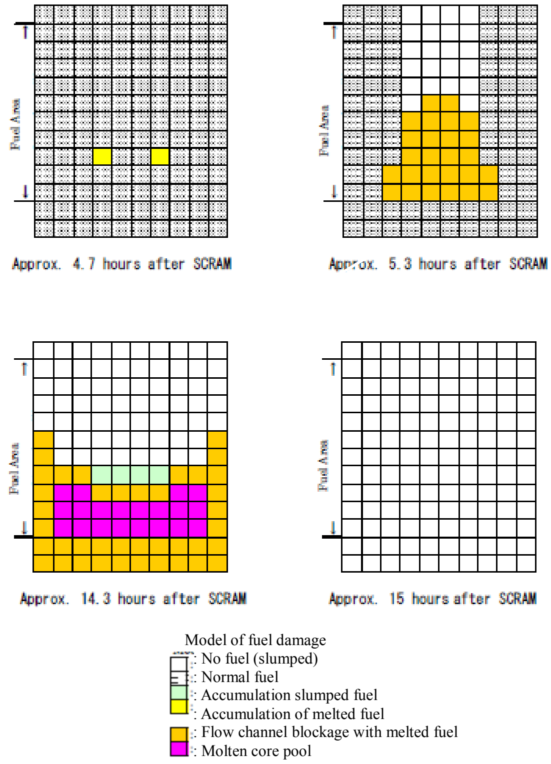


Fig.8 Makeshift water injection method employed by the tsunami-struck Fukushima Daiichi NPS (Unit 1).

Borated water has been injected into RPV by way of dotted line from Fire Engine, after the water both in Filtered Water Storage Tank and Condensate Storage Tank were exhausted. The water to be pumped by Fire Engine was switched to sea water when all the sources of fresh water were exhausted.





Reference: TEPCO Release [online]
http://www.tepco.co.jp/tepconews/pressroom/110311/
Modified by IJNS editor

Fig.9 Meltdown of the Fukushima Daiichi NPS (Unit 1) due to insufficient core cooling.
Progression of fuel melting of the reactor core in the reactor vessel was analyzed by MAAP code as shown in the four figures in the right-hand side. In 15 hours after the reactor scram, the core debris would drop down to the bottom of reactor vessel (see left-hand side figure).

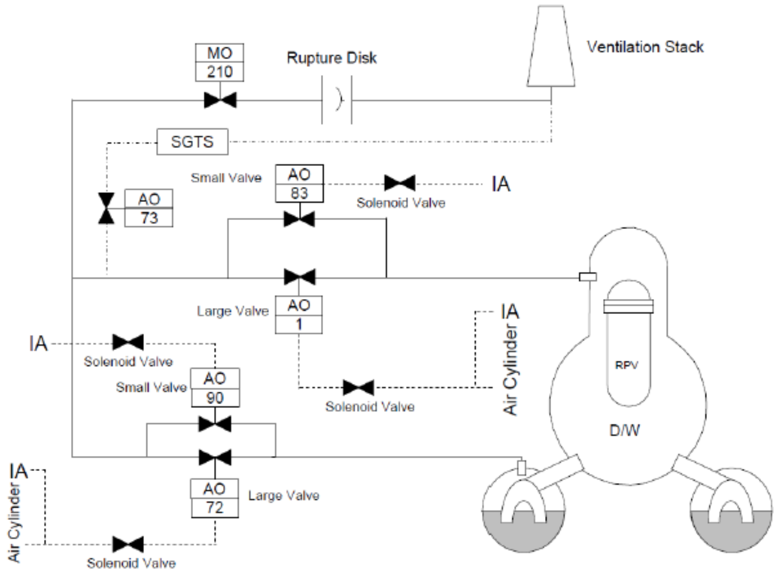


Fig.10 PCV Venting Facility of the Fukushima Daiichi NPS (Unit 1) installed as a countermeasure for severe accident management. This is to bypass the SGTS line (dotted line in the figure) to cope with high pressure situation of dry well.

AO: Air operated valve
MO: Motor operated valve
SGTS: Standby gas treatment system
DW: Dry well

Fig.11 Photo showing exterior view of reactor building of the Fukushima Daiichi NPS (Unit 1) after hydrogen explosion.
Reference: TEPCO Release [online] http://www.tepco.co.jp/tepconews/pressroom/110311/

5. Discharge of Radioactive Materials to the Environment

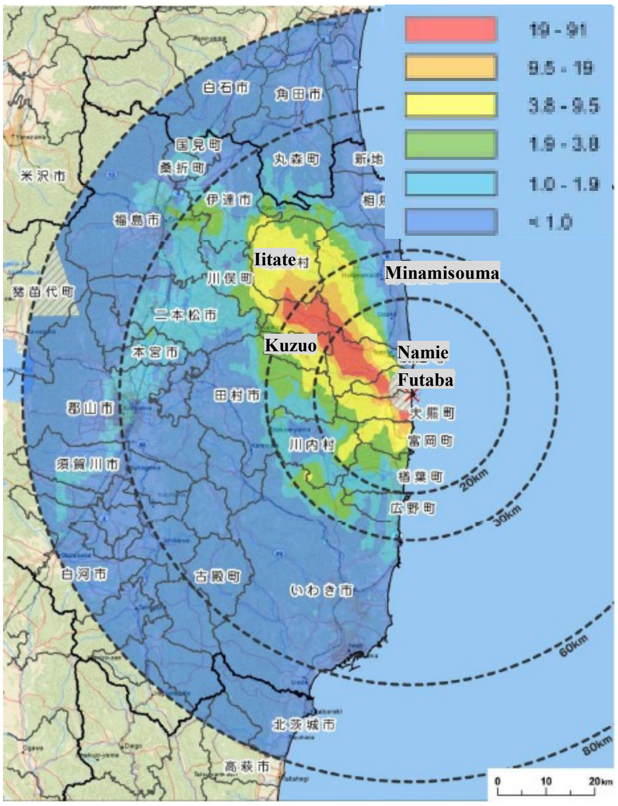


Fig.12 Air dose rate of one meter above ground level (μ Sv/hr) as of April 29. The value was synthesized from the two results of airborne monitoring, one by the Ministry of Education, Culture, Sports, Science & Technology (MEXT) and the other, United States Department of Energy (DOE).

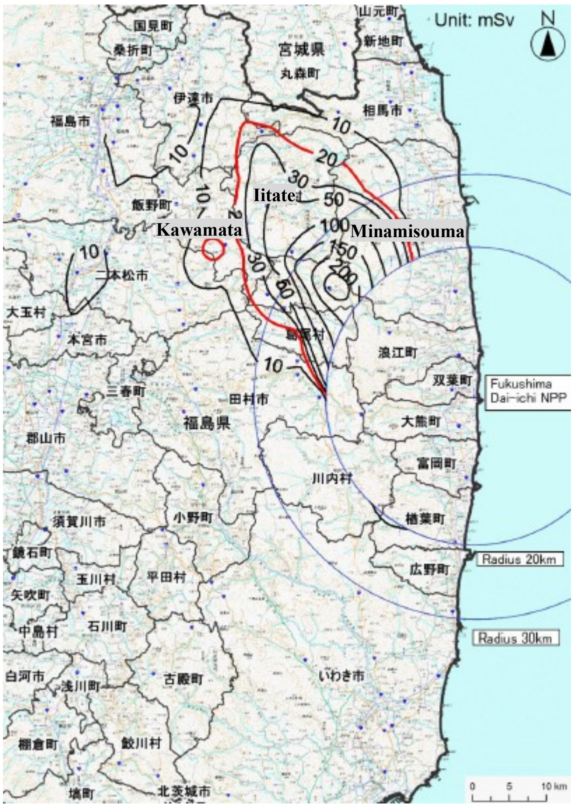


Fig.13 Estimated contour map of integrated dose (Until May 11, 2012) showing discharge of radioactive material by hydrogen explosion toward north west direction from Fukushima Daiichi NPS.

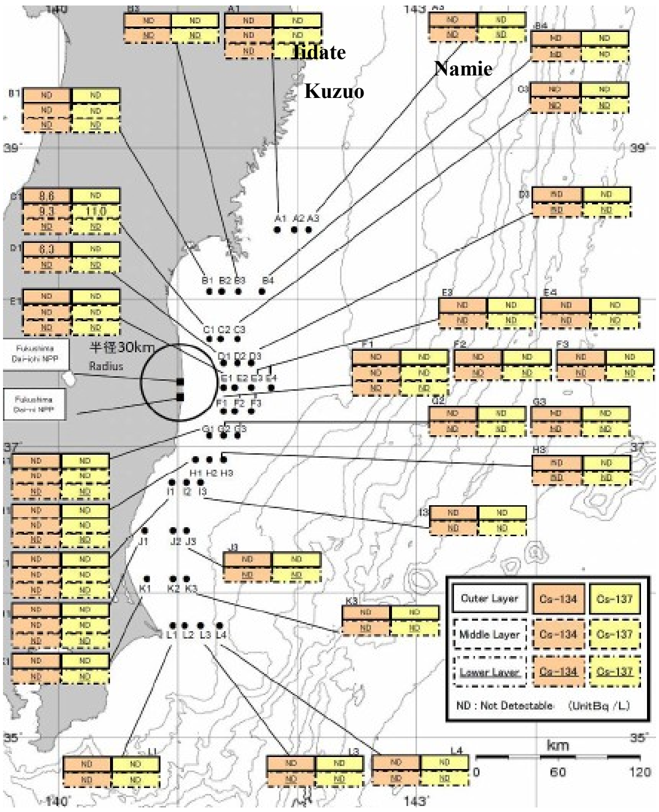


Fig.14 Readings of sea area monitoring showing detection of isotopes Cs-134 and Cs-137 in three layers from sea surface at various sampling posts along the coastal line from the prefectures of Miyagi, Fukushima, Ibaraki to Chiba. Only the both sampling post C1 and D1 just exterior of 30 km radius from the Fukushima Daiichi and Daini NPS still exhibited radioactivity. (May 9 -14, 2011)

6. Target plan to settle down the accident

Table 6 Roadmap issued by TEPCO on April 17 to settle the nuclear accident

<table>
<tr><th rowspan="2">Items</th><th rowspan="2">Issues</th><th colspan="2">Targets and Countermeasures</th></tr>
<tr><th>Step 1
" Steady decline of radiation dose"

(Attain within 3 months)</th><th>Step 2
"Release of radioactive materials is under control and radiation dose is being significantly held down"
(Attain within 3 to 6 months after achieving Step 1)</th></tr>
<tr><td rowspan="2">I Cooling</td><td>(1) Cooling the Reactors</td><td>①Maintain stable cooling
・ Nitrogen gas injection
・ Filling water above the top of active fuel.
・ Examination and implementation of heat exchange function.
② (Unit 2) Cool the reactor while controlling the increase of accumulated water until the PCV is sealed</td><td>③ Achieve cold shutdown condition (sufficient cooling is achieved depending on the state of each unit.)
・ Maintain and reinforce various countermeasures in Step 1.</td></tr>
<tr><td>(2) Cooling the Spent Fuel Pools</td><td>④Maintain stable cooling
・ Enhance reliability of water injection.
・ Restore coolant circulation system.
・ (Unit 4) Install supporting structure to prevent reactor building wall from collapsing.</td><td>⑤Maintain more stable cooling function with keeping a certain level of water to fill the pool
・ Remote control of coolant injection.
・ Examination and implementation of heat exchange function.</td></tr>
<tr><td rowspan="2">Ⅱx Mitigation</td><td>(3) Containment, Storage, Processing, and Reuse of Water Contaminated by Radioactive Materials (Accumulated Water)</td><td>⑥ Secure sufficient storage capacity to prevent high radiation level water from being released out of the site boundary
・ Installation of storage/ processing facilities.
⑦Store and process water of low radiation level
・ Installation of storage facilities/ decontamination processing.</td><td>⑧ Decrease the total amount of contaminated water
・ Expansion of storage/processing facilities.
・ Decontamination/ Desalination processing(reuse), etc</td></tr>
<tr><td>(4) Mitigation of Release of Radioactive Materials to Atmosphere and from Soil</td><td colspan="2">⑨ Prevent scattering of radioactive materials on buildings and ground / ⑩Cover the entire buildings (as temporary measure)
・ Dispersion of inhibitor
・ Removal of debris
・ Installing reactor building cover</td></tr>
<tr><td rowspan="2">Ⅲn Monitoring/ Decontamination</td><td rowspan="2">(5) Measurement, Reduction and Announcement of Radiation dose in the areas of Evacuation Order/Planned Evacuation/ Emergency Evacuation Preparation</td><td>⑪ Expand/enhance monitoring and inform of results fast and accurately
・ Examination and implementation of monitoring methods.</td><td>⑫Sufficiently reduce radiation dose in the areas of evacuation order/ planned evacuation/ emergency evacuation preparation
・ Decontamination/ monitoring of homecoming residents.</td></tr>
<tr><td colspan="2">(Note) With regards to radiation dose monitoring and reduction measures in the areas of evacuation order/ planned evacuation/ emergency evacuation preparation, TEPCO will take every measure by thorough coordination with the national government and by consultation with the prefectural and municipal governments.</td></tr>
</table>

Note: The above roadmap was modified by TEPCO on May 17, because the coolant leakage from the PCVs was found in Units 1 and 2. However, no substantial changes were made as to the schedule, although new efforts were added to the previous roadmap. In particular, in the review of the issues regarding the “Reactors,” the establishment of a “circulation cooling system” by which contaminated water accumulated in the bottom of reactor buildings is processed and reused for water injection into reactors, was prioritized for “cold shutdown” in Step 2.

Table 7 Status of Each Unit of Fukushima Daiichi NPS (As of May 31st)

Unit No.	Unit 1	Unit 2	Unit 3	Unit 5	Unit 6
Situation of water injection to reactor	Injecting fresh water via the Water Supply Line. Flow rate of injected water : 6.0 m^3/h	Injecting fresh water via the Fire Extinguish and Water Supply Line. Flow rate of injected water: 7.0m^3/h(via the Fire Protection Line), 5.0m^3/h(via the Feedwater Line)	Injecting fresh water via the Water Supply Line. Flow rate of injected water : 13.5 m^3/h	Water injection is unnecessary as cooling function of the reactor cores are in normal operation.	
Reactor water level	Fuel range A : Off scale Fuel range B : -1,600mm	Fuel range A : -1,500mm Fuel range B : -2,150mm	Fuel range A: -1,850mm Fuel range B: -1,950mm	Shutdown range measurement 2,164mm	Shutdown range measurement 1,904mm
Reactor pressure	0.555MPa g (A) 1.508MPa g(B)	-0.011MPa g (A) -0.016MPa g (B)	-0.132MPa g (A) -0.108MPa g (B)	0.023 MPa g	0.010 MPa g
Reactor water temperature	(Collection impossible due to low system flow rate)			83.0℃	24.6℃
Temperature related to Reactor Pressure Vessel (RPV)	Feedwater nozzle temperature: 114.1℃ Temperature at the bottom head of RPV: 96.8 ℃	Feedwater nozzle temperature: 111.5℃ Temperature at the bottom head of RPV: 110.6 ℃	Feedwater nozzle temperature: 120.9℃ Temperature at the bottom head of RPV: 123.2 ℃	(Monitoring water temperature in the reactor.)	
Dry well (D/W) Pressure, Suppression Chamber (S/C) Pressure	D/W: 0.1317 MPa abs S/C: 0.100 MPa abs	D/W: 0.030 MPa abs S/C: Off scale	D/W: 0.0999 MPa abs S/C: 0.1855 MPa abs	-	

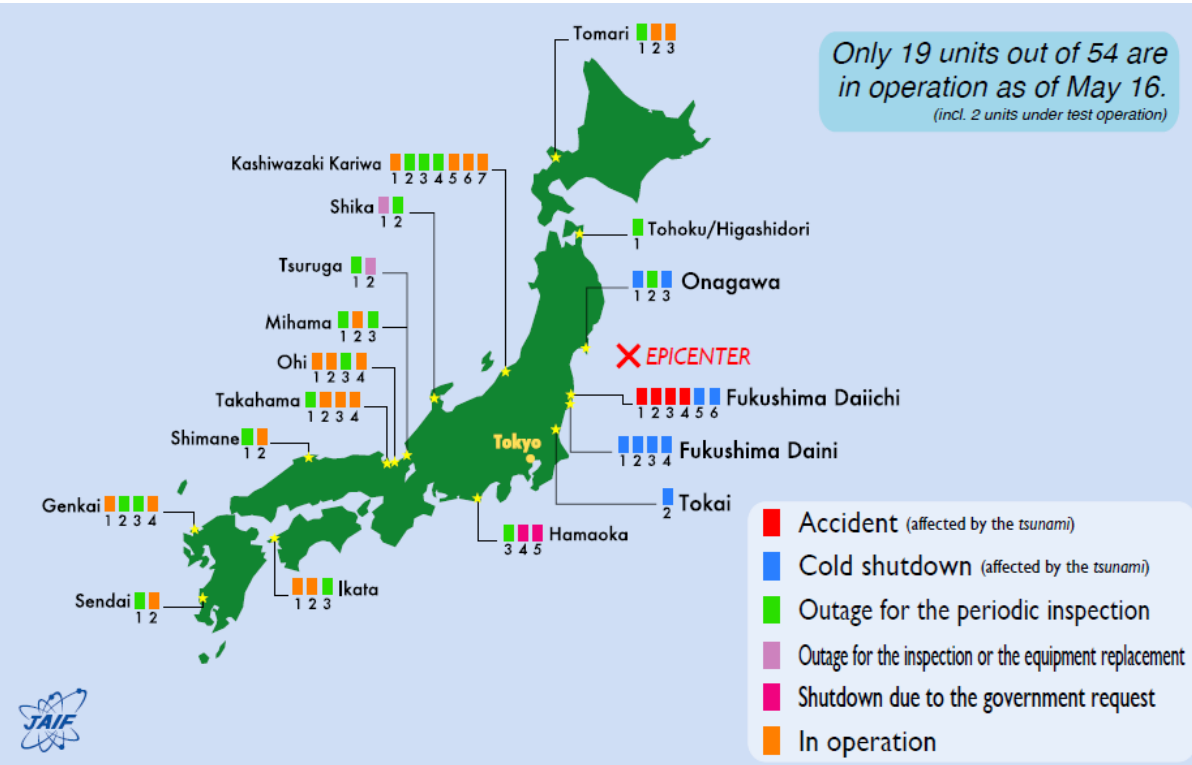


Fig.15 Current status of all the 54 nuclear power plants in Japan as of May 16, 2011
Reference: Japan Atomic Industrial Forum Inc.
[On-line] http://www.jaif.or.jp/english/fukushima/index.html