IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Occupational Radiation Protection during High Exposure Operations

Lessons Learnt from Occupational Radiation Protection in Past Accidents

Nuclear Accidents – Fukushima Accident –

Contents

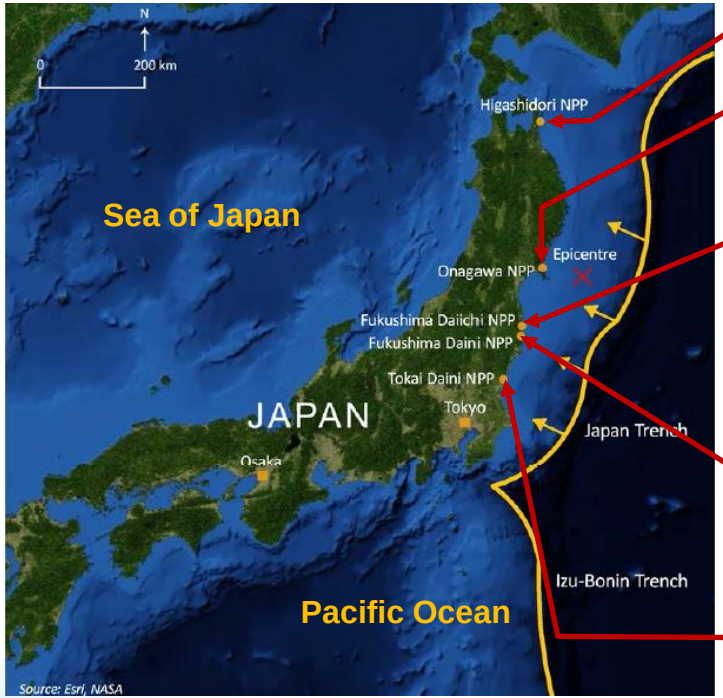
1. Overview of the Fukushima Accident

The Great East Japan Earthquake

- At 14:46 on 11 March 2011, Japan was rocked by 9.0 magnitude earthquake
- It was caused widespread damage to the country's eastern coastal region
- Tsunami damaged five nuclear power stations in the Pacific coast 50 minutes after the earth quake
- It was Higashidori, Onagawa, Fukushima Daiichi, Fukushima Daini and Tokai Daini NPSs
- Among them, Unit 1 to 3 of Onagawa, Unit 1 to 3 of Fukushima Daiichi, Unit 1 to 4 of Fukushima Daini and Unit 1 of Tokai Daini NPS were shutdown automatically. The others were under periodical inspection.
- This is just the beginning of the Fukushima Daiichi NPS (FDNPS) accident.

1. Overview of the Fukushima Accident

The Great East Japan Earthquake



Higashidori NPS
unit 1: 1,100MW

Onagawa NPS
unit 1: 524MW
unit 2: 825MW
unit 3: 825MW

Fukushima Daiichi NPS
unit 1: 460MW
unit 2: 784MW
unit 3: 784MW
unit 4: 784MW
unit 5: 784MW
unit 6: 1,100MW

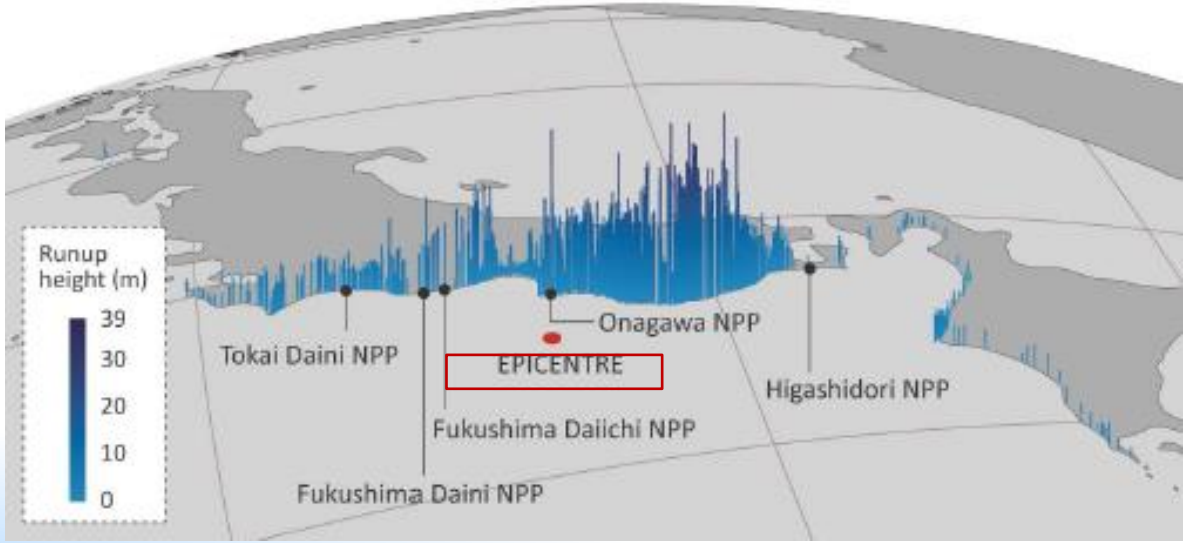
Fukushima Daini NPS
unit 1: 1,100MW
unit 2: 1,100MW
unit 3: 1,100MW
unit 4: 1,100MW

Tokai Daini NPS
unit 1: 1,100MW

1. Overview of the Fukushima Accident

Tsunami Generation

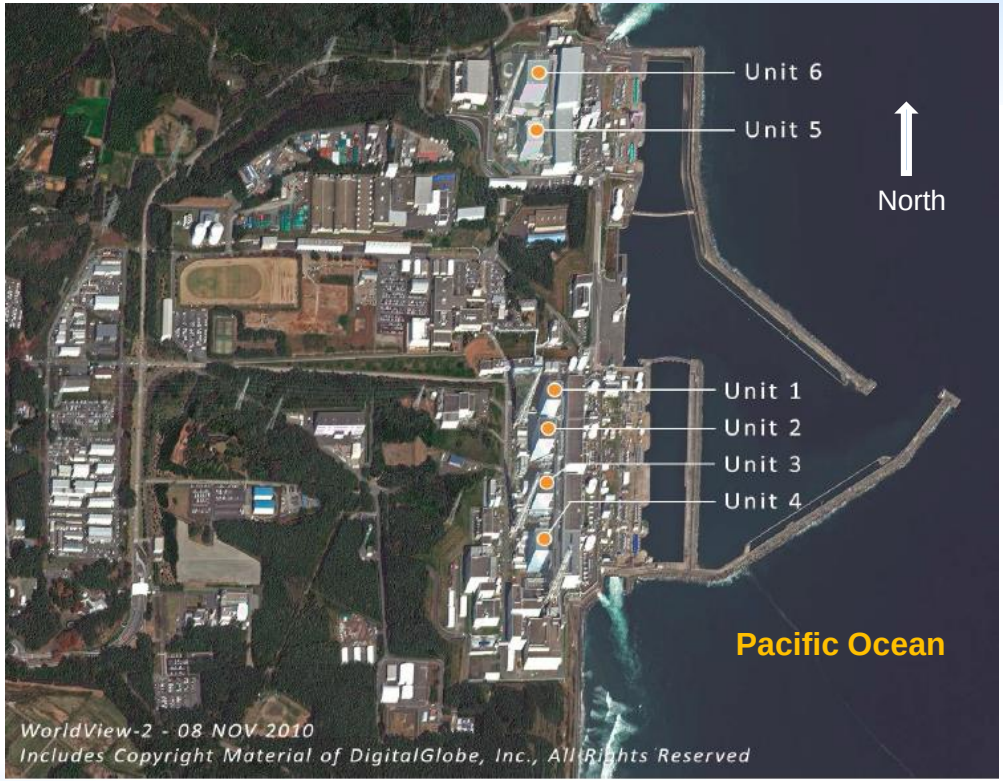
- The earthquake displaced a massive amount of water, giving rise to a series of large tsunami waves
- When these tsunami waves reached the coast, they had a devastating effect over a wide area based on the coastal geography and topography



1. Overview of the Fukushima Accident

Fukushima Daiichi Nuclear Power Station (FDNPS)

- Located along the central Pacific coast of Fukushima Prefecture, straddling the town of Futaba and Okuma
- The area of the site is approx. 3,500,000 m^2



1. Overview of the Fukushima Accident

Fukushima Daiichi Nuclear Power Station (FDNPS)

Unit	Commercial operation	Reactor type	Containment type	Output (MWe)	Main contractor
1	1971	BWR-3	Mark-1	460	GE
2	1974	BWR-4	Mark-1	784	GE/Toshiba
3	1976	BWR-4	Mark-1	784	Toshiba
4	1978	BWR-4	Mark-1	784	Hitachi
5	1978	BWR-4	Mark-1	784	Toshiba
6	1979	BWR-5	Mark-2	1,100	GE/Toshiba

- 6 BWRs with total capacity of 4,696 Mwe
- At the time of accident, units 4,5 and 6 were shut down for periodic inspection

1. Overview of the Fukushima Accident

Loss of the off-site power

- All reactors in operation were automatically shut down by the earthquake
- At same time, all off-site electric power supply to FDNPS were lost due to the destruction of transforming stations and a transmission tower

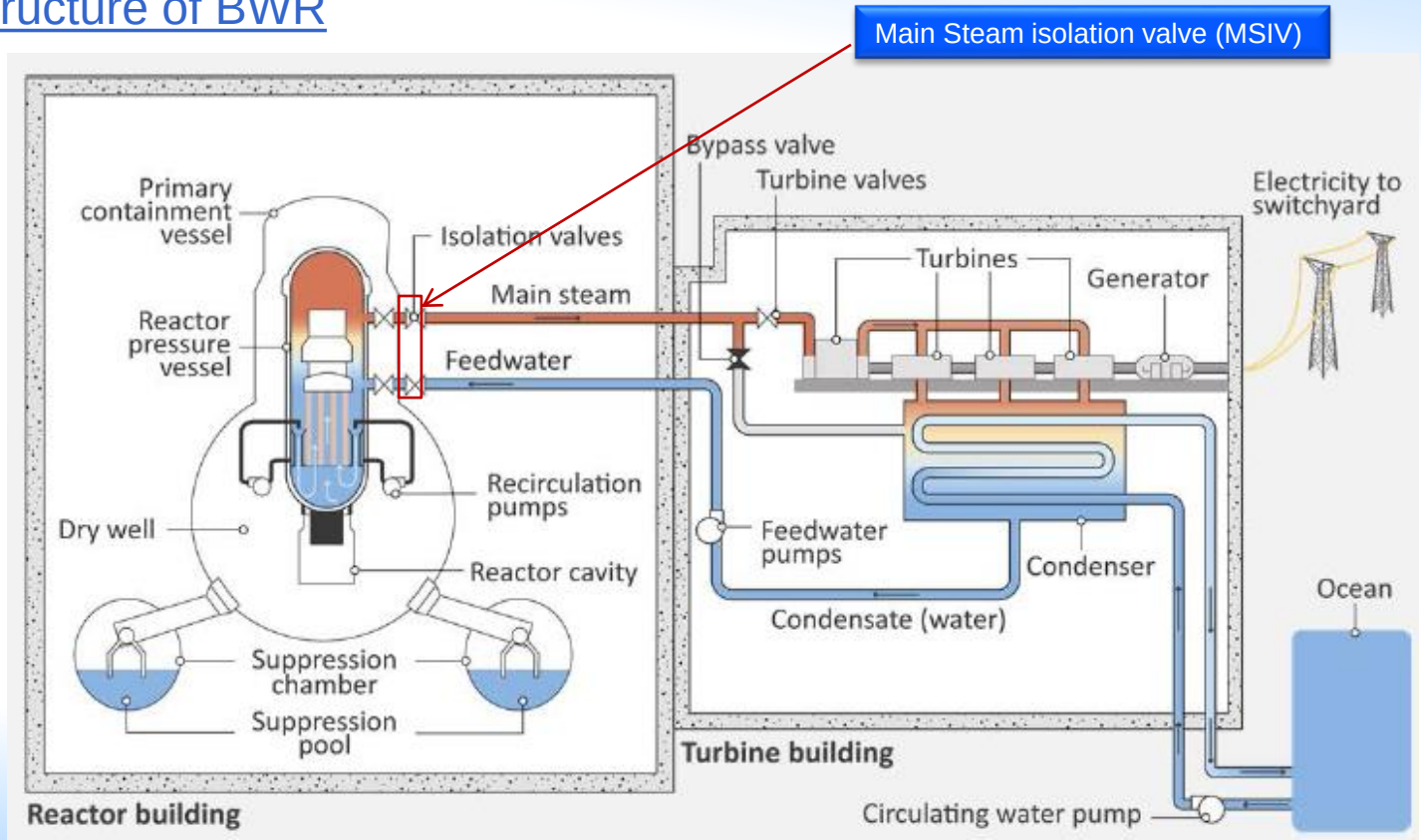
1. Overview of the Fukushima Accident

Start-up of EDGs and RCICs

- After shutdown, the nuclear fuel continued to generate decay heat.
- To prevent the nuclear fuel from overheating, this heat had to be removed by cooling systems that were mainly run or controlled by electrical power.
- Automatically the Emergency Diesel Generators (EDGs) restored AC power to the emergency busses and to the direct current (DC) power battery chargers, as designed.
- As a result of the power interruption, the reactors of Units 1–3 were automatically isolated from their turbine systems by the closure of all the Main Steam Injection Valves (MSIV).
- When the reactor is isolated, Reactor Core Isolation Cooling (RCIC) is provided by the systems designed for an isolated reactor under high pressure conditions which exist after reactor shutdown

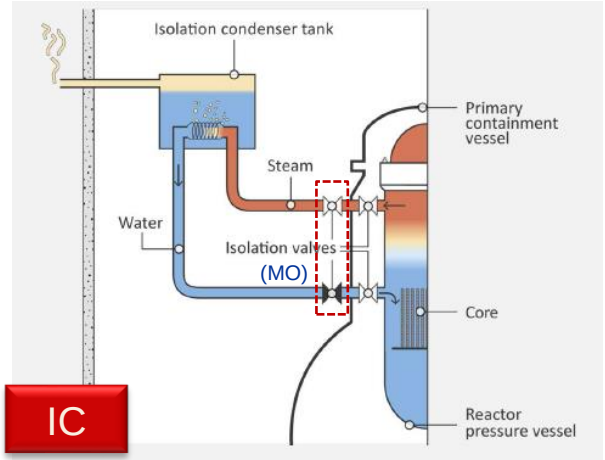
1. Overview of the Fukushima Accident

Structure of BWR

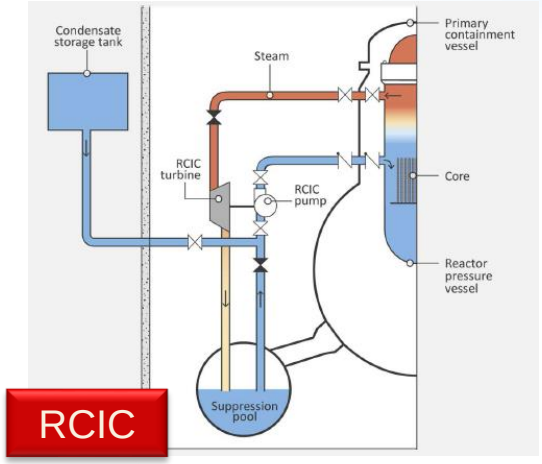


1. Overview of the Fukushima Accident

Reactor core isolation cooling



In Unit 1, as the reactor pressure increased, both loops of the isolation condenser (IC) system started automatically and continued to cool the reactor.



In Units 2–6, the steam from the reactor drove a small turbine which, in turn, ran a pump that injected water into the reactor at high pressure to cool the reactor.

1. Overview of the Fukushima Accident

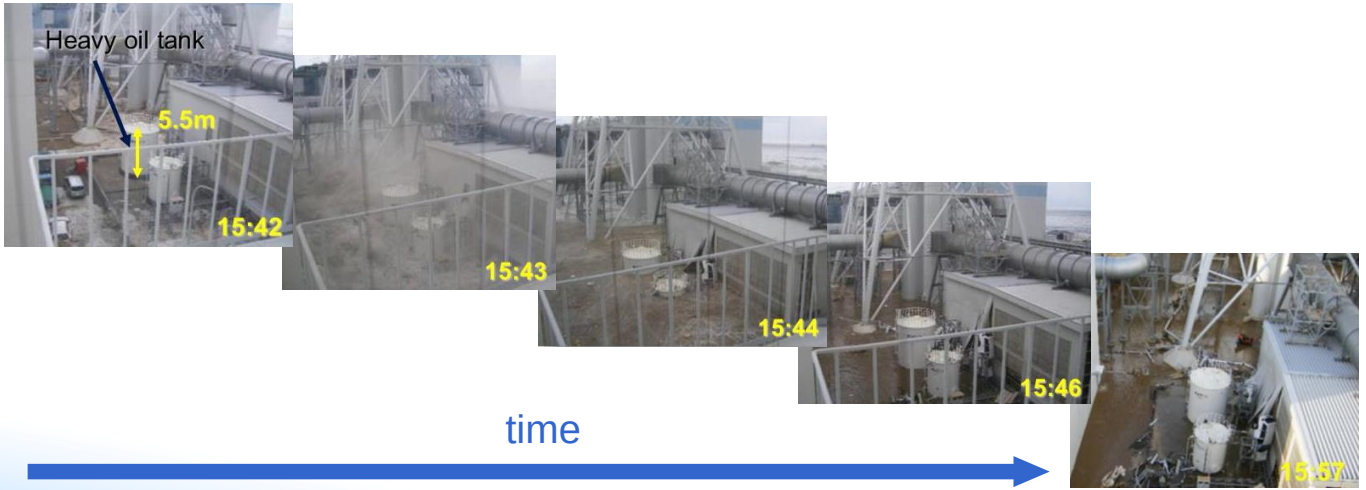
Impact of Tsunami

Afterward the wave by Tsunami flooded and damaged the unhoused seawater pumps and motors of all six units at the seawater intake locations on the shoreline, resulting in loss of ultimate heat sink events for all units

1. Overview of the Fukushima Accident

Impact of Tsunami (11th of March 2011)

Water entered and flooded all the reactor and turbine buildings, the common spent fuel storage building and diesel generator building, which damaged the buildings and the electrical and mechanical equipment inside at ground level and on the lower floors



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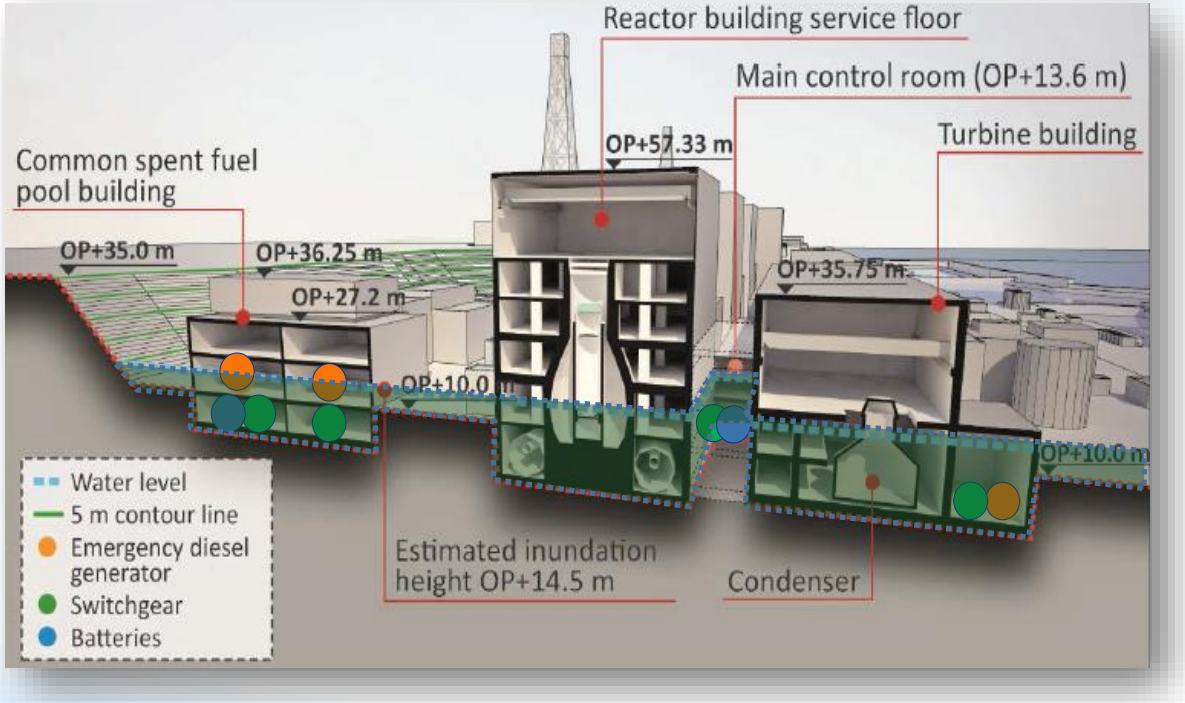
Impact of Tsunami

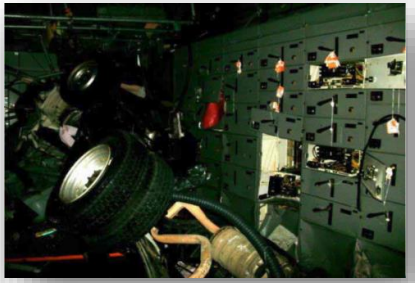


1. Overview of the Fukushima Accident

Impact of Tsunami

- The damaged equipment included the EDGs or their associated power connections, power distribution panels and switchgear equipment, which resulted in the loss of emergency AC power
- 13 EDGs were unusable except one of the air cooled EDGs — that of Unit 6, which was continuing to supply emergency AC power to the Unit 6 safety systems and allowing cooling of the reactor of Unit 6 and 5 by the power interchange

Power Center (P/C)



Metal Clad Switchgear (M/C)

EDG (before the accident)

All units at the FDNPS were equipped with on-site DC sources as an emergency power supply in an SBO (Station Black Out) situation, but the flooding also affected this equipment in Units 1, 2 and 4, inundating the DC batteries,

All indicators flickered in the main control room, and it disappeared all together soon

No one understood what had happened

No light ,
No sound,
No information,
No means of communications,
but with ascending dose rate


All instrumentation and control systems
became inoperable
Unit 1

The operators removed batteries from abandoned cars in the darkness,
and connected them as a power supply for the instrumentation and control.

1. Overview of the Fukushima Accident

Damage of power supply and core cooling system

- All the safety system of unit 1 were thoroughly destroyed, and this was the trigger to this severe accident
- Consequently, the fuels in each reactor were exposed without it being covered by water, and thereby the fuel claddings were damaged.

	Function	System	unit 1	unit 2	unit 3
Power supply	Power source	Ext. AC Power	×	×	×
		EDG	×	×	×
		DC Battery	×	×	OK
	Power supply board	P/C	×	OK	×
		M/C	×	×	×
Cooling system	High pressure core injection system	IC(#1), RCIC(#2-3), HPCI	×	partway	partway
	Low pressure core injection system	MUWP, RHR, etc	×	×	×

1. Overview of the Fukushima Accident

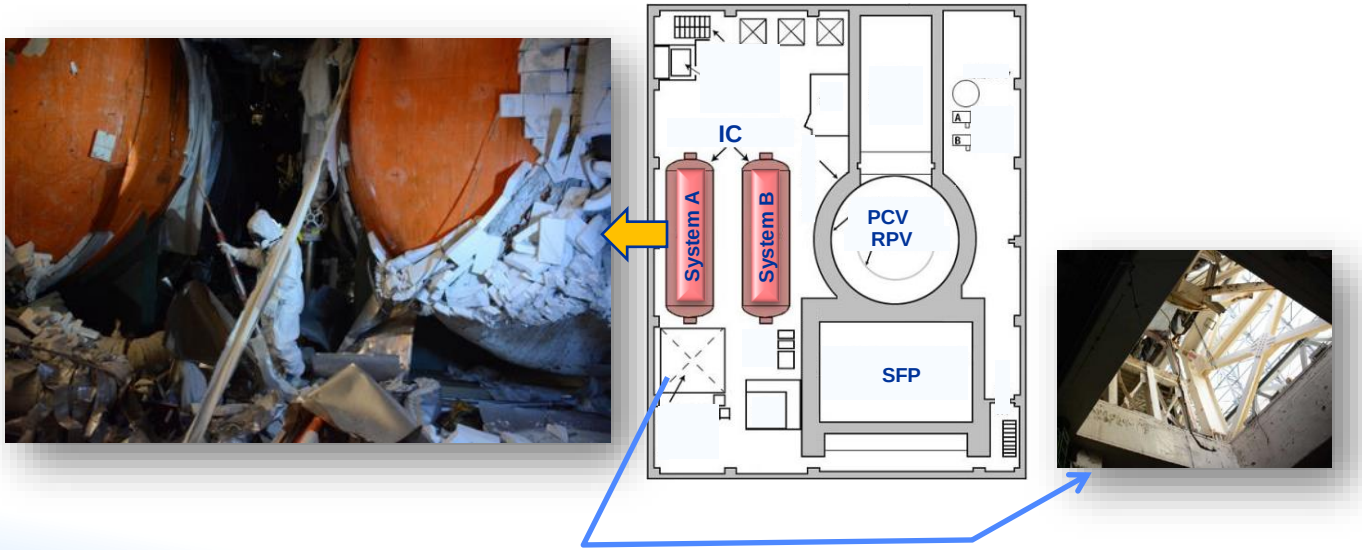
Unit 1 as a trigger of this accident

- One of the cause of this disaster is thought that the Motor Operated (MO) valves of the Isolation Condenser (IC) in the Unit 1 were closed from the beginning.
- Design policy of the Unit 1 was “Enclose radioactive substance in emergency”, so IC valves were designed to close in case of piping rupture
- In this accident MO valves were closed automatically by a false signal of “Piping rupture” because of DC power loss
- Owing to SBO (Station Black Out) and DC power loss operators could not recognize the malfunction of the IC and believed that the Unit 1 was kept cooling.

1. Overview of the Fukushima Accident

ICs

IC is a duplex heat exchanger in which condensed water falls by weight of gravity back into the reactor without using powered feed-water pumps



1. Overview of the Fukushima Accident

Detail of the accident in Unit 1

March 11

15:37: SBO by tsunami
18:46: Meltdown began
23:30: Radioactive substance began to leak into the environment

March 12

00:49 : PCV pressure exceeded the maximum operating level
05:46 : Alternative water injection using a fire engine began
10:17 : PCV vent had started
14:30 : PCV vent succeeded
15:30 : Work to connect the mobile voltage power supplies to Units 1 and 2 using an undamaged power panel in Unit 2 was completed
15:36 : Hydrogen explosion

This interrupted all recovery measures for unit 2 and 3

1. Overview of the Fukushima Accident

Detail of the accident in Unit 2

- In Unit 2, before raided the tsunami the RCIC had been operated and had kept moving after SBO for three days
- Mobile voltage power supplies completely connected to Unit 2 was damaged by the hydrogen explosion of Unit 1
- The fire engine and the hose that completed the preparation for pouring water into Unit 2 were damaged by the hydrogen explosion of Unit 3
- Thus, it reached the core damage, and hydrogen was generated
- The blow out panel on the side of Unit 2 opened by the impact of the hydrogen explosion of Unit 1, and hydrogen leaked outside without explosion

1. Overview of the Fukushima Accident

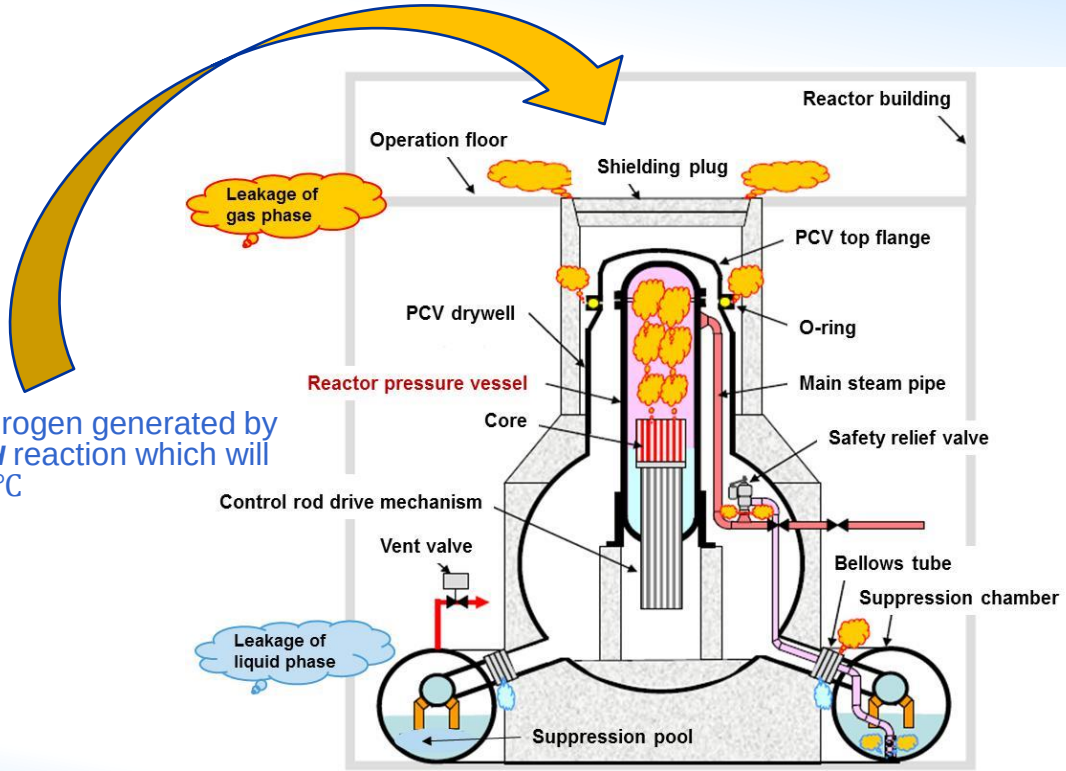
Detail of the accident in Unit 3

- Because the DC batteries escaped from flooding, driving and the control of RCIC and the high-pressure core injection system (HPCI) were able to be continued
- After 14 hours of continued operation of the HPCI, the Unit 3 operators decided to manually stop it and instead use the alternative means of injection at low pressure, concerning about the reliability and possible failure of the HPCI
- The Unit 3 HPCI was therefore turned off by the operators, who then proceeded to open the Safety Relief Valves (SRVs)
- However, all attempts to open the SRVs failed, and reactor pressure quickly increased above the level at which the DDFP could inject, stopping the cooling of the Unit 3 core about 35 hours after the SBO
- At 11:01 on 14 March, an explosion occurred in Unit 3

1. Overview of the Fukushima Accident

Hydrogen Explosion

Accumulation of hydrogen generated by $Zr + 2H_2O \rightarrow ZrO_2 + 4H$ reaction which will take place over 900℃



1. Overview of the Fukushima Accident

Core meltdown

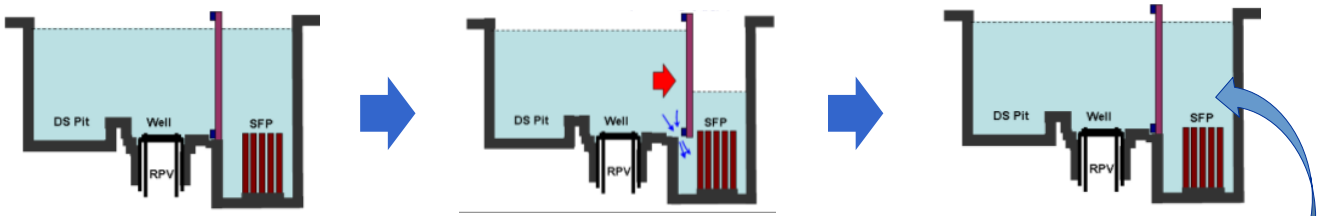
- By the loss of cooling measures the core meltdown in Unit 1 to 3 occurred
- As the result, radioactive material were released into out of reactor buildings and also environment of wide spread area
- Also hydrogen explosion were caused


hydrogen explosion in Unit 3

1. Overview of the Fukushima Accident

SFP in Unit 4

- Cooling the Spent Fuel Pool of Unit 4 that stored 1300 fuel assemblies was greatly feared
- By chance, the safety was secured



There was water for fuel exchange in the well before the accident

Due to the loss of cooling function, the water level of SPF had decreased by evaporation, which caused the difference of water pressure.
Then sealed gate was opened

Water level recovered

1. Overview of the Fukushima Accident

Stabilization

- On 20 March, almost exactly nine days after the Station Black Out (SBO), off-site power was restored to Units 1 and 2 through the temporary AC power system, ending the SBO in Units 1 and 2
- The SBO at Units 3 and 4 ended, after more than 14 days, when temporary off-site power to these two units was restored on 26 March 2011