TEPCO's Nuclear Power Plants suffered from big earthquake of March 11,2011

Follow up prepared at 4pm of March 23, revised April 13

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Recovery action is in progress. The presentation may contain misunderstandings.

The big earthquake

- Attached northern part of Japan at 2:46pm of March 11, 2011.
- Magnitude is 9 in Richter scale. The biggest in history.
- Some earthquakes occurred along the boundary of plates. Hundreds of km of the boundary moved, similar to the big earthquake in Indonesia.
- Big Tsunami attacked northern Japan and NPP (nuclear power plant). It was the biggest in history.
- There is no damage in the central Tokyo.
- Nuclear power plants and coal fired power plants were automatically shut down at the earthquake.

NPPs in Japan

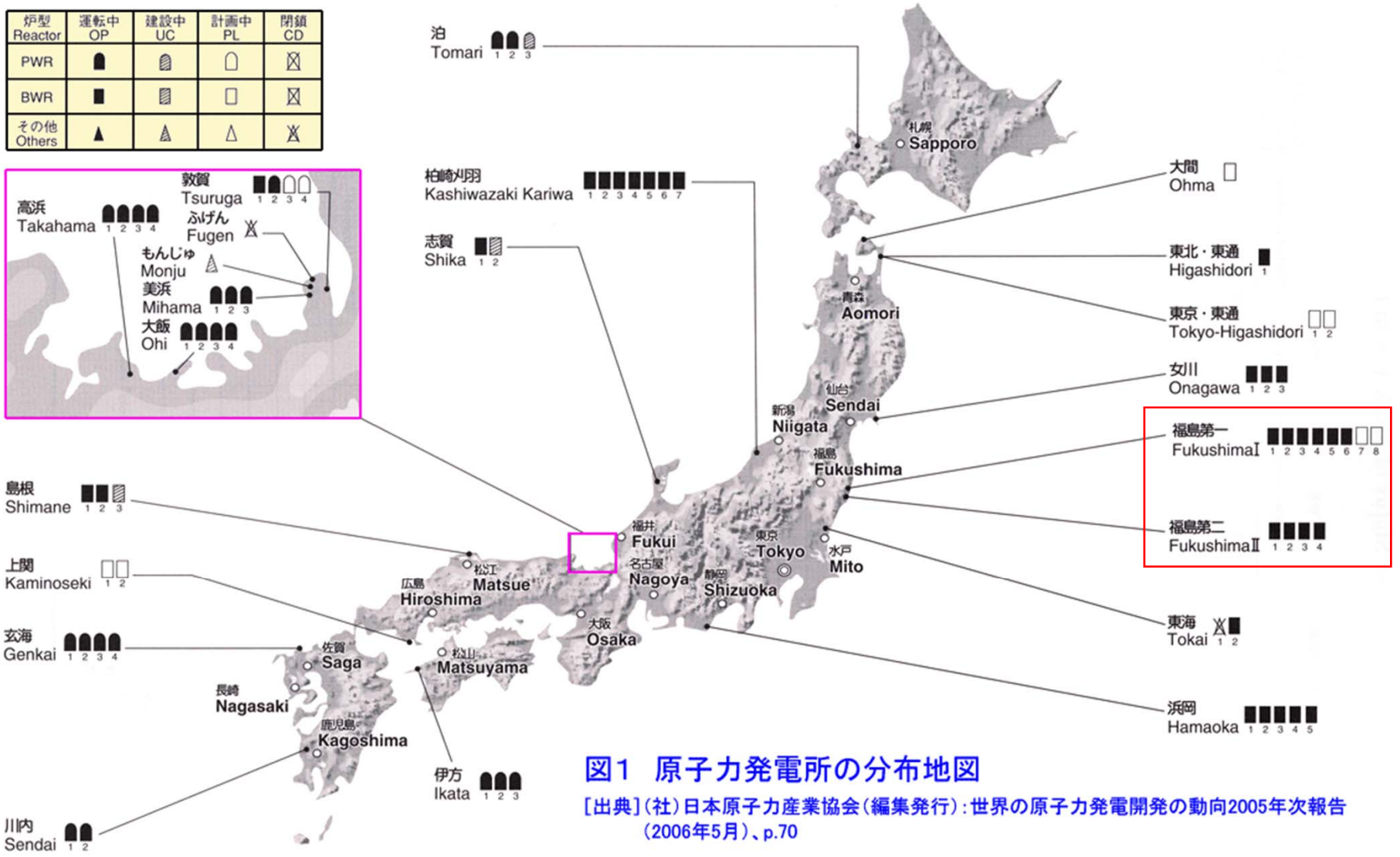


図1　原子力発電所の分布地図

[出典]（社）日本原子力産業協会（編集発行）：世界の原子力発電開発の動向2005年次報告（2006年5月）、p.70

Fukushima Daiichi(1F) & Daini(2F)

Site	*unit*	*Rx Type*	*Containment Type*	*Commercial Operation Start*	*Rated MWe*
Fukushima Daiichi	*1*	*BWR/3*	*Mark-I*	*1971*	*460*
	2	*BWR/4*	*Mark-I*	*1974*	*784*
	3	*BWR/4*	*Mark-I*	*1976*	*784*
	4	*BWR/4*	*Mark-I*	*1976*	*784*
	5	*BWR/4*	*Mark-I*	*1978*	*784*
	6	*BWR/5*	*Mark-II*	*1979*	*1100*
Fukushima Daini	*1*	*BWR/5*	*Mark-II*	*1982*	*1100*
	2	*BWR/5*	*Mark-II*	*1984*	*1100*
	3	*BWR/5*	*Mark-II (Improved)*	*1985*	*1100*
	4	*BWR/5*	*Mark-II (Improved)*	*1987*	*1100*

TEPCO Fukushima site 1 (1F)

Loss of AC power and Loss of ultimate heat sink

common cause failure by Tsunami

- 6 units: 4units (1F1-4) and 2units (1F5,6), separated between 100m
- Emergency DGs started at the earthquake. But Tsunami damaged ultimate heat sinks (sea water pumping and cooling system) of units 1F1-4. caused common cause failure
- Without ultimate heat sink, Emergency DG (need to remove its generated heat for operation) and spent fuel pool cooling do not work.
- IC (isolation condenser, unit 1) operated for one hour after the Tsunami. RCICs (Reactor core isolation cooling system, unit3,2) operated for 1,2days (RCIC operates with a turbine driven pump by the steam from the core with residual heat. It supplies water to RPV (reactor pressure vessel) from condensate water storage tank and suppression pool of CV. But it does not operate for long time.)
- Beyond design basis accident (severe accident), Loss of all AC power and loss of ultimate heat sink for 1F1-4. This is the reason why the plants got into trouble unit by unit after the Tsunami.
- Emergency procedures of severe accidents such as feed and breed, sea water injection, area evacuation were taken. (It was prepared in 1990')
- Emergency DG of 1F6 was not damaged by the earthquake and Tsunami and supplied emergency power to 1F5 and 6. Cross ties of the emergency power lines were set up at the emergency among 1F1-4 units and between 1F5 and 1F6.
- External power (off-site power) of 1F was not available until in the evening of March 19 at 1F2.

Fukushima site 1 (1F) summary

- 6 units , Unit #1, #3 and #2 in trouble. Unit #1: 460MWe BWR ,Unit #3,#2: 768MWe BWR

March 11

- 2:46pm: The earthquake happened. Plants automatically shut down. Offsite power lost. Emergency DG started up.
- 3:42pm Emergency DG(diesel generator) stopped due to loss of equipment cooling water. (Tsunami was bigger than expected.) All AC power was lost for 1F1-4 and consequential isolation from UHS(ultimate heat sink), except for IC (isolation cooling system) in 1F1. RCIC(reactor core isolation cooling system) in 1F 2 ***Blackout + (mostly) loss of UHS***
- IC operated for 1 hour. RCIC of unit 2 operated for 2days and stopped due to loss of DC power.
- SAM (Severe Accident Management) prepared in the 90's in place such as containment scrubbing venting, supply of water from portable water tank using Fire Protection pump or Fire Engine and inter-connection of power supply with other units.
- Site emergency announced. (After JCO criticality accident, emergency law was settled. It requires report to the central government.) Evacuation up to 20km (completed on March15) and stay in the house between 20- 30km around 1F, 10km around 2F.

Summary (continued)

Partial core melt and hydrogen explosion

March 12: 1F1 top floor of Reactor building (RB)

March 14: 1F3 in 3rd floor of RB

March 15: 1F2 in suppression chamber of CV

Note: It was NOT explosions of the reactors. Most radioactivity stays in the reactor pressure vessel. Feed and breed cool the fuels.

The spent fuel pools were covered by water that was supplied with special fire engines and now by motor driven pumps. The temperatures of the pools by remote sensing are low, 58C(1F1), 35C(1F2), 62C(1F3), 42C(1F4), 24C(1F5), 25C(1F6) at 1pm of March 20

Level 5 accident of IAEA

Successful water supply to 1F3 on March 19 and 1F4 on March 20

External power lines to 1F2 and 1F1 on March 19 and 1F5 and 1F6 on March 20.

Acceleration measured at the earthquake

507 gal (Design base 441gal) at 1F3, above DB

431 gal (Design base 448gal) at 1F6, below DB

New seismic standard (prepared 5years ago) required 600gal (lateral) and 400 gal (vertical acceleration), but improvement was not completed at 1F.

Tsunami: Max height ;14m, Building elevation: 10-12m

1F Unit 1 (1F1)

March 11:

- 15:42: Loss of all AC power reported. Emergency condenser cools the core.
- 16:36: Coolant injection impossible reported. (Isolation condenser stopped.)
- 20:50:Emergency evacuation within 2km declared by local government (Fukushima pref.)
- 21:23: Emergency evacuation in 3km and stay in houses in 3-10km declared by central government. Completed at 0:30 of March 12.

March 12

- 0:49 :CV pressure increase reported: Water level decreased. Fuel uncovered by water partly.
- 10:17 : CV vent started.
- Emergency evacuation in 3km by central government.
- 15:00 water level is low. (Fuels may be uncovered partly.) Water injection continued for feed and breed (discharge generated steam from RPV in the water of the suppression chamber of CV).
- 15:29: radiation monitor showed 1016micro Sv/h at the site

1F1

March 12

- 15:36 Shock vibration and white smoke observed. Hydrogen explosion occurred at the top of the reactor building. (Hydrogen was released in the reactor building.) Above 4th floor of reactor building (operation floor of fuel handling) destroyed. CV, RPV and spent fuel pool may be not damaged.(CV and RPV stay below 2m thick concrete. Spent fuels stay 12m deep pool. 4 TEPCO technicians injured and hospitalized.
- 15:40: radiation monitor showed 860 micro Sv/h, at 18:58 it shoed 70.5 micro Sv/h
- 882 micro Sv observed at 8:20 am of March 13. Highest 1204 micro Sv at 8:33am.
- 18:25:Emergency evacuation zone of 1F enlarged to 20km.
- 20:00 : Sea water with boric acid injected into RPV and CV by fire line. Completed 5:30am of March 13.

March 13

- 11am: Radioactivity was detected from 19 public (level is low.)
- 11pm: Fuel uncovered 1.7m

March 15

- 0:00: Sea water pump stopped, but restarted.
  Reactor pressure and water level are stable.
- 11:00 : Stay in houses declared in 20-30km of 1F , completed 14:00
- 13:00: Estimated fraction of damaged fuel was 43% and 70% at 15:25

March 23

- 0:23: RPV coolant injection by feed water line started

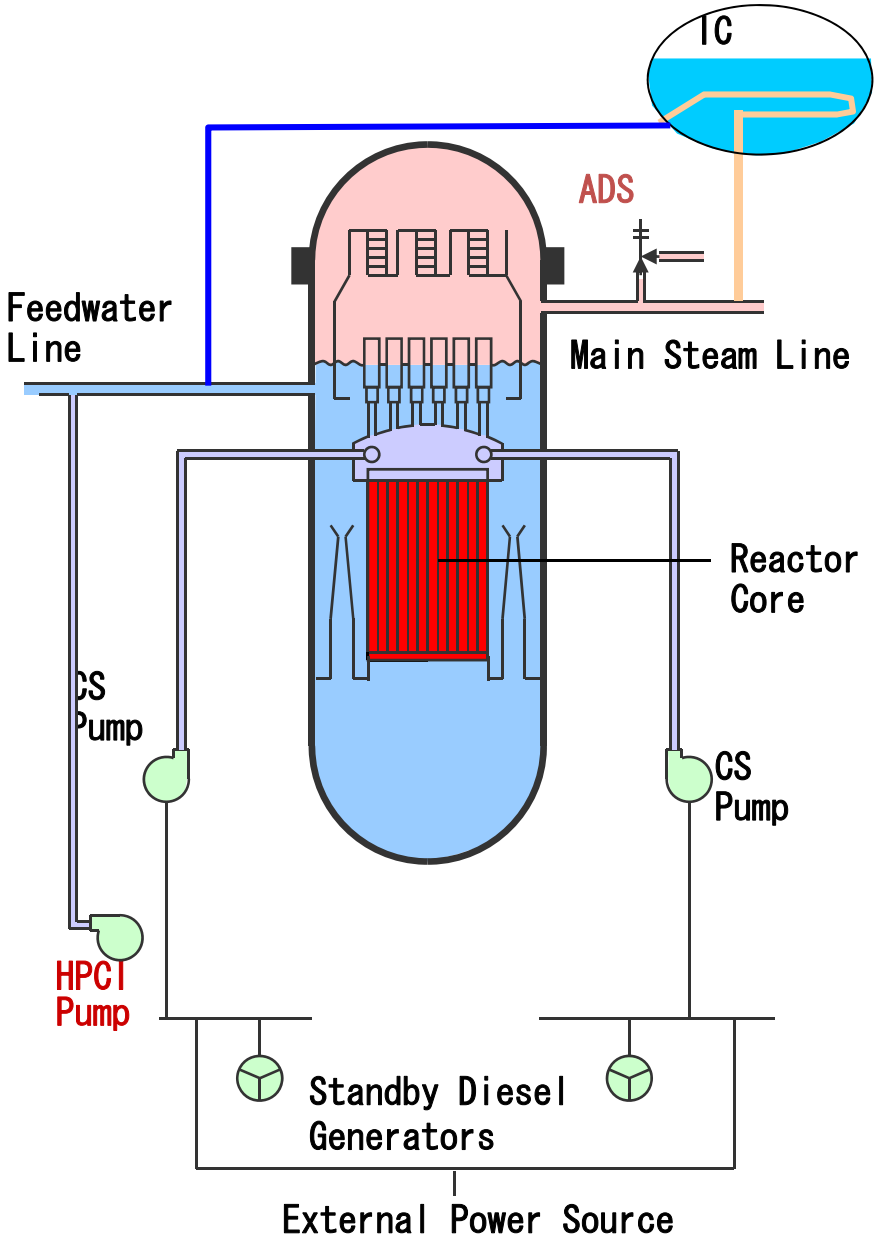
March 24

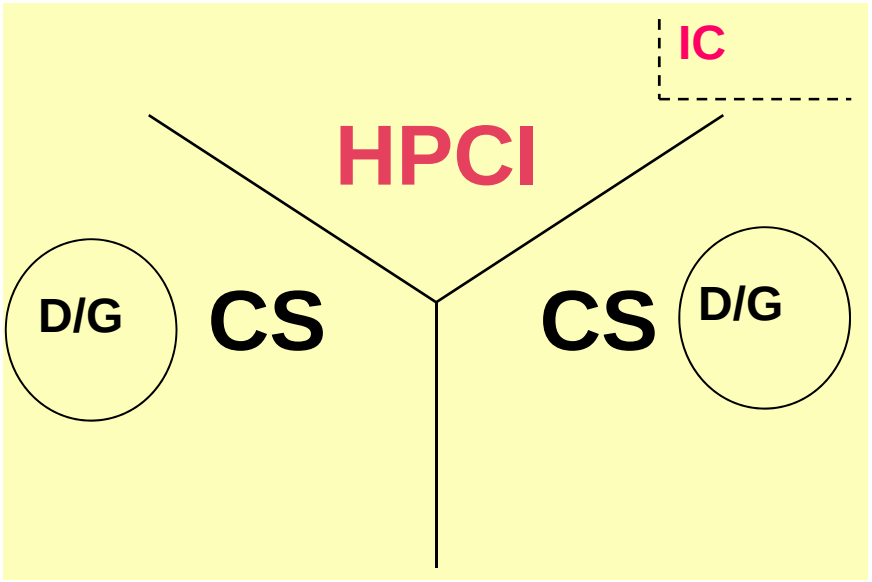
- Central control room lighted by external power .

March 25

- Normal water injection to RPV started

BWR/3 ECCS





HPCI : High Pressure Coolant Injection System

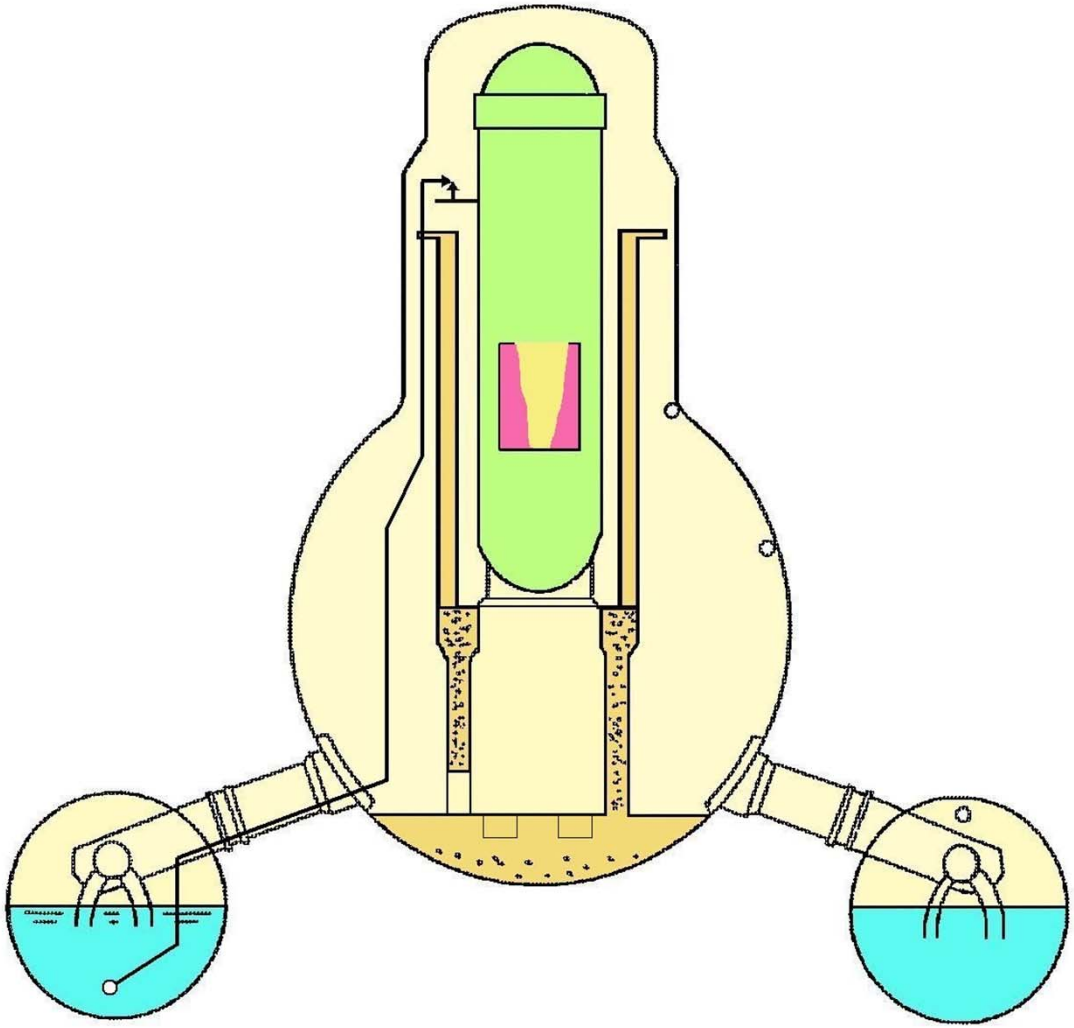
CS : Core Spray System

D/G : Standby Diesel Generator

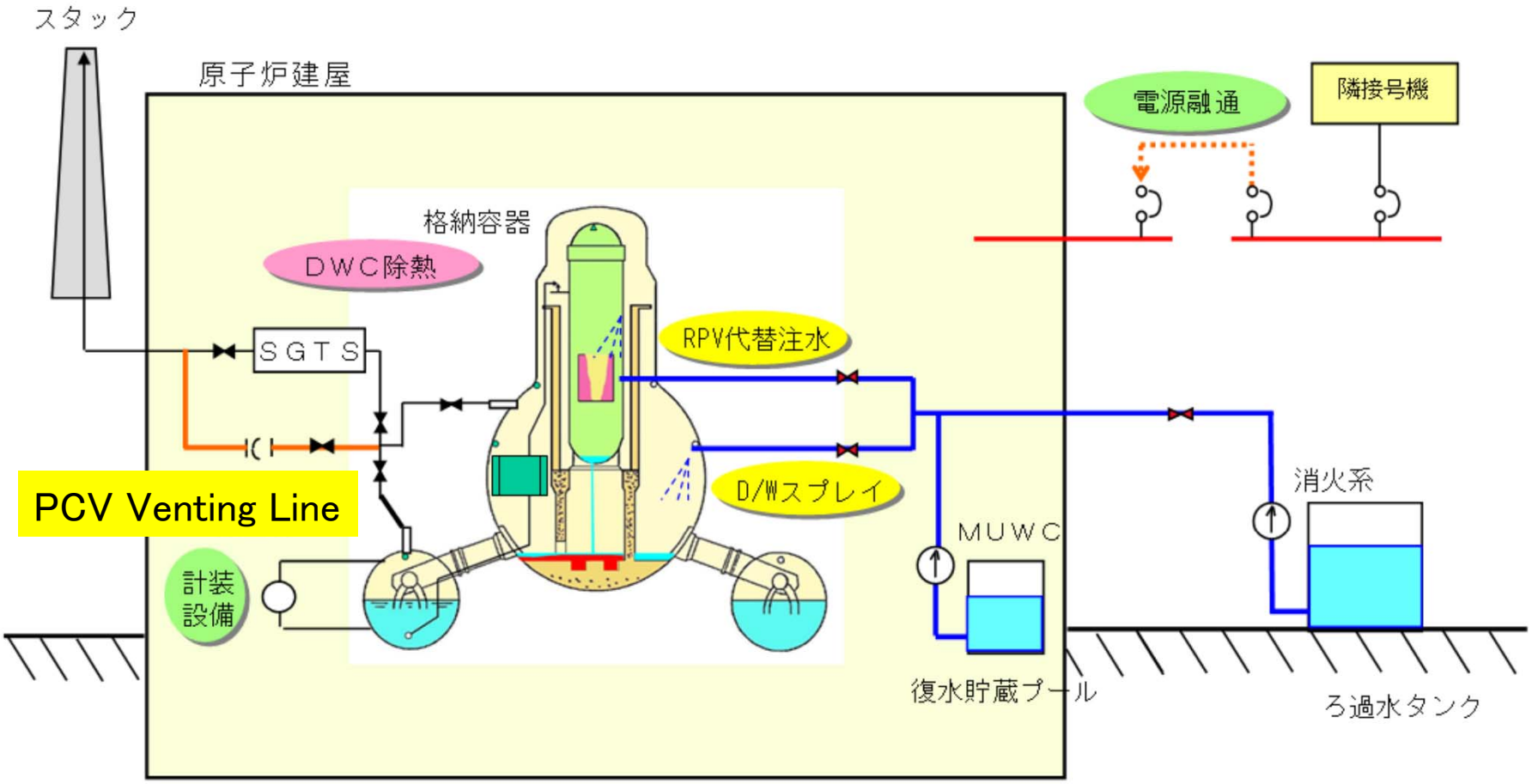
ADS : Automatic Depressurization System

IC : Isolation Condenser (Passive Driven, Non ECCS)

Mark-I Containment



Severe Accident Management Systems



1F3

March 11

- 15:42 Loss of all AC power reported. RCIC cools the core.

March 12

- 13:00: HPIC is used to inject water into RPV.
- 21:00: Prepared to CV vent.

March 13

- 5:10: HPIC stopped. RCIC did not restart. Loss of cooling reported to Gov.
- 8:41: Safety valve of RPV opened. Water with boron injected into RPV . CV vented.
- 8:56: radiation level exceeded.
- 11:00 also suffered partial fuel uncover of 1.30m , but covered again 2.1m at 11:30
- 13:00 Nuclear fuels uncovered 2m and continued at least 2 hours. Partial core melt occurred.
- 13:12: Sea water injection to RPV started. Injection was unstable.
- 14:15: radiation level exceeded.
- 15:29: Radiation dose at site boundary exceeded the level of the emergency law, 500 micro Sv/h.
- Radiation levels at the site fluctuated in relation with the fuels uncovered.
- 19:30: Nuclear fuels uncovered 2m.
- CV pressure high due to closure of valve, but opened again at 21:00

1F3

March 14

- 05:20 CV vent started
- 7:44: CV pressure high reported.
- 11:01: Hydrogen detonation in the upper part of reactor building. 11 people injured.
- CV integrity may be maintained.

March 15

- 07:05: Steam observed on the top of the reactor building.
- 10:22: 400mSv/h observed. The radiation dose in the site was the highest near unit 3.

March 16

- 6:40 and 8:47: 300mSv/h observed.
- 8:34 and 10:00: white smoke generated at the reactor building.

March 19

- Sea water supplied successfully to spent fuel pool by special fire engines for 13 hours, double of the water inventory of the pool.

March 20

- Sea water supply by fire engines continued

March 20

- 22:46 control room lighted.

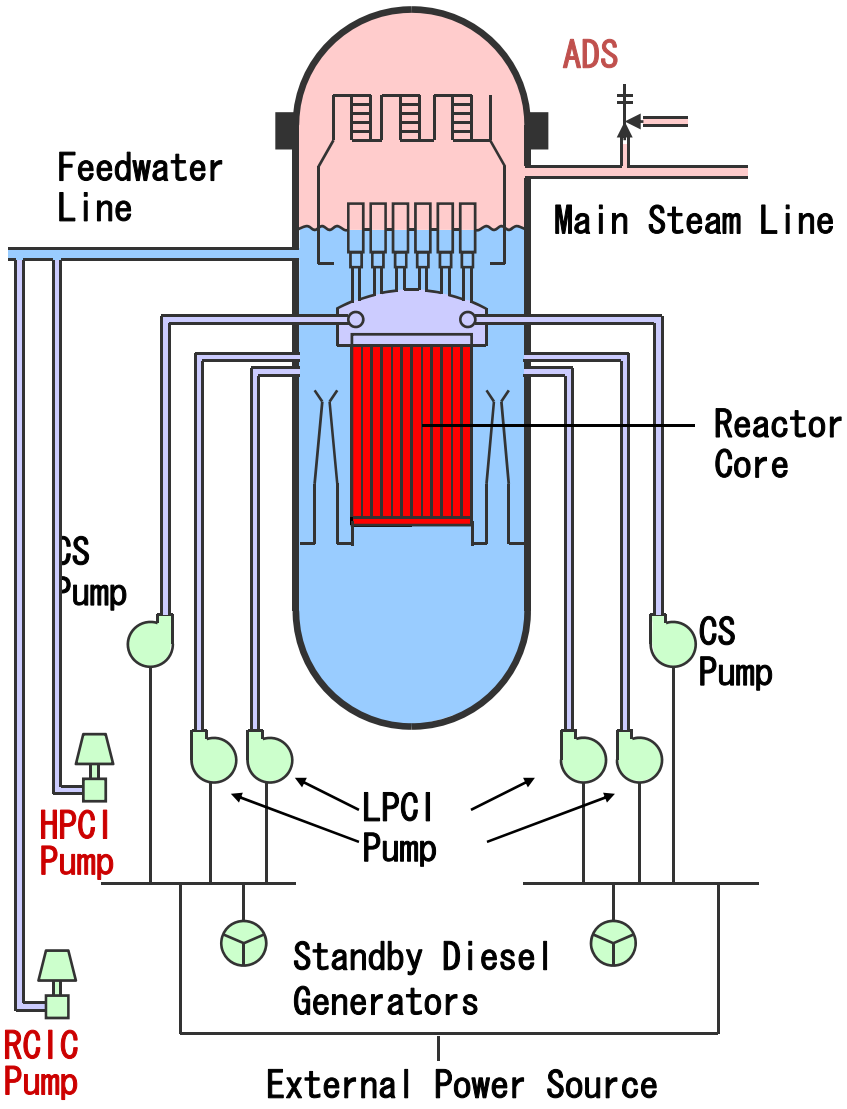
March 25

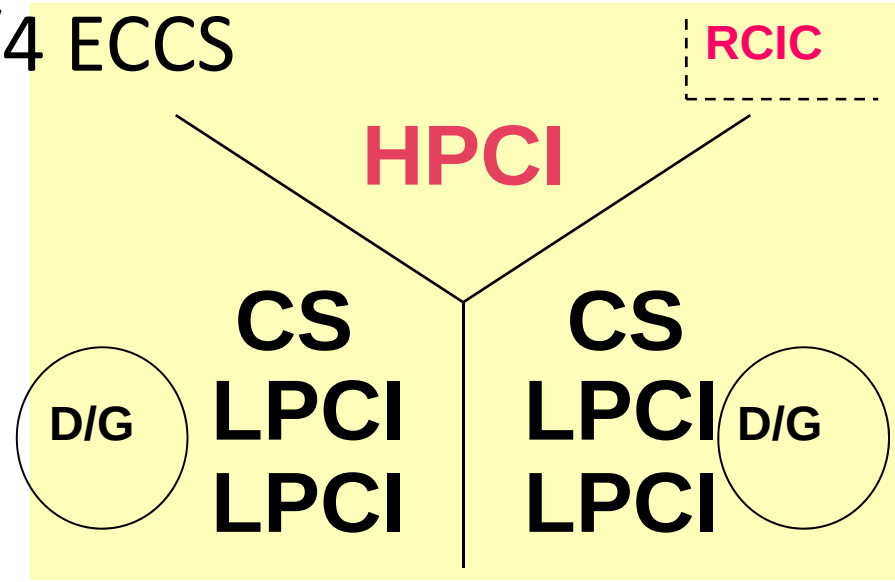
- 18:02 Normal water injection to RPV started.

March 28

- 20:30 Water injection by motor driven pump started

BWR/4 ECCS





HPCI : High Pressure Coolant Injection System (Turbine Driven)

CS : Core Spray System

LPCI : Low Pressure Coolant Injection System

D/G : Standby Diesel Generator

ADS : Automatic Depressurization System

RCIC : Reactor Core Isolation Cooling System (Turbine Driven, Non ECCS)

1F2

March 11:

- 15:42: Total loss of AC power reported
- 16:36: Cooling water injection impossible reported.

March 13

- 11:00 CV vent started

March 14

- 13:25:Loss of cooling reported. (RCIC stopped due to loss of DC power.)
- 16:34: Sea water injection to RPV started
- Low water level in RPV and High CV pressure continued. Mobile power supply was tried but not worked well.
- 17:00 Fuels were uncovered 80cm from the top.
- 18:30: due to the lack of oil of the pump, injection of sea water into RPV stopped and restarted. Nuclear fuels were fully uncovered for 2 hours 20minutes, but covered with water again at 21:34 above 2m.
- 22:50: CV pressure abnormality reported. Fuels fully uncovered at 11pm due to the increase of RPV pressure from the closure of depressurization valves
- Wall of top floor of the reactor building partly removed not to accumulate hydrogen.

1F2

March 15

- 0:00: CV vent started.
- 1:00: Sea water injected, but water level remained low. Fuels may be uncovered., but RVP pressure did not increase.
- 6:10: Detonation noise at suppression chamber, CV integrity may be lost.
- 7:50 : 1941 micro Sv/h at entrance gate and 8217 micro Sv/h at 8:31
- 8:25: White smoke at 5th floor of reactor building observed.
- 11:20: water level in RPV very low. Fuels may fully uncovered. Sea water injection continued. Radiation dose 3130 micro Sv/h observed at 1F2 at 21:37. Estimated fraction of damaged fuel was 33% on March 15.

March 20,22,25

- Sea water supplied to the spent fuel pool

March 26

- 10:10: Normal water injection to RPV
- 16:46: External power supplied to the main control room

March 27

- 18:31 Water injection to RPV by motor driven pump

1F4

- not in operation for annual inspection at the earthquake.

March 14

- 4:08 temperature of the spent fuel pool was 84 in C.

March 15

- Sound of explosion heard. Damage was found on the roof of the reactor building. It may be hydrogen explosion. The hydrogen may be generated by radiolysis of water in the spent fuel pool due to loss of external power and loss of UHS.
- 9:38: Fire was observed at the 3rd floor of the reactor building and extinguished by itself.
- All fuels (spent fuels and core fuels) located in the spent fuel pool for the annual inspection.

March 16

- 5:45: Fire were observed again on the top floor of reactor building again and extinguished by itself.
- Need to supply water into the pool (ordered to TEPCO by minister of METI)

March 20 and March 21

- Water supplied to the spent fuel pool by special fire engines of Japan Self-Defense Force (SDF)

1F5 and 1F6

- 1F5 safe shut down, but water level of RPV decreased slightly.
- 1F6 have Emergency DG without damage of Tsunami. The DG is used to supply water and cooling both 1F5 and 1F6.
- Spent fuel pool temperature increased slightly

March 19

- Spent fuel pool temperature decreased with the DG.
- Holes opened on the roof of the reactor buildings not to accumulate hydrogen

March 20

- External power line connected to the reactors
- Cold shut down 1F5 at 2:30pm, 1F6 at 7:27pm

Radiation levels

- Radiation level in the site varied with the fraction of reactor fuel uncovered.
- The highest radiation dose reported at site boundary was 15mSv/h of 1F.
- High radiation dose, 400-100mSv/h was observed on March 15. It maybe be the radiation from the contaminated walls fallen on the ground by the hydrogen explosion.
- 250mSv was permitted for the workers. Health effect may be observed at 500mSv in average. Dose limit of workers, 50mSv/y. 20mSv/y in 5year average.
- The exposure to the fire fighters supplied water to 1F3 on March 19 was below their limit, 100mSv.
- Dose limit of public is 1mSv/h. More than 400 times conservate to the dose of health effects observed.
- Radiation levels and radio activities outside the site is very low.

Radioactivities

- Most radioactivity remains in the reactors.
- The radioactive materials released may be mostly inert gas FP(fission product) and volatile FP. They are released at venting of CV. Inert gas will not accumulate. Iodine will be in the form of CsI. It is soluble in water and mostly remains in the reactor. Scrubbing by “feed and breed” is effective to keep CsI in the water of CV.
- Contamination of milk and vegetables above the permissible concentrations were found on March 19. The products are controlled by local government. But the amount of radioactivity was far below the level that the health effects are observed.
- The concentration limits are determined so that doses from the intake are equivalent to 5-10mSv
- The atomic bomb testing in the air in 1960’s released much more radioactivity in the environment.

Fukushima site # 2 (2F)

12km from 1F

Successful safe shut down by replacing sea water pump motors damaged by Tsunami

- 4 units: 1100MWe BWR, all in operation at the earthquake

March 11

- Sea water pumps of unit 1,2 and 4 did not work due to Tsunami. The motors were being replaced unit by unit until March 14.
- 20:00 External power recovered for all units.

March 12

- 12:15: Cold shut down of unit 3 (Sea water cooling of unit 3 was not lost by Tsunami)

March 14

- 1:24: Recovery of sea water cooling were successful for unit 1
- 7:13: and for unit 2.
- 13:40: Cold shut down unit 1
- 14:20: Cold shut down unit 2

March 15

- 7:15 : Cold shut down unit 4.

All reactors of 2F were in stable shut down condition.

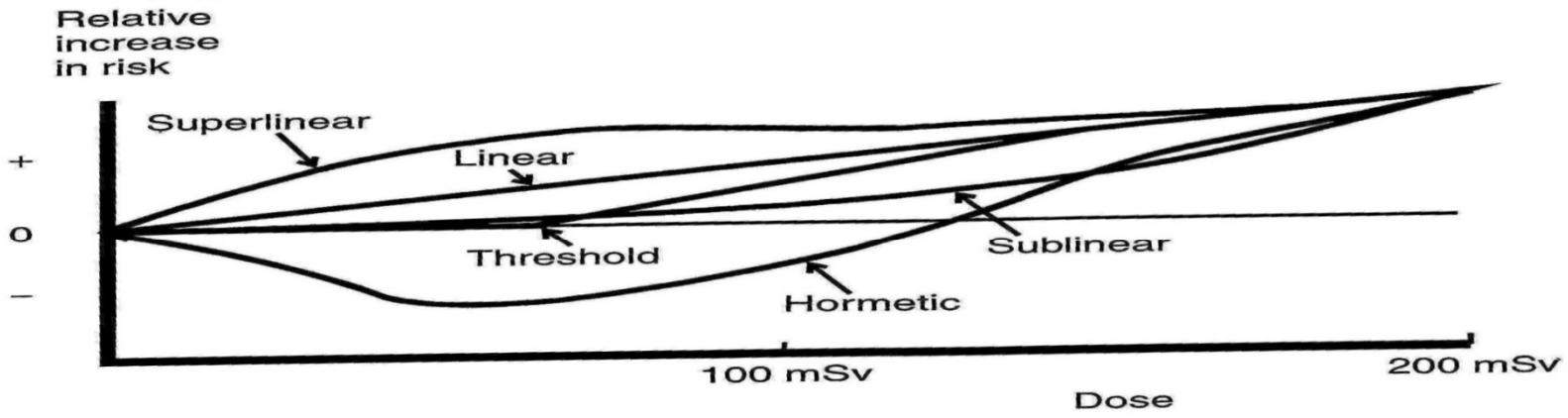


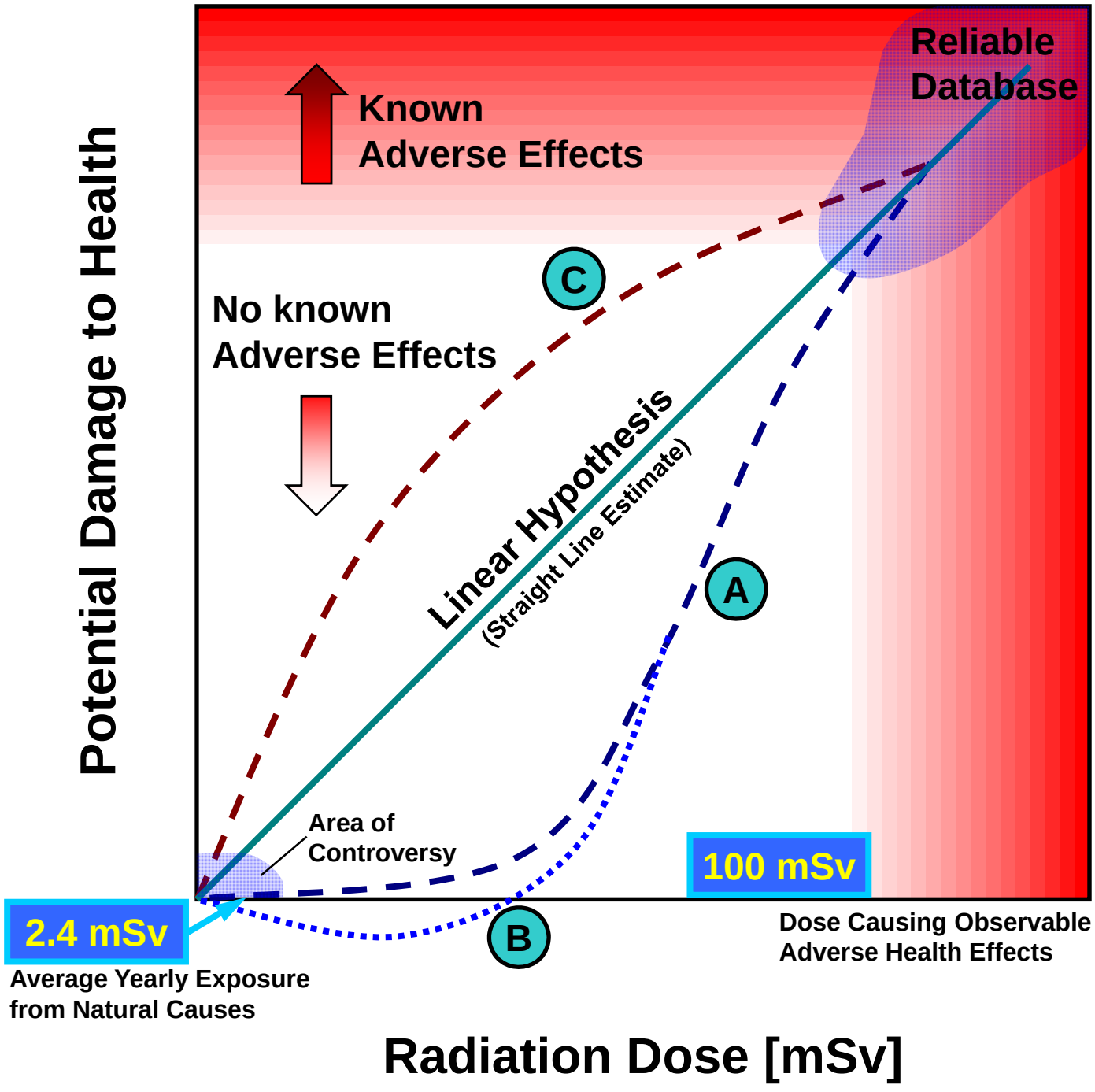
Fig. 1.14.2 Risk models at low dose

source；Don Lawson “Engineering Disasters” ASME, 2005

The health effects of radiation are observed above 200mSv. Health physics specialists gave several models at low dose as seen in the figure. It shows that there is no agreement of the health effects at low dose. We take linear extrapolation to zero from 200mSv. It assumes that low dose for example 1mSv causes increase of risk of the fraction of 200mSv. This hypothesis (model) is taken in the present regulation of radiation. This may be the source of the fear of radiation of the public. We suffer natural radiation every day. The dose is 2.4mSv/y . The radiation dose of the accident in the environment outside the exclusion area is low. We need not worry about the health effects of the low dose.

Please find linear non-threshold hypothesis (model) of health effects of low level radiation in
http://en.wikipedia.org/wiki/Linear_no-threshold_model

Please also refer to the book: “Radiation and Reason” by Wade Allison, Professor University of Oxford


Reliable Database
Known Adverse Effects
No known Adverse Effects
C
Linear Hypothesis
(Straight Line Estimate)
A
Potential Damage to Health
Area of Controversy
100 mSv
2.4 mSv
B
Dose Causing Observable Adverse Health Effects
Average Yearly Exposure from Natural Causes
Radiation Dose [mSv]