Fukushima Daiichi Nuclear Power Plant Accident and Radiation Health Effects

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http://www.f.waseda.jp/okay/index_en.html
The biggest earthquake and Tsunami

- Earthquake 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.
- Nuclear power plants and coal fired power plants were automatically shut down at the earthquake.
- The biggest tsunami struck the NPP (nuclear power plant) an hour later.
- Tsunami damaged sea water pumps and emergency diesel generators (DG) and caused common cause failure due to loss of AC power and loss of ultimate heat sinks of unit 1-4.
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 nuclear power plants

Unit 1: 460 MWe BWR, 1971 (in operation prior to event)
Unit 2: 784 MWe BWR, 1974 (in operation prior to event)
Unit 3: 784 MWe BWR, 1976 (in operation prior to event)
Unit 4: 784 MWe BWR, 1978 (in outage prior to event)
Unit 5: 784 MWe BWR, 1978 (in outage prior to event)
Unit 6: 1100 MWe BWR, 1979 (in outage prior to event)
Boiling water reactor nuclear power plant
Boiling water reactor

Reactor building
4F; fuel handling floor
Unit 1,3,4: hydrogen explosion

Spent fuel pool
8–12m deep

Containment vessel
Unit 2: detonation and lost integrity

Reactor pressure vessel
Unit 2 and 3: bottom leakage?
Mark-I Containment
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)
Fukushima site 1 (1F) unit 1-4
Loss of AC power and Loss of ultimate heat sink common cause failure by Tsunami

- 6 units: 4 units (1F1-4) and 2 units (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, unit 3,2) operated for 1,2 days (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.
Severe Accident Management Systems
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
(Hydrogen was generated by oxidation of fuel cladding tubes by zirconium-water reaction when fuels were uncovered by water.)
Note: It was NOT explosions of the reactors. Most radioactivity stays in the reactor.
“Feed and breed” (supplying water to the reactor and removing the residual heat by boiling) 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 are low, 58C(1F1), 35C(1F2), 62C(1F3), 42C(1F4), 24C(1F5), 25C(1F6) at 1pm of March 20

Level 7 accident of IAEA

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

External power lines were recovered and connected 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 5 years ago) required 600gal (lateral) and 400 gal (vertical acceleration), but improvement was not completed at 1F.

Tsunami: Max height 14-15m, Building elevation: 10-12m, (Tsunami height of safety evaluation was 5.7m)
Actions underway

• The next step is to establish a cooling loop with a heat exchanger. But high radiation dose of reactor and turbine buildings limits the recovery action.

• Removing contaminated water to the tank is in progress. It will reduce radiation dose.

• Large release of radioactivity by loss of cooling the reactors is not likely.
Radioactivity in the environment

- Most radioactivity was released at the hydrogen explosions on March 12 and 14.
- Radiation dose after the hydrogen explosions decreasing steadily.
- Hydrogen explosion is not the explosion of the reactor itself. Released radioactivity (iodine) is far less (100 times) than that of Chernobyl accident (explosion of reactor itself).
- The radioactive materials released from the reactor are mostly inert gas FP(fission product) and volatile FP. They are released to the reactor building at venting of CV and into the air at hydrogen explosions. Inert gas will not accumulate. Iodine is in the form of CsI. It is soluble in water.
• Contamination of milk and vegetables above the permissible concentrations were found on March 19. The products are controlled by local government and not in the market.
• Airborne radioactivity such as CsI fell on the ground by rain on March 20. The contamination of drinking water was detected. It decreased below the limit in a few days
• Iodine accumulate in the thyroids. Many children suffered thyroid cancer at Chernobyl accident, because the contaminated milk and food were NOT controlled. (Most children survived after the surgery.)
• The concentration limits are determined very conservatively far below the level that the health effects are actually observed. Annual dose limit of the public, 1mSv is 1 more than 100 times conservative from the actual health effects are observed. **It is not necessary to worry about the health effects.**
Radioactive water leakage to the sea

- Supplying water to the reactor for cooling is primarily important. But CV of unit 2 and 3 lost integrity and radioactive water from the reactors leaked into turbine buildings, ducts, pits and then to the sea.
- The leakage from the pit of unit 2 was stopped on April 5. The radioactivity concentration of sea water at discharge was decreased.
- Contamination of fish above the limit was reported. Fishermen of Fukushima and Ibaraki prefecture stopped fishing due to drop of the fish price. Contaminated fish is controlled and not sale in the market.
- Permissible level of contamination is determined in the same way as agricultural products. It is very conservative.
- Radioactivity of the sea water is monitored. High concentration is reported near the coast.
- The radioactivity will be diluted in the pacific ocean by mixing the cold current (Oya-shio) and warm current (Kuro-shio).
Health effect of radiation

• Acute effects (vomiting, death etc.) and latent effects (leukemia, cancer etc.). No genetic diseases are observed for humans.

• Both effects are observed above 200mSv.

• ICRP (International Commission of Radiation Protection) recommend radiation dose limit. Regulation follows the guideline. ICRP also recommends that radiation exposure should be as low as reasonably achievable (ALARA)

• Acute effects have the threshold dose, but latent effects of low level radiation need to be determined for regulation. It is estimated based on the linear non-threshold (LNT) model (hypothesis): Linear extrapolation of the radiation effects above 200mSv to zero. It assumes that the low dose have adverse health effects (cancer rate) in the fraction.
Health effect and dose limit

10Sv : 100% death
5Sv : 50% death
1Sv : 10% vomiting
0.25 Sv : Dose limit of radiation workers
0.1 Sv : No health effect (reference dose)
0.017 Sv : Annual exposure by natural radiation in Kerala (south India)
0.0024Sv : Annual exposure by natural radiation (world average)
0.0014Sv : Annual exposure by natural radiation in Japan
0.001 Sv : Annual dose limit of public (1mSv/y)

Health effects of radiation exposure are fairly well understood from the data of atomic bomb survivors, utilization of radiation and radio isotopes in 100 years, Chernobyl accident etc.
ICRP 2007 recommendations

Individual dose limit:

Occupational: 20mSv/y in 5 years
Public: 1mSv/y

Emergency exposures:

Occupational: 100mSv (rescue)
1000 or 500mSv (urgent rescue)
no restrictions (life-saving)

Public: 20-100mSv/y

Radon (at home and at work): 10mSv/y
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 outside the exclusion area is as low. We need not worry about the health effects of the low dose.


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

No known Adverse Effects

Potential Damage to Health

Radiation Dose [mSv]

2.4 mSv
Average Yearly Exposure from Natural Causes

100 mSv
Dose Causing Observable Adverse Health Effects

Known Adverse Effects

Reliable Database

Linear Hypothesis
(Straight Line Estimate)

Area of Controversy

(A) 2.4 mSv
Average Yearly Exposure from Natural Causes

(B) 100 mSv
Dose Causing Observable Adverse Health Effects

(C) Reliable Database

Potential Damage to Health

No known Adverse Effects

Radiation Dose [mSv]

- 100mSv in a single dose
- 100mSv in total in any month
- 5,000mSv as a total whole life exposures
- The figures are conservative, debatable within factor of 2, but not 10.

*Note: Health effect is bigger for the exposure at once than a long period, even if the total doses are the same.*
Is salt a poison?
Toxicity depends on the amount taken.

Salt is necessary for human body, but bad for health when large amount taken.

200g : will die.
20g/d : causes high blood pressure, increase in risk of heart disease and cancer
7g/d : no health effects
0g/d : will die.

The same as the radiation. Radiation and radioactive materials are generated by the big-ban of the universe. Human being evolved in the radiation environment.

Need not worry about the adverse health effect of low level radiation.

We know that Radon/Radium spa is good for health.
Natural radiation

- Source: cosmic ray and radioactive decay of radionuclides of ultra-long half lives such as uranium, thorium and K-40 and their daughter nuclides in the ground, air and human body.
- Half life in billion years: 4.468 (U-238), 0.704 (U-235), 14.05 (Th-232), 1.28 (K-40).
- Radium, Radon etc. are the daughter nuclides from the radioactive decay of the uranium, thorium: Ra-226 (HL=1620y) and Rn-222 (HL=3.8d) from U-238, Ra-228 from Th-232.
Artificial radionuclides in the environment

- Artificial Radionuclides in the Environment 2007 Geochemical Research Department, Meteorological Research Institute, JAPAN ISSN 1348-9739, Dec. 2007

- Measured for over 50 years in Tokyo and Tsukuba
- Fall out from atomic bomb testing in the air in 1950-80’s is the major source.
- 1000 times higher in 1960’s than at present
- Correlation with Kosa (yellow sand) event
Sr-90 and Cs-137 deposition in Tokyo and Tsukuba

Monthly deposition time series for $^{90}\text{Sr}$ and $^{137}\text{Cs}$ at the Meteorological Research Institute since 1957 to the present time
Annual Cs deposition
Stratospheric and re-suspension components

Fig. 13: Decreasing trends of annual $^{137}$Cs deposition observed at the MRI exhibiting the stratospheric and re-suspension components.
Sr and Cs deposition and Kosa (yellow sands) event

Fig. 15: Time series of $^{90}$Sr and $^{137}$Cs deposition comparing with number of the Kosa event recorded at meteorological observatories (nationwide)
Deposition of Pu and Cs

Fig. 18: Annual deposition of $^{239,240}$Pu observed in the MRI, Japan
summary

• Environmental radioactivity released at hydrogen explosions on March 12 and 14.
• The radioactivity is decreasing.
• Contaminated agricultural, marine products are controlled and not in the market.
• Further large release is not likely.
• Need not worry about the health effects of low level radiation.