The Challenges and Implications for Energy Education Following the Fukushima Nuclear Accident

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Presentation Notes and References will be available by next week at:

http://mavweb.mnsu.edu/tebbep/fukushima

Outline

- Introduction
- Fukushima Daiichi plant background
- Timeline of the event
- Radiation and health consequences
- Comparing Three Mile Island, Chernobyl, Fukushima
- Student perceptions

NSPE Code of Ethics

1. Hold paramount the safety, health, and welfare of the public.
2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

Source: http://www.nspe.org/Ethics/CodeofEthics/index.html

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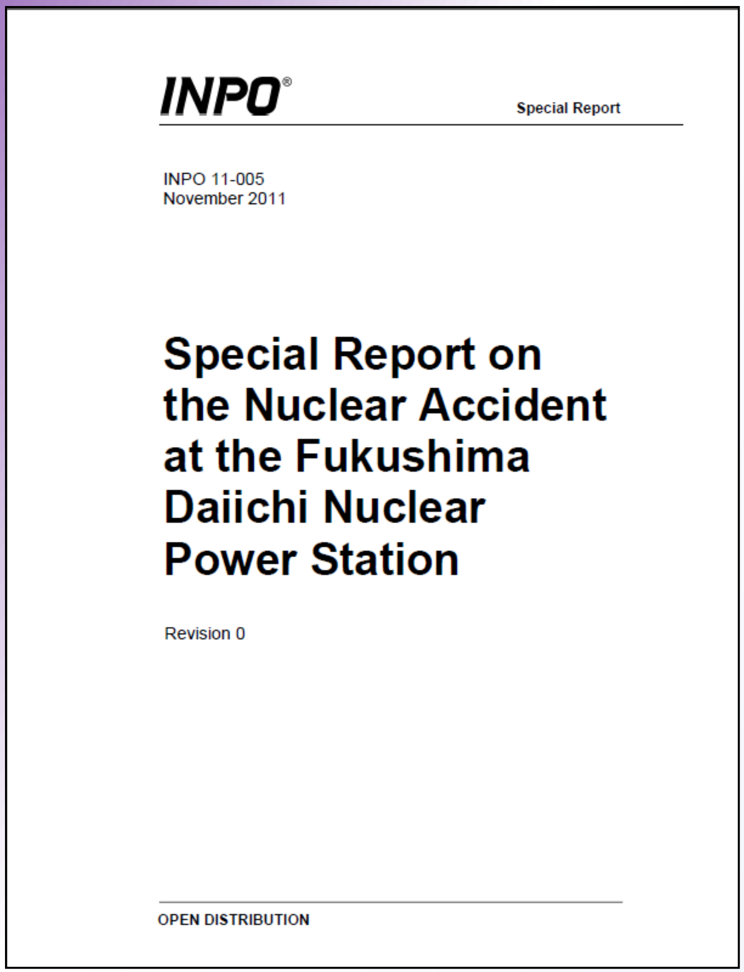

INPO

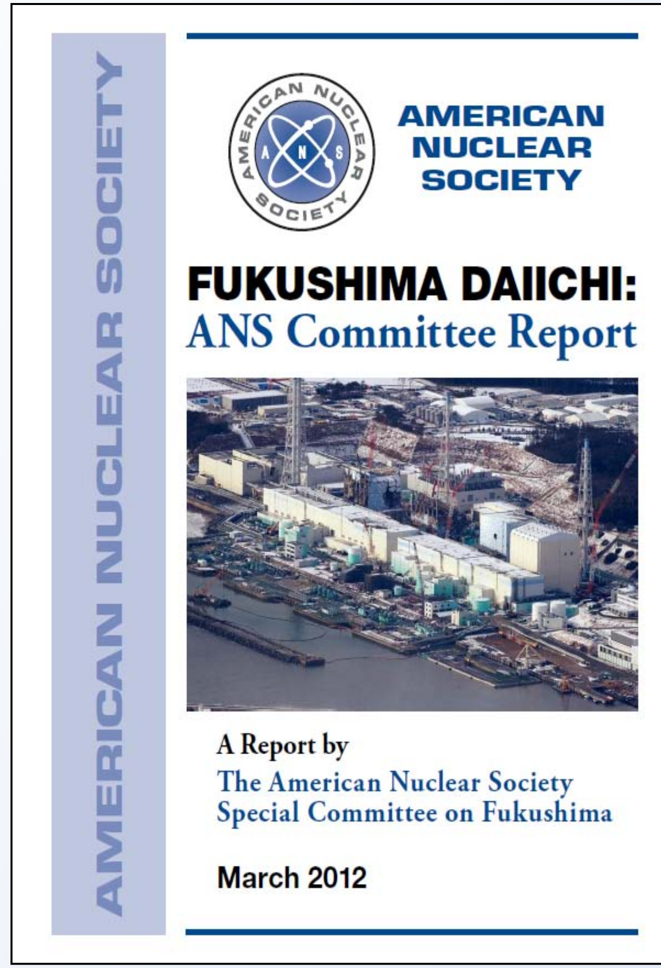
Special Report

INPO 11-005
November 2011

Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station

Revision 0

OPEN DISTRIBUTION


AMERICAN NUCLEAR SOCIETY

AMERICAN NUCLEAR SOCIETY

FUKUSHIMA DAIICHI:
ANS Committee Report

A Report by
The American Nuclear Society
Special Committee on Fukushima

March 2012

Test Your Knowledge

What type of nuclear reactor is used at Fukushima Daiichi?

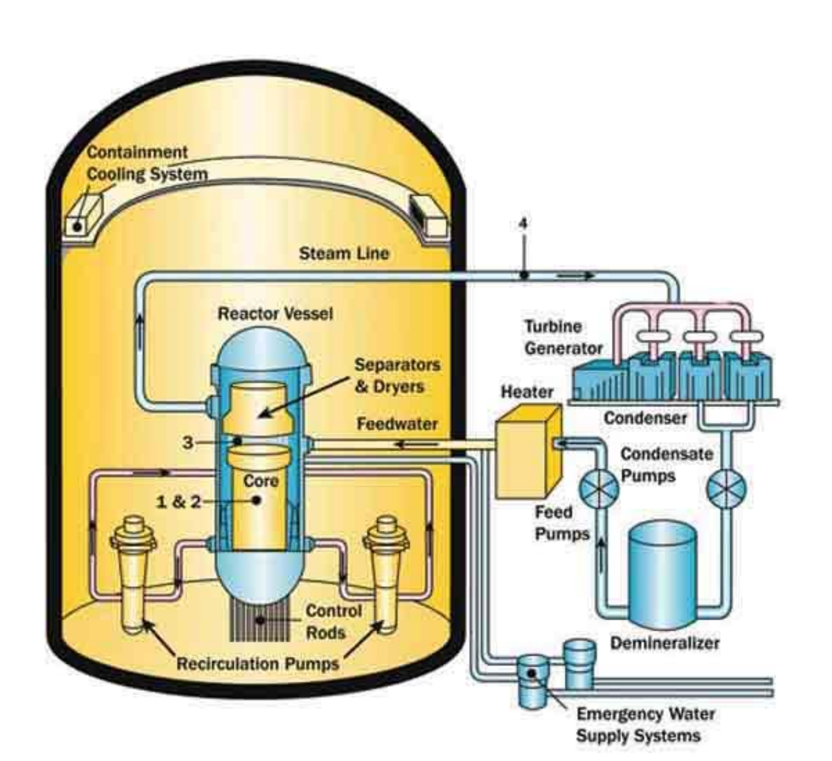
a) Pressurized Water Reactor (PWR)
b) Canada Deuterium Uranium (CANDU)
c) Boiling Water Reactor (BWR)
d) Gas Cooled Reactor (GCR)

Test Your Knowledge

What type of nuclear reactor is used at Fukushima Daiichi?

a) Pressurized Water Reactor (PWR)	**11 responses**
b) Canada Deuterium Uranium (CANDU)	**0 responses**
c) Boiling Water Reactor (BWR)	**2 responses**
d) Gas Cooled Reactor (GCR)	**1 response**

Boiling Water Reactor (BWR)



Source: U.S. Nuclear Regulatory Commission http://www.nrc.gov/reactors/bwrs.html

Fukushima Reactors

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Electrical Output (MW)	460	784	784	784	784	1100
Heat Output (MW)	1380	2381	2831	2381	2381	3293
Start of Operation	Mar-71	Jul-74	Mar-76	Oct-78	Apr-78	Oct-79
Main Contractor	GE	GE/Toshiba	Toshiba	Hitachi	Toshiba	GE/Toshiba

Source: “Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station”, Institute of Nuclear Power Operations, INPO 11-005, Nov. 2011.

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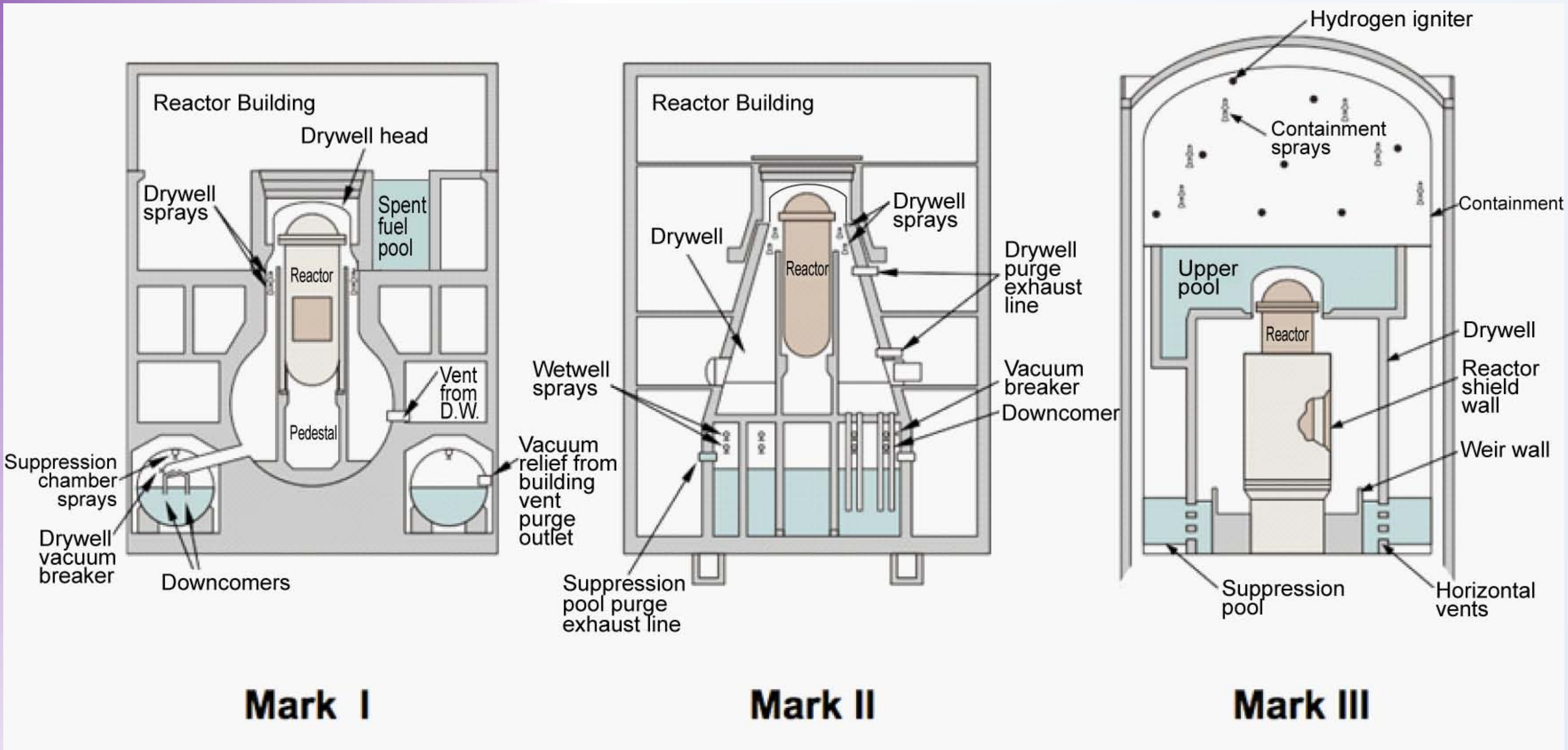
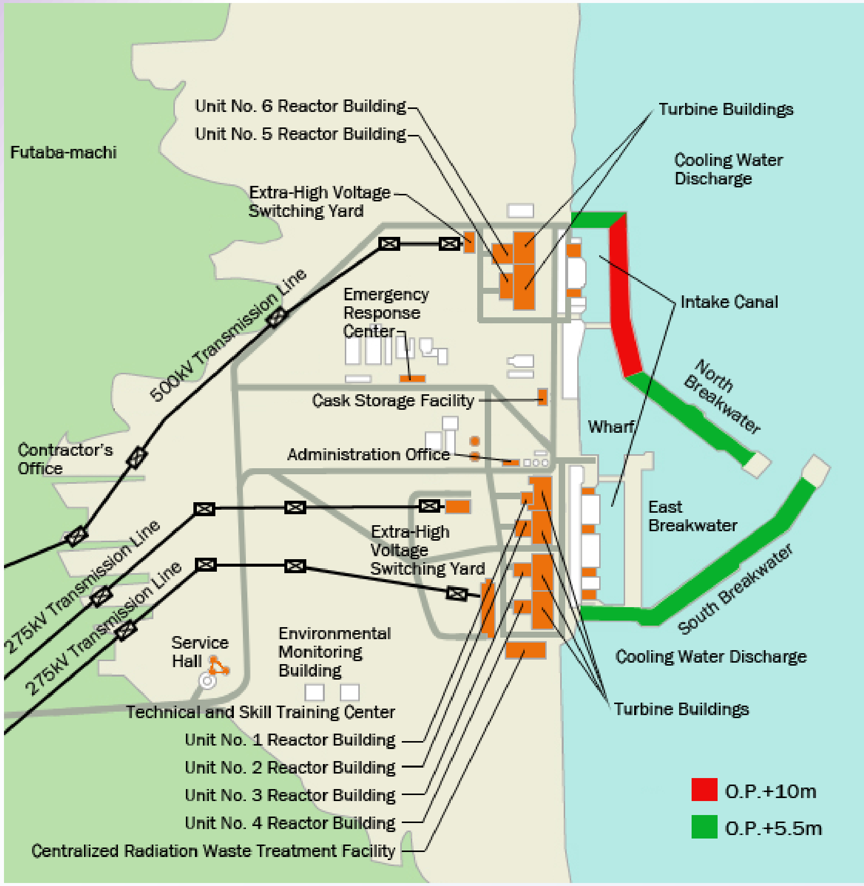


Source: "Fukushima Daiichi: ANS Committee Report", American Nuclear Society, March 2012.

Reactor Status on March 11

- Unit 1, 2, and 3 were operating at their rated power level.
- Unit 4 was in an outage state. All fuel had already been moved to the spent fuel pool.
- Units 5 and 6 were in cold shutdown but were fueled.



Source: "Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station", Institute of Nuclear Power Operations, INPO 11-005, Nov. 2011.

Earthquake and Tsunami

- At 2:46 p.m. on March 11, 2011 an earthquake measuring 9.0 on the Richter scale occurred off the coast of Fukushima Daiichi.
- The first of seven tsunamis reached the plant forty-one minutes later.
- The maximum tsunami height was 46 to 49 ft (14 to 15 m).
- The plant's tsunami design height was 18.7 ft (5.7 m).
- The site grade level for units 1-4 was 32.8 ft (10 m).

Source: "Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station", Institute of Nuclear Power Operations, INPO 11-005, Nov. 2011.

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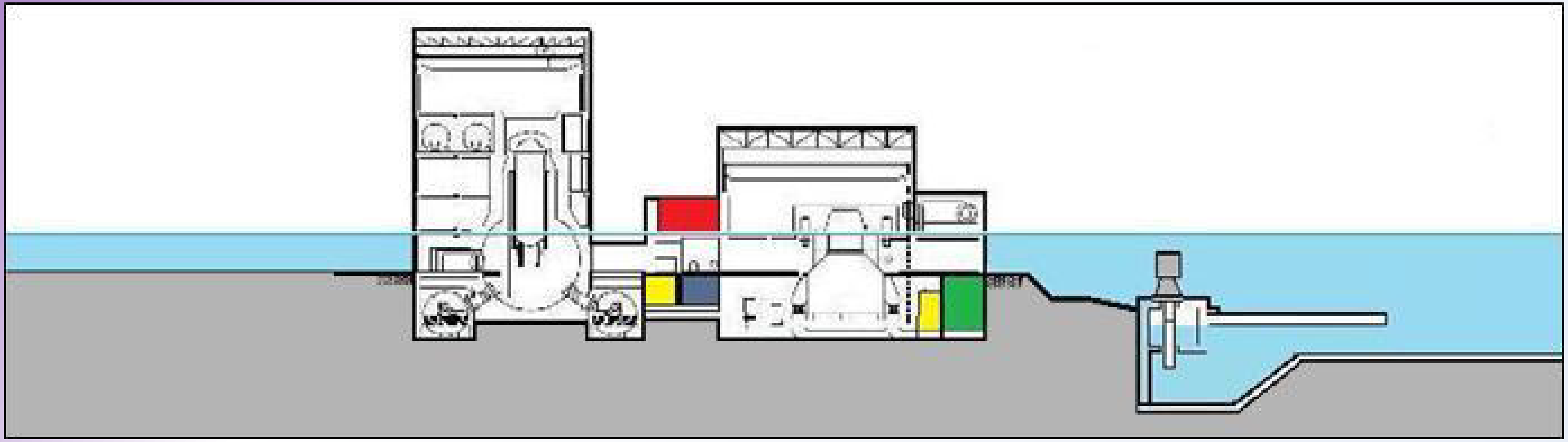
Source: Tokyo Electric Power Company http://photo.tepco.co.jp/en/index-e.html

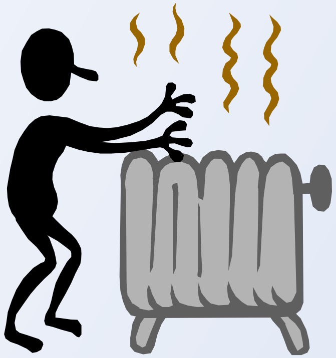


Source: “Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station”, Institute of Nuclear Power Operations, INPO 11-005, Nov. 2011.

Accident Analysis

- Seismic sensors “tripped” Units 1, 2, and 3 shutting them down.
- Outside electricity was lost when distribution towers were damaged.
- The emergency diesel generators at all units started as designed.

- A reactor “trip” stops the chain reaction; however, fission products continue to decay and generate heat.
- Active cooling must be maintained.



Source: “Fukushima Daiichi: ANS Committee Report”, American Nuclear Society, March 2012.

Initial Tsunami Impact

- Unit 5's two emergency diesel generators and two of three at Unit 6 failed.
- One air cooled, higher ground, generator at Unit 6 maintained operation.
- This one unit was able to depressurize and cool both Units 5 and 6.
- Cold shutdown was achieved by March 20th.

- Units 1-4 were damaged and lost all emergency diesel generators (AC).
- Units 1 and 2 lost battery backup while Unit 3 maintained some batteries (DC).

Source: "Fukushima Daiichi: ANS Committee Report", American Nuclear Society, March 2012.

A Moment of Background

A Moment of Background

- Zirconium has a low cross section for thermal neutrons.
- Zirconium alloys ("Zircaloy") are therefore used for fuel rod cladding.
- At high temperature zirconium reacts with steam (i.e. water) and oxidizes, releasing hydrogen gas.

$$Zr + 2\ H_2O \rightarrow ZrO_2 + 2\ H_2$$

NOTE: This is an exothermic reaction.

Unit 1 Summary

- The loss of DC power made monitoring instrumentation and the high pressure coolant injection system unavailable.
- Rising radiation levels by 10:00 p.m. and high containment pressure levels by 12:49 a.m. indicated possible core damage.
- Anticipating hydrogen production venting plans were started, including local evacuations.
- High radiation levels hindered the process and the high pressure may have caused a leak path to develop for the hydrogen.
- At 3:36 p.m. on March 12th a hydrogen explosion occurred in the reactor building.

Source: "Fukushima Daiichi: ANS Committee Report", American Nuclear Society, March 2012.

A Moment of Background

"Normal accidents emerge from the characteristics of the systems themselves. They cannot be prevented. They are unanticipated."

- Complex systems that are tightly coupled provide limitless combinations of events.
- The combinations are unforeseeable and exposure hidden connections.

Source: "Normal Accident at Three Mile Island", by Charles Perrow, Energy Politics, Vol. 18 No. 5, 1981.

Source: http://totallycoolpix.com/2011/03/japan-disaster-zone-one-week-on/

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Source: http://totallycoolpix.com/2011/03/japan-disaster-zone-one-week-on/

Unit 1’s you can’t make this stuff up.

- A diesel driven fire pump that had used to inject coolant stopped. Workers carried more fuel to the pump. Trying to restart the engine they depleted the batteries. They found new batteries but the engine still failed to start.

- The site had three fire engines that could be used for injection. One was damaged in the earthquake. One was near Units 5 and 6 but damage and debris blocked the road. The third had to be moved around a displaced heavy fuel oil tank and past a security gate that would not open because the power was off.

Source: “Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station”, Institute of Nuclear Power Operations, INPO 11-005, Nov. 2011.

Unit 1's you can't make this stuff up.

- Eventually the fire engine was used to inject water from a the Unit 1 fire protection tank. A second engine arrived and shuttled additional water from the Unit 3 tank to the Unit 1 tank. However, the Unit 1 tank only had one connection point.
- At 6:50 a.m. TEPCO was ordered to vent Unit 1 containment. However, some residents were not sure what direction to evacuate. TEPCO decided to wait until 9:00 a.m. to give them time to leave.

Source: "Special Report on the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station", Institute of Nuclear Power Operations, INPO 11-005, Nov. 2011.

Unit 3 Summary

- Recall the reactor core isolation cooling system (RCIC) is a reactor steam driven system to add water at a range of pressures. It ran for 20 hours before stopping.
- The high pressure coolant injection (HPCI) system also uses reactor steam driven turbines and could be run off the remaining battery. It ran for 15 hours before stopping.
- Using the reactor steam had the effect of lowering the reactor pressure vessel (RPV) pressure. When the RCIC and HPCI stopped pressure started to rise again.
- Fire engines started injecting freshwater with boron.

Source: “Fukushima Daiichi: ANS Committee Report”, American Nuclear Society, March 2012.

Unit 3 Summary

- The site eventually ran out of freshwater and systems were switched over to using seawater.
- The water level in the reactor never recovered. This could indicates a leak in the pressure vessel.
- Containment pressure rose, <u>but not as fast as expected</u>.
- Venting was attempted but the solenoid values did not work well without power.
- At 11:01 a.m. on March 14th a hydrogen explosion occurred in the containment building. Eleven workers were injured.

Source: “Fukushima Daiichi: ANS Committee Report”, American Nuclear Society, March 2012.


NTV Japan

Unit 4 Summary

- Unit 4 lost cooling and water supply to the spent fuel pool. The pool temperature increased.
- At 6 a.m. on March 15th a hydrogen explosion occurred.
- It was initially thought the hydrogen came from uncovered fuel in the pool.
- Water was added to the pool by fire engine, helicopter, and concrete pump.

Source: “Fukushima Daiichi: ANS Committee Report”, American Nuclear Society, March 2012.

Source: http://www.reuters.com/article/2011/03/19/us-japan-quake-idUSTRE72A0SS20110319.

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Source: Tokyo Electric Power Company http://photo.tepco.co.jp/en/index-e.html

Unit 2 Summary

- The RCIC ran for 70 hours. The HPCI was not available (no batteries).
- The RCIC stopped due to low water levels. Fire suppression lines could not be used to inject water because the RPV pressure was too high.
- Similarly, trouble with valves slowed this process and the fuel was uncovered before water injection could be started.
- Pressure rose in the containment building (but slower than expected). Efforts were made to vent.
- A “sound” was thought to be a hydrogen explosion.
- High radiation levels following the Unit 4 explosion forced the evacuation of some workers.

Source: “Fukushima Daiichi: ANS Committee Report”, American Nuclear Society, March 2012.

Unit 2 Summary

"It is not clear whether the designed vent path was ever in service."

Source: "Fukushima Daiichi: ANS Committee Report", American Nuclear Society, March 2012.

Test Your Knowledge

What percentage of the stored/spent fuel in the spent fuel pools at Fukushima Daiichi melted down?

a) 0 %
b) 4 %
c) 17 %
d) 32 %

Test Your Knowledge

What percentage of the stored/spent fuel in the spent fuel pools at Fukushima Daiichi melted down?

a) 0 % **4 responses**
b) 4 % **2 responses**
c) 17 % **5 responses**
d) 32 % **2 responses**

Spent Fuel Pools Summary

- Spent and stored fuel still experience nuclear decay while not being in a condition of criticality.
- If the resulting heat is not removed water covering the fuel can boil off.

- There was no damage to the Unit 5, Unit 6, and common pools.
- Debris from the explosion fell into the Unit 1 pool but without damage.
- Intermittent water addition to the Unit 2 pool was maintained and it was not damaged.
- Water addition to the Unit 3 and 4 pools was maintained with fire and concrete trucks.
- Damage to the Unit 3 fuel racks and Unit 4 support structure <u>may have</u> occurred due to debris.

Source: "Fukushima Daiichi: ANS Committee Report", American Nuclear Society, March 2012.

Wait a Second!

If the stored fuel in Unit 4 was undamaged, where did the exploding hydrogen come from?

It is believed a common set of pipes between Units 3 and 4 allowed hydrogen from Unit 3 to pass into Unit 4.

Source: “Fukushima Daiichi: ANS Committee Report”, American Nuclear Society, March 2012.

"Mr. Osborne, may I be excused? My brain is full."

A Moment of Background

Becquerel (Bq) – One disintegration per second

Curie (Ci) – 3.7 x 10^{10} Bq

Gray (Gy) – Absorbed radiation dose

Rad – Older unit for absorbed radiation dose

Sievert (Sv) – Effective or equivalent radiation dose to biological tissue

Rem – Older unit for equivalent radiation dose

1 Gy = 100 rad

1 mSv = 100 mrem

disintegrations per second ≠ counts per second

Test Your Knowledge

For the average person in the United States, normal radiation exposure per year is?

a) 1 mrem
b) 15 mrem
c) 360 mrem
d) 1100 mrem

Test Your Knowledge

For the average person in the United States, normal radiation exposure per year is?

a) 1 millirem **1 response**

b) 15 millirem **5 responses**

c) 360 millirem **7 responses**

d) 1100 millirem **1 response**

Test Your Knowledge

For the average person in the United States, normal radiation exposure per year is?

a)	1 millirem	**air travel (2006 miles)**
b)	15 millirem	**smoking cigarettes (1 pack/day)**
c)	360 millirem	**annual dose (natural)**
d)	1100 millirem	**CT scan (head and body)**

Source: U.S. Department of Energy
http://www.oakridge.doe.gov/external/PublicActivities/EmergencyPublicInformation/AboutRadiation/tabid/319/Default.aspx

Reference: "Calculate Your Radiation Dose", http://www.epa.gov/rpdweb00/understand/calculate.html

Health Consequences of Radiation

Using the linear no-threshold (LNT) hypothesis cancer risk can be approximated as:

1 % increase per additional100 mSv (10 rem)

Limits above normal for radiation workers are:

100 mSv over 5 years, 50 mSv max in a year

Limits above normal for the public from mining and nuclear plants are:

1 mSv per year

Source: http://www.world-nuclear.org/info/inf05.html

Radionuclides of Concern

Cesium-134	Half life of 2.1 years, beta emitter
Cesium-137	Half life of 30.2 years, beta emitter
	→Barium-137m Half life of 2.7 minutes, gamma emitter
Iodine-131	Half life of 8 days, beta emitter

Worker Health

- The maximum external dose recorded was 199 mSv.
- The maximum internal dose recorded was 590 mSv.
- The maximum total dose recorded was 670 mSv.
- Six workers received doses above the emergency dose limit of 250 mSv/year.
- 408 workers received doses above the normal dose limit of 50 mSv.

- Two workers died from flooding and one from getting trapped in a crane during the tsunami. Two other workers have died of unrelated causes since then.

Source: “Fukushima Daiichi: ANS Committee Report”, American Nuclear Society, March 2012.
“The Fukushima Death Toll:, http://asiancorrespondent.com/53036/the-fukushima-death-toll/

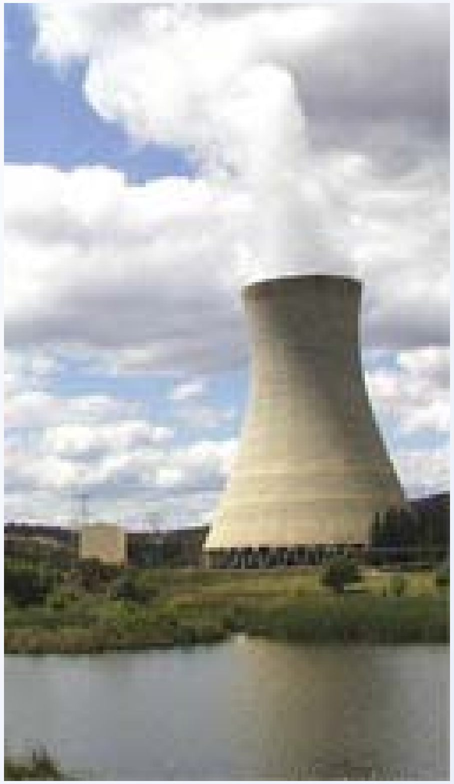
Iodine-131 and Thyroid Cancer

"The incidence of thyroid cancer in contaminated areas of the Ukraine and Belarus was triple that of normal thyroid cancer incidence in the area, although the study's authors acknowledge that more attention was paid to medical examinations and improved record-keeping in those areas affected by the Chernobyl event."

"One of the things we have learned about studying the after-effects of Chernobyl is that the kids who lived in areas of radioactive fallout who drank contaminated milk had a huge increase in thyroid cancer related to radioactive iodine." John Boice

Source: "Does Potassium Iodide Protect People from Radiation Leaks?" by Larry Greenemeier, Scientific American, March 15 2011.

Test Your Knowledge – What is this?

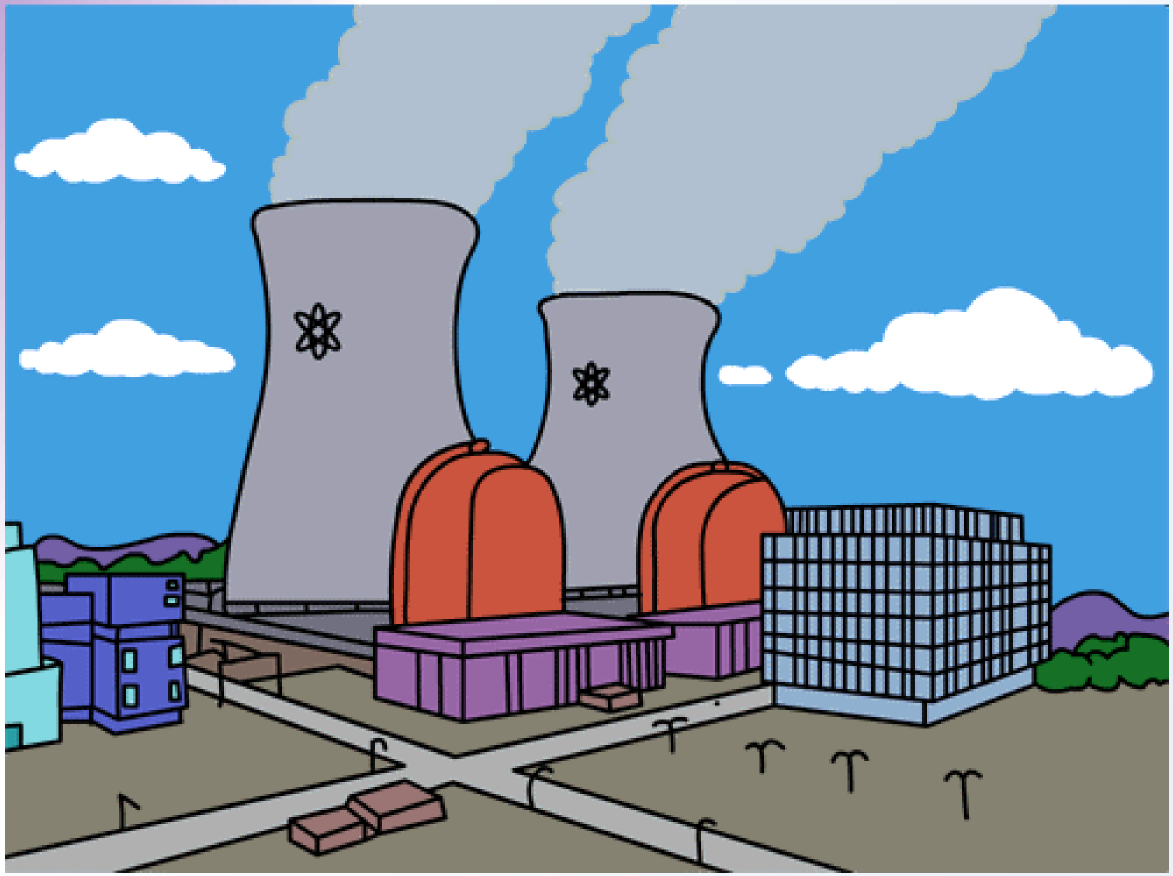


Test Your Knowledge – What is this?

Reference: http://www.industcards.com/st-coal-australia-nsw.htm

The Cooling Tower as a Symbol

- Reporters during Three Mile Island had little information and no access to the inside of the plant.
- With nothing else to show, reporters filmed the cooling towers. Often using clips from before the incident of normally functioning operation.
- The natural draft cooling tower continues to symbolize nuclear power. In fact, some people continue to believe the reactor is IN the cooling tower.



Reference: http://simpsons.wikia.com/wiki/Springfield_Nuclear_Power_Plant

Changing Generations

Three Mile Island (1979)

- A gallon of gas cost $0.86
- The Atari 400 computer sold for $549

Chernobyl (1986)

- A gallon of gas cost $0.89
- A Tandy 600 Portable computer cost $1599
- Internet Mail Access Protocol defined

Fukushima (2011)

- A gallon of gas cost $3.79
- Smartphones have similar computing power to a Cray of the 80’s

Source: http://www.thepeoplehistory.com/

Student's Information Resources

- "Crazy Bob's Webpage of Nuclear Information"
- Wikipedia
- Facebook
- Twitter
- Text messages
- Several hundred cable/satellite channels are competing for viewers.

There is an expectation that the answer is out there…
and it can be found quickly.

It Works Both Ways Though

"At the same time, I was on Twitter – and this is the first time Twitter has ever proved itself to be useful to me – and all my friends in Tokyo and the environs were tweeting in and we were starting to piece together what happened."

As time passed, Woolner said the gap between the reality he and others in Japan were experiencing and what international media was reporting seem(ed) to widen.

Source: "Misinformation Clouds Much Japan Coverage" by Craig Silverman, Columbia Journalism Review, March 25, 2011.

Is Fukushima the next Chernobyl?

- At Chernobyl the majority of radiation went directly into the air, while at Fukushima most was captured in water.
- Small amounts of potassium iodide tablets were distributed after Chernobyl, while it is unclear how many were distributed at Fukushima.
- Contaminated milk was not blocked at Chernobyl, while at Fukushima raw milk and vegetables were blocked.

- Chernobyl related cancer deaths are projected to be 16,000 (<0.1% increase)
- Extrapolating to Fukushima projected cancer deaths could be 1000.

Source: "The radiological and psychological consequences of the Fukushima Daiichi accident", by Frank Hippel, Bulletin of the Atomic Scientists, Vol. 67, 2011.

What's in a name?

Accident: an unfortunate incident that happens unexpectedly and unintentionally, typically resulting in damage or injury

an event that happens by chance or that is without apparent or deliberate cause

Disaster: a sudden accident or a natural catastrophe that causes great damage or loss of life

Source: Oxford Dictionaries http://oxforddictionaries.com/

Thank you for your attention.

http://mavweb.mnsu.edu/tebbep/fukushima