Fukushima Daiichi Nuclear Accident Update

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David Sanderson
Osher Lifelong Learning Institute
Fall 2014
Fukushima - Daiichi

THE REACTORS

THE ACCIDENT

THE CONSEQUENCES

THE LESSONS LEARNED
Nuclear Power in Japan on March 2011

- 54 operating nuclear reactors (49 GWe)
  - 30 BWR
  - 24 PWR
- Others under construction, testing, planning
- Nuclear produces 29% of Japan’s electricity
- Fukushima Daiichi: six boiling water reactors
Fukushima - Daiichi

Reactors 1, 2 and 3 operating

Reactors 4, 5 and 6 shutdown for maintenance, inspection, refueling
Fukushima Daiichi

Nuclear Reactors
• Unit 1: 439 MWe BWR, 1971
• Unit 2: 760 MWe BWR, 1974
• Unit 3: 760 MWe BWR, 1976
• Unit 4: 760 MWe BWR, 1978
• Unit 5: 760 MWe BWR, 1978
• Unit 6: 1067 MWe BWR, 1979

Used Fuel
• 6 pools, one per reactor (34%)
• 1 shared pool (60%)
• Dry cask storage (6%)

Photo from 1978
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Tohoku Earthquake
Tohoku Earthquake

- Japan was hit by a magnitude 9 earthquake on March 11 (2.46pm Japan time), centered offshore of the Sendai region (Tokyo is about 250km southwest).
- A 14 m (46 ft) tsunami followed, as well as significant aftershocks and fires at many industrial facilities.
- Over 10,000 dead, 17,400 missing and a scarcity of potable water, food and electricity over 1000s sq.mi. (Final count = more than 23,000 dead)
- Widespread destruction of electrical, transportation and communications infrastructure.
Tohoku Earthquake
11 March 2011 – 14:46
## Ground Acceleration

<table>
<thead>
<tr>
<th>Nr.</th>
<th>MWe</th>
<th>3.11 Observed (max. gal)</th>
<th>Design (Ss) (max. gal)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N-S</td>
<td>E-W</td>
</tr>
<tr>
<td>1Fuku1</td>
<td>460</td>
<td>460</td>
<td>447</td>
</tr>
<tr>
<td>1Fuku2</td>
<td>784</td>
<td>346</td>
<td>550</td>
</tr>
<tr>
<td>1Fuku3</td>
<td>784</td>
<td>322</td>
<td>507</td>
</tr>
<tr>
<td>1Fuku4</td>
<td>784</td>
<td>281</td>
<td>319</td>
</tr>
<tr>
<td>1Fuku5</td>
<td>784</td>
<td>311</td>
<td>548</td>
</tr>
<tr>
<td>1Fuku6</td>
<td>1100</td>
<td>298</td>
<td>444</td>
</tr>
</tbody>
</table>

**GAL = galileos**

\[
100 \text{ gal} = 0.102 \text{ g's}
\]

**VA Earthquake**

Highest Acceleration:

\[
\approx 120 \text{ gal}
\]
Acceleration Damage
SHUTDOWN / TRIP

- Reactor shuts down
- Cuts off turbine building
- Diesel generators start
- Emergency core cooling systems are supplied
- Plant is in a stable safe state
Tsunami
Tsunami
Tsunami
Tsunami
Tsunami
Tsunami
Tsunami
Tsunami
Tsunami
Tsunami
Tsunami
Plant Design Tsunami Height
- up to 6.5m

Actual Tsunami Height - 14+ m

Flooding:
- Diesel Generators
- Essential Service Water

Building Station Blackout
- Failure of all but one emergency core cooling systems

Accident Progression
Accident Progression
Accident Progression
Steam & water temp:
~ 550 F (~287 C)

No water going in
Steam going out

Relief valve opens
Accident Progression
Accident Progression
Accident Progression
Accident Progression
Accident Progression
Accident Progression
Unit 1 & 3
Accident Progression
Accident Progression
Unit 4
Accident Progression
Spent Fuel Pools
Timeline: First Two Days

**Mar 11**
- 1446: Quake; reactors 1, 2, 3 trip
- 1527: First tsunami wave
- 1546: 14 meter wave
- 1700: Water @ top of U-1 fuel
- 1930: U-1 core exposed

**Mar 12**
- 0415: U-3 fuel rods exposed
- 0650: U-1 core melted
- 1536: U-1 Rx Bldg explosion
- 1900: Sea water injected into U-1 Rx
Timeline: Third and Fourth Day

Mar 13

0242
U-3 injection stops

0700
U-3 water reaches top of fuel

0900
U-3 core damage begins

Mar 14

1101
U-3 reactor building explodes

1315
U-2 injection stops

1800
U-2 water reaches top of fuel

2000
U-2 core damage begins
Challenges

- **No electrical power**
  - No way to run equipment
  - Limited if any instrumentation
  - No lighting
  - Limited offsite communication

- **No heat sink**
  - No way to remove decay heat
  - Water in reactor boils away
  - Fuel damage/melt

- **No site access**
  - Roads to site were damaged
  - No way to deliver portable equipment

- **Personnel issues**
  - Long working hours
  - No sleeping accommodations
  - No communications with families
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THE LESSONS LEARNED
Radiation Release

- CT Scan: 6 - 18 mSv
- Monitoring underway for 2 million residents of Fukushima
  - 40% received less than 1 mSv;
  - <1% received more than 20 mSv
  - Remainder were between 1 and 20 mSv
- Significant doses occurred to some workers in the first few weeks
  - 167 workers received >100 mSv
  - Emergency dose limit was raised to 250 mSv until December 2011, now set at 100 mSv
Recovery

- March 12: Sea Water continued to be used for cooling Reactors
- March 15: Units 1 & 3 Stable
- March 17: Unit 2 Stable
- March 20: Units 5 & 6 in cold shutdown
- March 22: Power restored on site
- March 25: Switch to fresh water for core cooling
Recovery

- May 6: Enter Unit 1 building for the first time
- June 15: Sea Water Filtering system begins operation
- August 10: Circulating cooling water restored for all units
- Sept. 30: Units 1-3 are below boiling
- October 3: Japanese Government to assist with clean up efforts
Recovery

- Dec 19: All Units in cold shutdown
- Dec 26: Cancellation of Nuclear Emergency Situation was declared
Reactor Cores

• Major fuel melt in 3 units, but fuel remains essentially contained
• Unit 2 containment appears to be breached → soluble fission products released with cooling water
• Stable cooling with treated recycled water has been established
• Access gained to all three reactor buildings
• Nitrogen injected to ensure an inert atmosphere
Spent Fuel Pools

• The spent fuel storage pools survived the earthquake, tsunami and hydrogen explosions without significant damage to the fuel or significant radiological release, or threat to public safety.
• The new cooling circuits with external heat exchangers for the four ponds are working well and temperatures are normal.
• Analysis of water has confirmed that most fuel rods are intact.
• Fuel assemblies are now being removed from unit 4 pool.
## Spent Fuel Pools

<table>
<thead>
<tr>
<th>Unit</th>
<th>Removal of fuel from spent fuel pools</th>
<th>Fuel debris retrieval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>FY 2017</td>
<td>FY 2020 to 2022</td>
</tr>
<tr>
<td>Unit 2</td>
<td>FY 2017 to FY 2023</td>
<td>FY 2020 to 2024</td>
</tr>
<tr>
<td>Unit 3</td>
<td>2015</td>
<td>FY 2021 to 2023</td>
</tr>
<tr>
<td>Unit 4</td>
<td>2014</td>
<td>not applicable</td>
</tr>
</tbody>
</table>
Contaminated Water Management

• A large amount of contaminated water has accumulated on site.
• New water treatment plant commissioned in June 2011
• In 2013 a more sophisticated water treatment plant was commissioned.
• Some radioactivity has been released to the sea, but this has mostly been low-level and it has not had any significant impact beyond the immediate plant structures.
• Concentrations outside plant structures have been below regulatory levels since April 2011.
Groundwater Contamination

• Groundwater bypass built to reduce the groundwater level above the reactors by about 1.5 metres, discharging the uncontaminated water into the sea.
• This prevents some of it flowing into the reactor basements and becoming contaminated.
• An impermeable wall is being constructed on the sea-side of the reactors, and inside this, a frozen soil wall will further block water flow into the reactor buildings.
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THE LESSONS LEARNED
Design Basis and beyond

- Design Basis: what is it?
  - Anticipation of events that could happen
  - Installation of equipment to deal with these events
- Fukushima Design Basis included an earthquake and tsunami
  - This tsunami was much larger than original design
- What if the unexpected occurs beyond design basis?
Industry response (US)

- Review (again) all design bases
- Identify possible hazards that could be outside design bases
- Identify critical safety functions
- Make modifications, purchase equipment to
Possible hazards

- Earthquake
- Flooding
- High wind/tornado
- High/low temperature
Critical safety functions

- Decay heat removal
- Electrical power
- Reactor coolant inventory
- Containment integrity
- Support functions
  - Site access
  - Communication
  - Lighting
  - Life support
Modifications

- Emergency electrical hookups
  - Portable generators
- Emergency liquid connections
  - Keep fuel covered
  - Keep fuel cool
  - Portable pumps
  - Alternate sources of water
- A building to store the new equipment
- Plans to use the new equipment
- Plans to get resources from offsite
- Standardization across the industry