Fukushima Daiichi Nuclear Plant
Event Summary and
FPL/DAEC Actions
Fukushima Daiichi Nuclear Station

• Six BWR units at the Fukushima Nuclear Station:
  – Unit 1: 439 MWe BWR, 1971 (unit was in operation prior to event)
  – Unit 2: 760 MWe BWR, 1974 (unit was in operation prior to event)
  – Unit 3: 760 MWe BWR, 1976 (unit was in operation prior to event)
  – Unit 4: 760 MWe BWR, 1978 (unit was in outage prior to event)
  – Unit 5: 760 MWe BWR, 1978 (unit was in outage prior to event)
  – Unit 6: 1067 MWe BWR, 1979 (unit was in outage prior to event)
Fukushima Daiichi Unit 1

- Typical BWR 3 and 4 Reactor Design
- Some similarities to Duane Arnold Energy Center
Fukushima Daiichi Unit 1

Mechanism of Boiling Water Reactor Power Station

Primary Containment Vessel (Dry Well)
It would confine radioactive substances discharged from the reactor facilities if some pipes were broken by accident.

Reactor Pressure Vessel
It is made of 12cm thick steel and contains fuel, control rods, jet pumps, steam-water separator and steam dryer.

Primary Recirculation pump
It circulates water in the reactor pressure vessel and changes reactor power by changing water quantity.

Cleanup Water System
It maintains the purity of the water circulating through the reactor.

Pressure Suppression Pool (Suppression Chamber)
It always contains water. Should pipes in the primary containment vessel ever break, leaked steam would be conducted into the pool, where it would be cooled down and condensed with a large amount of water to suppress any rise in pressure in the primary containment vessel.

Control Rods
They are used to start and stop the reactor and to change reactor power (amount of nuclear fission) by individually inserting and extracting from the bottom of the reactor.
Fukushima Daiichi Unit 1

Secondary containment: Area of explosion at Fukushima Daiichi 1

Primary containment: Remains intact and safe

Boiling Water Reactor Design
Event Initiation

- The Fukushima nuclear facilities were damaged in a magnitude 8.9 earthquake on March 11 (Japan time), centered offshore of the Sendai region, which contains the capital Tokyo.
  - Plant designed for magnitude 8.2 earthquake. An 8.9 magnitude quake is 7 times in greater in magnitude.
- Serious secondary effects followed including a significant tsunami, significant aftershocks and a major fire at a fossil fuel installation.
Initial Response

- Nuclear reactors were shutdown automatically. Within seconds the control rods were inserted into core and nuclear chain reaction stopped.
- Cooling systems were placed in operation to remove the residual heat. The residual heat load is about 3% of the heat load under normal operating conditions.
- Earthquake resulted in the loss of offsite power which is the normal supply to plant.
- Emergency Diesel Generators started and powered station emergency cooling systems.
- One hour later, the station was struck by the tsunami. The tsunami was larger than what the plant was designed for. The tsunami took out all multiple sets of the backup Emergency Diesel generators.
- Reactor operators were able to utilize emergency battery power to provide power for cooling the core for 8 hours.
- Operators followed abnormal operating procedures and emergency operating procedures.
Loss of Makeup

- Offsite power could not be restored and delays occurred obtaining and connecting portable generators.
- After the batteries ran out, residual heat could not be carried away any more.
- Reactor temperatures increased and water levels in the reactor decreased, eventually uncovering and overheating the core.
- Hydrogen was produced from metal-water reactions in the reactor.
- Operators vented the reactor to relieve steam pressure - energy (and hydrogen) was released into the primary containment (drywell) causing primary containment temperatures and pressures to increase.
- Operators took actions to vent the primary containment to control containment pressure and hydrogen levels. Required to protect the primary containment from failure.
- Primary Containment Venting is through a filtered path that travels through duct work in the secondary containment to an elevated release point on the refuel floor (on top of the reactor building).
- A hydrogen detonation subsequently occurred while venting the secondary containment. Occurred shortly after and aftershock at the station. Spark likely ignited hydrogen.
Core Damage Sequence

Core Uncovered

Fuel Overheating

Fuel melting - Core Damaged

Core Damaged but retained in vessel

Core Melt-through

Some portions of core melt into lower RPV head

Containment pressurizes. Leakage possible at drywell head

Releases of hydrogen into secondary containment
Hydrogen Detonation at Unit 1

Reactor Building

Before Explosion

After Explosion

Refuel Floor
Mitigating Actions

- The station was able to deploy portable generators and utilize a portable pump to inject sea water into the reactor and primary containment.
- Station was successful in flooding the primary containment to cool the reactor vessel and debris that may have been released into the primary containment.
- Boric acid was added to the seawater used for injection. Boric acid is “liquid control rod”. The boron captures neutrons and speeds up the cooling down of the core. Boron also reduces the release of iodine by buffering the containment water pH.

Containment Flooding Effects

**Bad**
- Loss of vent capability
- Loss of pressure suppression
- Loss of SRVs
- Loss of vacuum relief
- Loss of electrical equipment
- Radioactivity release

**Good**
- Submerge RPV fuel/debris
- Quench ex-vessel debris
- Cool RPV internals
- Scrub fission products
- Protect containment
Emergency Response

• Equivalent of General Emergency declared to the event at Unit 1.
• Evacuation of public performed within 20 km (13 miles) of plant; approximately 200,000 people evacuated.
• Similar hydrogen detonation subsequently occurred at Unit 3 on Sunday, March 14th (Japan time). Primary containment remained intact at Unit’s 1 and 3 throughout the accident. There was considerable damage to the secondary containment (reactor building).
• Highest recorded radiation level at the Fukushima Daiichi site was 155.7 millirem. Radiation levels were subsequently reduced to 4.4 millirem after the containment was flooded. The NRC’s radiation dose limit for the public is 100 millirem per year.
• Several fatalities occurred at the station along with numerous injured workers.
• Authorities distributed Potassium-iodide tablets to protect the public from potential health effects of radioactive isotopes of iodine that could potentially be released. This is quickly taken up by the body and its presence prevents the take-up of iodine-131 should people be exposed to it.
• Over 300 after shocks have occurred and continue to challenge station response.
FPL/DAEC Response

• The Juno Beach Command Center has been staffed.
• The CNO is in direct contact with INPO, NEI, and the NRC.
• Extensive evaluations are underway to validate design capabilities and vulnerabilities of all FPL units for events such as earthquakes, flooding, and extended Station Blackouts.
• Operators and Emergency Response personnel maintain a high level of readiness to respond to events including severe accidents.
• Procedures are in place to respond to events including abnormal operating procedures, emergency operating procedures, and severe accident management guidelines.
• After 9/11, stations implemented Emergency Management Guidelines designed to optimize response to large scale events such as those experienced at Fukushima.
FPL/DAEC Response

• As part of the 9/11 response, stations took the following additional actions:
  – Procured portable diesel-driven pumps and developed procedures to use the portable pumps to inject water from external sources into the reactor, primary containment, spent fuel pool, hotwell, and condensate storage tanks.
  – Made modifications to the plant to provide connections for using the portable diesel-driven pump.
  – Developed procedures and staged equipment needed to manually open reactor relief valves and containment vent valves under loss of power conditions.

• FPL will continue to work with INPO, NEI and the NRC to access lessons learned and additional actions that can be taken to further enhance our readiness for severe accidents.