Nuclear Safety
Update on Fukushima Dai-ichi Nuclear Accident and IAEA response

Nuclear Installation Safety
Department of Nuclear Safety & Security
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IAEA
International Atomic Energy Agency
<table>
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<tr>
<th>Safety Function</th>
<th>Design Frontline Systems</th>
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<tr>
<td>Control reactivity</td>
<td>• Reactor protection system. Insertion of fuel roads</td>
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<td></td>
<td>• A manually initiated standby liquid control system (SLCS) as back-up</td>
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<td>Primary pressure protection</td>
<td>• Steam relief from the reactor vessel to the torus</td>
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<td>• Automatic depressurization system SRVs</td>
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<td>• Safety- relief valves (SRVs)</td>
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<td>Maintain primary coolant inventory</td>
<td>• Feedwater/condensate injection system from condensate storage tank (CST)</td>
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<td>• Isolation condenser, RCIC (high pressure)</td>
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<td>• High pressure core injection (HPCI)</td>
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<td>• Low pressure injection (part of RHR), Low pressure core spray</td>
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<td>• Essential service water</td>
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<td>• Firewater system (after reactor depressurization)</td>
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<td>Remove fuel decay heat</td>
<td>• Shutdown torus cooling system (STCS)</td>
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<td>• Torus cooling system (TCS)</td>
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<td>• Containment venting</td>
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<td>Containment systems</td>
<td>• Containment and reactor building isolation systems</td>
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<td>• Containment depressurization system</td>
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<td>• Standby gas treatment system (SGTS)</td>
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<td>• Exhausting filtered air from secondary containment</td>
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BWR Mark I Primary Containment Vessel and Torus
BWR Design Features

Fuel channels

RPV upper internal structures

Large lower plenum
BWR Design Features – small primary containment housed in large building

General Electric BWR Mark I

Drywell

Wetwell (Torus)

Reactor Bldg

Turbine Bldg
BWR Design Features

- Reactor Service Floor (Steel Construction)
- Concrete Reactor Building (secondary Containment)
- Reactor Core
- Reactor Pressure Vessel
- Containment (Dry well)
- Containment (Wet Well) / Condensation Chamber
- Vent Pipe systems
- Main Steam
- Main Feedwater
- Spent Fuel Pool
- Air
- N₂
The Emergency Core Cooling Systems are composed of:

1) Residual Heat Removal System
2) Low-Pressure Core Spray (for LOCA)
3) High-Pressure Core Injection (for LOCA)
4) Reactor Core Isolation cooling (UNIT 2,3 [BWR4])
BWR Mark I Containment

- Refueling bay
- Steel containment vessel
- Concrete shell ("drywell")
- Reactor vessel
- Spent fuel pool
- Secondary containment
- Wetwell ("torus")

Mark I Containment
Fukushima Dai-ichi Accident

- Earthquake → loss of off-site electrical power
- Tsunami → loss of on-site electrical power
- Station Blackout
  - Unable to cool the core → fuel damage/melt
  - Unable to cool/vent containment → release of radioactive material to environment
  - Hydrogen from fuel damage → explosions damage reactor buildings
Chronology of Events

- Earthquake
  - Magnitude 9.0
  - Ground acceleration at Units 1, 4 and 6 did not exceed the standard seismic ground motion (updated design basis),
  - Ground acceleration at Units 2, 3 and 5 did exceed the standard seismic ground motion
  - Reactors automatically shutdown
  - All six off-site power lines were lost
  - All 12 of the available plant's emergency diesel generators (EDG) started (1 EDG out of service)
  - ECCS systems started as designed
Chronology of Events

- Tsunami
  - Initial wave greater than 14 meters
  - First wave arrived 46 minutes after earthquake
  - Exceeded the design basis at all units
  - Extent of flooding was extensive, completely surrounding all of the reactor buildings
    - Loss of all nine available EDGs cooled by sea water
    - Loss of all but one of the three EDGs cooled by air
    - Loss of Units 1 and 2 125 V DC batteries
    - Loss of electrical distribution switchgear
    - Loss of ultimate heat sink - pumps and motors located at the intake were totally destroyed
Work conducted in extremely difficult conditions

- Uncovered manholes
- Cracks and depressions in the ground
- Work at night was conducted in the dark
- Many obstacles blocking access to the road
  - Debris from the tsunami
  - Rubble that was produced by the explosions that occurred in Units 1, 3 and 4
- All work was conducted with respirators and protective clothing and mostly in high radiation fields.
Unit 1 – Accident Progression

• Loss of all AC power - all safety and non-safety systems driven by AC power became unavailable
• Batteries were flooded, so no instrumentation and control was available, thereby hampering the ability of the operators to manage the plant conditions
• Lack of DC power for instrumentation required the use of car batteries, so only intermittent readings were available
Unit 1 – Accident Progression (Continued)

- Isolation condenser (IC)
  - Gravity driven natural circulation of coolant from the reactor pressure vessel (RPV) through a heat exchanger immersed into a large tank of water in the reactor building
  - Decay heat removal capacity of about 8 hours
  - Appears to have operated for about 11 minutes before tsunami - manually shutdown because the RPV temperature was dropping rapidly (in accordance with procedure)
  - Manually restarted 3 hrs 15 min later for about 7 minutes
  - Manually restarted again 3 hrs later
  - IC was the only system available to cool the core during this period and it eventually failed
Unit 1 – Accident Progression (Continued)

• Alternate process for injecting water
  • Low discharge pressure fire engine pump through the fire protection and makeup water condensate (MUWC) lines connected to the core spray line
  • Pressure was too high to inject
  • No power to open depressurization valves
  • RPV depressurized to the containment through an unconfirmed pathway
  • Fire engine pump could begin to inject freshwater into the core early on 12 March
• Alternate process for injecting water (cont.)
  • Over the next nine hours, approximately 80 tonnes of water was supplied to the core until the water supply ran out
  • About 3.5 hours after the explosion established a means to inject sea water (borated intermittently)
  • Discontinued on 25 March, once a source of fresh water was secured
  • Injection using fresh water continues
Based on calculations by TEPCO using an assumed estimated injection rate, the top of active fuel (TAF) was reached in Unit 1 about three hours after the plant trip. The core was completely uncovered two hours later. Core damage is calculated to have begun four hours after the trip, leading to the production of hydrogen. A majority of the fuel in the central region of the core was melted at 5.3 hours after the trip. At 14.3 hours after the trip, the core was completely damaged with a central molten pool and at 15 hours after the trip all fuel had slumped to the bottom of the vessel.
Unit 1 – Accident Progression (Continued)

- **Containment Response**
  - As steam was bled from the RPV the containment pressure increased
  - Became necessary to align the valves in order to vent the containment and reduce pressure
  - Venting requires instrument air as well as AC power
  - High radiation levels in the reactor building impeded the work
  - Beginning on the morning of 12 March, the operators attempted to open the valves manually
  - In the afternoon, an engine driven air compressor (typically used for construction work) and an engine-generator to provide AC power to a solenoid valve were used
  - At approximately 14:30 on 12 March, the operators confirmed a decrease in the dry well pressure, providing some indication that venting had been successful
  - Approximately an hour later, the first hydrogen explosion occurred at the site in the Unit 1 reactor building