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

Key Plant Systems (Mark-I)

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

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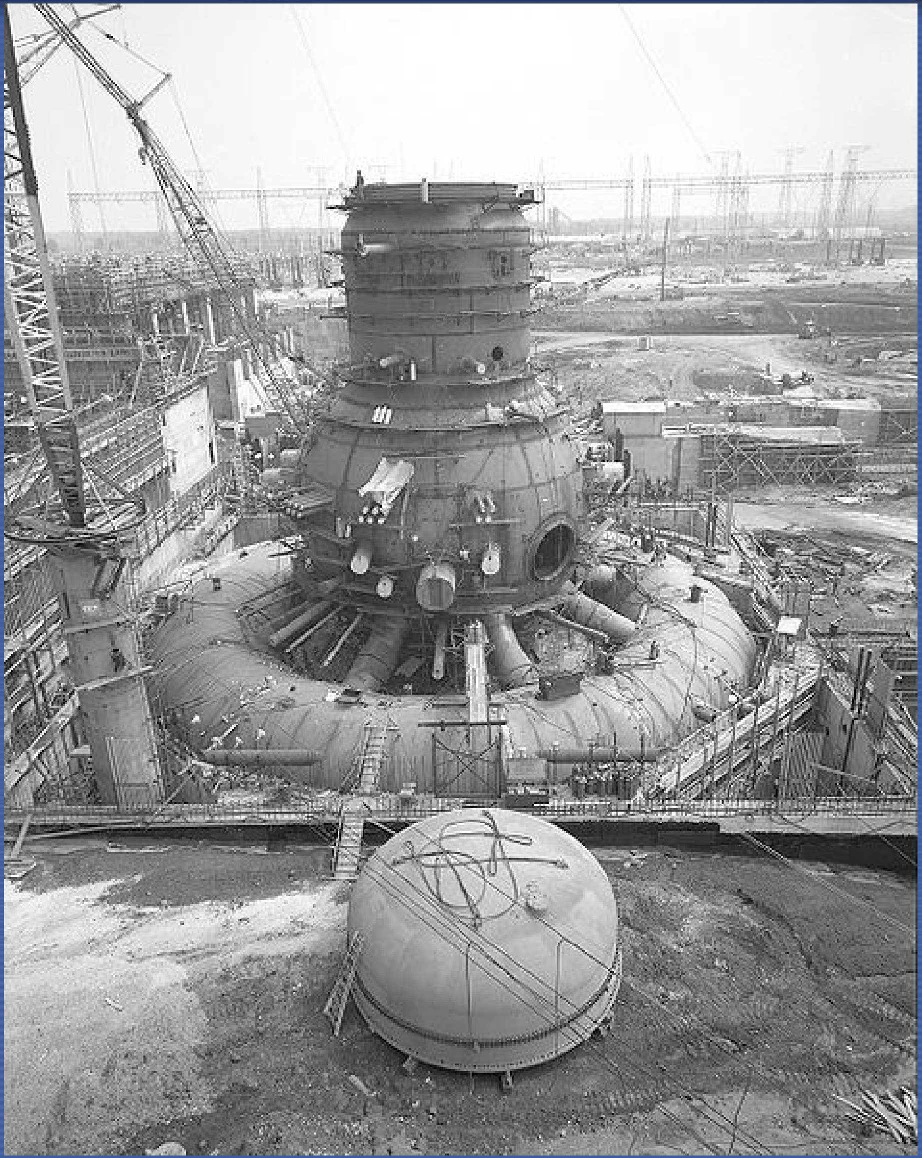
BWR Mark I Primary Containment Vessel and Torus



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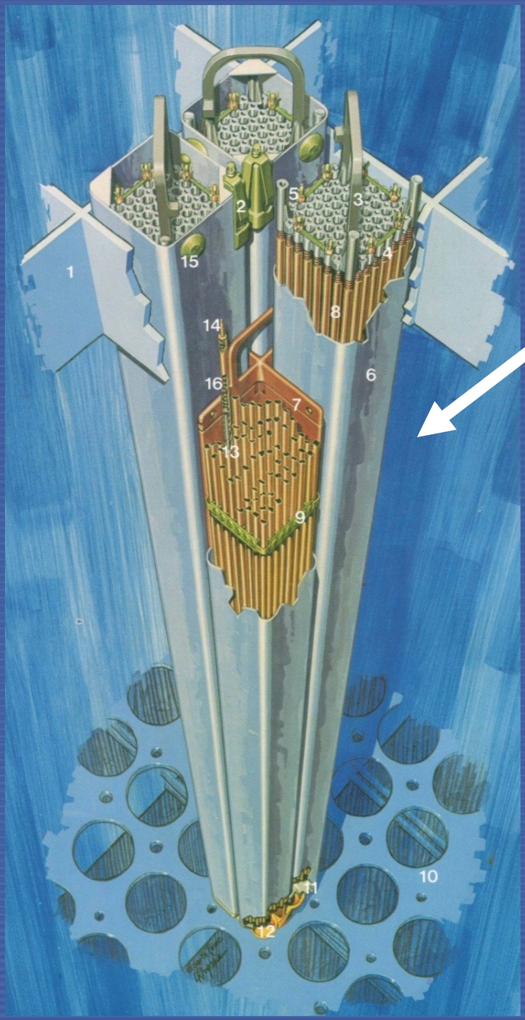
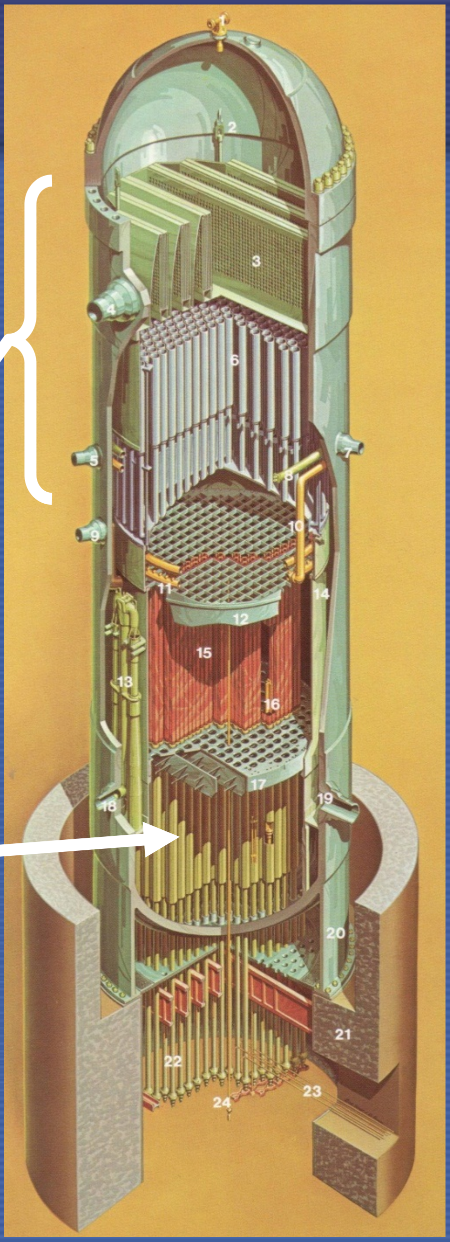
BWR Design Features



Fuel channels

RPV upper internal structures

Large lower plenum



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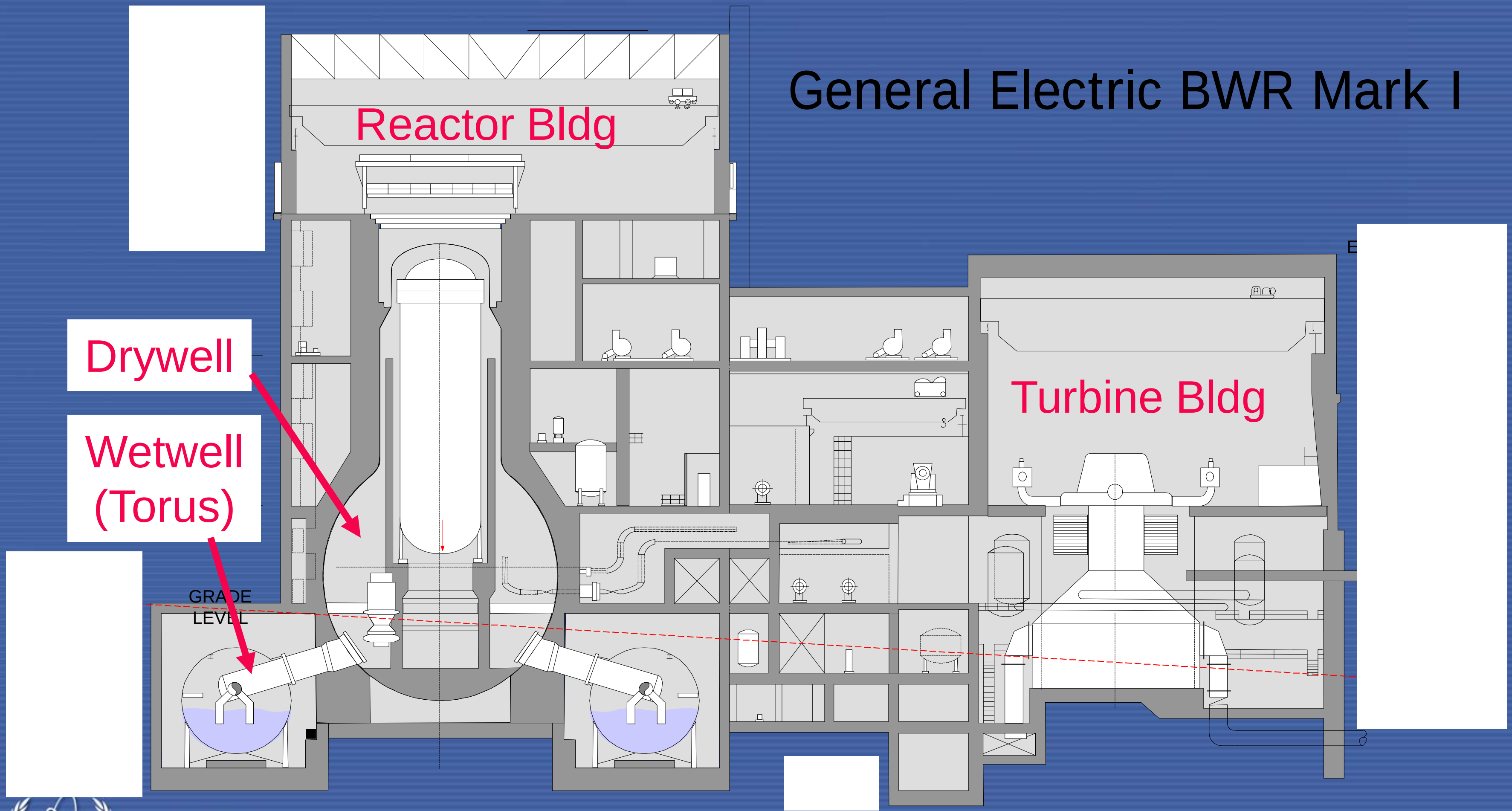
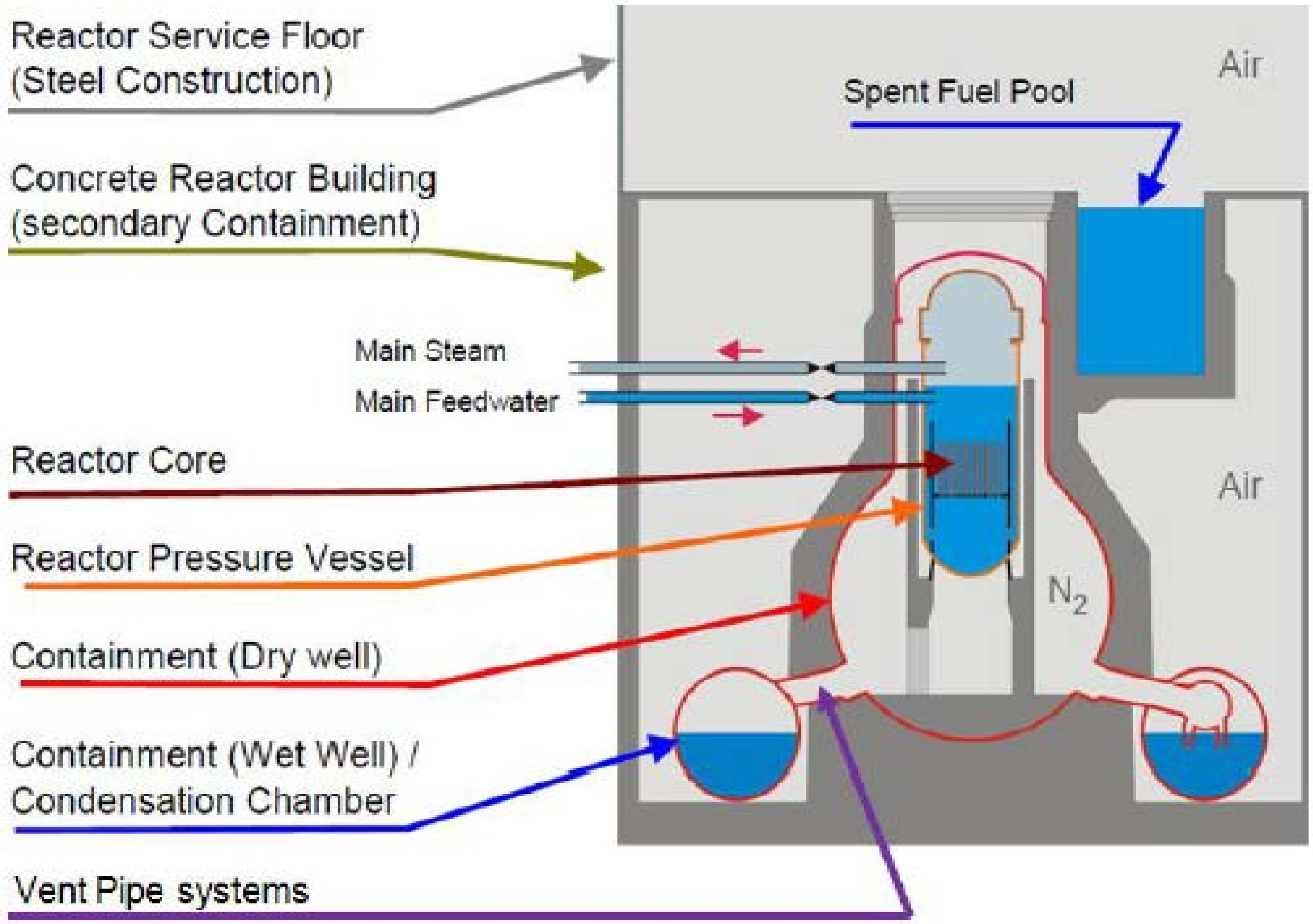
BWR Design Features – small primary containment housed in large building



BWR Design Features



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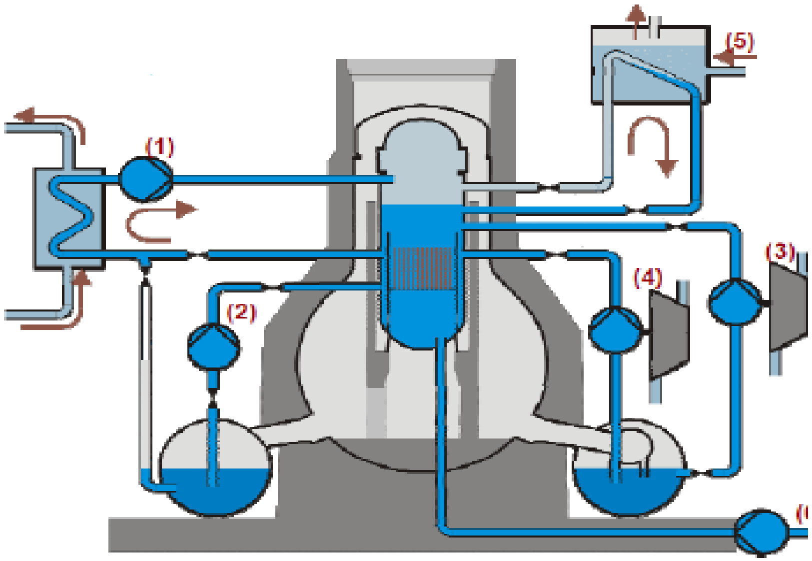
BWR Emergency Core cooling Systems



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])

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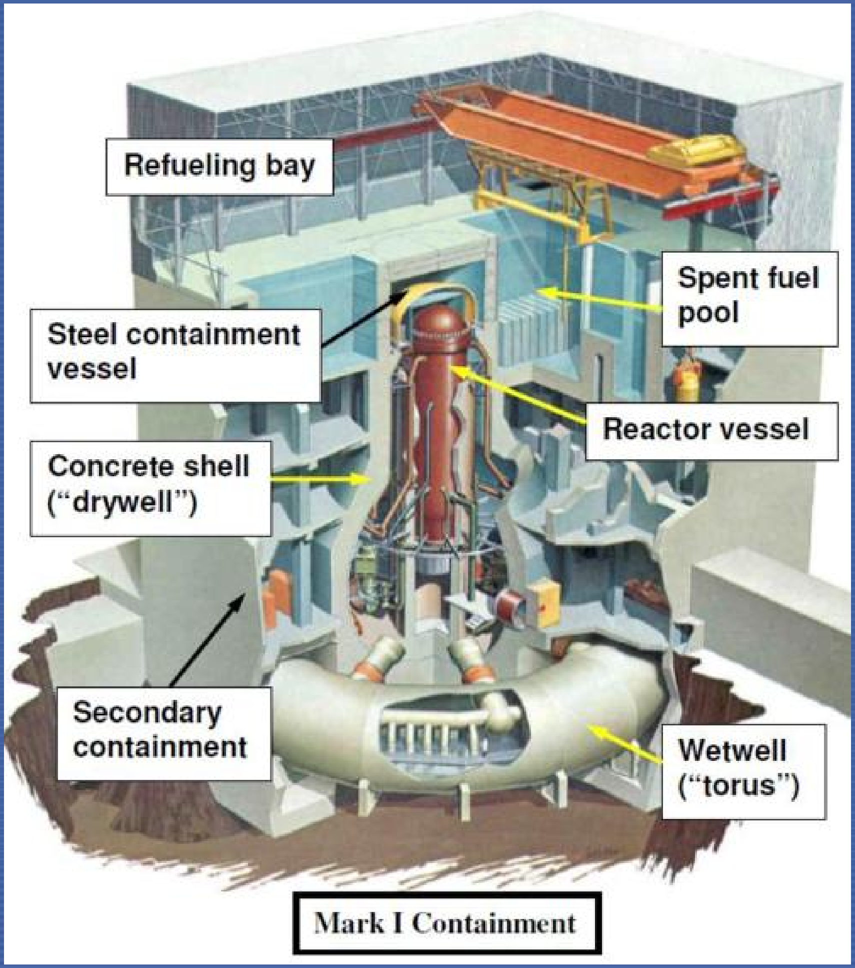
BWR Mark I Containment



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

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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

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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

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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.

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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

Unit 1 – Accident Progression (Continued)

- 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

Unit 1 – Accident Progression (Continued)

- 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

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