Lessons Learned Database
Individual Incident Summary Report

IChemE
Safety & Loss Prevention
Special Interest Group

Incident Title	**Multiple Nuclear Reactor Partial Meltdowns**	
Incident Type	Explosion	
Date	11th March 2011	
Country	Japan	
Location	Fukushima Daiichi	
Fatalities	**Injuries**	**Cost**
2259 (indirectly) – Ref .2	13	US$ 188 bn (2016) – Ref. 3

Incident Description

Credit: Keystone/Zuma/Shutterstock

Following a magnitude 9.0 earthquake on the Richter scale, 3 of 6 boiling water reactors (BWRs) operating at the time automatically shut down, as designed. However, all 6 external electrical power supplies failed due to earthquake damage. Emergency diesel generators started up as designed. However, approximately 41 minutes later, the plant was hit by a 15 m tsunami which damaged the sea cooling water pumps for the main condensers and auxiliary cooling circuits (including the residual heat removal system). It also drowned the diesel generators and inundated the electrical switchgear and battery systems. All 3 reactor cores melted within 3 days. Fortunately, there were no in-core steam explosions, but 13 people were injured by hydrogen explosions which breached their respective nuclear containment buildings, releasing radioactive material to the environment. More than 100,000 people within 20 km of the site had to be evacuated and 2259 (mainly elderly) people died during the evacuation process. This accident was eventually declared a Level 7 ("severe accident") on the International Nuclear Event Scale (INES).

Incident Analysis

Basic cause of the hydrogen explosions and release of radiation was overheating and extreme over-pressure of the reactor cores due to the total loss of offsite (earthquake) and onsite (tsunami) electrical power.

Critical factors included: 1) Coastal location (exposure to tsunami), 2) Magnitude of earthquake (tsunami wave height), 3) Loss of offsite and onsite electrical power (cooling systems disabled), 4) Loss of instrument power (reactor monitoring and control impeded), 5) Delayed injection of alternative water supply by fire crews (reactors under pressure due to core overheating), 6) Hydrogen was generated by fuel rod zirconium cladding reaction with water in the reactor core and/or radiolysis of hot water in the spent fuel ponds.

Root causes included: 1) Inadequate risk assessment (design basis used historical rather than recent seismic and weather data), 2) Failure to promptly implement tsunami countermeasures after maximum expected tsunami flood levels were reassessed in 2002 and found to exceed design basis levels for the plant (Japan believed its nuclear power plants were so safe that an accident of this magnitude was not credible), 3) Inappropriate plant layout (safety-critical electrical equipment located in turbine hall basements), 4) Inadequate operating procedures, 5) Inadequate emergency preparedness, 6) Inadequate crisis management, 7) Inadequate regulatory system (conflict of interest between government, safety regulator and operating company).

Lessons Learned

1) Distribution of potassium iodide to residents near the plant helped limit adverse health effects by preventing their thyroid glands absorbing radiation.
2) Nuclear power plants should be prepared to handle catastrophic natural disasters simultaneously at multiple reactors regardless of the cause.
3) Portable equipment to provide backup power and rapid injection of cooling water into the reactor core(s) and spent fuel pond(s) should be stored on site and designed for easy deployment in any area of the plant.

More Information

1) "The Fukushima Daiichi Accident – Report by the Director General", International Atomic Energy Agency (IAEA), Vienna, 2015: https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1710-ReportByTheDG-Web.pdf.
2) "Fukushima Daiichi Accident", World Nuclear Association, April 2020.
3) "An update from Fukushima, and the challenges that remain there", Tatsujiro Suzuki, Bulletin of the Atomic Scientists, 11th November 2019.

Industry Sector	Process Type	Incident Type
Power Generation	Nuclear	Explosion
Equipment Category	**Equipment Class**	**Equipment Type**
Mechanical	Vessels	Reactor

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