PCTRAN Analysis of Spent Fuel Pool at Fukushima Unit 4

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1. Introduction

The earthquake and tsunami has caused instant loss of offsite power. The scale-9 shock far exceeds plant design limit of scale 7.5 so it also disabled all onsite diesel generators. A complete station blackout (SBO) is thus the initiating event. Fukushima Daiichi Unit 1 is a GE BWR-3 rated 460/1380 MW (electric/thermal). Units 2 to 5 are BWR4 rated at 784/2381 MW. There are two external recirculation pumps. Jet pumps inside the reactor downcomer enhance the core flow for better efficiency. They all have Mark I (steel liner plus concrete drywell and torus-shaped suppression pool) containments. The emergency core cooling systems contain passive Reactor Coolant Isolation Cooling (RSIC) and Core Spray (CS) systems. Their respective turbines are driven by steam extraction following Main Steam Isolation Valves (MSIV) closure. Centrifugal pumps draw water from the condensate storage tank initially. When the tank inventory is exhausted, water source can be switched to the suppression pool for extended period. On the active side, the diesel generator-powered High Pressure Coolant Injection (HPCI) turns on low reactor water level. It extracts water from the condensate or suppression pool as well. When the reactor pressure is lowered, low-pressure coolant injection (LPCI) system provides large flow to reflood the core. Fig. 1 is the PCTRAN mimic during full-power steady state operation. During the March 11 event, the RCIC and CS lines were either destroyed by the earthquake or soon exhausted their water supply. Since no onsite AC power available, HPCI and LPCI were never initiated. When the core water lowered to expose the core, clad damage and hydrogen generation was observed. The operators decided to depressurize the reactor vessel by opening the Safety Relief Valves. Coolant was further boiled off from the reactor to expose more fuels. Sea water was used to cool the core. A mixture of steam, hydrogen and fission gas pressurized the primary containment (i.e. the drywell and suppression pool). Since BWR4's containment is typically inerted below 4% of oxygen content, in principle there is no chance for hydrogen explosion regardless of the hydrogen concentration. However, because the containment pressure might have exceeded its 4-atmosphere design pressure, leakage from the pressure boundary cracks might have occurred. The gas mixture then filled the external Reactor Building. Detonation condition has reached and then explosions occurred. These happened at Units 1, 3 and 4. The Reactor Building roof is an ordinary structure so it was blown off. Later water spray on top of the Reactor Buildings by either helicopters or fire engines had limited effect since water has difficulties to reach the damaged core. All above sequence of events can be simulated by PCTRAN/BWR with quantitative accuracy.

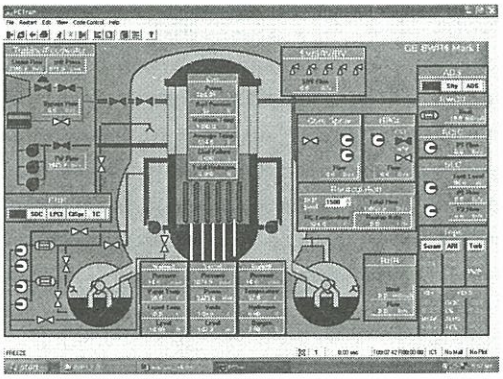

Fig. 1. PCTRAN BWR Mark I Mimic

2. Spent Fuel Pool Accident Simulator

Another significant event is loss of cooling/coolant at Fukushima Unit 4's spent fuel pool that has caused clad oxidation and radiological release. Micro-Simulation has another simulation product "SFP". Until now, spent fuel pool safety was overlooked and an independent hardened cooling system is necessary now. Shown below in Fig. 2 is SFP software's main mimic during normal operation. The pool is filled with freshly unloaded and previous cycles' discharged fuels. Their combined decay heat is removed by the cooling systems.

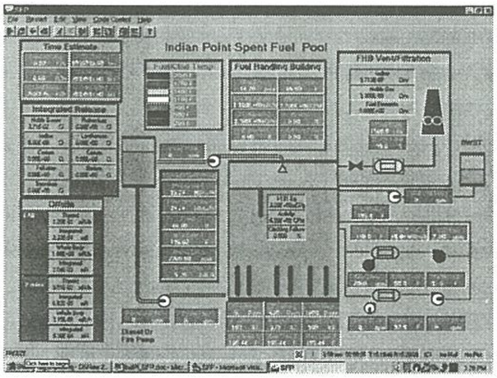

Fig. 2. Spent Fuel Pool Accident Simulator

Upon a loss of cooling or coolant event, the pool may heat up to boiling. Continued boiling exposes top of the fuels. Heatup of the exposed fuel may turn into cladding oxidation and radiological gas release. Scale of a pool's radiological inventory could be even more serious than a plant's, because a pool contains much more assemblies than a core. Since cracks can be developed at bottom of the pool - especially for Mark I and II containment the pool is located high above ground. A supplemental system should be a spray from atop of the pool with its own water storage and lines for outside makeup. Its piping and power supply should be independent and hardened to assure effectiveness in adversity. So, one of the lessons learned from Fukushima spent fuel pool release is: Every nuclear power plant in the world (both PWR and BWR) should add a hardened spray cooling system. Iodine and noble gases release source term is used by another MST program "RadPuff" for radiological dose dispersion projection. Mostly southeast wind prevailed in the next couple days so the plume was projected into the northwest direction.

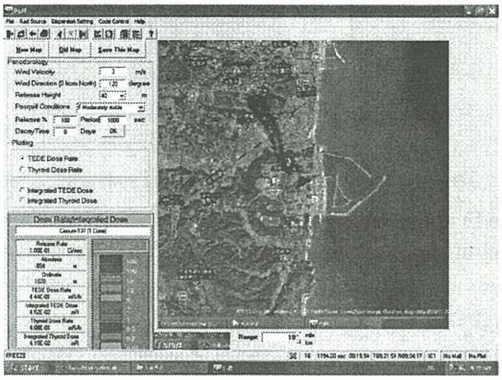

Fig. 3. RadPuff projection of dose dispersion following radiological release

3. Conclusion

The Fukushima event was unprecedented because it exceeded historical maximum for earthquakes. The succeeding tsunami aggregated the damage that knocked out crucial piping of passive emergency cooling systems and disabled all diesel generators. Given the initiating conditions PCTRAN is able to reproduce the plant behavior and radiological consequence. PWR is more resilient than BWR because of its steam generator secondary water inventory and size of containment. This gives larger margin to core damage and containment failure. Further review is still necessary to improve safety level. Spent fuel pool safety has been overlooked. A hardened and independent top spray system is necessary for all nuclear power plants.

4. Reference

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