Accident Analysis of Chinese CPR1000 in Response to Station Blackout

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1. Introduction

Following the accident at the nuclear power plant Fukushima Daiichi in Japan, the "stress tests" has become an important postulated accident analysis to ensure the effects of such events on a nuclear power plant is known and can be mitigated. Stress tests required evaluation of the consequences of loss of safety functions from any initiating event (e.g., earthquake or flooding) causing loss of electrical power, including station blackout (SBO). The SBO scenario involves a loss of offsite power, failure of the redundant emergency diesel generators, failure of alternate current (AC) power restoration and the eventual degradation of the reactor coolant pump (RCP) seals resulting in a long term loss of coolant [1, 2]. Using PCTRAN/CPR1000 [3], this study analyses the station blackout on a Chinese CPR1000 which is the most representative type reactor in terms of number of reactors, operating period, power capacity and geological distance from Korean Peninsula. Both the physical effects of the accidents as well as the releases of radioisotopes are calculated and discussed.

2. Methods and Results

The CPR1000 uses as its base of the M310 model of France. A 1086 MWe capacity, three-loop PWR, the CPR1000 has a design life that could extend beyond 40 years. Other changes to the original M310 design include eliminating a welded joint in the RPV, which shortens production time and eliminates the need to inspect the weld during operation. The CPR1000 reactor core comprises 157 fuel assemblies (active length 12 ft), enriched to 4.5% of U-235. The fuel assembly design is AREVA's 17x17 AFA 3G M5, which can be fabricated in China. The CPR1000 operates on an 18-month fuel cycle.

To simulate a station blackout it is required that the offsite AC supply is unavailable as well as all onsite emergency and non-emergency supplies. Tripping the RCPs and setting all supplies to off achieves this. Auxiliary feedwater is delivered by only one motor driven pump. This can be simulated by manually closing the feedwater supply valves to the steam generators. The simulation is done for 10400 seconds until the reactor vessel empties. Up to this point the data is valid for analysis. In Table I, the specific events are logged as it happened.

Table I: Accident Phenomena

Reset to IC #1
000000.0 sec, RCP #1 Capacity Change: 0%
000000.0 sec, RCP #2 Capacity Change: 0%
000000.0 sec, Offsite AC off:
000000.0 sec, Feed Pump #1 Position Change: 0%
000000.0 sec, Feed Pump #2 Position Change: 0%
000000.0 sec, Condensate Pump #1 Position Change: 0%
000000.0 sec, Emergency AC Bus A off:
000000.0 sec, Emergency AC Bus B off:
000000.0 sec, FWIV #1 Position Change: 0%
000000.0 sec, FWIV #3 Position Change: 0%
000000.0 sec, FWIV #2 Position Change: 0%
000000.0 sec, FWIV #4 Position Change: 0%
000000.5 sec, RCP-A trip
000000.5 sec, RCP-B trip
000000.5 sec, All MFW Pumps trip
000000.5 sec, MDAFW Pump #1 Position Change: 100%
000000.5 sec, MDAFW Pump #2 Position Change: 100%
000000.5 sec, TDAFW Pump Position Change: 100%
000000.5 sec, MDAFW Pump #1 Position Change: 0%
000000.5 sec, MDAFW Pump #2 Position Change: 0%
000002.5 sec, Scram Low RC Flow 87.0 %
000003.0 sec, Reactor Scram
000010.5 sec, D/G A Starts 10.0 Sec Delay
001032.5 sec, HPSI start low RX Press 118.1 bar
001032.5 sec, Containment Vent Valve #1 Position Change: 0%
006516.5 sec, RCDT ruptured
006702.5 sec, Containment Spray Starts 1.3 bar
7883.5 sec, Core Uncovered

With all active emergency systems deactivated, the plant SCRAMs at 3 seconds. The heat production from the fission chain is stopped and the reactor starts cooling down and depressurizing. At 2600 seconds departure from nucleate boiling occurs and the coolant is unable to cool the core. This results in increased pressure and coolant temperature. The coolant pressures and temperatures are depicted in Fig. 1 and Fig. 2.

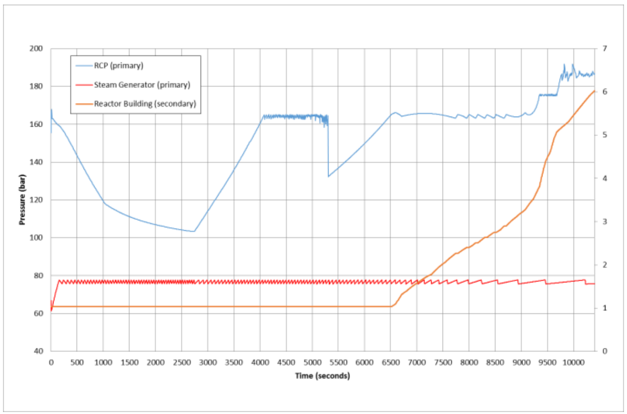

Fig. 1. Power plant pressures

From the initiation of the event the Steam Generators absorb some of the heat and the secondary pressure increases. At 75 bars the SG relief valves open and close continually to maintain the secondary loop pressure boundary intact. With the coolant heating up and expanding from 2600 seconds the primary pressure increases gradually to 162 bars when the safety valves open and close continually to maintain the primary loop pressure boundary intact, until the pressurizer is filled at around 5400 seconds. Once the pressurizer becomes solid, the steam bubble disappears and the pressure drops to under 140 bars before it starts rising again. At 6516 seconds the reactor coolant drain tank (RCDT) Ruptures and starts a leak into the containment building. Fig. 1 depicts the rise in containment pressure from this event. At this point coolant is lost into the containment and at 7883.5 seconds the core is uncovered. Once the core is uncovered the fuel temperature starts to rise as well as the coolant temperatures throughout the accident transient as depicted in Fig. 2.

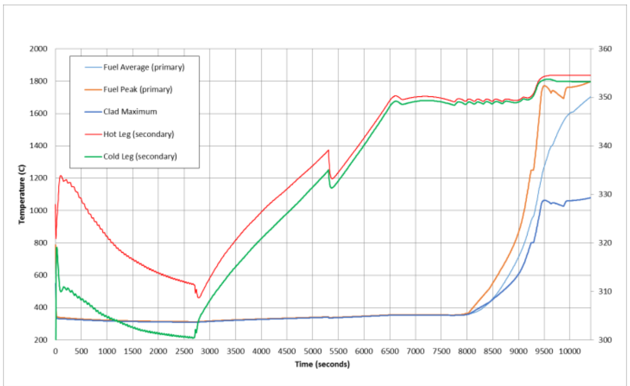

Fig. 2. Reactor system temperatures

In Fig. 3 below, the radioactivity released from radionuclides, noble gas isotopes and decay products into the containment building are depicted during the accident sequence. The calculation results in time depict the accumulated activity from the particular isotope at that in particular point in time. In particular, these releases are categorized as early releases once the break occurs, and releases that occur once fuel damage occurs.

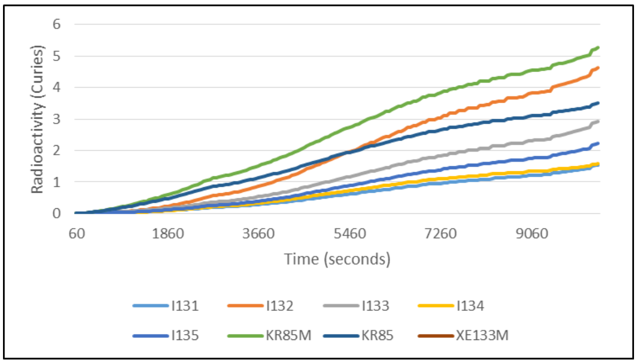

Fig. 3. Radiological releases during a station blackout

3. Conclusions

Station blackout simulation was conducted in this study. The resulting effects seen are consistent with other stress test station blackout tests used utilizing licensed simulation codes [1, 2]. An exact comparison is however not possible as the plants on which the simulations was done vary greatly and the limitations of availability to Chinese FSAR.

PCTRAN/CPR1000 is an extremely useful simulation package that provides engineers and scientists very accurate feedback to how a nuclear power plant would react as a whole under various plant conditions. It is able to do this extremely fast as well. As a training tool PCTRAN/CPR1000 provides hands-on experience with many of the primary plant operations and develops an intuitive understanding of the plant. This source-term estimation simulator as a part of radiological consequence assessment and prognosis system can be also used as technical support tool for the decision-making activities and strategy planning in Korea in case of nuclear accidents occurring in the neighboring country of China.

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