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Inherent Characteristics of Belated Core Damage Progression During an SBO at the SMART plant

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1. Introduction

Along with the SMART (System-integrated Modular Advanced ReacTor) design activity at KAERI [1], severe accident analyses are being performed with the MIDAS/SMR severe accident computer code [2]. In addition, inputs for the various severe accident scenarios are being prepared for the accident simulation and for the PSA activities.

Though the design for the SMART plant is not fixed yet, it is needed to get the idea how the plant responds to the severe accidents. Two major factors can be considered to affect the accident progression. One is the abundant water inventory in the reactor vessel and the other is the integral type reactor configuration which contains the core, pressurizer, reactor coolant pumps and steam generator cassettes inside the vessel together. In this paper, these two factors are examined in terms of the core damage progression.

2. Belated core degradation during an SBO scenario

2.1 Abundant water inventory and the formation of natural steam flow path inside the vessel

The SMART plant has its initial water inventory of about 180 tons in the reactor vessel. Comparing the water inventory per core thermal power between SMART and OPR1000, SMART has roughly 7 times larger water mass. This sufficient water inventory slows core uncovery and fuel heatup during the severe accident conditions.

During the normal operation, the coolant mainly flows from the core to the reactor coolant pumps, to the steam generator cassettes, to the flow mixing header assembly (FMHA), to the lower head, and finally back to the core. From the internal configuration of the SMART reactor, the same path may be open to the steam following the complete core uncovery. Then the steam coming out of the core flows back into the core through the steam generator cassettes and cools down the core, delaying the fuel heatup process.

2.2 Plant nodalization and SBO scenario assumptions

Figure 1 shows the nodalization for the SMART plant. The characteristics of the integral reactor were considered in defining the control volumes and junctions in the reactor vessel. The bypass core channels were defined at present for the flow between the core shroud and the baffle. Also the horizontal flow paths were defined to consider holes at the flow skirt in the lower plenum.

Though SMART has engineered safety features (ESFs) like an safety injection system (SIS), a passive heat residual removal system (PRHRS), and a shutdown cooling system, the SBO scenario considered here assumes no additional water supply into the core from these ESFs. Hence the response of the SMART plant to the most severe conditions can be seen from this scenario.

2.3 Analysis of core damage progression

For the analysis of the core damage progression, the MIDAS/SMR computer code was used, which adopts the heat transfer correlations for the helical steam generator geometry from TASS/SMR-S [3].

The water level changes in the vessel are shown in Figure 2. As shown, the core starts to uncover around 39,000 seconds (10.8 hrs) and the active core gets completely uncovered around 58,900 seconds (16.4 hrs). When the cavity flooding system fails, the reactor vessel fails around 140,000 seconds (38.9 hrs) due to creep rupture. The typical vessel failure time in PWRs, however, is around 2-3 hours [4]

Figures 3 and 4, respectively, show the fuel temperatures and the zircaloy masses in the central core ring. The fuel temperature reaches over 2000K near 54,500 seconds (15 hrs) and suddenly decreases below 1000 K, followed by slow temperature increase until the second temperature peak comes. The behavior of the cladding mass in two top-most nodes (115 & 114), showing about 30% and 70% of the initial mass left in their locations, indicates the incomplete oxidation of zircaloy in these fuel rods. This is understood by the newly supplied steam flow coming from the FMHA into the core. Figure 5 shows the steam mass flow rates between the core and the lower plenum. Steam starts to flow near 49,000 seconds and mainly from 54,200 seconds after the steam flow path is formed between FMHA and the core through the lower plenum, which cools down the fuel due to its high velocity in the core.

3. Conclusions

For the SBO sequence without additional water supply into the core, the core gets completely uncovered after 16 hours and the vessel fails near 39 hours when a cavity flooding system is not working.

Following the complete core uncovery, a steam flow path is formed through the flow skirt in the lower plenum and the clogged steam in the steam generator cassettes starts to circulate into the core, removing heat from the core and delaying the core oxidation process. This steam path is found to be unique to the SMART plant. Therefore the core damage progression in SMART is expected to be slower than in typical PWRs due to the abundant water inventory in the reactor vessel as well as the steam supply into the core following core uncovery, though the current inputs and nodalization scheme need to be refined.

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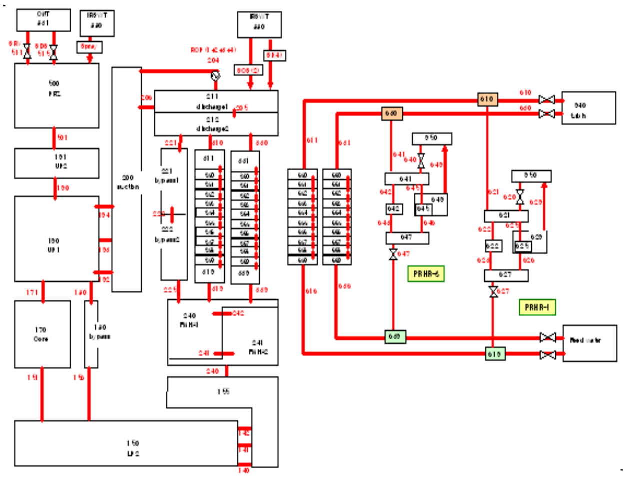

Figure 1 SMART nodalization for an SBO analysis

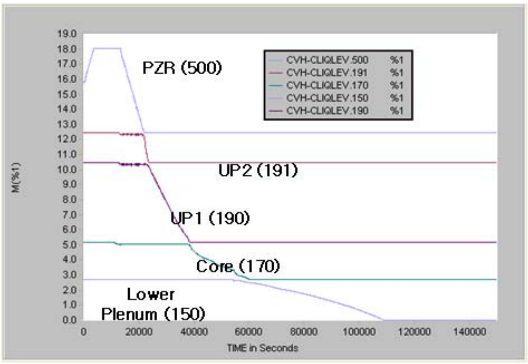

Figure 2 Water level changes in the reactor vessel

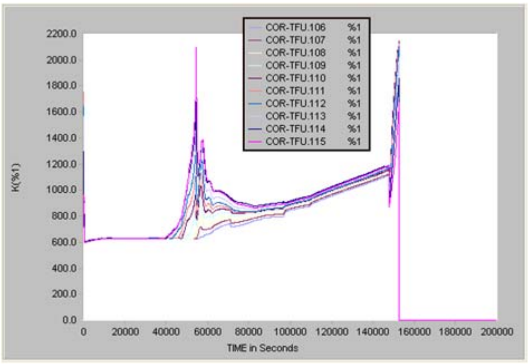

Figure 3 Central ring fuel temperatures behavior

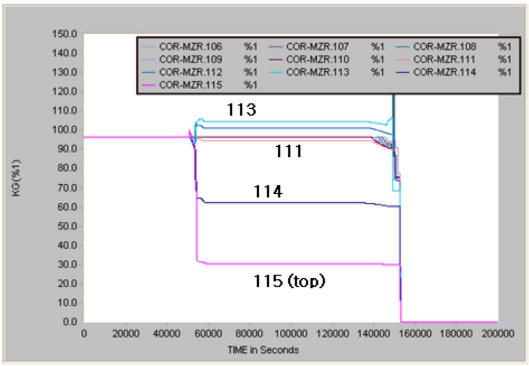

Figure 4 Zr mass distribution in the central ring

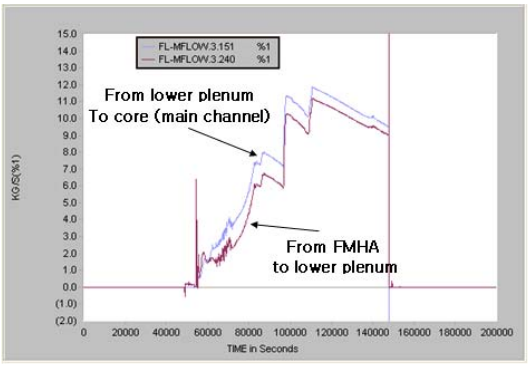

Figure 5 Steam flow rates in the lower vessel