Performance Experiments on the In-Vessel Core Catcher during Severe Accidents

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1. Introduction

A US-Korean International Nuclear Energy Research Initiative (INERI) project has been initiated by the Idaho National Engineering and Environmental Laboratory (INEEL), Seoul National University (SNU), Pennsylvania State University (PSU), and the Korean Atomic Energy Research Institute (KAERI) to determine if IVR is feasible for high power reactors up to 1500 MWe by investigating the performance of enhanced ERVC and in-vessel core catcher[1]. This program is initially focusing on the Korean Advanced Power Reactor 1400 MWe (APR1400) design. As for the enhancement of the coolability through the ERVC, boiling tests are conducted by using appropriate coating material on the vessel outer surface to promote downward facing boiling and selecting an improved vessel/insulation design to facilitate water flow and steam venting through the insulation in this program[2]. Another approach for successful IVR are investigated by applying the in-vessel core catcher to provide an "engineered gap" between the relocated core materials and the water-filled reactor vessel and a preliminary design for an in-vessel core catcher was developed during the first year of this program[3].

Feasibility experiments using the LAVA facility[4], named LAVA-GAP experiments, are in progress to investigate the core catcher performance based on the conceptual design of the in-vessel core catcher proposed in this INERI project. The experiments were performed using 60kg of Al_2O_3 thermite melt as a core material simulant with a 1/8 linear scale mock-up of the reactor vessel lower plenum. The hemispherical in-vessel core catcher was installed inside the lower head vessel maintaining a uniform gap of 10mm from the inner surface of the lower head vessel. Two types of the core catchers were used in these experiments. The first one was a single layered in-vessel core catcher without internal coating and the second one was a two layered in-vessel core catcher with an internal coating of 0.5mm-thick ZrO_2 via the plasma spraying process.

2. Experimental Methods and Results

LAVA-GAP-2 and LAVA-GAP-3 tests, which were conducted to investigate the performance of the in-vessel core catcher, focused on the effects of an internal coating. Except for the existence of the coating on the in-vessel core catcher, the other experimental conditions were the same in both the tests.

2.1 Descriptions of the LAVA-GAP Experiments

The LAVA-GAP experiments were conducted using 60kg of Al_2O_3 thermite melt as a corium simulant with a 1/8 linear scale mock-up of the reactor vessel lower plenum. The lower head vessel was made of carbon steel with an inner diameter of 500mm and a thickness of 25mm. After being generated in the melt crucible, the thermite melt was first delivered to the melt separator and then poured into the lower head vessel through the melt delivery nozzle with an inner diameter of 8mm. A hemispherical core catcher, made of carbon steel, was installed inside the lower head vessel maintaining a uniform gap of 10mm from the inner surface of the lower head vessel. The inner diameter and thickness of the in-vessel core catcher were 464mm and 8mm, respectively. Figure 1 is a schematic diagram of the LAVA-GAP experiments.

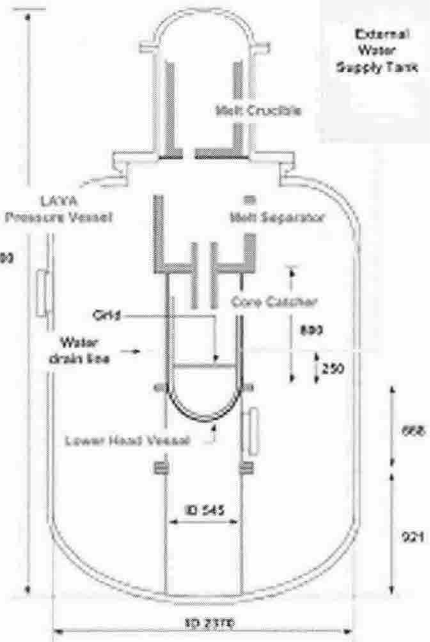
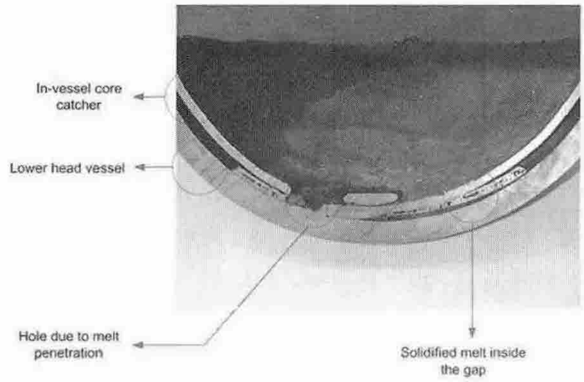


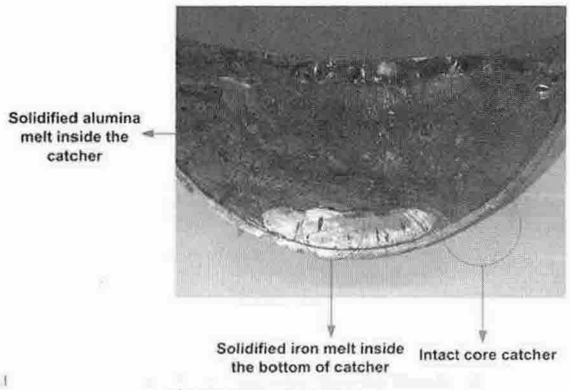
Figure 1. Schematic diagram of the LAVA-GAP experiments

2.2 Experimental Results

The in-vessel core catcher failed and stuck to the lower head vessel in the LAVA-GAP-2 test. To observe the failure configurations of the in-vessel core catcher, the solidified melt inside the core catcher was removed with force. Contrary to the LAVA-GAP-2 test, the in-vessel core catcher was intact in the LAVA-GAP-3 test. By comparing the experimental results of the two tests, the coating on the inner surface of the core catcher played a key role in maintaining the integrity of the core catcher in the LAVA-GAP-2 and the LAVA-GAP-3 tests. In the LAVA-GAP-2 test performed using the uncoated in-vessel core catcher, the core catcher failed; and the lower head vessel got into direct contact with the high temperature melt. In the LAVA-GAP-3 test, however, the lower head vessel did not have any thermal attack due to the intact in-vessel core catcher. Figure 2 presents a cross-sectional view of the core catcher after cutting the half section in the LAVA-GAP-2 test and the LAVA-GAP-3 test, respectively.



(a) LAVA-GAP-2 test



(b) LAVA-GAP-3 test

Figure 2. Cross-sectional view of the test section

Detailed photographs were taken using an optical microscope with a 10 to 200X magnification to precisely investigate the structures of the test specimen and to postulate the thermal histories of the base carbon steel. SEM (Scanning Electron Microscopy) analyses with EDX (Energy Dispersive X-ray) were performed to check on the chemical properties and oxidation of the test specimens. The test specimens were cut out of the solidified iron melt and the core catcher at the bottom.

According to the metallurgical inspections for the LAVA-GAP-3 test specimen, the base carbon steel had experienced severe thermal attack to the extent that the microstructures were changed and re-crystallization occurred. The carbon steel showed stable and pure chemical compositions without any oxidation and interaction with the coating layer. In terms of material performance, these metallurgical inspection results suggest that the ZrO_2 coating has a quite good performance.

3. Conclusion

The LAVA-GAP experiments were performed to investigate the performance of the in-vessel core catcher by relocated molten material in severe accident. Two types of in-vessel core catchers were used in this study. The first one is a single layered in-vessel core catcher without internal coating, and the other one is a two layered in-vessel core catcher with an internal coating of 0.5mm-thick ZrO_2 via plasma spraying process. Two tests, named the LAVA-GAP-2 test and the LAVA-GAP-3 test, were performed using an alumina melt as a core material simulant. In this study, the main focus was placed on the effects of the internal coating on the integrity of the in-vessel core catcher. The internal coating on the in-vessel core catcher played a key role in improving the integrity of the core catcher. In the LAVA-GAP-2 test, which was performed using the uncoated in-vessel core catcher, melt penetrated the core catcher and the core catcher was stuck to the inner surface of the vessel. On the other hand, in the LAVA-GAP-3 test, which was performed using the coated in-vessel core catcher, the in-vessel core catcher was intact and the lower head vessel experienced little thermal attack. From the current LAVA-GAP experimental results it was found that the internally coated in-vessel core catcher has better thermal performance compared with the uncoated in-vessel core catcher.

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