Analysis of the Flow Characteristics of Debris in the Nuclear Power Plant and Development of Debris Transport Visualization Test Facility

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1. Introduction

During the operation of the nuclear power plants, core cooling is performed using the emergency core cooling system (ECCS) in accordance with the plant specific emergency procedures in the event of design basis accidents such as main steam line break (MSLB) and loss of coolant accident (LOCA). Debris would be generated by high pressure jet from the initial accident are transferred to the containment recirculation sump located on the floor through the containment spray system (CSS) until the time of switching to the long-term core cooling mode by using the emergency core cooling system. The water is used as an inhaler of the pump of the ECCS, and small debris smaller than the mesh size of the filter would be passed through the sump and transferred to the core through the piping of the emergency core cooling system. If the coolant flow for core cooling is obstructed and the accumulation of debris is excessive, the residual heat removal function of the core may be reduced and the core cooling performance may not be maintained. In order to solve safety issues including these assumptions, the company is carrying out design changes such as improving insulation materials (fiber type debris) that cause problems or replacing chemicals that can form deposits.

In this study, the amount of debris into the core and the path of movement are experimentally identified with the amount of debris accumulated in order to come up with a fundamental solution to the safety issue by establishing a debris transport visualization test facility.

2. Test Condition and Test Facility

2.1 Test Condition

The purpose of the study is to present the margin of debris to the plants by examining and interpreting the characteristics of the debris (fiber) behavior in the reactor and the amount of debris that are accumulated in the reactor bottom (lower plenum) in the case of postulated accidents. As stated above, the test conditions have been decided with the amount of debris that are generated from the plants, the type, the characteristics, and a number of hydrodynamic and geometric conditions to present the margin of debris for each plant. The debris that may affect heat removal in the core include fibrous , particle, chemical, latent debris, however only fibrous debris have been used for the tests. Because the fibrous debris are dominant factor for flow resistance. The fiber used in test are NUKON^{TM}, the same product as the thermal insulation used in nuclear power plants. The size of the fibrous debris is aboutand 1 um size filter have been used to collect recirculated fibrous debris. The experimental temperatures are at room temperature, and the fluid used water without adding any additional material. The test matrix is shown in Table 1. In the case of flow conditions, the recirculation flow rate was set by natural circulation and the flow rate was adjusted by adjusting the level of the Mixing tank.

Table 1. Test Matrix

No.	Test ID	Flow Rate (Water Level)	Debris (Quantity)	Temp.	Remark
1	DTV-A01	150 LPM (Mixing tank 1,000L)	3 kg	RT (Room Temp.)	-
2	DTV-A02	300 LPM (Mixing tank 1,500L)	3 kg	RT (Room Temp.)	-
3	DTV-A03	300 LPM (Mixing tank 1,500L)	3 kg	RT (Room Temp.)	Flow skirt Bottom Plate

2.2 Test Facility

The facility has been established to derive the results of the flow characteristics and the amount of debris accumulation at lower plenum that are generated after the accident of pipe break at the nuclear power plants. The debris transport visualization test facility is divided into three parts according to the purpose of operation:
The first test facility to be introduced is the Debris Transport and Accumulation Model Test Part, including the simulated reactor vessel, which is considered to be the most important of the configured test facility. It is a Debris Transport and Accumulation Model Test Part with simulated reactor containers, which can be considered the most important part of the test facility. It is to check the characteristics of the debris injected through the Debris Injection and Coolant System Part, which is composed together, after being moved to the simulated reactor vessel by height difference. To verify

these characteristics, the simulated reactor vessel was made of acrylic. In addition, the flow characteristics of debris have been evaluated by simulating substructures such as Core Stop, Flow skirt, Instrument Nozzle Support Plate, Bottom Plate, and etc., which can affect the flow of debris at the bottom of the simulated reactor vessel.

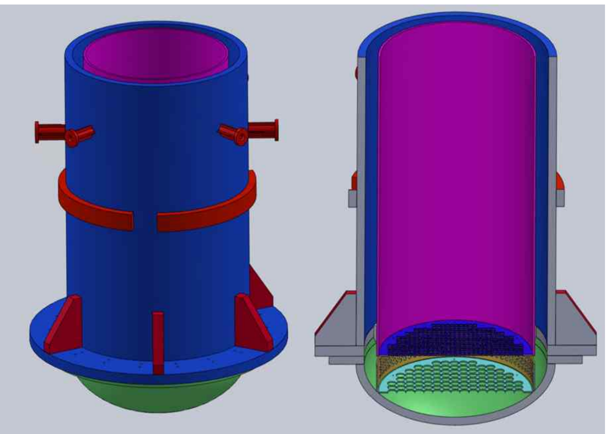

Figure 1. Debris Transport and Accumulation Model Test Part

The second test facility that are modified is the Debris Injection and Coolant System Part as shown in the figure. After the pipe break accident, the debris mixing tank and debris flow piping have been constructed by applying the lowest/maximum flooding level at the nuclear power plant to simulate the scenario of core cooling by natural circulation from a conservative perspective, excluding the injection method using the pump in the long-term core cooling mode. In particular, debris flow piping is designed to simulate both hot-leg break and cold-leg break scenarios, and is designed in 3 inches, 2 inches and 4 inches, consisting of hot-leg piping line, cold-leg piping line, and boil-off piping line, as shown in Figure 2.

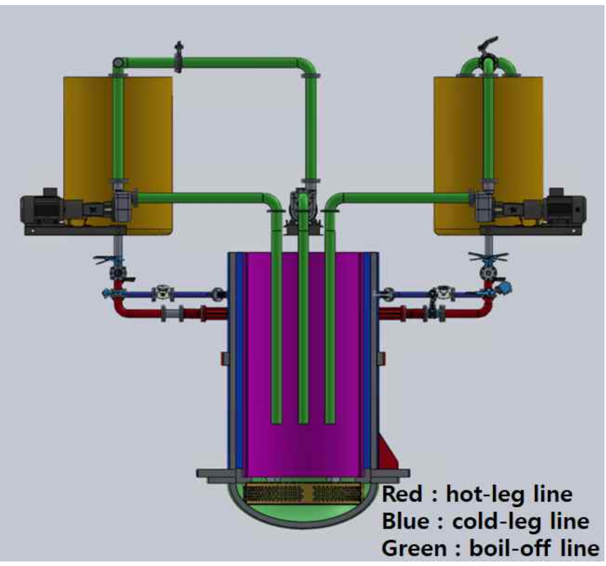

Figure 2. Debris Injection and Coolant System Part

The third Auxiliary Instrument System Part of the test facility is part of the auxiliary facility of the test facility cycle. It consists of a measuring device, such as a flowmeter, thermocouple, and a pressure gauge installed on a pipe or tank, and a main control system responsible for controlling the overall test facility using Program Logic Controller (PLC).

3. Test Result

In the debris transport visualization test, cooling water used for core cooling including ECC water during the long-term core cooling period after the accident of the nuclear power plants is leaked to the containment building through the fracture area. In addition, the flow characteristics of the incoming debris inside the reactor and how many debris are moved and accumulated into the core area through the downstream and internal structures of the reactor were evaluated by simulating the scenario of debris flowing back into the core after flood-up. The main results of the test were evaluated as the amount of debris collected by recirculating compared to the fibrous debris injected as shown in the following table 2. The flow characteristics of the debris injected are derived as shown in figure 4.

Table. 2. Test Result – Collected debris

	Weight before test (g)	Weight after test (g)	Collected debris (g)	Percent (%)
DTV-A01	777.621	2,450.321	1,672.700	55.76
DTV-A02	813.016	1,468.174	655.158	21.84
DTV-A03	819.833	1,060.208	240.475	8.01

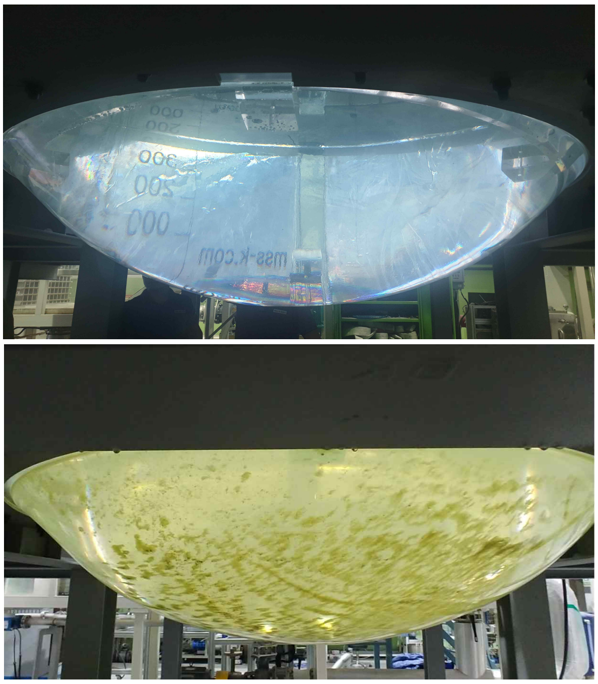

Figure 3. DTV-A01 Test Result - Lower Hemisphere Area of the Simulated Reactor Vessel

The DTV-A01 test result shows that 55.76% of the debris pass through the core area against the amount of debris injected. In addition, the DTV-A02 test result, which changed the flow condition to the plant condition 21.84% of debris passes through the core. The result of the DTV-A03 with the internal structure, which are Flow skirt and Bottom Plate have been evaluated 8.01% of debris passes through the core. In the case of DTV-A01, it has been confirmed that more than half of the debris injected were flooded-up in the reactor container and moved to the mixing tank through the boiler-off line and collected in the filter. The following figure 3 shows a result picture of the substructure in DTV-A01. In the case of such internal structures installed, it is possible to see that most of the fibrous debris has been deposited in the bottom floor by the internal structures. Compared with DTV-A01, it can be confirmed that the large amount of debris that have been clearly deposited.

Figure 4. DTV-A03 Test Result - Lower Hemisphere Area of the Simulated Reactor Vessel

4. Conclusion

The fiber debris injected into the mixing tank are injected into the simulated reactor container through pipes and downcomer. It also showed the flow characteristics of slowly descending to the bottom floor according to the density of fibrous debris by the filled fluid in the simulated reactor container. In addition, when the internal structures have been installed it was found that most of the fibrous debris has been accumulated in the bottom floor by the internal structure. All of the tests carried out were collected with a 1um filter to collect recirculated fibrous debris, and the amount of collected debris has been evaluated after drying the filter after finishing the test. These test results show that only about 8% of debris reach the core when the internal structure is installed, and most debris are deposited by the internal structure. Based on this, it is possible to secure information on the transport of debris into the core during plant accident and to provide design margins for new nuclear power plants. Also it can provide safety margins to solve the safety issues for the amount of debris entering the core after the plant accident.

ACKNOWLEDGMENTS

This research was supported by Development of Debris Transport Visualization in Reactor Vessel Test Facility for Nuclear Power Plants Safety through the National Research Foundation of Korea(NRF) funded by the Ministry of Science and Information and Communications Technology(MSIT).
(2018M2A8A1084229)

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