

Safety Analyses on Loss of Class IV power for the HANARO fuel test loop

S. K. Park, J. M. Lee, B. S. Sim, D. Y. Chi, S. H. Ahn

Korea Atomic Energy Research Institute, P.O.B. 105, Yuseong-ku, Daejeon Korea 305-600

skpark@kaeri.re.kr

1. Introduction

A fuel test loop (FTL) for irradiation tests is under development at the HANARO. The construction of the FTL had been completed at the beginning of last year and pre-service tests have been carried out. The safety of the FTL including the PWR test fuels which will be installed at the end of this year should be verified for design basis accidents and anticipated operational occurrences (AOOs).

This paper deals with the thermal-hydraulic transient analyses and the prediction for a departure from a nucleate boiling ratio (DNBR) during a loss of class IV power for the HANARO fuel test loop, which is one of the AOOs.

2. Analysis Methods

2.1 Design Features of the Fuel Test Loop

The FTL consists of an in-pile test section (IPS) and an out-pile system (OPS). The IPS is located at the IR1 hole of the HANARO core and the test fuels are installed in the IPS. The OPS is categorized into the main cooling water system (MCWS), the emergency cooling water system (ECWS), and so on. The MCWS controls the pressure, temperature, flow rate and chemical properties of the main cooling water during a normal operation. The ECWS supplies emergency cooling water to the IPS in an emergency.

The safety control system of the FTL is classified into the HANARO protection system and the FTL protection system. The HANARO protection system provides a fast scram from the high flow, low flow, high pressure, low pressure and high temperature set-points of the main cooling water. The FTL protection system isolates the IPS from the OPS and injects the emergency cooling water to the IPS from the high flow, low-low flow, low-low pressure, and high-high temperature set-points of the main cooling water.

The electric power system of the HANARO consists of class I, II, III and IV. The class IV power is commercial alternating current power and classified as a non-nuclear safety class. The electric power for all pumps and heaters of the FTL is categorized as the class IV. When main cooling water pump (MCWP) shutdowns due to the loss of class IV power, the safety control system generates low flow and low-low flow signals. Therefore the HANARO

shutdowns fast and emergency cooling water injection occurs for the FTL.

2.2 Thermal-Hydraulic Modeling

Multi-dimensional Analysis of Reactor Safety (MARS) computer code was used for the thermal-hydraulic transient analyses and the DNBR prediction during the AOOs [1-3].

The MCWS including the IPS and the ECWS were modeled. The other systems connected to the MCWS are not included in the MARS modeling.

The test fuel zone was modeled with a pipe with 14 sub-volumes. The IPS vessel, flow divider, and fuel transport leg were modeled as heat structure components because of the generated gamma heat due to a neutron irradiation. The gamma heat was modeled as a heat source. The test fuels were modeled as heat structure components with 14 axial nodes and 11 radial meshes respectively. The maximum linear heat rate studied in this work is 369.6W/cm. The cladding diameters of the test fuels are 9.5mm respectively and the pitch is 13.8mm.

105% of the normal operation power and a normal coolant temperature plus 6°C were used for all the analyses.

3. Results

Anticipated operational occurrences considered as the FTL design bases are as follows:

- inadvertent closure of the loop isolation valves,
- safety relief valve discharge,
- loss of main cooling water flow,
- loss of class IV power, and
- loss of main cooler feed water.

The present study only deals with the loss of class IV power. This anticipated operational occurrence is assumed to occur due to a failure of electric power system.

The critical heat flux (CHF) correlations of the MARS code are not adequate to predict the DNBR for the test fuels of the FTL because of geometric differences. It is well known that a CHF is highly dependent on the geometric features of a boiling surface. Therefore a series of CHF experiment was performed at the same geometry of the test fuels and the flow path of the IPS. As a result of the experiment a correction function for the 1986 AECL Look-UP Table was developed [4]. The newly

developed CHF was used for the DNBR prediction for the AOO.

When main cooling water pump shutdowns due to the loss of class IV power, the HANARO is tripped by low flow signal and the FTL protection system is actuated by low-low flow signal. The actuation of the FTL protection system means that the IPS is isolated by the closure of loop isolation valves and that the emergency cooling water is injected into the IPS, in which test fuels are placed.

The main cooling water flows at the main cooling water pump discharge and the IPS are as shown in Figure 1. As the main cooling water pump shutdowns, main cooling water flow rates decrease drastically. The HANARO trip occurs at 1.59 seconds and the emergency cooling water injection commences at 1.94 seconds after the loss of class IV power. The cooling water flow rate at the IPS remains nearly constant after about 4 seconds.

Figure 2 shows the DNBRs for the loss of class IV power. The legends in Figure 2 indicate the lower and upper limits of the analysis range for the flow rate and pressure. The DNBRs decrease drastically to a minimum level and then increase with an oscillation. The fast decrease of the DNBRs is because of the decrease of the flow rate due to the shutdown of the main cooling water pump and the closure of loop isolation valves. The increase of the DNBRs after about 3 seconds is because of an increase of the flow rate due to an emergency cooling water injection and because of a decrease of fission power due to the HANARO trip. The minimum DNBR is predicted as 2.32, which meets the design limit of the DNBR for the FTL.

It is indicated that the safety control system of the FTL functions adequately and that the emergency cooling water system has sufficient cooling capabilities for the AOO during the early and long term cooling stages. The MARS also predicts that the maximum peak pressure of the IPS is lower than the 110% of the design pressure.

4. Summary

Thermal-hydraulic transient analyses have been carried out for a loss of class IV power for the HANARO fuel test loop. The DNBRs have also been calculated.

From the present analyses of the test fuels, the results are summarized as follows:

- 1) The HANARO fuel test loop has sufficient emergency cooling capabilities,
- 2) The minimum DNBR is greater than the design limit DNBR,
- 3) The maximum peak pressure of the IPS is lower than the 110% of the design pressure.

REFERENCES

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- [4] Critical Heat Flux Report on 3-Pin Rod Bundle for PWR Reactors, KAERI/TR-3350/2007, Korea Atomic Energy Research Institute, 2007.

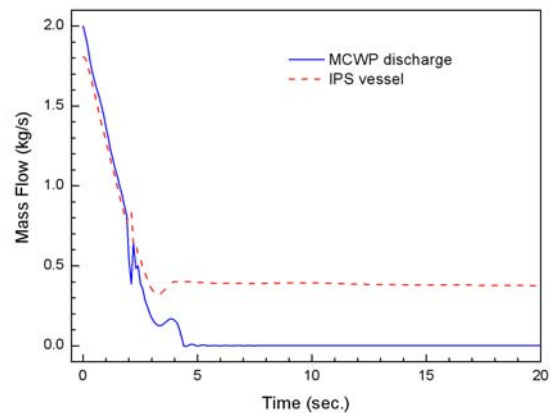


Fig.1. Cooling water flows for loss of class IV power.

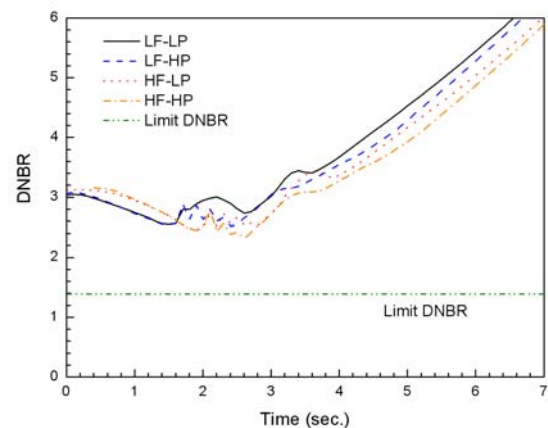


Fig.2. DNBRs for loss of class IV power.