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Inadvertent Closure of Loop Isolation Valves for the HANARO fuel test loop

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1. Introduction

A fuel test loop (FTL) for irradiation tests is under development at the HANARO. The construction of the FTL was completed at the beginning of this year and pre-service tests will also be carried out this year. 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 operational occurrences (AOOs).

The FTL has loop isolation valves to separate the nuclear safety systems from the non-nuclear safety systems and to establish a flow path for an emergency cooling in an emergency. However, a loss of normal cooling water will occur if an isolation valve is closed inadvertently. This paper deals with the thermal-hydraulic transient analyses and the prediction for a departure from a nucleate boiling ratio (DNBR) during an inadvertent closure of the loop isolation valves, which is one of the AOOs.

2. Analysis Methods

2.1 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.

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 an inadvertent closure of the loop isolation valves [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. Figure 1 shows the linear heat rates used for the thermal-hydraulic analyses during an inadvertent closure of the loop isolation valves. 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.

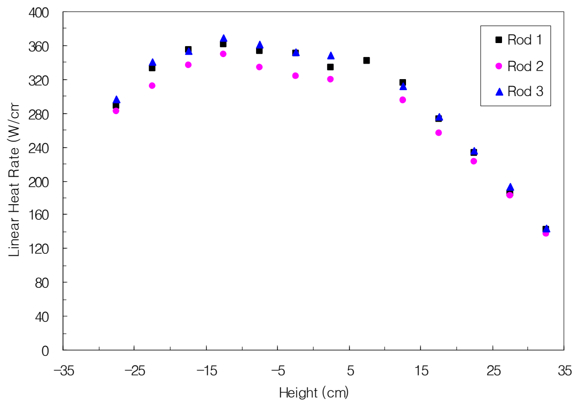

Fig.1. Linear heat rates for the PWR test fuels.

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 the main cooling water flow,
- loss of the class IV power, and
- loss of the main cooler feed water.

The present study only deals with an inadvertent closure of the loop isolation valves. This anticipated operational occurrence is assumed to occur due to a mechanical failure of one valve among the four loop isolation valves or a wrong actuation signal.

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.

There are four loop isolation valves on the cold leg and hot leg for the main cooling water system. Two valves are installed in series on each leg. The thermal-hydraulic transient analyses were carried out for a hot leg valve closure, a cold leg valve closure, and a hot and cold leg valve closure respectively. The thermal hydraulic behavior and the system response of the FTL for the three events are similar. The HANARO is tripped due to the low flow signal and the FTL protection signal is actuated by the low-low signal. The actuation of the FTL protection signal means that the IPS is isolated by the loop isolation valves and that the emergency cooling water is supplied to the test fuels.

It is shown 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.

Especially Figure 1 shows the DNBRs for an inadvertent closure of the loop isolation valves. The legends in Figure 1 indicate the lower and upper limits of the analysis range for the flow rate and pressure. Actual operation range should be determined by considering the uncertainties of the instruments for the operational parameters. 105% of the normal operation power and a normal coolant temperature plus 6℃ were used for all the analyses. 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 a closure of a loop isolation valve. The increase of the DNBRs after 2.5seconds is because of a decrease of the flow rate due to an injection from the emergency cooling water system. The minimum DNBR is predicted as 1.87, which meets the design limit of the DNBR for the FTL.

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 an inadvertent closure of the loop isolation valves of 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

[1] MARS Code Manual Volume I: Code Structure, System Models, and Solution Methods, KAERI/TR-2812/2004, Korea Atomic Energy Research Institute, 2004.

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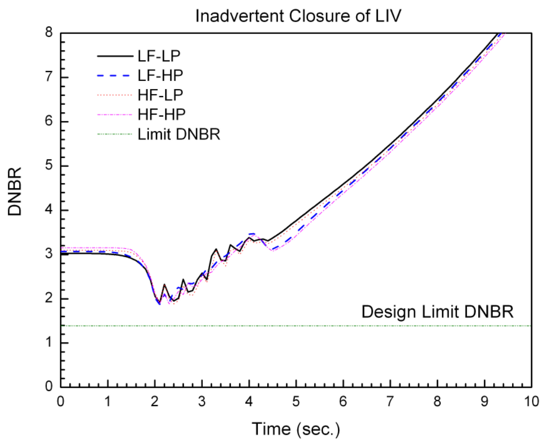

Fig.2. DNBRs for inadvertent closure of loop isolation valves.