Prediction on the DNBR of the Fuel Test Loop for the Over-Power Transient of the HANARO

S. K. Park, 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 fuel test loop was completed at the beginning of this year and pre-service tests are being carried out. The design basis accidents and operational occurrences (AOOs) have been completed for the fuel test loop including test fuels for pressurized water reactors.

The fuel test loop has no any means to control the power of test fuels. The thermal power of the test fuels depends on the power of the HANARO. This paper deals with the thermal-hydraulic transient analysis and the prediction on a departure from a nucleate boiling ratio (DNBR) during an over-power transient of the HANARO, 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 the HANARO over-power transient [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 cladding diameters of the test fuels are 9.5mm respectively and the pitch is 13.8mm.

The initial conditions for the over-power transient analysis of the HANARO are described in Table 1. The maximum linear heat rate of the test fuels is 38.34kW/m.

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,
- loss of the main cooler feed water, and
- over-power transient of the HANARO.

The present study only deals with an over-power transient of the HANARO.

The maximum power of the HANARO occurs at a break of the exit pipe of the HANARO heavy water tank. Figure 1 shows the power transient of the HANARO. The power of the HANARO reaches the maximum value of 141% of the initial power. And then the power decreases abruptly. It was assumed that the power of the test fuels was proportional to the power of the HANARO.

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. 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.

The HANARO is tripped due to the high power signal from the HANARO protection system. No signals to shut down the HANARO from the fuel test loop are generated. Also an actuation of the emergency cooling water system of the fuel test loop does not occur.

The power of the test fuels increases linearly after the break of the exit pipe of the HANARO heavy water tank occurs. The temperature and pressure of the main cooling water increase slightly until a high power trip signal of the HANARO occurs. And then the temperature and pressure decrease slightly.

Figure 2 shows the DNBRs for the over-power transient of the HANARO. The legends in Figure 2 indicate the lower and upper limits of the analysis range for the flow rate and pressure. An 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 moderately to a minimum value and then increase abruptly. The decrease of the DNBRs is because of the increase of fission power and coolant temperature. The increase of the DNBRs after 234 seconds is because of the decrease of fission power and coolant temperature. The minimum DNBR is predicted as 2.07, which meets the design limit of the DNBR for the fuel test loop.

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 for the fuel test loop have been carried out for the over-power transient of the HANARO. The DNBRs have also been calculated.

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

1) The emergency cooling water system of the fuel test loop is not actuated for the over-power transient of the HANARO,
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.
[2] MARS Code Manual Volume II: Input Requirements, KAERI/TR-2811/2004, Korea Atomic Energy Research Institute, 2004.
[3] RELAP5/MOD3 Code Manual Volume IV: Models and Correlations NUREG/CR-5535-V4, 1995.
[4] Critical Heat Flux Report on 3-Pin Rod Bundle for PWR Reactors, KAERI/TR-3350/2007, Korea Atomic Energy Research Institute, 2007.

Table 1. Initial conditions for the over-power transient analysis of the HANARO

Parameters	Values
Average linear heat rate, kW/m	30.96
Peak linear heat rate, kW/m	38.34
IPS flow rate, kg/s	1.52 ~ 1.80
IPS inlet temp., ℃	306.3
Pressurizer press., MPa	14.4 ~ 16.5

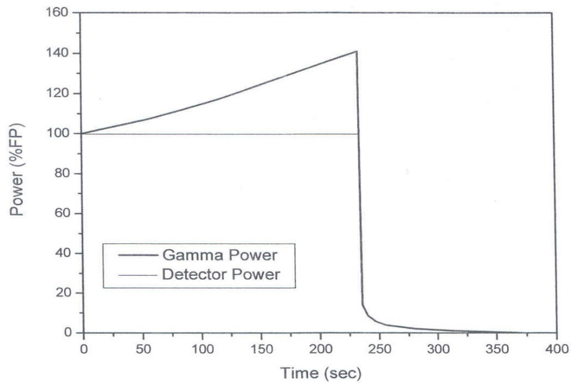

Fig.1. Over-power transient of the HANARO.

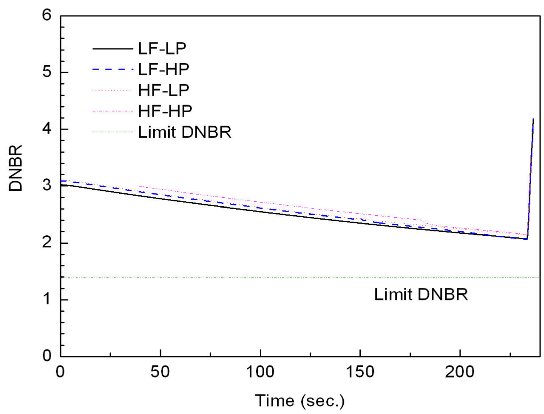

Fig.2. DNBRs for the over-power transient of the HANARO.