Analysis of Anticipated Operational Occurrences for 3-Pin Fuel Test Loop

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1. Introduction

3-Pin Fuel Test Loop (FTL) is under development to meet the increasing demand on fuel irradiation and burn up test required the development of new fuels in Korea. It is designed to provide the test conditions of high pressure and temperature similar to the operational conditions of the commercial PWR and CANDU power plants. This paper deals with the analysis of the emergency core cooling capability of the FTL for the anticipated operational occurrences (AOOs) of the PWR fuel test mode.

2. System Description

The FTL consists of an in-pile test section (IPS) and out-pile system (OPS). The IPS is located at the IR1 hole of HANARO core [1] and designed as a double pressure vessels charged with an insulation gas to provide a reliable pressure boundary and an effective thermal insulation. The OPS provides the proper fuel test conditions such as pressure, temperature, flow rate and chemistry in a normal operation, and safety functions in abnormal and emergency conditions. The OPS has emergency cooling water system (ECWS) to remove the IPS heat subsequent to anticipated operational occurrences (AOO) and design basis accidents (DBA). The accumulators charged with nitrogen gas and depressurization vent valves provide the means to inject cooling water into the IPS.
The FTL has HANARO and FTL protection systems. HANARO protection system provides fast scram from the high flow, low flow, high pressure, low pressure and high temperature of the IPS. 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 of the IPS.

3. Thermal Hydraulic Modeling

Multi-dimensional Analysis of Reactor Safety (MARS) computer code has been used for the prediction of the emergency core cooling capability of the FTL [2,3,4].

The modeling of the FTL has been developed for the analysis of the anticipated operational occurrences and the inputs for the MARS code have been prepared. The main cooling water system (MCWS), the IPS and the ECWS are modeled. The other systems connected to the MCW system are not included in the modeling.

The test fuel zone is modeled with a pipe having 7 sub-volumes. The IPS vessel, flow divider, and fuel transport leg are modeled as a heat structure component because of gamma heating. The test fuel is modeled as a heat structure component having 7 axial nodes and 11 radial meshes. Table I describes the fuel data for PWR fuel test mode.

Table II shows the trip parameters and set points for the protection system actuation signals for the PWR fuel test mode. The actuation of the HANARO trip is delayed by 0.615 second and the actuation of the FTL is also delayed by 0.41 second.

Table I. Test Fuel Data.

Parameter	PWR
Fuel clad OD (mm)	9.50
Pitch (mm)	13.8
Length (mm)	700
Rod numbers	3
Average Linear Heat Rate (kW/m)	30.0
Maximum Linear Heat Rate (kW/m)	41.6

The thermal hydraulic inputs are determined so that the departure from nucleate boiling ratio (DNBR) is predicted conservatively. The 105% of the rated power, the 95% of the rated flow, the 98% of the rated pressure, and the 102% of the rated temperature are used for the inputs.

Table II. Trip Parameters and Set Points.

	Parameter	PWR
HANARO Trip	Low flow (kg/s)	1.28
	High flow (kg/s)	1.84
	High temperature (°C)	331.5
	Low pressure (MPa)	14.13
	High pressure (MPa)	17.24
FTL Trip	Low-low flow (kg/s)	0.96
	High-flow (kg/s)	1.84
	High-high temperature (°C)	339.5
	Low-low pressure (MPa)	13.4

4. Results

The safety requirements for the FTL are based on the Standard Review Plan (SRP) used for US commercial power plants where applicable to the FTL. A review was made for the transient analyses that would be applicable in order to verify the adequacy of the FTL design and its emergency cooling water system. As a result of the review, the anticipated operational occurrences considered in this design are as follows:

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

The inadvertent close of loop isolation valve is assumed to occur due to a mechanical failure of one valve among the four loop isolation valves or a wrong close actuation signal. The safety relief valve discharge comes from a mechanical failure of the safety valve. The loss of main cooling water flow is supposed to occur due to the failure of the main cooling water pump or flow control valves. The loss of class IV power makes the main cooling water pump shut down. The loss of main cooler feed water means a loss of the cooling function of the main cooler.

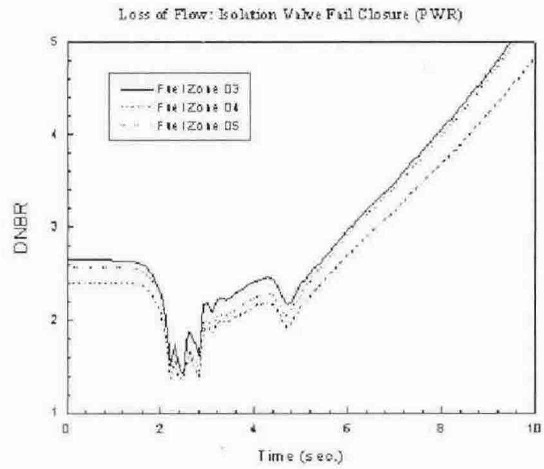
HANARO is tripped due to the low flow signal for the inadvertent close of loop isolation valve, the loss of main cooling water flow, and the loss of class IV power. For the safety relief valve discharge, HANARO is tripped due to the low pressure signal. The high temperature signal trips HANARO for the loss of main cooler feed water. The FTL trip is followed the HANARO trip.

The design requirement for the emergency cooling water system is that the departure from nucleate boiling must not occur for anticipated operational occurrences. In the analysis the departure from nucleate boiling ratio (DNBR) was predicted from the results of the MARS one-dimensional code. The CHF correlation of AECL 86 look-up table included in the MARS code is not adequate to predict the DNBR because of the geometrical deference of the flow path and the unheated surface area of the FTL test section. Sub-channel analysis might be also needed for the more accurate prediction of the DNBR. At present analysis the DNBR resulted from the MARS code was used for the evaluation of the performance of the emergency cooling water system.

The severe case for the anticipated operational occurrences is the inadvertent close of loop isolation valve in view of thermal hydraulic transient and the DNBR. Figure 1 is the DNBR for the inadvertent close of loop isolation valve. The 4 loop isolation valves are installed at the hot and cold legs. Three kinds of loop isolation valve close were considered. They are the inadvertent close of cold leg loop isolation valve, hot leg loop isolation valve, and dual leg loop isolation valve. The responses of the thermal hydraulic transient to the accidents and the DNBR are similar to each case. The minimum DNBR is predicted as 1.37, which meets the design criteria of 1.3 for the FTL, and the maximum peak pressure of the IPS is lower than the 110% of the design pressure.

5. Summary

The performance of the ECWS was predicted for the anticipated operational occurrences. The inadvertent close of loop isolation valve is the most severe case for the five anticipated operational occurrences considered in this design and meets the design criteria of the ECWS. The correlation of critical heat flux for the geometry of three pins and sub-channel analysis will be studied in the feature.



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