Transactions of the Korean Nuclear Society Spring Meeting
Gwangju, Korea, May 30-31, 2013

Experimental Investigation on core cooling effect in accordance with the bypass debris for WH Type Plant

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1. Introduction

The containment building prohibits radioactive materials release to environment and facilitates core cooling in the event of a postulated Loss of Coolant Accident (LOCA) in the Nuclear Power Plant (NPP).

The discharged water from the break point and containment spray is collected in a sump for recirculation by the emergency core cooling system (ECCS) and the containment spray system (CSS).

Generally, the strainer with perforated screen is installed in the containment sump to prohibit the debris passing to downstream area and to protect the components of the ECCS and the CSS. The strainer must supply sufficient net positive suction head (NPSH) to the ECCS pump and the CSS pump and prevent debris into the fuel regions in the recirculation mode.

However, some fibrous material, particulates and chemical products may be ingested into the ECCS and subsequently, into the reactor coolant system (RCS). This could be concerns for long term core cooling (LTCC) when recirculating the cooling water (coolant) from the containment sump. During operation of ECCS to recirculate coolant from the containment sump, debris in the recirculating coolant may accumulate on the fuel rod causing resistance to flow for core cooling.

This in-core downstream effect test was performed to measure the debris effects of fuel regions when the ECCS is operated in the recirculation mode in Westinghouse (WH) Type Pressurized Water Reactor (PWR).

2. Methods and Results

The PWR Owners Group (PWROG) developed a common test protocol for testing of the PWR plant, and test procedures, debris details, pressure drop acceptance criteria for testing, and test matrix were developed based on this protocol [1] and WCAP-16793-NP [4].

2.1 Test Procedure

2.1.1 Procedure

The test procedure for in-core downstream test is outlined as following steps.

1) A WH Type Fuel Assembly(FA) of 2.5 m height is installed into the FA pool, and the mixing pool is filled with water.
2) Debris quantities are measured and verified.
3) Pump is started, and the flow is set.
4) Stabilize at a constant temperature ± 1°C.
5) Start data acquisition system.
6) Record the clean head loss.
7) Add particulate debris to system, record the head loss.
8) Add fiber in loop and at least two turnover times are allowed to pass between additions. Record the head loss.
9) Add chemical precipitates and record the head loss.
10) The Head loss is allowed to reach a predefined steady state for test termination. Record the final head loss and terminate the test.

2.1.2 Debris Preparation

1) Particulate

The particulate debris is represented by ground silica (SiO_2) powder that is 10μm ±5μm in diameter. The NRC Safety Evaluation [2] identified particle size as a key parameter for the selection of representative debris. Specifically, it states that major contributors to head loss are the increasing smaller particles.

2) Fiber

Fibrous debris is represented by fiberglass insulation. The fiber length distribution for this test is listed below;

- Fiber length < 500 μm : 71% ± 10%
- 500 μm ≤ Fiber length < 1,000 μm : 10% ± 10%
- Fiber length ≥ 1,000 μm : 19% ± 10%

Typically above fiber distribution is based on strainer bypass test result. And total amount of bypassing fiber debris of test assumes 27.3 kg.

Generally, the 157 fuel assembly is 157 loaded in the reactor of WH PWR. The standard amount of fiber debris is 174 g per fuel assembly.

3) Chemical Products

There assumes one kind of chemical product such as $NaAlSi_3O_8$ which may be generated in the Recirculation sump.

The chemical products debris are prepared according to chemical products generation assessment result and WCAP-16530-NP [3] methodology. The test use AlOOH as a chemical debris, which has been shown by Argonne National Laboratory to produce the highest pressure drop among all of the chemical precipitants [5].

2.2 Test Parameters

2.2.1 Parameters

In case of cold leg (CL) break, the core flow is only what is required to make up for core boiling to remove the decay heat.

The representative CL flow rate through core to be tested is 3 gpm (11.4 lpm) for WH plants [1].

For a break of hot leg (HL), the flow rate to be tested is calculated to divide 9000 gpm by 157 and its value is

57 gpm (215 lpm). The HL break condition at the maximum flow rate represents the most conservative test conditions and should be used for testing designed to define debris limits.

2.2.2 Acceptance Criteria (dP_{debris})

The available driving head (dP_{avail}) is a plant specific. The pressure drop due to debris(dP_{debris}) is determined by the in-core down stream test.

$$dP_{avail} > dP_{debris}$$

$$\Delta P_{avail} = \Delta P_{dz} - \Delta P_{flow}$$

where:

ΔP_{avail} : total available driving head

ΔP_{dz} : pressure head due to liquid level between core inlet header and reactor core

ΔP_{flow} : pressure head due to flow losses in the RCS

The dP_{debris} values associated with a specific amount of debris should be measured. This test provides dP_{debris} value that corresponds to specific debris loading.

WH Type plant is calculated using reactor vessel and steam generator(SG) drawing materials as below.

At Hotleg(HL) break

ΔP_{DC} = Elevation head due to liquid in the DC and SG to spillover elevation

$= (Z_{so} - Z_{c\text{-}in}) (\rho_{DC})/144 \text{ in}^2 = 21.4$ psi

Z_{so} : SG or HL spillover elevation

$Z_{c\text{-}in}$: Elevation of bottom of the core

ρ_{DC} : Liquid den. in DC and SG

ΔP_{core} ; Elevation head due to liquid in the core

$= (Z_{brk} - Z_{c\text{-}in}) (\rho_{core})/144 \text{ in}^2 = 6.7$ psi

Z_{brk} : Elevation of the break (bottom of hotleg) (ft)

ρ_{core} : density in core

Therefore, the dP_{avail} is calculated as below:

$$\Delta P_{avail} = 21.4 \text{ psi} - 6.7 \text{ psi} = 14.7 \text{ psi}$$

At Coldleg break

Pressure drop across the bottom nozzle = 1.5 psi [1]

2.3 The Results of Evaluation

The results of pressure drop test at standard fiber amount and various amounts of particulate and chemical debris condition are lower than acceptance criteria. Figure 2-2 presents differential pressure transmitter locations to measure pressure drop in fuel region. The example of pressure drop values of each measurement point for debris addition and time elapse are presented in Figure 2-3. An example of debris accumulation in fuel region during test is showing in Figure 2-4.

The result of 1:1 ratio of particulate : fiber test produces the highest head loss and the chemical debris effect continuously increasing until some amount of chemical debris addition and then saturated. If the circulating water contains only particulate debris, the head loss without the chemical debris effect is almost same as the clean head loss

Fig. 2-1 Test Column

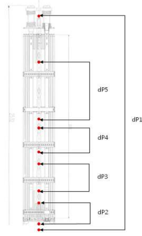

Fig. 2-2 Sensor locations

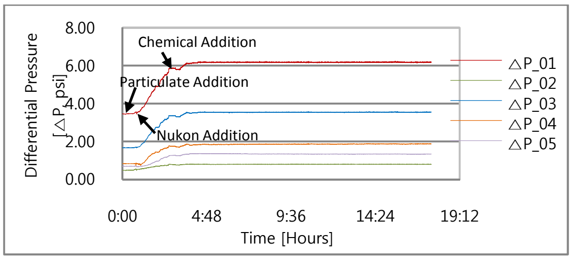

Figure 2-3 example of test result

Figure 2-4 Debris accumulation at Fuel Grid (Top, Middle, Bottom)

3. Conclusions

The purpose of the in-core downstream is to justify acceptance criteria for the amount of debris that can reach the RCS and confirm the heating effect of fuel assembly by the in-core downstream effect.

In the hot leg break and cold leg break condition, the test results show that the highest pressure drop(below 11.0 and 0.3 psi) meet the acceptance criteria.

So the fuel may be cooled appropriately for the long term core cooling in the event of a LOCA.

REFERENCES

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[5] ML080600223, "Technical Letter Report on Evaluation of Chemical Effects; Studies on Precipitates Used in Strainer Head Loss Testing," January, 2008