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In-Core Downstream Effect for CANDU

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1. Introduction

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

The process water discharged from the break and containment spray is collected to the sump area.

The strainer with perforated screen is installed in sump area to prohibit the debris passing to downstream area and to protect the components of the Emergency Core Cooling System(ECCS) and the Containment Spray System (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 some chemical products may be introduced into the ECCS and the reactor coolant system (RCS). This phenomenon could be harmful 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 in the flow path within the fuel bundle causing resistance to flow for core cooling.

The in-core downstream effect test was performed to measures the debris effects of fuel regions when the ECCS is operated the recirculation mode in CANDU.

2. Methods and Results

The CANDU plant is a horizontal fuel assembly type, and it is not adequate wholly application Pressurized Water Reactor Owners Group(PWROG) test protocol [1]. The debris preparation method uses this protocol and others use developed method for this purpose.

2.1 Test Procedure

2.1.1 Procedure

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

1) Three fuel bundles are inserted into the test loop.
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 : 70% ± 10%
- 500 μm ≤ Fiber length < 1,000 μm : 10% ± 10%
- Fiber length ≥ 1,000 μm : 20% ± 10%

Typically above fiber distribution is based on strainer bypass test result. And total amount of bypassing fiber debris of test assumes 10.5 kg. The total number of fuel channel of CANDU reactor is 380 and there are two (2) heat transport system(HTS). Under the LOCA condition, one (1) HTS is isolated and other HTS is working by ECC system. The only 1/2 fuel assembly channels (190) are subjected to ECC flow. Therefore, the standard amount of fiber debris is 55.3g per fuel assembly.

3) Chemical Products

Generally, there are three (3) kinds of chemical products such as $Ca_3(PO_4)_2$, AlOOH and $NaAlSi_3O_8$ which may be generated in CANDU ECCS sump.

The chemical products debris are prepared according to chemical products generation assessment result and WCAP-16530-NP-A[3] methodology.

2.2 Test Parameters

2.2.1 Parameters

The CANDU reactor core has 380 fuel channels and they are distributed in 4 flow path. Each flow path has 7 groups consisting of 95 fuel channels and Each group has 11 ~ 19 fuel channels [4].

In the Large Break Loss of Coolant Accident (LBLOCA) analysis, in case of the 100% reactor outlet header(ROH) break, the ECC recirculation flow rate of each group is generally 35~ 40kg/s [4].

To be conservatism, it is assumed that each group has same flow rate of 40 kg/s. Therefore, to get the single channel flow rate, 40 kg/s flow rate is multiplied by 7 and divided by 95.

Single channel flow rate

= 40 kg/s × 7 ÷ 95

= 2.95 kg/s = 177 kg/min

2.2.2 Acceptance Criteria (dP_{debris})

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

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

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

where:

ΔP_{avail} = total available driving head

ΔP_{dl} = 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.

Typically, the coolant inlet and outlet headers of CANDU plant are located at 4.26 ~ 8.82 m higher than reactor core region, therefore the dP_{dl} is in range of 6.18 ~ 12.79 psi. To be conservative, the minimum dP_{dl} of 6.18 psi is adopted to decide the acceptance criteria of head loss.

The pressure head due to flow losses of dP_{flow} under an accident condition is not known. In this test, the dP_{flow} is assumed as ~ 20 % of dP_{dl}. Therefore, the dP_{avail} is calculated as below;

$$\Delta P_{avail} = 6.18\ psi - 1.24\ psi = 4.94\ psi$$

2.3 The Results of Evaluation

The standard fiber amount and various amounts of particulate and chemical debris test shows the pressure drop is much lower than acceptance criteria. For conservation, increased fiber debris test as two times and four times of standard amount shows the pressure drop satisfies the acceptance criteria. Figure 2-1 shows test column of CANDU fuel bundle and Figure 2-2 presents differential pressure transmitter locations to measure pressure drop in fuel bundle region. The 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 bundle during test is showing in Figure 2-4.

The 1:1 ratio of particulate : fiber shows higher head loss than other ratio 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. And it is increased according to the amount of the fiber debris and chemical debris.

Figure 2-1 Test Column for Fuel Bundle

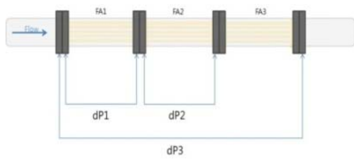

Figure 2-2 Sensor locations for measuring the pressure drop

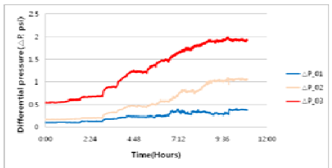

Figure 2-3 Test result(two times of standard fiber)

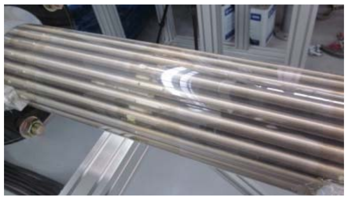

Figure 2-4 Debris accumulation in fuel bundle

3. Conclusions

The purpose of the in-core downstream test of CANDU fuel bundle in this report is to justify acceptance criteria for the amount of debris that can reach the RCS and confirm the heating effect of fuel buddle by the in-core downstream effect.

In the hot leg break condition, the test results shows that pressure drop meet the acceptance criteria as much as four times of standard fiber debris.

Therefore the fuel may be cooled appropriately for the long term core cooling in the event of a LOCA in the Nuclear Power Plant.

REFERENCES

[1] PWROG Letter OG-09-107, “Transmittal of PWROG Fuel Assembly Debris Capture and Head Loss Protocol to PWROG Members,” March, 2009.

[2] NEI 04-07, Rev. 0 “Pressurized Water Reactor Sump Performance Evaluation Methodology,” December, 2004.

[3] WCAP-16530-NP-A, “Evaluation of Post-Accident Chemical Effects in Containment Sump Fluids to Support GSI-191,” March, 2008.

[4] Wolsong Unit 1 FSAR