Design of Test Facility to Evaluate Boric Acid Precipitation Following a LOCA

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1. Introduction

The U.S.NRC has identified a concern that debris associated with generic safety issue (GSI) - 191 may affect the potential precipitation of boric acid due to one or more of the following phenomena [1]:

- Reducing mass transport (i.e. mixing) between the core and the lower plenum (should debris accumulate at the core inlet)
- Reduced lower plenum volume (should debris settle in the lower plenum), and,
- Increased potential for boric acid precipitation (BAP) in the core (should debris accumulate in suspension in the core)

To address these BAP issues, KHNP is planning to conduct validation tests by constructing a BAP test facility. This paper describes the design of test facility to evaluate BAP following a LOCA.

2. Design of Test Facility

2.1 Tests Requirements

The PWROG proposed to show that the following phenomena of concerns will not increase the potential for BAP in the core and thus compromise core cooling.

- Core inlet blockage (GSI-191)
- Lower plenum settling (cold-leg break case)
- Debris concentration in the core (chemical and buffering agents)

The effects in-vessel debris has on mixture level swell should be investigated as it relates to liquid carryover to the hot-leg of nuclear power plants.

The effectiveness of alternate flow paths at diluting the core region should be established when debris blockage forms near the core inlet and the primary flow path between the core and lower plenum is lost.

2.2 Success Criteria

- It should be demonstrated that, with reasonable assurance, LTCC is maintained over a range of debris loads and allow removing excessive conservatisms to get to > 15 g per fuel assembly (FA).
- Only GSI-191 has been performed without BAP issues and the debris issues are tested without heated rods.
- Since the flow distributions are not uniform across the core inlet, core mixing characteristics should be verified.
- 'Plant Mixing' vs. 'Test Mixing' are to be compared
  - obstacles in lower plenum
  - mechanical mixing in lower plenum
  - find out other method of increasing mixing

2.3 Scaling Method

The general objective of this scaling is to obtain the physical dimensions for the BAP test facility capable of simulating the heat transfer, mass transport, and mixing behavior of importance to BAP and LTCC. In order to develop a properly scaled test facility, the following specific objectives should be met for the PWR operational modes of interest.

- Obtain the similarity groups which should be preserved between the test facility and the full-scale prototype.
- Establish priorities for preserving the similarity groups.
- Assure that important processes have been identified and addressed.
- Provide specifications for test facility design.
- Quantify biases due to scaling distortions.

Meeting the scaling objectives of the previous section presents a formidable challenge. Therefore, to assure that these objectives are met in an organized and clearly traceable manner, a general scaling methodology for the BAP facility has been developed. The model for this scaling methodology is primarily drawn from the U.S.NRC's severe accident scaling methodology presented in NUREG/CR-5809 [5].

2.3.1 Power-to-Volume Scaling Analysis Method

The traditional approach to designing small-scale thermal hydraulic test facilities has been to use power to-fluid volume scaling. This approach has been successfully applied in various studies in the nuclear industry.

The optimum condition for this scaling approach occurs when the scale model implements the same working fluid as the prototypic system and when the scale model is built using similar materials, is full height, and is operated at the same pressure.

This generally results in constructing a very tall and thin scale model.

2.3.2 Ishii-Kataoka Scaling Analysis Method

The similarity criteria derived from this scaling analysis method permit a variable power-to-volume ratio while maintaining core exit conditions identical in the model and prototype. These criteria include the power to- volume similarity criterion.

The advantage of using Ishii's power density scale simulation is that a full-length test facility, which implements the same working fluid, the same pressure, and structural materials, is not needed to satisfy the scaling criteria. This permits added flexibility in the design choices.

A reduced height scale model, which gives a better representation of multi-dimensional effects in the plenum and downcomer regions, can be designed.

2.3.3 Hierarchical Two-Tiered Scaling Analysis Method

The H2TS analysis method will be utilized to develop the similarity criteria necessary to scale the system components and processes of importance to BAP and LTCC. The H2TS method was developed by the U.S.NRC and is fully described in Appendix D of NUREG/CR-5809 [5].

2.4 Test Description

Tests are performed with heated rod bundles in the presence of debris (particles, fiber, and chemical), buffering agents (TSP or NaOH), and boron.

Test facility includes the following:

- Half of full of prototypic FA height
- Two fuel assemblies
- Top and bottom nozzles
- Fuel rods (heated rods) and spacer grids
- Control rods
- Test loop

2.4.1 Fuel Assemblies

Two of 16×16 or 17×17 fuel assemblies are used in the test facility, as shown in Fig. 1.

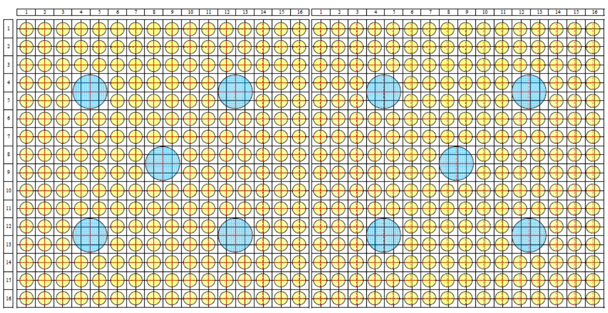

Fig. 1. Two of 16×16 or 17×17 fuel assemblies

2.4.2 Fuel Rods

The rod diameter can be either 0.374 in or 0.382 in depending on the FA type, as shown in Fig. 2.

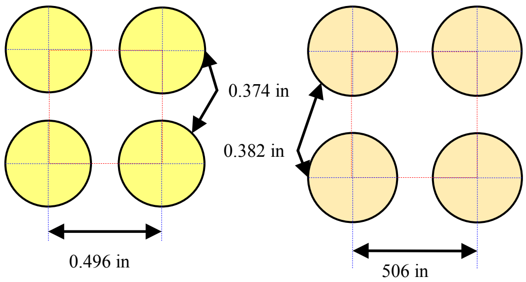

Fig. 2. Fuel rods (heater rods)

2.4.3 Flow Injection System

Natural convection for simulating cold-leg break case is applied. If flow instability happens, forced convection is applied.

2.4.4 Vessel Assembly

- Downcomer region
- Lower head region
- Core support region
- Core region
- Upper plenum
- Barrel/baffle region

3. Conclusions

The design of BAP test facility has been developed by KHNP. To design the test facility, test requirements and success criteria were established, and scaling analysis of power-to-volume method, Ishii-Kataoka method, and hierarchical two-tiered method were investigated. The test section is composed of two fuel assemblies with half of full of prototypic FA height. All the fuel rods are heated by the electric power supplier. The BAP tests in the presence of debris, buffering agents, and boron will be performed following the test matrix.

REFERENCES

[1] WCAP-17788-NP, Rev. 0, "Comprehensive Analysis and Test Program for GSI-191 Closure (PA-SEE-1090)," July 2015.

[2] OG-13-205, "PWR Owners Group, NRC Technical Concerns Regarding Boric Acid Precipitation in the Presence of In-vessel Fibrous Debris and the Consequential Effects on Long-Term Core Cooling (PWROG PA-SEE-1090 and PA-SEE-1072)," ADAMS Accession Number ML14161A043, May 2013.

[3] WCAP-16793-NP, Rev. 2, "Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Recirculating Fluid," October 2011.

[4] U.S.NRC, "Final Safety Evaluation by the Office of Nuclear Reactor Regulation: Topical Report WCAP-16793-NP, Revision 2," April 2013.

[5] NUREG/CR-5809, "An Integrated Structure and Scaling Methodology for Severe Accident Technical Resolution," 1991.