Enclosure 3

UAP-HF-12060
Docket No. 52-021

US-APWR Core Inlet Blockage Test Plan for Test Conditions in 2012 (Rev.0)

March-2012
(Non-Proprietary)

US-APWR

Core Inlet Blockage Test Plan for Test Conditions in 2012

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Revision History

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1. INTRODUCTION

GL 2004-02 (Reference 1) was issued to request licensees to address the effects of post-LOCA debris on long-term core cooling (LTCC) including sump strainer downstream effects. In order to address the plant-specific aspect of this issue, Mitsubishi Heavy industries Ltd (MHI) issued a technical report "US-APWR Sump Strainer downstream Effects." (Reference 2)

The technical report assesses the US-APWR systems and components downstream of the containment sump strainers to ensure that these systems and components will operate as designed under post LOCA conditions with debris-laden post-LOCA fluid. The report incorporates the lessons learned and concerns from GSI-191 and GL 2002-04. It was prepared in accordance with NEI 04-07 and published NRC staff expectations. The report also meets the intent of previous industrial studies in the U.S. as adapted to the US-APWR design. The report concludes that operation under post LOCA conditions with debris-laden post-LOCA fluid will not result in a flow rate below that required for LTCC because the US-APWR is a low fiber plant equipped with high performance strainers. Fuel cladding temperatures will remain below those required by 10CFR50.46.

It is the opinion of MHI that the technical report conclusions adequately address the issue and therefore, testing is not necessary for the Design Certification evaluation. However, MHI will supplement the report with a core inlet blockage test to provide the NRC with additional supporting information.

Core inlet blockage test program utilized a mockup fuel assembly with full-gap space which represents plant configuration (Reference 3). The NRC is concerned about conservatism during full-gap tests since more debris is allowed to bypass the fuel region than during half-gap tests (Reference 4). Therefore, MHI performed additional tests with half-gap size between fuel assembly and test section (Reference 5).

To resolve NRC concerns regarding delay time of debris transportation to the core (Reference 6), MHI changed the recirculation water flow paths to the RWSP. Additional core inlet blockage tests are needed due to these changes resulting in an increase in chemical debris loading.

2. OBJECTIVE

The objective of the core inlet blockage test is to obtain pressure drop data through an US-APWR fuel assembly mock-up that simulates debris build-up. The data will be used to demonstrate that sufficient driving head is available to maintain adequate flow to remove decay heat during post-LOCA recirculation in the event of fuel assembly debris build up. This will provide the NRC with confirmation that Long Term Core Coolability is adequately maintained in the US-APWR.

3. TEST CONFIGURATION

The core inlet blockage test will be conducted using the test loop shown in Figure 1. The loop consists of a test section, variable speed circulation pumps, water reservoir and connecting piping. The water is circulated by the pump, and the flow rate is controlled by the pump speed. A constant flow rate is maintained during each test run. The flow direction can be changed by valves so that either forward or backward flow mode can be selected. The debris-laden fluid is stored in the tanks and injected into the main flow as required. The debris-laden fluid is continuously mixed in the tank so as to prevent debris from agglomeration and sedimentation.

The test section is a transparent acrylic duct which enables visual observation. It contains a mock-up assembly shown in Figure 2 to simulate the US-APWR fuel, [ ]. The test section therefore represents 1/257 of the US-APWR core. The mock-up assembly is comprised of 17x17 fuel rods [ ]. The test section is equipped with pressure taps as shown in Figure 3, and differential pressure between the pressure taps is measured with pressure transducers.

The mock-up assembly is considered as a conservative representation of the full-scale fuel assembly when appropriate scaling is applied. The pressure drop over the downstream grid spacers that will trap smaller amount of debris will be substituted with the pressure drop over the upstream spacers. [ ].

As shown in Figure 4, the test section is the half-gap size in actual core between a fuel assembly and wall.

4. TEST CONDITION

The test conditions are shown in Table 1. Case 1 is performed to obtain pressure drop through the non-debris laden assembly as reference data. Case 2 through 4 are determined based on post-LOCA conditions described in section 4.1.

The test will be performed at flow conditions simulating post-LOCA reactor core with room temperature water at atmospheric pressure. The use of the room temperature fluid conservatively covers the post-LOCA core condition. The post-LOCA core flow conditions will be simulated assuming the identical flow rate for a single assembly. High kinematic viscosity of the room temperature fluid yields low Reynolds number flow in the core, and the low Reynolds number flow yields a generally higher pressure drop coefficient. In addition, the dynamic pressure is larger at low temperature due to the temperature dependence of the water density. Therefore, the evaluation of the pressure drop coefficient at room temperature is conservative.

As for the atmospheric pressure, in the post-LOCA core where long term cooling is an issue, the pressure has nearly reaches atmospheric pressure when considering a large break LOCA that would generates large amount of debris. Furthermore, there is little effect of the pressure conditions for flow character on the downstream test. Therefore, the use of atmospheric pressure is considered appropriate.

4.1 Post-LOCA Conditions

The post-LOCA conditions are represented by the following three (3) state-points in consideration of the LOCA scenarios, break points and operation modes.

- Hot-leg break
- Cold-leg break
- Cold-leg break after hot-leg switch over

These state-points are illustrated in Figure 5.

4.2 Flow Rate Conditions

The flow rates in Table 1 are selected as bounding conditions that cover possible core flow rates in the post-LOCA conditions. The flow rates are determined as 1/257 of the actual US-APWR core flow rate. The flow direction is either forward (normal direction) or backward (reverse direction) depending on the post-LOCA injection mode.

The flow rate for Case 2 is a maximum flow rate in the forward direction that occurs during the hot-leg break. This flow rate is determined as the flow rate of four safety injection (SI) pumps with non-debris-laden flow being injected through direct vessel injection (DVI) nozzle.

The flow rate for Case 3 is the flow rate that meets the boil-off flow rate to maintain the core covered with the coolant. This represents the lower bound of the possible flow rate during the post-LOCA recirculation.

Case 4 represents the maximum flow rate in the backward direction that occurs during the cold-leg break after the hot-leg switch over. In the US-APWR design, two of the four SI pumps will be switched from the (DVI) nozzle to the hot-leg after 4 hours. The maximum flow rate in this case is determined as the flow rate of the two SI pumps, which is the case that the injected fluid through the hot-leg passes through the core from the top to the bottom and that through the DVI nozzle spills out from the break location in the cold-leg.

4.3 Debris Conditions

The evaluation of the amount of bypass debris is described in this section. The estimated debris generated upstream of the strainer (in containment) is summarized in Table 2. MHI applies 1) the alternative bypass ratio supported by bypass fiber test result is considered as "strainer bypass debris", which possibly bypasses the sump strainer, 2) reduction based on core bypass flow and DVI to hot-leg switch over time for cold-leg break, considered as "core bypass debris". The amount of debris introduced into the test loop is scaled to 1/257 and the amount is shown in Table 3.

Since the effect of fibrous to particulate debris ratio is an industry issue (Reference 7), two tests may be conducted with varying fiber to particle ratio shown in Table 4 at limiting flow condition selected from Table 1 upon the availability of the test results.

5. TEST PROCEDURE

The test will be performed by following steps.

1. The test loop is filled with water.
2. The difference pressure is measured with non-debris laden condition.
3. The debris is introduced to the water flow, and difference pressure is measured.
4. The measurement is continued until the difference pressure stabilizes or reaches its pressure loss criterion after all the debris for the test is added. The pressure loss criterions will be identified by the flow rate and driving head that corresponds to a LOCA scenario (pipe break location and operation mode)
5. The visual observation of the fuel assembly is performed after the test
6. The test loop and mock-up assembly are cleaned after each test run.

6. EVALUATION

6.1 Evaluation Method

The test results are evaluated at the data point where the total measured differential pressure over the mock-up assembly shows its maximum during a single test run. [

] as shown in equation (1). This method ensures the conservatism as discussed in section 3.

[ ] (1)

6.2 Acceptance Criteria for the Pressure Drop

In order to maintain the LTCC, the acceptance criteria ($DP_{available}$) for the pressure drop due to the debris bed build-up are defined in relation to a maximum available driving force ($DP_{drivingforce}$).

As described in the previous section, $DP_{drivingforce}$ is determined by break location and operation mode. $DP_{available}$ is calculated from the following equation (2), where DP_{flow} is pressure drop over the entire flow loop (primary circulation system and the core) evaluated based on the specified flow rate for each state point.

$$DP_{available} = DP_{drivingforce} - DP_{flow} \qquad (2)$$

The acceptance criteria are $DP_{available}$. The acceptance criteria are compared against the calculated DP, which is the pressure drop over full scale fuel assembly calculated from the test data.

$$DP_{available} > \text{Calculated DP} \qquad (3)$$

7. QUALITY ASSURANCE PROGRAM

This test will be performed under the quality assurance program of US-APWR (Reference 8) that satisfies 10 CFR Part50 Appendix-B, ASME NQA-1-1994 and 10 CFR Part21.

8. TENTATIVE TEST SCHEDULE

The schedule of the core inlet blockage test is shown in Table 5.

9. REFERENCES

1. U.S. Nuclear Regulatory Commission, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors", Generic Letter 2004-02, September 2004.
2. Mitsubishi Heavy Industries, Ltd., "US-APWR Sump Strainer Downstream Effects", MUAP-08013-P Revision 2, August 2011.
3. Mitsubishi Heavy Industries, Ltd., "US-APWR Core Inlet Blockage Test", MUAP-10021-P Revision 0, November 2010.
4. Mitsubishi Heavy Industries, Ltd., "MHI's Response to US-APWR DCD RAI No.716-5527 Revision 2 (SRP 06.03)", UAP-HF-11076, March, 2011.
5. Mitsubishi Heavy Industries, Ltd., "US-APWR Additional Core Inlet Blockage Test", MUAP-11022 Revision 0, October, 2011.
6. U.S. Nuclear Regulatory Commission, "US-APWR DCD RAI No. 815-5986 Revision 3, SRP Section: 06.03 – Emergency Core Cooling System –Application Section: 6. 3.", August 23, 2011.
7. U.S. Nuclear Regulatory Commission, "Evaluation of Treatment of Effects of Debris in Coolant on ECCS and CSS Performance in Pressurized Water Reactors and Boiling Water Reactors", NUREG/CR-7011, May, 2010.
8. Mitsubishi Heavy Industries, Ltd., "Quality Assurance Program Manual (US-APWR Project Addenda)", UES-20080024 Revision 11, December 2011.

Figure 1 Schematic drawing of the test loop

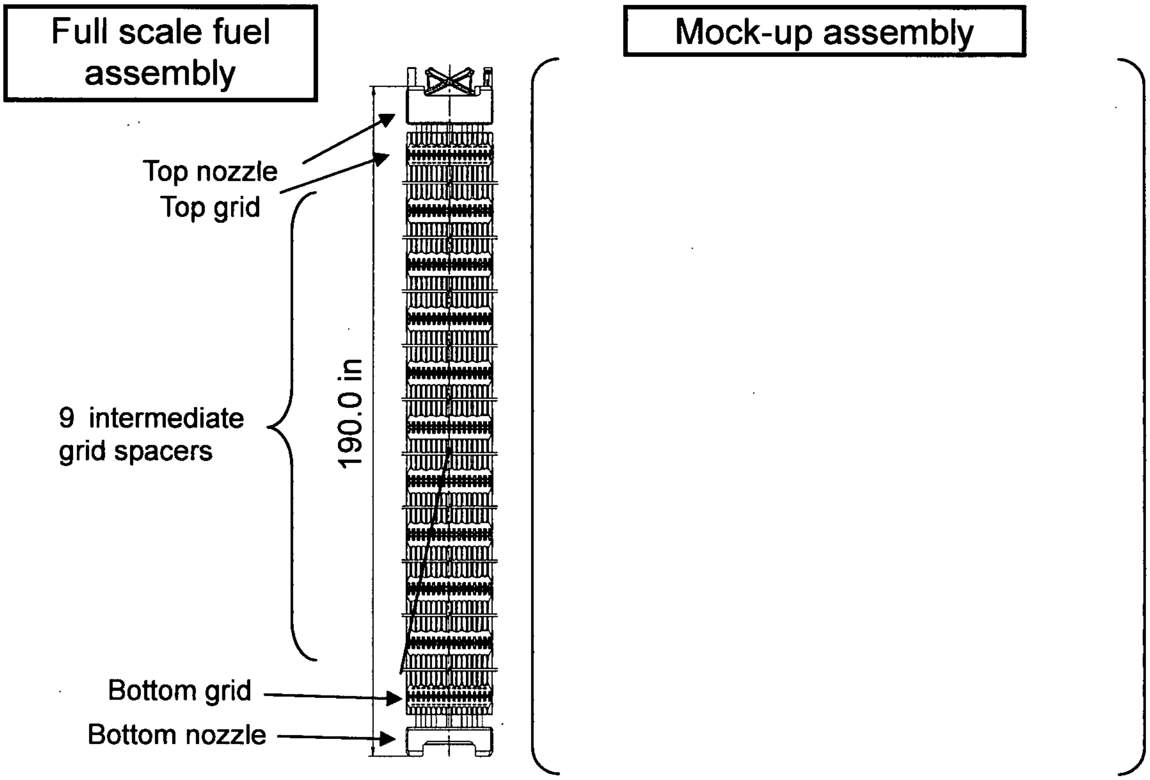
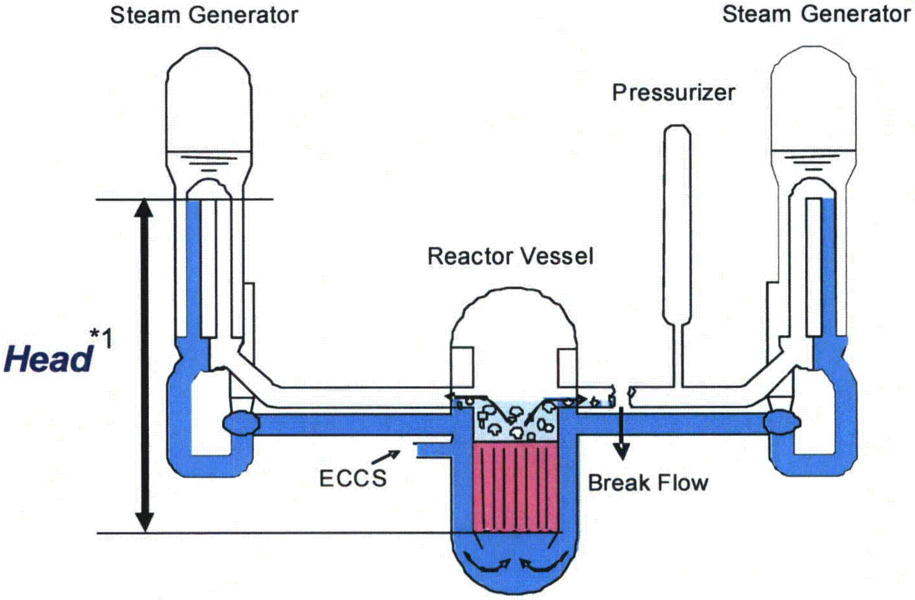


Figure 2 Comparison of the mock-up assembly for the test and full-scale assembly

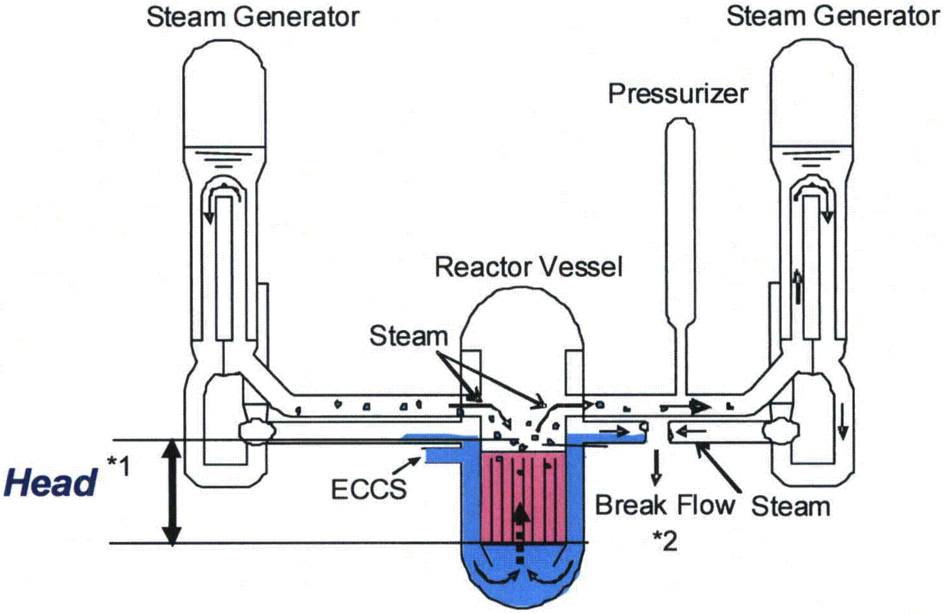
Figure 3: Test section and measurement positions

Figure 4: Half-gap size of test section



*1 Driving head reaches its peak right before the flow begins to spill over the shortest SG tubes

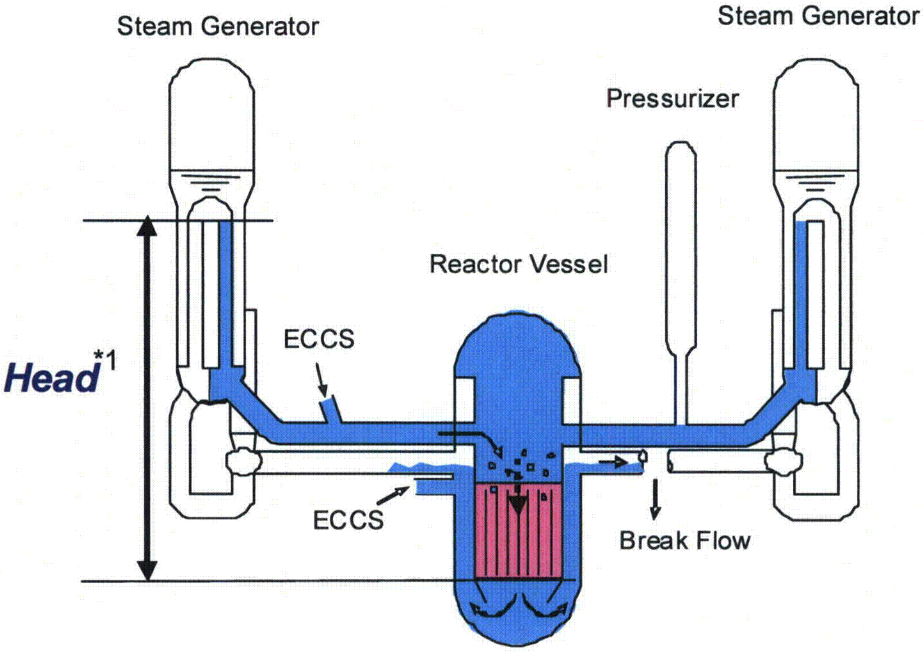
(a) Hot-leg break



*1 Driving head is defined as downcomer head and core head considering boiling
*2 Injected water spills out at the cold-leg piping level

(b) Cold-leg break

Figure 5: Illustration of the post-LOCA conditions (1/2)



*1 Driving head reaches its peak right before the flow begins to spill over the shortest SG tubes

(c) Cold-leg break after hot-leg switch over

Figure 5: Illustration of the post-LOCA conditions (2/2)

Table 1: Test conditions of flow rate

Case	Scenario	Flow direction	Test Flow Rate *1	US-APWR Flow Rate	Remarks
1	Non-debris-laden condition	Forward /Backward	Variable	-	
2	HL Break	Forward	22.8 gpm	5848gpm	Max. safeguard flow rate of Four(4) SI
3	CL Break	Forward	3.5 gpm	907gpm	Boil off flow rate at 850s
4	CL Break after HLSO	Backward	11.4 gpm	2924gpm	Max. safeguard flow rate of two(2) SI

*1:1/257 of the minimum required flow rate for the US-APWR

Table 2: Debris types and quantities

Table 3: Test condition of debris quantities

Table 4: Test matrix

Table 4: Schedule of the core inlet blockage test