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GSI-191 FA Test Report for PWROG – Low Particulate-to-Fiber Ratio Tests - NP

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1.0 BACKGROUND INFROMATION

1.1 Nomenclature

C/L Cold Leg

CSS – Containment Spray System

ECCS – Emergency Core Cooling System

FA – Fuel Assembly

GSI – General Safety Issue

H/L Hot Leg

LOCA – Loss of Coolant Accident

P/F ratio – Particulate to Fiber ratio

PWROG – Pressurized Water Reactors Owners Group

RV – Reactor Vessel

TSP – Trisodium Phosphate

1.2 Background

General Safety Issue – 191 (henceforth referred to as GSI-191) originated in 2002 with the concern of the regulator about the Long Term Core Cooling of PWR reactors following a LOCA event. Under this scenario, after the Boron Water Tank is exhausted, the suction of the Emergency Core Cooling System and the Containment Spray System would switch to the sump pool. At that point the debris (mechanical and chemical) that by-passes the strainers can reach the core. The mechanical debris (particulates and fiber) can come from the insulation and other components inside the containment. This mixed debris, specific to each plant, may consist of fibrous material (from the failure of insulation such as NUKON, and Temp Mat), particulates (from the failure of materials such as coatings, and microporous insulation), Reflective Mirror Insulation (RMI), and other miscellaneous debris types. This 'generated' debris will then mix with other latent and miscellaneous fibrous and particulate debris that has already become loose in containment as the sump pool fills with reactor coolant from the break. The chemical debris consists predominantly of precipitates. The specific precipitates are dependent upon plant buffer type and the pH of the sump medium. The predominant ones are [1]: aluminum oxyhydroxide (AlOOH), sodium aluminum silicate ($NaAlSi_3O_8$), and calcium phosphate ($Ca_3(PO_4)_2$) (the latter only identified in the presence of trisodium phosphate (TSP)).

The initial approach to the question of Long Term Core Cooling was analytic in nature [2], [3]. Using extensive modeling both Westinghouse Co. and AREVA showed that under some reasonable assumptions, the Long Term Core Cooling following a LOCA event is ensured. However, the regulator raised doubts regarding the core inlet clogging. Under this scenario, the coolant would be precluded from reaching the core by debris and chemical precipitates depositing on the fuel assemblies Bottom Nozzle. Consequently, a test program was established to investigate this hypothesis. The test program is governed by a Test Protocol included in Appendix G of [4]. The tests were conducted in two locations: a Westinghouse Co. internal facility for Westinghouse fuel, and an independent lab, Continuum Dynamics Incorporated (CDI) located in New Jersey, for AREVA fuel.

The two facilities were similar in terms of general test loop architecture. A schematic of the test loop is shown in Figure 1-1

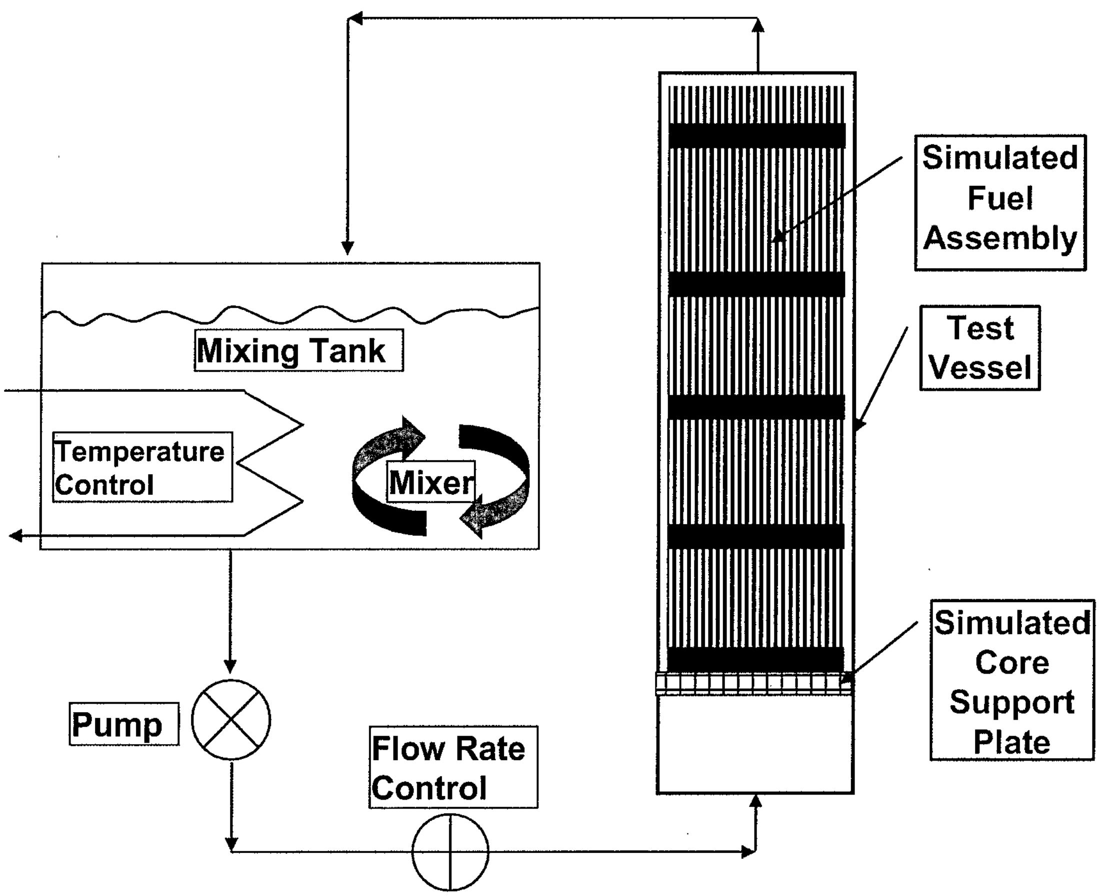

Figure 1-1: Conceptual Arrangement of Test Loop

The tests were conducted in three campaigns:

1. The initial set of tests was conducted in 2008, and was characterized by a high particulate-to-fiber ratio. The results were documented in reference [5]. The test matrix is reproduced in Table 1-1.
2. The second set of tests was conducted at low particulate-to-fiber ratios. These tests are documented in the current document, in Appendix A.1 per reference [6]. The test matrix is reproduced in Table 1-2.
3. The third set of tests groups all tests performed after May 2010. These tests consisted of one cross-test at Westinghouse, and a high temperature test at CDI. These tests are also documented in the current document. For the cross-test there is no formal reference. The plots

are derived from hand notes taken by AREVA personnel who witnessed the test. The high temperature test is documented in Appendix 0, per reference [7]. The test matrix is reproduced in Table 1-3.

In the next section we discuss these test results in more detail.

Table 1-1: First Set of Tests – High Particulate-to-Fiber Ratios

Test	Flow (gpm)	Particulate (g)	Fiber (g)	Chemical (g)	Final P:F	Total Assembly dP before Chem (psid)	Total Assembly dP after Chem (psid)	Final Flow after Chem (gpm)	Notes	Reference
FM-FPC-W-1	44.7	13152	110	4540	120	9.5	8.67	44.7		[4]
FG-FPC-W-2	44.7	13152	150	4540	88	6.8	7.13	44.7		[4]
CM-FPC-W-3	44.7	13152	150	4540	88	7.6	7.36	44.7		[4]
FG-FPCSC-W-5	44.7	13152	150	4540	88	1.6	2.07	44.7	Added 6 lbs Calcium Silicate	[4]
FG-FPMC-W-6	44.7	13152	150	4540	88	6.7	7.63	44.7	Added 1.2 lbs Microtherm	[4]
FG-FPC-CE-7	11.0	7950	150	5900	53	6.2	8.65	11.0		[4]
FG-FPC-W-10	3.0	13152	100	4540	132	2.3	2.31	3.0		[4]

Table 1-2: Second Set of Tests – Low Particulate-to-Fiber Ratios

Test	Flow (gpm)	Particulate (g)	Fiber (g)	Chemical (g)	Final P:F	Total Assembly dP before Chem (psid)	Total Assembly dP after Chem (psid)	Final Flow after Chem (gpm)	Notes	Reference
1-FG-FPC	3	380	75	833	5.0	1.61	12.93	1.7		[6]
2-FG-FPC	3	810	18	833	45.0	0.11	0.53	3		[6]
3-FG-FPC	45	1500	150	833	10.0	9.96	12.98	40.9		[6]
4-FG-FPC	45	1500	150	833	10.0	8.93	12.91	40.3		[6]
5-FG-FPC	45	150	150	833	1.0	13.18	13.13	0		[6]
6-FG-FPC	45	150	100	833	1.5	9.37	13.03	0	Water temp 105degF, all other runs 70	[6]
7-FG-FPC	44.7	60	60	833	1.0	6.26	13.91	0	fiber blended for an additional 300 seconds	[6]
8-FG-FPC	45	150	60	417	2.5	7.86	13.33	0	baked fiber supplied by W blended for 60 seconds	[6]
9-FG-FPC	44.7	20	20	833	1.0	1.33	13.95	12.6		[6]
10-FG-FPC	44.7	150	46	16.5	3.3	3.05	13.91	0		[6]
11-FG-FPC	44.7	150	60	417	2.5	5.65	14.1	0		[6]
12-FG-FPC	44.7	15	15	833	1.0	0.61	2.7	44.8		[6]
13-FG-FPC	44.7	30	15	833	2.0	0.67	2.56	44.7		[6]

Table 1-3: Third Set of Tests

Test	Flow (gpm)	Particulate (g)	Fiber (g)	Chemical (g)	Final P:F	Max dP before Chem (psid)	Max dP after Chem (psid)	Final Flow after Chem (gpm)	Notes	Reference
Cross-test 2010	44.7	150	150	N/A	1.0	~16	>18	0	The first batch of chemical precipitate caused the pressure to exceed the loop mechanical limits, and the pump was automatically stopped.	For information only
High temp	44.7	25	25	833	1.0	0.9	13.8	7.5	The temperature was maintained at 130 deg F throughout the test, and the chemical precipitate introduction was more gradual, starting with very small increments, and progressing to larger batches towards the end.	[7]

2.0 TEST RESULTS DISCUSSION

From the first and second set of tests we can formulate a few conclusions:

1. The quantity and composition of the debris load and the flow rate are key parameters which determine the pressure drop across the test assembly.
2. The high flow rate cases (corresponding to the Hot Leg Break for W and B&W plants) are the most limiting.
3. The ratio of particulate to fiber content is also a major factor. The lower particulate to fiber ratio (near 1:1) test cases have proven to be the limiting cases in both the AREVA and Westinghouse H/L break tests.
4. The debris deposition pattern is dependent on the P/F ratio. For high ratios (excess particulate with respect to fiber) the debris deposits on all Spacer Grids, forming debris layers on the underside, in both the AREVA and Westinghouse tests. For low P/F ratios, the debris accumulates on the Lower End Grid for the AREVA tests.
5. The Bottom Nozzle design is not the limiting location for debris accumulation, for any combination of flow conditions, and particulate and fiber load. This has been proven by testing several designs, including the FUELGUARD, and the Coarse Mesh TRAPPER.

One important characteristic of the low particulate-to-fiber ratio tests was that the two facilities (Westinghouse and CDI/AREVA) produced substantially different results. While the AREVA tests indicated a debris tolerance of 15 grams of fiber per fuel assembly at 1:1 particulate-to-fiber ratio (Run 12-FG-FPC in Table 1-2), the Westinghouse results, of early 2009 seemed to indicate a much higher debris tolerance (150 grams of fiber per fuel assembly). As a consequence, an investigation into the possible cause for this discrepancy was undertaken. The results are documented in reference [8]. The conclusion of that study was that the debris clogging tests were operating at high blockage ratios, and, as a consequence, small variations in the loop parameters, test article, or the debris bed structure could result in large, one order of magnitude changes in debris tolerance. To be able to decide whether the results discrepancy was due to the test article design differences or to the test loop and/or debris characteristic differences, a partial cross-test (AREVA fuel assembly in the Westinghouse loop) was carried out in September 2010, together with two control tests aimed at reproducing the previous Westinghouse results. The main conclusion of these tests is twofold:

1. The two test loops (RTU/Westinghouse, and CDI/AREVA) behave differently. From Figure 2-1 it is apparent that the CDI results with the AREVA fuel assembly were not reproduced in the RTU/Westinghouse loop using the AREVA test assembly. Further, the debris deposition pattern was different: multiple beds in the RTU loop vs. single bed in the CDI facility. Also, the strength of the debris beds was lower in the RTU loop. The lower grid debris bed punctured at 6 psid in the RTU loop, while in the CDI loop it withstood more than 13 psid.
2. The AREVA and Westinghouse Fuel Assemblies behaved virtually identically in the RTU/Westinghouse loop. This is based on Figure 2-1, by comparing the AREVA and Westinghouse test assembly results in the RTU loop.

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Figure 2-1: Control and Cross-Test Results (w/o chemicals)

Note: Data is for information only

Following the new knowledge gained from the cross-tests of 2010, a conservatism reduction effort has been initiated. As part of this effort, run 1-FG-FPC-0711 was conducted. The exercise was based on the hypothesis that higher coolant temperature together with a more incremental introduction of the chemical debris, would result in a debris tolerance benefit.

Hence, a more aggressive fiber load of 25 grams per Fuel Assembly was used (details about the test protocol are presented in reference [7]). The test was carried out on both the AREVA and Westinghouse assemblies, in the CDI loop under identical conditions. While these new test conditions failed to produce a higher fuel assembly debris tolerance, it is worthwhile to note that the AREVA and Westinghouse assemblies behaved very similarly in the CDI facility. From the results plotted in Figure 2-2 it is apparent that the evolution of the pressure drop as the debris introduction progressed over time was almost the same, with the Westinghouse assembly recording somewhat higher pressure drops.

Based on the high fiber load cross-test and control test of 2010 and the low fiber load tests of 2011, it can be concluded that the design differences between the AREVA and Westinghouse assemblies have no discernible influence on the debris tolerance, and the results differences must be attributed to the differences in test loop design, test chemicals, air entrainment, etc...

Figure 2-2: CDI Tests with Elevated Temperature

Note: Westinghouse data is for information only

Based on the high fiber load cross-test and control test of 2010 and the low fiber load tests of 2011 it can be concluded that:

1. The Fuel assembly design differences between a Westinghouse 17x17 and an AREVA 17x17 have no meaningful influence on the debris tolerance levels for the purposes of Long Term Core Cooling.

2. There are important differences between the CDI/AREVA loop, and the RTU/Westinghouse loop. These loop differences are likely responsible for the differences in results at the two sites.

3.0 REFERENCES

1. 51-9070610-001, Chemical Precipitation Analysis for St. Lucie Unit 2 Using WCAP-16530-NP, April 2008.
2. WCAP-16793-NP, Revision 0, Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Re-circulating Fluid, May 2007.
3. 51-9013299-000, Boron Precipitation Analysis Review for B&W Plants, June 2006.
4. WCAP-16793-NP, Revision 1, Evaluation of Long-Term Cooling Considering Particulate, Fibrous and Chemical Debris in the Re-circulating Fluid, April 2009.
5. 51-9102685-000, GSI-I 91 FA Test Report for PWROG, March 2009.
6. 38-9138869-000, "AREVA Fuel Assembly Test Report – CDI Report 10-02, Rev.3" May 2010.
7. 38-9169728-000, "AREVA Fuel Assembly Test Report – CDI Report 11-14, Rev.0" September 2011.
8. 12-9134547-000, GSI-191 Fuel Assembly and Head Loss for Long Term Core Cooling - Test Comparison, April 2010.

APPENDIX A: TEST RESULTS

A.1 Second Test Set Results

These results are discussed in more detail in reference [6]. Here, we are only reproducing the relevant pressure drop and flow rate plots, together with relevant test parameters.

Figure A-1: Run 1-FG-FPC Results

Figure A-2: Run 2-FG-FPC Results

Figure A-3: Run 3-FG-FPC Results

Figure A-4: Run 4-FG-FPC Results

Figure A-5: Run 5-FG-FPC Results

Figure A-6: Run 6-FG-FPC Results

Figure A-7: Run 7-FG-FPC Results

Figure A-8: Run 8-FG-FPC Results

Figure A-9: Run 9-FG-FPC Results

Figure A-10: Run 10-FG-FPC Results

Figure A-11: Run 11-FG-FPC Results

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Figure A-12: Run 12-FG-FPC Results

Figure A-13: Run 13-FG-FPC Results

High Temperature Test Results

These results are discussed in more detail in reference [7]. Here, we are only reproducing the relevant pressure drop and flow rate plots.

Figure A-14: Run 1-FG-FPC-0711 Results