3.2.1.3 Coupon racks

The coupon racks were produced with plastic piping made of CPVC of 1.5 in. diameter.
The racks were designed to prevent galvanic corrosion which test coupons do not contact with other coupons, other parts.
Width of each coupon in the rack is 0.6 in.
The racks were reinforced by the angle steel of two inches in width ×1/6 in. in thickness.
The weight of a coupon rack is 20.5 Ibm(9.3 kg).
External view of the coupon rack is shown in Figure 3.2-8 and Figure 3.2-9.

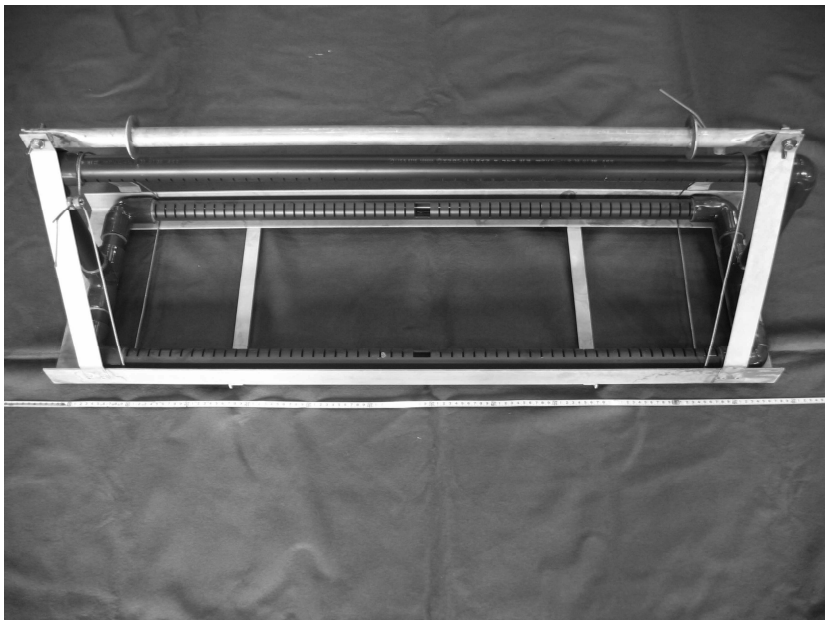

Figure3.2-8 Photo of coupon rack

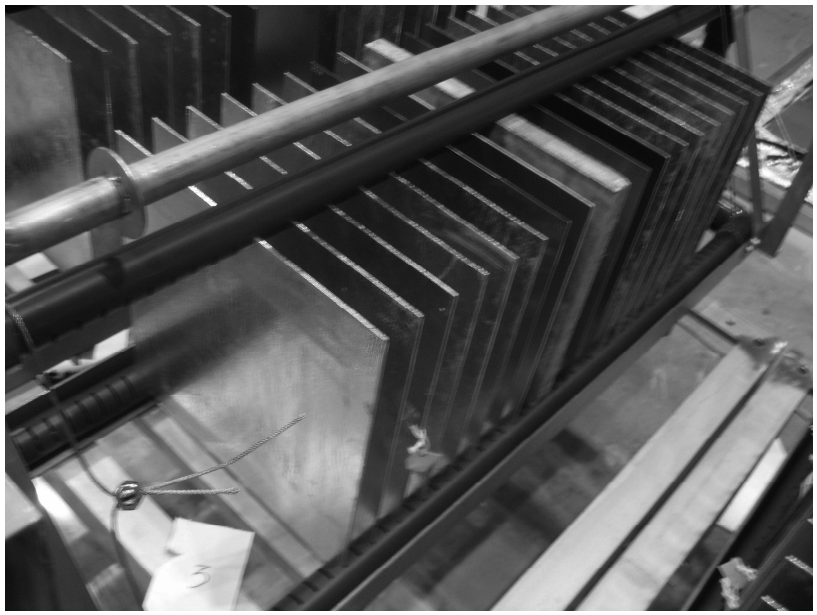

Figure3.2-9 Photo of coupon rack with coupons

3.2.1.4 Tank Insulation

The outer wall of test tank was insulated with fiberglass.
The surface area of the test tank and the cover lid is about 130 ft^2.
Moreover, pipes were insulated by fiberglass to keep test water temperature and for the burn prevention.
The heat loss during recirculation operation is estimated about 1.7 KW.

3.2.1.5 Tank Heaters

The heater in test tank was made with titanium sheath, to prevent corrosion in the test solution for test operation period,
Test water temperature was controlled by one heater and the tank has two heaters with capacity of 3.5 KW.

3.2.1.6 Pump Selection

Material of pump with touching test solution was made of SUS304 and with teflon seal for chemically endured by boric acid and sodium tetra borate solution.
Circulating pump was selected to throw maximum flow rate of 100 gpm (380L/min).
The pump had variable rotating speed controller to control constant flow rate in regardless with change of the pressure loss of the system.
The specified flow rate of recirculation test solution was about 52.8 gpm (200L/min).
Two respectively feed water headers in test tank put following the waterline along upper portion of coupon rack in test solution of the tank. The headers consist of the pipe about 1in. of diameter that provides with symmetry hole of water feed.
The photograph of the selected circulating pump is shown in Figure 3.2-10.

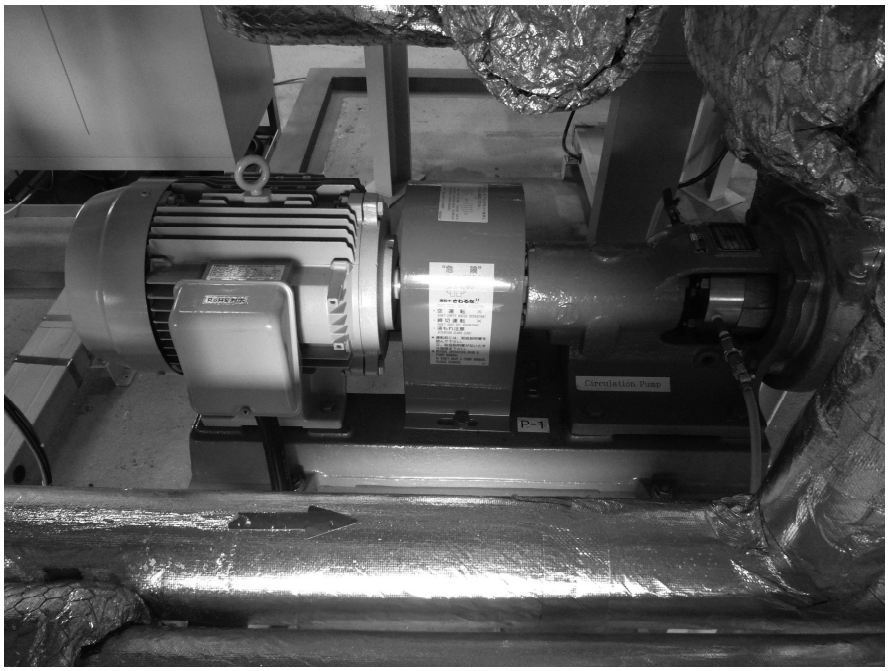

Figure3.2-10 Circulation pump

3.2.1.7 others

Recirculation test apparatus has preparation tank to make test solution and feed pump to supply test solution from preparation tank to test tank.
The preparation tank is equipped with the agitator made of stainless steel and the heater made of stainless steel and of diameter 3.6 ft, 4.8 ft in height.
The heater capacity of preparation tank is 5.5 KW.
The feed pump of preparation tank was selected no seal type made of stainless steel.
Feed water pipe of preparation tank to test tank was insulated by fiberglass.

3.2.2 Autoclave Test Apparatus

3.2.2.1 Materials

Components of the test vessel and piping, etc. were designed by material stainless steel that are chemically endured at range of pH 3.0-9.0 of the mixed liquid for pure water, boric acid, lithium hydroxide (LiOH), and hydrochloric acid (HCl) and the temperature of 284 °F.
Sampling bottle was used glass beaker to endure chemically test solution and to endure thermally temperature at 149 °F.

The filter on sampling line to collect solid substance was used material stainless steel type 316(SUS316) to endure chemically test solution and thermally temperature 284 °F.
The coupon rack is made of teflon of 7.5 in. in diameter, and the racks were designed to prevent galvanic corrosion which test coupons do not contact with other coupons, other parts.
The agitator in test vessel is made of SUS316.

3.2.2.2 Tank Sizing

The test vessels made of SUS316 have volume capacity of 2.6 gallons with column shape which 7.9 in. in diameter ×12.6 in. in height. The tests were conducted with test solution of 1.8 gallons.
Moreover, the coupon rack with 7.5 in. in diameter × 5.9 in. height and agitator are set up in the test vessel.
The view of autoclave test apparatus is shown in Figure 3.2-11 and drawing of the test vessel is shown in Figure 3.2-12. The photograph of interior for test vessel is shown in Figure 3.2-13 and 14.

Figure 3.2-11 View of two Autoclave Test Apparatus

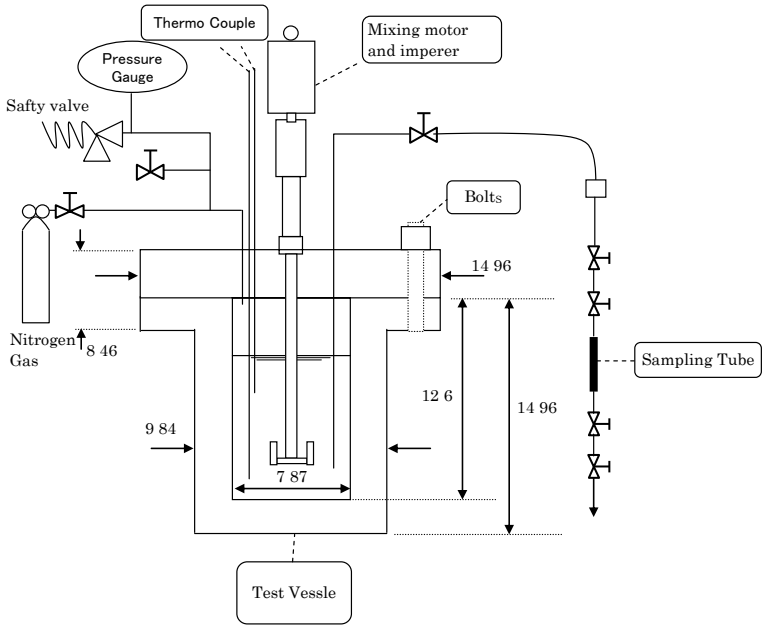

Figure 3.2-12 Drawing of Autoclave Test Vessel. Dimensions are in inches.

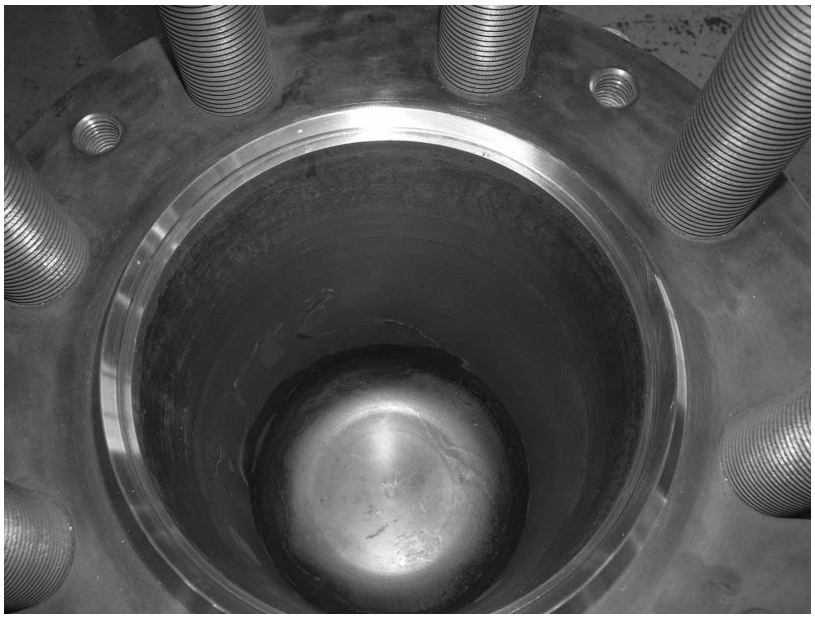

Figure3.2-13 Interior aspect of test tank

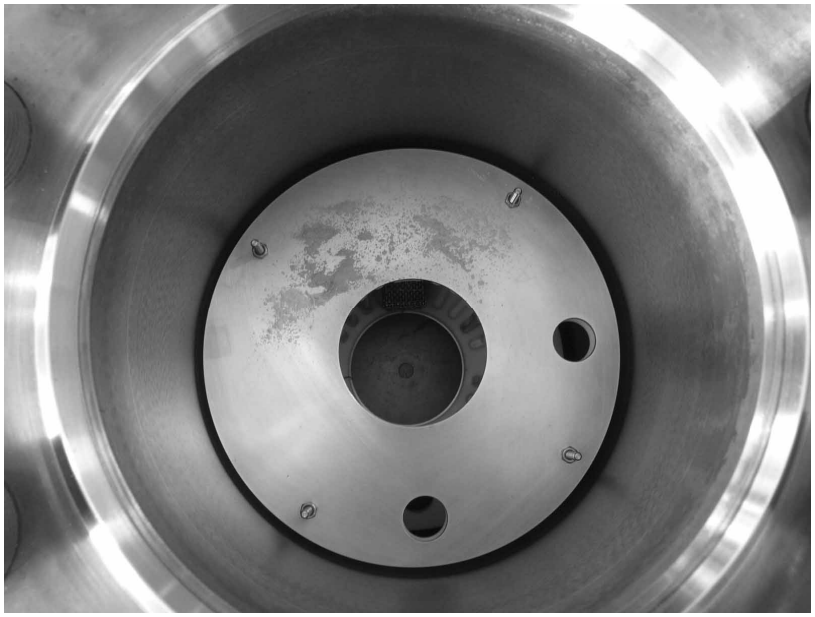

Figure3.2-14 Interior aspect of test tank with coupon rack

3.2.2.3 Coupon Rack

Test coupons are fixed between top and bottom of coupons with spacer made of Teflon . Smaller size of coupons is fixed by using Teflon string and stainless steel wire after insulation by Teflon.

The coupon rack externals photograph and the outline drawing are shown in Figure 3.2-15 and 16.

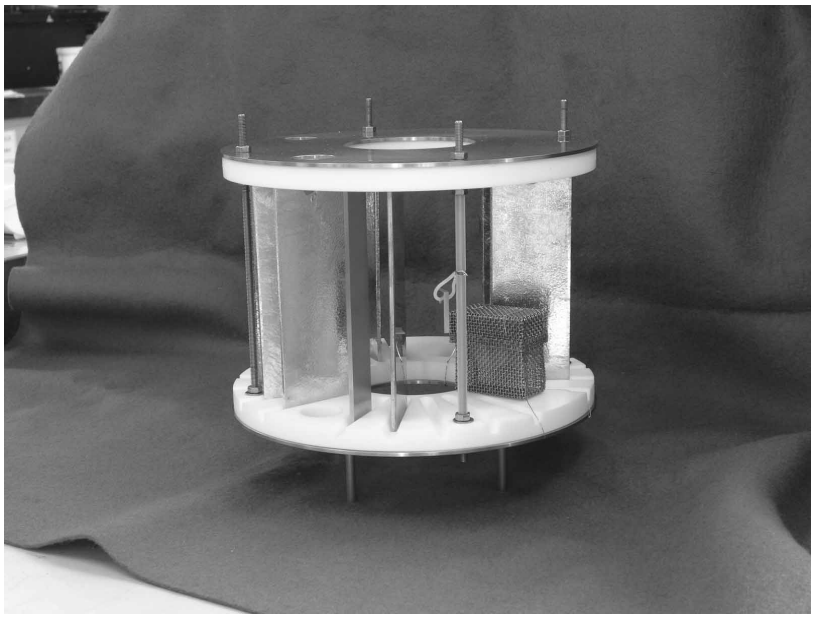

Figure3.2-15 Coupon rack with test coupons

Figure3.2-16 Drawing of coupon rack. Dimensions are in inches.

3.2.2.4 Tank Insulation

The heater was installed to surround the test vessel and the test tank surroundings were protected with heatproof cement to insulate it from heat.

3.2.2.5 Tank Heaters

To achieve high temperature test condition, the heater of the tank has capacity of[ ]KW.
The test solution temperature is controlled by the heater input base on test solution temperature measurement.
The heater power supply falls as when the upper bound temperature is set to 302 °F.

3.2.2.6 Others

To take solution sample in the state of test temperature, sampling line is connected to vessel head.
And to take solution sample lower than 212 °F, nitrogen pressurizing line is connected to vessel head.
Safety pressure valve is set to 1.5 MPa to avoid abnormally pressure increase inside test vessel.

3.3 Experimental Plan and Test Matrix

Chemical effect tests were conducted by recirculation test for long term and autoclave tests for short term post-LOCA.

(Recirculation test)

Recirculation test simulated 30days long term duration post-LOCA.

(Autoclave tests)

Autoclave tests simulated 100Hours short term duration post-LOCA.

3.3.1 Physical Parameters

Physical conditions of US-APWR such as temperature, water volume, flow rate, etc. were shown in Table 3.3-1 together with this chemical effect tests condition.

Table 3.3-1 Physical Parameters of US-APWR and Chemical Effect Tests

Items		US-APWR Condition	Test Condition	
			Recirculation Test	Autoclave Test
Post-LOCA Recirculation Sump Water Volume (Min.)		43000 ft^3 (1218m^3)	Tank Water Volume 264 gallon (1 m^3)	Test Vessel Water Volume 1.8 gallon (7 L)
RCS Water Volume(Min.)		83700gallon (317m^3)		
Recirculation Water Flow Rate(max.)		15960 gpm (3625 m^3/h)	0-52.8 gpm (0-200 L/min)	Solution agitated
Spray Water Flow Rate	Max.	9800 gpm (2226 m^3/h)	0-7.9 gpm (0-30 L/min)	All coupons are submerged in solution.
	Min.	5290 gpm (1201 m^3/h)		
	Flow/Area Ratio(Velocity)	0.00125ft/s (0.038 cm/s)	0-0.00125 ft/s (0-0.038 cm/s)	
Recirculation Sump Water Temperature	Initial	120 °F (49°C)	149 °F constant	1, 149 °F constant 2, max. 284 °F transient
	Max.	256°F (124°C)		
	Long Term	Less than 149 °F (65 °C)		
Test duration		—	30 days	100 Hours (24 Hours :acid. condition)

Recirculation flow rate is 200 L/min(52.8 gpm), which recirculation water turnover is about 10 times per hour.(sump water turnover is 1-2 times per hour)

(1) Temperature

Figure 3.3-1 compares the estimated sump water temperature profile (solid line, Ref. 5), which has a peak at 256 °F, to the recorded temperature profile of the standard condition of the transient temperature autoclave test (dashed line). The test temperature profile is maintained above 284 °F for one hour surrounding the 3 hour point, which is approximate to the peak autoclave temperature. The estimated temperature profile has its peak value of 256 °F around 2 hours. The figure shows that the test temperature bounds the estimated temperature, as a whole, with a large margin, and that the inversion during the first hour is so small that its effect on the validity of the test is negligible.

Figure 3.3-1 Short Term of Recirculation Sump Water Temperature Profile

Figure 3.3-2 compares the test temperature and estimated sump water temperature of the recirculation test from 100 hours to 30 days. The test temperature is maintained around 149 °F over the entire test period and it completely bounds the estimated temperature.

Figure 3.3-2 Long Term of Recirculation Sump Water Temperature Profile

(2)Test Duration
Recirculation test was performed for 30 days.
Autoclave tests were performed for100Hours which was targeted short term duration immediately post-LOCA except for acidic condition tests. Acidic condition tests were performed for 24 Hours.

(3)Recirculation flow rate
In recirculation test, the test solution was fed from test tank to recirculation system through solution line and spray line, and then the solution was fed back to test tank.
Total maximum flow rate of recirculation is 52.8 gpm and the maximum spray flow rate is 7.9 gpm.
The ratio of spray flow rate to CV (containment vessel) cross sectional area in the US-APWR was targeted to be the same as the ratio of spray flow rate to test tank cross sectional area. In autoclave tests, the test solution was agitated inside vessel without recirculation.

3.3.2 Chemistry Parameters

Chemistry parameters of the sump water in the US-APWR plant are shown in Table 3.3-2.
Chemistry parameters of the test solution for the recirculation test and autoclave tests are shown in Table3.3-3
The test solution was controlled to be more alkaline to obtain conservative corrosion and elusion data results from the coupons. Tests with boric acid, LiOH, NaTB environments were also performed with an alkaline environment in the sump water.
Boric acid concentration was calculated from minimum of recirculation sump water volume and of RCS water volume based on minimum of boric acid concentration for US-APWR.
Li concentration was calculated from dilution of maximum of Li concentration in RCS water by mixture with recirculation sump water volume in US-APWR.
NaTB concentration was calculated by dissolution of maximum NaTB quantity in recirculation sump water and RCS water in US-APWR.

Both recirculation test and autoclave tests were performed under condition above-mentioned as standard base condition.

Acidic and alkaline condition tests were performed as sensitivity examination in autoclave tests to confirm the influence with environment in addition to standard condition changed.
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Table 3.3-2 Chemistry condition for US-APWR

Item		Plant condition	Test condition as Standard	Remarks
Recirculation sump water boric acid conc.(as B)	Max.	4200 ppm	3200 ppm	(4000 ppm×1218 m^3+0 ppm×317 m^3) / (1218 m^3+317 m^3) More alkaline condition at post-LOCA with mixture of sump water and RCS water, which is conservative for corrosion.
	Min.	4000 ppm		
RCS Boric acid conc(as B)	Max.	2250 ppm		
	Min.	0 ppm		
RCS Li conc.	Max.	3.5 ppm	0.7 ppm	(0ppm × 1218 m^3+3.5ppm×317 m^3)/(1218 m^3+317m^3) More alkaline condition as same as boric acid condition.
	Min.	0 ppm		
NaTB dose（max.）		22 ton	14 g/L	22ton／(1218 m^3+317m^3)
HCl conc.（max.）		0-100 ppm	0,50,100 ppm	conservatively estimated HCl value that may be generated during 100Hours, 30day post-LOCA

Recirculation sump water volume(min.) : 43000 ft^3 (1218 m^3)
RCS water volume(min.) :83700gallon (317 m^3)

Table 3.3-3a Chemistry condition for Recirculation test

Temp (deg F)	Buffering Agent	Boron (ppmB)	NaTB (gram/liter)	HCl (ppm)	Li (ppm Li)	pH*
149	H_3BO_3+NaTB	3200	14	100	0.7	7.8

＊：pH value is defined by the chemistry concentration, is approximate value.
＊：estimated HCl value that may be generated during 30 day post-LOCA

Table 3.3-3b Chemistry condition for Autoclave test

	Run		Temp. (deg F)	Buffering Agent	Boron (ppm B)	NaTB (gram/liter)	HCl (ppm)	Li (ppm Li)	pH*
A-7	(acidic)	Constant Temp.	149	H_3BO_3	4200	0	0	0	4.3
A-2	**Standard condition**		**149**	**H_3BO_3 +NaTB**	**3200**	**14**	**50**	**0.7**	**7.8**
A-3	(alkaline)		149	H_3BO_3 +NaTB	3200	40	50	0.7	8.4
A-8	(acidic)	Transient Temp.	284	H_3BO_3	4200	0	0	0	4.3
A-5	**Standard condition**		**284**	**H_3BO_3 +NaTB**	**3200**	**14**	**50**	**0.7**	**7.8**
A-6	(alkaline)		284	H_3BO_3 +NaTB	3200	40	50	0.7	8.4

＊：pH value is defined by the chemistry concentration and is an approximate value.
＊：estimated HCl value that may be generated during 100Hours post-LOCA

3.3.3 Test Materials

Amount of test materials in US-APWR and in chemical effect tests are shown in Table 3.3-4. Amount of test materials in the tests was simulated with US-APWR condition to conserve each ratio of amount of materials to sump circulation water volume.
In the recirculation test, materials were placed in submerged and un-submerged areas to simulate the chemistry effects in the US-APWR.
In autoclave tests, all test materials were placed in test solution.

Table 3.3-4 Sump debris sources for US-APWR and tests

Material	US-APWR condition		Tests condition as required			
			Recirculation test Note3			Autoclave tests Note4
	Containment Quantity	Material/Sump Water Ratio Note1	Materials	Sub merged (%) In pool	Un-sub merged (%) Spray zone	Materials In pool
Nukon™ insulation	14.38 ft^3 (0.41 m^3)	0.00027 ft^3/ ft^3 (0.00027 m^3/ m^3)	0.023 lbm (10 g Note2)	100	0	0.00016 lbm (0.073 g Note2)
Concrete particulate	170 lbm (77.1 kg)	0.003 lb/ ft^3 (0.05 kg/ m^3)	0.11 lbm (50 g)	100	0	0.0008 lbm (0.35 g)
Galvanized steel	242000 ft^2 (22500 m^2)	4.5 ft^3 (14.7 m^2/ m^3)	158 ft^2 (14.7 m^2)	0	100	1.1 ft^2 (1025 cm^2)
Aluminum Note5	810 ft^2 (75 m^2)	0.015 ft^2/ ft^3 (0.05 m^2/ m^3)	0.53 ft^2 (0.05 m^2)	0	100	0.0037 ft^2 (3.4 cm^2)
Concrete	1050 ft^2 (97.5 m^2)	0.019 ft^2/ ft^3 (0.06 m^2/ m^3)	0.68 ft^2 (0.06 m^2)	0	100	0.0048 ft^2 (4.4 cm^2)
Carbon Steel	8000 ft^2 (743 m^2)	0.15 ft^2/ ft^3 (0.48 m^2/ m^3)	5.2 ft^2 (0.48 m^2)	0	100	0.036 ft^2 (34cm^2)
Copper	21500 ft^2 (2000 m^2)	0.40 ft^2/ ft^3 (1.3 m^2/ m^3)	14.0 ft^2 (1.3 m^2)	0	100	0.098 ft^2 (91 cm^2)

Note1 Based on the minimum-water volume which is total of minimum sump water volume (43000) ft^3 (1218 m^3) and the RCS volume (317m^3).

Note2 To be converted to a mass to volume ratio based on the specific fiberglass density(2.4 lb/ft^3)(38 kg/m^3).

Note3 Test tank volume of recirculation test is 264 gallon(1 m^3)

Note4 Test tank volume of autoclave tests is 1.8 gallon(7 Liters). All tests materials are sub-merged.
Note5 5052 alloy is used as a representative material of sheet metals.

The amount of test materials was simulated to be consistent with US-APWR as shown in Table 3.3-4.
The test coupon condition in chemical effect tests is shown in Table 3.3-5.

Table 3.3-5 Quantity of chemical debris coupons for tests

Material	Recirculation Test			Autoclave Tests		
	Quantity as required		Test condition	Quantity as required		Test condition
	Quantity	Number of pieces Note1	Number of pieces Note1	Quantity	Number of pieces Note2	Number of pieces Note2
Nukon™ insulation	0.023 lbm (10 g)	0.023 lbm (10 g)	0.11 lbm (50 g)	0.00016 lbm (0.073 g)	0.00016 lbm (0.073 g)	0.0008 lbm (0.35 g)
Concrete particulate	0.11 lbm (50 g)	0.11 lbm (50 g)	0.11 lbm (50 g)	0.0008 lbm (0.35 g)	0.0008 lbm (0.35 g)	0.0008 lbm (0.35 g)
Galvanized steel	158 ft^2 (14.7 m^2)	77.5	78	1.1ft^2 (1025 cm^2)	9.9	11
Aluminum	0.53 ft^2 (0.05 m^2)	0.26	1	0.0037 ft^2 (3.4 cm^2)	0.62	1
Concrete	0.68 ft^2 (0.06 m^2)	0.29	1	0.0048 ft^2 (4.4 cm^2)	0.66	1
Carbon Steel	5.2 ft^2 (0.48 m^2)	2.6	3	0.036 ft^2 (34 cm^2)	0.62	1
Copper	14.0 ft^2 (1.3 m^2)	6.9	7	0.098 ft^2 (91 cm^2)	0.88	1

Note1 Size of coupons for recirculation test.

Galvanized steel, Aluminum, Carbon Steel, Copper :

12 in. square, 0.1in. thick. (30.5*30.5*0.25 cm)

Concrete : 12 in. square, 1 in. thick. (30.5*30.5*2.5 cm)

Note2 Size of coupons for autoclave tests.

Galvanized steel, Copper : 4.7 in. * 1.6 in., 0.1 in. thick.(12*4*0.25 cm)

Carbon Steel : 4.7 in. * 0.8 in., 0.1 in. thick. (12*2*0.25 cm)

Aluminum : 0.4 in. * 0.8 in., 0.1 in. thick.(1*2*0.25 cm)

Concrete : 0.5 in. cubic. (1.3*1.3*1.3 cm, 2 faces are covered with fixing plate)

3.4 Test Procedure and Methods

3.4.1 Test Operation

The general practices for testing given in a portions of ASTM G4(Ref.6) and G31 (Ref.7) were used, as applicable, to perform the test. Detailed test procedures or instructions were developed.

3.4.1.1 Recirculation Test

The following general sequence of events is to be followed for the testing:

1) The cleanliness of the test loop shall be verified. Between test runs the loop shall be cleaned in accordance with applicable portions of ASTM A 380-99 (Ref.8), Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems. No observable scale or sediment shall be present in the test tank or loop piping, and the loop water conductivity (after cleaning) shall be < 5 mS/m and turbidity shall be < 0.3 NTU.

2) The preparation (pre-mix) tank shall be filled with demineralized water, heat and chemicals added and adjusted as required for the initial test run conditions temperature. The chemical analysis of the demineralized water and preparation tank water shall be recorded.

3) The sample coupons and other test material (insulation, debris) shall be placed onto the test sample racks inside the recirculation test tank.

4) The preparation (pre-mix) conditioned water will be transferred into the test tank (this takes approximately 10 minutes).

5) The temperature of the system and flow rates shall be adjusted to the required operating temperature and flow rates. Once established, record the test time and this becomes t = 0.

6) Operation of the test loop shall be performed with conditions representative of postulated post-LOCA conditions.

7) Fluid sampling shall be performed at 24 hour intervals. Sample size for filtered and unfiltered fluid shall be limited to 250 ml each for the circulating test.

8) The fluid level shall be monitored daily. Provisions should be established to determine the change in fluid volume versus fluid level. It is intent to not add fluids after the start of the test to make up removed liquid from sampling and vaporization. However, to factor into the analysis, the volume of fluid lost shall be necessary.

3.4.1.2 Autoclave Tests

The following general sequence of events is to be followed for the testing:

1) The cleanliness of the test vessel shall be verified. Between test runs the vessel shall be cleaned in accordance with applicable portions of ASTM A 380-99 (Ref.8), Standard Practice for Cleaning, Descaling, and Passivation of Stainless Steel Parts, Equipment, and Systems. No observable scale or sediment shall be present in the test vessel, and the vessel water conductivity (after cleaning) shall be < 5 mS/m and turbidity shall be < 0.3 NTU.

2) The sample coupons and other test material (insulation, debris) shall be placed into the test sample racks and inserted into the test vessel.

3) The preparation (pre-mix) vessel shall be filled with demineralized water and chemicals added and adjusted as required for the initial test run conditions. The chemical analysis of the demineralized water and test water shall be recorded.

4) Transfer the contents from the pre-mix tank to the autoclave.

5) The autoclave shall be set to operating temperature and establish t = 0 once temperature is achieved.

6) The autoclave shall be operated to achieve the required temperature profile provided in Figure 3.3-1.

Increase temperature of liquid in the vessel from room temperature to 284°F within approximately 2 hours.
A temperature of liquid in the vessel shall be kept at 284 °F in 1hour.

Decrease temperature of liquid in the vessel following 100 hours and establish t=end.

7) Samples shall be obtained every 24 hours during test run except low pH test which samples shall be obtained every 4 hours until 12 hours over. Sample size for liquid shall be limited to 20-25 ml for the autoclave test.

3.4.2 Test Termination Criteria

The criteria for termination are based on the following:

1. The first long time core cooling test was run for 30 days.
2. Maximum duration of long time core cooling test is limited to 30 days. Duration of subsequent test runs following the initial run will be determined after evaluating the results of the first run, and will consider establishing steady state conditions.
3. Maximum duration of the autoclave test will be limited to 100 hours.
4. Low pH (Acidic) test of the autoclave test might be terminated after 24hours.

3.4.3 Examination of Test Samples

Since the purpose of this test program is to identify the type and mass of corrosion products that may form in the post-LOCA environment, it is essential that all masses of all species are accounted for in the experiment. The locations of these species can be on the surface of the metallic coupons, on the surface of the fiberglass samples, as precipitate in the tank, and in solution.

3.4.3.1 Test coupon Examination

Coupons used in the test should be weighed and photographed before and after testing. Prior to weighing, the coupons shall be dried to remove moisture from the attached corrosion products.
These records and the coupons are to be retained for later use.

3.4.3.2 Fiberglass Sample Examination

Similarly, the fiberglass samples used in the test should be weighed and photographed before and after testing. Specific attention is to be given to possible collection of gelatinous material on the surface of the fiberglass. Prior to weighing, the coupons shall be dried to remove moisture. These records and the fiberglass samples are to be retained for later use.

3.4.3.3 Precipitate/Sediment Examination

Sediment characterization includes, as appropriate and feasible determining the mass and volume collected, determination of constituents (e.g., fiberglass, latent particulate, precipitate, etc.), whether amorphous or crystalline, elemental composition and speciation. Specific direction concerning characterization shall be provided jointly by the project managers/test program leads.

3.4.3.4 Fluid Sample Examination

Analyses of fluids shall be performed to characterize dissolved material in the test loop and environments of loop chemistry. For elements whose concentration may vary during a test run, frequent analyses shall be performed. These elements include Al, B, Ca, Cu, Fe, Ni, Si, Mg, Na, and Zn.

For all grab samples, a visual assessment (color, suspended material, etc.) of the sample shall be noted as soon as possible after the sample is taken from the test loop.

In preparation for collecting a grab sample, the sample line shall be flushed with a minimum volume equivalent to three sample line lengths. To assure a representative sample, the flow rate used during line flushing and sampling shall be sufficient to assure flow is sufficient to maintain all species in suspension in the sample line. Excess solution removed from the loop during sampling shall be collected and returned to the loop.

The volume of sample to be removed shall be sufficient to measure pH, turbidity and boron concentration on the unfiltered sample and to allow for filtration of an appropriate volume of solution through a 0.45 micron filter for collection of suspended material. A small amount of the grab sample fluid will be set aside for other analyses.

The sample for filtration should be filtered as rapidly as possible after collection to assure that precipitation of any material has not resulted from a decrease in sample temperature. The filtered material should be dried and weighed. The filtrate shall be collected and stored at ambient temperature in a sealed container and observed for at least 1 week to determine if precipitates form upon standing.

A sample should be evaluated as rapidly as possible after collection for the existence of gelatinous material in the grab sample fluid. One possible method of evaluation is to measure the viscosity of the sampled fluid.

Samples shall be stabilized for future ICP analyses.

3.5 QA Program

This tests were performed under the quality assurance program of Takasago R&D Center that satisfies Appendix-B to 10 CFR Part 50, 10 CFR Part 21 and is approved by Nuclear Energy Systems Quality and Safety Management Department of MHI.