Figure E.4-1 RMI Test Debris

E.4.2 Coatings

For the U.S EPR containment strainer testing, coatings are categorized into two debris types:

- coating chips
- coatings as particulate

During the debris transport test performed in December 2009, a small amount of coating chips were introduced to the test apparatus. The majority of chips, when viewed with an underwater camera, appeared to cover the top 12 inches of submerged retaining basket screen where a higher velocity flow towards the strainer appeared to exist. Chips that were not caught in the initial current near the water surface appeared to sink to the floor of the retaining basket. Due to these observations, it was determined that the qualified epoxy coatings would be tested in both particulate and chip form for conservatism. This conservatively increased the total epoxy coating source term by 34%. The qualified epoxy coatings are represented as “acylic powder or walnut shell powder.” This amount of particulate coating was weighed and added to the flume. The same amount of coating chips were weighed and added to the flume.

For coatings acting as particulate debris, acrylic powder was used as a surrogate material for epoxy coatings and tin powder was used as a surrogate material for inorganic zinc coatings. The acrylic powder has an average density of approximately 77.4 lb_m/ft^3. The acrylic coatings have a similar density, size and shape characteristics to plant containment coatings and are a suitable surrogate material. The tin powder has a particle density of 445.3 lb_m/ft^3 as compared to 457 lb_m/ft^3 for inorganic zinc. Since inorganic zinc is considered a hazardous material, tin powder was used as the surrogate material. Figure E.4-2 depicts examples of coating chips used for testing. Figure E.4-3 and Figure E.4-4 depict examples of the acrylic powder and tin powder used in testing, respectively.

Figure E.4-2 Coating Chips

Figure E.4-3 Acrylic Powder

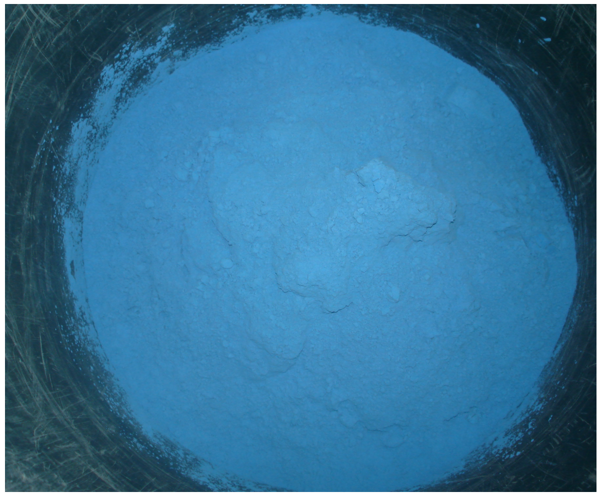
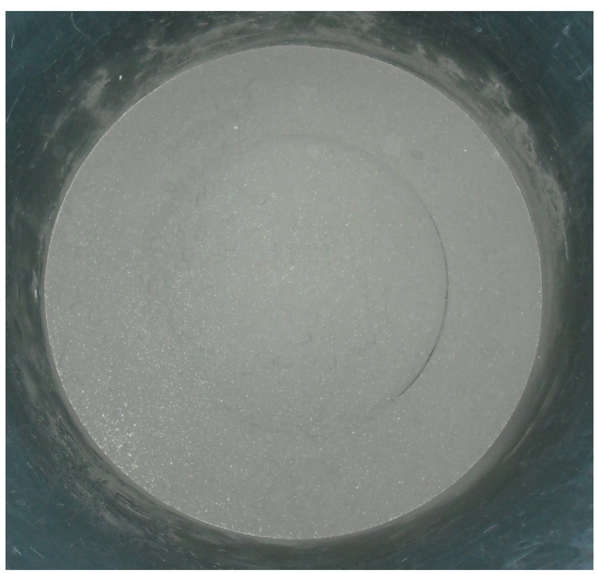


Figure E.4-4 Tin Powder



E.4.3 Fiber

Fiber material used for testing is NUKON fiber. NUKON fiber was tested as fines and shredded into fines using a debris shredder. Figure E.4-5 depicts an example of the NUKON fines fiber used for testing.

Figure E.4-5 NUKON Fines Fiber

E.4.4 Particulate

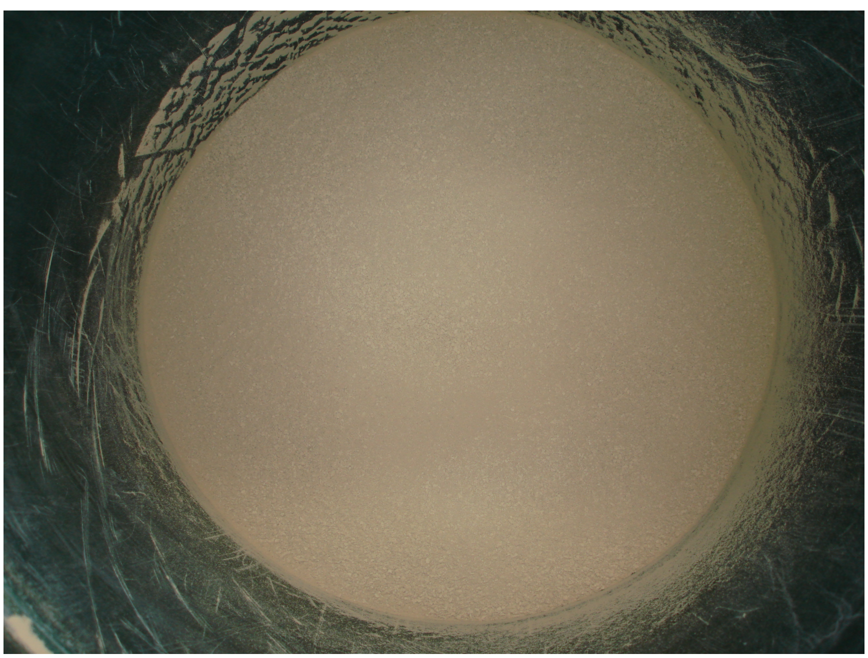
The particulate debris used for testing is comprised of:

- latent dirt and dust mix (prepared by Performance Contracting Incorporated)
- coatings (particulate)
- microtherm

Figure E.4-6 depicts a sample of the latent dirt and dust mix. Figure E.4-7 depicts a sample of microtherm.

Figure E.4-6 Latent Dirt and Dust Mix

Figure E.4-7 Microtherm



E.4.5 Miscellaneous Debris

During the Debris Transport Test conducted in December 2009, miscellaneous debris materials were added to the flume to document how these items responded to the test flow conditions. The miscellaneous debris consists of various debris items expected to be found in containment. The specific miscellaneous debris used for testing is listed in Section E.5.

E.4.6 Chemical Debris

The predicted chemical precipitates generated after a postulated LOCA in the U.S. EPR containment are calcium phosphate ($Ca_3(PO_4)_2$) and sodium aluminum silicate ($NaAlSi_3O_8$). Since $NaAlSi_3O_8$ is considered hazardous, aluminum oxyhydroxide (ALOOH) is used as a surrogate. Because the characteristics of $NaAlSi_3O_8$ are similar to AlOOH, ALOOH is used for testing in lieu of $NaAlSi_3O_8$.

E.5 Debris Quantities and Introduction Sequence

E.5.1 Phase 1 Testing - Debris Transport Test No. 1

For the Debris Transport Test, debris was manually added to the fume flow above the retaining basket. Table E.5-1 provides the debris allocation and flume flow rate for the Debris Transport Test. The following is the list of debris and approximate sizes introduced into the flume during the Debris Transport Test.

- leather work glove
- plastic glove
- caution tag (6 inch x 3 inch plastic material)
- caution label (yellow ribbon 2.5 feet in length)
- white cloth (1 foot x 1.5 feet)
- 2 plastic tie wraps (1 foot and 2 feet long)
- ¾ inch nylon rope (2 feet long)

- plastic chain link (1.5 feet long)
- plastic bag (1foot x 2 feet)
- ear plugs (1 set connected with an elastic string)
- ear plugs (1 set in a plastic bag)
- ¼ inch x ¼ inch RMI
- ½ inch x ½ inch RMI
- 4 inch x 4 inch RMI
- coating chips (5/8 inches and smaller)

Table E.5-1 Debris Allocation and Flume Flow Rate for the Debris Transport Test

Scaling Factor 9.37%			Wt Conversions	Debris Scaled		
Debris Type	U/M	Quantity	(lbs / ft^3 or ft^2)	(lbm)	Units	Debris Form / (Surrogate)
Fibers (Design Basis)						
NUKON (Small Fines)	ft^3	n/a	2.4	n/a	lbm	Shredded Fiber (Binder Burned Out)
Latent Fibers	lbm	n/a	n/a	n/a	lbm	Shredded Fiber
			Total Fibrous Debris	0.0		
RMI						
Total RMI	ft^2	2098.87				
RMI (1/4" x 1/4")	ft^2	111.24	0.0813	0.85	lbm	
RMI (1/2" x 1/2")	ft^2	444.96	0.0813	3.39	lbm	
RMI (1" & 2")	ft^2	1017.95	0.0813	7.76	lbm	
RMI Larges (4" and 6") (Limited to 25% RMI total)	ft^2	524.72	0.0813	4.00	lbm	
			Total RMI Debris	15.99		
Particulates						
Latent Particulate; Dirt & Dust	lbm	n/a	n/a	n/a	lbm	PCI PWR Dirt Mix (85% of Latent Debris)
Microtherm	ft^3	n/a	15.0	n/a	lbm	Microtherm® Free Flow
Coatings (lbs)						
Qualified Coatings	lbm	459.82	94	43.10	lbm	Acrylic Paint Chips (5/8" and smaller)
Qualified Coatings	lbm	n/a	457	n/a	lbm	IOZ Powder (Tin Powder)
Unqualified Coatings	lbm	n/a	94	n/a	lbm	Acrylic Powder or Walnut Shell Powder
			Total Particulate Debris	43.10		
Chemical Debris Concentrations						
Sodium Aluminum Silicate (Unknown)	lbm	n/a	n/a	n/a	lbm	Chemical Surrogate - AlOOH
Calcium Phosphate (Unknown)	lbm	n/a	n/a	n/a	lbm	Chemical Surrogate - $Ca_3(PO_4)_2$
Aluminum Oxyhydroxide (Unknown)	lbm	n/a	n/a	n/a	lbm	Chemical Surrogate - AlOOH
			Total Surrogate Debris	0.0	lbm	
Miscellaneous Debris						
Labels, Stickers, Tape, Placards, Tags	ft^2	100.00	n/a	note 1	ft^2	Miscellaneous Debris

Flume Water Level	ft	9.25	
Scaling Factor	%	9.37%	
Target Flume Flow	gpm	307.81	

note 1: scaled miscellaneous debris is provided as a combination of various debris items

E.5.2 Phase 2 Testing - Clean Strainer Head Loss Test No. 1

For the Clean Strainer Head Loss Test, no debris was added into the test flume. Table E.5-2 lists the five (5) flume flow rates for the Clean Strainer Head Loss Test.

Table E.5-2 Flume Flow Rates for the Clean Strainer Head Loss Test

Scaling Factor 9.37%			Wt Conversions	Debris Scaled		
Debris Type	U/M	Quantity	(lbs / ft³ or ft²)⁴	(lbm)	Units	Debris Form / (Surrogate)
Fibers (Design Basis)						
NUKON (Small Fines)	ft^3	n/a	2.4	n/a	lbm	Shredded Fiber (Binder Burned Out)
Latent Fibers	lbm	n/a	n/a	n/a	lbm	Shredded Fiber (Binder Burned Out)
			Total Fibrous Debris	0.0		
RMI						
Total RMI	ft^2	n/a				
RMI (1/4" x 1/4")	ft^2	n/a	0.0813	n/a	lbm	
RMI (1/2" x 1/2")	ft^2	n/a	0.0813	n/a	lbm	
RMI (1" & 2")	ft^2	n/a	0.0813	n/a	lbm	
RMI Larges (4" and 6") (Limited to 25% RMI total)	ft^2	n/a	0.0813	n/a	lbm	
			Total RMI Debris	0.0		
Particulates						
Latent Particulate; Dirt & Dust	lbm	n/a	n/a	n/a	lbm	PCI PWR Dirt Mix (85% of Latent Debris)
Microtherm	ft^3	n/a	15.0	n/a	lbm	Microtherm® Free Flow
Coatings (lbs)						
Qualified Coatings	lbm	n/a	94	n/a	lbm	Acrylic Chips (5/8" and smaller)
Qualified Coatings	lbm	n/a	457	n/a	lbm	IOZ Powder (Tin Powder)
Unqualified Coatings	lbm	n/a	94	n/a	lbm	Acrylic Powder or Walnut Shell Powder
			Total Particulate Debris	0.0		
Chemical Debris Concentrations						
Sodium Aluminum Silicate	lbm	n/a	n/a	n/a	lbm	Chemical Surrogate - AlOOH
Calcium Phosphate	lbm	n/a	n/a	n/a	lbm	Chemical Surrogate - $Ca_3(PO_4)_2$
Aluminum Oxyhydroxide	lbm	n/a	n/a	n/a	lbm	Chemical Surrogate - AlOOH
			Total Surrogate Debris	0.0	lbm	
Miscellaneous Debris						
Labels, Stickers, Tape, Placards, Tags	ft^2	n/a	n/a	n/a	ft^2	Miscellaneous Debris

Flume Water Level	ft	9.25	
Scaling Factor	%	9.37%	
25% Below Target Flow	gpm	230.85	
12.5% Below Target Flow	gpm	269.33	
Target Flume Flow	gpm	307.81	
12.5% Above Target Flow	gpm	346.28	
25% Above Target Flow	gpm	384.76	

E.5.3 Phase 2 Testing - Design Basis Debris Loaded Strainer Head Loss Test No. 2

For the Design Basis Debris Loaded Strainer Head Loss Test, debris introduction started by first adding the particulate debris to the flume. The particulate debris introduction sequence was based on the most transportable particulate added first, followed by the next most transportable debris. Particulate debris was added into the flume via the debris introduction locations shown in Figure E.3-8 and Figure E.3-10. Table E.5-3 and Table E.5-4 provide the debris allocation and flume flow rate for Test No. 2. The sequence for debris introduction and amounts is as follows:

Fine Particulate Debris

Batch 1: 100% of Microtherm (1.55 lb_m)

Batch 2: 100% of acrylic powder particulate debris (35.40 lb_m)

Batch 3: 105.5% of dirt & dust (21.10 lb_m)

Batch 4: 100% of tin powder particulate debris (90.00 lb_m)

Note: An additional 5% of dirt and dust was added to the test flume to account for any particulate debris lost in transit.

Fine Fibrous Debris

Batch 5: approximately 10% of the total fine NUKON fibers (0.5 lb_m)

Batch 6: approximately 90% of the total fine NUKON fibers (4.60 lb_m)

Note: Batch 5 was added to the test flume directly between the retaining basket and strainer. Batch 6 debris introductions consisted of approximately 0.5 lb_m of fibrous debris per 33 gallon container to prevent fibrous debris agglomeration.

Coating Chips Debris

Batch 7: 100% of the qualified epoxy coatings – chips (12.00 lb_m)

Note: Based on the results of a debris transport test conducted in December 2009 it was observed that coating chips attached to the retaining basket screen near the surface of the flume. For conservatism, the qualified coatings debris source term was added to the flume in both particulate and chips form, essentially doubling that debris source term.

Chemical Precipitate Debris

Aluminum oxyhydroxide (AlOOH) and calcium phosphate (Ca3(PO4)2) were introduced to the flume over a 13 hour period. The first three batches of ALOOH were added to the flume in approximately 5.8 gallon amounts. The first three batches of Ca3(PO4)2 were added to the flume in approximately 13.4 gallon amounts. After the first three batches of each chemical precipitant were added to the flume, the flume reached its prototypical chemical concentration. After the first three batches, the ALOOH and Ca3(PO4)2 were added to the flume in approximately 4.4 and 10.2 gallon amounts, respectively, until 100% of the scaled quantity by mass of chemical was introduced into the test flume. The purpose of the chemical batching was to prevent the flume from becoming overly concentrated with chemical debris and possibly causing the chemical to settle quicker to the flume floor. Refer to Table E.5-4 for the chemical batching volumes.

The chemical addition was comprised of approximately 40 total batches of each chemical precipitate until 100% of the chemical debris source term was introduced to the flume. The batching process comprised of one ALOOH batch introduction followed by one Ca3(PO4)2 batch introduction, with a five minute interval in between the two precipitates. One flume turnover (14 minutes) was allotted before the next batch of AlOOH was introduced to the test flume.

The following observations were made during the Design Basis Debris Loaded Strainer Head Loss Test:

- Visual observation of the strainer area at various times during the design basis test showed no signs of vortexing around the strainer.
- With a fiber bed restricting flow on the wetted retaining basket, the coating chips were propelled directly to the open retaining basket screen. The chips quickly

created a bed on the retaining basket as the water level increased leading to basket overflow.

- During the initial basket overflow, some coating chips flowed into the strainer area. The strainer head loss did not change from this occurrence.
- The retaining basket successfully retained debris and prevented any change in strainer head loss.
- Following the testing, drain down of the test apparatus revealed little debris at the strainer.

Table E.5-3 Debris Allocation and Flume Flow Rate for the Design Basis Debris Loaded Strainer Head Loss Test

Scaling Factor 9.37%			Wt Conversions	Debris Scaled		
Debris Type	U/M	Quantity	(lbs / ft^3 or ft^2)	(lbm)	Units	Debris Form / (Surrogate)
Fibers (Design Basis)						
NUKON (Small Fines)	ft^3	6.62	2.4	1.49	lbm	Shredded Fiber (Binder Burned Out)
Latent Fibers	lbm	37.50	n/a	3.51	lbm	Shredded Fiber (Binder Burned Out)
			Total Fibrous Debris	**5.00**		
RMI						
Total RMI	ft^2	2098.87				
RMI (1/4" x 1/4")	ft^2	111.24	0.0813	0.85	lbm	
RMI (1/2" x 1/2")	ft^2	444.96	0.0813	3.39	lbm	
RMI (1" & 2")	ft^2	1017.95	0.0813	7.76	lbm	
RMI Larges (4" and 6") (Limited to 25% RMI total)	ft^2	524.72	0.0813	4.00	lbm	
			Total RMI Debris	**15.99**		
Particulates						
Latent Particulate; Dirt & Dust	lbm	212.50	n/a	19.92	lbm	PCI PWR Dirt Mix (85% of Latent Debris)
Microtherm	ft^3	1.00	15.0	1.41	lbm	Microtherm® Free Flow
Coatings (lbs)						
Qualified Coatings	lbm	126.50	94	11.86	lbm	Acrylic Powder or Walnut Shell Powder
Qualified Coatings	lbm	958.70	457	89.86	lbm	IOZ Powder (Tin Powder)
Unqualified Coatings	lbm	250.00	94	23.43	lbm	Acrylic Powder or Walnut Shell Powder
			Total Particulate Debris	**146.47**		
Chemical Debris Concentrations						
Sodium Aluminum Silicate	kg	77.0	(2.2 lbs/kg)	15.91	lbm	Chemical Surrogate - AlOOH
Calcium Phosphate	kg	81.0	(2.2 lbs/kg)	16.74	lbm	Chemical Surrogate - $Ca_3(PO_4)_2$
Aluminum Oxyhydroxide	kg	0.00	(2.2 lbs/kg)	0.00	lbm	Chemical Surrogate - AlOOH
			Total Surrogate Debris	**32.65**	lbm	
Miscellaneous Debris						
Labels, Stickers, Tape, Placards, Tags	ft^2	100.00	n/a	n/a	ft^2	Miscellaneous Debris

Flume Water Level	ft	9.25	
Scaling Factor	%	9.37%	
Target Flume Flow	gpm	307.81	

Table E.5-4 Chemical Debris Additions and Flume Flow Rate for the Design Basis Debris Loaded Strainer Head Loss Test

	Pump Flow (gpm)	Pump Flow (ft^3 / sec)	Flume Depth (ft)	Flume Volume (cu ft @ 9.25')	Pipe Volume (cu ft)	Total Volume (cu ft)	Total Volume (gal)	Flume Flow (cfs)	One flume cycle (sec)	1 Flume Turn Over FTO (min)	2 Flume Turn Over FTO (min)
Pump Flow Rate During Chem. Batching	307.81	0.686	9.25	519.39	31.60	550.99	4,121.70	0.686	803.44	14.0	28.0

Chemical Debris Concentrations	U/M	Quantity	(lbs / ft^3 or ft^2)	Scaled Quantity	Qty w/ Bump Ups	U/M
Chemical Bump Up Added for Soluability	%	1.0%		9.37%		
Chemical Bump Up to Eliminate Bag Filters	%	1.4%				
Sodium Aluminum Silicate	max lbm	169.75		15.91	16.30	lbm
Aluminum Oxyhydroxide	max lbm	0.00		0.00	0.00	lbm
Calcium Phosphate	max lbm	178.60		16.74	17.15	lbm
			Total Surrogate Debris	32.65	33.45	lbm

	Plant Calculated lbm	Scaled Test lbm	Chemicals	Plant Conc	Flume Conc	U/M	lbs to = Plant Conc	lbs / batch to start; 1 PTO in between	lbs / batch thereafter; 1 PTO in between	Est No. of PTO's Req'd	EST Minutes to Introduce Chemicals
Aluminum Oxyhydroxide	169.75	16.30	ALOOH	0.000392	0.003955	lbs/gal	1.61	0.5329	0.4037	39.40	552
Calcium Phosphate	178.60	17.15	Cal Phos	0.000412	0.004161	lbs/gal	1.70	0.5607	0.4248	39.40	197
Totals	348.35	33.45	Totals	0.000804	0.008116	lbs/gal	3.31	1.0936	0.8285	39.40	749
				433,242	4,121.7	gal		Batch Sizes			
				57,916	551.0	ft^3		33.00%	25.00%		12.48

Conversion of "grams / liter" to "lbs / gallon"			
	1 gram	=	0.0022 lbs
	1 liter	=	0.26417 gallons
	1 g / l	=	0.00835 lbs / gallon
	11 g / l	=	0.0918 lbs / gallon
	5 g / l	=	0.04173 lbs / gallon

Batch Volumes				
33% Batches @	0.53 lbm	=	5.81	gal of ALOOH mix
25% Batches @	0.40 lbm	=	4.40	gal of ALOOH mix
33% Batches @	0.56 lbm	=	13.44	gal of Cal Phosphate mix
25% Batches @	0.42 lbm	=	10.18	gal of Cal Phosphate mix

E.5.4 Phase 2 Testing - Fibrous Debris Only Sample Bypass Test No. 3 and 3A

For Test No. 3, the fiber was introduced to the flume in two batches. The first batch consisted of the mass of fiber that could potentially create a thin bed on the retaining basket and strainer surface. This first batch amount is 3.3 lb_m. The second batch consisted of the remaining fibrous debris. Two flume turnovers totaling 28 minutes were allotted between fiber batch introductions. The first 0.5 lb_m of batch 1 was introduced between retaining basket and the front of the strainer. All other batches were added to the flume via the debris introduction tank and debris pump. Strainer head loss was negligible throughout the entire test. Table E.5-5 provides the debris allocation and flume flow rate for Test No. 3 and 3A. The sequence for debris introduction and amounts is as follows:

Fibrous Debris

Batch 1: (3.4 lb_m for Test No. 3 and 3.3 lb_m for Test No. 3A).

Batch 2: Fine NUKON fibers (1.7 lb_m for Test No. 3 and 1.8 lb_m for Test No. 3A).

After Test No. 3 was complete, the water in the test flume was slowly drained. A visual inspection of the strainer showed no fibrous debris on the strainer screen.

Test No. 3A was performed using the same procedure and debris amounts used for Test No. 3. Strainer head loss was negligible throughout Test No. 3A and visual observations after the test showed the strainer was free of debris.

Table E.5-5 Debris Allocation and Flume Flow Rate for the Fibrous Debris Only Sample Bypass Test

Scaling Factor 9.37%			Wt Conversions	Debris Scaled		
Debris Type	U/M	Quantity	(lbs / ft^3 or ft^2)	(lbm)	Units	Debris Form / (Surrogate)
Fibers (Design Basis)						
NUKON (Small Fines)	ft^3	6.62	2.4	1.49	lbm	Shredded Fiber (Binder Burned Out)
Latent Fibers	lbm	37.50	n/a	3.51	lbm	Shredded Fiber (Binder Burned Out)
			Total Fibrous Debris	5.00		
RMI						
Total RMI	ft^2	2098.87				
RMI (1/4" x 1/4")	ft^2	111.24	0.0813	n/a	lbm	
RMI (1/2" x 1/2")	ft^2	444.96	0.0813	n/a	lbm	
RMI (1" & 2")	ft^2	1017.95	0.0813	n/a	lbm	
RMI Larges (4" and 6") (Limited to 25% RMI total)	ft^2	524.72	0.0813	n/a	lbm	
			Total RMI Debris	0.0		
Particulates						
Latent Particulate; Dirt & Dust	lbm	n/a	n/a	n/a	lbm	PCI PWR Dirt Mix (85% of Latent Debris)
Microtherm	ft^3	n/a	15.0	n/a	lbm	Microtherm® Free Flow
Coatings (lbs)						
Qualified Coatings	lbm	n/a	94	n/a	lbm	Acrylic Powder or Walnut Shell Powder
Qualified Coatings	lbm	n/a	457	n/a	lbm	IOZ Powder (Tin Powder)
Unqualified Coatings	lbm	n/a	94	n/a	lbm	Acrylic Powder or Walnut Shell Powder
			Total Particulate Debris	0.0		
Chemical Debris Concentrations						
Sodium Aluminum Silicate	lbm	n/a	n/a	n/a	lbm	Chemical Surrogate - AlOOH
Calcium Phosphate	lbm	n/a	n/a	n/a	lbm	Chemical Surrogate - $Ca_3(PO_4)_2$
Aluminum Oxyhydroxide	lbm	n/a	n/a	n/a	lbm	Chemical Surrogate - AlOOH
			Total Surrogate Debris	0.0	lbm	
Miscellaneous Debris						
Labels, Stickers, Tape, Placards, Tags	ft^2	100.00	n/a	n/a	ft^2	Miscellaneous Debris

Flume Water Level	ft	9.25	
Scaling Factor	%	9.37%	
Target Flume Flow	gpm	307.81	
Strainer and Basket Surface Area	ft^2	130.77	
Thin Bed Size	ft	0.010	
Required Fiber for 1/8" Bed	ft^3	1.36	
Required Fiber for 1/8" Bed @ 2.4 lbm/ft^3	lbm	3.27	
Total Fibrous Debris	lbm	5.00	
Thin Bed Batches	#	1.53	

E.5.5 Phase 2 Testing - Debris Loaded Strainer Head Loss Thin Bed Test No. 4

For Test No. 4, the particulate debris introduction sequencing was based on the most transportable particulate added first, followed by the next most transportable debris. The Microtherm and acrylic powder particulate debris was added to the flume with the debris introduction tank and trash pump. The 'dirt and dust' and tin powder were added through the observation window using the debris introduction chute. Next, the first thin bed batch was introduced through the debris introduction tank and trash pump. The first thin bed batch corresponded to the fiber amount that may potentially lead to a thin bed on the strainer and the retaining basket. The second batch of fiber was added to the test flume 1 hour and 2 minutes after the completion of the first batch once the retaining basket measured head loss stabilized. Table E.5-6 and Table E.5-7 provides the debris allocation and flume flowrate for Test No. 4. The sequence for debris introduction and amounts is as follows:

<u>Fine Particulate Debris</u>

Batch 1: 100% of Microtherm (1.55 lb_m)

Batch 2: 100% of acrylic powder particulate debris (35.40 lb_m).

Batch 3: 105.5% of dirt & dust (21.10 lb_m)

Batch 4: 100% of tin powder particulate debris (90.00 lb_m)

<u>Fine Fibrous Debris</u>

Batch 5A: approx. 10% of total fine NUKON fibers (0.5 lb_m)

Batch 5B: approx. 57% of total fine NUKON fibers (2.9 lb_m)

Batch 6: approx. 33% of total fine NUKON fibers (1.7 lb_m)

Note: Batch 5A was added to the test flume between the retaining basket and strainer. Batch 6 debris introductions consisted of approximately 0.5 lb_m of fibrous debris per 33 gallon container to prevent fibrous debris agglomeration.

Coating Chip Debris

Batch 7: 100% of the U.S. EPR Qualified Epoxy Coatings – Chips (12.00 lb_m)

Note: Based on the results of the debris transport test conducted in December 2009, it was observed that coating chips attached to the retaining basket screen near the surface of the flume. For conservatism, the qualified coatings debris source term was added to the flume in both particulate and chips form, essentially doubling that debris source term.

Chemical Precipitate Debris

Aluminum oxyhydroxide (AlOOH) and calcium phosphate (Ca3(PO4)2) were introduced to the test flume over a 9 hour period. The first three batches of ALOOH were added to the flume in approximately 5.8 gallon amounts. The first three batched of Ca3(PO4)2 were added to the flume in approximately 13.4 gallon amounts. After the first three batches of each chemical precipitant were added to the flume, the flume reached its prototypical chemical concentration. After the first three batches, the ALOOH and Ca3(PO4)2 were added to in approximately 4.4 and 10.2 gallon amounts, respectively, until 100% of the scaled quantity by mass of chemical was introduced into the test flume. The purpose of the chemical batching was to prevent the flume from becoming overly concentrated with chemical debris, thus causing the chemical to settle quicker to the flume floor. Refer to Table E.5-7 for the chemical batching volumes.

Approximately 40 total batches of each chemical precipitate were added to the test flume until 100% of the chemical debris source term was introduced to the flume. The batching process comprised of an ALOOH introduction followed by a Ca3(PO4)2 introduction, with a five minute interval in between the two precipitates. One flume turnover (14 minutes) was allotted before the next batch of AlOOH was introduced to the test flume. However, the batching process was expedited after the first 15 total batches. The batch timing changed to 3 minute intervals between chemicals and only ½ flume turnover (7 minutes) between batches.

The following observations were made during Test No. 4:

- Visual observation of the strainer area showed no signs of vortexing around the strainer.
- The fiber bed created by the first batch alone created a greater head loss across the basket. The second fiber batch addition brought the basket to within one foot of overflow.
- The chips rapidly created the overflow condition of the retaining basket. A large quantity of chips overflowed to the strainer area. The strainer head loss remained stable.
- After the test, flume drain down showed little debris on the strainer screen.

Table E.5-6 Debris Allocation and Flume Flow Rate for the Thin Bed Test

Scaling Factor 9.37%			Wt Conversions	Debris Scaled		
Debris Type	**U/M**	**Quantity**[2,3]	**(lbs / ft^3 or ft^2)**	**(lbm)**	**Units**	**Debris Form / (Surrogate)**
Fibers (Design Basis)						
NUKON (Small Fines)	ft^3	6.62	2.4	1.49	lbm	Shredded Fiber (Binder Burned Out)
Latent Fibers	lbm	37.50	n/a	3.51	lbm	Shredded Fiber (Binder Burned Out)
			Total Fibrous Debris	**5.00**		
RMI						
Total RMI	ft^2	2098.87				
RMI (1/4" x 1/4")	ft^2	111.24	0.0813	0.85	lbm	
RMI (1/2" x 1/2")	ft^2	444.96	0.0813	3.39	lbm	
RMI (1" & 2")	ft^2	1017.95	0.0813	7.76	lbm	
RMI Larges (4" and 6") (Limited to 25% RMI total)	ft^2	524.72	0.0813	4.00	lbm	
			Total RMI Debris	**15.99**		
Particulates						
Latent Particulate; Dirt & Dust	lbm	212.50	n/a	19.92	lbm	PCI PWR Dirt Mix (85% of Latent Debris)
Microtherm	ft^3	1.00	15.0	1.41	lbm	Microtherm® Free Flow
Coatings (lbs)						
Qualified Coatings	lbm	126.50	94	11.86	lbm	Acrylic Powder or Walnut Shell Powder
Qualified Coatings	lbm	958.70	457	89.86	lbm	IOZ Powder (Tin Powder)
Unqualified Coatings	lbm	250.00	94	23.43	lbm	Acrylic Powder or Walnut Shell Powder
			Total Particulate Debris	**146.47**		
Chemical Debris Concentrations						
Sodium Aluminum Silicate	kg	77.0	(2.2 lbs/kg)	15.91	lbm	Chemical Surrogate - AlOOH
Calcium Phosphate	kg	81.0	(2.2 lbs/kg)	16.74	lbm	Chemical Surrogate - $Ca_3(PO_4)_2$
Aluminum Oxyhydroxide	kg	0.00	(2.2 lbs/kg)	0.00	lbm	Chemical Surrogate - AlOOH
			Total Surrogate Debris	**32.65**	lbm	
Miscellaneous Debris						
Labels, Stickers, Tape, Placards, Tags	ft^2	100.00	n/a	n/a	ft^2	Miscellaneous Debris

Flume Water Level	ft	9.25	
Scaling Factor	%	9.37%	
Target Flume Flow	gpm	307.81	
Strainer and Basket Surface Area	ft^2	130.77	
Thin Bed Size	ft	0.010	
Required Fiber for 1/8" Bed	ft^3	1.36	
Required Fiber for 1/8" Bed @ 2.4 lbm/ft^3	lbm	3.27	
Total Fibrous Debris	lbm	5.00	
Thin Bed Batches	#	1.53	

Table E.5-7 Chemical Debris Additions and Flume Flow Rate for the Thin Bed Test

	Pump Flow (gpm)	Pump Flow (ft^3 / sec)	Flume Depth (ft)	Flume Volume (cu ft @ 9.25')	Pipe Volume (cu ft)	Total Volume (cu ft)	Total Volume (gal)	Flume Flow (cfs)	One flume cycle (sec)	1 Flume Turn Over FTO (min)	2 Flume Turn Over FTO (min)
Pump Flow Rate During Chem. Batching	307.81	0.686	9.25	519.39	31.60	550.99	4,121.70	0.686	803.44	14.0	28.0

Chemical Debris Concentrations	U/M	Quantity	(lbs / ft^3 or ft^2)	Scaled Quantity	Qty w/ Bump Ups	U/M
Chemical Bump Up Added for Soluability	%	1.0%		9.37%		
Chemical Bump Up to Eliminate Bag Filters	%	1.4%				
Sodium Aluminum Silicate	max lbm	169.75		15.91	16.30	lbm
Aluminum Oxyhydroxide	max lbm	0.00		0.00	0.00	lbm
Calcium Phosphate	max lbm	178.60		16.74	17.15	lbm
			Total Surrogate Debris	32.65	33.45	lbm

	Plant Calculated lbm	Scaled Test lbm	Chemicals	Plant Conc	Flume Conc	U/M	lbs to = Plant Conc	lbs / batch to start; 1 PTO in between	lbs / batch thereafter; 1 PTO in between	Est No. of PTO's Req'd	EST Minutes to Introduce Chemicals
Aluminum Oxyhydroxide	169.75	16.30	ALOOH	0.000392	0.003955	lbs/gal	1.61	0.5329	0.4037	39.40	552
Calcium Phosphate	178.60	17.15	Cal Phos	0.000412	0.004161	lbs/gal	1.70	0.5607	0.4248	39.40	197
Totals	348.35	33.45	Totals	0.000804	0.008116	lbs/gal	3.31	1.0936	0.8285	39.40	749
				433,242	4,121.7	gal		Batch Sizes			
				57,916	551.0	ft^3		33.00%	25.00%		12.48

Conversion of "grams / liter" to "lbs / gallon"			
	1 gram	=	0.0022 lbs
	1 liter	=	0.26417 gallons
	1 g / l	=	0.00835 lbs / gallon
	11 g / l	=	0.0918 lbs / gallon
	5 g / l	=	0.04173 lbs / gallon

Batch Volumes				
33% Batches @	0.53 lbm	=	5.81	gal of ALOOH mix
25% Batches @	0.40 lbm	=	4.40	gal of ALOOH mix
33% Batches @	0.56 lbm	=	13.44	gal of Cal Phosphate mix
25% Batches @	0.42 lbm	=	10.18	gal of Cal Phosphate mix

E.6 Test Results

E.6.1 Debris Transport Test

The Debris Transport Test determines the transportability of reflective metallic insulation (RMI), coatings (in the form of paint chips), and miscellaneous debris including other miscellaneous debris. Section E.5.1 lists the debris types used for the Debris Transport Test. The test results conclude the debris was captured and contained within the retaining basket. Table E.6-1 details the Debris Transport Test results.

Table E.6-1 Debris Transport Test Results

Debris Type	Debris Transport Response
leather work glove	* floated on the surface of the water
plastic glove	* floated on the surface of the water
caution tag (6 inch x 3 inch plastic material)	settled on retaining basket floor
caution label (yellow ribbon 2.5 feet in length)	* floated on the surface of the water
white cloth (1 foot x 1.5 feet)	* floated on the surface of the water
2 plastic tie wraps (1 foot and 2 feet long)	settled on retaining basket floor
¾ inch nylon rope (2 feet long)	settled on retaining basket floor
plastic chain link (1.5 feet long)	* floated on the surface of the water
plastic bag (1 foot x 2 feet)	* floated on the surface of the water
ear plugs (1 set connected with an elastic string)	* floated on the surface of the water
ear plugs (1 set in a plastic bag)	* floated on the surface of the water
¼ inch x ¼ inch RMI	settled on retaining basket floor
½ inch x ½ inch RMI	settled on retaining basket floor
4 inch x 4 inch RMI	settled on retaining basket floor
coating chips (5/8 inches and smaller)	* most floated on the surface

* These debris items were observed to float on the surface of the water and lay against the retaining basket screen due to the direction of the test flume flow.

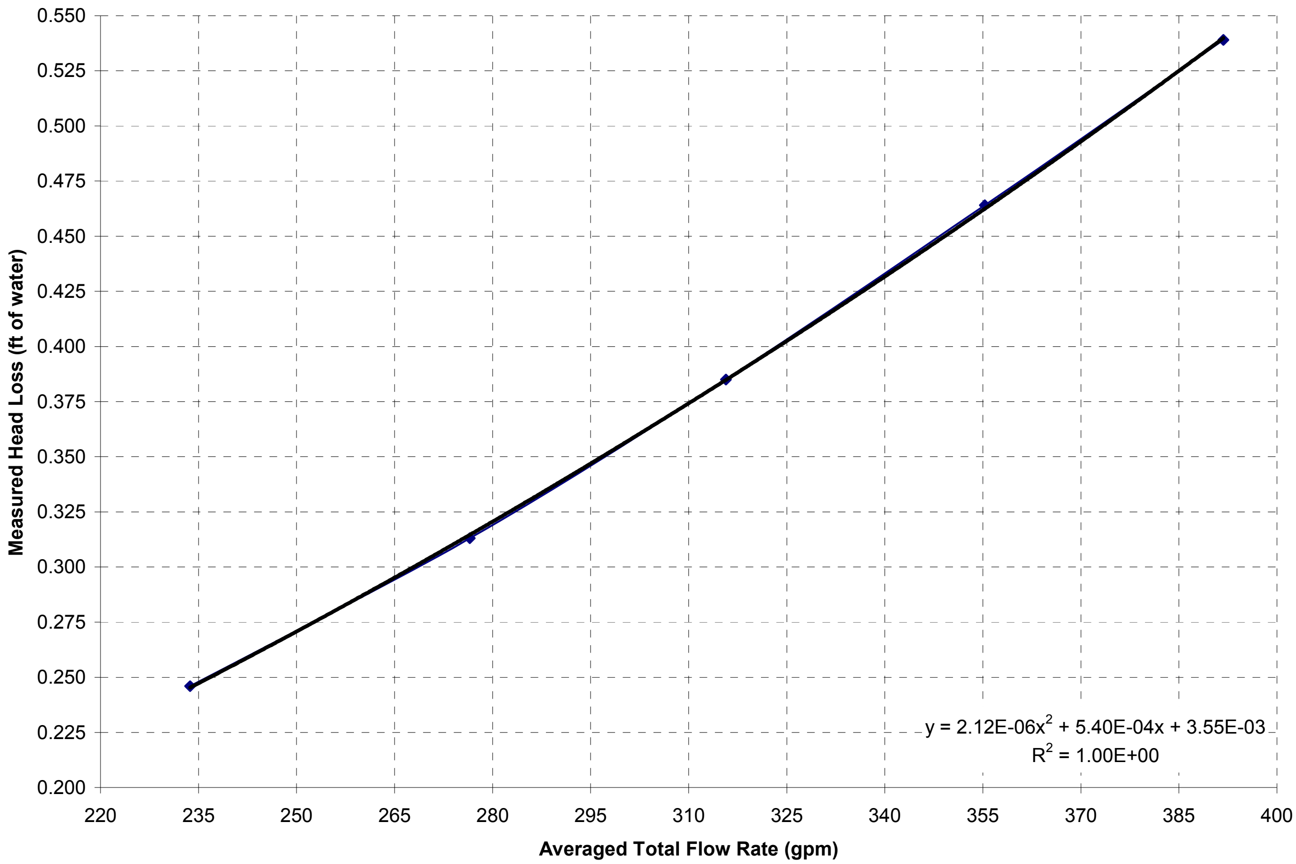
E.6.2 Clean Strainer Head Loss Test

The Clean Strainer Head Loss Test determines the head loss of the clean strainer for five different flume flow rates. For this test, the measured flow rates, head losses, and water temperatures were averaged over the test duration once the desired flow rate was achieved. Table E.6-2 summarizes the clean strainer head loss results for the target flow rates. Figure E.6-1 provides a plot of the measured clean strainer head loss versus the average total flow rates for the Clean Strainer Head Loss Test.

Table E.6-2 Clean Strainer Head Loss Test Results

Target Flow (gpm)	Measured Basket Flow (gpm)	Measured Mini-Flow (gpm)	Measured Total Flow (gpm)	Temperature (°F)	Measured Strainer Head Loss (ft. H_2O)
230.9	204.8	28.9	233.7	116.2	0.246
269.3	247.6	28.9	276.5	118.1	0.313
307.8	286.9	28.8	315.7	119.3	0.385
346.3	326.5	28.8	355.3	120.7	0.464
384.8	363.4	28.4	391.8	119.9	0.539

Figure E.6-1 Clean Strainer Measured Head Loss vs. the Average Total Flow Rates



E.6.3 Design Basis Debris Loaded Strainer Head Loss Test

The Design Basis Debris Loaded Strainer Head Loss Test determines the debris bed head loss for the U.S. EPR design basis accident. The maximum and average measured head losses recorded during the test period are presented in Table E.6-3. During this test, the maximum head loss occurred prior to the completion of particulate addition and before fiber and chemicals were added to the test apparatus.

Table E.6-3 Maximum and Average Measured Head Loss for the Design Basis Debris Loaded Strainer Head Loss Test

	Hour	Total Flow (gpm)	Temp (°F)	Measured Basket Head Loss (ft. of water)	Strainer Head Loss (ft. of water)
Average	N/A	316.8	115.9	6.27	0.377
Maximum	00.13	328.0	118.2	0	0.414

The strainer and retaining basket head loss data recorded during Test No. 2 is graphed in Figure E.6-2. As indicated in Figure E.6-2, the strainer head loss remains constant throughout the test. The retaining basket overflows after the addition of coating chips, and then remains constant until the final batch of chemical debris is added to the test flume. Following the final batch of chemical debris, an approximate 1.3 inch measured increase in retaining basket head loss occurs over a period of 3.6 hours. Towards the end of the test there was a slight increase in the recorded retaining basket head loss caused by evaporation of water in the test apparatus. Following the test, the flume was drained revealing an essentially clean strainer screen. Figure E.6-3 shows the strainer screen following flume drain down.

Figure E.6-2 Strainer and Retaining Basket Head loss Data for the Design Basis Debris Loaded Strainer Head Loss Test

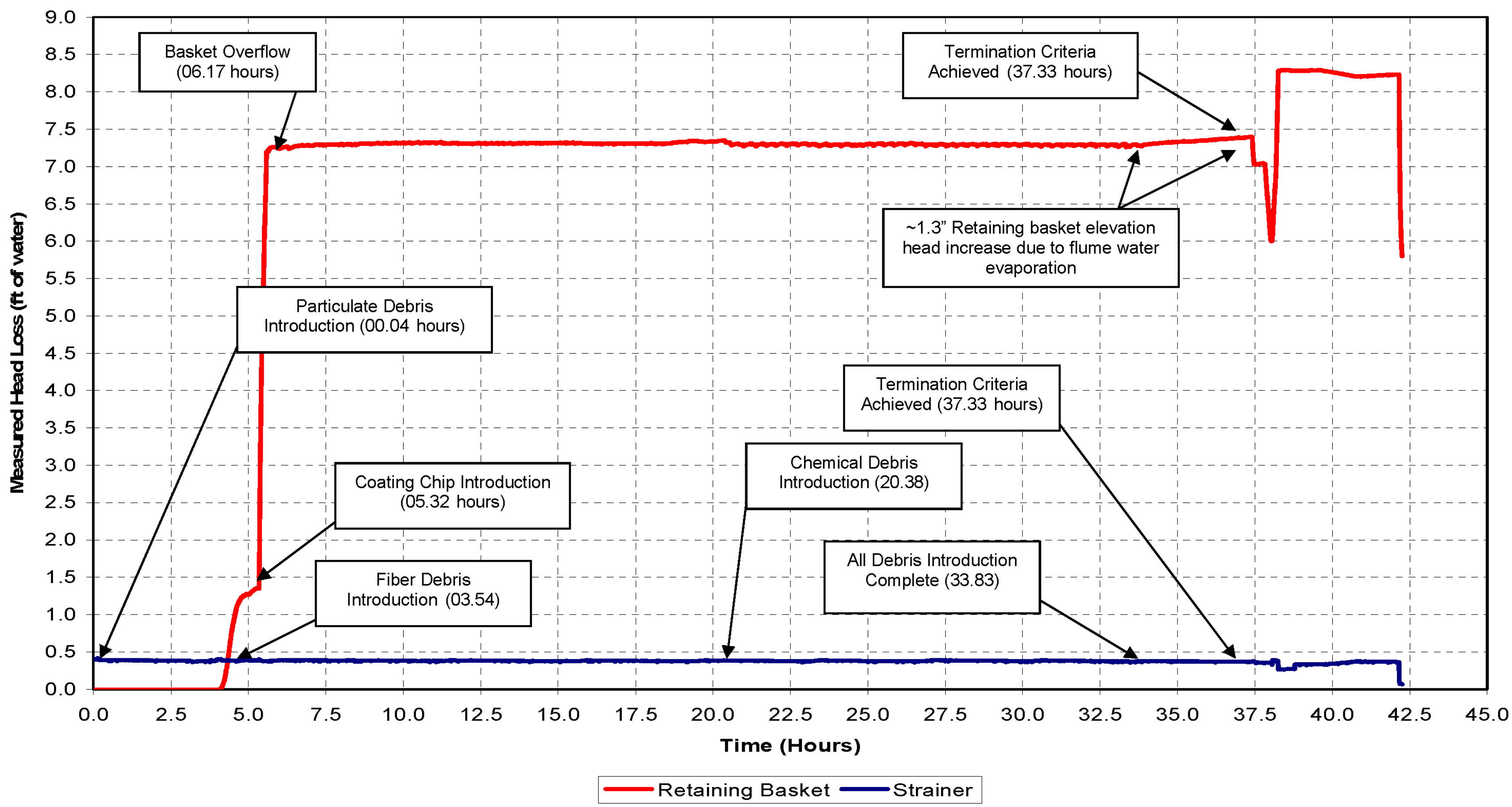
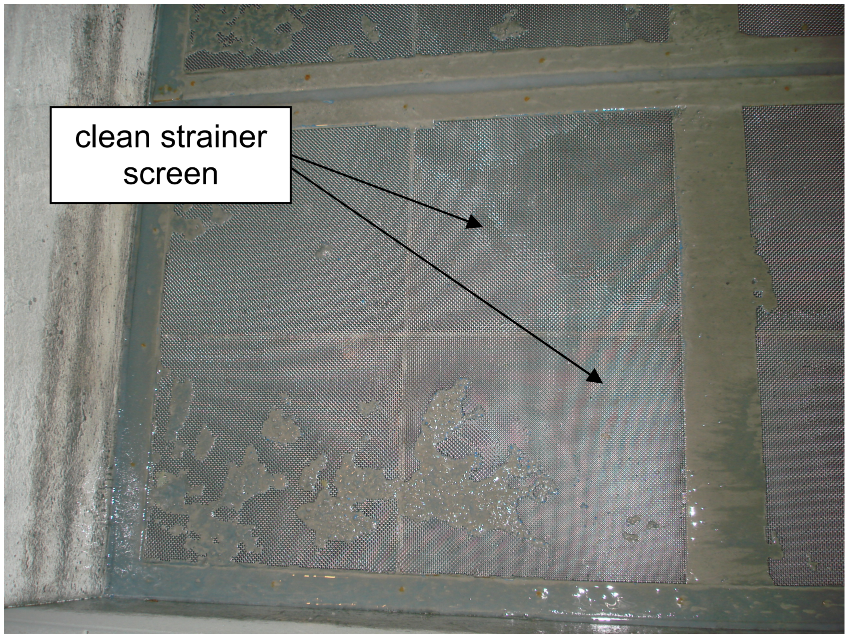


Figure E.6-3 Strainer Screen After Flume Drain Down Following the Design Basis Debris Loaded Strainer Head Loss Test



E.6.4 Fibrous Debris Only Sample Bypass Test

The Fibrous Debris Only Sample Bypass Test establishes the transport characteristics of fibers introduced incrementally up through the maximum design basis fiber load. This test also evaluates how a fibrous debris bed forms on the retaining basket and strainer. Debris bypass testing was performed during this type test to provide debris bypass results for downstream analysis.

The Fibrous Debris Only Sample Bypass Test was originally performed as Test No. 3. After Test No. 3 was terminated, the debris introduction pump was dismantled and a small amount of fibrous debris was found within the pump's internals. For this reason, Test No. 3 was invalidated and the test was repeated as Test No. 3A.

Test No. 3A used the same procedures used in Test No. 3. The head loss data measured during the Fiber Debris Only Sample Bypass Test No. 3A is shown in Table E.6-4. The debris loaded head loss shown for Test 3A is not used as a design basis head loss since only one debris constituent was introduced for the test and chemical effects were not present. After all of the fibrous debris was introduced to the test flume, the debris introduction pump was dismantled to verify remnants of fiber did not remain in the pump internals. A small amount of debris was discovered and re-introduced to the test flume through the observation window after the pump was dismantled.

Table E.6-4 Head Loss Data for Fibrous Debris Only Sample Bypass Test No. 3A

Time	Procedure Action	Total Flow (gpm)	Temp (°F)	Measured Basket Head Loss (ft. of water)	Strainer Head Loss (ft. of water)
09:02:42	1st batch of fiber added	318	114	0.0	0.375
09:20:18	1st batch completed	317	113	0.0	0.376
09:48:21	2nd batch of fiber added	314	115	0.001	0.388
09:51:39	2nd batch completed	319	115	0.015	0.385
13:21:56	test termination	312	120	0.091	0.391

Fiber bypass sampling was conducted during Test 3A. These samples are analyzed for percent bypass and used for downstream effects analysis. A total of thirteen samples were drawn and analyzed. The results of the analysis quantify the amount of fibrous debris that penetrated the strainer during testing. Table E.6-5 provides a summary of the bypass test results. Results of testing and analysis conclude a total fibrous debris bypass percentage of 34.4%.

Table E.6-5 Bypass Test Results

TEST 3A			LENGTH						Diameter			Flow Rate	Smpl Size
Sample	Time (min)	Fibers (per smpl)	Long (%)	Med (%)	Short (%)	Long (μm)	Med (μm)	Short (μm)	Thick (μm)	Med (μm)	Thin (μm)	(gpm)	(mL)
B	N/A	94	8%	52%	40%	900	300	80	10	6	3	280.9	25
1	0	90	16%	66%	18%	1200	350	80	10	7	3	285.4	25
2	4	1501	8%	61%	31%	1100	300	90	12	7	4	290.4	25
4	14	11150	3%	53%	44%	1200	250	90	11	7	3	281.9	25
5	19	22360	2%	54%	44%	850	250	90	10	6	3	288.3	25
6	24	20707	2%	49%	49%	1100	250	90	10	7	3	287.6	25
9	39	10747	4%	48%	48%	950	300	80	12	7	3	288.1	25
10	44	10467	2%	47%	51%	850	250	90	10	6	4	285.0	25
11	49	9300	2%	46%	52%	1100	250	80	11	7	3	288.6	25
12	54	8080	2%	40%	58%	850	300	80	10	7	3	291.0	25
17	106	137	4%	52%	44%	1300	250	90	12	7	3	290.9	25
22	176	108	3%	65%	32%	950	250	80	11	7	3	287.0	25
27	246	163	8%	59%	33%	900	250	80	11	7	3	288.5	25

E.6.5 Debris Loaded Strainer Head Loss Thin Bed Test

The Debris Loaded Strainer Head Loss Thin Bed Test determines if a higher head loss is possible with a thin bed of fibers, particulate, and chemical debris present, rather than with the design basis quantity of debris. For the Debris Loaded Strainer Head Loss Thin Bed Test, a plot of the strainer and retaining basket head loss is presented in Figure E.6-4. Based on results of testing, there was no formation of a thin bed on the strainer. Upon draining the flume after test termination, the strainer screen appeared nearly free of debris. Figure E.6-5 shows the strainer screen following the flume drain down.

Figure E.6-4 Strainer and Retaining Basket Head Loss Data for the Thin Bed Test

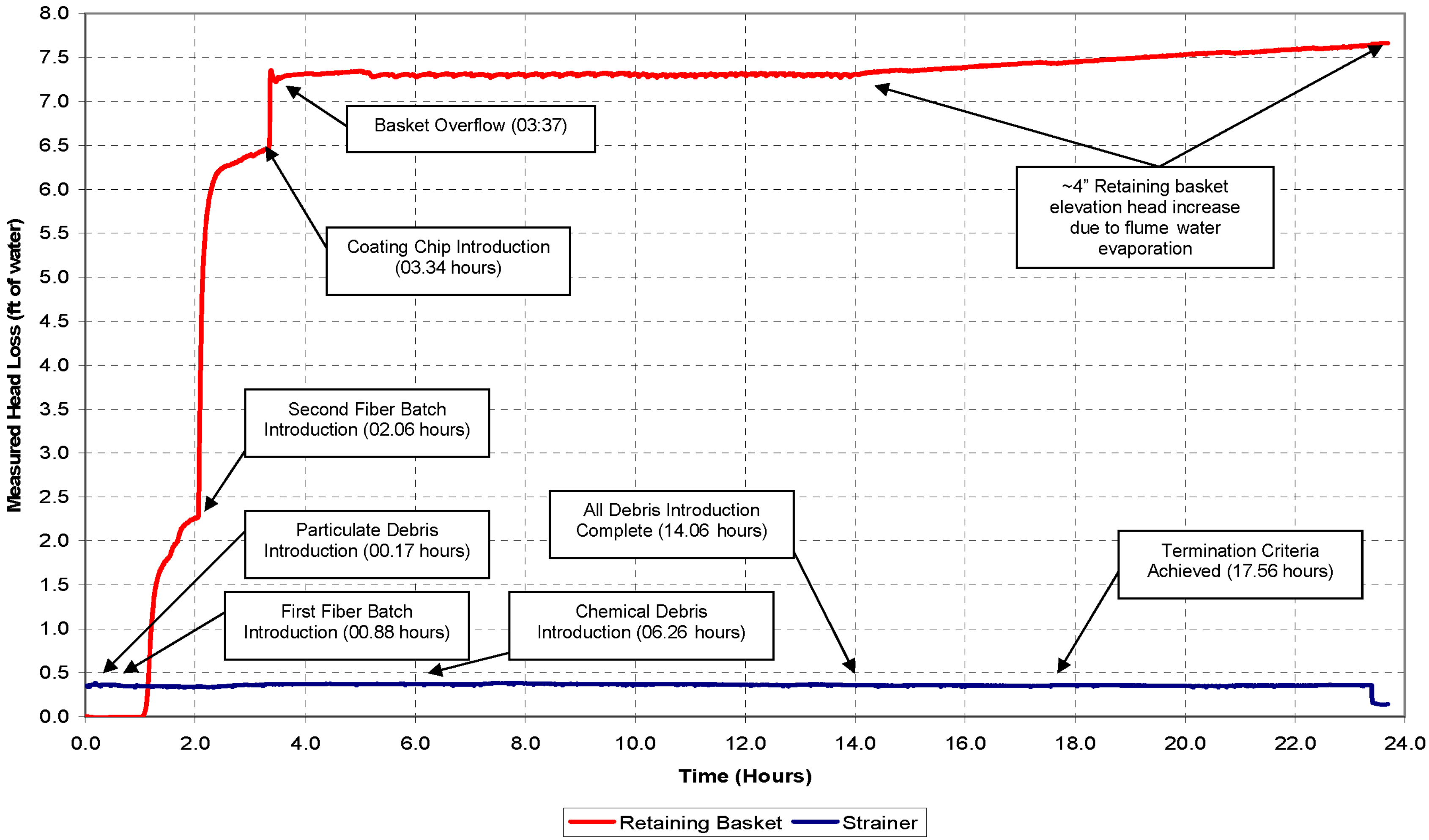
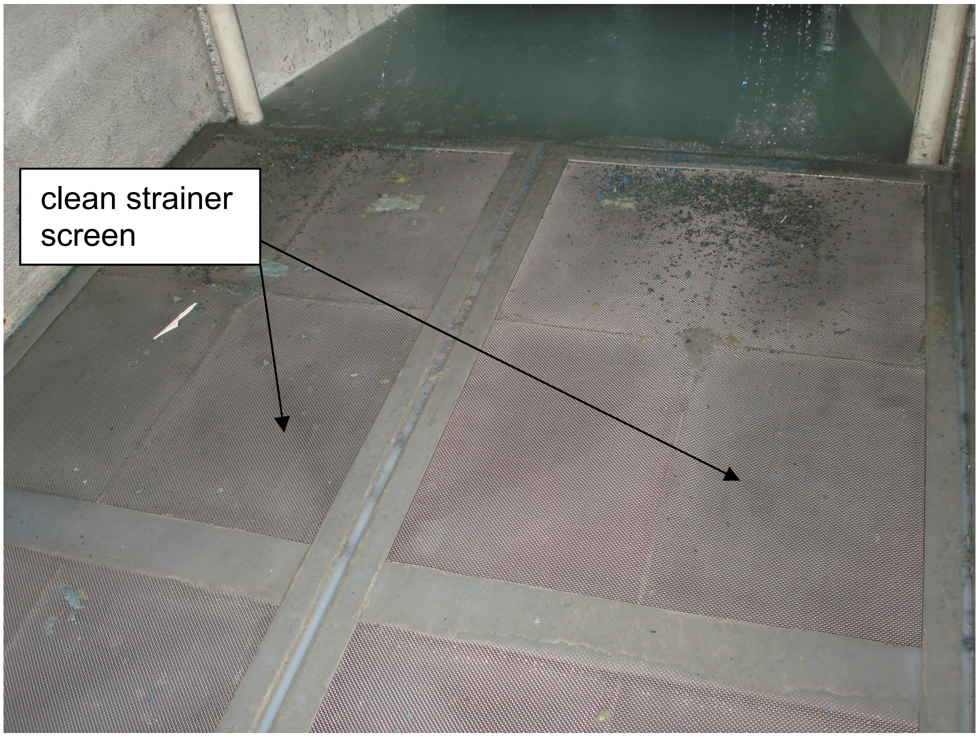


Figure E.6-5 Strainer Screen After the Flume Drain Down Following the Thin Bed Test



E.7 Conclusions

A total of five type tests were performed to evaluate and confirm the ECCS strainer performance. The following conclusions are provided.

E.7.1 Debris Transport Test

The results of the Debris Transport Test are provided in Section E.6.1. The test results demonstrate that the test debris was entirely captured and contained within the retaining basket. Therefore, it is concluded that there are no adverse effects to the ECCS strainer operation.

E.7.2 Clean Strainer Head Loss Test

The Clean Strainer Head Loss Test results are presented in Table E.6-2. A plot of the measured clean strainer head loss versus the measured testing target flow rates presented in Figure E.6-1. The test results demonstrate that the clean strainer has minimal head loss. The strainer head loss associated with the scaled design basis test flow of 307.8 gpm is approximately 0.385 feet. During this test, the strainer showed no visual observations of vortexing.

E.7.3 Design Basis Debris Loaded Strainer Head Loss Test

The Design Basis Debris Loaded Srainer Head Loss Test results are presented in Table E.6-3 and Figure E.6-2. Based on Table E.6-3, the maximum strainer head loss was 0.414 feet of water as compared to the clean strainer head loss of 0.385 feet. During testing, the retaining basket was challenged with the design basis debris source term and effectively prevented the fibrous debris from reaching the strainer. Following the test, the flume was slowly drained of water to reveal an essentially clean strainer. The design basis test debris load had a negligible impact on the ECCS strainer head loss.

E.7.4 Fibrous Debris Only Sample Bypass Test

The Fibrous Debris Only Sample Bypass Test was performed as Test No. 3A. The maximum measured retaining basket and strainer head losses for Test No. 3A are presented in Table E.6-4. The test results demonstrated that the strainer head loss was negligible. Bypass samples were taken during Test 3A to analyze the percent bypass fraction for downstream effects analysis. Table E.6-5 details the bypass test results. Results of testing and analysis yield a total fibrous debris bypass percentage of 34.4%.

E.7.5 Debris Loaded Strainer Head Loss Thin Bed Test

The results of the Debris Loaded Strainer Head Loss Thin Bed Test are similar to the test results of the Design Basis Debris Loaded Strainer Head Loss Test. A plot of the strainer and retaining basket head loss is presented in Figure E.6-4. The retaining basket successfully protected the strainer from fibrous debris. With the absence of fiber at the strainer, it was not possible for a thin bed to form on the strainer. Following the test, drain down of the flume revealed a strainer screen that was nearly free of debris.

In summary, the ECCS strainer performance testing demonstrates the effective and reliable performance of the U.S. EPR design for GSI-191. The retaining basket effectively functions to limit and prevent most debris from reaching the ECCS strainer. The strainer design, complemented by the design mitigation features of the retaining basket, provides significant head loss margin for the ECCS strainer. Testing demonstrates that the strainer head loss is conservatively less than 0.5 feet of water as compared to a strainer design head loss of approximately 5.0 feet.

ECCS strainer testing conservatively challenged the “defense in depth” design of the U.S. EPR with the addition of over 100% of the design basis debris source term to one of the four sets of retaining basket/strainer combinations in the U.S. EPR design.

E.8 References

1. NEI 04-07 Vol. 1 (Methodology), “Pressurized Water Reactor Sump Performance Evaluation Methodology,” December 2004.

2. NEI 04-07 Vol. 2 (Safety Evaluation), “Pressurized Water Reactor Sump Performance Evaluation Methodology,” December 2004.

3. “NRC Staff Review Guidance Regarding Generic Letter 2004-02 Closure in the Area of Strainer Head Loss and Vortexing” March 2008.