VOGTLE GSI-191 RESOLUTION PLAN AND CURRENT STATUS NRC PUBLIC MEETING

MAY 21, 2015

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AGENDA

- Introductions
- Meeting Objectives
- Overview of Resolution Methodology
- Example Calculations
- Quality Assurance
- Conclusions
- Staff Questions and Concerns

MEETING OBJECTIVES

- Obtain staff feedback on the overall GSI-191 resolution path for Vogtle
- Describe change in strainer head loss strategy (currently planning to use 2009 head loss test results)
- Discuss use of deterministic vs. best estimate inputs in the evaluation
- Provide additional information on treatment of unqualified coatings (follow-up to November 2014 NRC meeting discussion)

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OVERVIEW OF METHODOLOGY

- Resolution plan modified based on recent changes in South Texas Project (STP) pilot plant methodology
  - No longer planning to perform head loss testing to develop a rule-based head loss model (as presented to the NRC in November 2014)
  - Conventional and chemical head loss for break-specific debris loads will be determined based on 2009 Vogtle head loss testing
  - Will continue to quantify risk by evaluating conditional probability of GSI-191 failures for different equipment configurations
- Will also continue to use best-estimate inputs for some parameters in the GSI-191 Risk-Informed Software

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BEST-ESTIMATE INPUTS

- Containment temperature
- Pool temperature
- Containment Spray (CS) activation
- Pool volume/level
- Pool pH
- Emergency Core Cooling System (ECCS) flow rates
- Unqualified Coatings (UQC)failure
- Debris transport fractions
- Aluminum corrosion
- Calcium and aluminum precipitation
- Strainer geometry
- Net Positive Suction Head (NPSH) margin

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VOGTLE PLANT LAYOUT

- Westinghouse 4-loop PWR (3,626 MWt per unit)
- Large dry containment
- Two redundant ECCS and CS trains
  - Each train has an RHR pump, a high head pump, an intermediate head SI pump, and a CS pump
  - SI and high head pumps piggyback off of the RHR pump
- Maximum (runout) flow rates:
  - RHR 4,500 gpm/pump
  - CS 3,200 gpm/pump
- Two redundant containment air cooling trains

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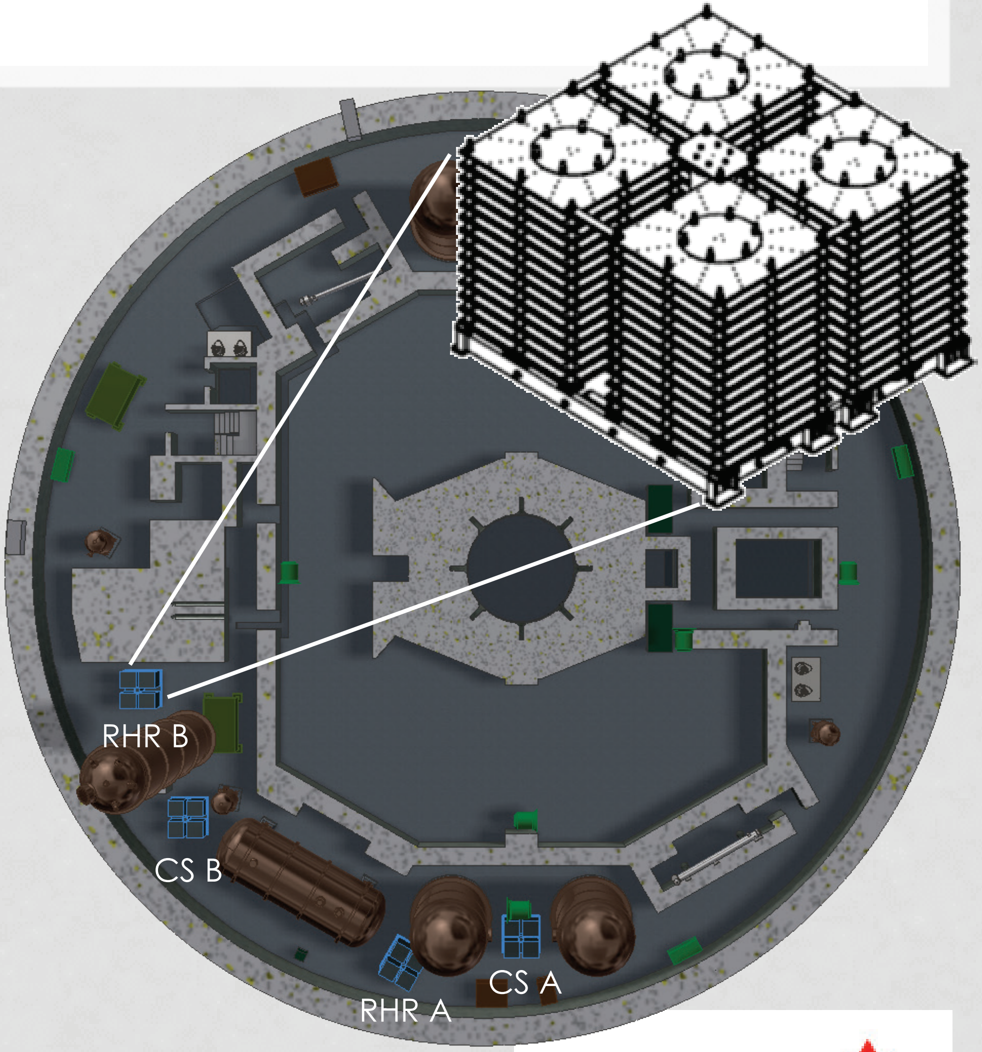
STRAINER ARRANGEMENT

- Two RHR and CS pumps each with their own strainer
- Each strainer is similar with four stacks of disks
  - RHR strainer: 18-disk tall, 765 ft^2, height of 5.6 ft
  - CS strainer: 14-disk tall, 590 ft^2, height of 4.6 ft
  - Perforated plate with 3/32" diameter holes



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PLANT RESPONSE TO LOCAS

- Plant response includes the following general actions:
  - Accumulators inject (breaks larger than 2 inches)
  - ECCS injection is initiated from the RWST to the cold legs via RHR, SI, and High Head pumps
  - Containment spray is initiated from the RWST via CS pumps (hot leg breaks larger than 15 inches)
  - RHR pumps switched to cold leg recirculation at RWST lo-lo alarm
  - CS pumps switched to recirculation at RWST empty alarm
  - CS pumps secured at least 1.5 hours after start of recirculation
  - RHR pumps switched to hot leg recirculation at 7.5 hours
- Containment conditions are break-specific
  - Break flow rate
  - Pool volume/level
  - Pool temperature
  - Containment pressure (Containment Spray Actuation Setpoint Reached?)
  - Containment temperature
  - Pool pH

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BEST-ESTIMATE FLOW RATE

- Flow rates determined from best-estimate thermal-hydraulic modeling using RELAP5/MELCOR

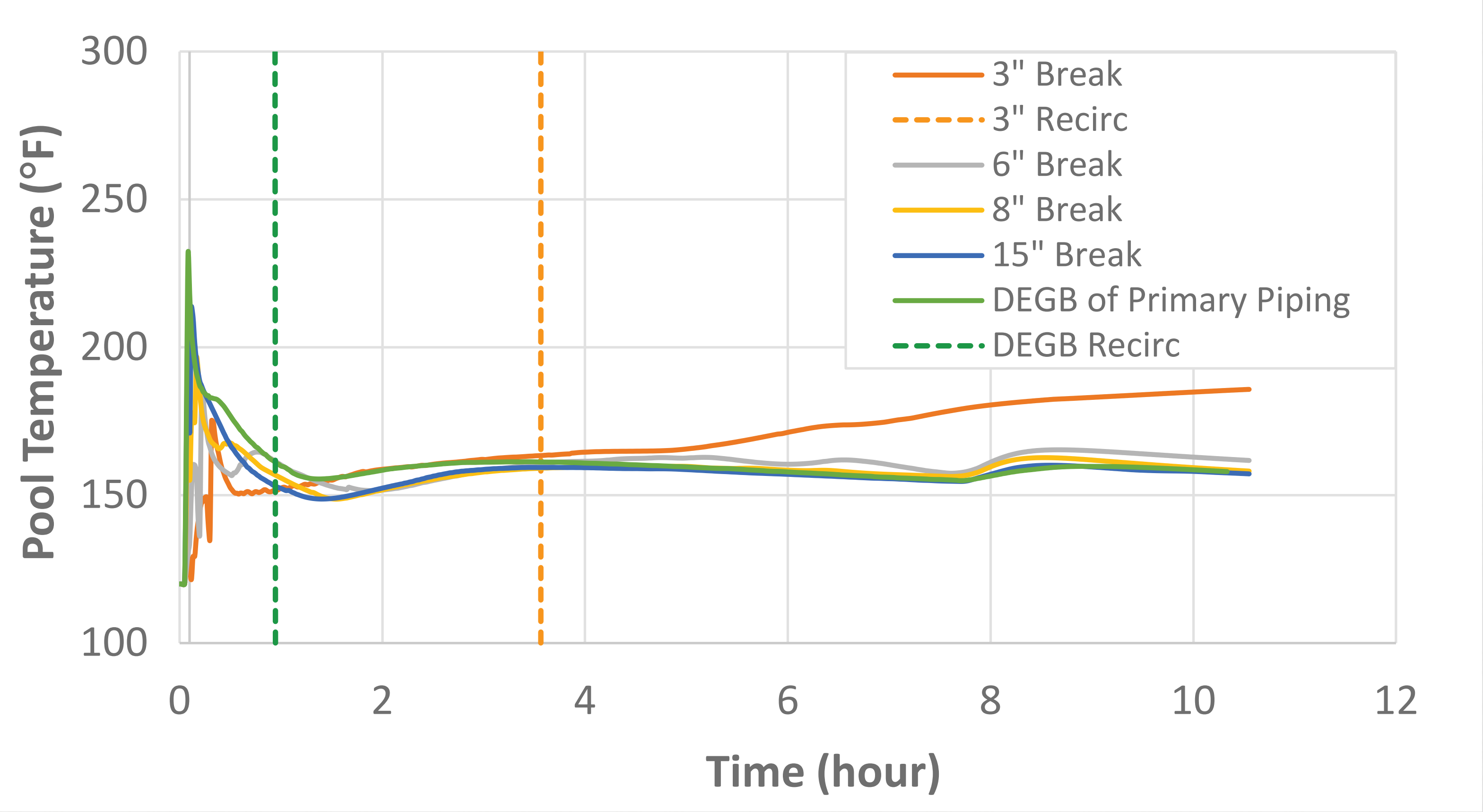
Break Size (in)	Injection (gpm)	CL Recirculation (gpm)	HL Recirculation (gpm)
3	2,914	2,591	2,287
6	6,420	5,801	5,361
8	7,358	6,903	5,875
15	8,367	7,490	6,242
27.5	8,396	7,615	6,293
29	8,461	7,595	6,278

All flow rates based on two train operation

CONTAINMENT POOL WATER LEVEL

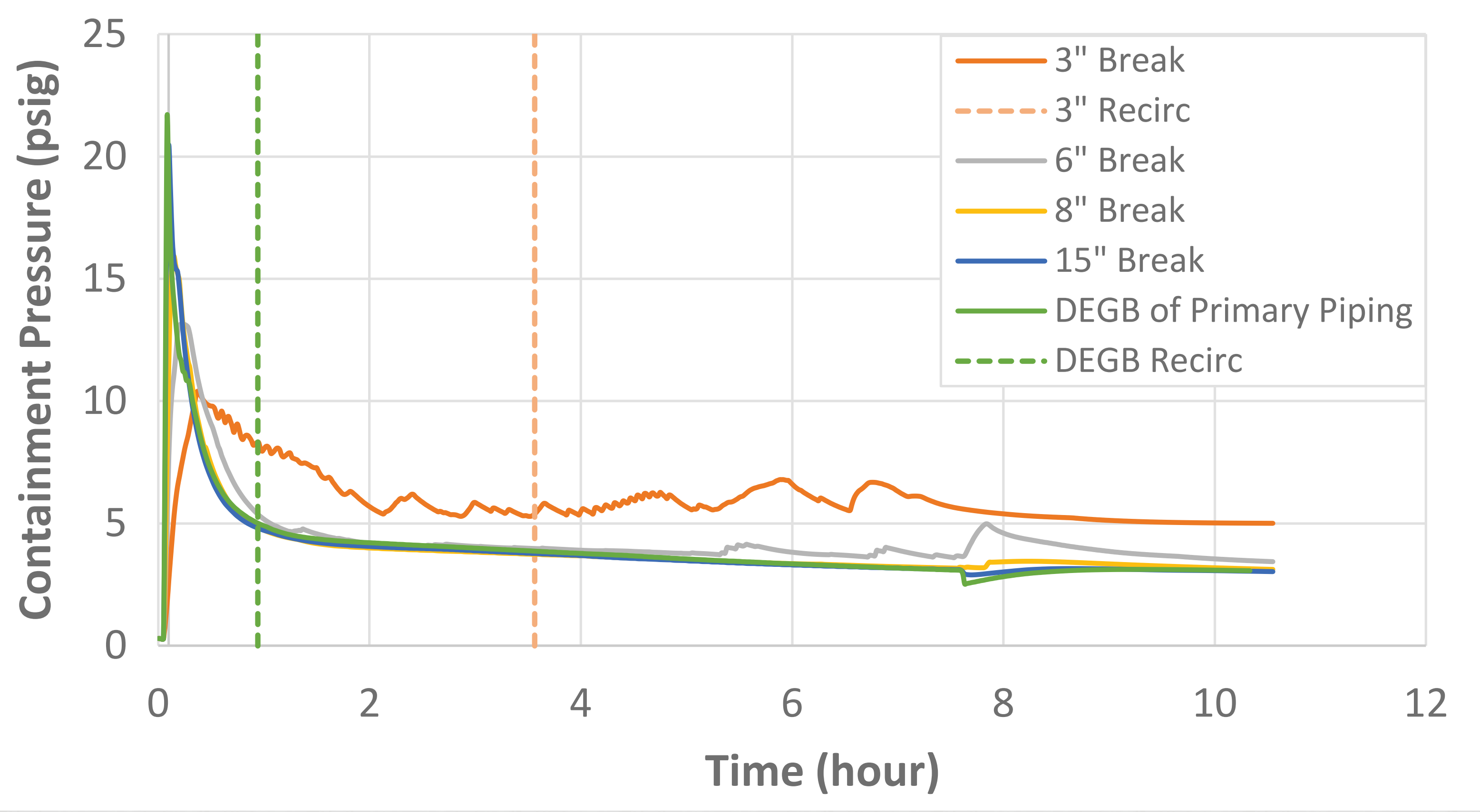
- Sump pool depth is evaluated on a break-specific basis
- The evaluation considers break location and size for the appropriate contribution of RWST, RCS and SI accumulators to pool level
- The resulting sump pool depth ranges between 3.5 ft and 9.1 ft during sump recirculation
  - 3.5 ft – Minimum water level 60 hours after an SBLOCA
  - 9.1 ft – Maximum water level at CS switchover to recirculation for an LBLOCA

BEST-ESTIMATE POOL TEMPERATURE

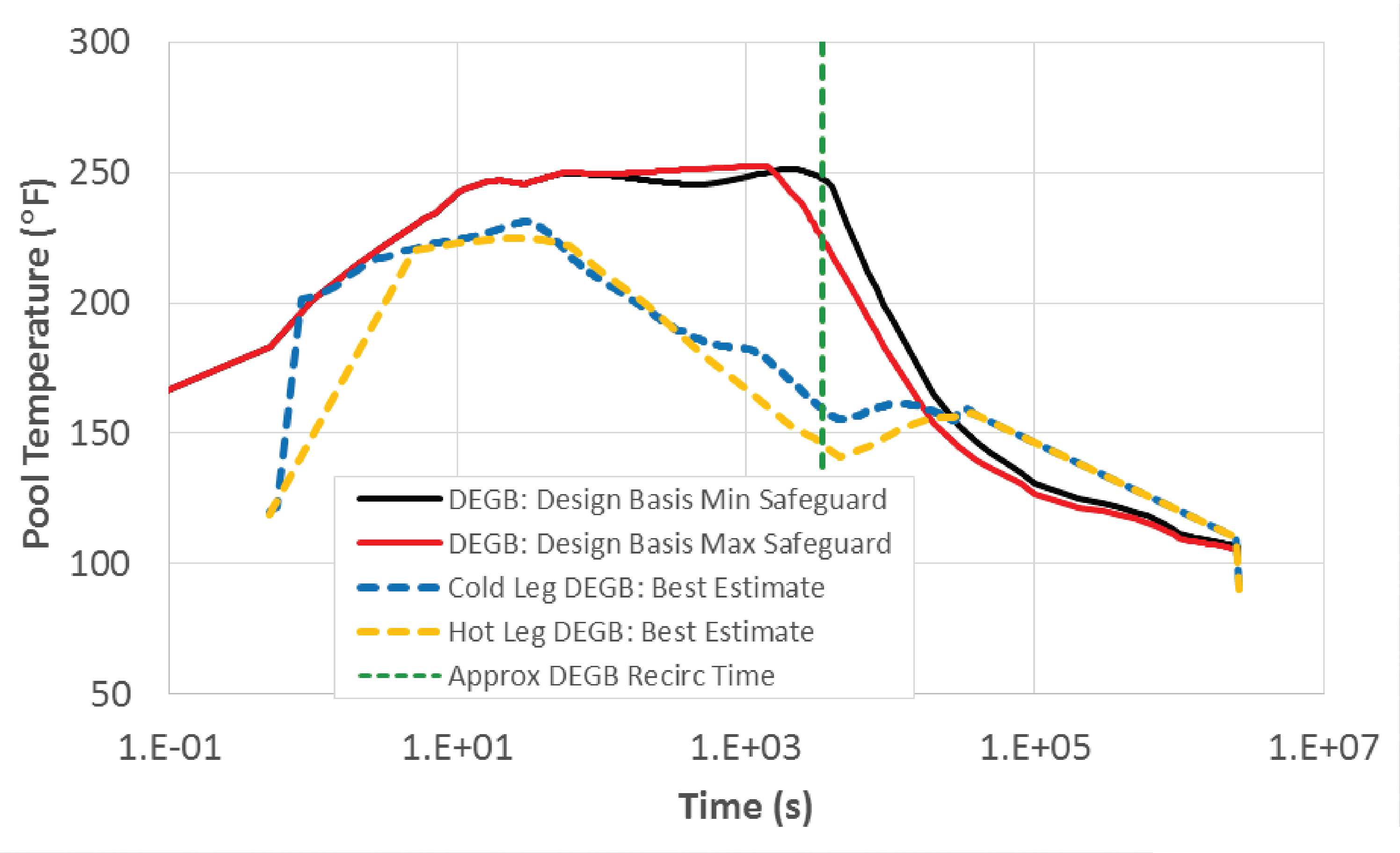


Note that the 3" break temperature profile is artificially high because manual actions were not modeled, and the lower flow rates for a 3" break result in less energy transfer to the ultimate heat sink

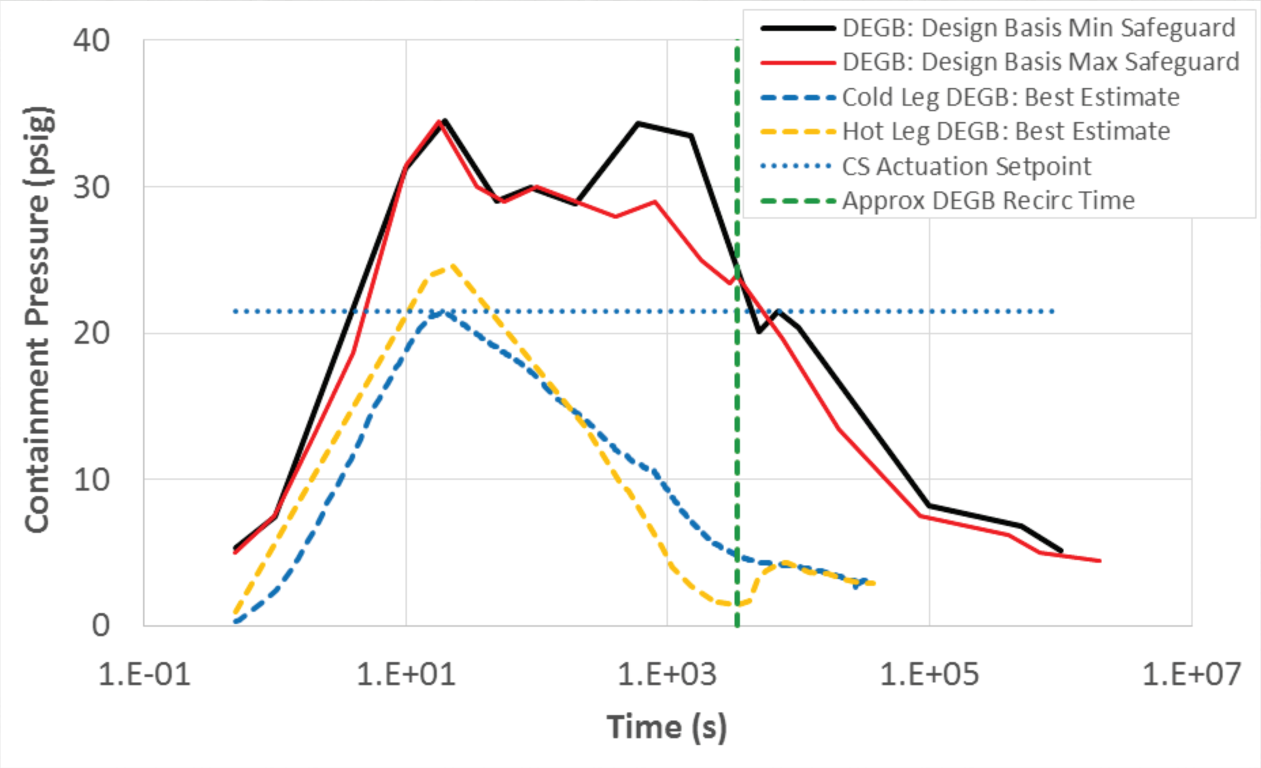
BEST-ESTIMATE CONTAINMENT PRESSURE



POOL TEMPERATURE COMPARISON



CONTAINMENT PRESSURE COMPARISON



- Curves illustrate the basis for containment spray actuation logic
- For analysis purposes (NPSH and gas voiding) containment pressure conservatively reduced to saturation pressure when pool temperature is >212 °F and atmospheric when pool temperature is 212 °F or less

CONTAINMENT POOL pH

- Sump pool and spray pH is evaluated on a break-specific basis
- The evaluation considers the best-estimate, time-dependent addition of RCS, Accumulator, and RWST water volumes, best estimate boric acid concentrations, and the estimated TSP dissolution rate
- pH is calculated as a function of boric acid and TSP concentrations using Visual MINTEQ
- Best Estimate pH: ~7.2 @ room temperature

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DEBRIS GENERATION

- Insulation and qualified coatings
  - Automated analysis with containment CAD model
  - Calculate quantity and size distribution for each type of debris
  - Partial breaks from ½ inch to double-ended guillotine breaks (DEGBs) for all Class 1 welds in containment
  - ZOIs consistent with deterministic approach

Nukon	17D
Qualified Epoxy & IOZ with Epoxy topcoat	4D
Interam Fire Barrier Material	11.7D

- Unqualified coatings and latent debris quantities are identical for all breaks

INSULATION AND QUALIFIED COATINGS QUANTITIES

- Debris quantities vary significantly across the range of possible breaks, and are calculated for each break
  - Nukon: 0 ft^3 to 2,229 ft^3
  - Qualified epoxy: 0 lb_m to 219 lb_m
  - Qualified IOZ: 0 lb_m to 65 lb_m
  - Interam fire barrier: 0 lb_m to 60 lb_m

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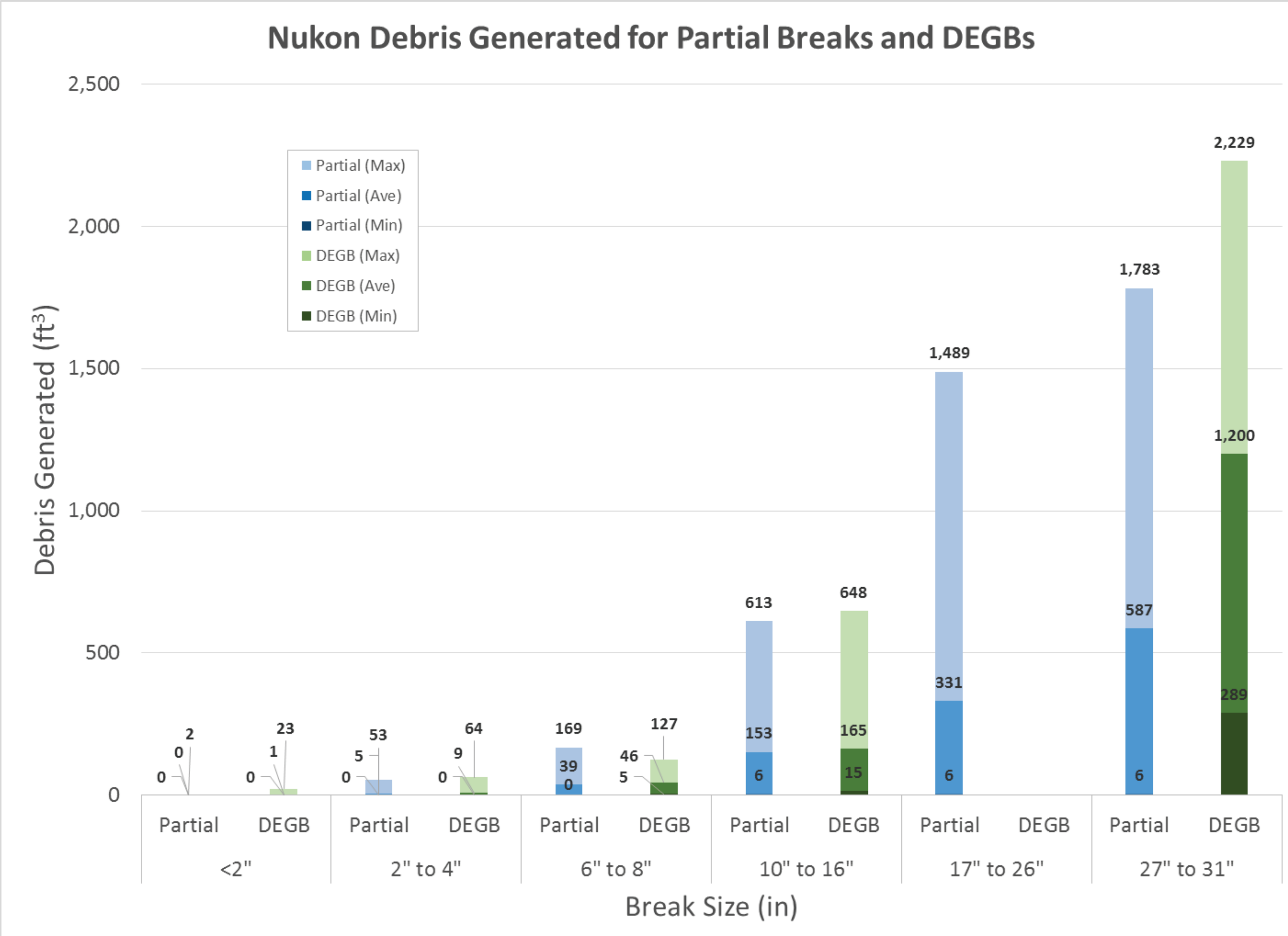
NUKON DEBRIS GENERATED



UNQUALIFIED COATINGS

- Types of Unqualified Coatings at Vogtle
  - Inorganic Zinc (IOZ)
  - Alkyd
  - Epoxy
- IOZ and alkyd coatings were assumed to fail as 100% particulate
- Types of unqualified epoxy coatings at Vogtle that have been DBA tested:
  - Starglaze 2001
  - Amerlock 400
  - Keeler & Long 4129 / 5009 / 6129
- DBA testing shows that some unqualified coatings systems will not completely delaminate after exposure
- Some of the Vogtle qualified coating systems may have been applied correctly, but were listed as unqualified because quality control inspections were not completed

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UNQUALIFIED EPOXY SIZE DISTRIBUTION

- Unqualified epoxy coatings without DBA testing are assumed to fail as particulate
- Unqualified epoxy coatings with DBA testing are assumed to fail as both particulate and chips
  - Comanche Peak DBA testing showed that epoxy coatings failed as chips
  - EPRI test report stated that the failure mode of the tested epoxy top coats is flaking (i.e., failure as chips)
  - Diablo Canyon testing showed that epoxy debris formed inside containment is expected to remain in large pieces (1-2 in^2 chips) as long as the debris stays moist and is exposed to wet heat
- Results of Comanche Peak paint chip characterization are applied to the size distribution of epoxy coatings at Vogtle
  - 12% particulate
  - 37% fine chips (15.6 mil)
  - 9% small chips (0.125 – 0.5 inch)
  - 21% large chips (0.5 – 2 inch)
  - 21% large curled chips (0.5 – 2 inch)

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UNQUALIFIED COATINGS LOCATIONS

Coating Type	Upper Containment Quantity (lb_m)	Lower Containment Quantity (lb_m)
Epoxy	1,602	1,099
Alkyd	0	31
IOZ	24	3
Total	**1,626**	**1,133**

- Coatings that fail in upper containment would have a reduced transport fraction for breaks where containment sprays are not initiated

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UNQUALIFIED COATINGS FAILURE TIMING

Coating Type	Time-Dependent Failure Fraction		
	0 to 0.5 hours	0.5 to 6 hours	6 to 172 hours
Epoxy	0 to 25%	0 to 25%	0 to 100%
Alkyd	0 to 25%	0 to 25%	0 to 100%
IOZ	0 to 25%	0 to 100%	0 to 100%

- Time-dependent failure based primarily on BWROG testing of various unqualified coatings systems and applications
- Coatings that fail in upper containment after sprays are secured would have a reduced transport fraction
- Any coatings that don't fail by 172 hours are assumed to fail by 14 days (100% total failure for all unqualified coatings)

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DEBRIS TRANSPORT

- Using logic tree approach defined in NEI 04-07 consistent with industry developed methods for deterministic closure
  - Blowdown
  - Washdown
  - Pool fill
  - Recirculation
  - Erosion

TRANSPORT - WASHDOWN

- Containment Sprays On
  - All fines (fiber and particulate) washed to lower containment
  - Retention of small and large pieces caught on gratings estimated based on Drywell Debris Transport Study
  - Washdown to various areas proportional to flow split
- Containment Sprays Off
  - Assumed 5% washdown for fines due to condensation and 0% for small pieces

FIBER TRANSPORT FRACTIONS TO ONE RHR STRAINER

Debris Type	Size	1 Train w/ Spray	2 Train w/ Spray	1 Train w/o Spray	2 Train w/o Spray*
Nukon	Fines	58%	29%	23%	12%
	Small	48%	24%	5%	6%
	Large	6%	3%	7%	6%
	Intact	0%	0%	0%	0%
Latent	Fines	58%	29%	28%	14%

* This pump lineup was evaluated for different break locations. The transport fractions shown are the bounding values for an annulus break near the strainers.

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PARTICULATE TRANSPORT FRACTIONS TO ONE RHR STRAINER

Debris Type	Size	1 Train w/ Spray	2 Train w/ Spray	1 Train w/o Spray	2 Train w/o Spray
Unqualified Epoxy	Fines	58%	29%	47%	23%
	Fine Chips	0%	0%	0%	4%
	Small Chips	0%	0%	0%	4%
	Large Chips	0%	0%	0%	3%
	Curled Chips	58%	29%	6%	9%
Unqualified IOZ	Particulate	58%	29%	16%	8%
Unqualified Alkyd	Particulate	58%	29%	100%	50%
Interam	Fines	58%	29%	23%	12%
Qualified Epoxy	Fines	58%	29%	23%	12%
Qualified IOZ	Fines	58%	29%	23%	12%
Latent dirt/dust	Fines	58%	29%	28%	14%
RCS Crud	Fines	58%	29%	23%	12%

*Unqualified coatings transport fractions are preliminary and may change based on recent changes to the unqualified coatings calculation

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CHEMICAL EFFECTS

- Overview
  - Chemical precipitate quantities are determined for each break
- Corrosion/Dissolution Model
  - Corrosion and dissolution of aluminum and calcium is determined primarily using the WCAP-16530 methodology with the following inputs:
    - Best-estimate temperature profiles
    - Best-estimate pH profile
    - Break-specific debris quantities
  - UNM release equations will be used for aluminum in TSP within the applicable temperature and pH limitations

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CHEMICAL EFFECTS

- Solubility
  - No credit will be taken for calcium solubility
  - ANL solubility equation (ML091610696) will be used to credit aluminum solubility
  - Aluminum will remain dissolved up to the calculated solubility limit
- Precipitate Type
  - 2009 strainer head loss test results used calcium phosphate and sodium aluminum silicate (WCAP-16530 surrogates)

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MAXIMUM DEBRIS GENERATED

- Bounding quantities of Nukon, Interam and qualified coatings for DEGB in Loop 1&4 SG compartment

Debris type	Quantity	Notes
Nukon	2,229 ft^3	Including all size categories
Interam	60 lb_m	30% fiber and 70% particulate
Qualified coatings	249 lb_m	IOZ and epoxy
Unqualified coatings	2,759 lb_m	IOZ, alkyd, and epoxy
Latent fiber	4 ft^3	15% of total latent debris; 2.4 lb_m/ft^3
Latent particulate	51 lb_m	85% of total latent debris
Miscellaneous debris	2 ft^2	Total surface area of tape and labels

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DEBRIS QUANTITIES AT ONE RHR STRAINER

Debris Type	2009 Test Quantity	Bounding Hot Leg Break (two trains with CS)	Bounding Cold Leg Break (2 trains, no CS)	Bounding Cold Leg Break (single train no CS)
Nukon	119.8 ft^3	337.4 ft^3	72.7 ft^3	145.5 ft^3
Latent fiber	4.4 ft^3*	1.1 ft^3	0.5 ft^3	1.1 ft^3
Interam	327.8 lb_m*	0 lb_m	0 lb_m	0 lb_m
Qualified coatings	786.7 lb_m*	27.3 lb_m	8.8 lb_m	17.6 lb_m
Unqualified coatings	3,244.8 lb_m*	575.3 lb_m	458.8 lb_m	917.5 lb_m
Latent particulate	59.5 lb_m*	14.8 lb_m	7.1 lb_m	14.3 lb_m
Sodium aluminum silicate	100.6 lb_m	17.8 lb_m	8.5 lb_m	17.0 lb_m
Calcium phosphate	59.6 lb_m	57.4 lb_m	56.0 lb_m	112.1 lb_m

* These tested quantities exceed currently estimated values for all breaks under all equipment combinations at Vogtle

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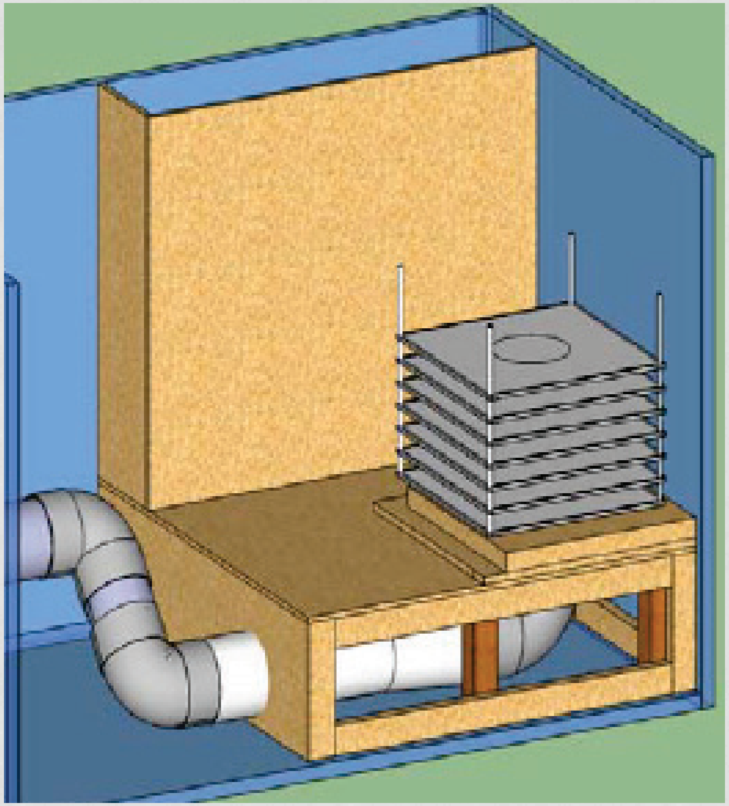
2009 STRAINER HEAD LOSS TESTING

- Testing consistent with the NRC March 2008 Guidance
- Tank test with prototypical 7-disk strainer module
  - Total area of 69 ft^2
  - Walls and suction pipe arranged consistent with plant strainer
- Bounding RHR strainer approach velocity for runout flow rate (4,500 gpm)



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2009 TESTING DEBRIS LOADS

- Nukon debris quantity based on 7D ZOI
- Chemical precipitates quantity from WCAP-16530
- The following debris surrogates used
  - Nukon and latent fiber: Nukon
  - Coatings: Silicon carbide (1 – 100 micron)
  - Latent particulate: Silica sand w/ size distribution consistent with NEI 04-07 Volume 2 (fine sand - < 2000 microns)
  - Interam fire barrier: Interam E-54A

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2009 TEST PROCEDURE

- Debris introduction consistent with the NRC March 2008 Guidance
- For thin-bed testing, all particulate added first followed by small batches of fiber fines
- For full-load testing, fiber and particulate mixture added in batches with constant particulate to fiber ratio
- Chemical debris batched in last
- Head loss allowed to stabilize after each chemical addition

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2009 TEST RESULTS

Debris Load	Thin-bed test head loss (ft)	Full-load test head loss (ft)
Fiber + Particulate	0.63[1]	5.46[2]
After calcium phosphate[3]	1.65	6.57
After sodium aluminum silicate[3]	2.60	11.80

Note:

1. Equivalent bed thickness of 0.625 inches, added in 5 fiber only batches, each 1/8" equivalent thickness
2. Equivalent bed thickness of 1.913 inches, added in 4 batches, each 0.478" equivalent thickness
3. Each chemical separately added in 3 equal batches

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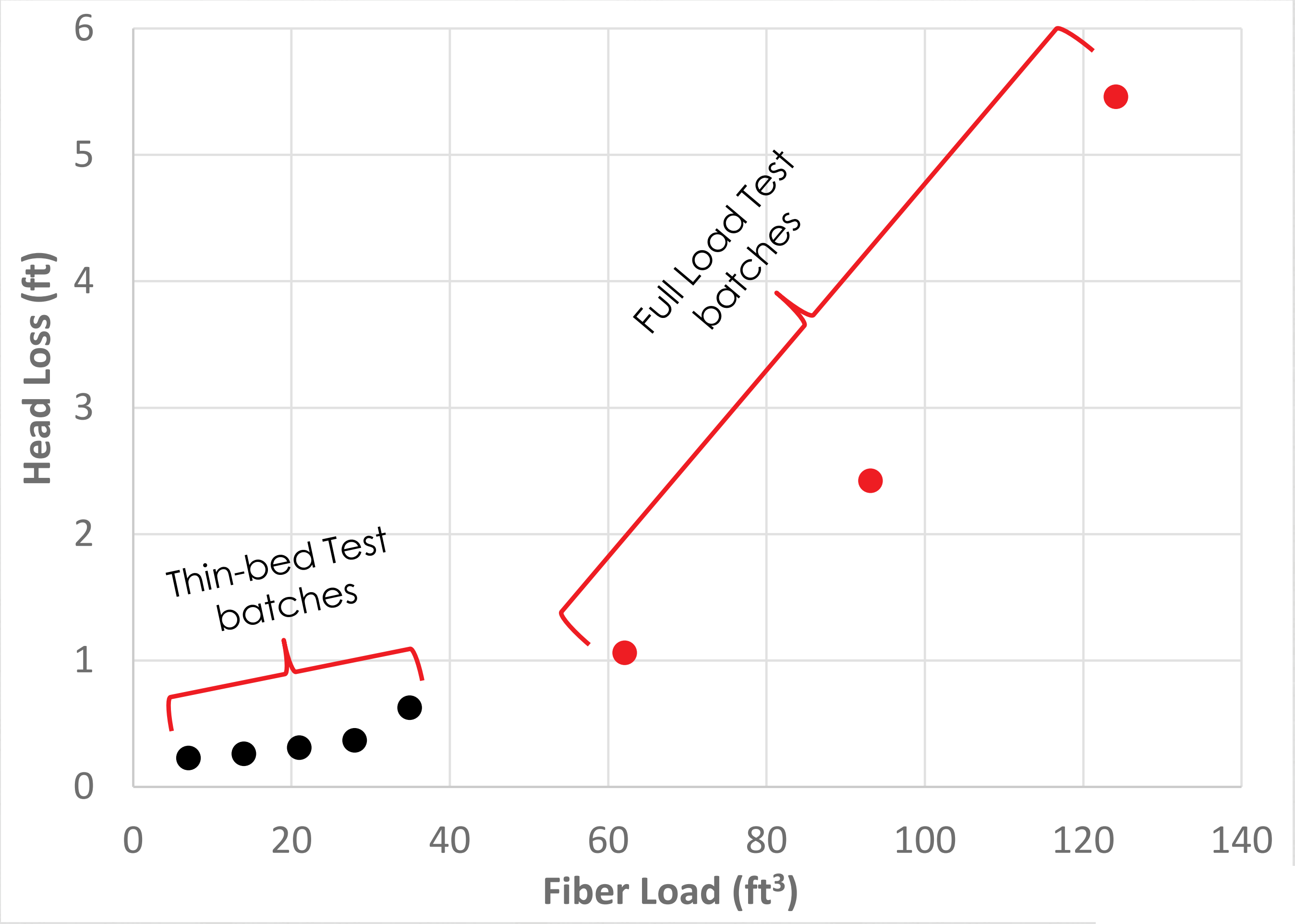
APPLICATION OF 2009 RESULTS

- Conventional debris head loss will be linearly interpolated between data points (debris was batched in)
- Chemical precipitate head loss will be based on a step function for intermediate loads
- Head loss will be scaled as a function of the average approach velocity and temperature based on the results of the flow sweeps performed at the end of the thin-bed and full-load tests
- Results will be extrapolated to 30 days
- Breaks that exceed the maximum tested fiber quantity, particulate quantity, or chemical precipitate quantity will be assigned a failing head loss value

2009 TEST RESULTS - CONVENTIONAL HEAD LOSS



Interpolated head loss values between data points

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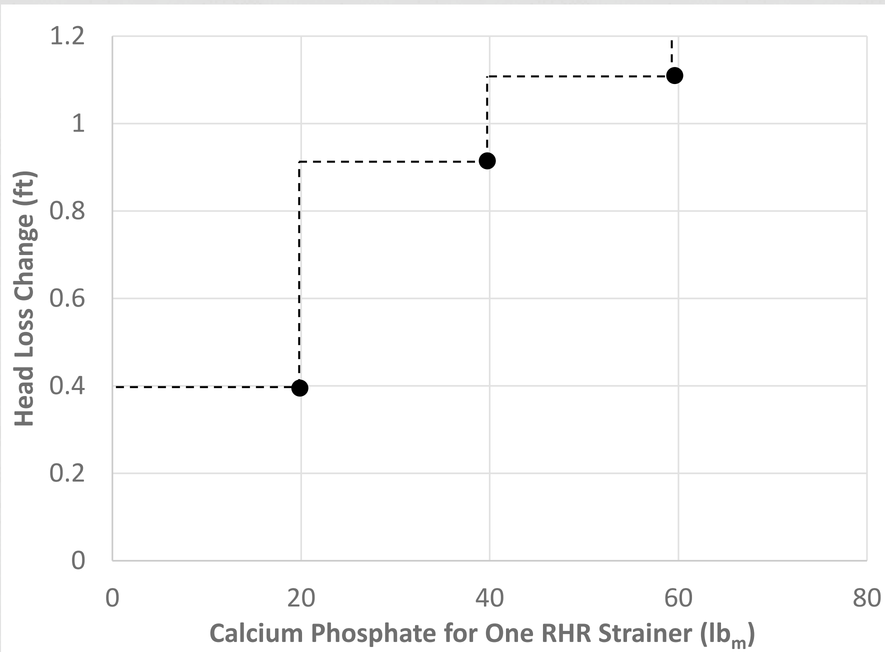
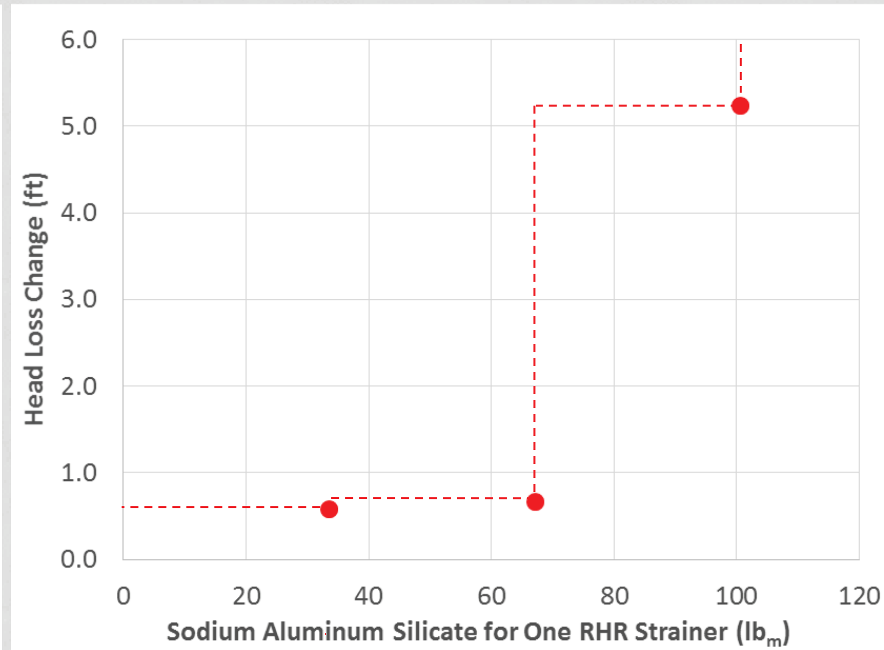
2009 TEST RESULTS – CHEMICAL HEAD LOSS





- Chemical precipitates are assumed to pass through the strainer and not contribute to head loss when fiber load is less than 1/16" theoretical bed thickness
- Utilized step-wise head loss for both chemical types

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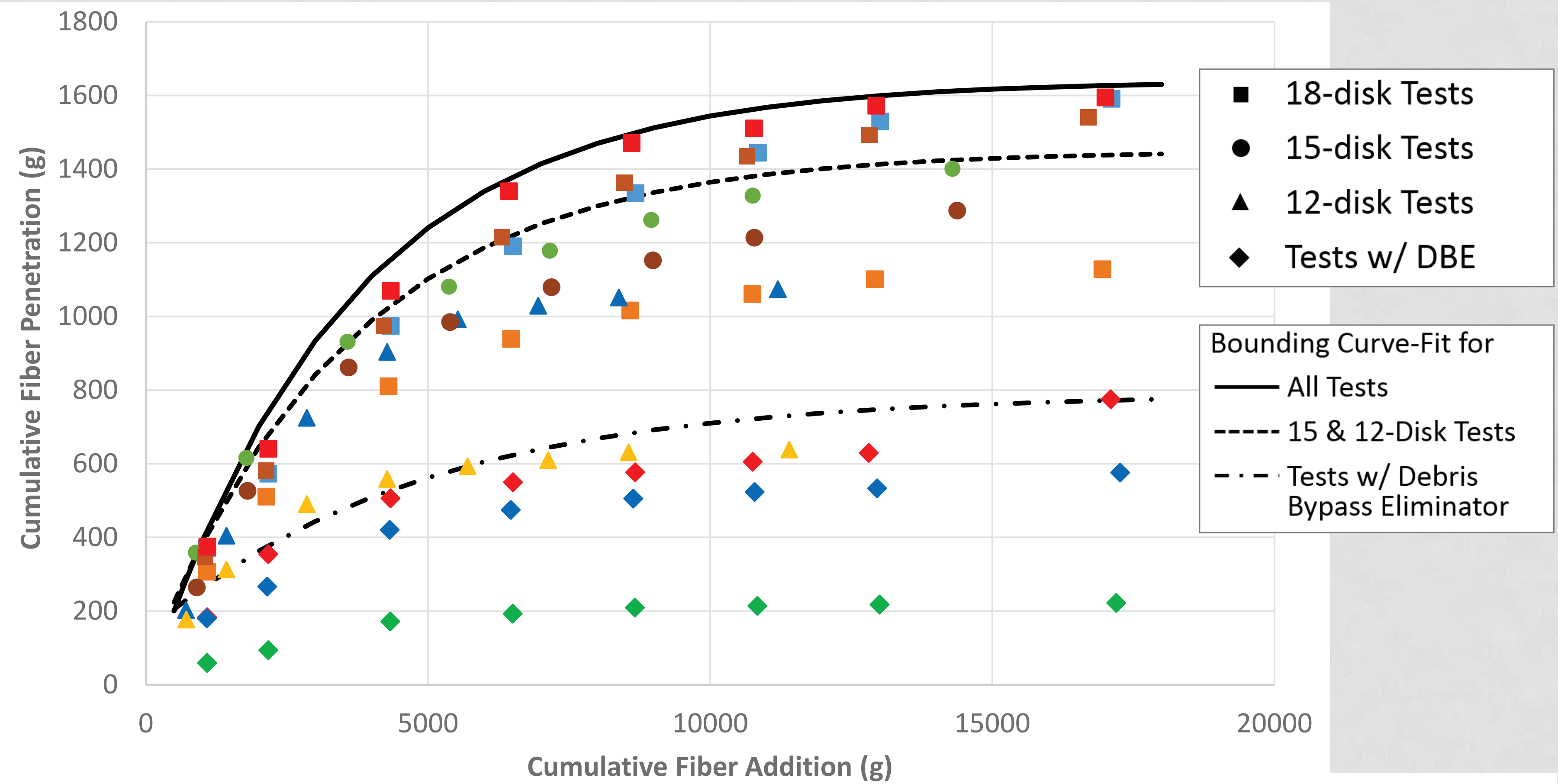
STRAINER ACCEPTANCE CRITERIA

- RHR and CS Pump NPSH Margin
  - Unsubmerged margin = half of submerged strainer height
  - For fully submerged strainer, the NPSH margin is calculated using break-specific water level and flow rates
    - Minimum NPSH margin is 16.6 ft at 210.96°F and a containment pressure of -0.3 psig
- Structural
  - Strainer stress analysis is based on a crush pressure of 24.7 ft for the RHR strainers and 23.0 ft for the CS strainers
- Gas void
  - 2% void fraction at pump inlet

FIBER PENETRATION TESTING

- Eleven tank tests were performed at Alden in 2014 for various strainer approach velocities, number of strainer disks and boron / buffer concentrations
- Nukon prepared into fines per latest NEI Guidance
- A bounding curve fit will be used to evaluate maximum fiber penetration

FIBER PENETRATION RESULTS



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IN-VESSEL EFFECTS

- Transport/accumulation of fiber to the core that penetrates RHR strainers is dependent on break location and flow path
  - Hot leg break during cold leg recirculation: 100% accumulation on core
  - Hot leg break during hot leg recirculation: 0% accumulation on core
  - Cold leg break during cold leg recirculation: ratio of boiloff flow rate (time-dependent) divided by recirculation flow rate
  - Cold leg break during hot leg recirculation: 0% accumulation on core
- Currently using placeholder values for core blockage and boron precipitation acceptance criteria
  - 75 g/FA for hot leg breaks
  - 7.5 g/FA for cold leg breaks
  - Values will be modified as necessary based on results of PWROG testing

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EXAMPLE CALCULATIONS

- Analytical results showing whether a given break passes or fails are highly dependent on the assumptions and models used to evaluate the break
- For example, if sprays are not initiated for a given break:
  - Less water is injected from the RWST (potentially resulting in a partially submerged strainer)
  - A smaller fraction of debris is washed down to the containment pool
  - Corrosion/dissolution is reduced (unsubmerged materials)
  - A larger fraction of debris in the pool is transported to the RHR strainers
- If the strainers are partially submerged:
  - Effective strainer area is reduced giving a higher average approach velocity and a greater debris bed thickness
  - Acceptance criterion is half the submerged strainer height
  - Degasification does not occur
- It is not always obvious what conditions are bounding

BEST ESTIMATE VS. BOUNDING CONDITIONS

- Three sets of simulations were performed to evaluate the full range of breaks (over 28,000 breaks - from ½" to DEG breaks - on each Class 1 weld)
  - Best-estimate conditions
  - Bounding strainer conditions
  - Bounding in-vessel conditions
- Each set of simulations included cases evaluating all equipment running and a single RHR pump failure
- Bounding simulations included both min and max input conditions for variables with competing effects (e.g., a higher pool temperature profile is conservative for NPSH margin and degasification, whereas a lower pool temperature profile is conservative for head loss)

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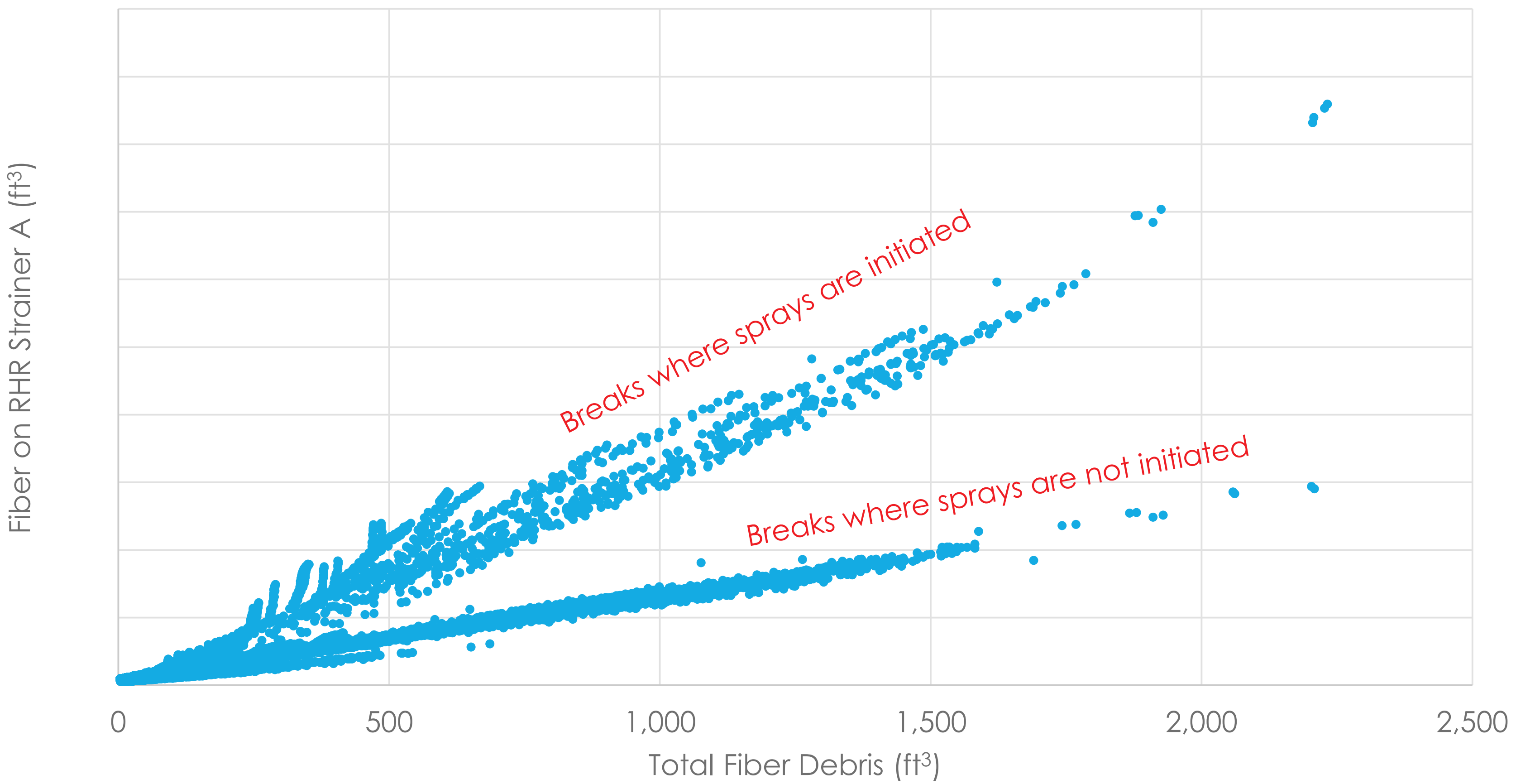
KEY INPUT PARAMETER DIFFERENCES

Input Parameter	Base Case	Bounding Strainer Conditions	Bounding In-Vessel Conditions
CS Termination Time	Best-estimate	Min/Max	Minimum
Hot Leg Switchover Time	Best-estimate	Best-estimate	Maximum
RWST Injection Volume	Best-estimate	Min/Max	Best-estimate
Pool Temperature Profile	Best-estimate as f(break size)	Best-estimate/Maximum with drop to 90 °F	Best-estimate
ECCS Flow Rate	Best-estimate as f(break size)	Maximum	Min/Max
CS Flow Rate	Best-estimate	Minimum	Minimum
Pool pH	Best-estimate	Maximum with drop to 7	Maximum with drop to 7
Unqualified Coatings Failure	Best-estimate	100% at Time 0	100% at Time 0
Unqualified Epoxy Size	Best-estimate	100% particulate	100% particulate
Miscellaneous Debris Area	Best-estimate	Best-estimate	Minimum
Debris Transport	Best-estimate	Maximum	Maximum
Debris Penetration	Maximum	Minimum	Maximum

BASE CASE RESULTS

- The following slides show overall simulation results for all of the breaks evaluated under the base case conditions

BASE CASE RESULTS (ALL PUMPS RUNNING)



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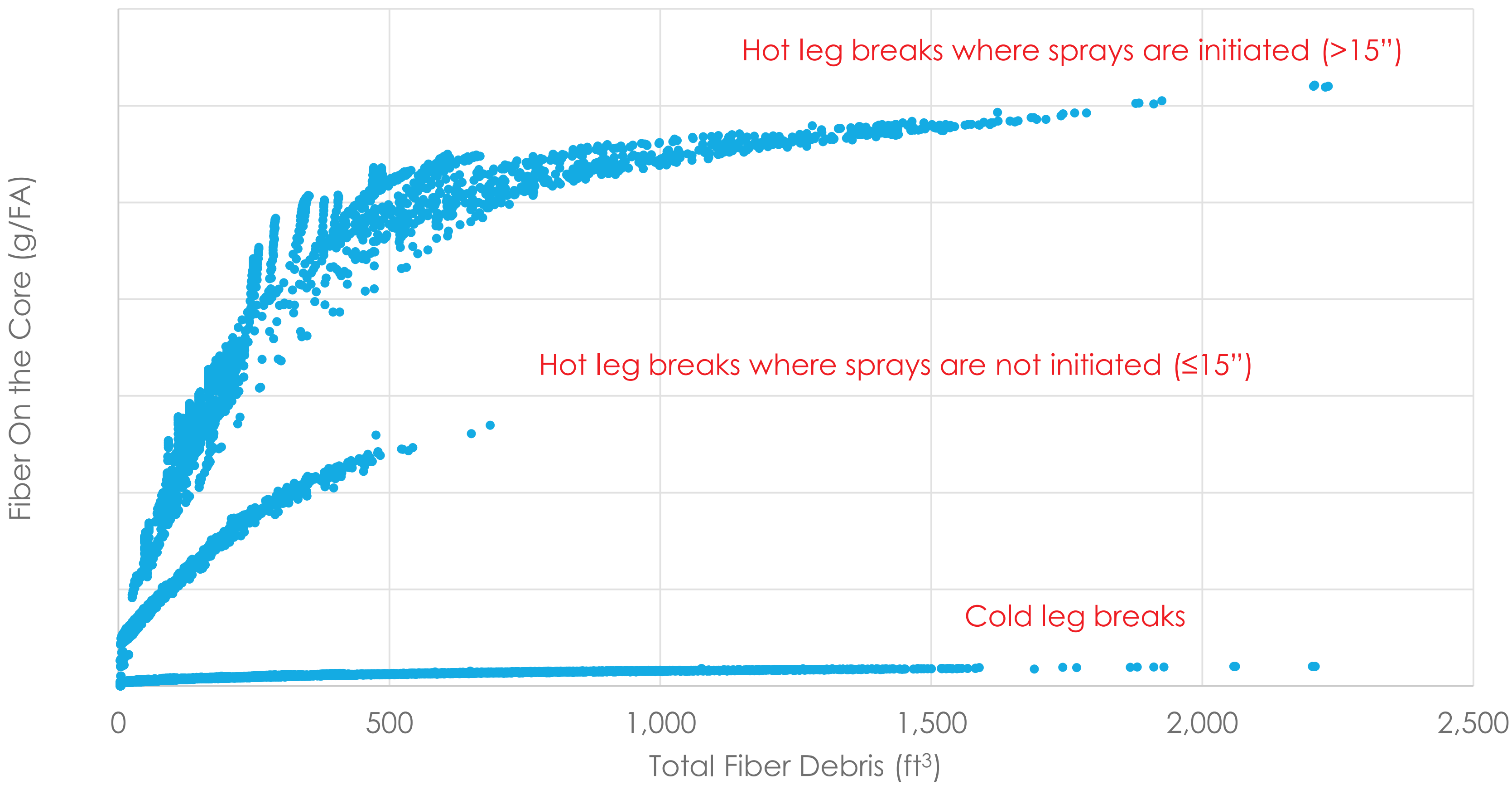
BASE CASE RESULTS (ALL PUMPS RUNNING)



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TIME-DEPENDENT RESULTS FOR SPECIFIC BREAKS

- The following slides show time-dependent results for the following individual breaks evaluated under base case conditions
  - Hot leg break with max fiber generation (all pumps running)
  - Cold leg break with max fiber generation (all pumps running)
  - Hot leg break with max fiber generation (1 RHR failure)

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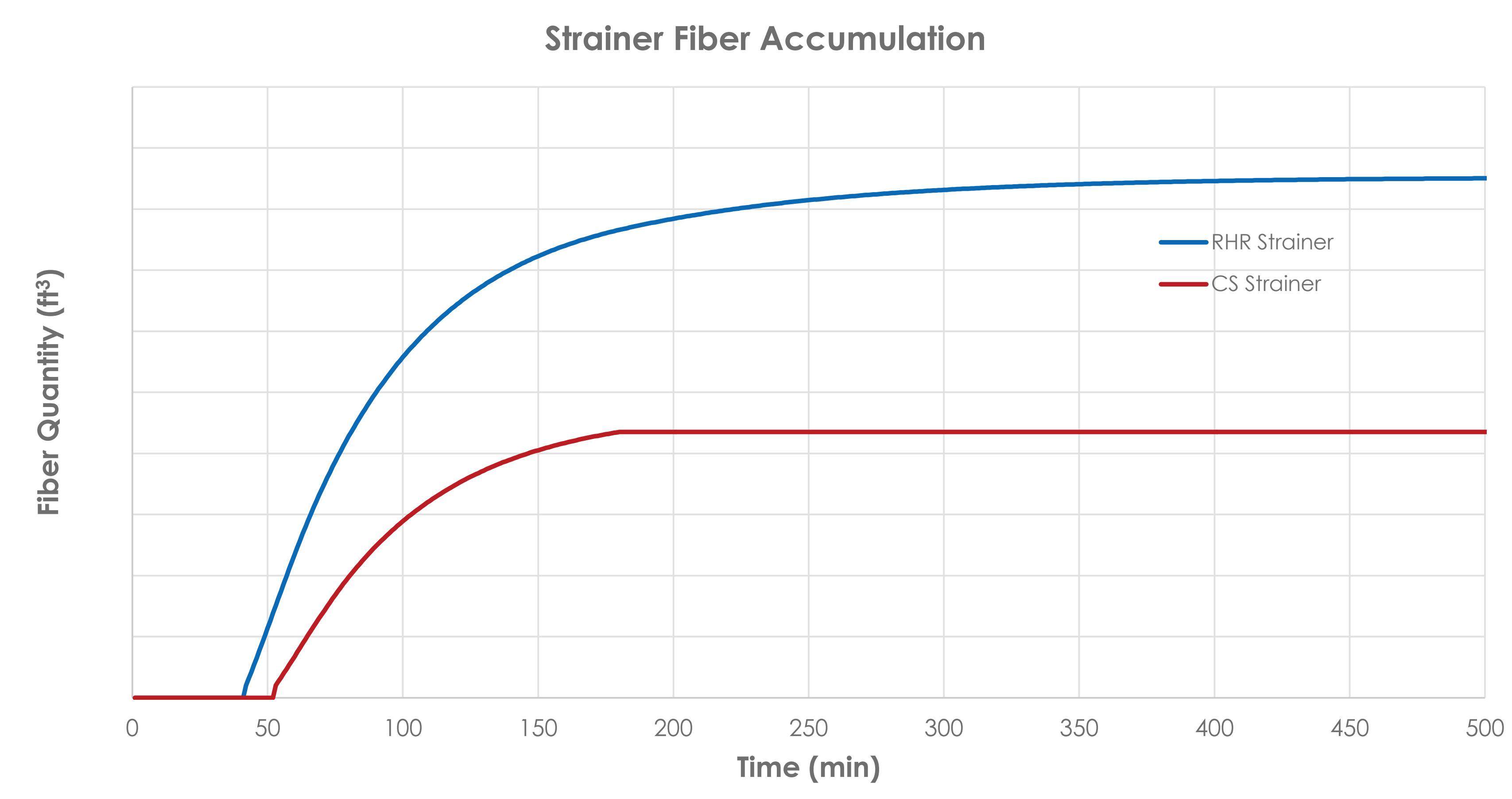
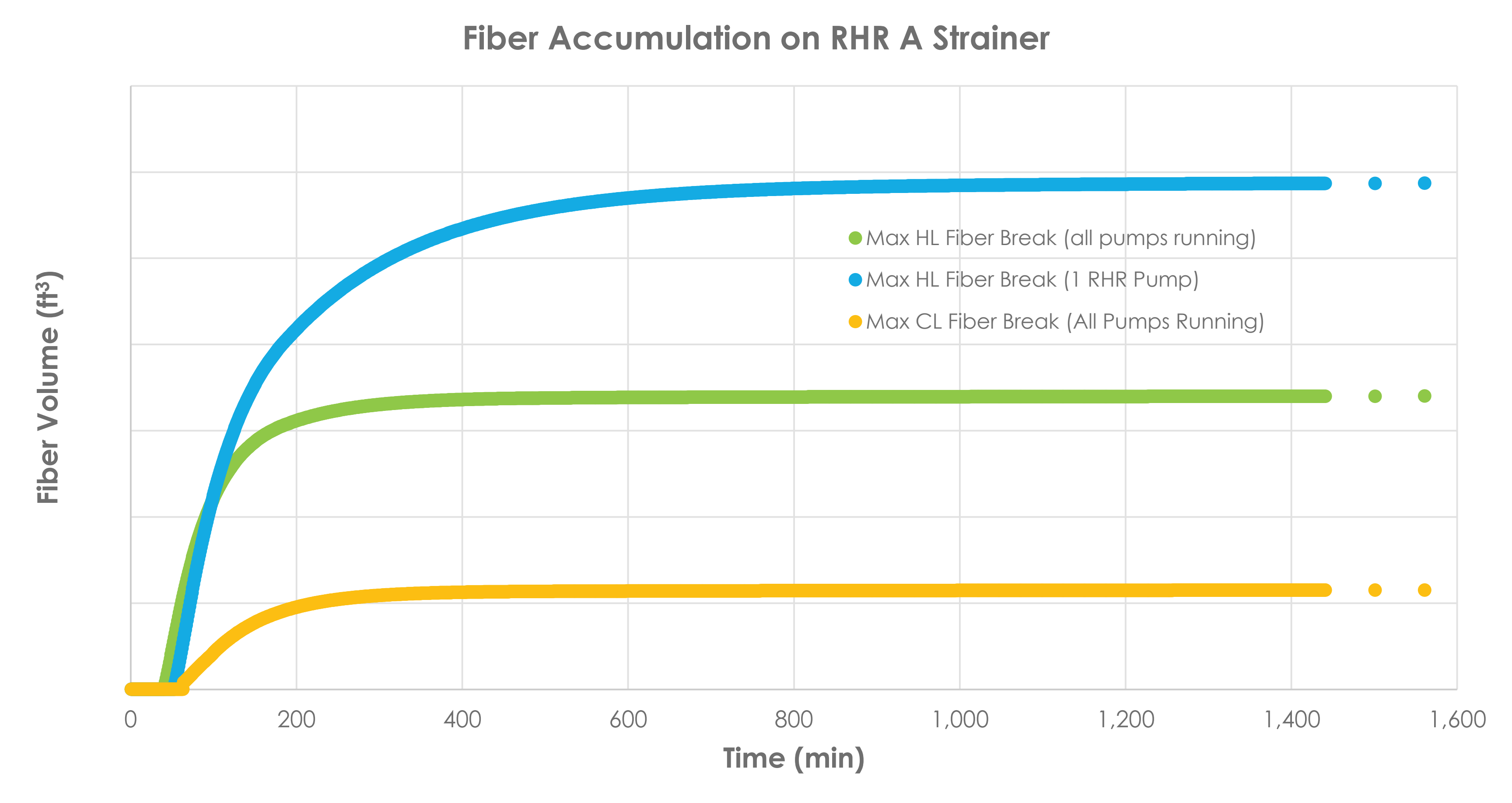
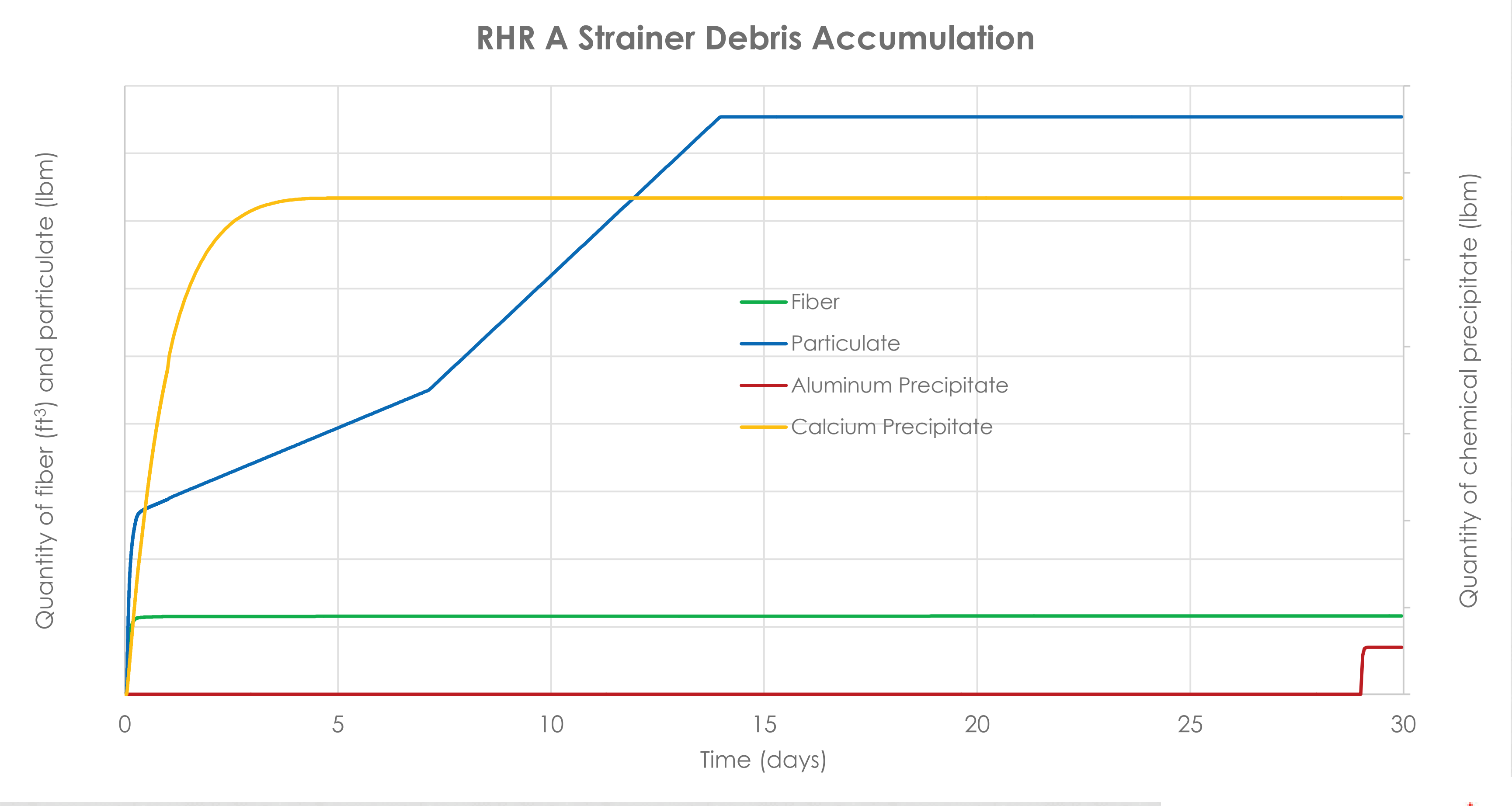
FIBER ACCUMULATION FOR MAX FIBER HOT LEG BREAK (ALL PUMPS RUNNING)



COMPARISON OF FIBER ACCUMULATION ON RHR A STRAINER



DEBRIS ACCUMULATION FOR MAX FIBER COLD LEG BREAK (ALL PUMPS RUNNING)



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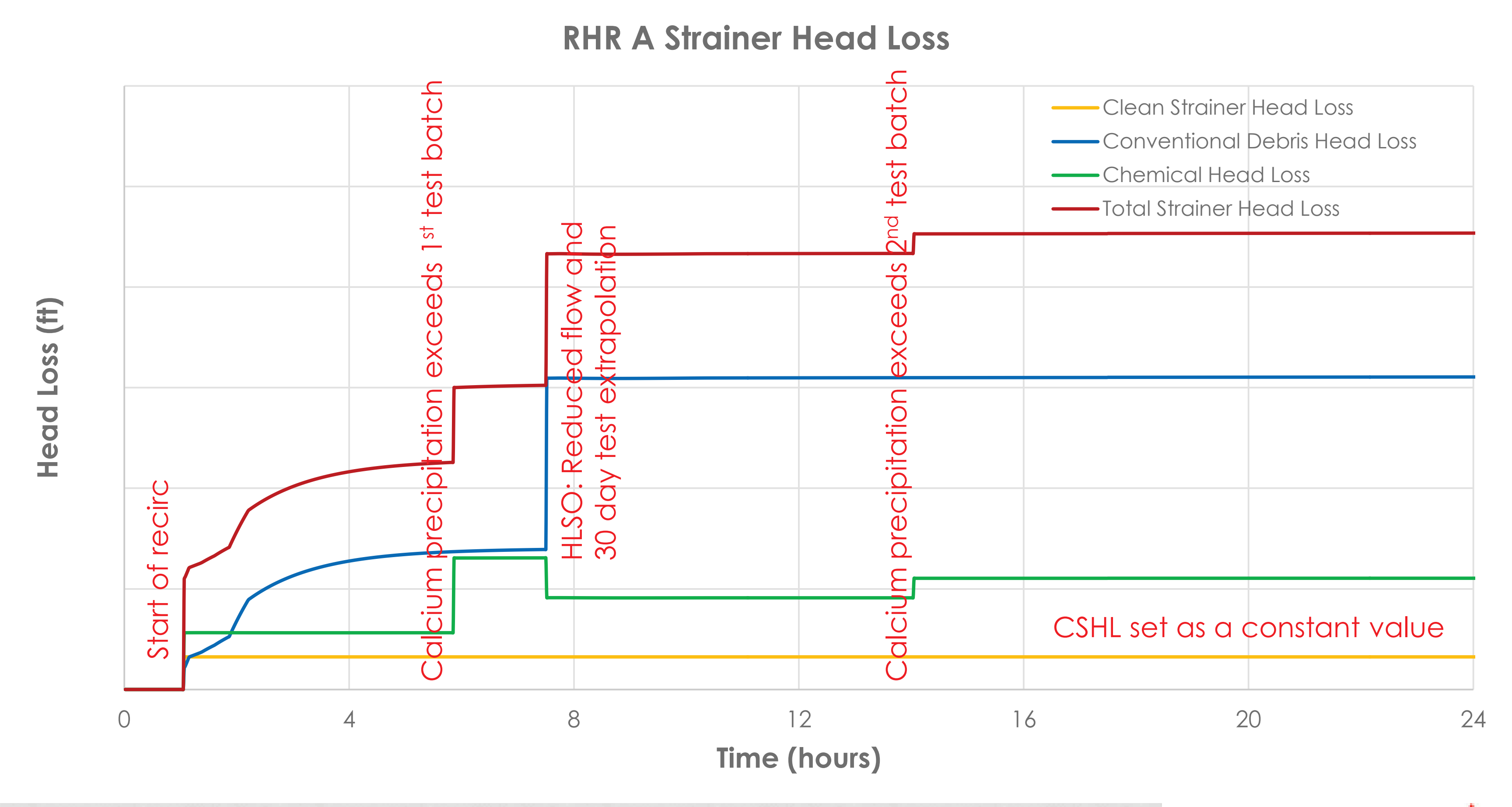
RHR STRAINER HEAD LOSS FOR MAX FIBER COLD LEG BREAK (ALL PUMPS RUNNING)



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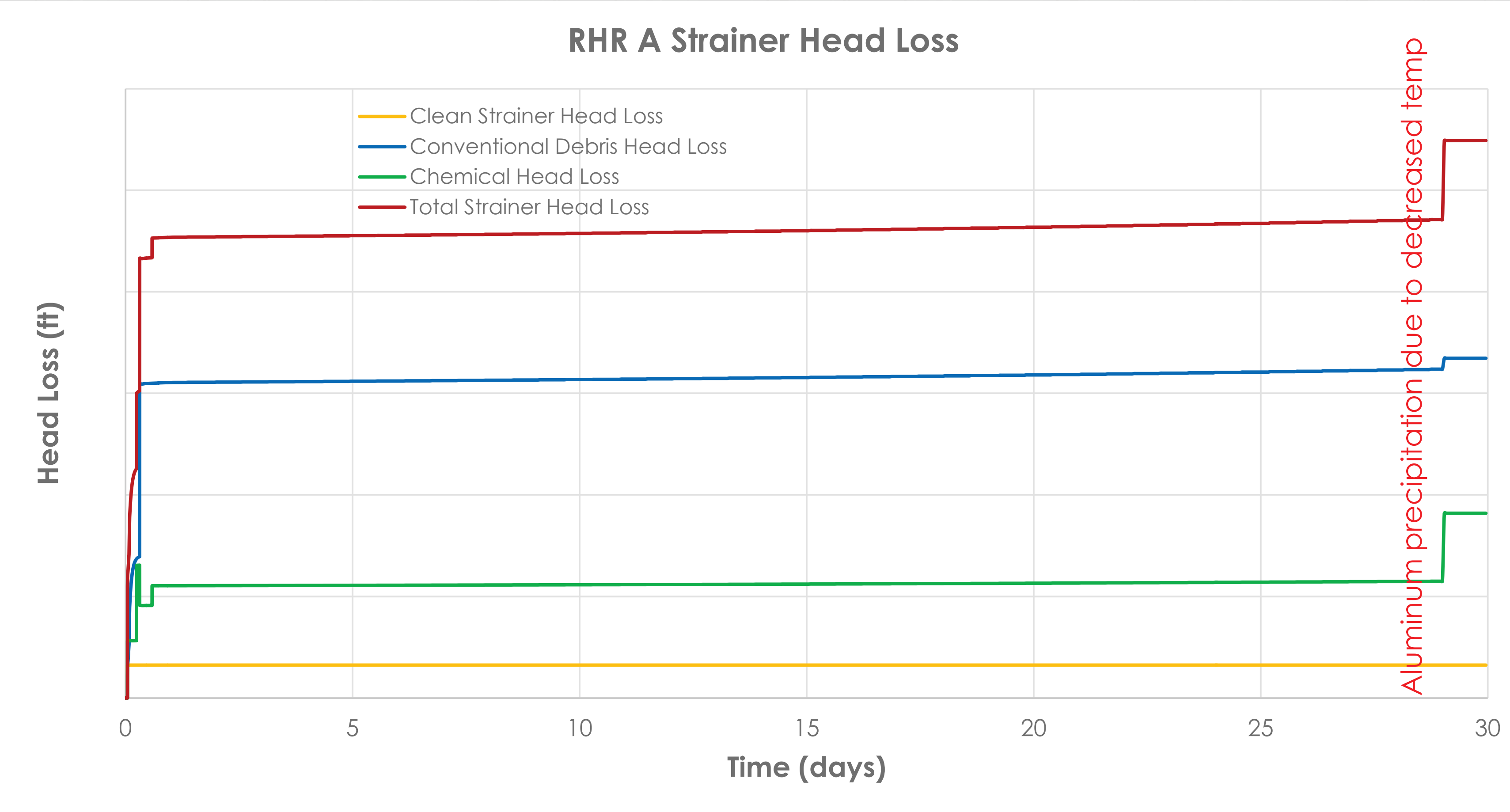
RHR STRAINER HEAD LOSS FOR MAX FIBER COLD LEG BREAK (ALL PUMPS RUNNING)



CONDITIONAL FAILURE PROBABILITIES

- Base case preliminary results
  - Core conditional failure probability (CFP) worse when all pumps are operating
  - Strainer CFP worse with 1 RHR pump operating
- Bounding strainer conditions
  - No core failures, but significantly more strainer failures than base case
- Bounding core conditions
  - More core failures, but fewer strainer failures than base case

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RISK QUANTIFICATION

- The change in core damage frequency (ΔCDF) and change in large early release frequency (ΔLERF) due to issues related to GSI-191 can be estimated based on:
  - LOCA frequencies
  - Equipment configuration probabilities
  - GSI-191 conditional failure probabilities

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LOCA FREQUENCY

- Break-specific LOCA frequencies (using the hybrid methodology developed by the STP pilot project) were used to determine the GSI-191 conditional failure probabilities for small, medium, and large breaks
- LOCA frequencies from PRA model of record were used to calculate risk
  - Small (1/2"-2") break frequency: 5.8E-04 yr^{-1}
  - Medium (2"-6") break frequency: 4.9E-04 yr^{-1}
  - Large (6"-31") break frequency: 1.2E-06 yr^{-1}

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EQUIPMENT CONFIGURATION PROBABILITY

- Most likely situation would be that all equipment is available and fully functional
- Equipment failures due to non-GSI-191 related issues can have a major effect on GSI-191 phenomena (debris transport, flow splits, temperature and pressure profiles, etc.)
- There are many possible equipment failure combinations (RHR pumps, containment spray pumps, charging pumps, SI pumps, fan coolers, etc.)
- At Vogtle, GSI-191 effects can be reasonably represented or bounded for most equipment failure combinations by the cases where all pumps are running or a single RHR pump fails

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EQUIPMENT CONFIGURATION PROBABILITY

- LBLOCA
  - All equipment available bounding or reasonably representative for:
    - No pump failures: 78.9%
    - 1 or 2 CS pump failures: 17.7%

    } 96.6%
  - 1 RHR pump failure bounding or reasonably representative for other equipment failure configurations: 3.4%
- MBLOCA/SBLOCA
  - All equipment available: 93.5%
  - 1 RHR pump failure bounding or reasonably representative for other equipment failure configurations: 6.5%

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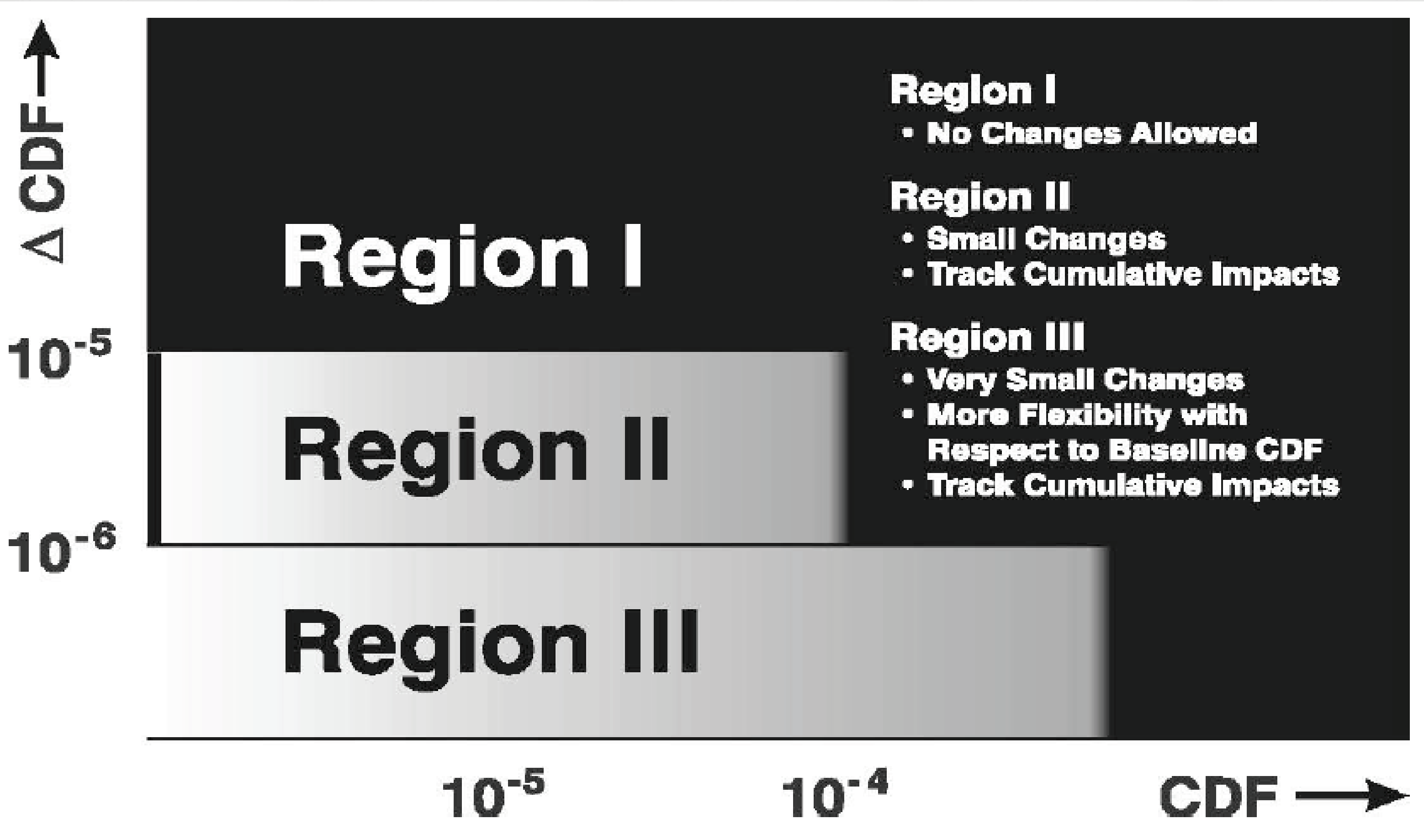
GSI-191 RISK (BASE CASE)



▲ Base case

QUALITY ASSURANCE

- Majority of GSI-191 calculations have been prepared as non-safety related under vendor Appendix B QA programs
- Additional GSI-191 calculations have been prepared as non-safety related following work practices established by vendor Appendix B QA program
- Head loss testing in 2009 was conducted and documented as safety related under vendor Appendix B QA program
- Penetration testing was conducted and documented as non-safety related following work practices established by vendor Appendix B QA program
- Chemical effects testing was conducted and documented as non-safety following a QA process consistent with the testing performed for the STP pilot project
- Thermal-hydraulic modeling was prepared and documented as non-safety following a QA process consistent with the modeling performed for the STP pilot project

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CONCLUSIONS

- Models used to analyze GSI-191 phenomena at Vogtle are consistent with methods accepted for deterministic evaluations
- Preliminary results indicate that risk associated with GSI-191 is very low

QUESTIONS?