Wolf Creek GSI-191 Resolution Plan and Current Status

NRC Public Meeting

November 18, 2020

Agenda

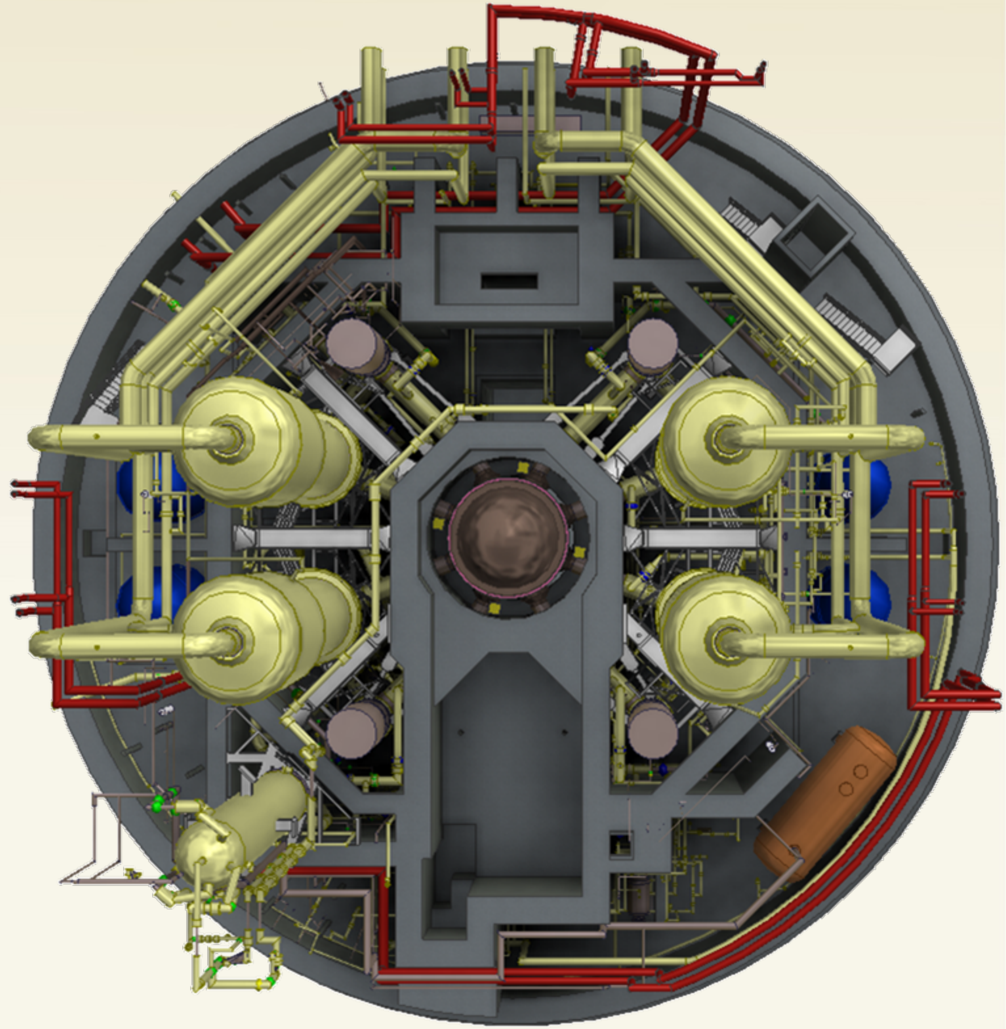
- Meeting Objectives
- Overview of Plant Specific Features
- Overview of Threshold Break Size Methodology
- Determination of Threshold Break Size
  - Strainer evaluation
  - In-vessel downstream effects
- Risk and Uncertainty Quantification
- Adoption of TSTF-567
- Methodology for Operability Evaluation
- Submittal Format and Schedule

Meeting Objectives

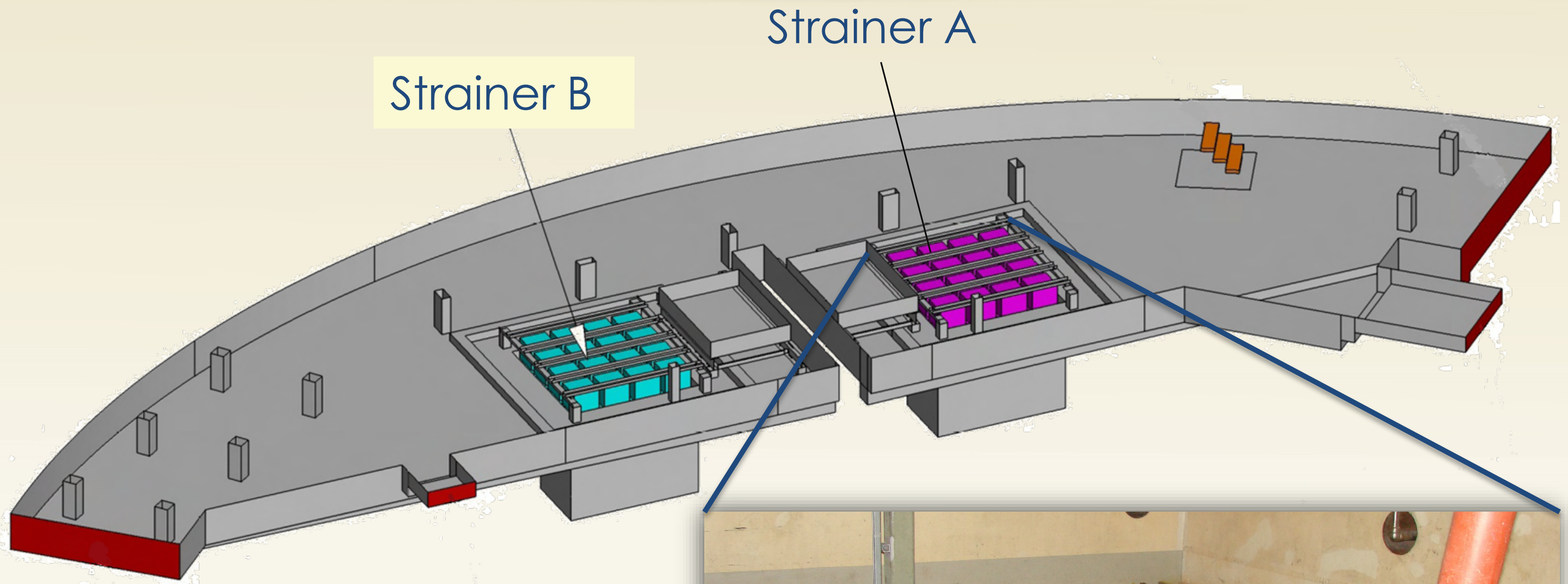
- Communicate current Wolf Creek plan for GL 2004-02 response
- Obtain staff feedback on the overall resolution path for Wolf Creek
- Identify areas of concern from the NRC on the approach

Wolf Creek Plant Layout

- Westinghouse 4-loop PWR (3,565 MWt)
- Two redundant ECCS and CS trains
  - Each train has an RHR pump, CCP, SIP, and CS pump
  - SIP and CCP piggyback off of the RHR pump discharge during recirculation
- Two independent and redundant containment air cooling trains



Overview of Sump Strainers



Overview of Threshold Break Size Methodology

- Licensees have used various risk-informed GSI-191 methods including RoverD, the conditional failure probability (CFP) approach, and the alternate break methodology
- Wolf Creek has chosen to use a different approach called the threshold break size methodology
- This approach is more conservative than RoverD and the CFP approach, but can be implemented in a simplified manner and does not require risk integration software (e.g., NARWHAL or CASA Grande)

Overview of Threshold Break Size Methodology

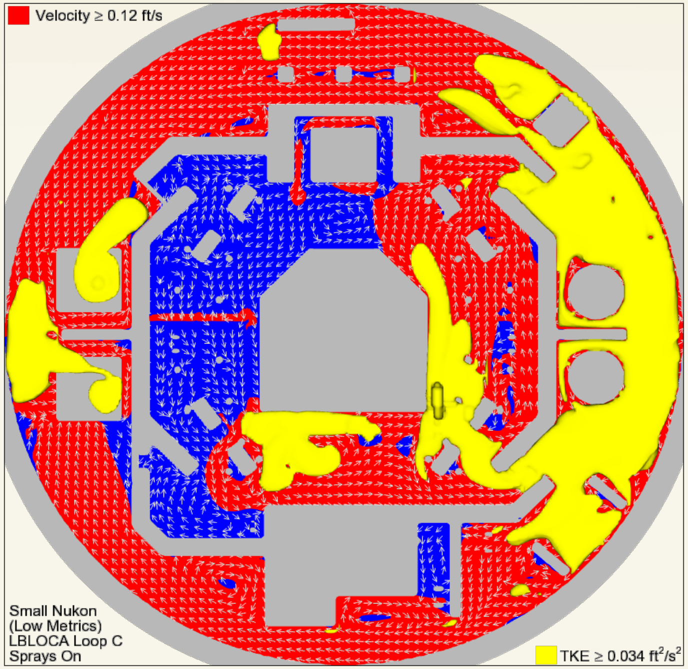
- Intermediate analyses required for overall GSI-191 evaluation (e.g., debris generation and transport) are generally consistent with deterministic and risk-informed methods previously reviewed and accepted by the NRC
- Strainer head loss and in-vessel effects evaluations identify largest break size with no failures for any weld locations—this is the threshold break size
- All breaks larger than threshold break size are conservatively assumed to fail
- Threshold break size is based on bounding equipment configuration and is conservatively assumed to apply to all equipment configurations

Overview of Threshold Break Size Methodology

- Risk quantification is performed outside the PRA model
- ΔCDF is calculated with a simple interpolation of NUREG-1829 LOCA frequencies at the threshold break size
- ΔLERF is calculated based on the conditional large early release probability (CLERP) for a large LOCA given core damage
- CLERP is determined from the PRA model and the CLERP value is multiplied by ΔCDF to calculate ΔLERF
- The base CDF and LERF values are obtained from the PRA model for comparison with RG 1.174 acceptance guidelines

Debris Generation and Transport Analyses

- Overall approach for debris generation and transport similar to Vogtle
- BADGER used for debris generation evaluation
- Debris transport analyzed for blowdown, washdown, pool fill and recirculation
- CFD models used for recirculation transport



Treatment of Reactor Cavity Breaks

- No breaks at the reactor nozzles are postulated due to plant geometry per previous PWROG letter*
- Hot and cold legs are held by whip restraints that limit lateral movement of piping
- Maximum allowable lateral movement is less than pipe wall thickness
- RCP tie rods preclude cold leg separation from reactor nozzle
- Steam generator lower lateral supports preclude hot leg separation from reactor nozzle

* ADAMS Accession No. ML100710710 and ML100570364

Determination of Threshold Break Size

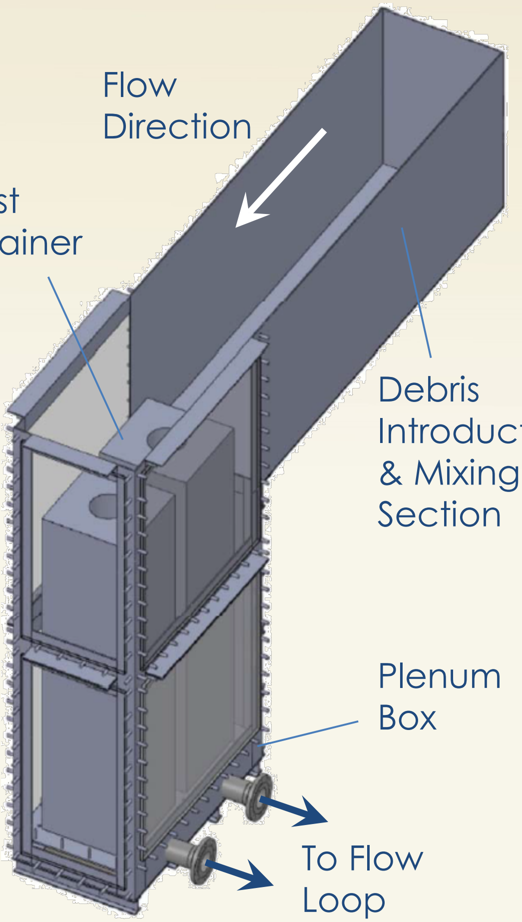
- Threshold break size defined such that breaks up to this threshold do not fail any GSI-191 criteria
  - Strainer head loss
    - ✓ Strainer structural limit
    - ✓ Pump NPSH margin
    - ✓ Strainer degasification and flashing
  - In-vessel downstream effects (core blockage)
  - Air entrainment due to vortexing
  - Ex-vessel downstream effects
  - Upstream effects
- Threshold break sizes for strainer head loss and in-vessel effects determined separately; the smaller of the two is the overall threshold break size

Strainer Evaluation

- Threshold break size for strainer evaluation determined by meeting following criteria
  - Strainer head loss lower than strainer structural limit
  - Minimum pump NPSH margin stays positive
  - Void fraction at pump suction < 2%
  - No flashing downstream of the strainer
  - No air-entraining vortexing
- Strainer evaluation used the bounding equipment configuration with single train failure
  - Maximizes strainer flow rate and debris load on the active strainer

Strainer Evaluation

- Head loss testing performed in 2016 at Alden
  - Overall approach consistent with tank tests observed by NRC at Alden
  - Performed one full debris load test and one thin-bed test
  - Used two prototypical strainer stacks with no modifications
  - Followed NEI guidance on fiber preparation
  - Used pre-made AlOOH to represent chemical debris
  - Bounded breaks up to 10" for debris loads and strainer approach velocity under single train operation

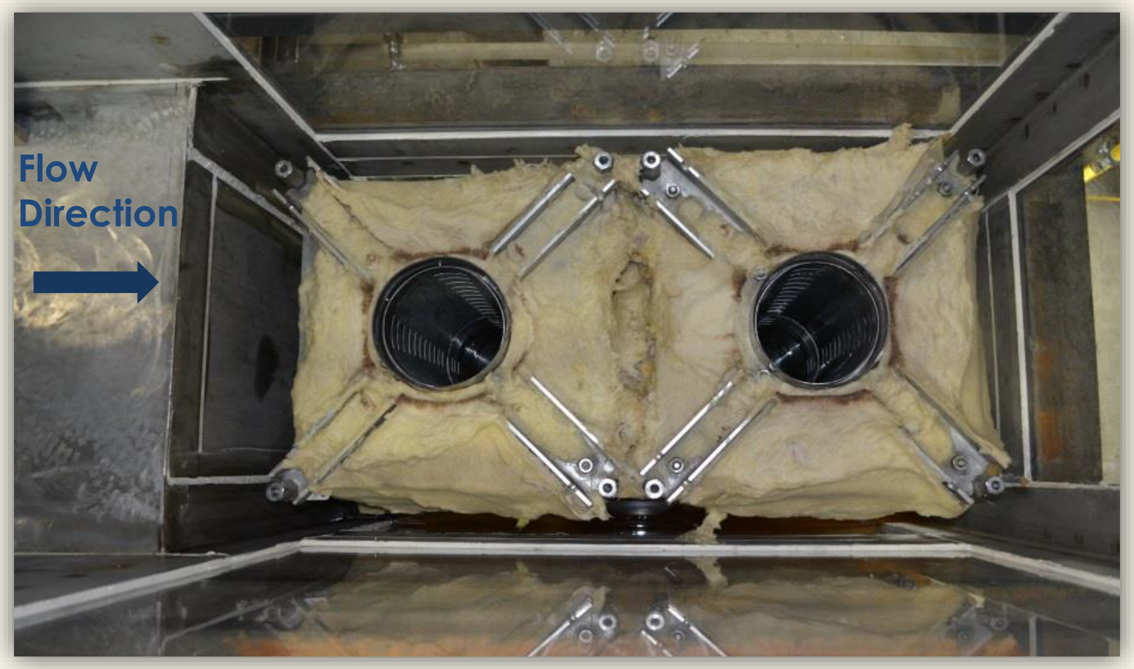


Strainer Evaluation

- Determined total strainer head loss for breaks up to 10”
  - Measured debris head losses adjusted to plant conditions (e.g., temperature and flow rate) using flow sweep data taken from testing
  - Debris head loss combined with clean strainer head loss to determine total strainer head loss
- Demonstrated strainer evaluation acceptance criteria are met for breaks up to 10”

In-Vessel Downstream Effects

- Threshold break size for in-vessel was determined based on HLB debris limit following NRC review guidance
- Performed a fiber-only penetration test in 2016 at Alden
  - Removed every other disks and seismic cables to avoid bridging
  - Used 5-μm filter bags to collect penetrated fiber
  - Bounded breaks up to 10” for fiber load and strainer approach velocity
- Developed curve-fit from test data for fiber penetration as function of fiber loading on strainer



In-Vessel Downstream Effects

- Determined in-vessel fiber load using WCAP-17788 methodology
  - Divided recirculation phase into smaller time steps
  - Calculated debris arrival at sump strainers for each time step based on pool volume and pump flow rates
  - Evaluated fiber penetration fractions based on strainer fiber load for each time step using curve-fit from testing
  - Analyzed most limiting equipment configurations (both RHR pumps operating with failure of one or both CS pumps)
  - Performed sensitivity to capture the worst combination of inputs (e.g., pool volume, RHR pump flow rate)
  - Assumed all fiber that reaches reactor accumulate at core inlet with no credit of alternate flow paths (AFPs)
- Used "Box 4" path from NRC review guidance to demonstrate applicability of WCAP-17788 AFP analysis to Wolf Creek for breaks up to 10"

In-Vessel Downstream Effects

Parameters	WCAP-17788 Revision 1 Values	WCGS Values
Nuclear Steam Supply System (NSSS) Design	Various	Westinghouse
Fuel Type	Various	Westinghouse 17 x 17
Barrel/Baffle Configuration	Various	Upflow
Minimum Chemical Precipitation Time (t_{chem})	143 minutes (t_{block}, WCAP-17788, Vol 1, Table 6-1)	24 hours
Maximum HLSO Time	24 hours (t_{chem})	10 hours
Maximum Core Inlet Fiber Load for 10" HLB	WCAP-17788, Volume 1, Table 6-3	94.29 g/FA (Failure of both CS pumps)
Total In-Vessel Fiber Limit for 10" HLB	WCAP-17788, Volume 1, Section 6.4	
Minimum Sump Switchover (SSO) Time	20 minutes	13 minutes
Maximum Rated Thermal Power	3658 MWt	3565 MWt
Maximum AFP Resistance	WCAP-17788, Volume 4, Table 6-1	WCAP-17788, Volume 4, Table RAI-4.2-24
ECCS Flow per FA	8 – 40 gpm/FA	37.8 to 52.9 gpm/FA

In-Vessel Downstream Effects

- Maximum in-vessel fiber load for breaks up to 10" exceeds core-inlet fiber limit but are bounded by total in-vessel fiber limit in WCAP-17788
  - WCAP core-inlet fiber limit conservatively low based on assumption of uniform fiber bed at core inlet
  - "Licensees may justify that a non-uniform debris bed will form at the core inlet allowing adequate flow to assume LTCC, even though the average debris load per FA metric is exceeded"

In-Vessel Downstream Effects

- Earliest Wolf Creek SSO time (13 min) not bounded by that assumed in WCAP analysis (20 min)
  - The 13 min SSO time represents shortest injection model duration and was calculated very conservatively
    - ✓ Maximum pump flow rates based on 0 psig containment pressure
    - ✓ All pumps operating with no credit for pump startup time
    - ✓ Minimum RWST volume based on Tech Spec limit
  - Wolf Creek decay heat at SSO lower than that used in WCAP

	Decay Heat at SSO (MWt)	SSO Time (min)	Thermal Power (MWt)	Decay Heat Model
WCAP-17788	**87.4**	20	3,658	10CFR50 Appendix K model (1971 ANS Standard + 20%)
Wolf Creek	**78.8**	13	3,565	1971 ANS Standard + 2σ

In-Vessel Downstream Effects

- WCAP analysis assumed all debris arrives at core inlet within 60 sec after start of SSO
  - ✓ Wolf Creek core inlet fiber load reaches WCAP limit 7.1 min after SSO
- Wolf Creek core inlet fiber load reaches 94.29 g/FA >1 hr after SSO
  - ✓ Sensitivity runs in WCAP-17788 Vol 4 showed much reduced peak cladding temperature and no core-wide uncover when core inlet resistance linearly ramps up over 1 hour or 2 hours

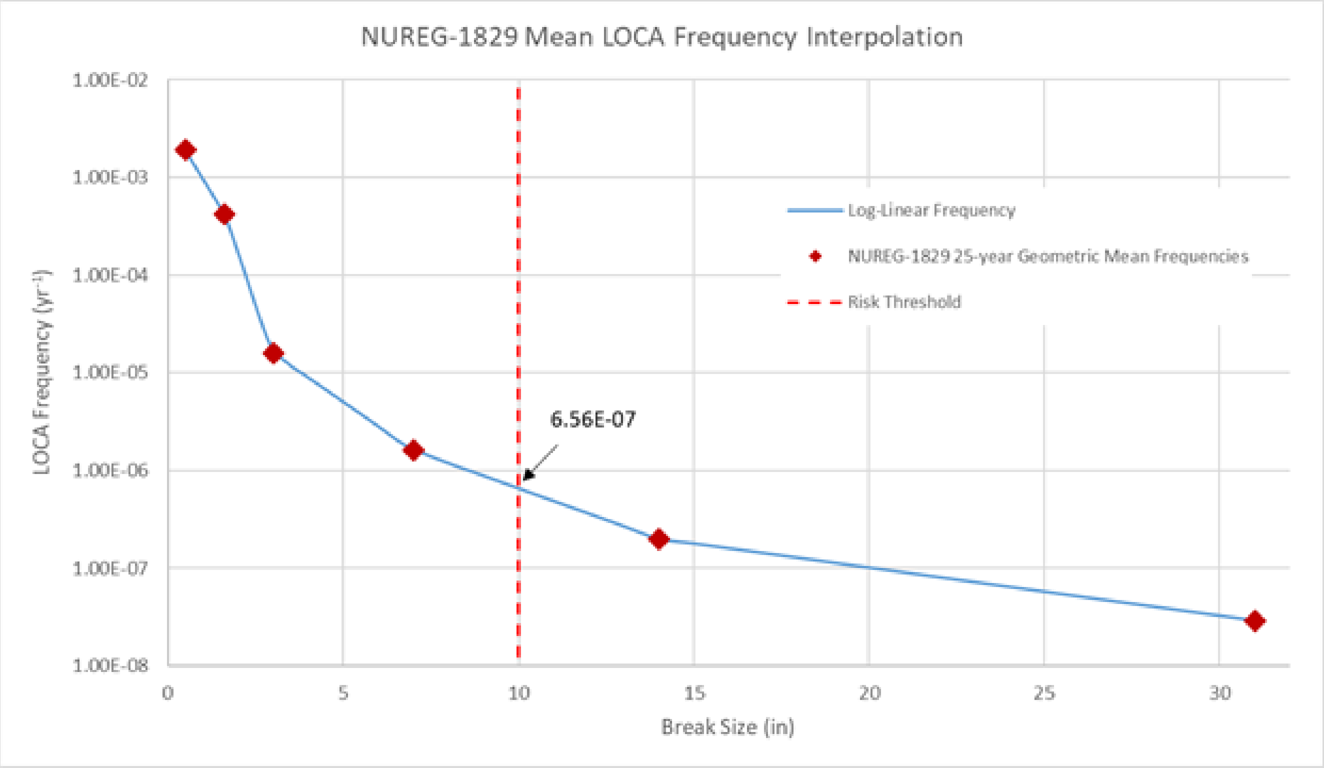
• Wolf Creek ECCS flow per FA bounded by WCAP analysis as it exceeds min flow analyzed in WCAP
  - Debris bed with highest resistance formed at min flow
  - Unstable debris bed at higher flow rates

Risk Quantification

- GSI-191 risk quantification considered the following events
  - Small, medium, and large LOCAs due to:
    - ✓ Pipe breaks
    - ✓ Failure of non-piping components
    - ✓ Water hammer
  - Secondary side breaks inside containment that result in a consequential LOCA that requires sump recirculation
  - Fire-induced RCP seal LOCAs
  - Seismically-induced LOCAs
- Events were evaluated using a combination of quantitative (conservative or bounding) and qualitative methods

Risk Quantification

- Given a threshold break size of 10 inches for pipe break LOCAs, ΔCDF was calculated to be 6.6E-07 yr^{-1}



Risk Quantification

- Water hammer induced LOCAs, fire induced LOCAs, and other external events were determined to have no GSI-191 risk contribution
- Frequency of seismically induced large breaks was calculated using two separate methods:
  - 6.9E-07 yr^{-1} based on representative fragility parameters from EPRI 3002000709
  - 3.9E-07 yr^{-1} based on site-specific fragility parameters and the guidance in NUREG-1903
- All seismically induced large breaks were conservatively assumed to result in strainer failure, so frequency is equivalent to ΔCDF

Risk Quantification

- Secondary side breaks do not generally require ECCS recirculation for long term decay heat removal
- However, subsequent failures following the initiating event (e.g., a stuck open PORV or loss of aux feedwater) could require recirculation to support feed and bleed cooling
- The PRA model was used to calculate a bounding risk contribution assuming that all secondary side breaks that require sump recirculation will fail due to the effects of debris
  - ΔCDF = 6.5E-08 yr^{-1}
  - ΔLERF = 1.1E-10 yr^{-1}

Risk Quantification

- Baseline CDF and LERF values are relatively high due to fire risk contribution

PRA Model	CDF (yr^{-1})	LERF (yr^{-1})
Internal Events	7.25E-06	7.31E-08
Internal Flooding	9.06E-06	3.77E-08
Internal Fire	5.49E-04	1.33E-05
High Winds	3.40E-06	7.98E-09
Total	**5.69E-04**	**1.34E-05**

- CDF and LERF are outside the RG 1.174 guidelines for Region II (1E-04 and 1E-05, respectively)

Risk Quantification

- GSI-191 risk quantification results are within RG 1.174 Region III guidelines

Hazard	ΔCDF (yr^{-1})	ΔLERF (yr^{-1})
Piping and Non-Piping LOCAs	6.6E-07	1.9E-11
Water Hammer Induced LOCAs	0.0	0.0
Secondary Side Breaks	6.5E-08	1.1E-10
Fire Induced LOCAs	0.0	0.0
Seismically Induced LOCAs	6.9E-07	2.0E-11
Other External Hazards	0.0	0.0

- ΔCDF and ΔLERF values from various hazards are not added together since bounding methods were used to calculate values

Uncertainty Quantification

- Uncertainty quantification considers:
  - Parametric uncertainty
  - Model uncertainty
  - Completeness uncertainty
- Completeness uncertainty was qualitatively determined to be low
- Most parameters and models used for Wolf Creek GSI-191 risk quantification are conservative inputs or consensus models that do not require uncertainty quantification

Uncertainty Quantification

- An evaluation of GSI-191 inputs identified only one parameter that was not conservative or bounding:
  - Mean LOCA frequency values
- ΔCDF was recalculated using the 5th and 95th percentile values, which showed a range of 3.1E-09 yr^{-1} to 2.2E-06 yr^{-1} (compared to the base value of 6.6E-07 yr^{-1})

Uncertainty Quantification

- An evaluation of GSI-191 models identified only three models that are not consensus models:
  - Continuum break model
  - Geometric aggregation of LOCA frequencies
  - Seismic LOCA frequency based on EPRI 3002000709
- ΔCDF was recalculated using alternative models:
  - DEGB-only model is qualitatively less conservative than continuum break model for threshold break methodology
  - Arithmetic aggregation of LOCA frequencies are almost an order of magnitude higher than geometric aggregation
  - Seismic LOCA frequency is lower based on site-specific fragilities and the guidance in NUREG-1903

Uncertainty Quantification

Base Case Input or Model	Sensitivity Case Input or Model	ΔCDF (yr^{-1})	ΔLERF (yr^{-1})
Pipe Break Risk Based on 25-year GM LOCA Frequency Input	Pipe Break Risk Based on 25-year Geometric 5^{th} Percentile Input	3.1E-09	8.8E-14
	Pipe Break Risk Based on 25-year Geometric 95^{th} Percentile Input	2.2E-06	6.2E-11
Pipe Break Risk Based on Continuum Break Model	Pipe Break Risk Based on DEGB-Only Model	< 6.6E-07	< 1.9E-11
Pipe Break Risk Based on Geometric LOCA Frequency Model	Pipe Break Risk Based on Arithmetic LOCA Frequency Model	5.2E-06	1.5E-10
Seismic Risk Model Based on Representative Fragility Parameters from EPRI 3002000709	Seismic Risk Model Based on Site-Specific Fragility Parameters and the Guidance in NUREG-1903	3.9E-07	1.1E-11

Adoption of TSTF-567

- Wolf Creek Tech Spec is consistent with NUREG-1431
- Wolf Creek plans to implement Tech Spec changes following the TSTF-567 model application
- Wolf Creek will review TSTF-567 and the NRC's SE to ensure that the justifications in TSTF-567 and the SE are applicable to Wolf Creek

Operability Evaluation

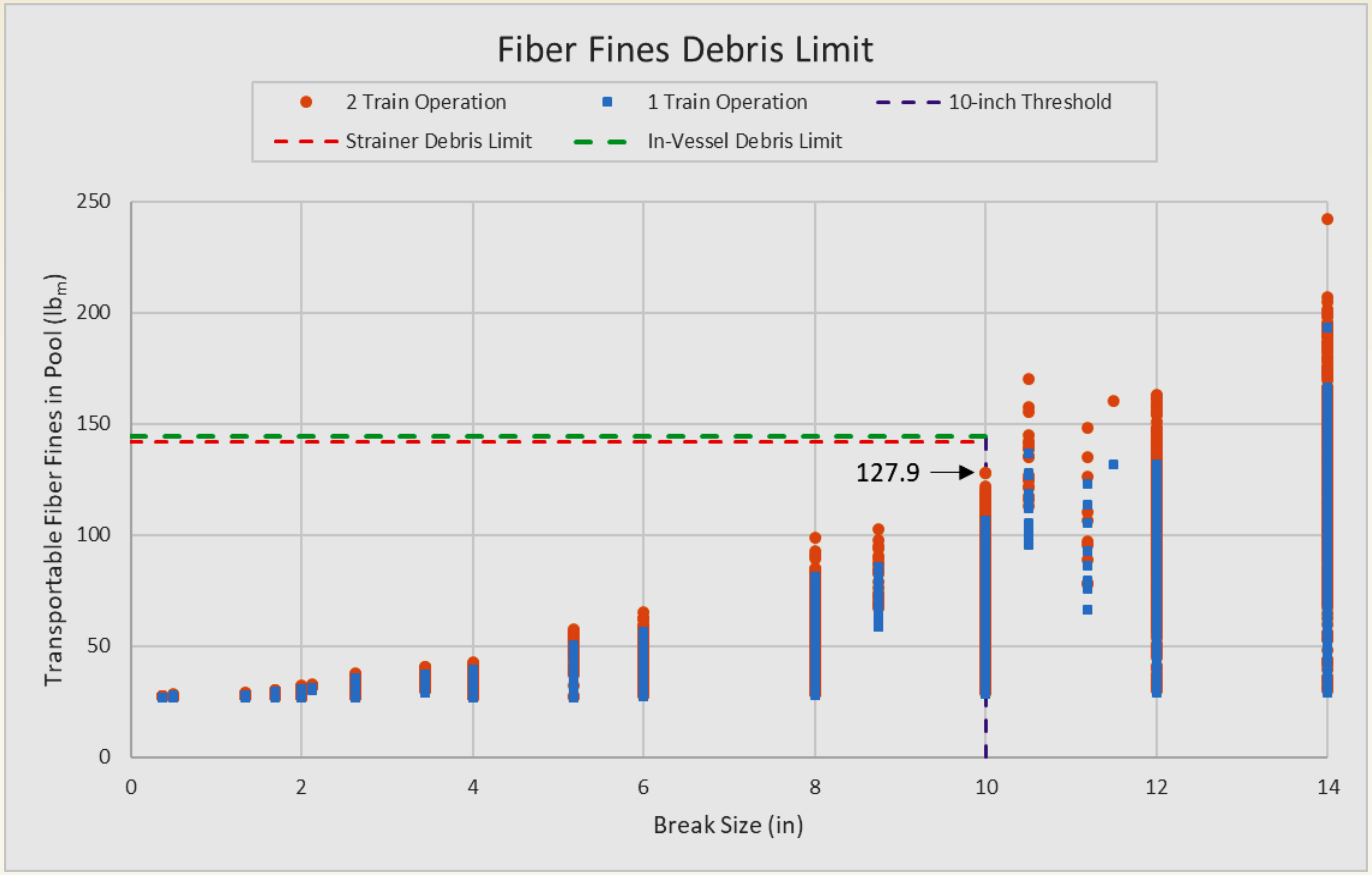
- With approval of risk-informed GSI-191 LAR, new design basis for Wolf Creek will be that risk increase due to GSI-191 failures is within RG 1.174 Region III (i.e., a ΔCDF less than 1E-06 yr^{-1})
- The current NRC guidance does not allow the use of risk to address operability issues
- Debris limits are therefore defined to ensure plant stays within its design basis and can be used for operability determinations
- The plant design basis is maintained if none of the breaks smaller than threshold break size (10 inches) cause any GSI-191 failures

Operability Evaluation

- Strainer and in-vessel debris limits were developed to ensure that breaks ≤ 10 inches do not fail
- The debris limits were derived based on worst equipment configurations for strainer and in-vessel
  - Single train failure for strainer evaluation
  - Two RHR pumps operating with failure of both CS pumps at the start of recirculation for in-vessel effects
- The 10-inch threshold break size conservatively assumed to apply to all equipment configurations

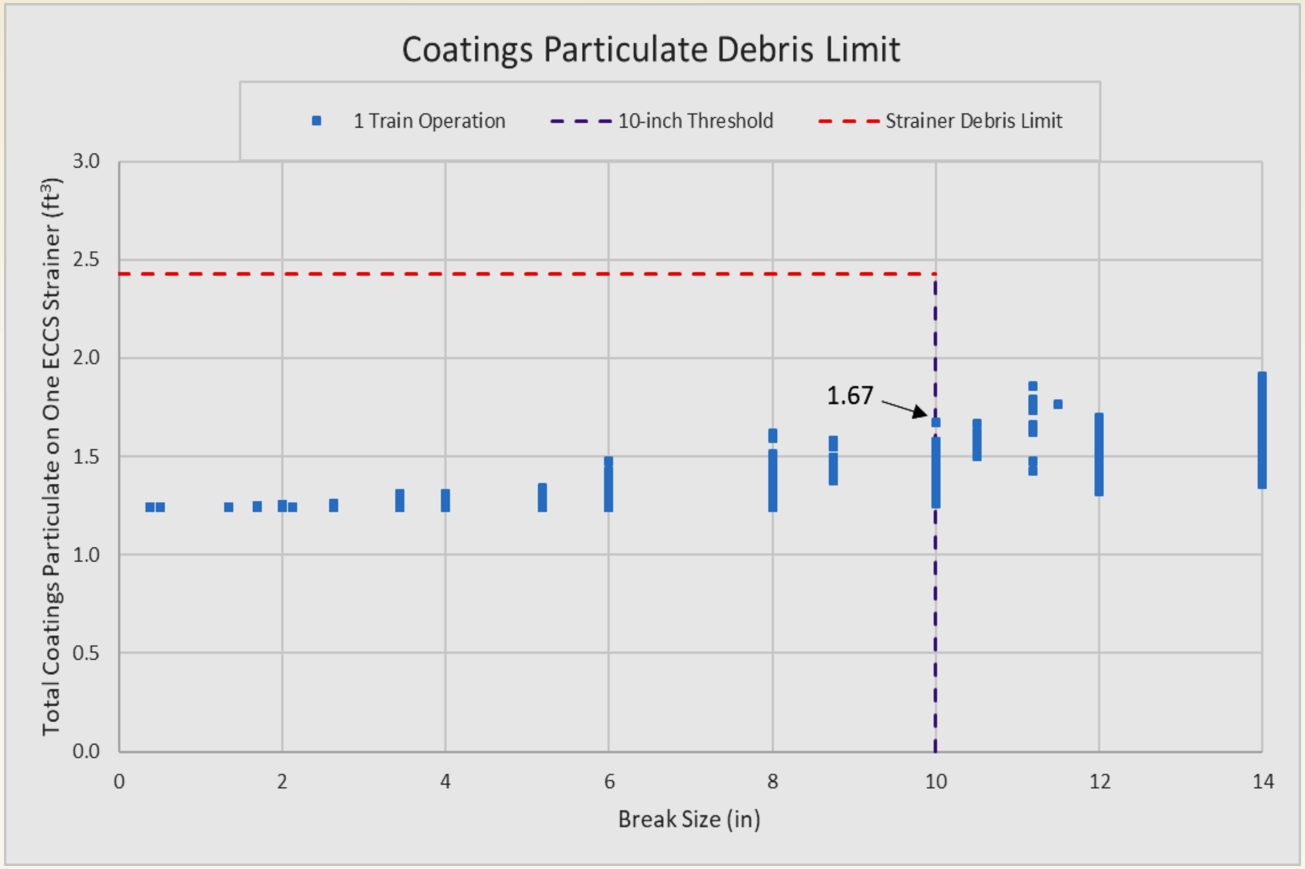
Debris Limits

- For fiber fines, more limiting debris margin between strainer and in-vessel is used



Debris Limits

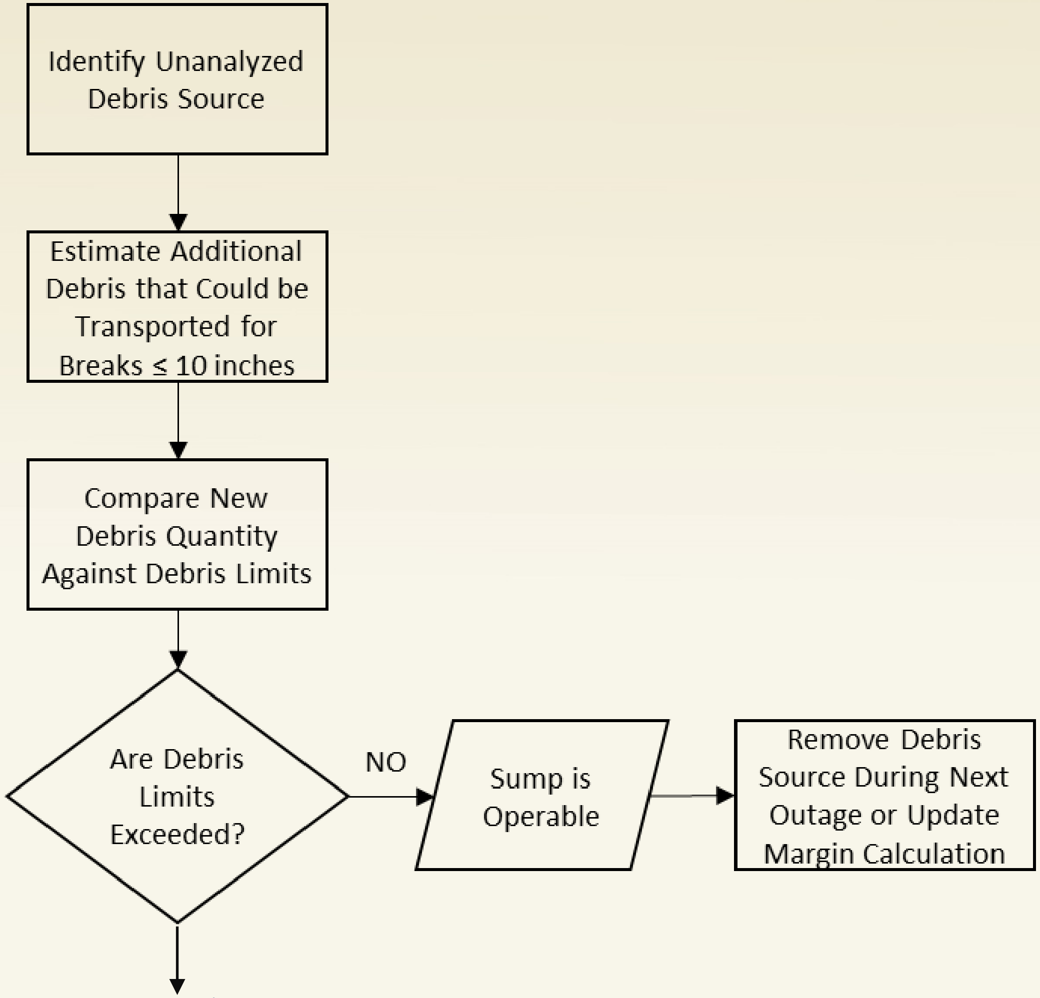
- Debris limits for all other debris types are based on strainer evaluation



Debris Limits

Debris Type	Debris Limit	Max Debris Quantity for Breaks ≤ 10”	Available Margin
Fiber Fines (lb_m)	144.1	119.6	24.5
Total Fiber Fines, Small Pieces, and Large Pieces (lb_m)	322.5	235.8	86.7
Latent Particulate (lb_m)	122.2	54.2	68.0
ThermoLag Particulate (ft^3)	0.50	0.51	0
Coatings Particulate (ft^3)	2.43	1.67	0.76
Degraded Paint Chips (ft^2)	158.4	0	158.4
Miscellaneous Debris (ft^2)	20.0	7.1	12.9

Operability Evaluation



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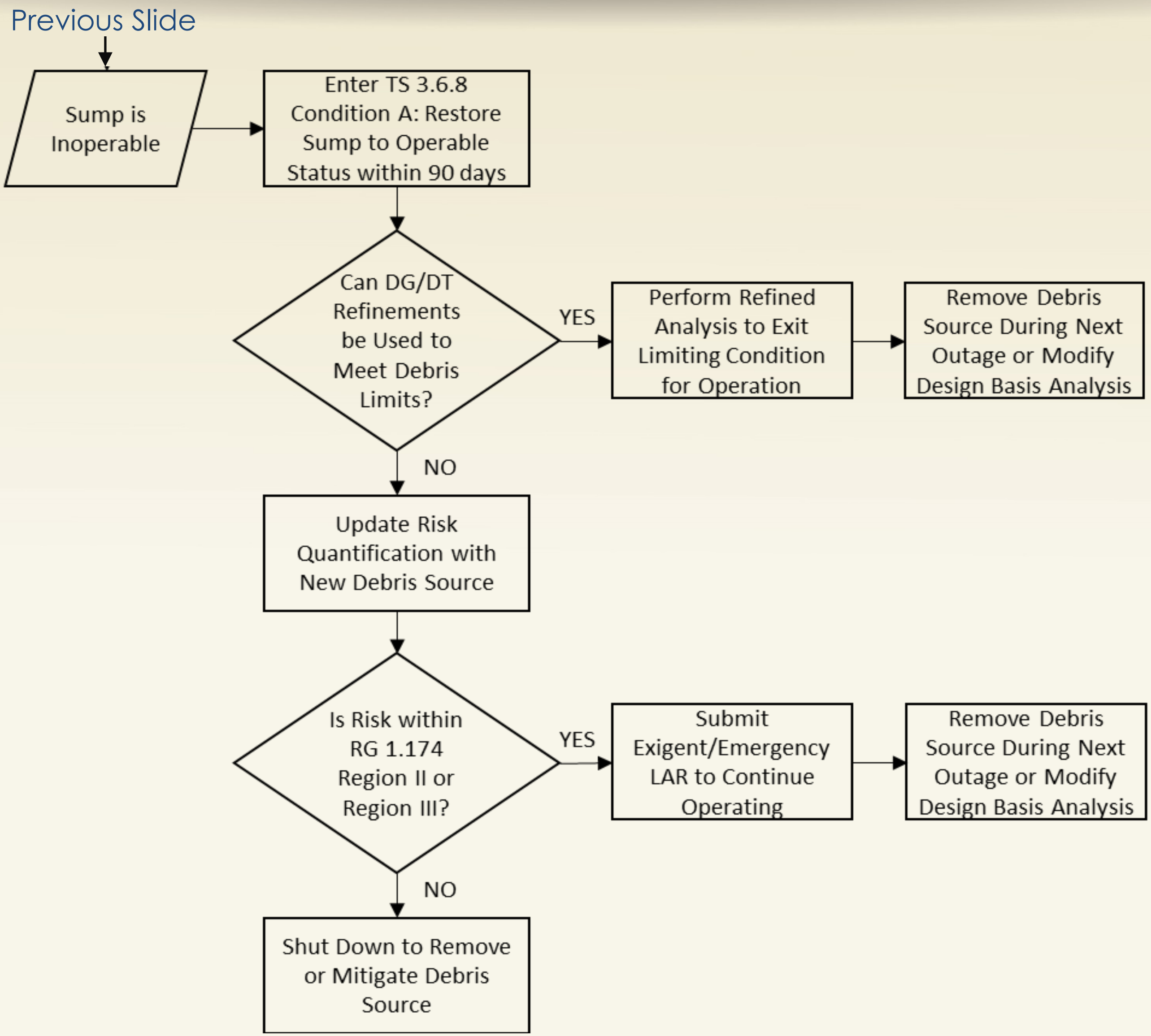
Operability Evaluation



Submittal Content

- Proposed LAR submittal includes the following:
  - Attachment 1: License Amendment Request
    - ✓ Implementation of risk-informed approach for GSI-191
    - ✓ Implementation of TSTF-567
  - Attachment 2: Request for Exemption from certain requirements of 10 CFR 50.46 (a)(1)
  - Attachments 3 to 6: Proposed Changes to Tech Spec (markup and clean version), Tech Spec Bases, and USAR
  - Attachment 7: Overview of Risk-Informed Approach
  - Attachment 8: Updated GL 2004-02 Responses
  - Attachment 9: Defense in Depth and Safety Margins

Submittal Schedule

- Wolf Creek is currently working on the updated responses to GL 2004-02
- Final review by Wolf Creek licensing scheduled 2/3/2021 – 3/4/2021
- Current projected date for submittal to the NRC: April 2021

Closing

- Questions?