Potential for Loss of NPSH Due to LOCA Debris Accumulation on PWR ECCS Sump Screens

Parametric Evaluations and Results

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Technical Presentations

① Overview of Parametric Evaluations and Results

② Relationship to Ongoing GSI-191 Research Program

③ Industry Survey(s) and Accident Sequence Development

④ Head Loss Modeling and Threshold Strainer Loadings

⑤ Insulation Debris Generation Calculations

⑥ Other Sources of Debris

⑦ Debris Transport and Accumulation: Expts and Analyses

⑧ Summary and Discussions

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Overview of Parametric Evaluations and Results

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Presentation Outline

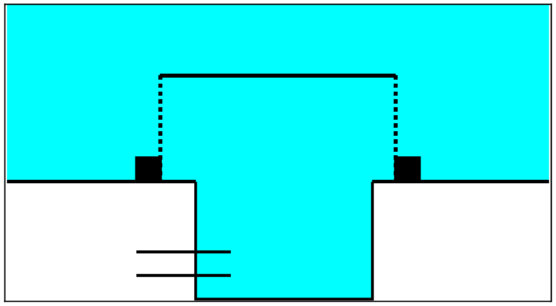
- Description of Potential Safety Concern
- Purpose of the Parametric Evaluations
- Special Technical Considerations
- Technical Methodology
- Scope and Results of Parametric Evaluations

Technical details and assumptions will be presented and discussed as part of accompanying presentations

Definition of Failure

- Fully Submerged Sump Screens

$$\Delta H_{screen} \geq NPSH_{margin}$$

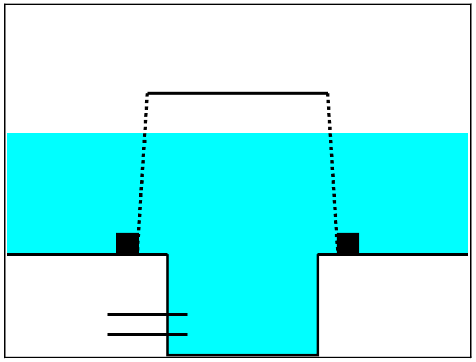


- Partially Submerged Sump Screens

$$\Delta H_{screen} \geq NPSH_{margin}$$

or

$$\Delta H_{screen} \geq \tfrac{1}{2} \text{ of pool height}$$



Purpose of Parametric Evaluations

- Perform analyses that will demonstrate - generically - whether loss of $NPSH_{margin}$ due to debris accumulation on recirculation sump screen is a significant safety concern
  - Initiators of Concern: LLOCA, MLOCA, or SLOCA
  - Pumping Systems Analyzed: ECCS (LPSI and HPSI) and CS
    - » Analyses addressed debris generation, debris transport, debris accumulation, and the resulting head loss across the sump screen.
    - » Analyses addressed variability in relevant plant features such as screen area, sump configuration, debris sources, etc.
    - » Some relevant plant features could not be addressed, such as: debris location, containment configuration, etc.

Technical Considerations

- Parametric analyses provide an effective mechanism for “generic” assessment of PWR susceptibility to sump-screen blockage concerns
  - » Construct parametric cases as closely to actual plants as possible. A total of 69 parametric cases were used in the parametric analyses
  - » Range of likely conditions possible in the industry and incorporate variations like insulation type in proportion to their “reported” occurrence
  - » Not designed to determine vulnerability of a specific plant to sump failure
  - » Form credible technical means to determine if sump blockage issue is a generic concern

- “Favorable” and “Unfavorable” assumptions were used
  - » To quantify parameters or variables for which data could not be or was not available. For example:
    - – ECCS flow rate following LOCA; Single train vs. two-train considerations
    - – Debris transport fractions; Finer debris only vs. finer and larger debris
    - – Types of debris expected to reach the sump screen; Used survey responses
    - – Variables for which licensee response was not available (limited cases)

"Favorable" and "Unfavorable" Assumptions

- Example to demonstrate how favorable and unfavorable assumptions were used in this study
  - Unfavorable assumptions are not the "Worst-case" or "Bounding" assumptions
  - Engineering judgment used to select the appropriate range. Special studies (and experiments) to address this issue.
  - General philosophy: "examine" if problem exists even under favorable assumptions

Parameter	Analyses Conducted	Favorable Analyses	Unfavorable Analyses
Head Loss	NUREG/CR-6224. Bumpup factors for particulate debris. Cal-Sil Head Loss Data Validated for use	Neglect RMI . Treat Cal-Sil as just another particulate debris. Treat all fiber as fiber glass	Neglect simultaneous existance of RMI and Fiber. Treat Cal-Sil as just another particulate debris.Use "worst" fiber

Technical Objectives

- Evaluate each parametric case and develop insights regarding potential for sump failure associated with that case and identify important plant features that contributed to the outcome

- Qualitative ranking: express outcome in terms of linguistic variables
  - » **Very Likely** grade was assigned when head loss caused by debris accumulation exceeded $NPSH_{Margin}$ when evaluated using "favorable" assumptions.
    - » Typically in such plants, significant fraction of insulation is fiber-glass and calcium-silicate, combined with plant design features that allow higher transport.
  - » **Unlikely** grade was assigned when head loss caused by debris accumulation is less than the $NPSH_{Margin}$ when evaluated using "unfavorable" assumptions.
    - » Typically in such plants, very small fraction of insulation is fiber-glass and calcium-silicate, combined with plant design features that preclude higher transport. These plants still need further evaluation because "unfavorable" analyses did not consider transport and accumulation of larger debris in the initial stages.
  - » **Possible** and **Likely** grades were assigned for intermediate cases

Technical Methodology

Chronological Order of Occurrence

① Types of Debris in Containment

② Debris Generation

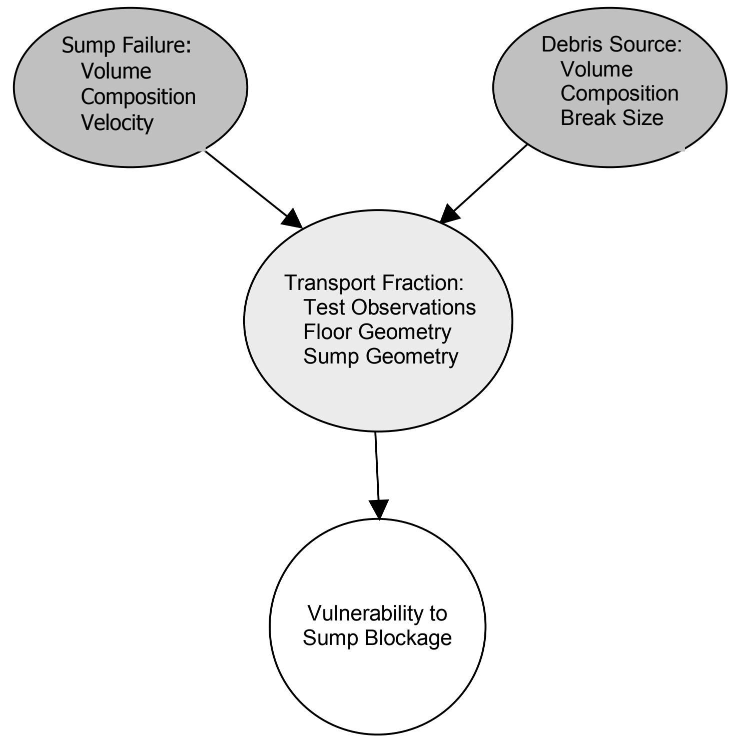
③ Transport in Air

④ Transport in Water

⑤ Debris Accumulation and Head Loss

⑥ Sump Failure

Present Approach



<u>Advantage:</u>
Present Approach introduces the highest quality information and the most refined models before more subjective arguments are invoked.

Technical Methodology

- ⓿ Define Parametric Cases that adequately represent range of likely conditions in the industry,
- ❶ Estimate minimum debris loading necessary to cause sump-screen blockage of sufficient magnitude to exceed ECCS/CS $NPSH_{margin}$,
- ❷ Estimate the quantity of debris that might be generated and use these estimates to derive minimum transport fractions for each insulation type,
- ❸ Estimate likely transport fractions for each debris and compare them with the minimum transport fractions calculated in step ❷,
- ❹ Estimate expected range of debris that could accumulate on the screen,
- ❺ Estimate expected range of head loss due to debris accumulation.

Description of Parametric Cases

- 69 Parametric Cases were constructed for analysis
  - Each case based on an operating PWR unit
  - Sump configuration based on survey responses
    - » Plant drawings were provided by most licensees responding to the survey
  - Piping configuration based on volunteer plant data
    - » LLOCA and MLOCA validated for six USI A-43 plants
  - Type of thermal insulation based on survey responses
    - » Containment average volume fractions. Fire barrier materials not included
  - Plant response to LOCA based on MELCOR and RELAP simulations
    - » Spray set points, HPSI flow rates and success criteria from plant sources
  - $NPSH_{Margin}$ based on licensee responses to GL 97-04
  - "Favorable" and "Unfavorable" estimates for
    - » ECCS/CS response, transport fractions

Construction of a Parametric Case #17

Plant Parameter	Value
Sump Screen Area ☑	57 ft^2
NPSH Margin	1.1 ft-water CS and RHR 13 ft-water for HPSI
ECCS Pump Flow Rates (Sprays On) ☑ SLOCA ECCS Flow (assuming CS) All ECCS Flow	 10800 GPM 15100 GPM
Sprays Activation Pressure	5 psig Containment Spray actuation likely for 2-in. line because containment volume is 10^6 ft^3 (relatively small)
Containment Free Area	Net area 6740 ft^2 Narrowest channel close to the strainer is 9 ft wide. Assuming 6 ft water height in this channel flow area in the close proximity is about 60 ft^2; results in about 0.4 ft/s.
Fan Cooler	Not safety class.
Pool Levels ☑ At Switchover Maximum Height	 5.4 ft (@20 min) 6.78 ft (@24 min)
Sump Submergence ☑	Completely Submerged both at switch over and later. Base plant uses "cylindrical" basket strainers arranged vertically on the floor.
Sump Location	Remote
Sump Screen Orientation	Vertical with respect to approaching flow
Sump screen approach velocity	At 10, 800 gpm it is approximately 0.4 ft/s.
Sump Screen Clearance	0.178 in.
Insulations Types ☑	Fiberglass Blankets Kaowool Blankets Jacketed Cal-Sil
Relative Fractions of Insulation Fibrous (Fiberglass and Kaowool) Cal-Sil	 74.6% 25.4%

GSI-191 Survey: Licensee Response

Licensee response to NRC GL 97-04

FSAR and Plant Data

GSI-191 Survey: Licensee Response

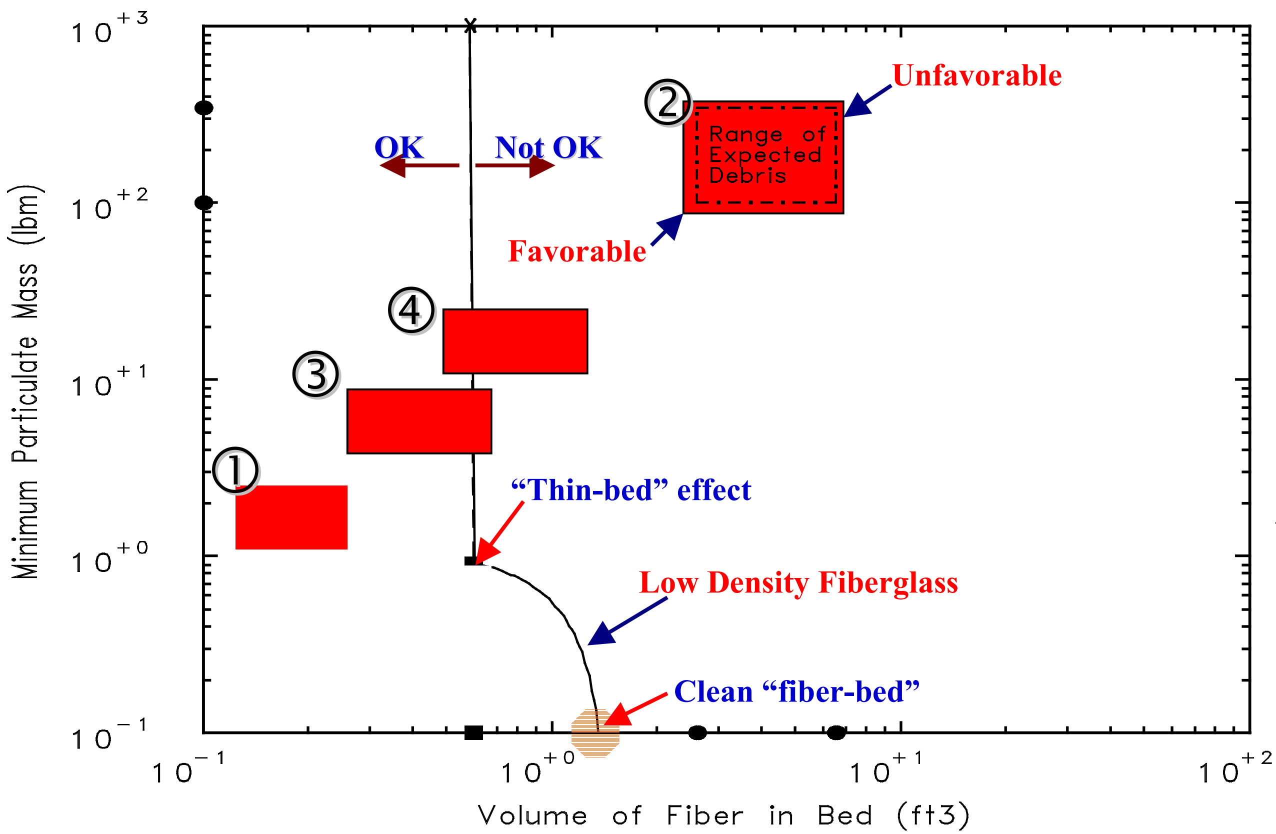
LANL Interpretation of GSI-191 Survey Responses

GSI-191 Survey: Licensee Response

☑ Variable for which favorable and unfavorable assumptions were used

Parametric Case #17 Results

Comparison of Threshold Debris Loadings and Range of Expected Debris Loadings



Criteria:

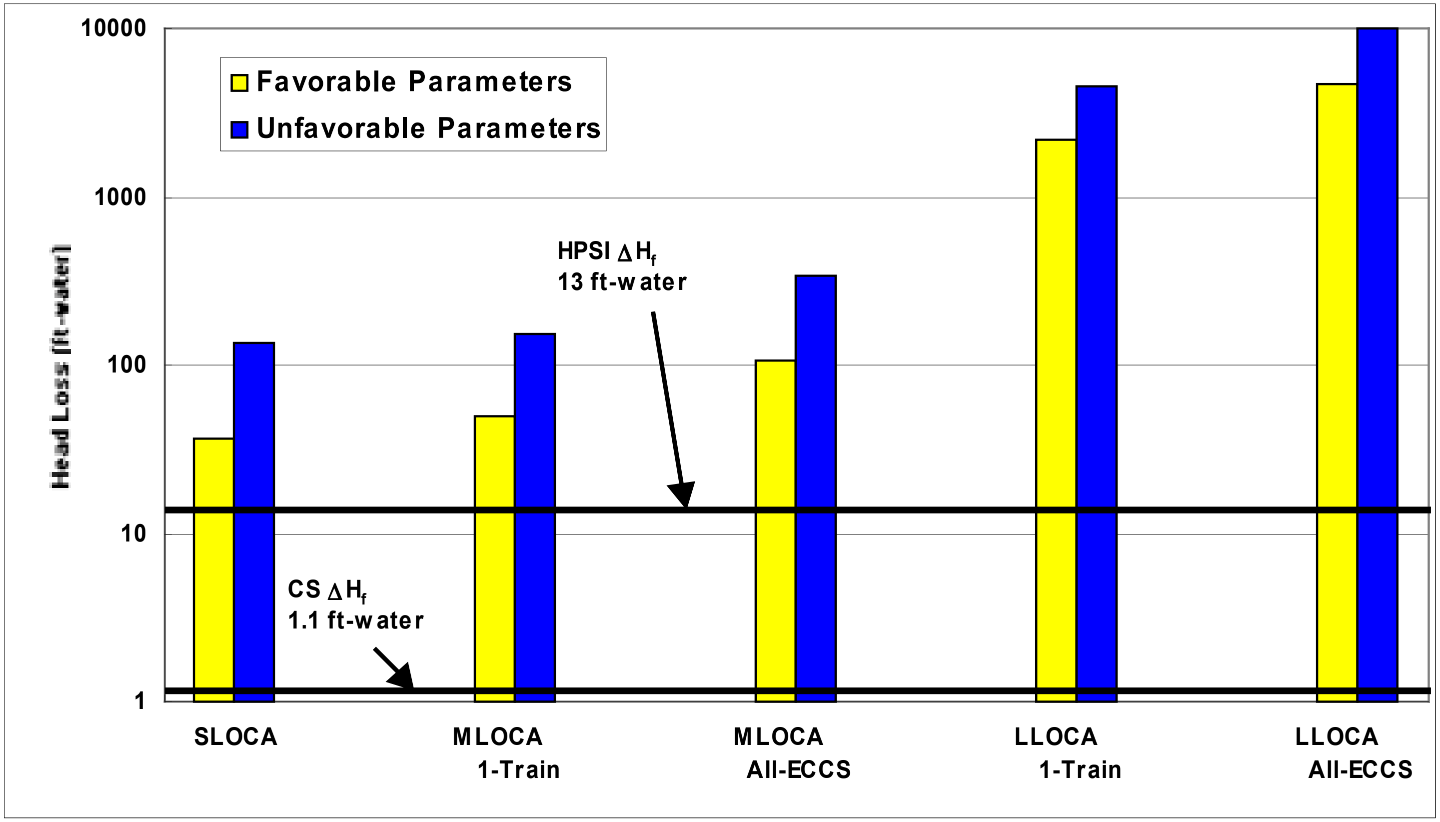
① Unlikely
② Very likely
③ Possible
④ Likely

Separate charts for

- LLOCA, MLOCA, SLOCA
- LPSI, CS and HPSI

Parametric Case #17 Results

Comparison of Expected Head Losses with $NPSH_{margin}$ for Various Systems



Summary of Parametric Analyses

Sump Failure Potential	SLOCA	MLOCA	LLOCA
Very Likely	23	32	57
Likely	10	8	4
Possible	10	3	0
Unlikely	26	26	8
Total	69	69	69

- Most parametric cases analyzed for LLOCA resulted in sump failure. Several SLOCA cases resulted in sump failure.

- The 69 parametric cases developed for this evaluation provide a reasonable representation of operating PWRs, so the results form a credible technical basis for making a determination of whether sump blockage is a generic concern for PWRs.

- Parametric calculations have several limitations that make them unsuitable for making a determination of whether a specific plant is vulnerable to sump failure.

Limitations of Parametric Evaluations

Favorable

- Special effects of calcium-silicate and other particulate debris are not addressed in the analysis
- Chemical precipitation and formation of gelatinous particulates not addressed
- Linkup between air ingestion and lowered sump level caused by debris accumulation not analyzed
- Important information on location of fibrous and cal-sil insulation not included in analysis

Unfavorable

- Important information on location of fibrous and cal-sil insulation not included in analysis
- Effect of plant design on transport not addressed in analyses
- Possible changes in $NPSH_{Margin}$ not addressed in analyses
- Do not identify time to sump failure
- Mixture of actual, design and licensing plant data

Useful Insights: Threshold Debris Loadings

- Very small quantities of fibrous and particulate debris would be sufficient to cause blockage:
  - Approximately 1 ft^3 of fibrous insulation combined with 10-20 lbs. of particulate material is sufficient to raise sump blockage concerns for 40 out of 69 cases.
    - » 1 ft^3 of fibrous insulation is used to insulate 1/2-ft segment of 28-inch cold leg (basis: 3.5-inch thick low density blankets). Some plants also use fibrous insulation as fire barrier material.
    - » 1 ft^3 of dust weighs in excess of 100 lb.
- Small volumes of RMI fragments would again be sufficient to cause blockage:
  - Accumulation of 1000 ft^2 of RMI is sufficient to raise blockage concerns in 8 out of 69 cases.
    - » Potential for significant accumulation of RMI resulting in excessively large head losses is unlikely, except for 3 out of 69 cases.

Useful Insights: Important Plant Features

- Types and Fractions of Insulation in Containment
  - Fiberglass and calcium-silicate insulation fractions
  - Presence of other mass-type insulation fragments
- Assumptions related to Containment Spray and ECCS Actuation and Operation
  - Single train v. design operation
  - Operator actions related to containment sprays
- Location and Layout of Recirculation Sump
  - Exposed, remote or intermediate sumps
  - Horizontal, inclined or vertical
- Sump Screen Design
  - Screen area and screen submergence

Useful Insights: Results of Analyses

- Two-phase water jets exhibited damage to cal-sil and fiber-glass higher than previously measured for BWR conditions
  - » Tests were conducted at 1400 psi and 301 ^{o}C
- Debris Transport tests showed that small shreds of fibrous insulation and loosely attached fibers can stay in suspension and transport at velocities as small as 0.05 ft/s.
  - » In 3-D tank tests, debris accumulation continued for several hours
- Calculations using DBA approved models suggested that large quantities of precipitants can be generated by chemical interactions
  - » Gelatinous precipitants found at TMI. Even larger quantities if coating contribution is included
- Accumulation and head loss testing has shown that small shreds and loosely attached fibers can build up uniformly on vertical screens with mesh-sizes of up to 1/4-inch and filter out cal-sil and other particulate
  - » Filtration results in very high head losses