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

Head Loss and Threshold Debris Volumes

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Technical Approach

The following analyses were carried out for each parametric case

① Define Failure Criterion Appropriate for the Parametric Case
- » Conditions based on levels at switchover (unfavorable)

② Select Debris Types used for Head Loss Estimates
- » Favorable and Unfavorable analyses
- » Used Licensee responses to GSI-191 Industry Survey

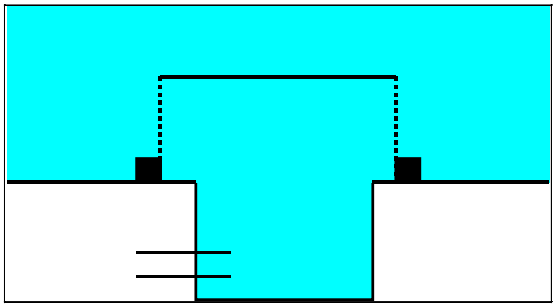
③ Select Appropriate Head Loss Correlation
- » Reflective Metallic Insulation (NRC SER Appendix-K)
- » Fibrous Debris with Particulates (NRC NUREG/CR-6224)

④ Use Head Loss Correlation to Determine Threshold Strainer Loadings
- » Reflective Metallic Insulation
- » Fibrous Debris with Particulates (FTDL -- Charts)

Sump Failure Criteria

- Fully Submerged Sump Screens

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

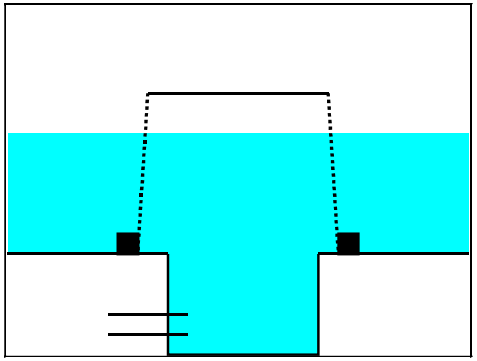


- Partially Submerged Sump Screens

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

or

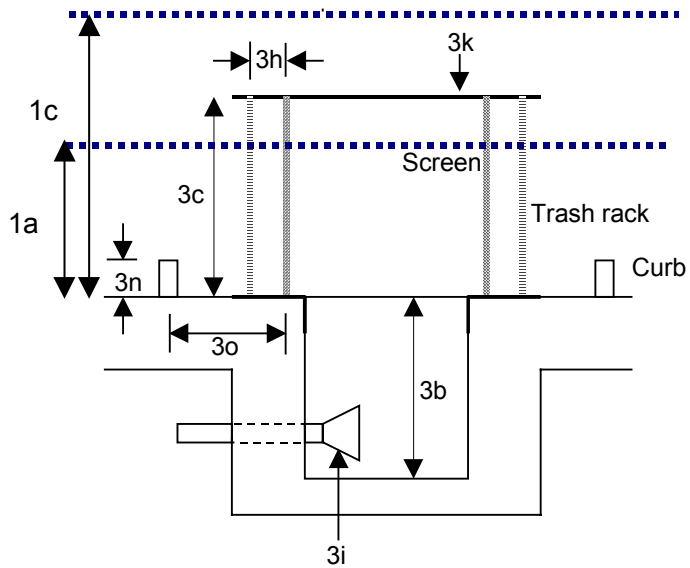
$$\Delta H_{screen} \geq \tfrac{1}{2} \text{ of pool height}$$



Sump Submergence and Effects

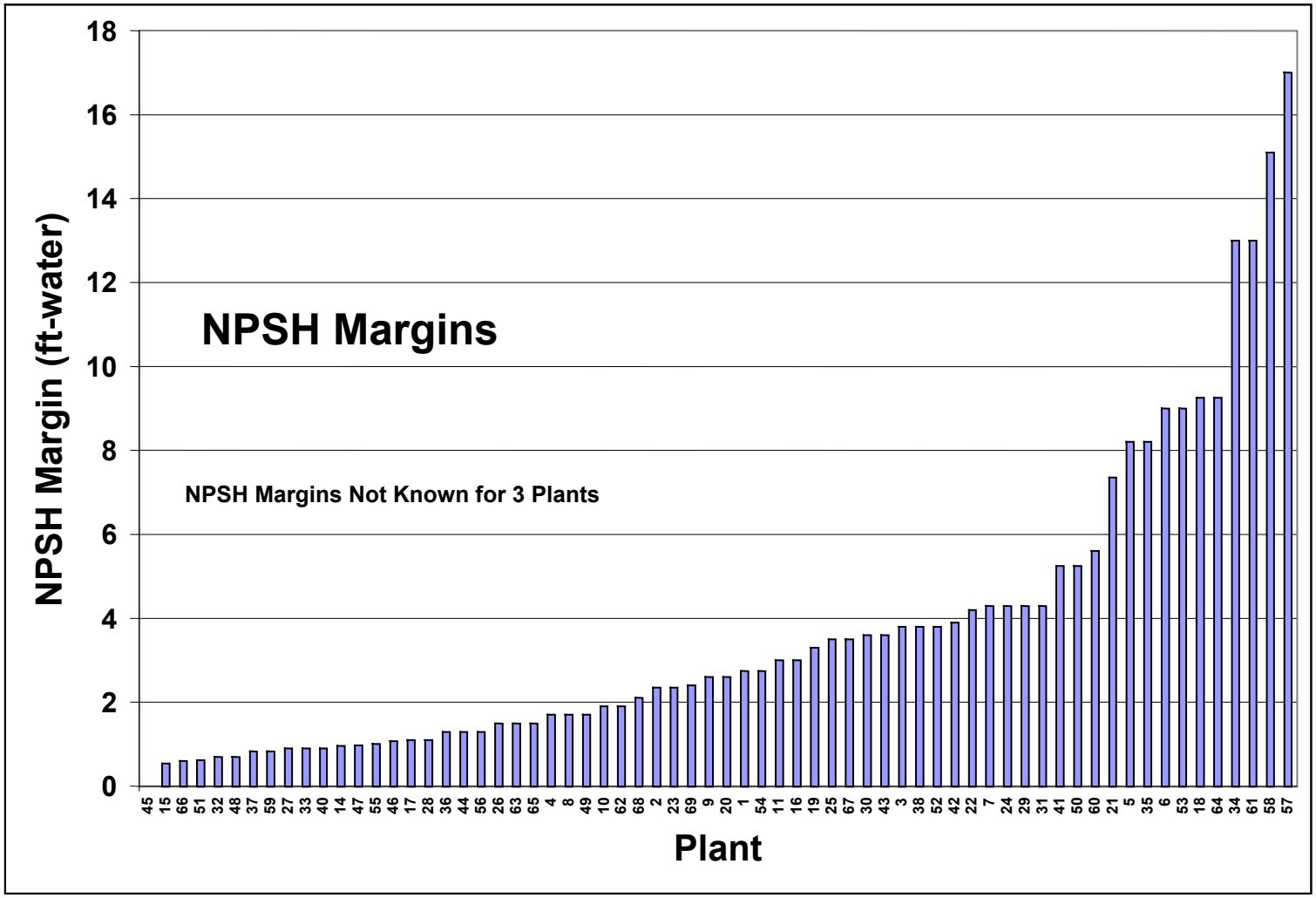
- Submergence level is determined from analysis of Survey Responses
  - Height of water pool on containment floor > or ≤ height of sump above floor
- Submergence effects two variables
  - Maximum allowable head loss
  - Screen area available for deposition

Our analyses do not address increased potential for air ingestion

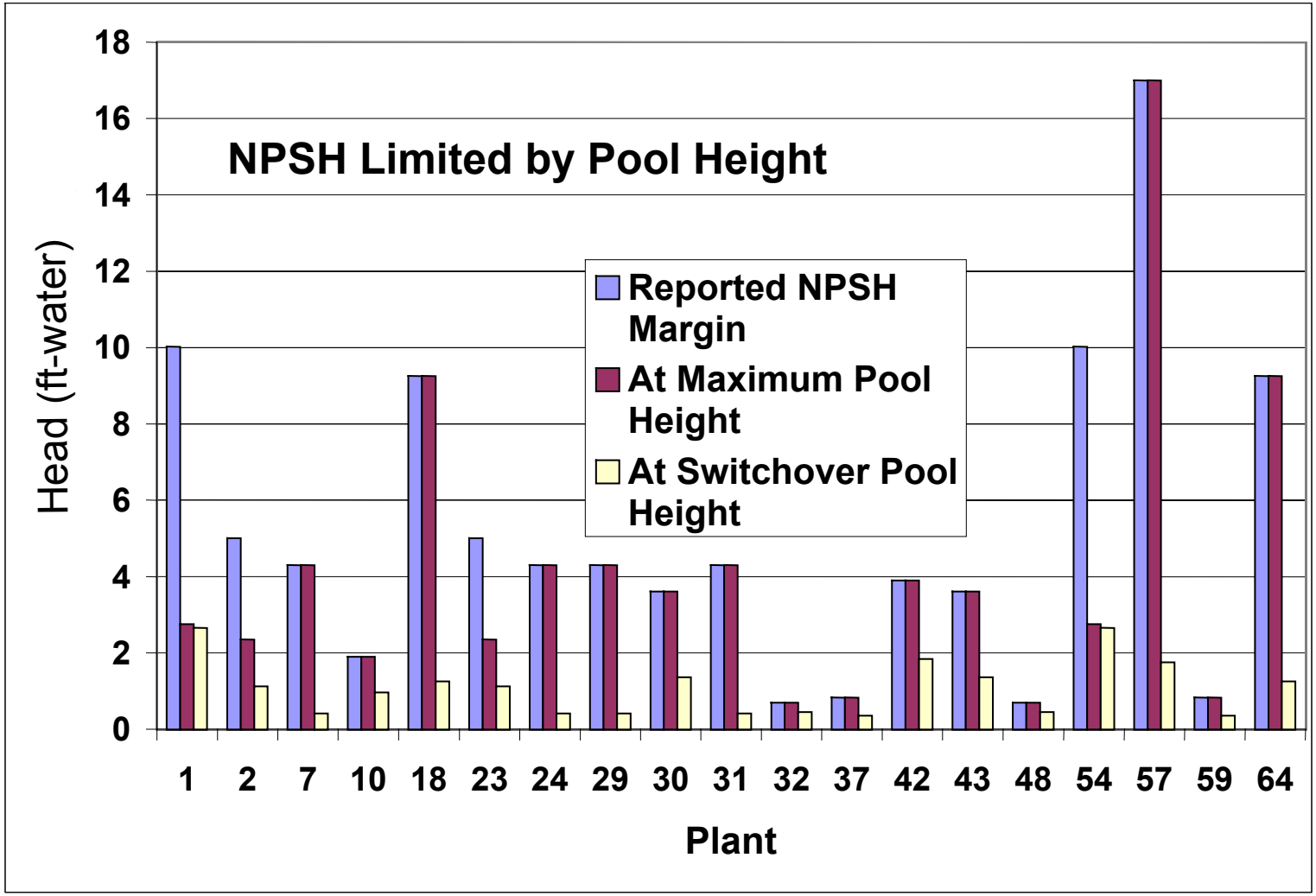


Question #	Information
3a	No. of cont. sumps
3b	Sump depth
3c	Height above floor
3d	Whether it has screen
3e	Screen area
3f	Screen hole size
3g	Trash rack status
3h	Dist. between trash rack and screen
3I	Trash rack area
3j	Trash rack hole size
3k	Solid plate
3l	Vortex suppressor
3m	Debris curb
3n	Debris curb height
3o	Dist. between debris curb and screen
1a	Height of water pool on containment floor at time of switchover
1c	Maximum height of water pool on the containment floor

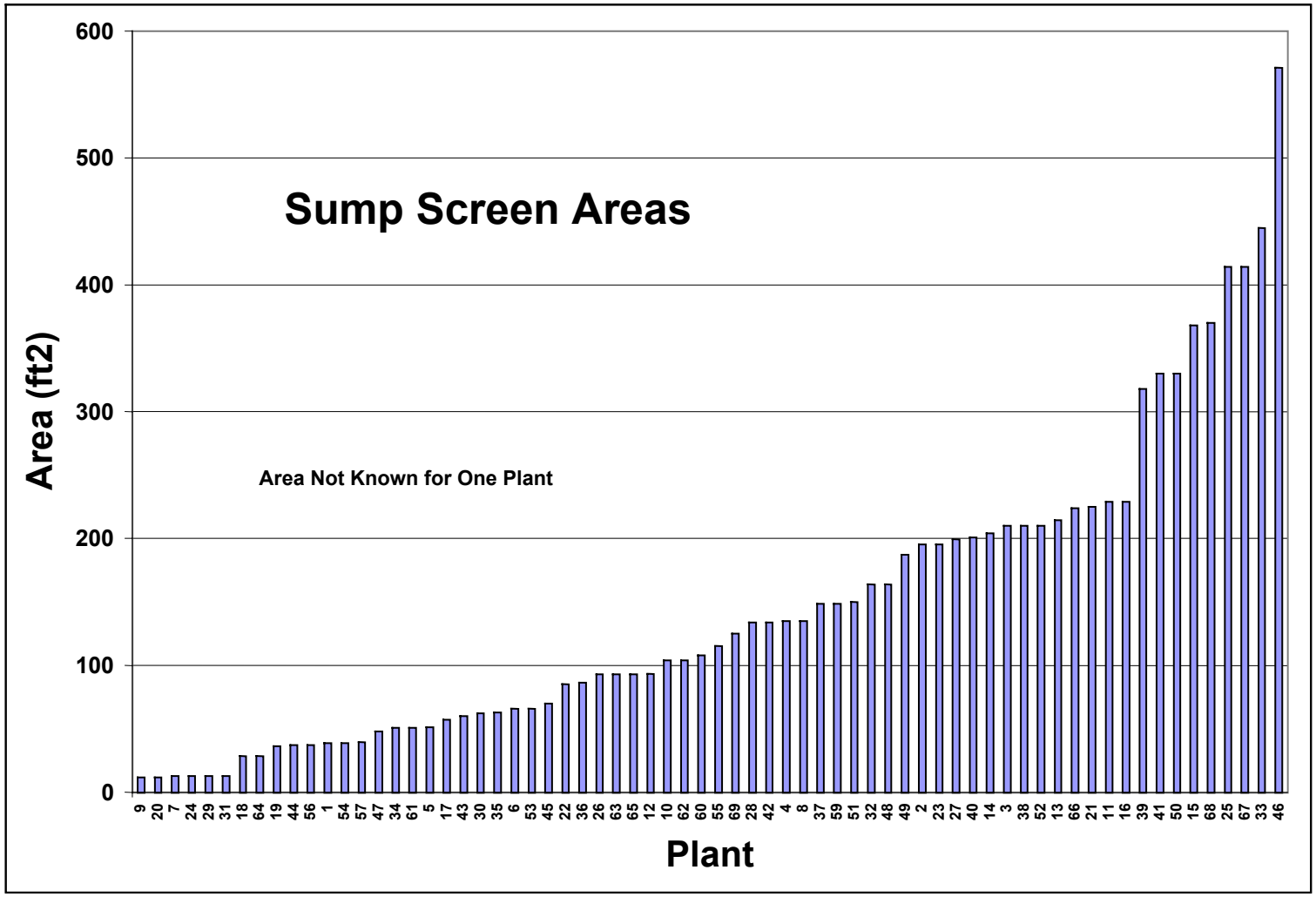
NPSH Margins for Operating PWR Plants



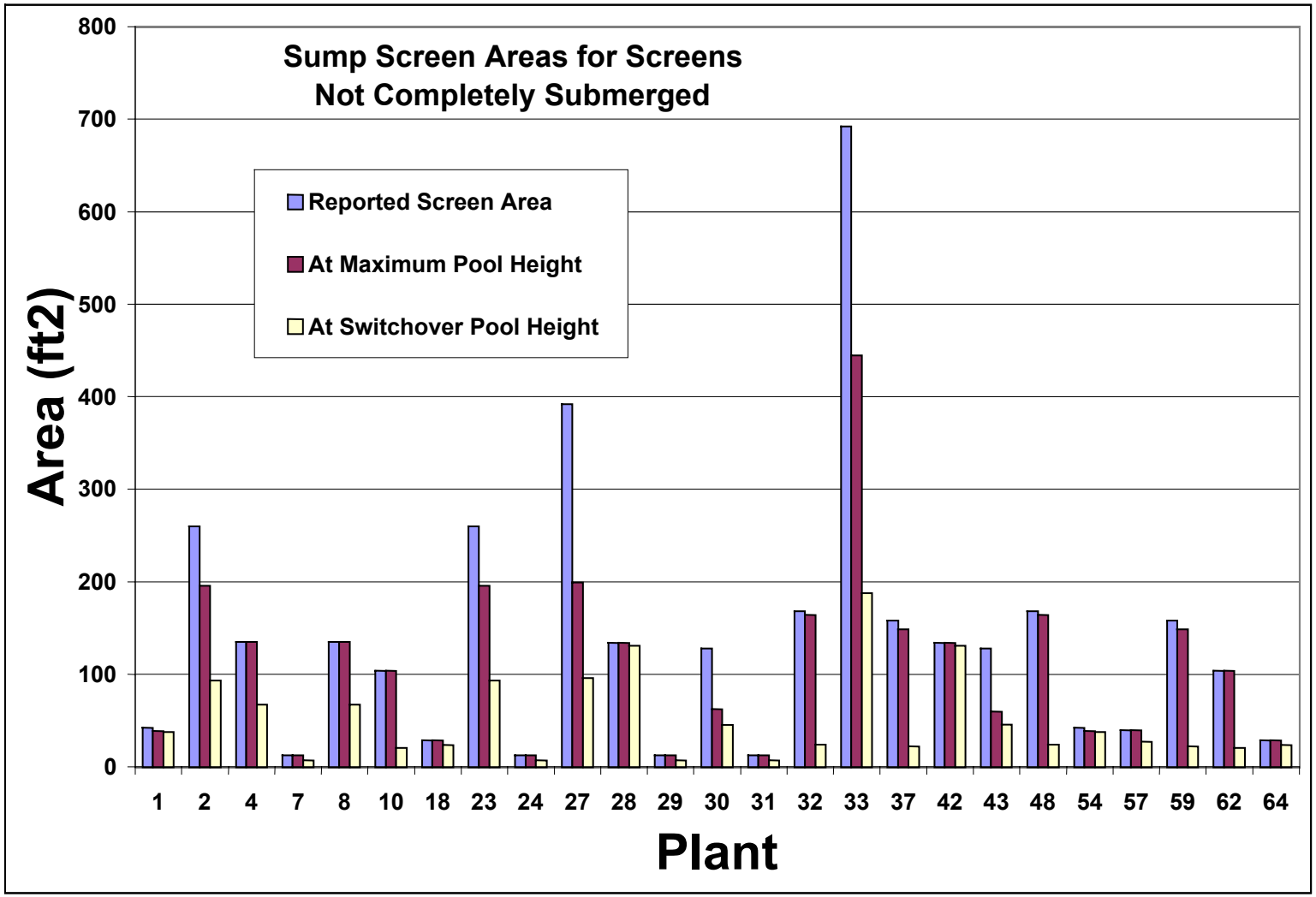
ΔH_f for Screens Not Completely Submerged



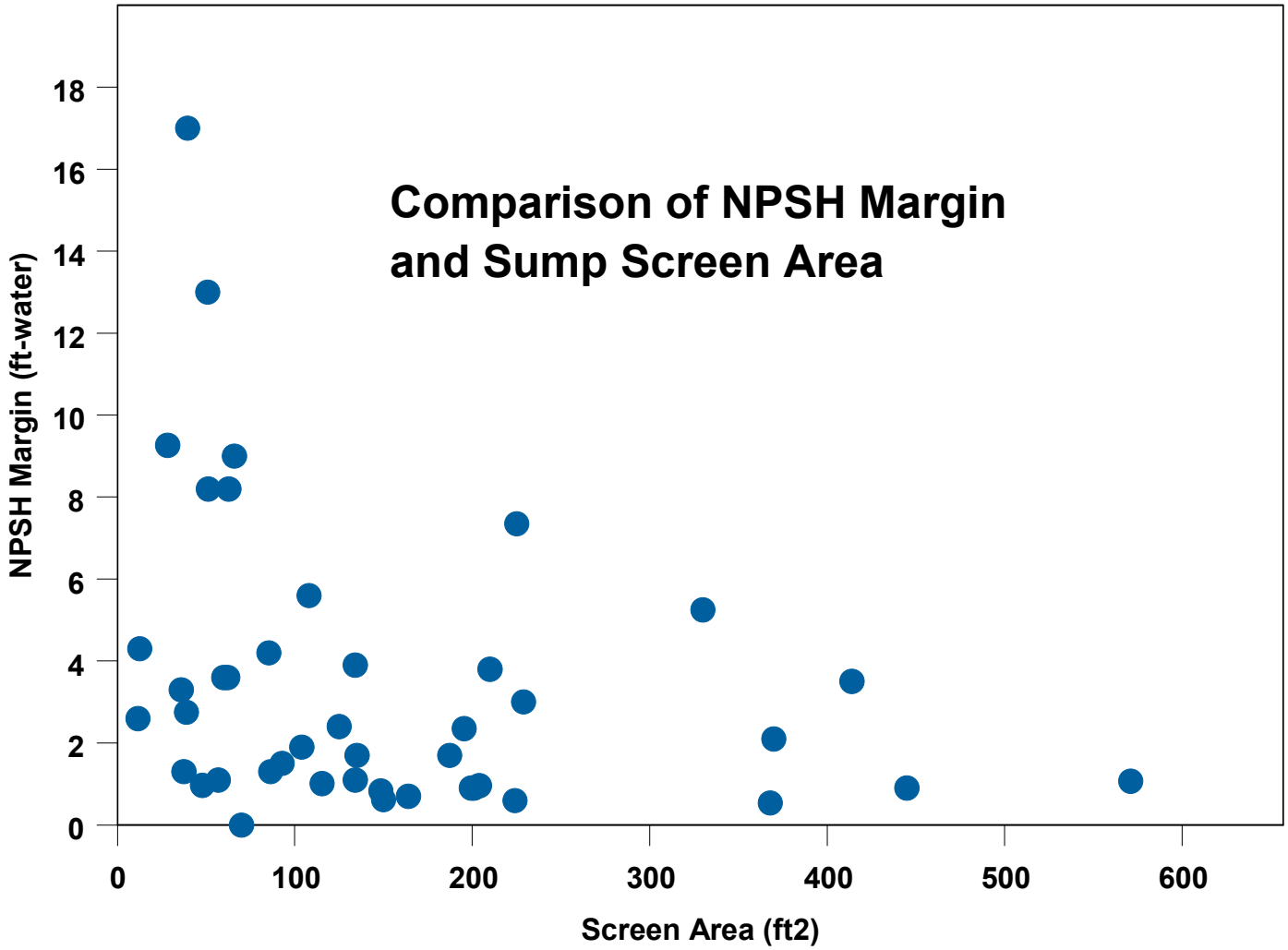
Screen Areas for Operating PWR Plants



Areas for Screens Not Completely Submerged



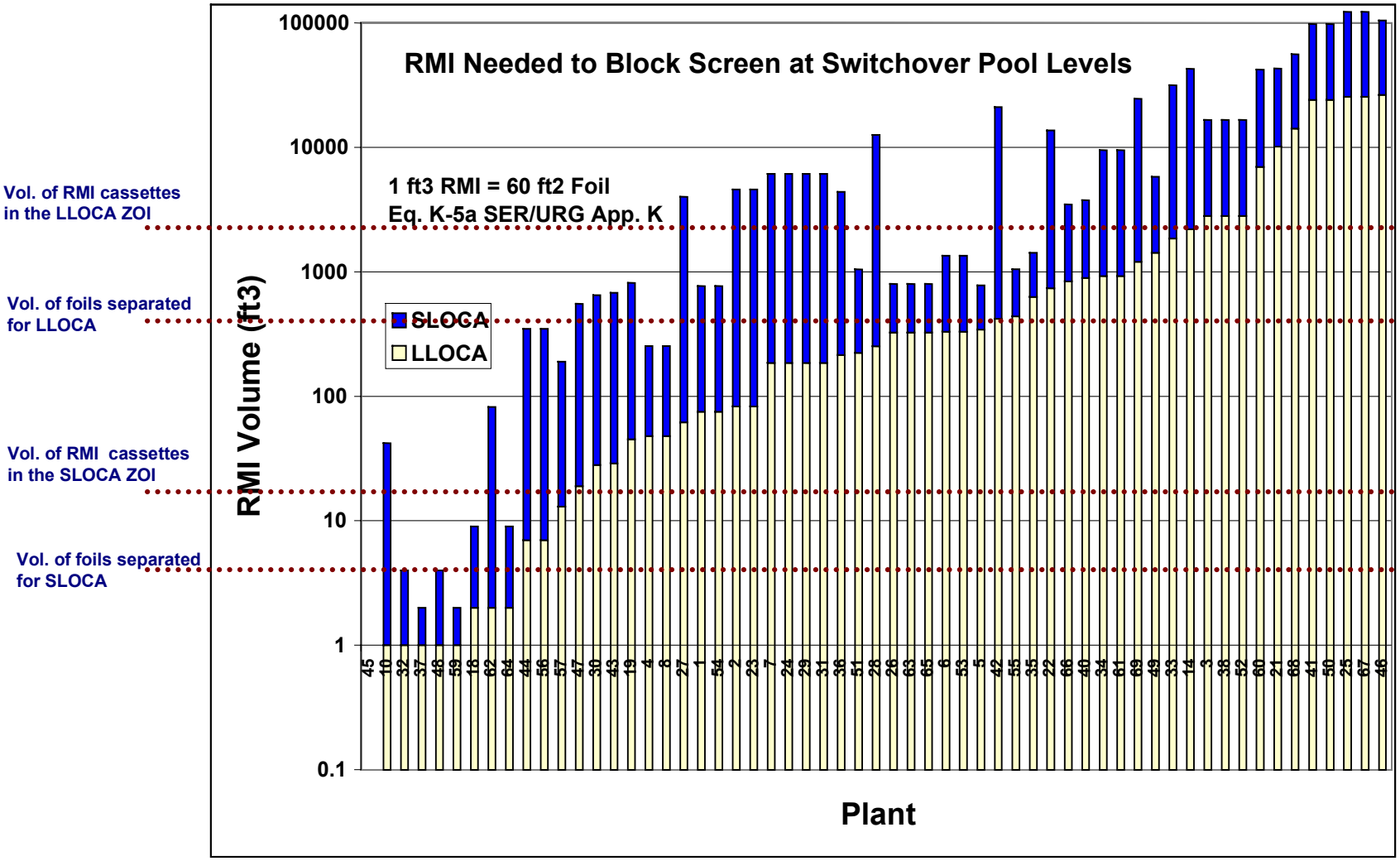
Small Screens and/or Margins Indicate Problem



RMI Sump Blockage Potential

- Determine RMI Foil Area Required to Cause Head Loss Equal to Failure Criteria (Threshold Area)
  - Apply Experimentally Derived Head Loss Correlation to Predict Head Loss
    - NRC Safety Evaluation Report (SER) for BWROG URG, Appendix K
    - Developed Using Both BWROG-Sponsored And NRC-Sponsored Test Data
    - $\approx \Delta H = 0.108\ U^2\ A_{foil} / A_{screen}$
    - Development of Correlation Considered Experimental Uncertainty
- Relate RMI Foil Area to Debris Volumes
  - 1 ft^3 RMI = 60 ft^2 Foil Used in Parametric Study
- Estimate Likelihood of Sufficient Debris Bed Formation
  - Debris Generation
  - Transport to Sump Screen
    - Location of Sump Relative to Break
  - Debris Accumulation on Screen
    - Velocities and Turbulence Near Sump
    - Orientation of Sump Screen

Threshold RMI Blockage Volumes



Fiber/Particulate Sump Blockage Potential

- Determine Potential Head Loss for Specific Screen Area, Pump Flow Rate, and Type of Debris
  - Head Loss Predicted Using NUREG/CR-6224 Correlation
- Determine Threshold Quantities of Debris Capable Causing Head Loss That Exceed Failure Criteria
- Estimate Ranges of Debris Quantities Likely Generated, Transported, and Accumulated on Sump Screen Following SLOCA, MLOCA, AND LLOCA
- Compare Ranges of Accumulated Debris to Threshold Quantities to Judge Likelihood of Long-Term Recirculation Failure for Each Parametric Case

NUREG/CR-6224 Head Loss Correlation

- Developed Using Expressions Applicable to Porous Media Pressure Drops.
- Considers Compressibility of Fiber Bed
- Validated by Comparison with Data from NRC-Sponsored and Industry-Sponsored Experiments. Typically Valid for:
  - Fiber Beds Thicker Than ~1/8-inch
  - Pressure Drops Less Than ~ 50 ft-water/inch
- Basic Correlation

$$\frac{\Delta H}{\Delta L_o} = Units \left[3.5\, S_v^{\,2} \left(1-\varepsilon_m\right)^{1.5} \left[1 + 57\left(1-\varepsilon_m\right)^3\right] \mu\, U + 0.66\, S_v \frac{\left(1-\varepsilon_m\right)}{\varepsilon_m} \rho_w\, U^2 \right] \left(\frac{\Delta L_m}{\Delta L_o} \right)$$

- Compressibility Function

$$\frac{\Delta H}{\Delta L_o} = \left[\left(\frac{1}{\alpha} \right) \left(\frac{\Delta L_o}{\Delta L_m} \right) \right]^{\frac{1}{\gamma}}$$

Numerous public domain reports validated applicability of this correlation to a variety of fiber and particulate combinations

Thin Bed Effects

- Formation of a thin bed of fibrous debris starts to filter out particulate debris. This decreases bed porosity and causes large head loss. Bed resembles "soil" rather than fibrous bed.

Experimental confirmation of thin-bed effects

BWROG URG Tests 6-8 added fiber and particulate debris to 25000 gallon tank. Strainer area is 18 ft^2. Measured head loss is given below

Screen Velocity	Debris Added to Poo		Head Loss	Observations
(ft/s)	Fiber (ft3)	Part. (lbs.)	ft-water	
0.31	0.20	500	26	DP increasing
0.31	0.40	60	12	
0.31	0.40	180	24	
0.31	0.80	180	42	DP increasing
0.31	1.20	16	42	DP increasing

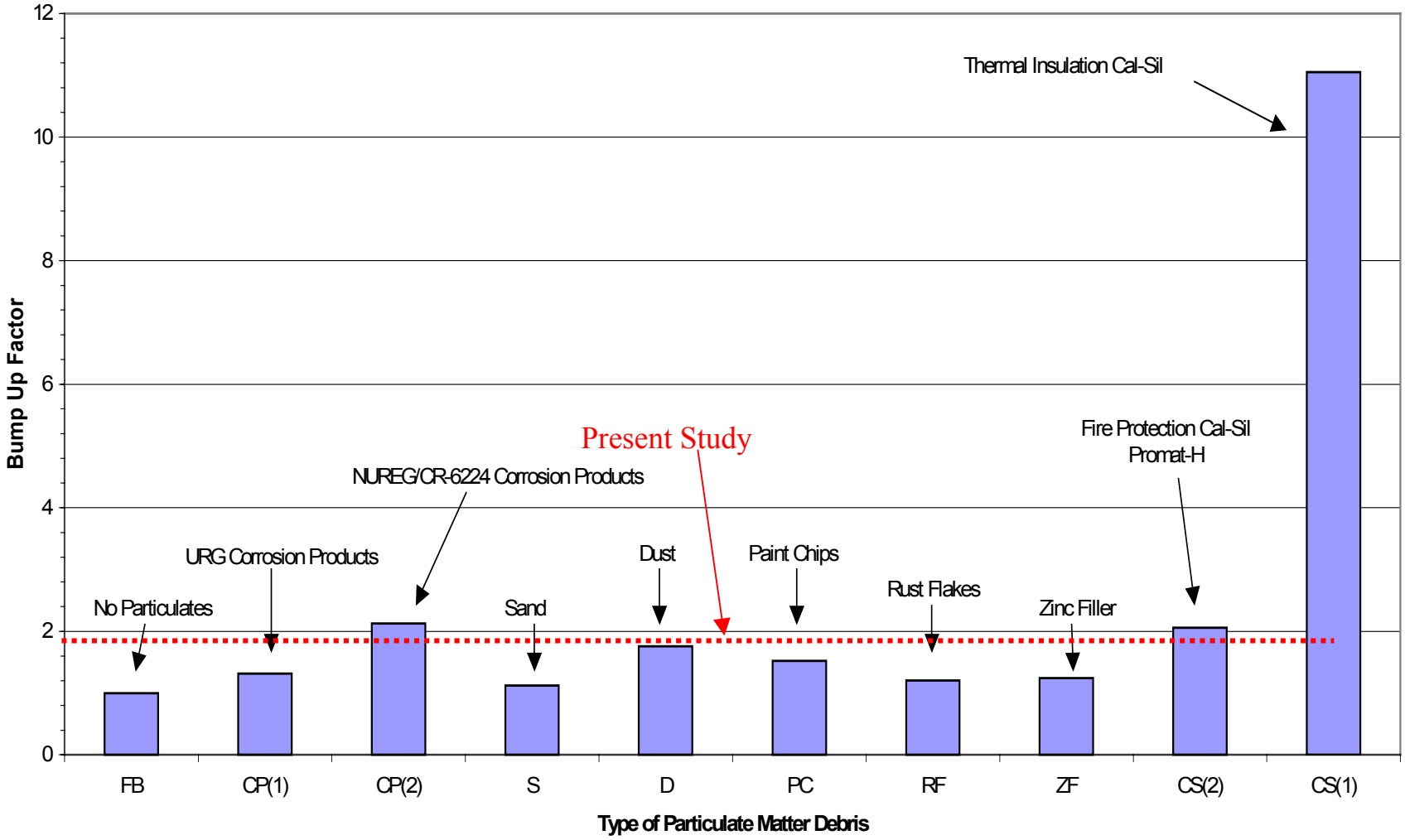
Types of Debris Considered

- Fibrous Insulation
  - Low Density Fiber Glass (LDFG)
  - Fine Fiber
  - High Density Fiber Glass (HDFG)
- Particulate
  - Resident Dust and Dirt
  - Concrete Dust from Break Jet Erosion
  - Fail Containment Coatings
  - Zn and Al Precipitation Byproducts
  - Particulate Insulation Debris (e.g., Calcium Silicate)

Generic Particulate Assumed for Study

- A Generic PWR Particulate was Assumed for the Parametric Study Due to Large Uncertainties Associated with Debris Types, Masses, and Properties.
- Head Loss Impacts of the Generic PWR Particulate were estimated using NUREG/CR-6224 correlation,
- Justification for Generic PWR Particulate Based on BWROG Experimentally Derives Bump-Up Factors for a Variety of Particulate Debris.
  - Ratio of Head Loss with Particulate to That Without Particulate
  - Bump-Up Factors Ranged from 1 to 2 for Most Types of Particulate, Exception: Calcium Silicate Insulation Debris
- Except for Cal-Sil, Use of Generic PWR Particulate Adequate for Parametric Study

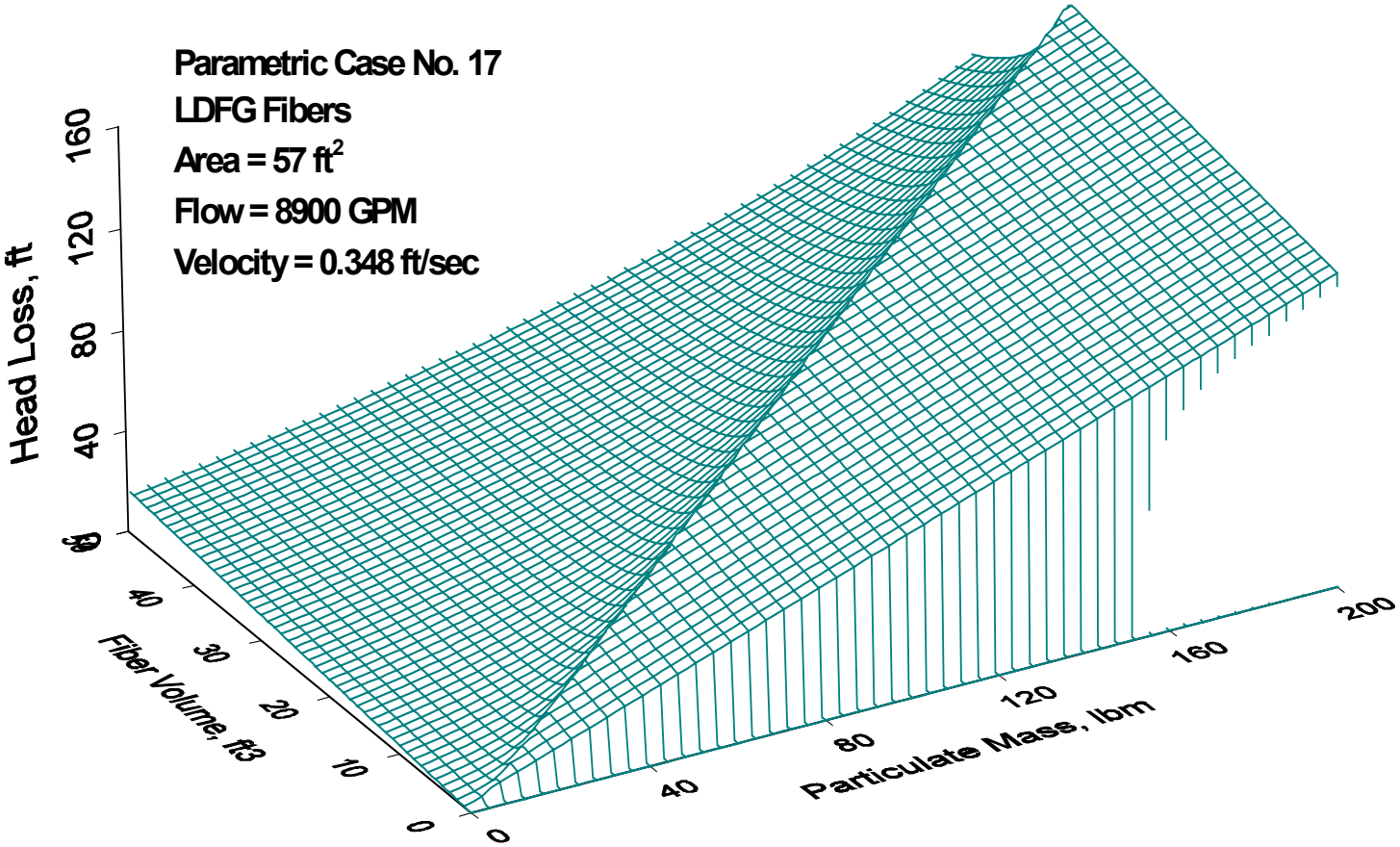
Comparison of BWROG Bump-Up Factors



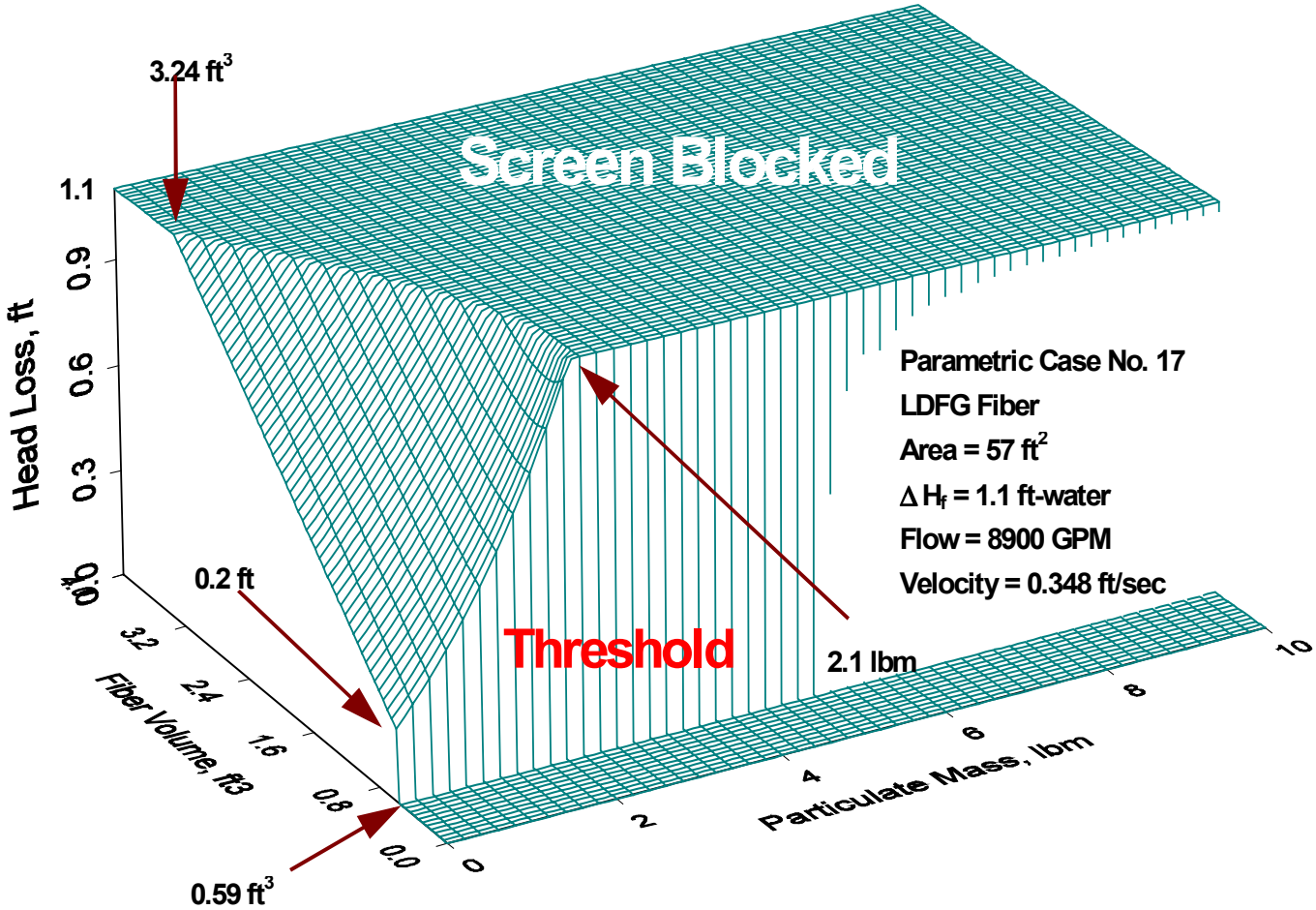
Treatment of Cal-Sil Insulation Debris

- Threshold Particulate Masses Calculated Using Generic PWR Particulate Properties
- Expected Cal-Sil Debris Masses Added to Particulate Debris Ranges
- Treatment Adequate for Parametric Study Because Result Conservative with Respect to Study Objectives
- Treatment Highly Non-Conservative with Respect to Estimating Sump Screen Head Losses

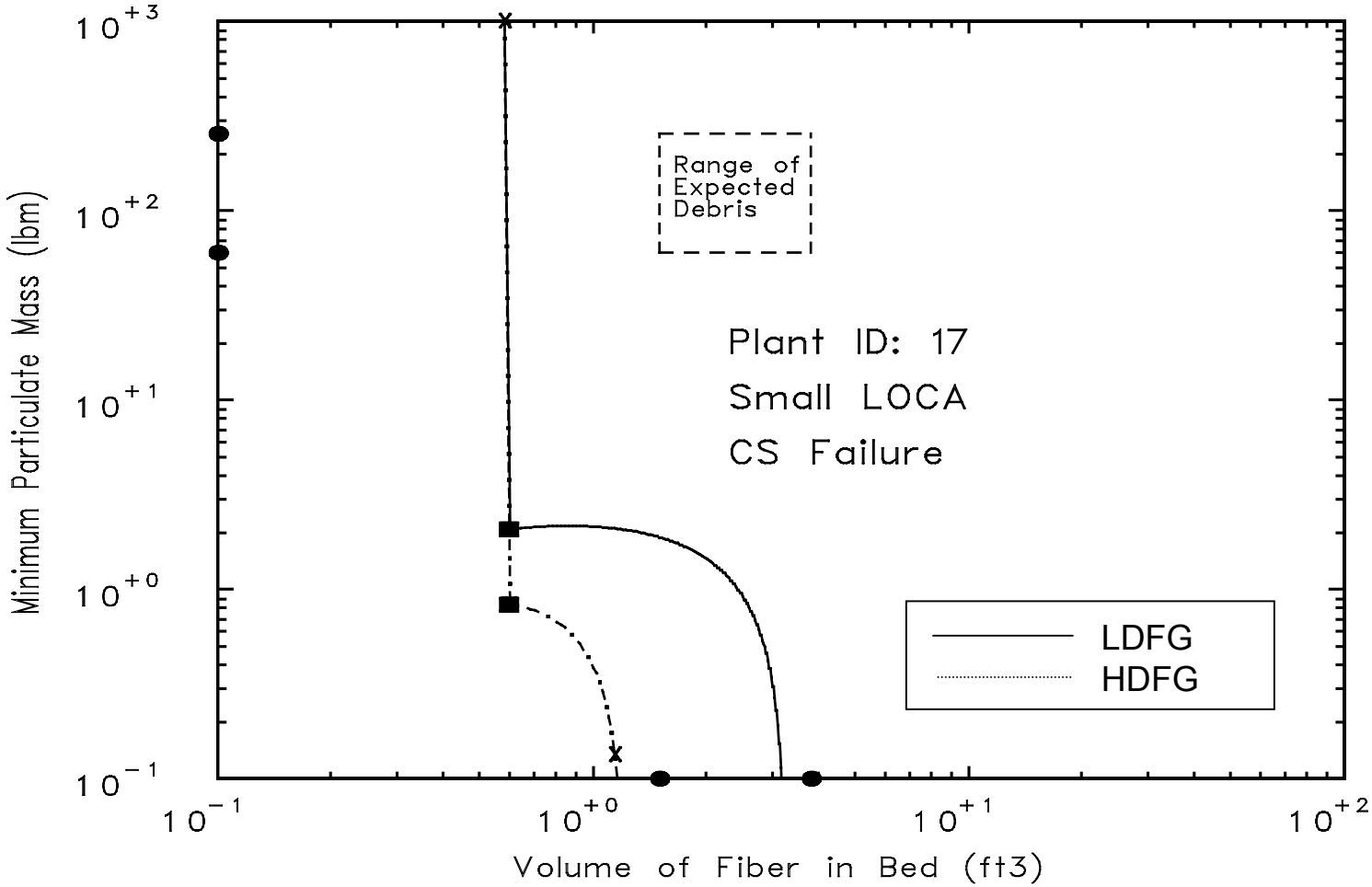
Example Potential Head Loss



Example Threshold Debris Quantities



Comparison of Threshold to Debris Range

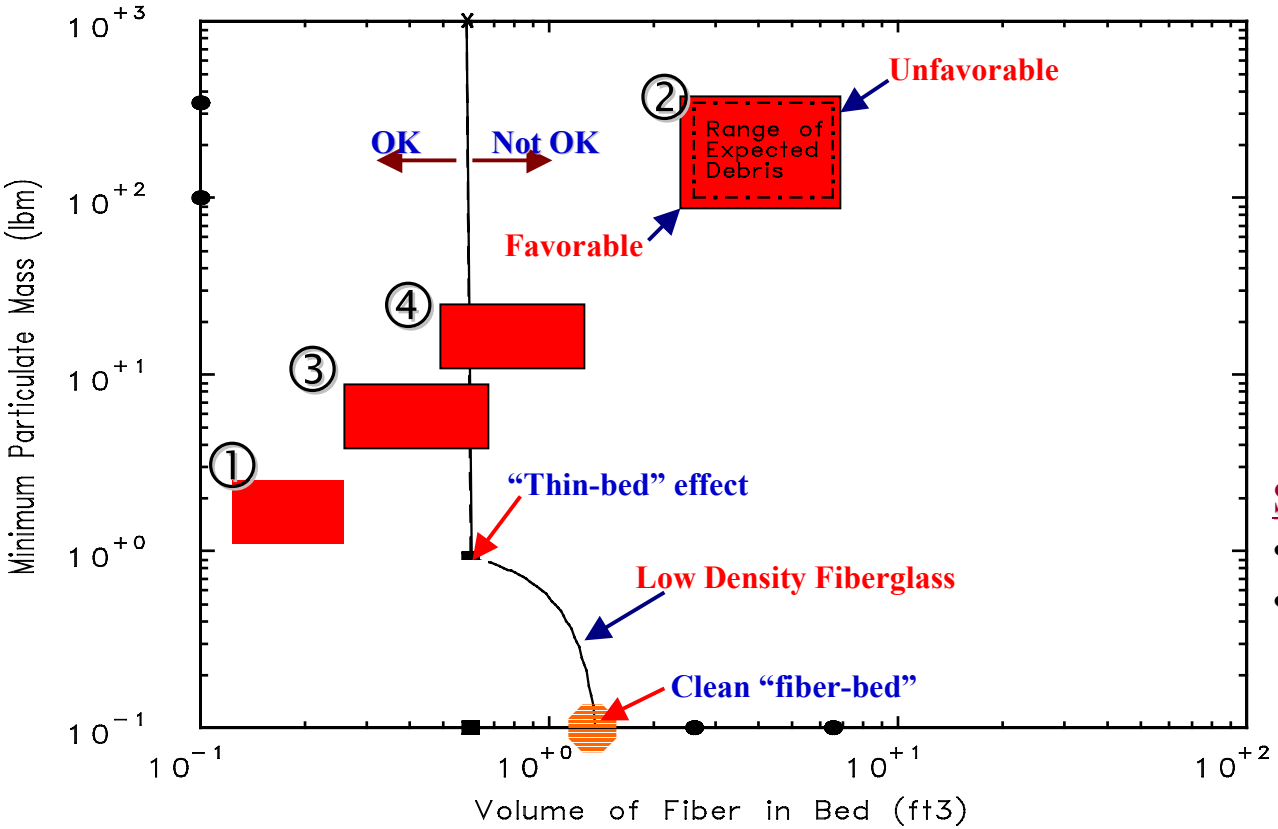


Relative Likelihood of Screen Blockage

- Likelihood of Sump Screen Blockage Judgments Based on Comparison of Ranges of Expected Debris to Threshold Debris Quantities
- Likelihood Categories Included:
  - Unlikely
  - Possible
  - Likely
  - Very Likely
- Categories Illustrated in Next Slide

Parametric Case 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

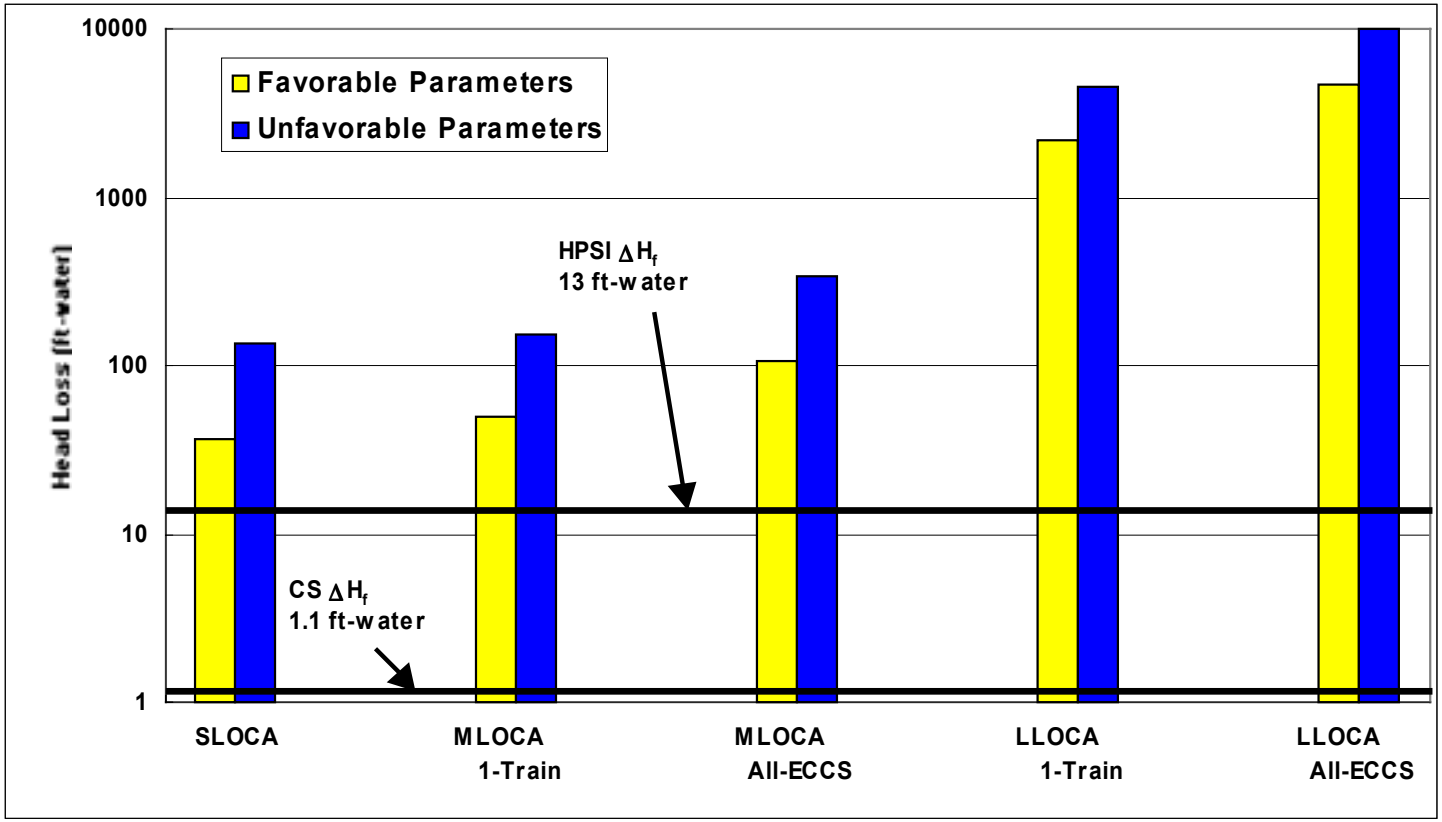
- Large, Med. and Small LOCA
- LPSI, CS and HPSI

Potential Head Losses for Specific Case

- Favorable Conditions Predict Lower Range of Potential Head Losses
- Unfavorable Conditions Predict Upper Range of Potential Head Losses
- Note that Head Losses Greater Than About 50-ft-water/inch-debris are Beyond Range of Validity for Correlation.
- Head Losses Illustrated in Next Slide

Parametric Case Results

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

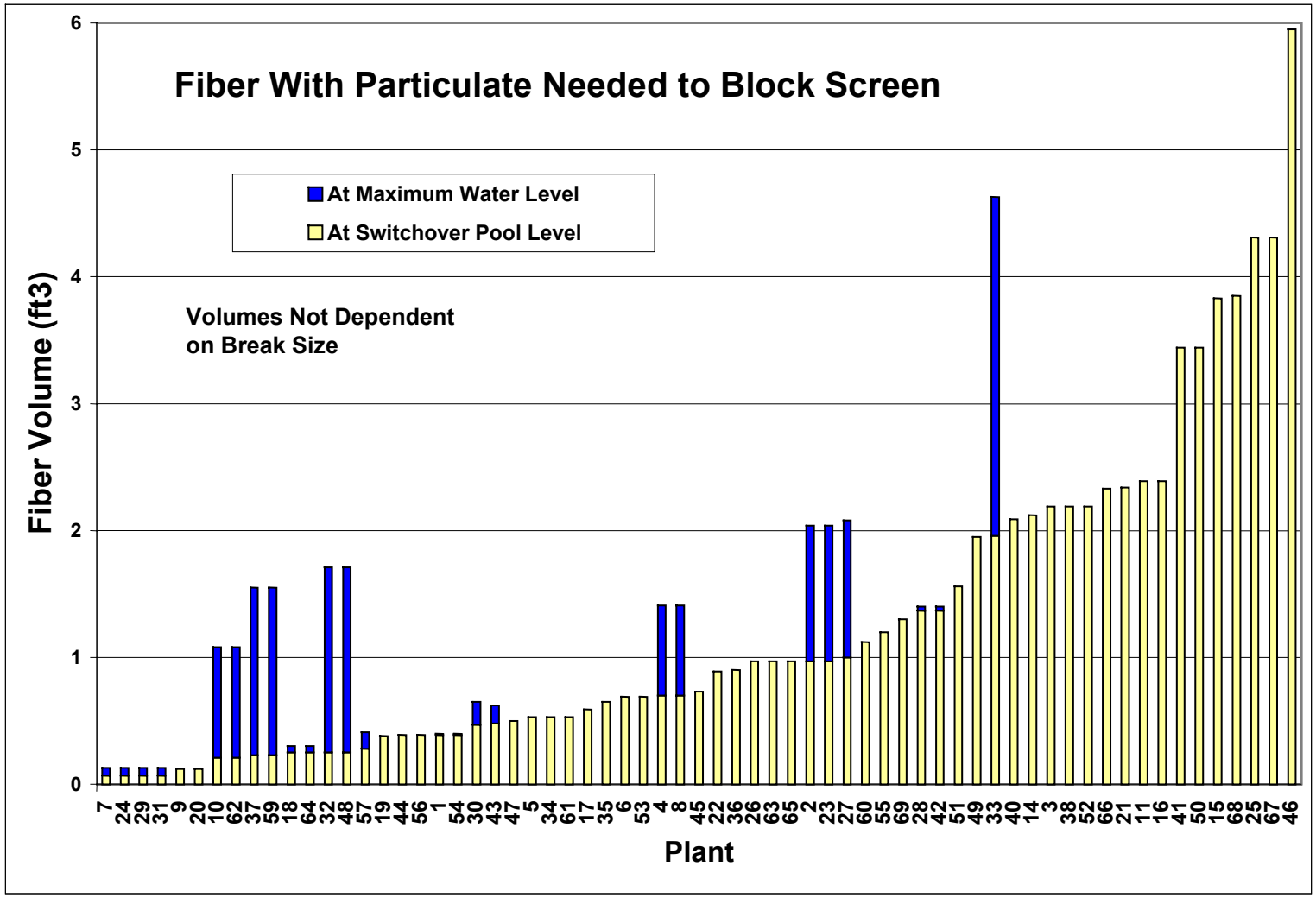


Threshold Results

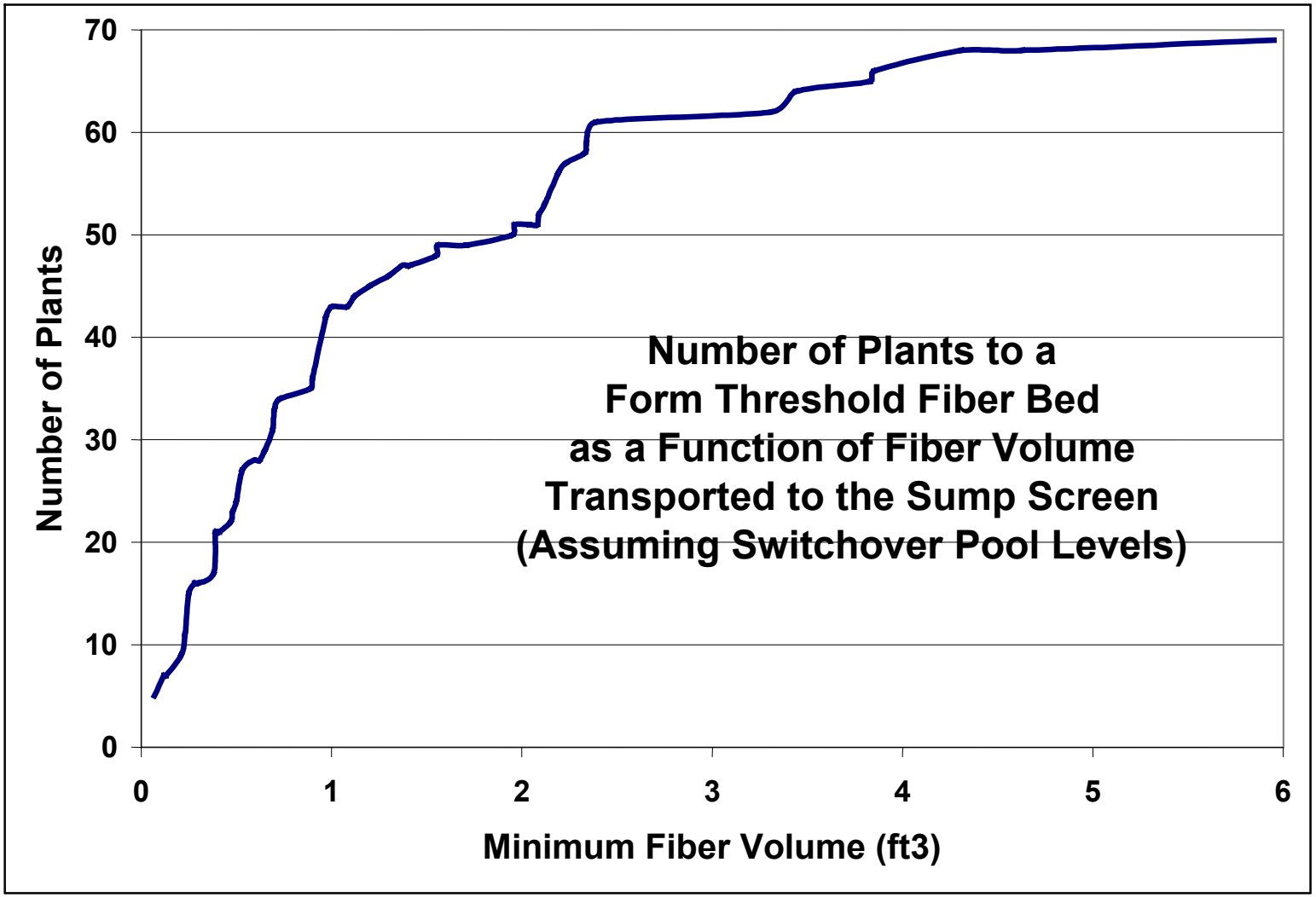
- Threshold Quantities
  - Volume of Fiber Needed to Form 1/8-inch Debris Layer on Sump Screen (Depends on Screen Area)
  - Mass of Particulate Needed to Cause Sump Screen Blockage Once a Threshold Fiber Layer is Established

- Cumulative Results
  - Number of Cases Forming Layer Versus Fiber Volume
  - Range (Favorable to Unfavorable) in Number of Cases Predicting Failure at Specified Masses of Particulates

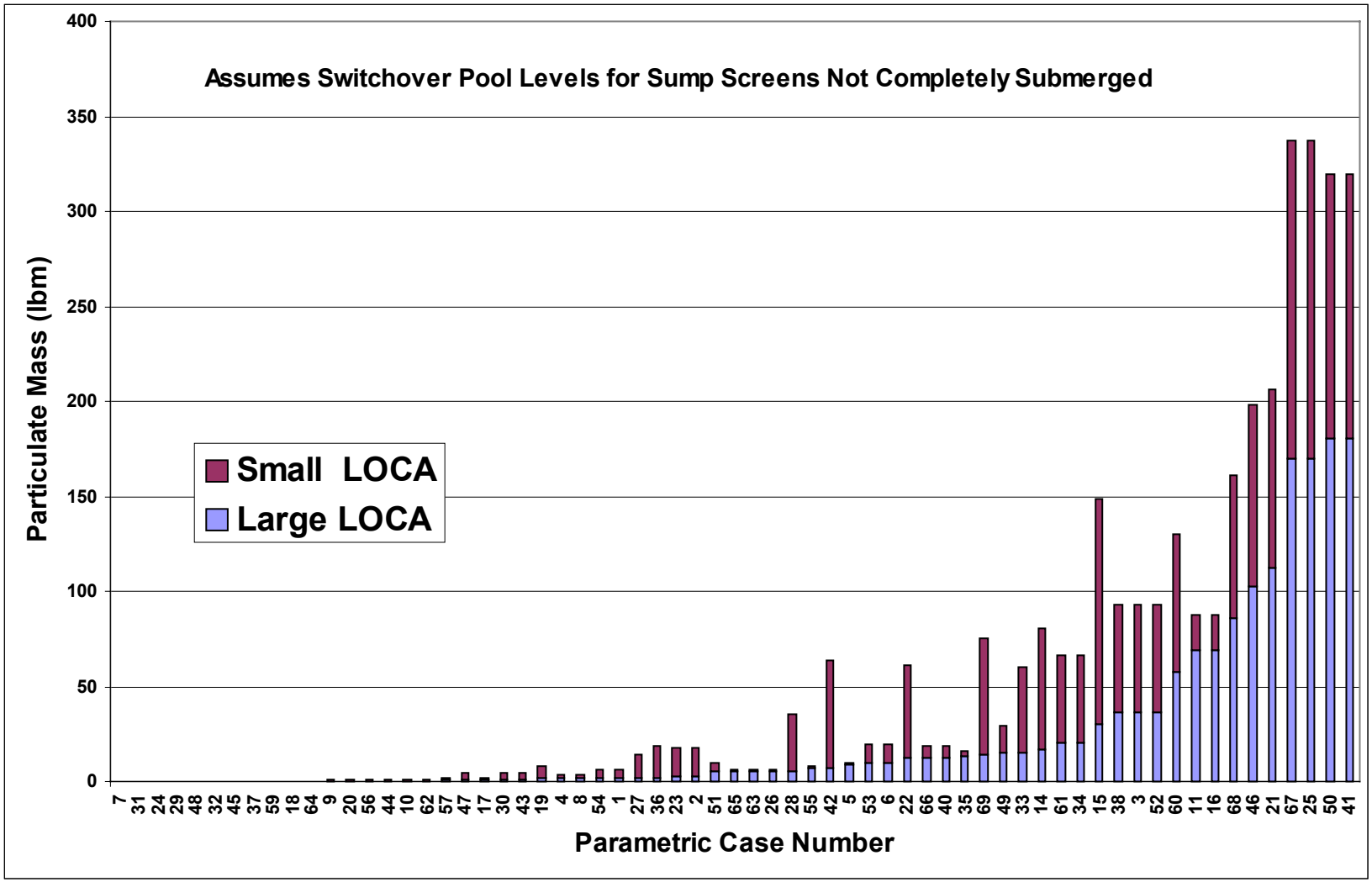
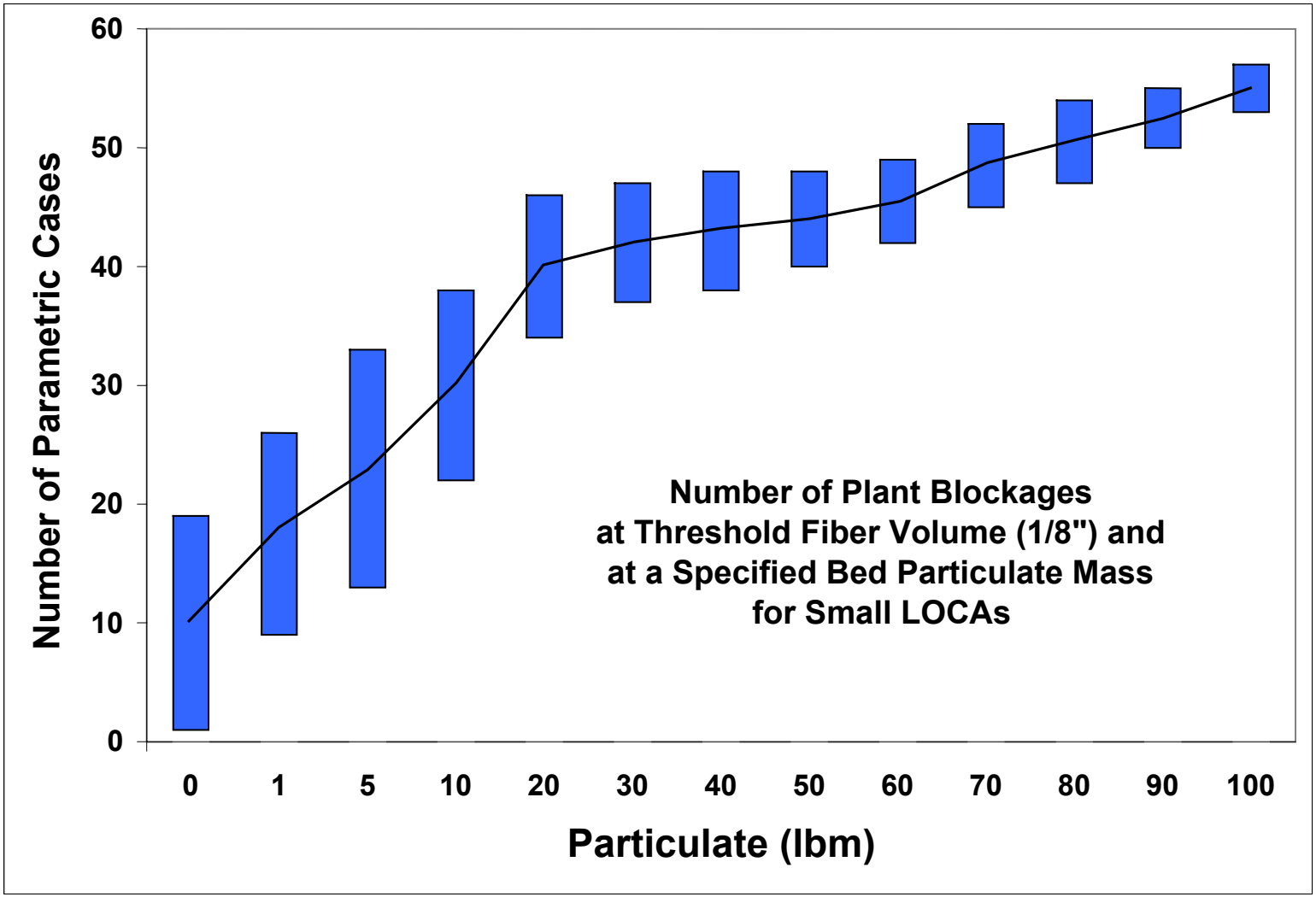
Threshold Fiber Volume (Case-By-Case)



Threshold Fiber Volume (Cumulative)



Threshold Particulate Mass



Threshold Particulate Mass (Cumulative)