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

Debris Transport and Accumulation

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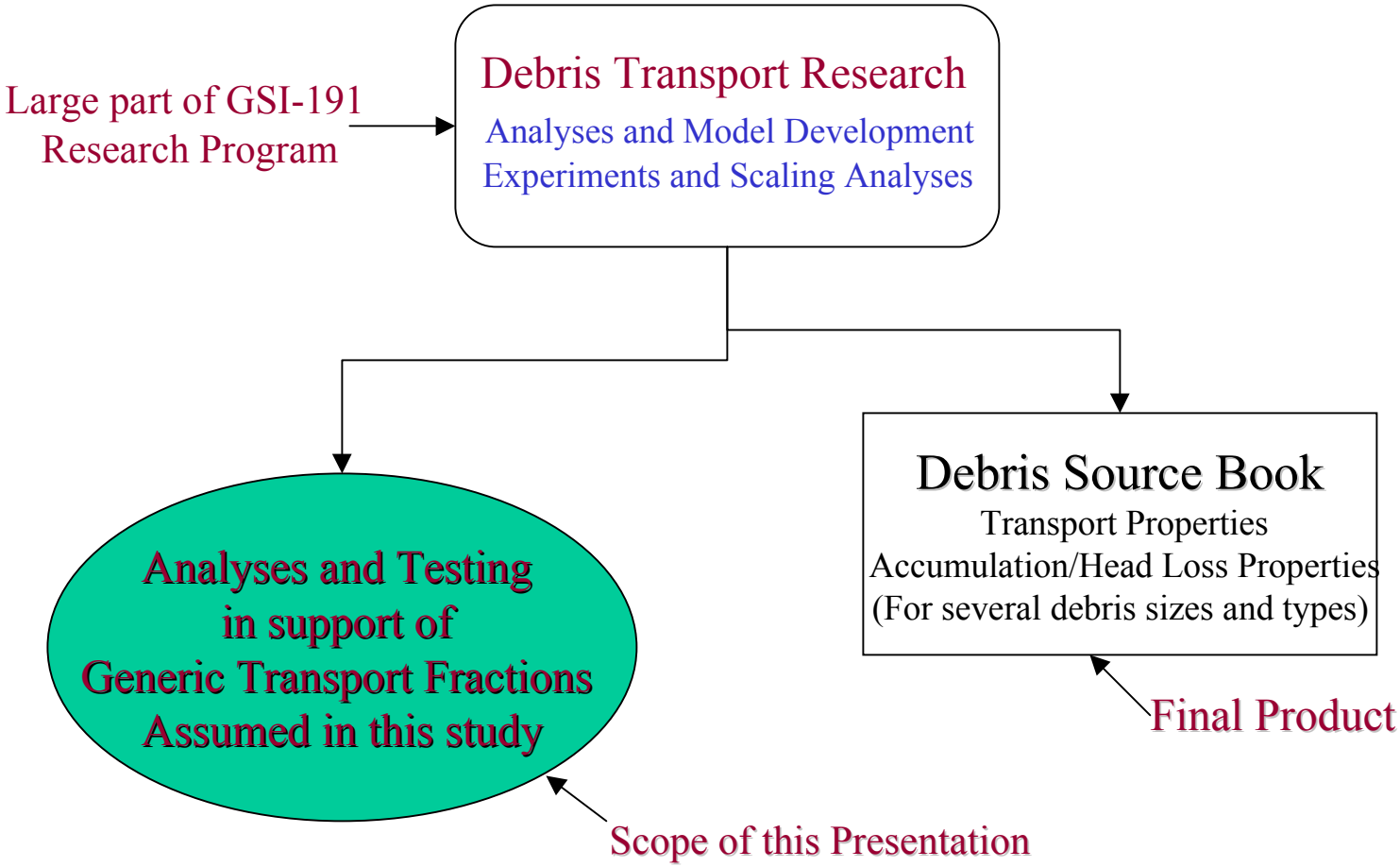


Presentation Outline

- Purpose of Debris Transport Analyses & Testing
- Information Sought
- Special Technical Considerations
- Debris Transport Methodology
- Scope of Testing In Support of Parametric Analyses
- Results of Testing Program (A. Maji)
- Use of Results in the Parametric Analyses
- Predicted Values for Range of Debris

Purpose of Debris Transport Analyses

- Step ❶ Provided Minimum Debris Necessary to Cause Sump Screen Blockage (Threshold Values)
  - Need to confirm Basic Assumption: (a) Uniform 1/8-inch thick beds would form on the screen surface and filter out particulate debris passing through it and those beds can survive significant head losses across them, and (b) Buildup of such beds is possible even for screen mesh clearance size of 1/4-inch.
- Step ❷ Provided "Generic" and "Case-Extrapolated" Values for the quantity of fibrous debris in the ZOI
- Present transport testing and analyses address the following questions:
  - What is the minimum transport fraction necessary to induce sump blockage? How do these minimum transport fractions compare with the range of expected transport fractions?

    Min. Transport Fraction = (Threshold Debris Volume)/(Debris Volume in ZOI)
  - For each case evaluated, what is "range of expected debris volumes"? How do they compare with threshold values

Information Sought

- Debris Accumulation and Head Loss Characteristics of 'Loosely attached fibers' and small shreds
  - Studied in the reconfigured linear flume.

- Generic transport fractions for small shreds
  - Derived interpreting test data and computer simulations
    - » Linear Flume Test Data (Debris transport characteristics)
    - » 3-D Tank Setup (Range of Floor Transport Fractions)
    - » Computer Simulations

- The focus is to obtain 'plausible' transport fraction range for fibrous debris. Not the best-estimate values

Technical Considerations

- Only debris of present interest is fibrous debris (surrogates LDFG and Fine Fiber used in present testing)

- Linear flume testing demonstrated the following
  - Large Debris initially float for up to 30 minutes. While afloat they can be transported by even small fluid velocities. After they sink very high velocities would be needed to move them. Their transport is very plant specific and must address issues such as switchover time and screen orientation.
  - Small shreds can be transported at velocities as low as 0.1 ft/s (loosely attached fibers at 0.05 ft/s). Their settling velocities are lower and small levels of turbulence can keep them in suspension for prolonged periods of time (in 3-D tank tests debris transport occurred for several hours). They are susceptible for further destruction. Their transport can be treated generically

- Present analyses made the following assumptions
  - Large debris do not contribute towards screen blockage. A very favorable assumption. Assumption made to simplify parametric analyses
  - Pursue tests and analyses to address transport and accumulation characteristics of small shreds and loosely attached fibers.

Debris Transport Phenomenology

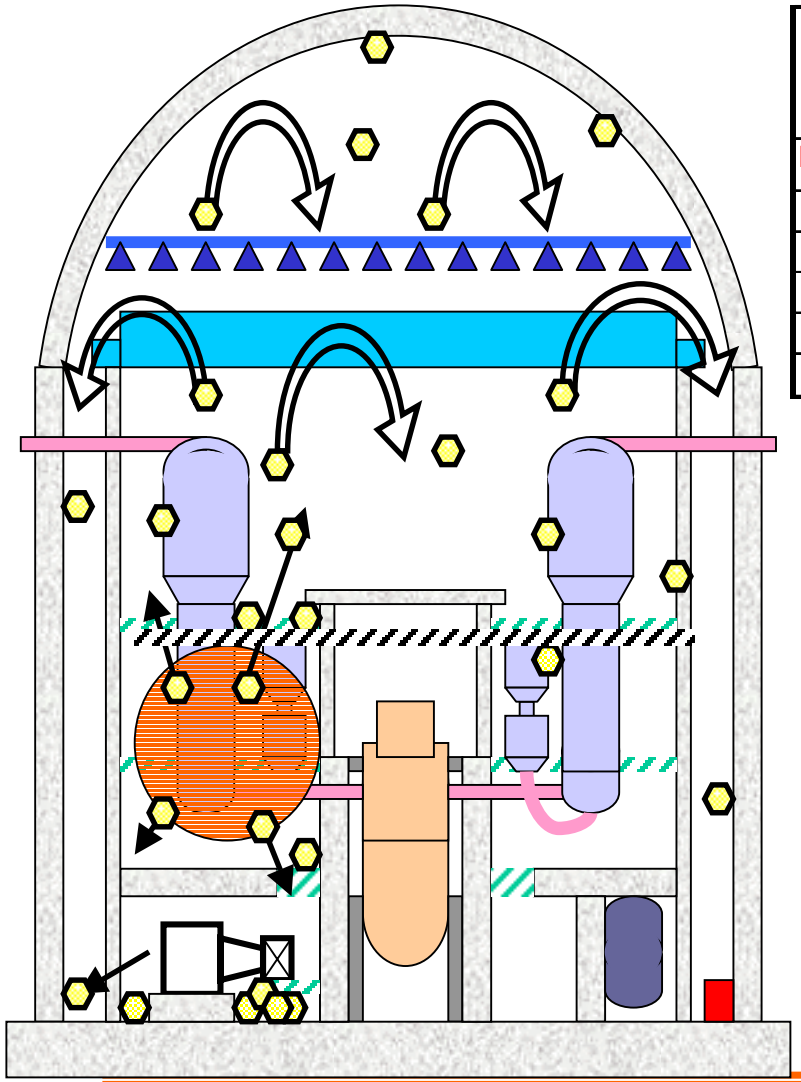
0 -1 sec	Blowdown	Injection	> t_{recirc}
Debris Generation →	Transport in Air →	Short-Term Transport →	Long-Term Transport
Large Debris	Liquid& Vapor Phase	ECCS+Spray Rate	Recirc. Flow Rate
Small Debris	Steam Flow Patterns	Washdn. and Erosion	3-D Flow Rates
	To Upper Containment	Non Directed Flow	Containment Layout
	To Inactive Sumps	Residual Turbulence	Turbulence Levels
Testing of Insulations	Primary Tools • MELCOR/CONTAIN • Parametric Analyses Outcome • Location and fraction of debris. • Boundary conditions for the later parts	Primary Tools • Experiments • FLOW-3D Outcome • Location and fraction of debris at t_{recirc}. • Boundary conditions for the later parts	Primary Tools • Experiments • FLOW-3D • Parametric Analyses Outcome • Fraction of debris at sump screen

Debris Transport Methodology

ZOI Inventory	Debris Size	Blowdown	Wash-down	Water Transport
				Upper
			Spray On	
				Lower
		Steam/Cont.		
				Upper
	Small		Spray Off	
				Lower
				Upper
		Water/Pool		Lower
				Upper
				Lower
	Large	Assumed Not Transported (Favorable)		

- ZOI Inventory
  - Debris Generation Modeling discussed already
- Debris Size
  - BWR URG used air jet data to estimate fraction of "fines"
  - Two-phase jets exhibit more severe destruction
- Blowdown Transport
  - Fraction entrained by steam (mist) flow across the containment
  - Fraction deposited into pool stays in the pool
- Washdown Transport
  - Primary Means sprays
- Water Transport
  - Focus of testing and analyses

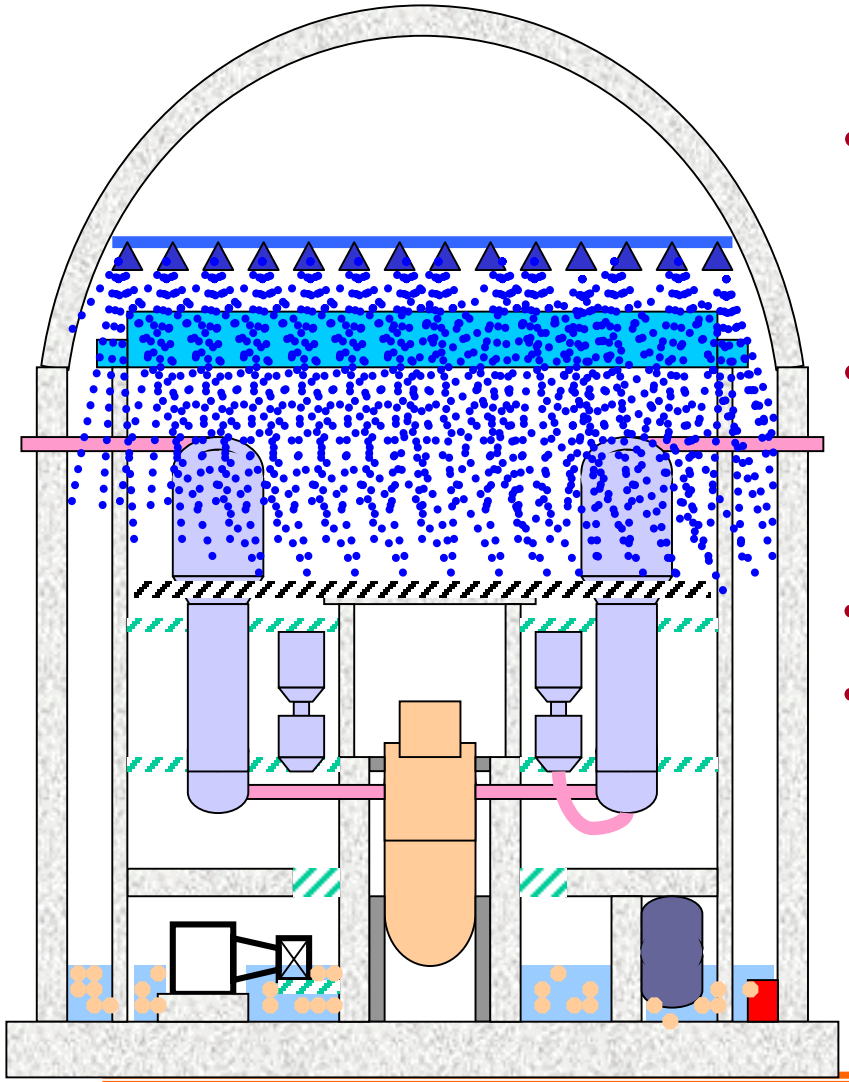
Blowdown Debris Transport: Large Dry



Time (sec)	Containment Pressure (psi)	Containment Temperature (oF)	Humidity (%)
PWR Containment Conditions			
0	15	95	40-100
25	45	300	100
300	37.5	225	100
1 hrs	17.5	150	80
6 hrs	17.5	150	80

- Flow has no dominant direction
  - Velocities > 30 ft/s away from the break location into upper and lower containment and annulus
  - String eddies in the open area; turbulence
- Small debris would be distributed through out the containment
- Large debris either on floor or gratings
- All distribution done in < 30 sec

Cont Spray Washdown: Large Dry



- Containment Sprays Introduce Water
  - In excess of 8000 GPM
  - Form Liquid Films few mm thick
- Small debris would be washed down
  - Experimental evidence
  - Simple Scoping Calculations Confirm
- Break Flow Erodes Debris right Beneath
- Debris in the Floor Pool

Within 10-20 min all debris would be in the Pool

Debris Transport Evaluations: LLOCA

ZOI Inventory	Debris Size	Blowdown	Wash-down	Water Transport
			0.75	Upper
			Spray On	
		0.6		Lower
		Steam/Cont.		
	0.4		0.05	Upper
	Small		Spray Off	
				Lower
1.0				
		Water/Pool		Upper
		0.4		
				Lower
	0.6			
	Large	Assumed Not Transported (Favorable)		

Note: Analyses used best available models. Nevertheless engineering judgement is a major component of these estimates. Sensitivity analyses demonstrate that overall outcome would not change even if individual values are changed by ± 25%

- Debris Size
  - Based on data it is assumed that 40% of the debris would be in the form of small debris
  - Even if this fraction is set to 30% as per BWROG URG the results would not change significantly
- Blowdown Transport
  - Fraction entrained by steam (mist) is assumed to be 60%
  - MELCOR analyses show that this fraction distributes throughout the containment.
- Washdown Transport
  - Primary Means sprays. Film drainage models in MELCOR were used for ice-condenser. Similar models are being developed for Large-Dry
  - Transport fraction of 75% is a reasonable estimate.

Debris Transport Evaluations: SLOCA

ZOI Inventory	Debris Size	Blowdown	Wash-down	Water Transport
			0.75	Upper
			Spray On	
		0.25		Lower
		Steam/Cont.		
	0.4		0.05	Upper
	Small		Spray Off	
				Lower
				Upper
			1.0	
		Water/Pool		Lower
		0.75		
				Upper
			1.0	
				Lower
	0.6			
	Large	Assumed Not Transported (Favorable)		

- Blowdown Transport
  - Fraction entrained by steam (mist) is assumed to be 25%
  - This assumption reflects the fact that 2-inch breaks do not induce very high vapor velocities (~ 4 ft/s). Debris is likely to fall down in close vicinity rather than being carried upwards
  - Higher water fraction implies debris would likely be wet at the time of generation and thus heavier

Note: Analyses used best available models. Nevertheless engineering judgement and sensitivity analyses are major components of these estimates.

Scope of Testing

- Use 3-D tank setup to measure transport fractions
  - Conduct tests at conditions judged to be representative of 'range of flow conditions expected to exist on the containment floor following a postulated LLOCA and SLOCA'

	Generic Plant	Tank Tests
Diameter	130 ft	13 ft
Water Height	5 ft	9-16 in.
LLOCA flow	> 10000 gpm	140-150 gpm
SLOCA	2750 - 10000	40 gpm

Tank testing parameters chosen to ensure that on an average flow conditions in the tank setup are less severe (lower horizontal velocities and lower turbulence levels) than conditions expected to exist in actual containments

  - Measure Transport fractions for extended periods of time

- Use Linear Flume to examine debris accumulation on vertical screen at a variety of approach velocities and debris loadings. Determine if analysis assumptions regarding accumulation is accurate

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Derivation of "Generic" Transport Fractions: LLOCA

ZOI Inventory	Debris Size	Blowdown	Wash-down	Water Transport		Sequence Fraction
				0.75		0.14
			0.75	Upper		
			Spray On	0.35		0.06
		0.6		Lower		
		Steam/Cont.		0.75		0.01
	0.4		0.05	Upper		
	Small		Spray Off	0.35		0.00
				Lower		
1.0				0.75		0.12
		Water/Pool		Upper		
		0.4		0.35		0.06
				Lower		
						0.00
	Large	Assumed Not Transported (Favorable Assumption)				
		Sprays	Favorable	Unfavorable		
		On	0.12	0.26		
		Off	0.06	0.13		

Basis for Water Transport

Favorable (0.35)

- On an average 35% of added debris was transported to the sump screen in 3-D tank tests within the first 15-30 minutes

Unfavorable (0.75)

- CFD simulations suggest that in many containments transport velocities would be much higher. A transport fraction of 75% chosen to reflect this finding
  - Net Recirc flow >> 10000 gpm in many plants

Derivation of "Generic" Transport Fractions: SLOCA

ZOI Inventory	Debris Size	Blowdown	Wash-down	Water Transport		Sequence Fraction
				0.65		0.05
			0.75	Upper		
			Spray On	0.25		0.02
		0.25		Lower		
		Steam/Cont.		0.35		0.00
	0.4		0.05	Upper		
	Small		Spray Off	0.15		0.00
				Lower		
1.0				0.65		0.20
				Upper		
				0.25		0.08
		Water/Pool		Lower		
		0.75		0.35		0.11
				Upper		
				0.15		0.05
				Lower		
						0.00
	Large	Assumed Not Transported (Favorable Assumption)				
		Sprays	**Favorable**	**Unfavorable**		
		On	0.09	0.24		
		Off	0.05	0.11		

Basis for Water Transport

Favorable (0.25 and 0.15)

- On an average 15% of added debris was transported to the sump screen in 3-D tank tests at 40 gpm. A value of 25% was used for conditions representative of HPSI (2750 gpm) and CS (4000 gpm)

Unfavorable (0.65 and 0.35)

- CFD simulations suggest that in many containments transport velocities would be much higher.
- Also in many cases location of generation can be very close to the sump (breaks can be in remote sump)

Net Transport Fraction

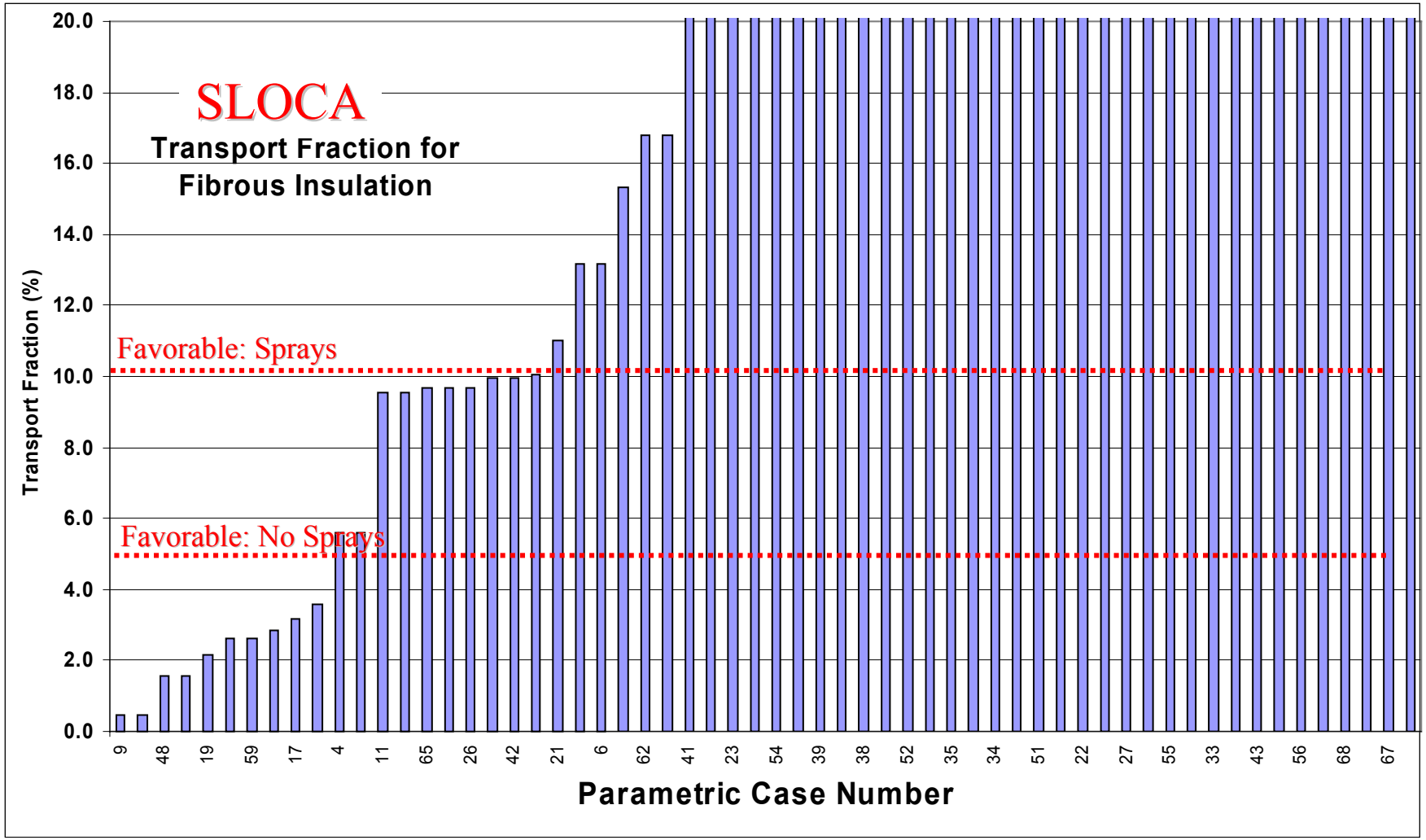
Transport Conditions	Favorable Transport Conditions	Unfavorable Transport Conditions
SLOCA with Sprays Inactive	5%	10%
SLOCA with Sprays Active All MLOCAs and LLOCAs where sprays would automatically activate	10%	25%

The remaining favorable assumptions include:

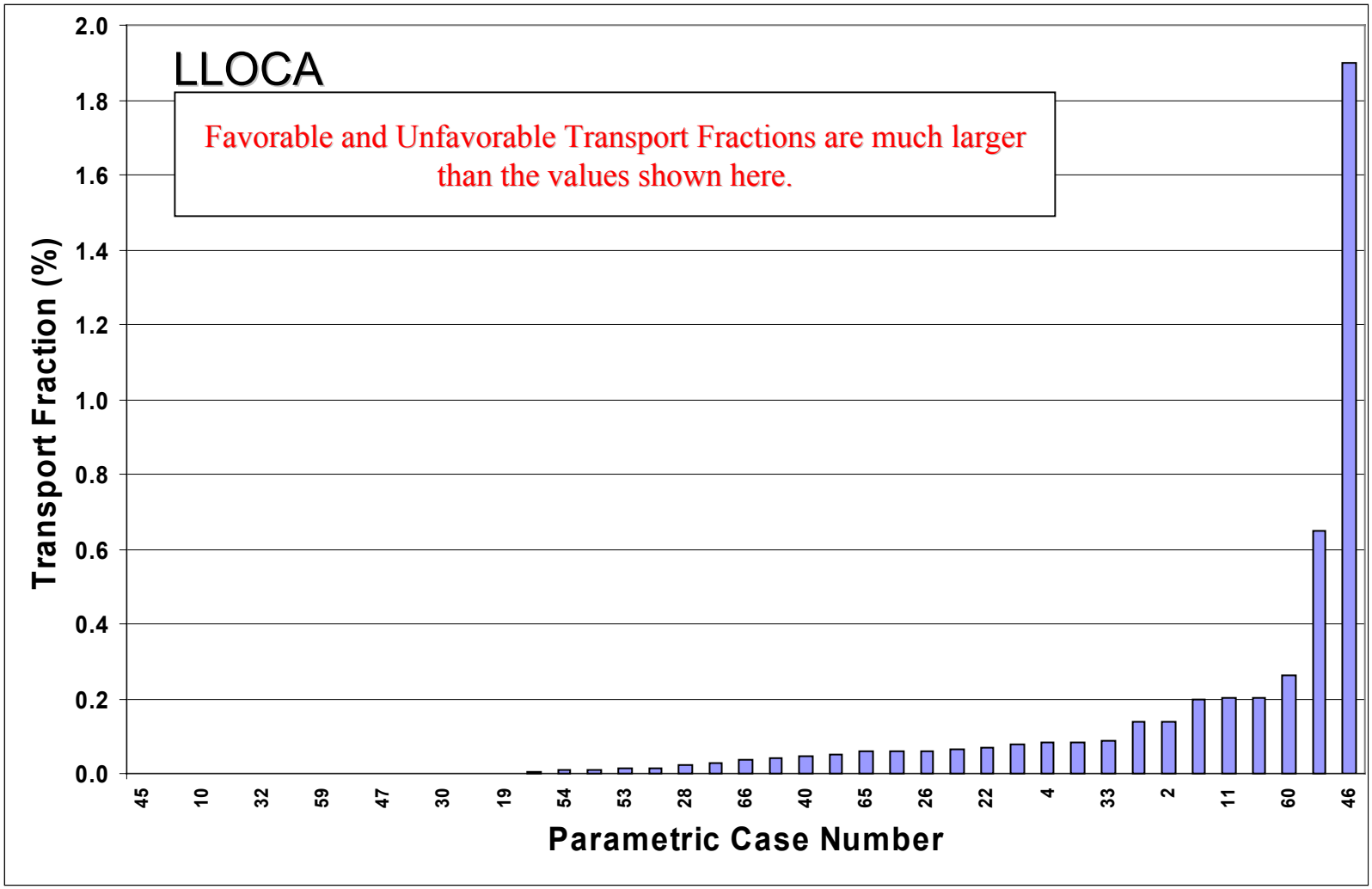
»Transport and accumulation of large debris not considered. This may be very important for exposed sumps and sumps with horizontal screens

»Erosion and corrosion mechanisms to degrade shreds and pieces not considered

Minimum Transport Fraction V. "Generic" Values

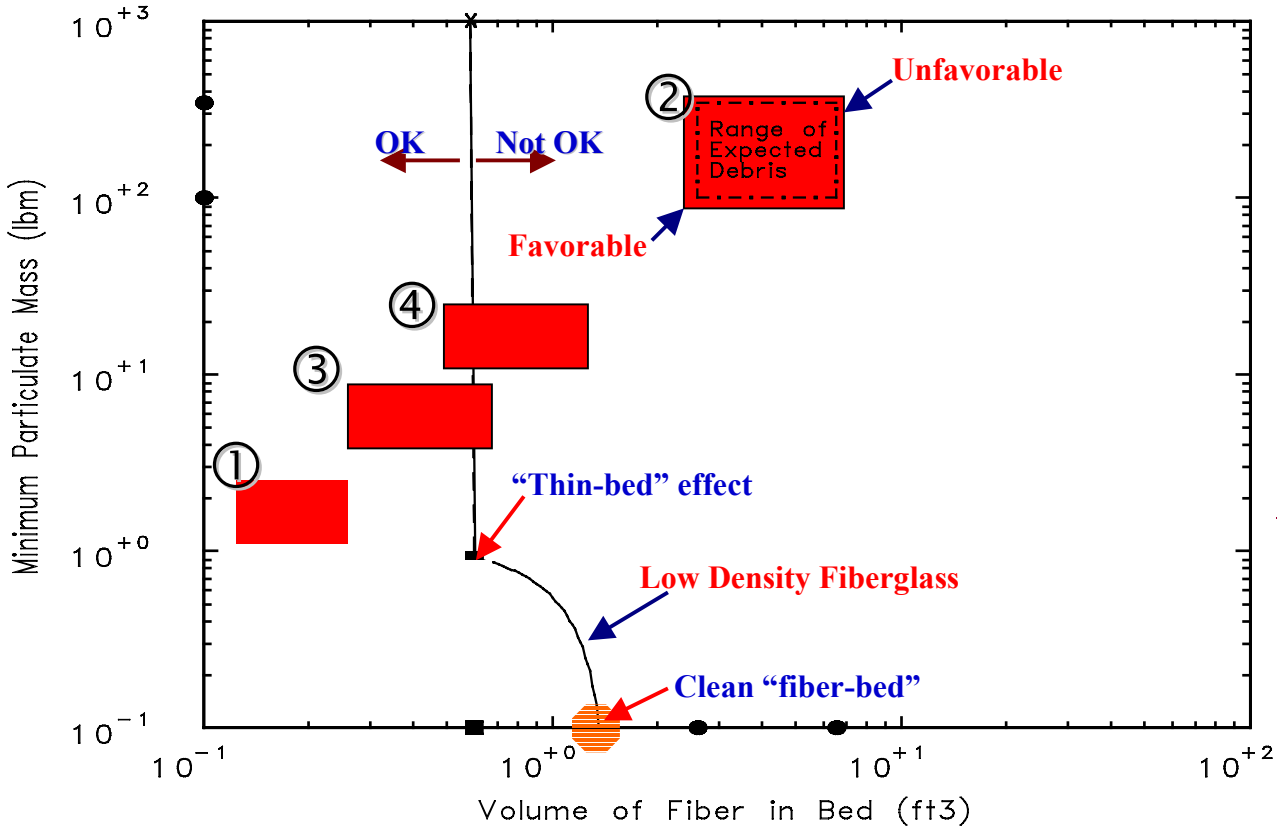


Minimum Transport Fraction V. "Generic" Values



Threshold Debris Loadings and Range of Expected Debris Loadings

Appendix-B provides case-by-base charts for each case



Criteria:

① Unlikely
② Very likely
③ Possible
④ Likely

Separate charts for

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