US NRC Assessment of Nuclear Power Plant ECCS Sump Performance

U. S. NRC
Commissioner Briefing
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REFERENCE PACKAGE

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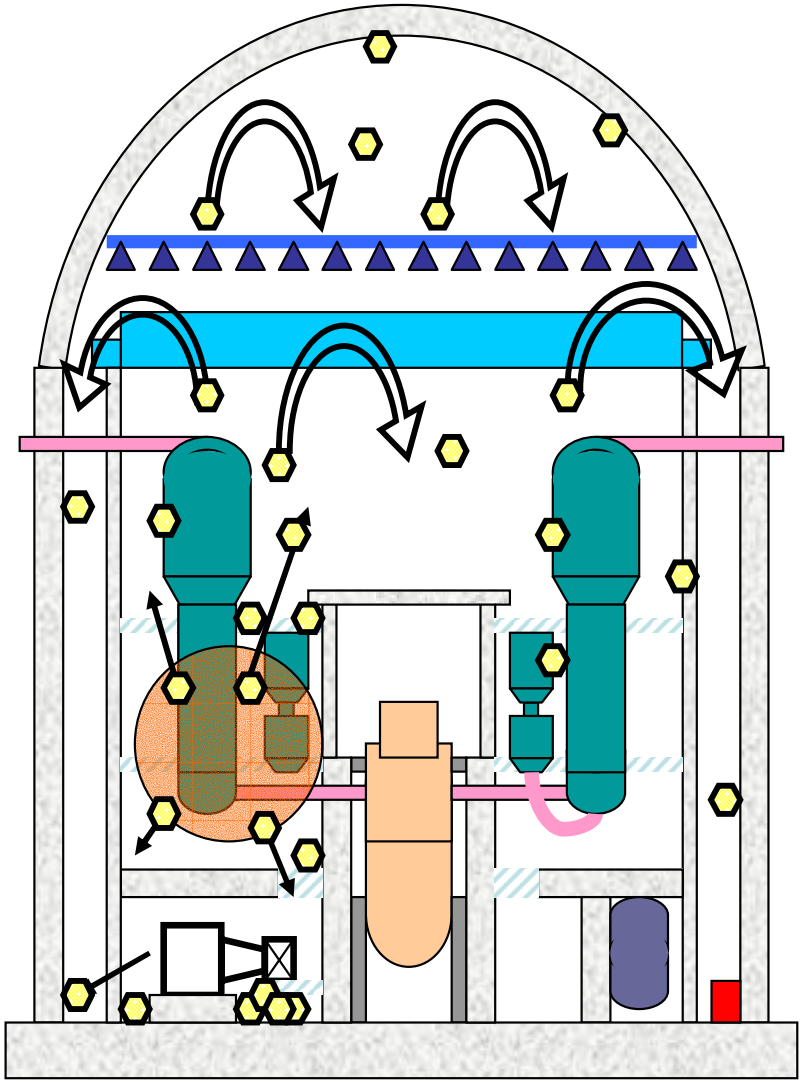
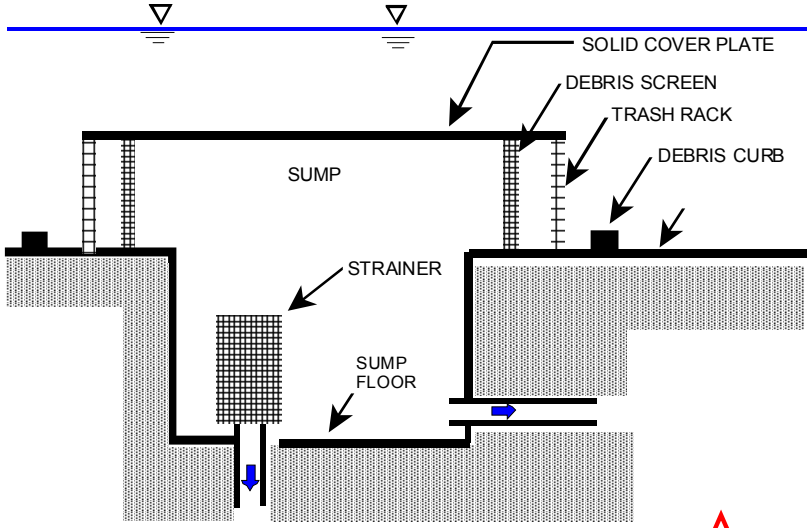
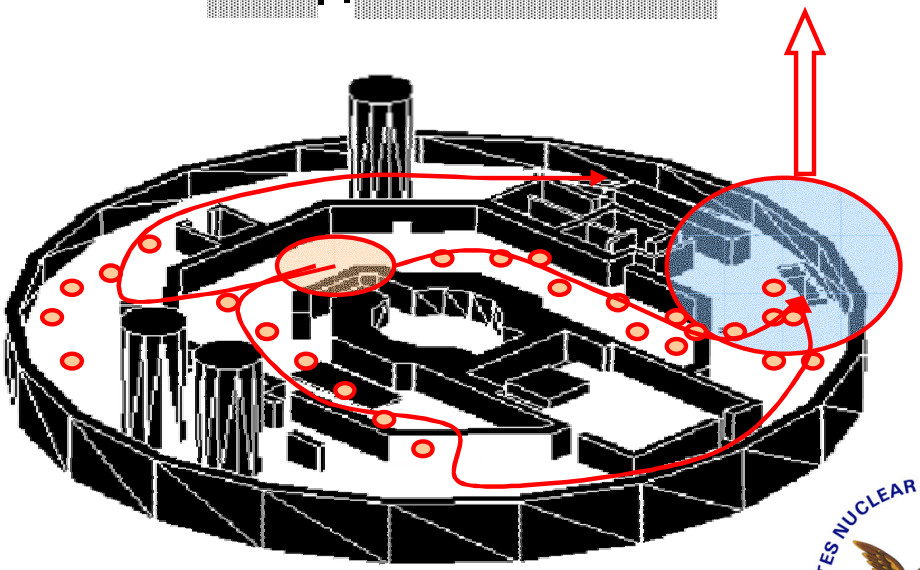
Opening Remarks







Contents

Information Requested:

- Issue History
- BWR issue/concerns/resolution
- PWR Background
- PWR Regulatory approach/basis
- Ongoing testing
- Policy issues
- Current status

Issue History

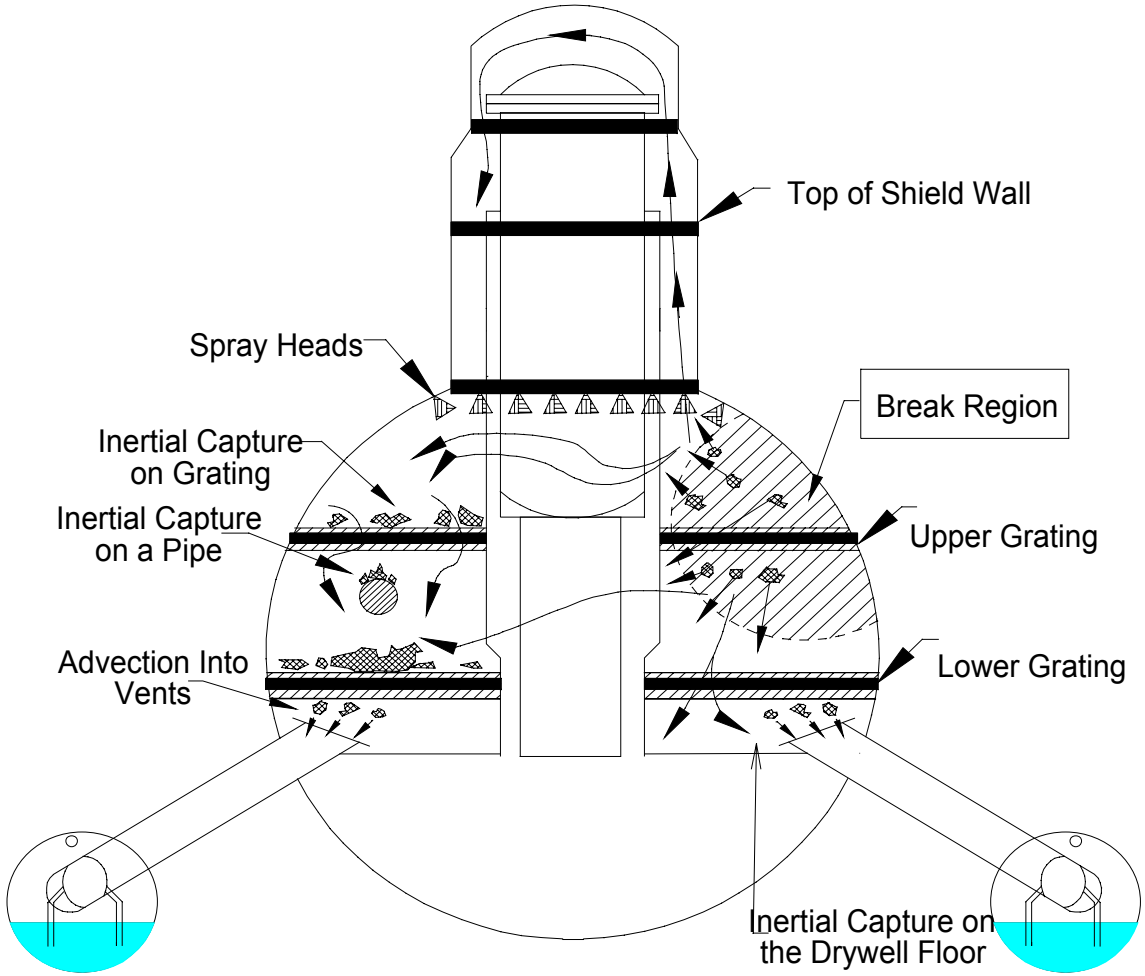
Regulatory Requirements For Core Cooling

- 10 CFR 50.46(b)(5), Long-term Cooling
- 10 CFR 50, Appendix A, Criterion 35, Emergency Core Cooling

Issue History

- USI A-43 issued in 1979 to address concerns with emergency suction strainer performance
  - closed in 1985 (GL 85-22 and RG 1.82, Revision 1)
  - Did not impose new regulatory requirements (no backfit)
  - Recommended replacing 50% sump blockage design assumption with a mechanistic assessment
- BWR events lead to Bulletins 93-02,95-02, and 96-03; request BWRs take action to ensure ECCS safety function
- GSI-191 established in 1996 to re-assess PWR sump performance due to BWR events and Research findings

BWR Issue/Concerns



A. Blowdown Phase

BWR Issue/Concerns

Table B-1 Mark I Large Liquid Break LOCA Sequence[1]

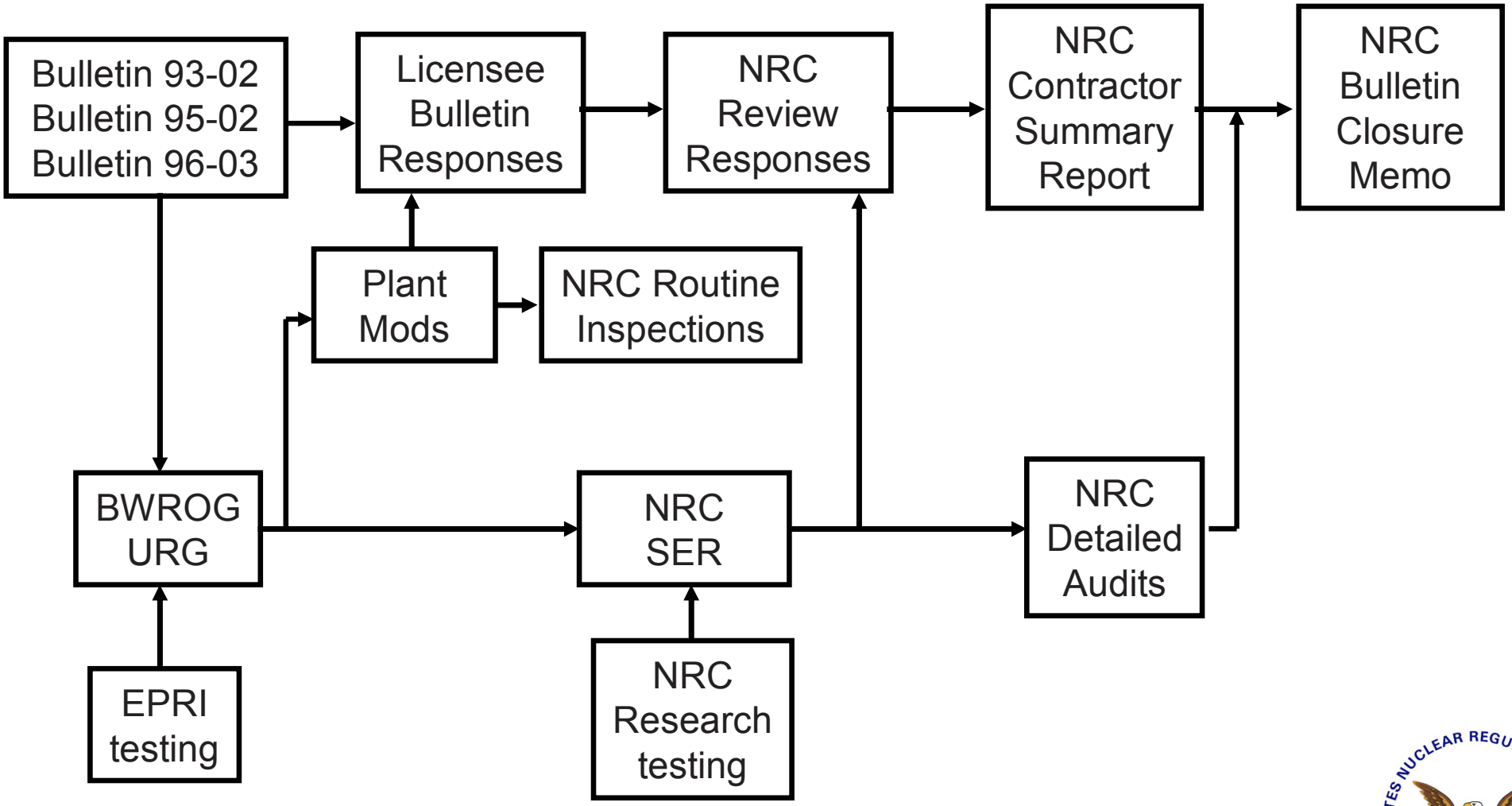
Time (sec)	HPCI[2]	LPCS	LPCI	RCIC[2]	Comments
0	Initiation	Initiation	Initiation		High Drywell LOCA Signal (2 psi)
5-7				Initiation	Low Water Level 2
5-10		Pump Start (312 gpm Min Flow BP)	Pump Start (1000 gpm Min Flow BP)		Offsite Power Available
15-25	Vessel Inj 2700 gpm				Constant Flowrate
20-30				Vessel Inj. 400 gpm	Constant Flowrate
~40[3]		Vessel Inj. 2350 gpm			Flowrate is a Function of Vessel Pressure
~45	Inj. Stops			Inj. Stops	Low Vessel Press
~50[3]			Vessel Inj. 13500 gpm		Flowrate is a Function of Vessel Pressure
~80		3000 gpm	15500 gpm		Design Flowrate

Notes:
(1) All the flows are for a generic plant.
(2) Initially take suction from condensate storage tank.
(3) For main steam line break LP ECCS injection 60-70 seconds.

BWR Issue/Concerns

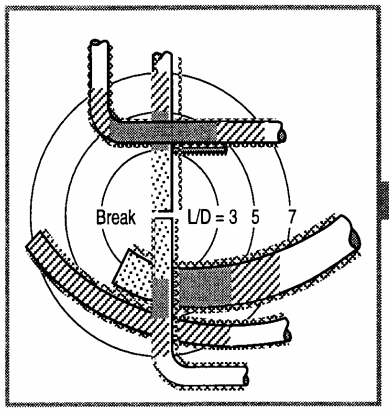
Accident Class	CDF Crediting Recirculation Core Cooling Available (1/yr)	CDF Not-Crediting Recirculation Core Cooling Available (1/yr)	Ratio of Not-Crediting to Crediting Recirculation Core Cooling Available
LOCA - Large	2E-07	2E-05	100
LOCA – Small & Medium	2E-06	3E-04	150
Transient	1E-05	4E-03	400
Station Blackout	1E-05	2.2E-5	2.2
ATWS	1E-06	2.3E-6	2.3
ISLOCA	2E-08	3E-08	1.5
Total	**2.3E-05**	**4.4E-03**	**190**

BWR Resolution

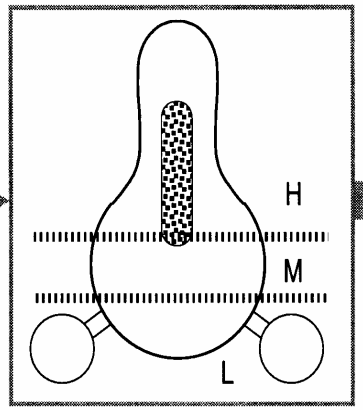


BWR Resolution Summary

DEBRIS GENERATION



DRYWELL LOCATION EFFECTS



SUPPRESSION POOL TRANSPORT

- Volume and size distribution of debris present (e.g., insulation, particulates, etc.)
- LOCA induced dynamics (e.g., chugging, blowdown)
- Debris transport (e.g., settling, turbulence)
- Transport to intake screen, cake buildup and particulate filtration

STRAINER FAILURE CRITERIA

- Head loss due to debris buildup
- Predicted head loss is greater than NPSH margin

DESTRUCTION FACTORS

L/D	Fraction
3	0.75
5	0.6
7	0.4

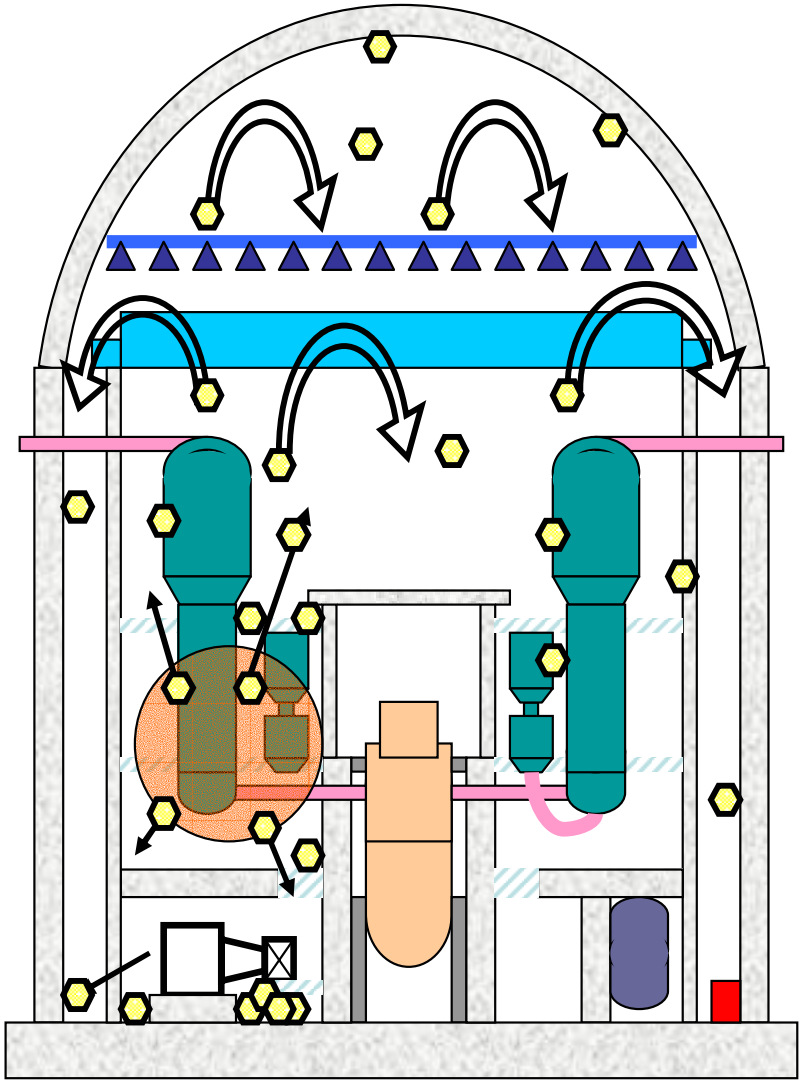
DRYWELL TRANSPORT FACTORS

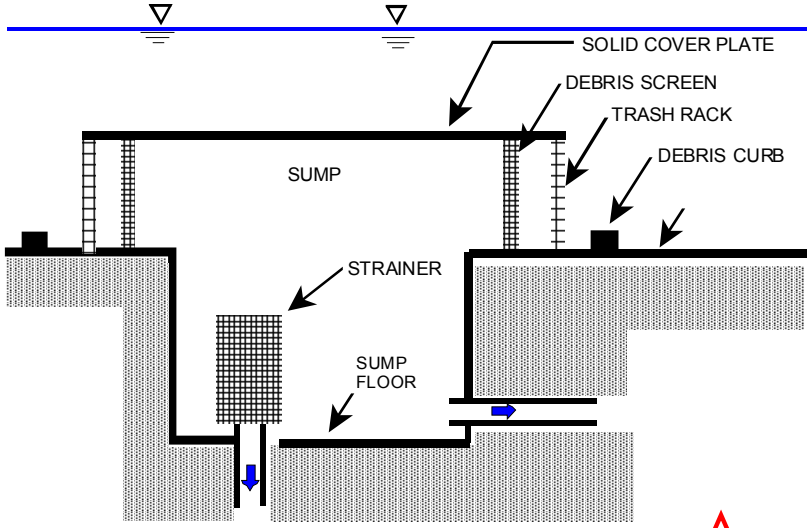
Region	Fraction
H	0.25
M	0.5
L	0.75

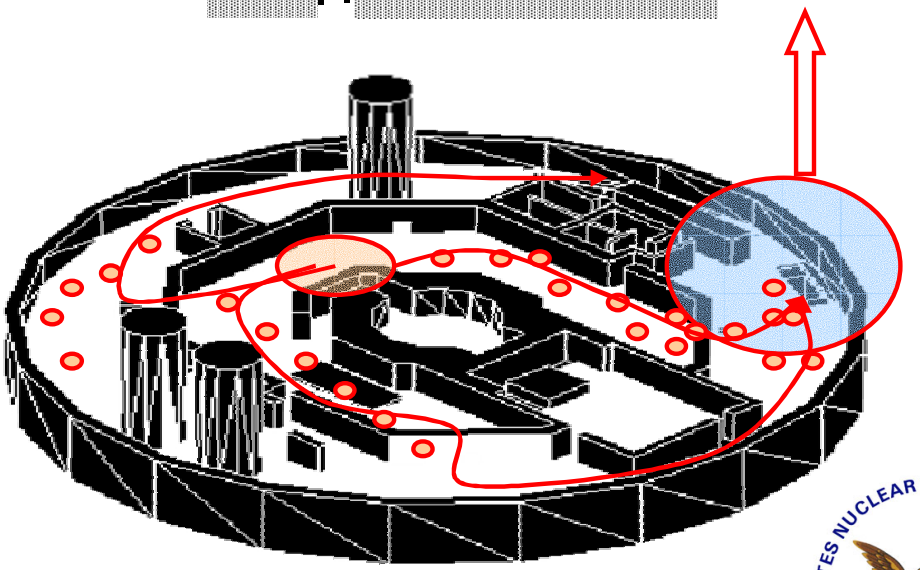
TERMINOLOGY

Destruction Factor:	Fraction of insulation assumed to be destroyed and transportable (i.e., fines and shreds) by the break jet.
Drywell Transport Factor:	Fraction of transportable debris that could travel from the drywell to the suppression pool due to a combination of blowdown and washdown.
Particulates:	Very small non-insulation debris that is generated during a LOCA (drywell particulates) or exists prior to a LOCA (sludge).

PWR Background
LB LOCA Description







PWR Background
LB LOCA Progression

NUREG/CR 6770 Table 10: CL DEGB - Large Dry Containment (MELCOR)									
Parameter	**Blowdown Phase**			**Injection Phase**			**Recirculation Phase**		
	0+	**20 s**	**45 s**	**45 s**	**15 min**	**27 min**	**27 min**	**2 h**	**24 h**
RCS pressure at break (psia)	2250	393	55						
RCS temperature at break (°F)	531	291	250	250	173	144	144		
Break flow velocity (ft/s)	296	930	100						
Break flow quality	0	0.25	0.3	0.3	0				
Safety injection (gpm)				11500	11500	11500			
Recirculation flow (gpm)							17500	11800	11800
Spray flow (gpm)				0	5700	5700	5700		
Containment pressure (psig)	0	36	33	33	11.5	7	7	1.5	0
Containment temperature (°F)	110	305	250	250	190	163	163	115	95
Pool depth (ft)					2	3.5	3.5	3.5	3.5
Pool temperature (°F)					212	187	187	125	100

PWR Background
Risk Insights

- Baseline:

  CDF = 3.3E-6/year (LOCA without debris accumulation being considered)
- Non-Plant Specific Estimate (Parametric Study):

  CDF = 1.5E-4/year (LOCA with debris accumulation)
- Operator Recovery Actions:

  CDF = 5E-6/year (LOCA with debris accumulation with operator recovery actions)

PWR Regulatory Approach/Basis

- Two Phase Approach
  - Bulletin 2003-01, “Potential Impact of Debris Blockage on Emergency Sump Recirculation at Pressurized Water Reactors” (Issued June 2003)
  - Generic Letter 2004-02, “Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized Water Reactors” (Issued September 2004)

PWR Regulatory Approach/Basis
Bulletin 2003-01

- Bulletin 2003-01
  - Informs licensees of the issue
  - Requests licensees to confirm compliance with 10 CFR 50.46(b)(5)
  - Evaluate/Implement Interim Compensatory Measures (ICM) to reduce risk
  - All Bulletin Responses have been reviewed, RAI's issued. 6 Close-out letters issued.

PWR Regulatory Approach/Basis
Bulletin 2003-01 (cont.)

Interim Compensatory Measures (ICM) to reduce risk:

- Operator training on indications and responses to sump clogging
- Delay switchover to recirculation
- Alternate water sources to refill RWST or for injection
- Aggressive containment cleaning or Foreign Material Control
- Ensuring containment drainage paths are unblocked
- Ensuring sump screens are free of adverse gaps and breaches
- Owner's Group recommended compensatory measures

PWR Regulatory Approach/Basis
Generic Letter 2004-02

- Action Requested
  - Plant specific evaluation using a mechanistic analysis to demonstrate compliance
  - Description and schedule of corrective actions and plant modifications (if required)
- Submittal Schedule
  - 90 day response (March 7, 2005) – planned actions and schedule to complete the evaluation
  - September 1, 2005 response – results of evaluations, modification schedules, licensing action requests
- Implementation Inspections (NRC Regions)

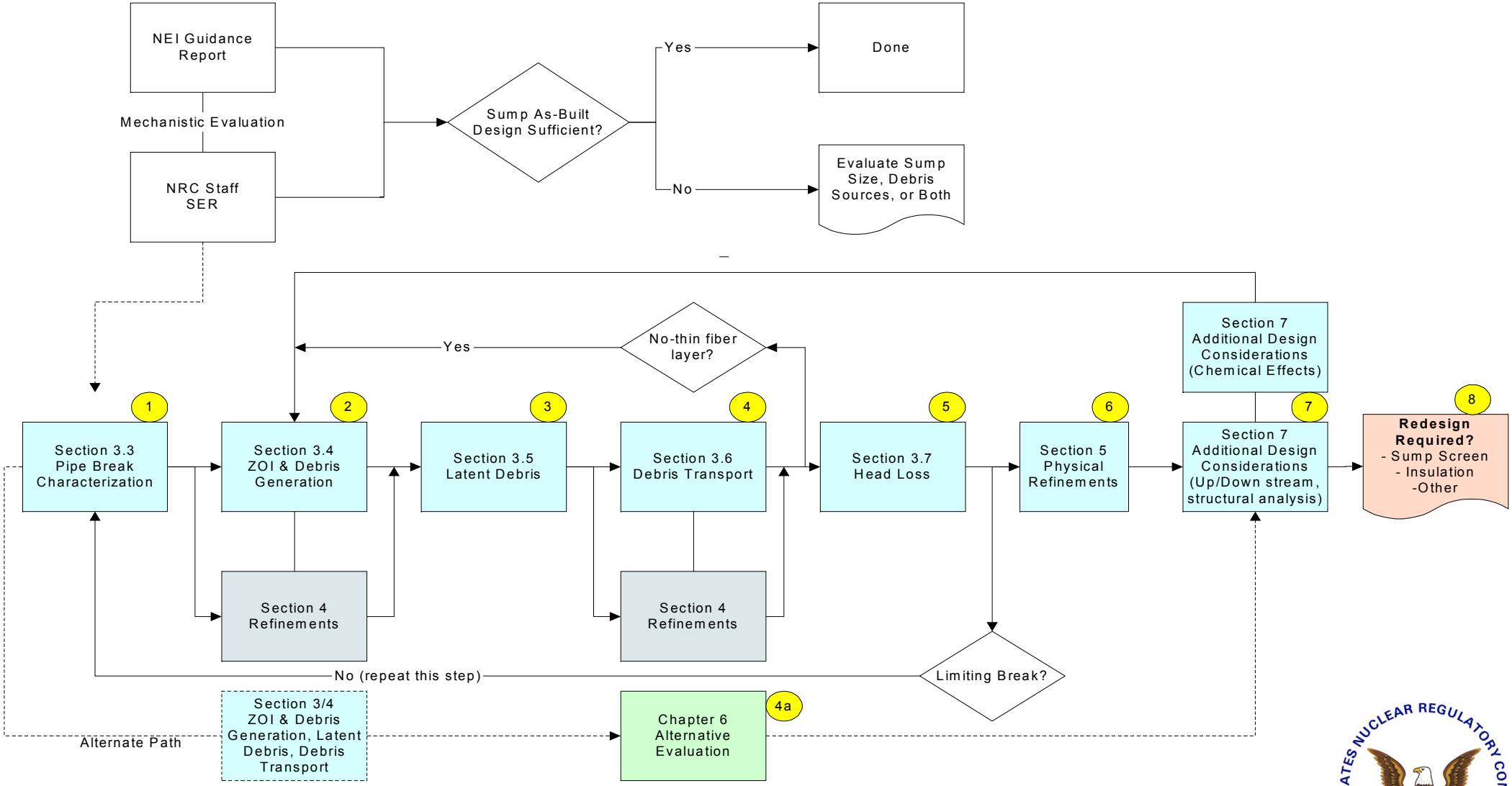
PWR Regulatory Approach/Basis
NRC Safety Evaluation (SE)

- Provides NRC approved methodology for evaluation of sump screen performance as required by GL 2004-02
- Covers ALL main topics
- Developed using NEI guidance with Staff evaluation and enhancement (SE)

PWR Regulatory Approach/Basis
NRC Safety Evaluation (Cont.)

- SE Development Included
  - Several public meetings with the staff beginning in 1997 to discuss GSI-191 resolution strategies and issues of concern
  - Independent research and work from NRR, RES and LANL
  - NEI's submittal of Guidance Report (GR) NEI 04-07, "PWR Containment Sump Evaluation Methodology (May 2004, July 2004)
- Staff Review Of The NEI 04-07 Submittal Concluded
  - Portions of the proposed guidance report were acceptable and technically justified, and
  - Some portions needed additional supplementation because the methods did not contain sufficient guidance, supporting data, or analysis to justify their technical basis. For these areas, the staff has provided limitations, modifications, recommendations and/or alternative guidance to that offered in the GR.

PWR Regulatory Approach/Basis
Sump Evaluation Process



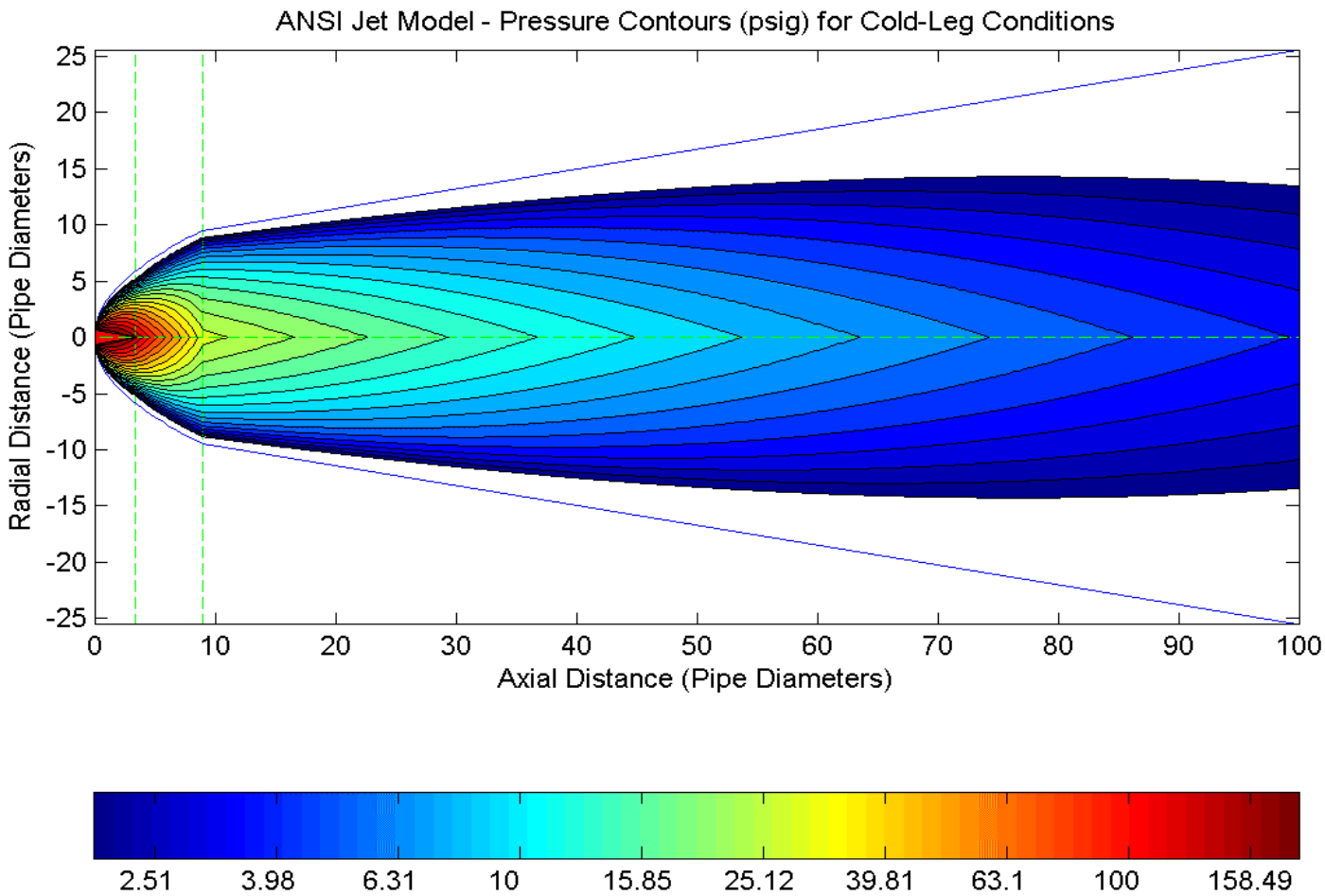
NRC SE Major Topics
Break Selection

- Limiting break location criterion – head loss across the sump screen
  - Maximum amount of debris transported
  - Worst combination of debris mixes transported
- Break size and piping system considerations
- Consider all phases of the accident scenario
- Issues for thin bed effect and calcium silicate behavior

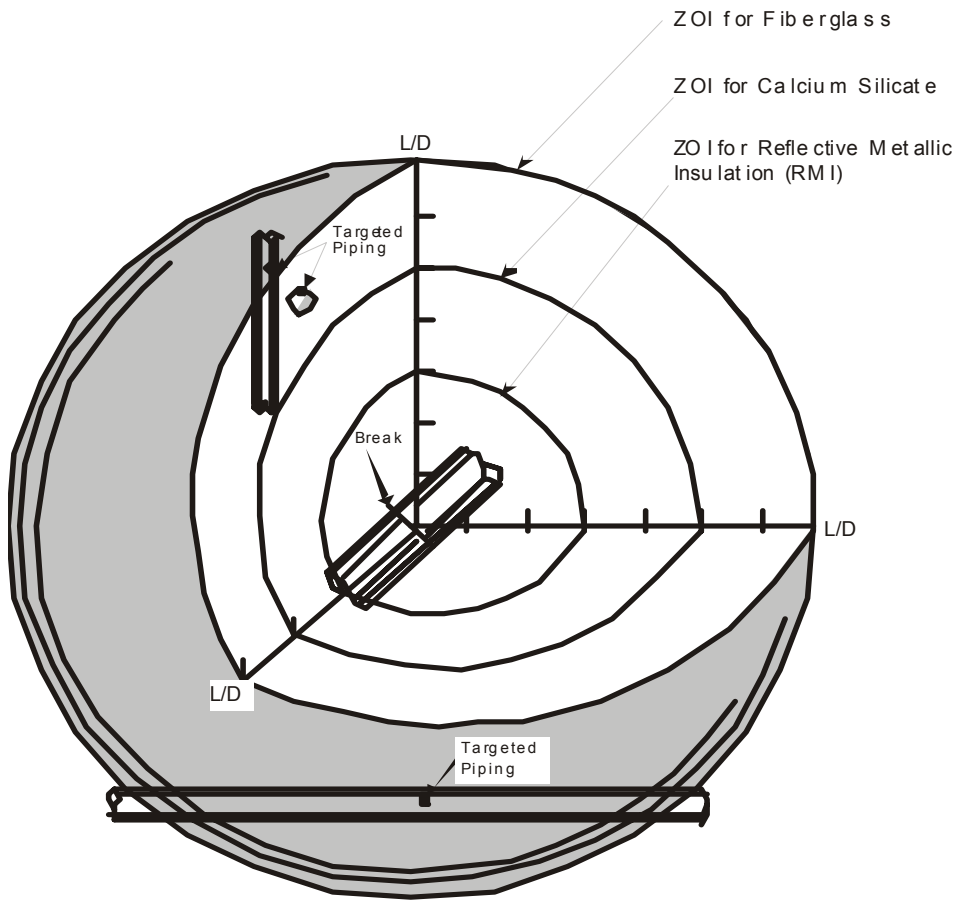
NRC SE Major Topics
Debris Generation / ZOI

- ZOI determined using ANSI/ANS 58.2 1988 free jet model
  - two freely expanding jets,
  - destruction pressures reduced by 40% to account for two phase jet effects
  - truncation allowed at robust barriers limits impact
- Use of debris specific destruction zones
- Debris characterized for transport & head loss input
  - Coatings considered special case
  - All other debris types

NRC SE Major Topics
Example: Debris Generation



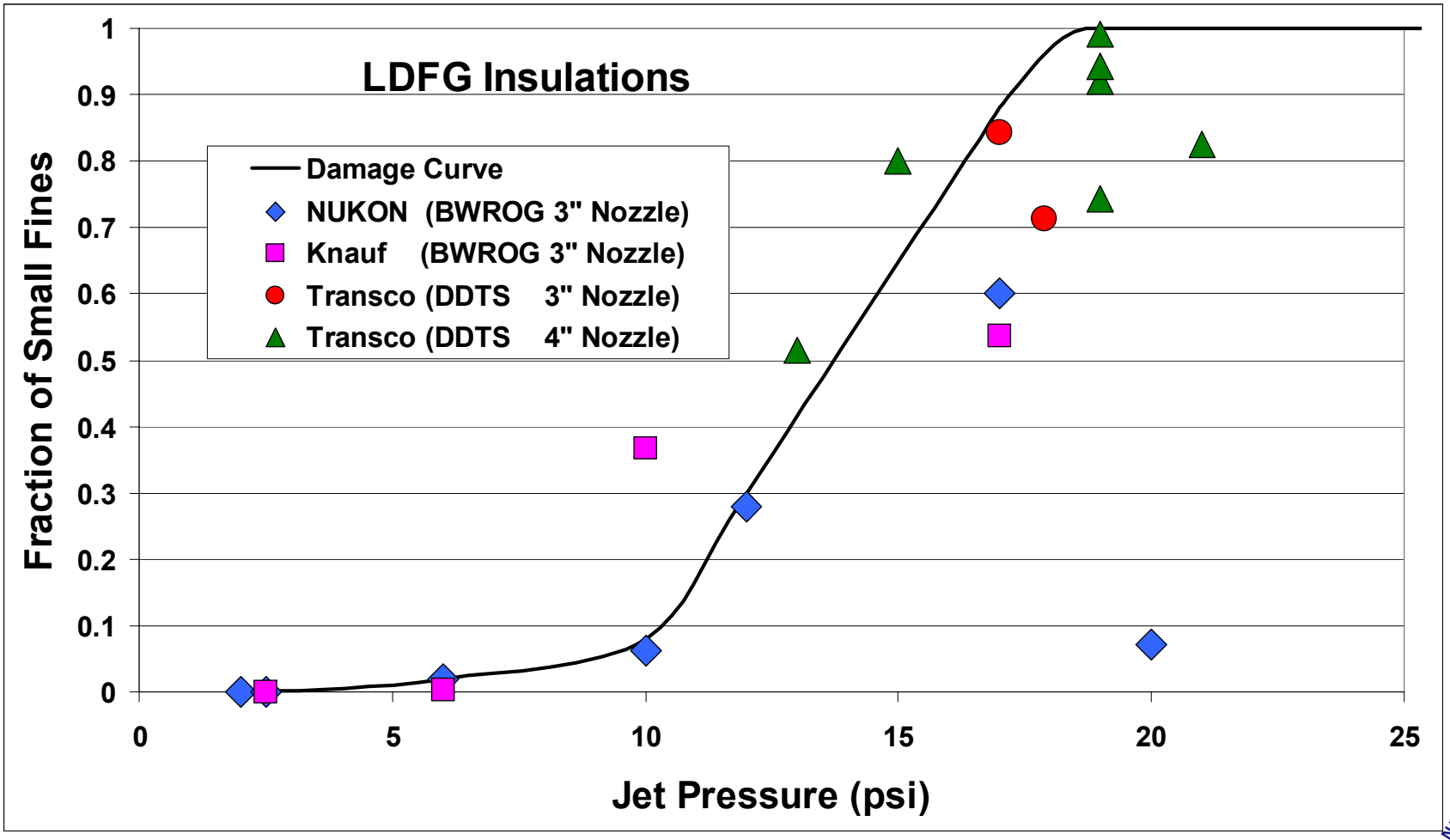
NRC SE Major Topics
Example: Debris Generation



Note:
L = Distance from break to target
D = Diameter of broken pipe

Pressure Equivalent Spherical ZOI

NRC SE Major Topics
Example: Debris Characterization

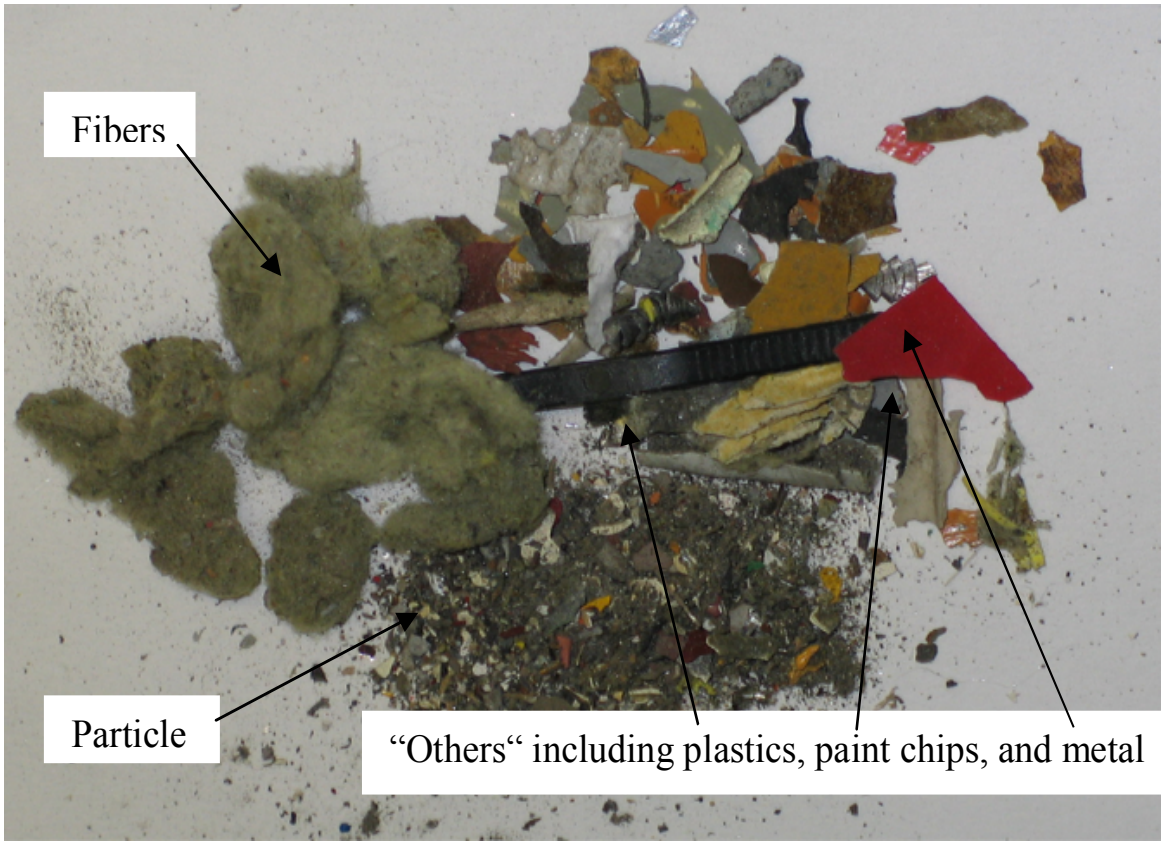


NRC SE Major Topics
Latent Debris

Latent Debris is defined as miscellaneous dirt, fiber, and foreign material found in containment

- Both physical characteristics and total inventory impact sump screen head loss
- For all RMI plants, latent debris may be the dominant contributor to formation of a thin bed
- Five steps for evaluating (estimate surface area, evaluate buildup, characterize debris, fractionalize surface area, calculate quantity)

NRC SE Major Topics
Example: Latent Debris Sample

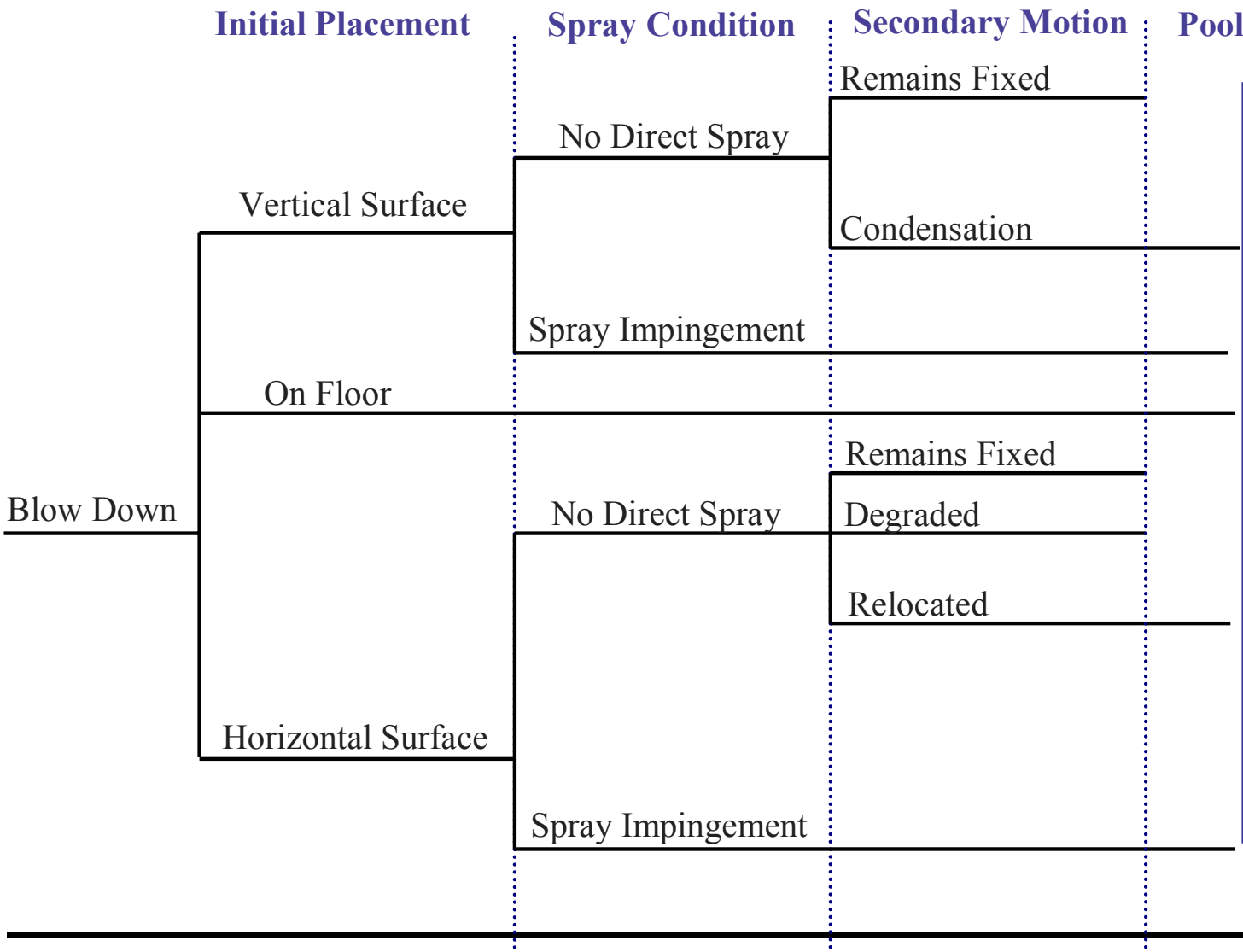


Representative Latent Debris Sample

NRC SE Major Topics
Debris Transport

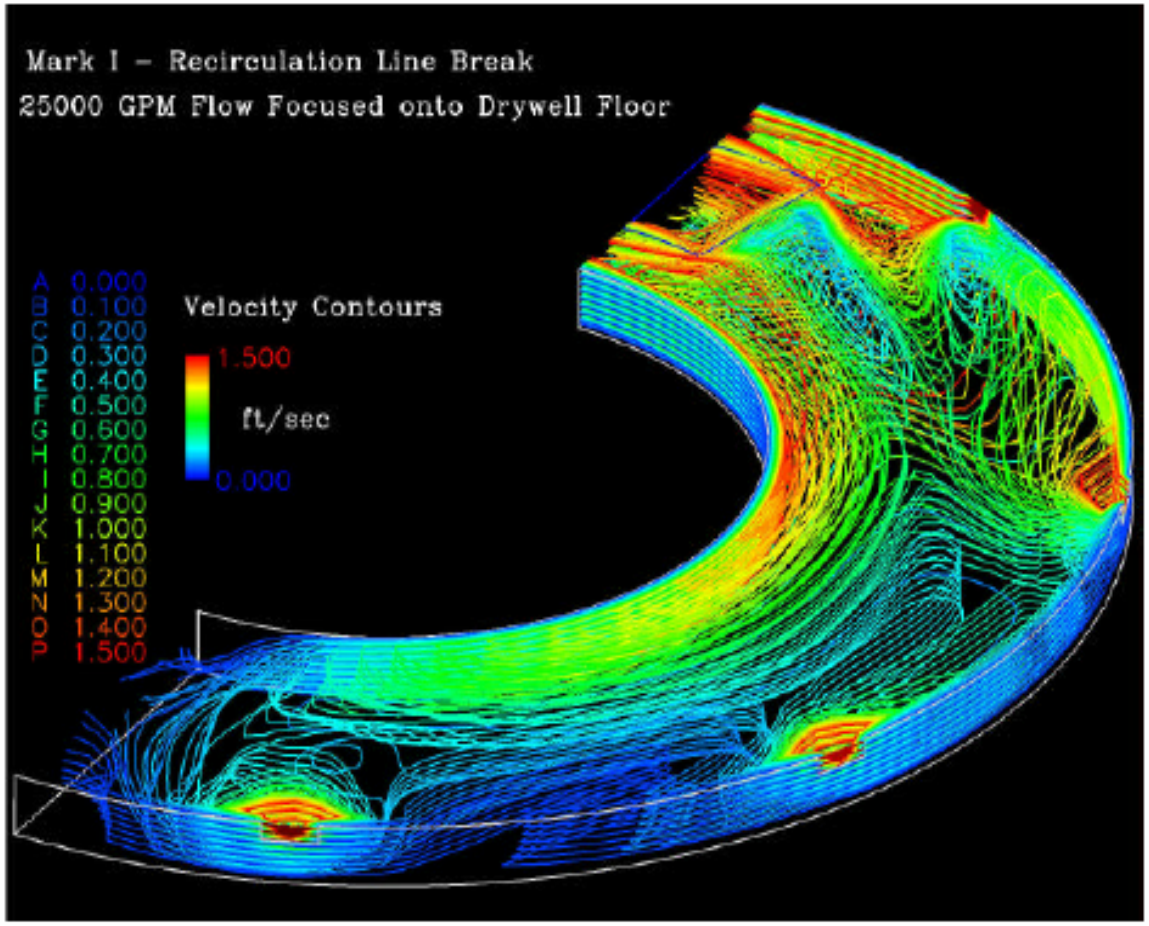
- Based on NUREG/CR-6762 logic tree
- Consider blowdown, washdown, pool fill, and pool recirculation
- Can use nodal network or CFD
- Small fines vs. Large pieces
- Active vs. Inactive pools

NRC SE Major Topics
Debris Transport



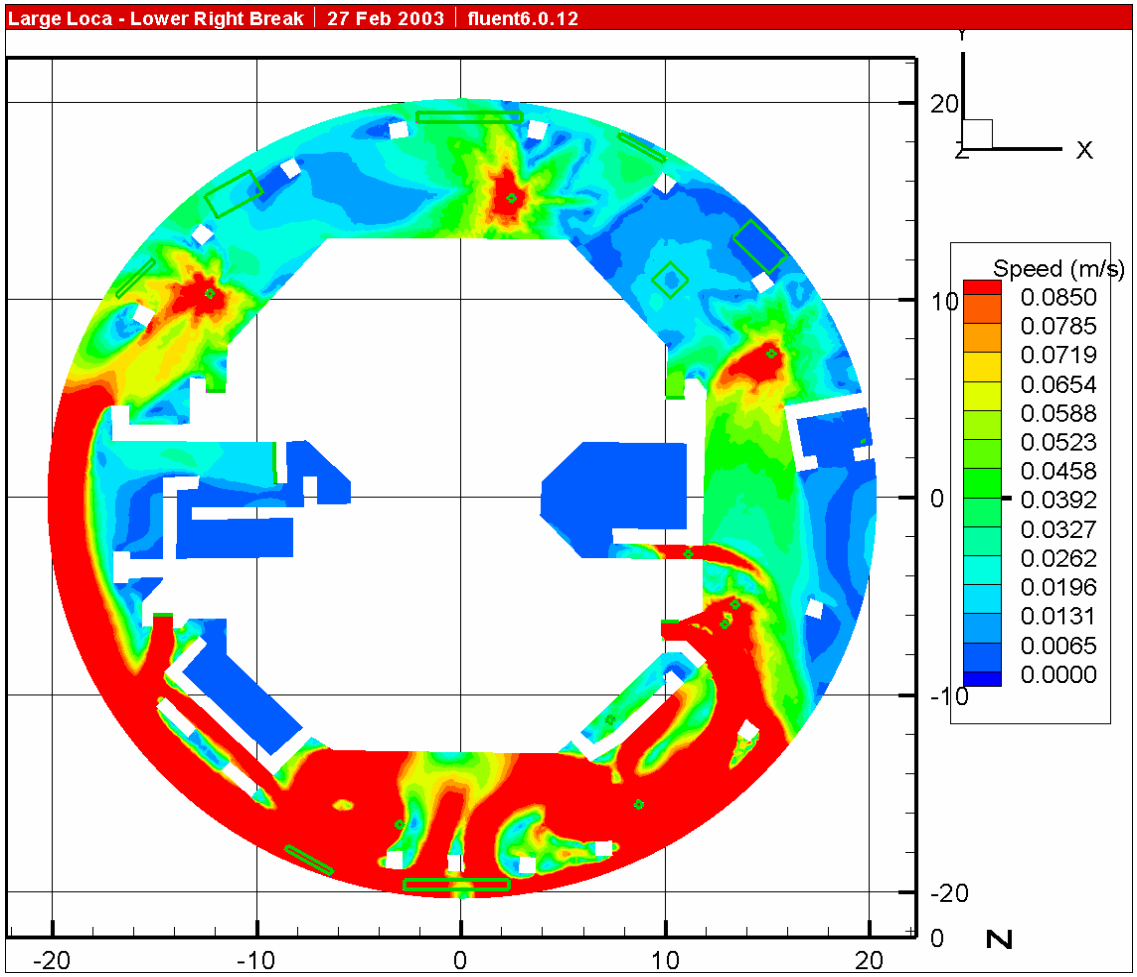
- Logic charts for each debris type and size
- Use different tools for each phase of transport
- Engineering judgment and simple calculations used to quantify branches
- Demonstrates systematic and traceable approach to vulnerability assessment
- Degree of conservatism can be compared to plausibility of physical mechanisms

NRC SE Major Topics
Debris Transport



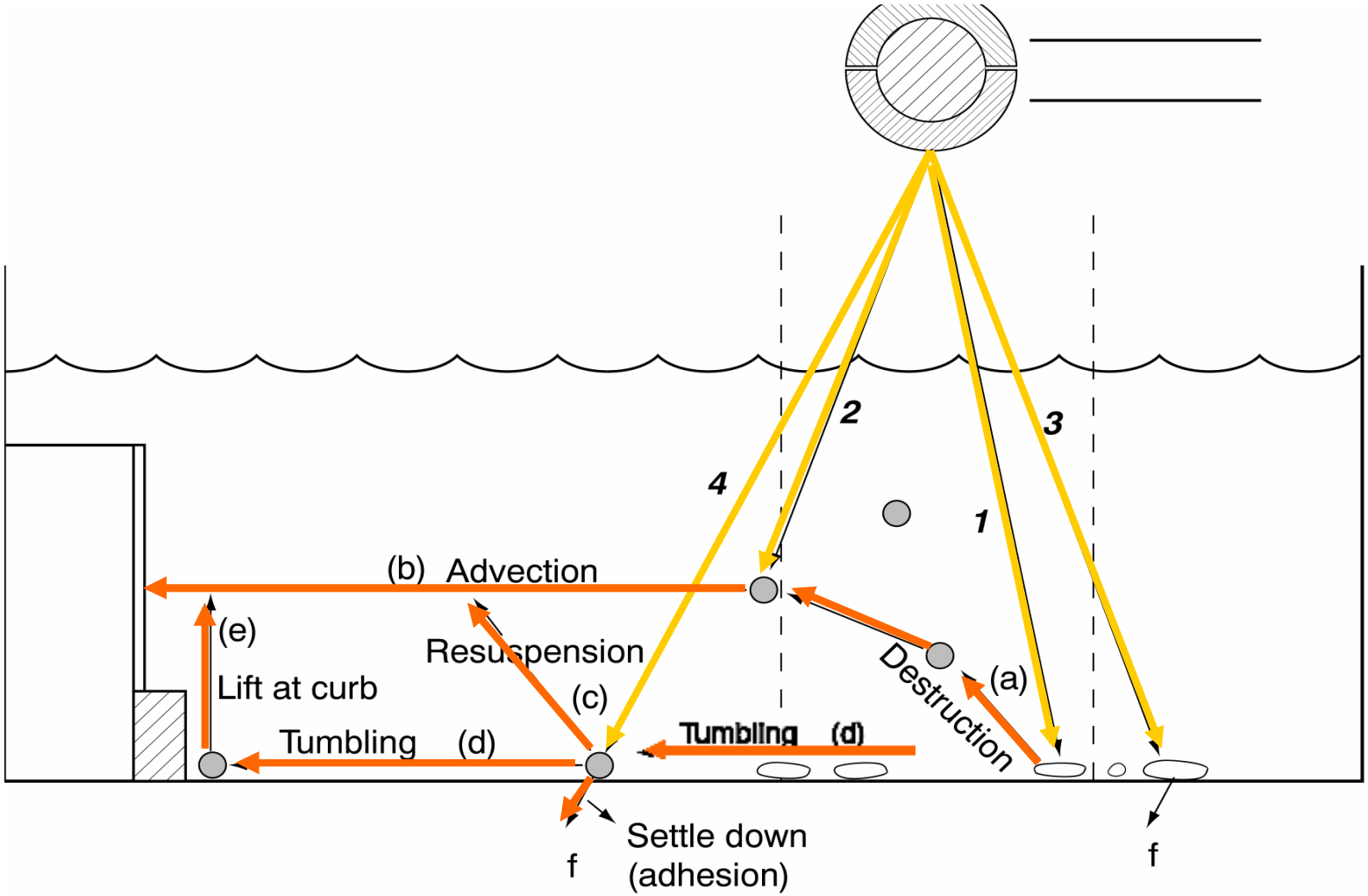
BWR CFD Simulation of Mark I Flow Patterns

NRC SE Major Topics
Debris Transport



PWR CFD LB LOCA in lower-right, speed > RMI threshold in red

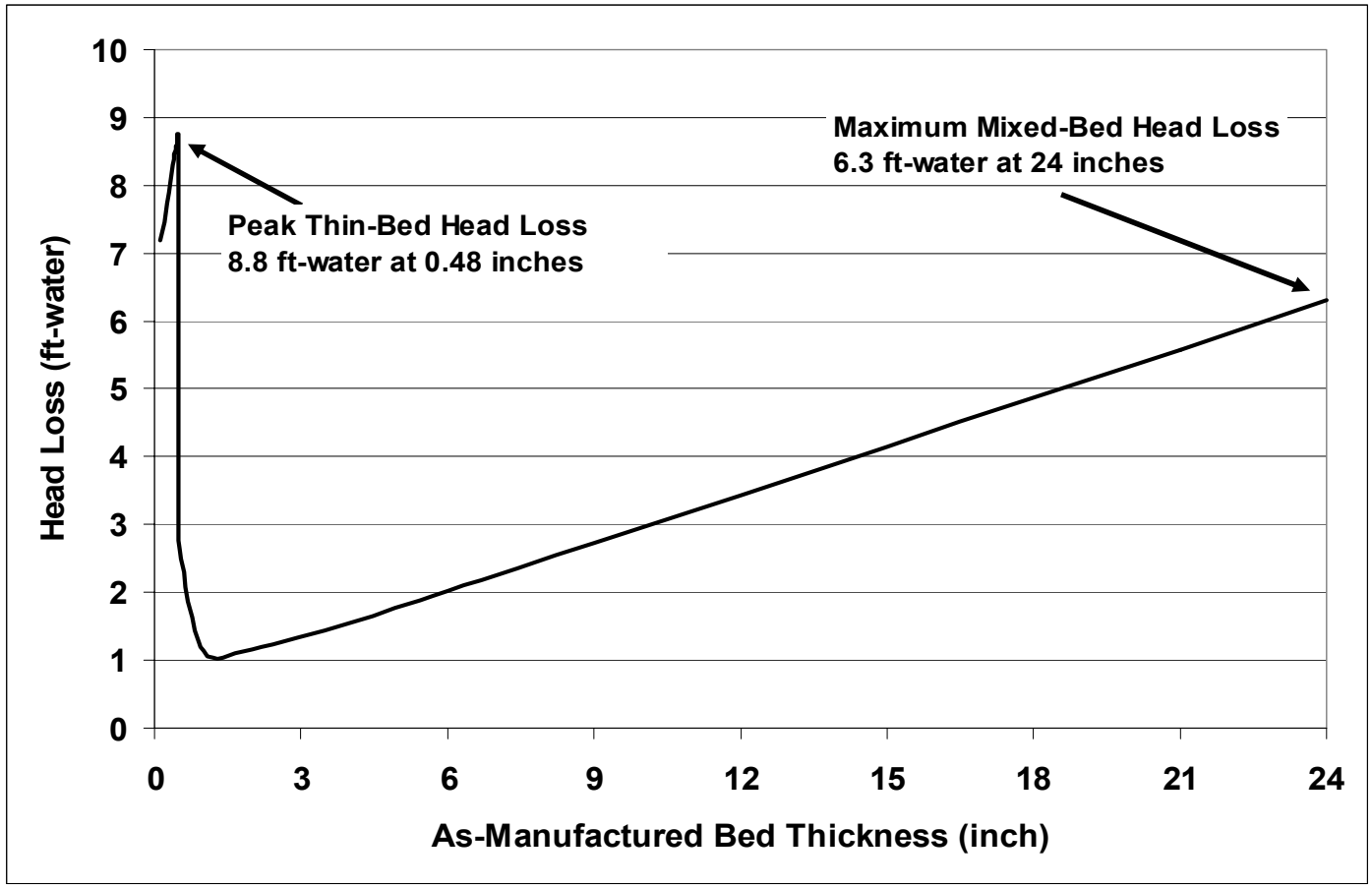
NRC SE Major Topics
Debris Transport



NRC SE Major Topics
Head Loss

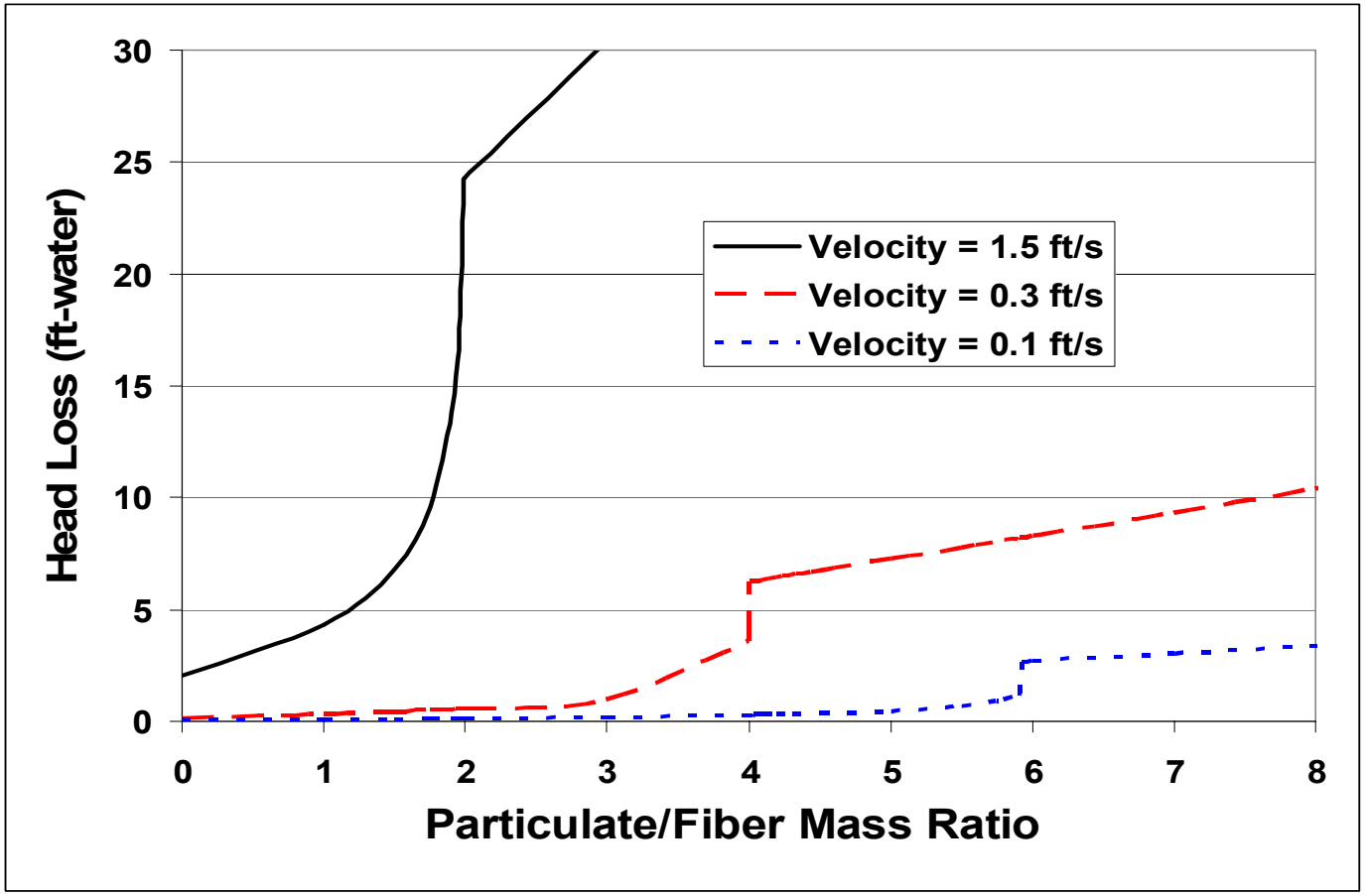
- Head loss calculated per NUREG-6224, if applicable
- Thin Bed Effect and its impact
  - thin layer fibrous bed mixed with particulate
  - bed porosity approaching the particulate sludge limit
  - can produce very high head loss

NRC SE Major Topics
Head Loss



Example Head Loss curve

NRC SE Major Topics
Head Loss



Parametric example of Thin-Bed formation

NRC SE Major Topics
NUKON/Particulate Head Loss Results

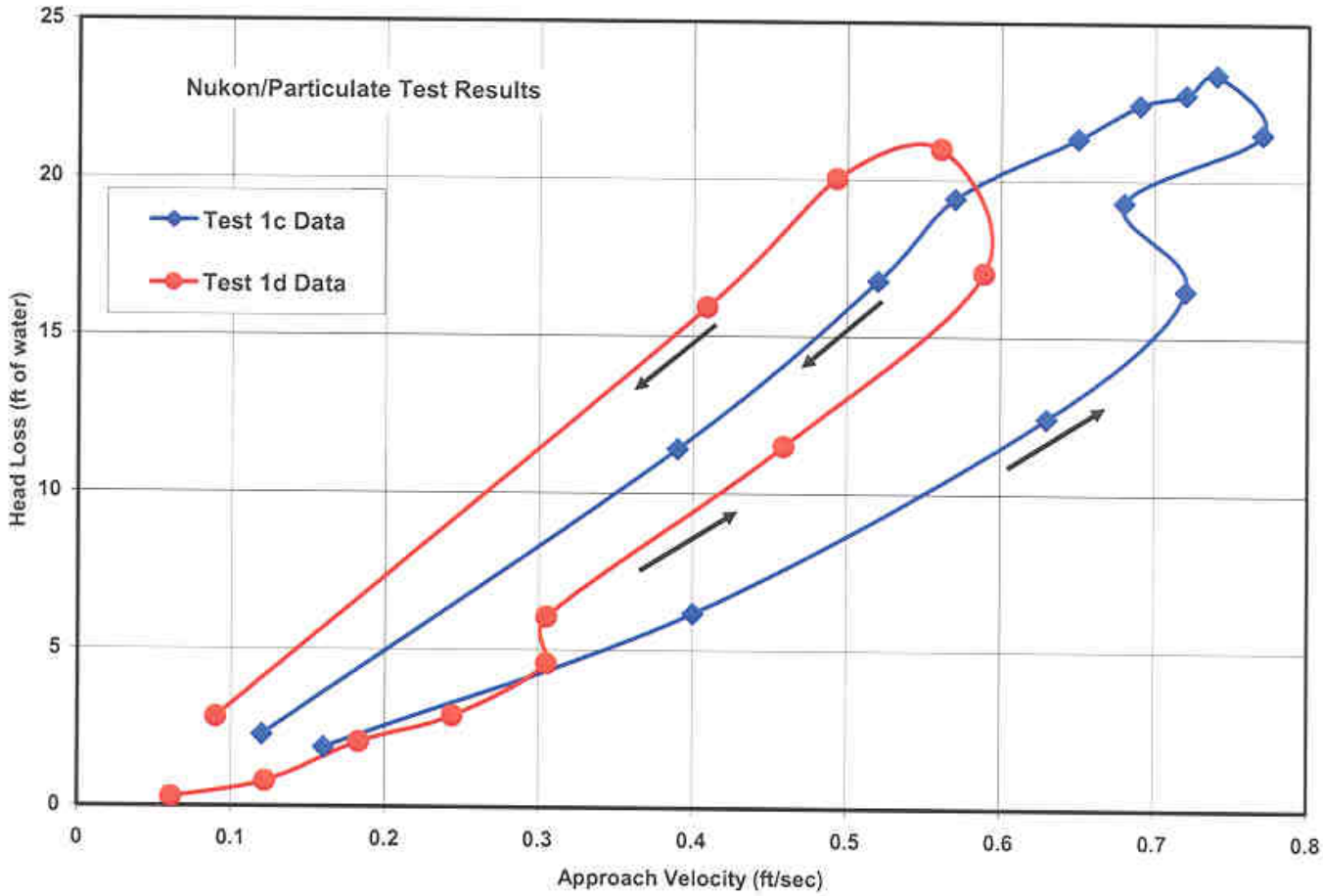


Figure 3.7. Measured head loss for NUKON™ fiber bed with particulate for two fiber bed thicknesses.

NRC SE Major Topics
Head Loss Chemical Precipitation Effects

- Potential for formation of ‘gelatinous’ or ‘amorphous’ material(s) as a result of water chemistry, metallic corrosion, insulation leaching
- Chemical reaction results could affect future NRC regulatory guidance and oversight
  - Long-term head loss
  - Type and quantity of debris sources

NRC SE Major Topics
Upstream/Downstream Effects

- Need to consider conditions of operation, mission times, wear/abrasion, blockage mechanisms, engineering evaluation of ECCS and CS
  - Blockage of flow paths
  - Wear and abrasion of surfaces
  - Blockage of flow clearances through fuel assemblies

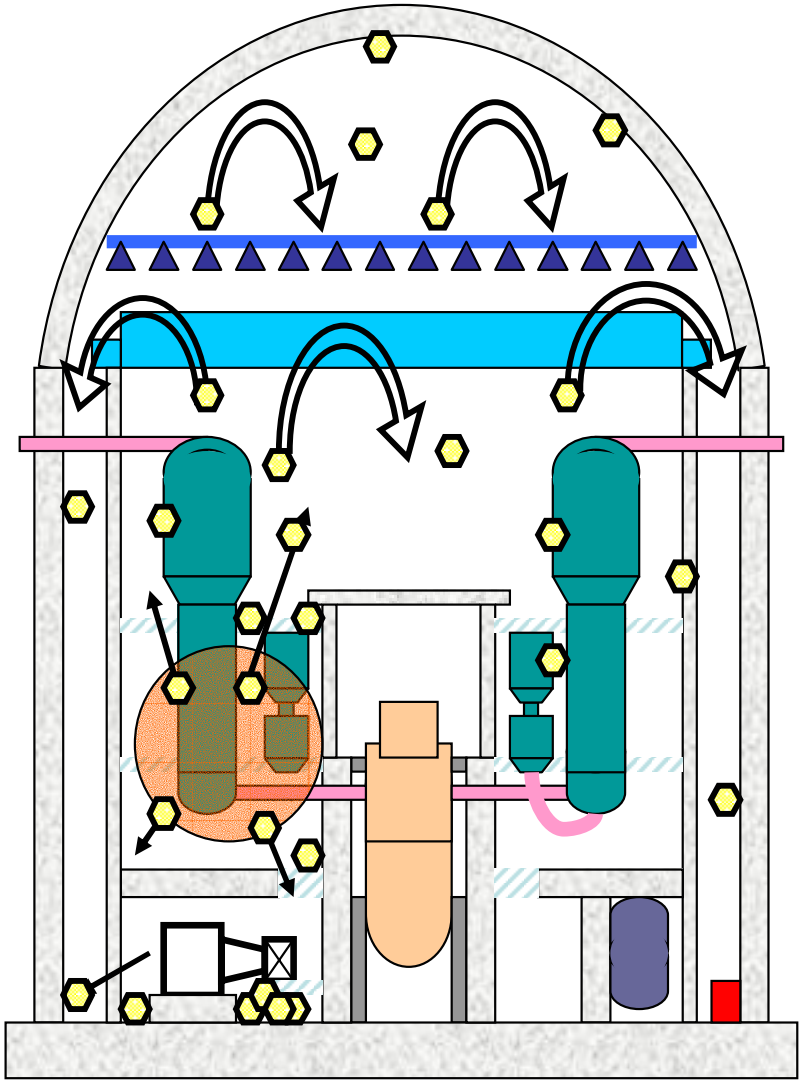
NRC SE Major Topics
Sump Structural Analysis

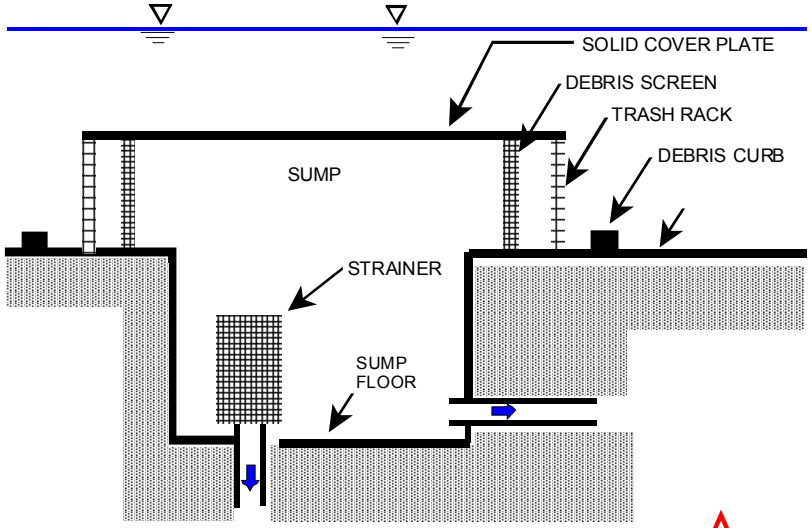
1. Verify maximum differential pressure at maximum debris load and rated flow rates
2. Address geometry concerns (mesh and frame vs. perforated plate)
3. Material selection acceptable for post-accident environment
4. Consider hydrodynamic loads due to a seismic event (plant specific)

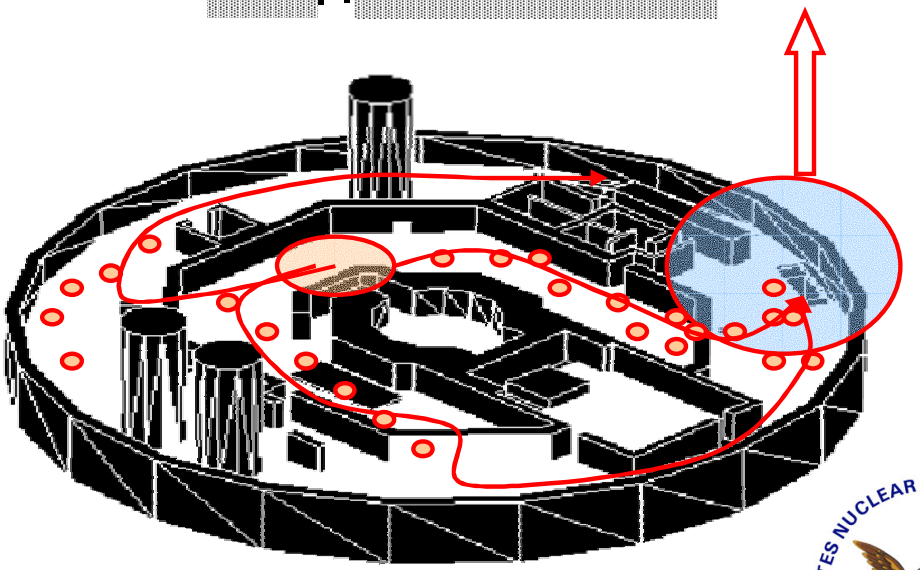
NRC SE Major Topics
Alternate Evaluation

- Similar to the 10 CFR 50.46 risk informed rulemaking
  - Safety-related and single failure-proof considerations
  - May require plant-specific exemptions or license amendments
  - NPSH margin to demonstrate adequate core cooling flow and containment cooling
  - Risk-informed aspects
    - Associated plant modifications and operator actions
    - Analyses performed consistent with RG 1.174
- Define a “debris generation” LOCA break size
  - All auxiliary piping attached to the RCS
  - Break size equivalent to the area of a double ended rupture of a 14 inch diameter pipe (approximately 197 square inches)
- Region I analyses - RCS breaks up through and including the “debris generation” break size (customary design basis analyses)
- Region II analyses - RCS break sizes larger than the “debris generation” break size

ECCS Sump Evaluation Summary
PWR







ECCS Sump Evaluation Summary
Simple PWR Evaluation

Demonstration Calculations				
For a W-4 Loop with Large Dry Containment - assume 10,000 ft3 of fibrous insulation, latent fiber approx 20 ft3		10,000		
Assume each SG, RV, PZR approx 1300 ft3 (6 big items)	1300	7800		
Remaining miscellaneous insulation		2200		
ZOI fraction of SG	0.9	1170		
ZOI fraction of miscellaneous insulation (compartment)	0.25	550		
Total estimate of debris		1720		
Transport Phase (approximate percentages/values)	Small Fines		Large Pieces	
	factor	ft3	factor	ft3
Debris Profile Fraction	55%	912	45%	808
Fraction transported to Upper Levels by Blowdown	90%	839	65%	509
Fraction transported directly to Pool	10%	73	35%	299
Fraction Washed Down into Pool	70%	595	20%	107
Fraction transported to Inactive Pools	5%	27	5%	57
Fraction in pool transported to Sump Screens	100%	625	75%	264
Fraction of Debris Generated That Accumulates on Sump Screens	70%	629	35%	267
With a 100 ft2 screen, small fines only, yields an approx debris depth of	6	ft		
A debris bed of 6 ft, with a particulate load of 300 #, would yield an estimated head loss of 10-17 ft				
All RMI/Latent Fiber Only				
For Latent Fiber only - 20 ft3 (all small fines, overall transport 70%)	14	ft3 bed		
	0.14	ft = 1.7 inches thick		
Back calculate a 1/8 (0.125) inch bed, results in latent debris volume of	1.04	ft3 bed on 100 ft2 screen		
	1.5	ft3 of latent fiber		
Practical Solutions: double jacket fiber insulation, modify sump screen, refine ZOI model, trash racks/barriers, operator actions, revised setpoints, change insulation types, etc…				

ECCS Sump Evaluation Summary
Potential Mitigation Strategies

Integrated Plan (addresses ALL major topics)

- Modification of insulation types/jacketing
- Plant cleanliness programs
- Midstream debris interceptors
- Operator actions to secure unnecessary flowpaths
- Larger, Complex, Submerged screens
- Test and approve back-flush to dislodge compacted debris
- Active screen sweep and collection concepts
- Innovative porous media designs on top of existing screens

PWR Regulatory Approach/Basis Evaluations & Oversight

- Pilot Program Approach
  - Staff is working with potential pilot plants
  - Meetings to identify issues
  - Permits early problem resolution
- In-Depth Plant Review Program Approach
  - Vendor
  - Methodology used/overall performance
  - Screen design
- Regional Inspections

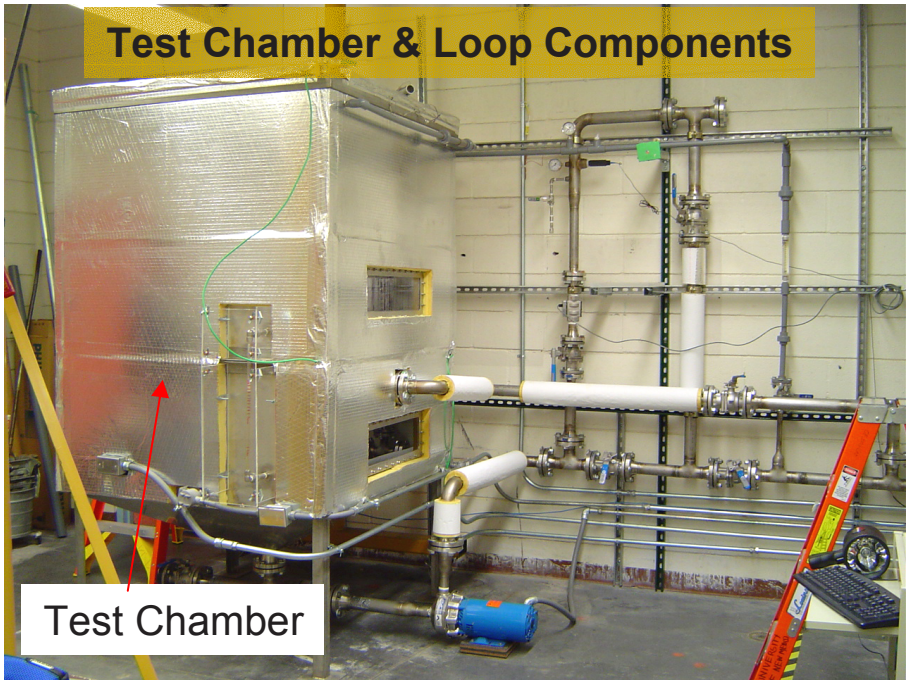
NRC Regulatory Overview Communications

- Development of GSI-191 Communication Plan
  - Communicates key messages to internal and external stakeholders
  - Highlights evaluation strategies and proposed resolution schedules
  - Promotes openness with NEI, LANL, PWR owners groups, and the public
  - Includes public PWR Sump Website
- Generic Communications – Two Phase Approach
  - Bulletin 2003-01, (Issued June 2003)
  - Generic Letter 2004-02 (Issued September 2004)

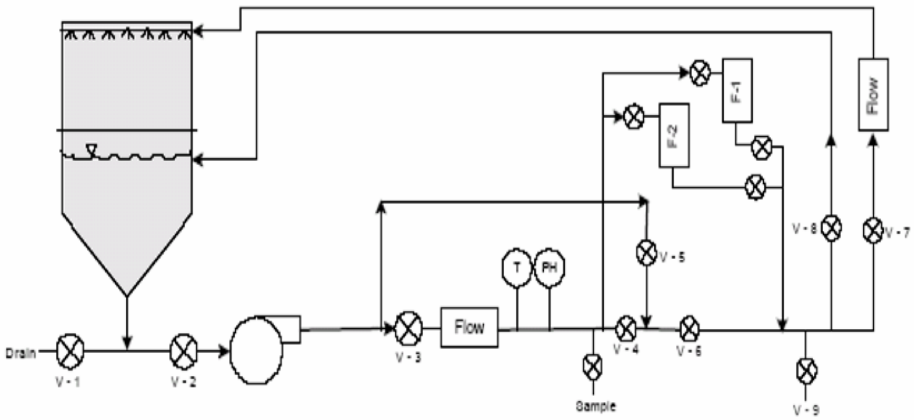
Ongoing Testing
Research Supporting GL 2004-02

- **Chemical effects**: Determine if sump pool environment generates by-products which contribute to sump clogging
- **Debris Transport & Head loss**: Confirmatory research on debris transport of coatings and head losses associated with PWR containment materials with and without chemical effects
- **Downstream effects**: Confirmatory research on the effect of injected debris on HPSI throttle valve performance

Ongoing Testing
Integrated Chemical Effects Testing (ICET)



Test Loop Schematic



- Evaluate corrosion byproducts and the formation of gel-type compounds
- Testing consists of multiple 30-day tests.
- Testing and characterization procedures and requirements were developed jointly by the NRC and industry.
- Testing results are shared between the NRC and industry.

Ongoing Testing
Description of Integrated Chemical Effects Testing

- Tests simulate five unique chemical environments with scaled amounts of containment materials.
- Tests 1 - 4 completed; test 5 is scheduled to begin on 7/26.
- Chemical by-products have been observed in tests 1 - 4.

Test Number	Buffering Agent	Insulation Material
1	Sodium Hydroxide: pH ≈ 10	100% Fibrous (NUKON)
2	Tri-sodium Phosphate: pH ≈ 7	100% Fibrous (NUKON)
3	Tri-sodium Phosphate: pH ≈ 7	80% Particulate (CalSil) 20% Fibrous (NUKON)
4	Sodium Hydroxide: pH ≈ 10	80% Particulate (CalSil) 20% Fibrous (NUKON)
5	Sodium Tetraborate: pH ≈ 8.5	100% Fibrous (NUKON)

Ongoing Testing
Possible Implications of ICET Findings

Chemical product formation

- Tests have shown that small variations in chemical composition may lead to significantly different chemical by-products.
- Products formed in plant-specific environments need to be examined for differences with ICET by-products.

Head loss contributions from chemical effects

- Nature of head loss is likely fundamentally different from typical debris loading.
- International testing has shown that significant head loss is possible under certain conditions.

Downstream Effects

- The possibility of chemical by-products being formed or transported downstream of sump strainer screen and degrading either component performance or ECCS functionality should be examined.
- Blockage or wear of downstream components is another consideration to be examined.

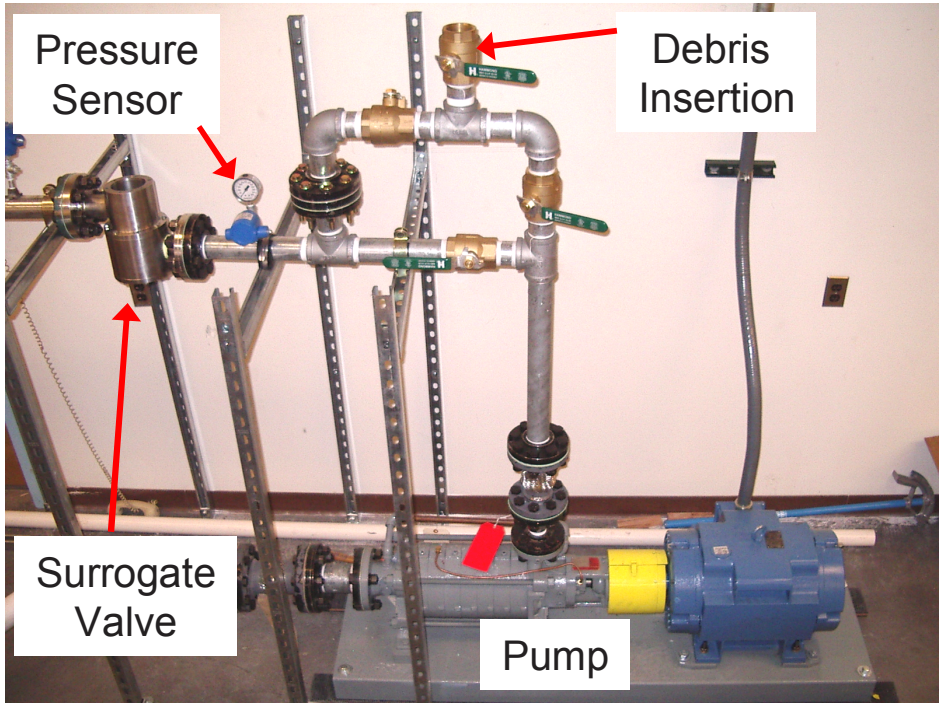
Ongoing Testing
Debris Transport and Head Loss

- **Objectives**:
  - Develop a mechanistic understanding of debris transport and head loss processes.
  - Develop predictive head loss correlations
- **Debris transport and characterization**
  - Testing transportability of “fine” particulate and larger coating chips to the sump screen
- **Head loss testing**
  - PWR fibrous and particulate insulation and coatings in inert environments
  - Focus on lower approach velocities to simulate modified designs
  - Head loss contributions of chemical effects in PWR debris beds
- **Improved analytical head loss model**

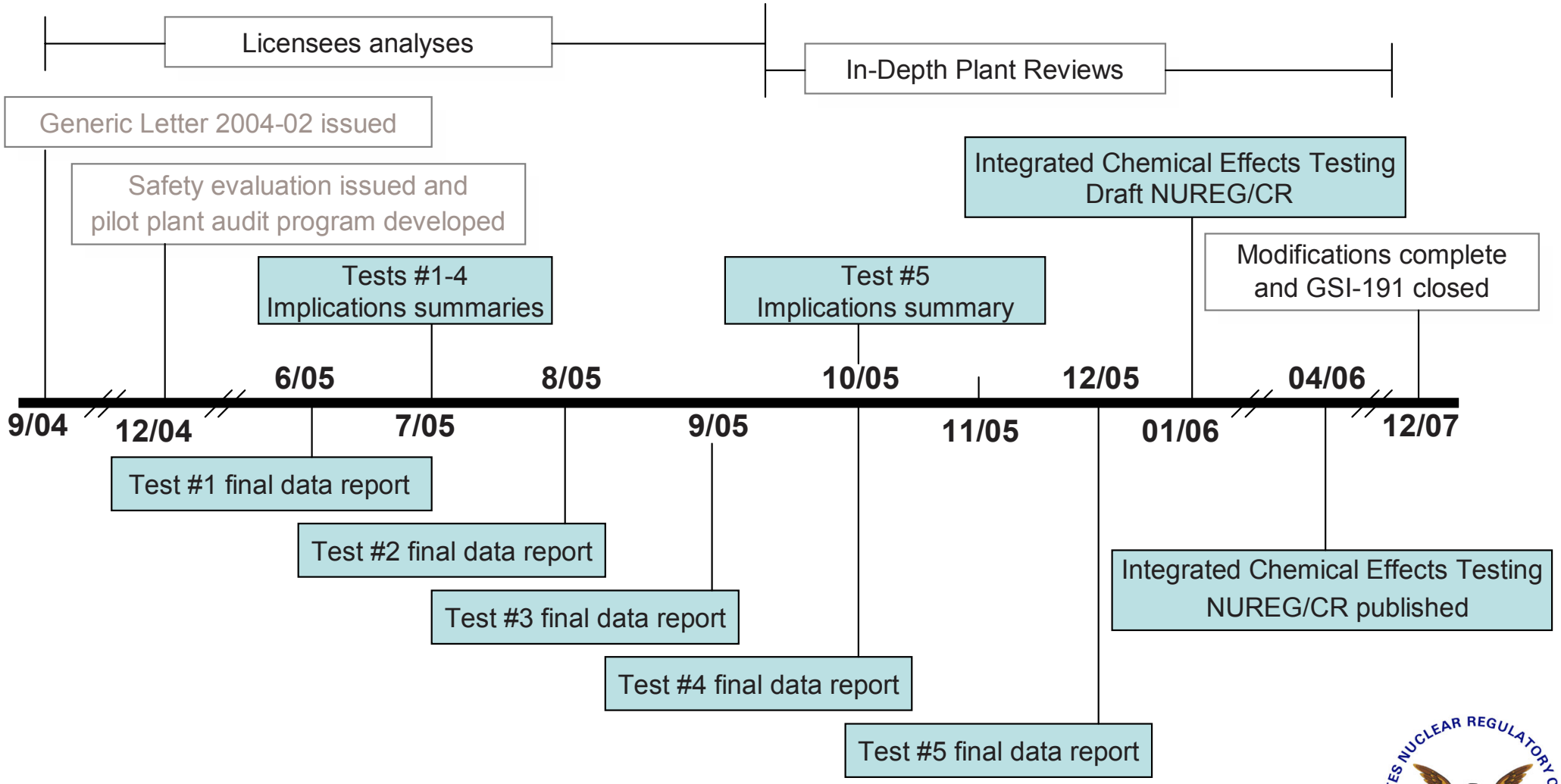
Ongoing Testing
Downstream Effects Testing

- **Objective**: Understand physical characteristics of debris which can pass through sump strainer screens and affect a HPSI throttle valve blockage
- Debris pass-through under PWR conditions
  - Fibrous, particulate, and reflective metal insulations
  - Representative approach velocities
- Two-step throttle valve testing
  - Baseline and single debris type
  - Multiple debris-types

Downstream Effects Loop



Ongoing Testing
Timeline for Chemical Effects Testing



LEGEND:
Shaded boxes – products of research under NRC/EPRI MOU
Final data reports - LANL reports, reviewed by NRC and EPRI/industry
Implications summaries – NRC reports, implications of test results for licensee analyses

NRC Regulatory Overview
Resolution Schedule

• Bulletin 2003-01 issued	June 2003
• Generic Letter issued	September 2004
• Safety evaluation issued	December 2004
• Licensee analysis complete	September 2005
• In-Depth Plant Reviews	Apr 2006 – Dec 2007
• All modifications complete	December 2007
• GSI-191 closed out	December 2007

NRC Policy Issues
Compliance / Operability Issues

- Regulatory Compliance
  - Existing licensing basis in effect until GSI 191 resolution
- GSI-191 Resolution Date: 12/31/07
  - All plant & licensing basis modifications are to be completed by this date
  - New methodology not “required” until after this date
- Compliance After 12/31/07
  - Based on new licensing basis incorporating new methodology

NRC Policy Issues Resolution Schedule

- Issue identified some time ago (GSI issued in 1996)
- NRC has openly communicated expectations to industry
  - Bulletin 2003-01, GL 2004-02, GSI-191 Safety Evaluation
  - Letter B. Sheron to A. Pietrangelo 8/25/04
  - NEI Workshop 12/1/04
  - Public meetings (1/27/05, 4/13/05, & 6/30/05)
- NRC Expects Industry to maintain schedule (Detailed submittals by Sept. 05, Implementation by Dec. 07)
  - Recent audit & vendor information indicate resolution is achievable

NRC Policy Issues
Issue Resolution

- Industry has responsibility to resolve, NRC responsibility to evaluate
  - Staff is willing to evaluate industry data to relax conservatisms
- Industry needs to show a detailed plan for resolving these issues
- Industry has “burden of proof” for any proposed delay (will need to show PRA and financial risk factors)

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