Agenda for February 14, 2001 Public Meeting

Time	Topic	Speaker
9:00 - 9:30	Introductions	NRC NEI
9:30 - 10:30	Responses to NEI's Comments Concerning Risk Calculations	LANL
10:30 - 10:50	PRA Insights	PWROGs
10:50 -12:00	Debris Generation Testing and Analysis	LANL
12:00 - 1:30	Lunch (sandwich shop at training center will be closed)	
1:30 - 2:00	Debris Transport Test Program	UNM
2:00 - 2:30	Integrated Tank Testing of Debris Transport	UNM LANL
2:30 - 3:00	Exposure Survey Results	PWROGs
3:00 - 3:15	Break	
3:15 - 3:45	Considerations for Additional Coatings Research	NRC
3:45 - 4:30	Potential Changes to RG 1.82	NRC
4:30 - 5:00	Question and Answer Session	

<< Meeting Must End Promptly at 5:00pm >>

Agenda for February 15, 2001 Public Meeting

Time	Topic	Speaker
9:00 - 9:30	Introductory Remarks	NRC LANL
9:30 - 10:30	Tank Test Demonstration	UNM

Introduction

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Division of Engineering Technology
Engineering Research Applications Branch

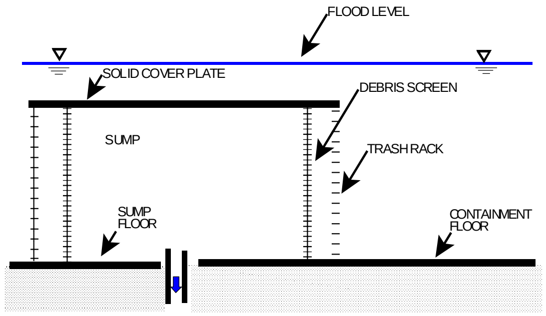
Contact:
Michael Marshall, 415-5895

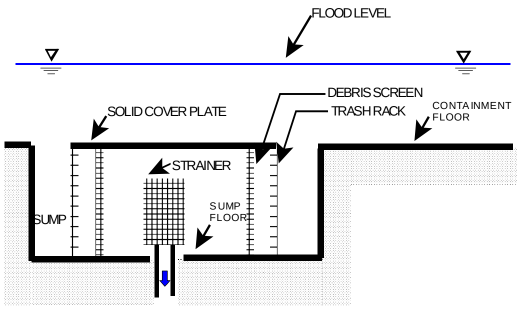
Public Meeting
Albuquerque, NM
February 14, 2001

Purpose of Public Meeting

- Inform external stakeholders of ongoing analytical and experimental work being conducted as part of PWR sump screen blockage study.

- Provide external stakeholders an opportunity to discuss PWR sump screen blockage study with NRC staff and contractors.





Today's Agenda

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9:30 - 10:30	Responses to NEI's Comments Concerning Risk Calculations		LANL
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12:00 - 1:30	Lunch (sandwich shop at training center will be closed)		
1:30 - 2:00	Debris Transport Test Program		UNM

Today’s Agenda

Continued

Time	Topic	Speaker
2:00 - 2:30	Integrated Tank Testing of Debris Transport	UNM LANL
2:30 - 3:00	Exposure Survey Results	PWROGs
3:00 - 3:15	Break	
3:15 - 3:45	Considerations for Additional Coatings Research	NRC
3:45 - 4:30	Potential Changes to RG 1.82	NRC
4:30 - 5:00	Question and Answer Session	
	<< Meeting Must End Promptly at 5:00pm >>	

Tommorow's Agenda

Continued

Time	Topic	Speaker
9:00 - 9:30	Introductory Remarks	NRC LANL
9:30 - 10:30	Tank Test Demonstration	UNM

Pressurized Water Reactor Sump Screen Blockage Study

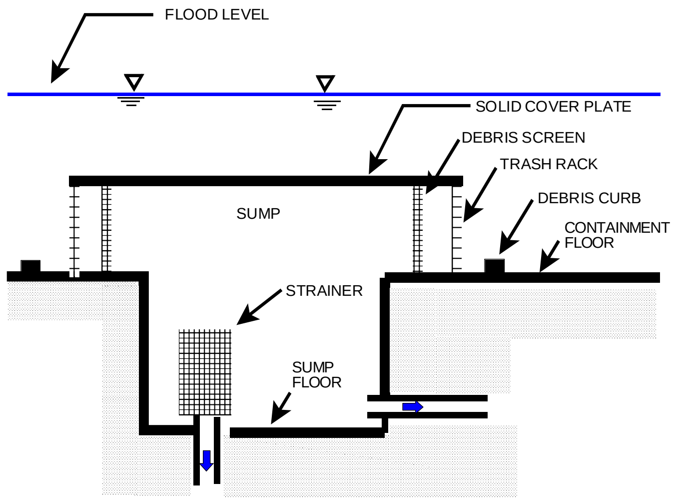
Continued

! Potential Safety Concern

- The accumulation of debris on sump screens will increase the resistance across the screen and thus reduce the net positive suction head available to the emergency core cooling system pumps drawing suction from the sump.

! Regulation

- 10 CFR 50.46, "Acceptance Criteria for Emergency Core Cooling Systems for Light Water Nuclear Power Reactors" requires all LWRs to provide a ECCS that is designed to meet five criteria. One of those criteria is long-term cooling.



! Purpose of Study

- Determine if have a safety problem
- If a safety problem is confirmed, then identify resolution

<< adequate long-term post-LOCA cooling >>

Pressurized Water Reactor Sump Screen Blockage Study

Continued

! Background

" Regulatory Guide 1.82, Rev. 0 (1974)
- 50% Blockage of Screen or Sump

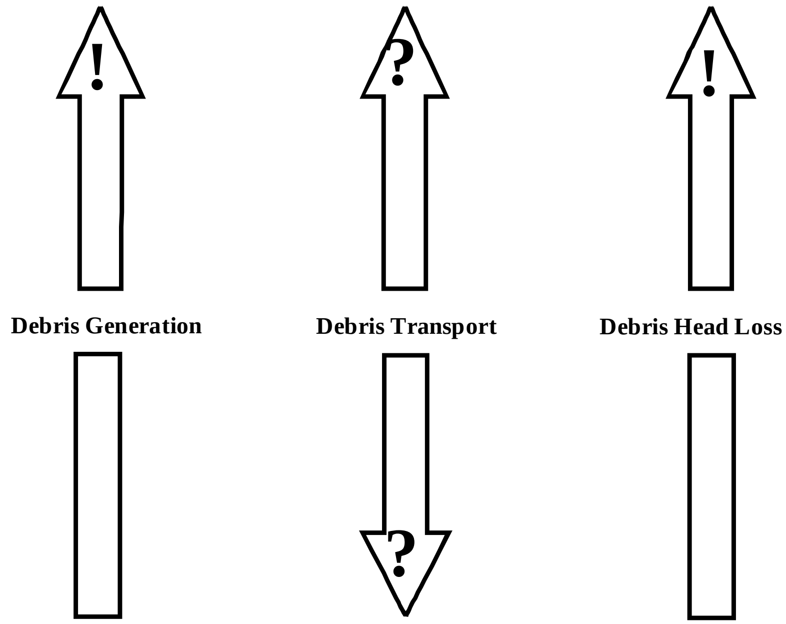
" USI A-43 (1981 - 1985)
- NUREG-0897
- Regulatory Guide 1.82, Rev. 1
- Generic Letter 85-22

" BWR Suction Strainer Blockage Study (1992 - 1996)
- Barsebäck
- NUREG/CR-6224 Study
- Regulatory Guide 1.82, Rev. 2
- NRC Bulletin 96-03

" PWR Sump Blockage Study (1998 -)

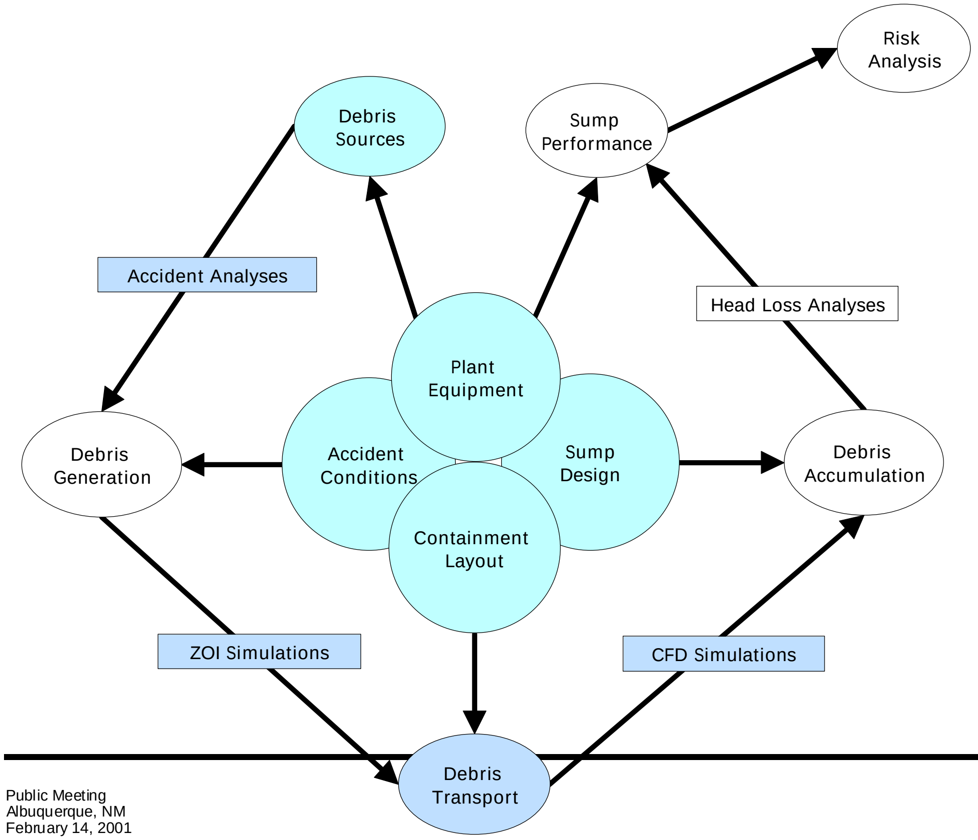
Pressurized Water Reactor Sump Screen Blockage Study

Continued



Pressurized Water Reactor Sump Screen Blockage Study

Continued



PRA Modeling Approach to Resolve GSI-191:
Response to NEI Comments Concerning Risk Calculations

D. V. Rao

Decision Applications Division (D-11)

Los Alamos National Laboratory

Los Alamos, NM 87545

Background

- **LANL Proposed a Risk Modeling approach in support of GSI-191 Resolution**
  - The approach was presented at the *PWR Sump Blockage Public Meeting (*March 2000)
  - A Report documenting the approach was prepared and Submitted to NRC
  - Modifications were made to the approach to accommodate peer review comments and other NRC direction
  - LANL is in the process of performing the study
- **NEI Forwarded the comments in June**
  - Comments centered primarily on the presentation and some of the explanations provided during the presentation
  - We address each comment in this response

Comment #1

…… LANL Approach is different and more complicated than what (NEI) task force had envisioned.

Response #1

- **Approach presented by LANL included mathematical formulation of some of the steps described only qualitatively in Step 6 of NEI approach "*Determine Risk Impact Due to Unacceptable Sump Blockage*". It is our belief that as NEI wrestles with the problem of developing a PRA model framework that addresses specific steps described in Step 6, the NEI approach would become gradually more complex (and may even resemble that of LANL). In other words, the complexity, in our opinion, is a reflection of the maturity of LANL approach. Qualitatively, at least, this is the only major difference between the NEI approach and the NRC approach.**

Comment #2

...... We recommend that it (LANL Approach) be subject to a focused peer review.

Response #2

- **LANL approach has been peer reviewed by individuals internal to the project as well as those external to the project**
  - LANL GSI-191 Project Team Review
  - LANL Peer Review
  - NRC GSI-191 Project Team Review
  - NRC Peer Review

Comment #3

The NRC should reconsider how the event phenomena are modeled and eliminate the masking effort of the current risk model. Collapsing all the event phenomenology into one node will not use the risk insights to the optimum level.

If an event tree simplification is required, some plant systems behavior may be approximated by consolidated ET nodes. This allows for adding more of phenomenological branching nodes. Plant systems behavior is of secondary importance to this assessment.

Response #3

- LANL/NRC disagree with NEI's characterization of the approach as masking. One of the criteria for selecting the approach is that it be tractable.

- LANL intends to explicitly model each phenomenon of interest. A variety of logic charts, tables and figures would be used to illustrate the results of ongoing modeling activities and how they were used in the risk assessment.

- During the discussions, LANL stated that we would use Small Event Tree and Large Fault Tree framework for PRA modeling. We have not stated that this approach limits our ability to include top-events in the ET. Adding phenomenological branching nodes and following the logic for each postulated break location would result in an event tree that is large and incomprehensible.

Comment #4

Dr. D. V. Rao's comment of weighting factors, either one or zero, appears inconsistent with the LANL presentation….

It is unclear how this process will retain traceability, to the extent needed to verify results…..
We recommend that the weighting (Wi) be assigned the fraction of the total initiating event frequency for a particular break set.

The information provided at the meeting is not sufficiently detailed for us to understand the NRS staff's method to incorporate risk insights into the resolution of GSI-191. We request that NRC staff provide in the near future additional details….

We understand the NRC staff plans to account for licensing basis versus most likely plant systems response as described in slides 4 and 7. ….
It remains unclear what the significance of the results of the exercise will be, or how it will be done.

Responses #4

- The presentation describes the NRC approach. Dr. Rao was giving an example. We believe he was misquoted here.

- As previously described, the traceability will be maintained through supporting logic charts, tables and figures. At a minimum, for each break we would assign an unique identifier and associate the estimated quantity of debris generated, transported, accumulated and head loss implications. In addition, we will provide the rationale for arriving at each estimate.

- Our first reaction was to assign a fraction for each break set (e.g., total LOCA frequency is 1E-5; postulated breaks 100; average break frequency is 1E-7). After further deliberation, it was decided to retain flexibility to assign variable weighting factor such that we can treat each break frequency differently. This approach is consistent with SNL, LANL, INEL, LLNL and some industry experts opinions that not all breaks are equally likely.

Responses #4 (Contd….)

- **It was not the purpose of the presentation to explain how risk insights will be incorporated into resolution of GSI-191. The purpose of the presentation was to explain how the risk metrics would be calculated.**

- **In reponse to the peer review comments, NRC is no longer planning to use licensing versus most likely plant response in the PRA study.**

Comment #5

Dr. Darby's slide expresses the concern with the need for and the ability to model sequences "to component level." The modeling of plant component performance prior to nodes reflecting recirculation should not require significant new work for this program….

Response #5

- **We are not “Squeezing” any phenomenological model in favor of component modeling.**

- **Slide simply states that one of the specifications for selecting the modeling approach is that it *be* extensible to component level. We have no plans to extend the model to component level at the present time. We *may* use “component modeling” if we believe that some of the mitigation strategies are too complex to be handled in the ET (and component modeling is better suited) or other such special needs arise.**

Comment #6

We agree that an evaluation of the impact of this issue on large early release frequency (LERF) form containment should be performed.

It is less obvious that a detailed sequence is required….

LERF is an unlikely event, even with early failure of recirculation cooling.

Response #6

- **LANL introduced an event tree node "CONT COOLING" to address the possibility of containment cooling failure leading to containment failure. This does introduce several sequences which involve containment failure. No determination has been made as to which of these sequences will be binned to early-failure category. Further evaluations are underway.**

Comment #7

At the meeting D. V. Rao asked if the PWR Owners group had information regarding likelihood of events involving a high energy line break (e.g., MSLB) with consequential steam generator tube rupture….

NUCLEAR ENERGY INSTITUTE

Kurt Cozens
SENIOR PROJECT MANAGER, ENGINEERING
NUCLEAR GENERATION DIVISION

May 26, 2000

Mr. Michael L. Marshall, Jr., Project Manager
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

SUBJECT: Comments on NRC Sponsored Risk-Assessment Efforts to Resolve GSI-191, *Assessment of Debris Accumulation on PWR Sump Performance*

PROJECT NUMBER: 689

Dear Mr. Marshall:

In March, the NRC staff conducted a meeting to discuss its ongoing GSI-191 research at which Los Alamos National Laboratory (LANL) presented a summary of risk assessment work being performed. In addition, the NEI Sump Performance Task Force presented an integrated, risk-informed decision-making process to address GSI-191. During the meeting, the NRC staff invited comments on its risk assessment effort.

We appreciate the efforts of the NRC staff and its contractor to prepare the presentations. The task force provides the following observations and comments with the hope that they will promote additional discussion.

1. The task force's presentation outlined a risk-informed, integrated decision-making approach that we believe would help focus appropriate attention and resources on the most important aspects of the containment sump debris issue. Seven main steps were identified and discussed, along with a general description of what would need to be done to accomplish each step. The enclosed LANL presentations included information that addresses these steps, although the approach is different and more complicated than what task force had envisioned.

2. The LANL presentation suggested they could perform a risk-assessment of PWR post-accident sump performance with debris in the containment recirculating fluid. The modeling process uses a complicated set of steps to combine all debris effects into a single event tree node. This is an extremely important aspect of the risk analysis. We recommend that it be subject to a focused peer review.

3. The model node form for debris generation, transport, and accumulation on the sump screen(s) presently combines the separate individual physical events, all of which must occur sufficiently to affect net positive suction head (NPSH) at the sump screen. This simplification masks extensive research (testing and computer modeling) results by subsuming them into a complex calculation for this single event tree node.

   The LANL risk modeling approach makes it difficult to determine how the test results and analyses are reflected in the risk model. Considerable NRC resources are being expended to develop an understanding of the various phenomena associated with debris generation and transport, and sump screen blockage. We anticipate that these physical insights will be important to understanding the risk of post-accident sump in operability. Unfortunately, the contractor's model masks this understanding because the results are provided in terms of risk importance rather than the physical significance. LANL explained that this risk approach is being used to allow construction of a model that can be accommodated by the available PRA software. This logic does not justify masking the physical events.

   We recommend that:

   - The NRC staff reconsider how the event phenomena are modeled and eliminate the masking effect of the current risk model. Collapsing all the event phenomenology into one node will not use the risk insights to the optimum level.
   - If an event tree simplification is required, some plant systems behavior may be approximated by consolidated event tree nodes. This allows for adding more of phenomenological branching nodes. Plant systems behavior is of secondary importance to this assessment.

4. Dr. D. V. Rao's comment on the use of weighting factors, either one or zero, appears inconsistent with the LANL presentation. The presentation combined the conditional probabilities of recirculation failure for particular combinations of debris sets for a given break set, and for particular combinations of break sets for a given accident sequence. See slides 40 through 44. We provide the following observations:

- It is unclear how this process will retain traceability, to the extent needed to verify the results, between the:
    - initiating event frequency;
    - fraction of this frequency that is contributed by any particular break set; and
    - probability that any particular break set generates sufficient debris to be of concern to sump screen blockage sufficient to cause insufficient NPSH for the recirculation pumps.

  This traceability is important to the understanding of events that might challenge post-accident sump operability. We recommend that the weighting factor, (W_i) be assigned the fraction of the total initiating event frequency for a particular break set. Based on the presentation (slide 44), this was apparently not intended.

- Use of the second weighting factor (W_{ik}) is easier to understand. However, it is not clear how a meaningful weighting factor will be defined because the probability obtained from the summation is representative of the probability that insufficient NPSH will occur for a given break set in a given accident sequence. A clarification of this is important to understanding the events that might challenge post-accident sump operability. The recommendation provided in Comment 3 addresses this concern.

- The information provided at the meeting is not sufficiently detailed for us to understand the NRC staff's method to incorporate risk insights into the resolution of GSI-191. We request the NRC staff to provide in the near future additional details, including examples of the calculations involved, for review.

- We understand that the NRC staff plans to "account for licensing versus 'most-likely' plant systems response" as described in slides 4 and 7 of the enclosure. Although this was discussed at the meeting, it remains unclear what the significance of the results of the exercise will be, or how it will be done. We request the NRC staff provide additional explanation of this at a public meeting in the near future.

5. Dr. Darby's presentation (slides 4 and 7) expressed concern with the need for and the ability to model sequences "to the component level." The modeling of plant component performance prior to nodes reflecting recirculation should not require significant new work for this program. There is only one component of concern for this issue, the sump screens, which if "failed" due to excessive blockage, results in failure of the low head ECCS pumps in recirculation mode. A reasonable and insightful assessment of risk due to sump debris should not require any significant amount of component-level modeling. Thus, the ability to

model components should not become an important factor in "squeezing" the important part of the model, which is the modeling of debris generation, transport, and accumulation. The recommendation provided in Comment 3 addresses this concern.

6. We agree that an evaluation of the impact of this issue on large early release frequency (LERF) from containment should be performed. It is less obvious that a detailed event sequence model is required. For some events on the accident sequence list (see slide 9 of the enclosed presentation), LERF is an unlikely event, even with early failure of recirculation cooling. Examples would be transients, including loss of offsite power, and "small-small LOCA."

   As an alternative, we recommend that the NRC staff assess if each specific initiating event is likely to be a contributor to a release that is both large and early, in accordance with the Regulatory Guide 1.174 definition. It is unnecessary to model a detailed LERF event tree when PRAs indicate a large early release is not of concern.

7. At the meeting, D. V. Rao asked if the PWR owners groups had information regarding the likelihood of events involving a high energy line break (e.g., main steam or main feedwater line) with consequential steam generator tube rupture, and the possible debris-related sump blockage as a result. Potential frequencies for these events are not available.

We appreciate the opportunity to offer comments. If you have any questions, please call me at (202) 739-8085.

Sincerely,

Kurt Cozens

Kurt Cozens

KOC/
Enclosure

c: Mr. Robert B. Elliot, U.S. Nuclear Regulatory Commission
Mr. Aleck W. Serkiz, U.S. Nuclear Regulatory Commission

PWR Sump Blockage Study:
Debris Generation Testing and Analyses

D. V. Rao

Probabilistic Risk and Hazard Analysis Group (D-11)

Decision Applications Division

Los Alamos National Laboratory

Los Alamos, New Mexico

Objectives of Testing and Analysis Program

- **Perform Two-Phase Jet Impact Tests to:**
  - Measure the minimum jet impingement pressure to induce incipient damage on insulations used on PWR piping.
  - Determine the damage mechanism and to collect and analyze the debris generated by the jet destruction.
  - Compare measured destruction pressures with those measured using air jets and water jets. Develop a rationale for scaling test data to US PWR operating conditions.

- **Use the data appropriately to define a zone of influence (ZOI) to estimate the amount of debris that would be generated by a postulated PWR LOCA.**

Presentation Outline

- **Briefly summarize existing test data and need for additional testing**
- **Describe the test program**
  - –Existing Ontario Power Generation Test Rig and Test Plans
  - –Proposed Modifications and the Need
- **Preliminary list of insulation materials to be tested**
- **Proposed use of test data**

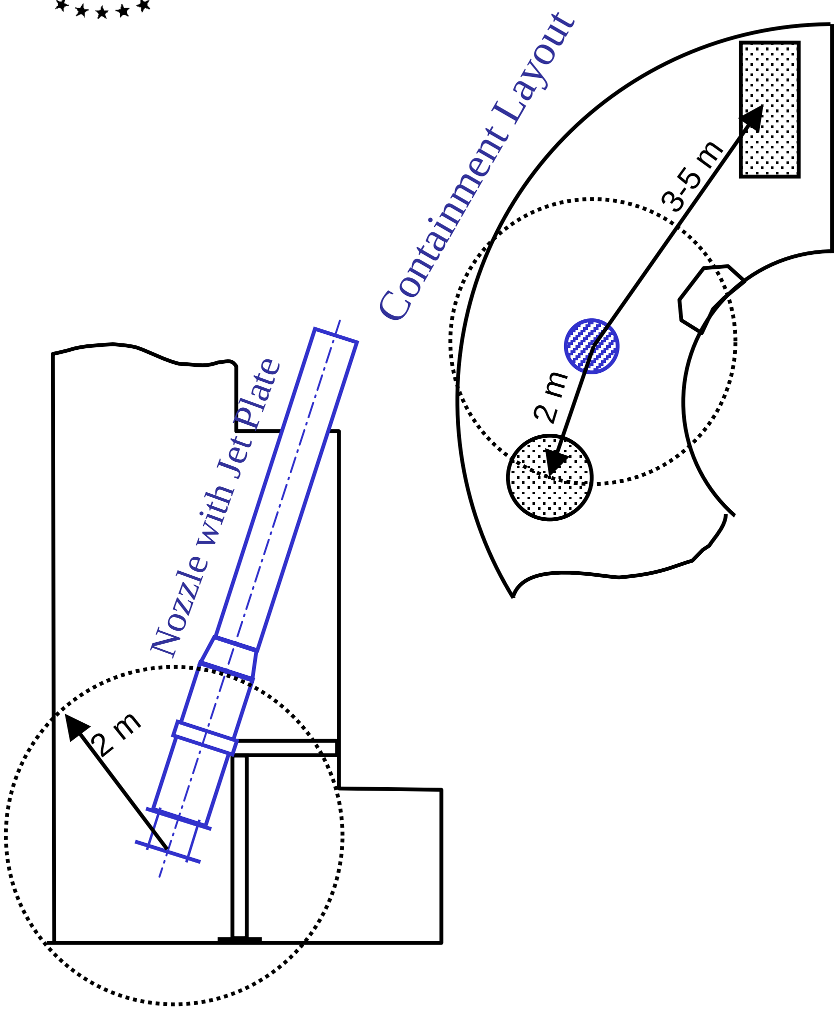
Review of Past Experiments

- **NRC/HDR: Two-Phase Blowdown Tests (USI A-43)**
- **NRC/ARL: Water Jet Impingement Tests (USI A-43)**
- **NRC/Karlstein: Steam Jet Tests (BWR Study)**
- **BWROG: Air Jet Impact Tests (BWR Study)**

There are other tests performed in Europe

- Many are proprietary
- Some of the insulation materials are not applicable to US PWRs

NRC/HDR Two-Phase Jet Tests



Test Conditions

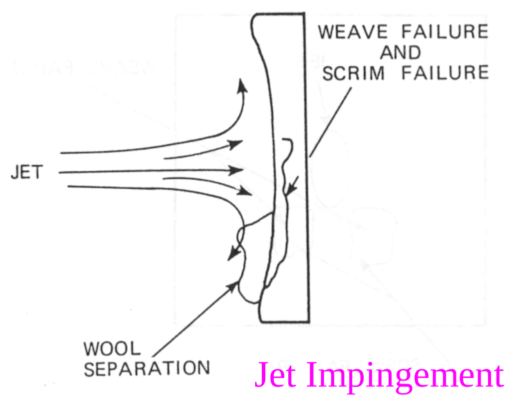
- Break Diameters: 200 mm, 350 mm, and 430 mm ++
- Steam and Subcooled Water Conditions
  - 110 Bars and 280 to 315 ^{o}C
- Blowdown durations ranged from <1 to 60 sec

Key Findings

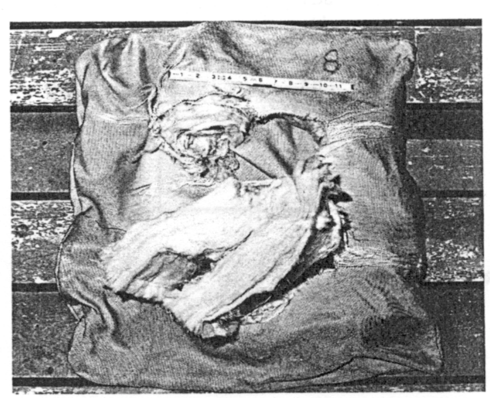
- Glass fiber insulation destroyed within 2 meters of the break nozzle
- Spalled concrete, blown open hatchways and damaged coatings.
- RMI destroyed or thrown away within 4 to 6 meters
- Destroyed debris distributed through out containment

++No Fiber tests.

NRC/ARL Water Jet Impingement Tests



Jet Impingement Schematic



Damaged Material

Objective:

Measure water stagnation pressures necessary to induce damage. Understand damage mechanism.

Elements of Testing Program

- Measure size distribution of generated debris
- Debris generated for P_{stag} of 30 psi

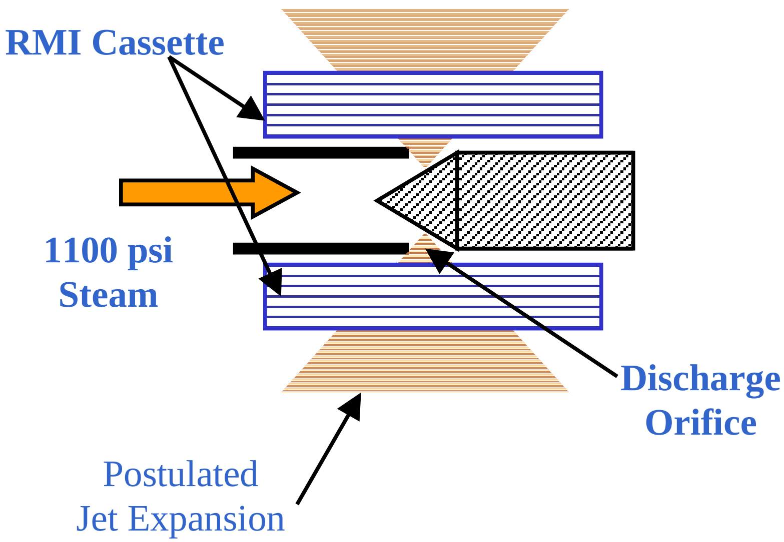
Operating Parameters

- Jet Stag. Pressures: 5 to 65 psi ($P_{stag} = P_{\infty} + \frac{1}{2}\rho V^2$)
- Jet Nozzle: 2-in.
- Target Blanket: 2-ft x 2-ft
- Insulation: Nukon with different designs
- Fixed axial distance (2D)

Debris Generation: NRC/Karlstein Tests

Objective:

Generate prototypical debris that subsequently can be used in head-loss testing and suppression pool testing.



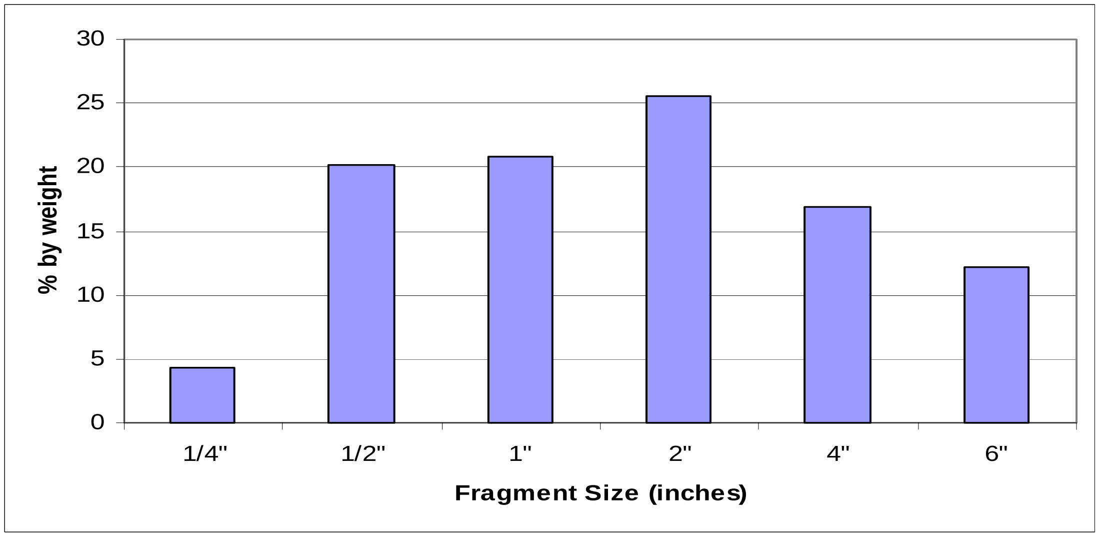
Elements of Testing Program

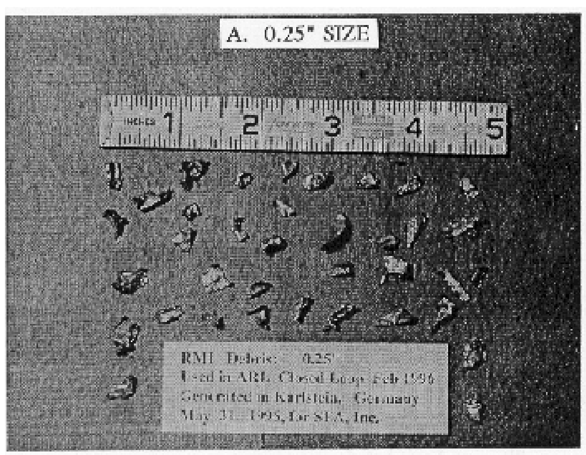
- Measure size distribution of generated debris

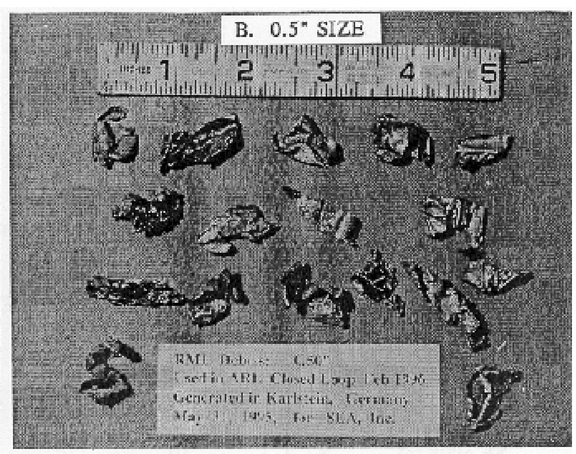
Operating Parameters

- Jet stagnation pressure of 1100 psia
- Jet pipe diameter 10 inches
- Target pipe diameter 10 inches
- Insulation: RMI

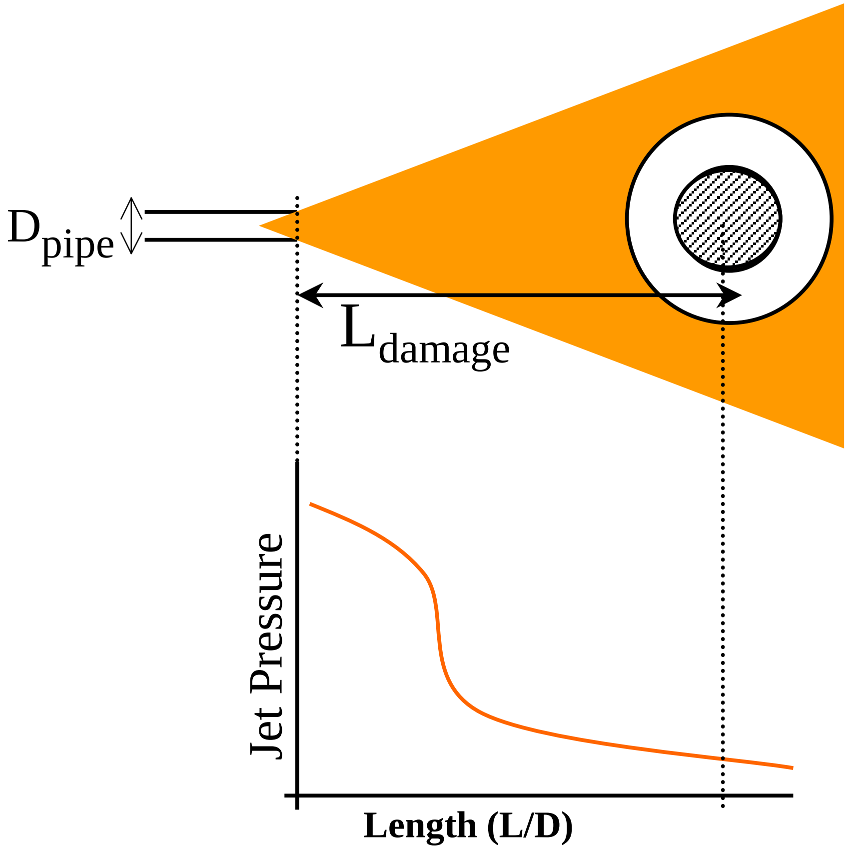
Size Distribution of Debris Generated







Debris Generation Testing: BWROG/CEESI



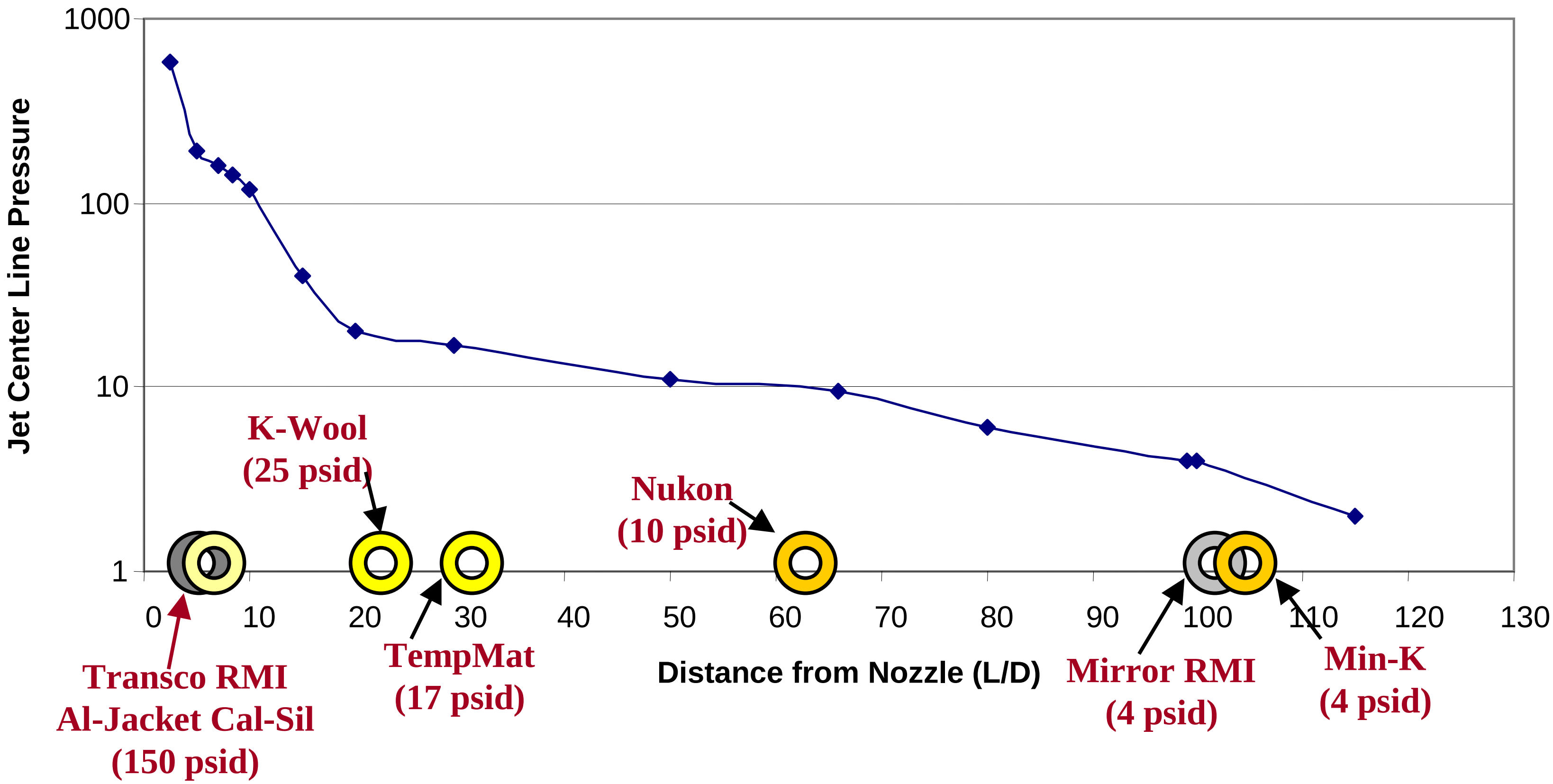
Elements of Testing Program

- Determine location of incipient damage
- Measure jet pressure corresponding to that location
- Measure size distribution of generated debris

Operating Parameters

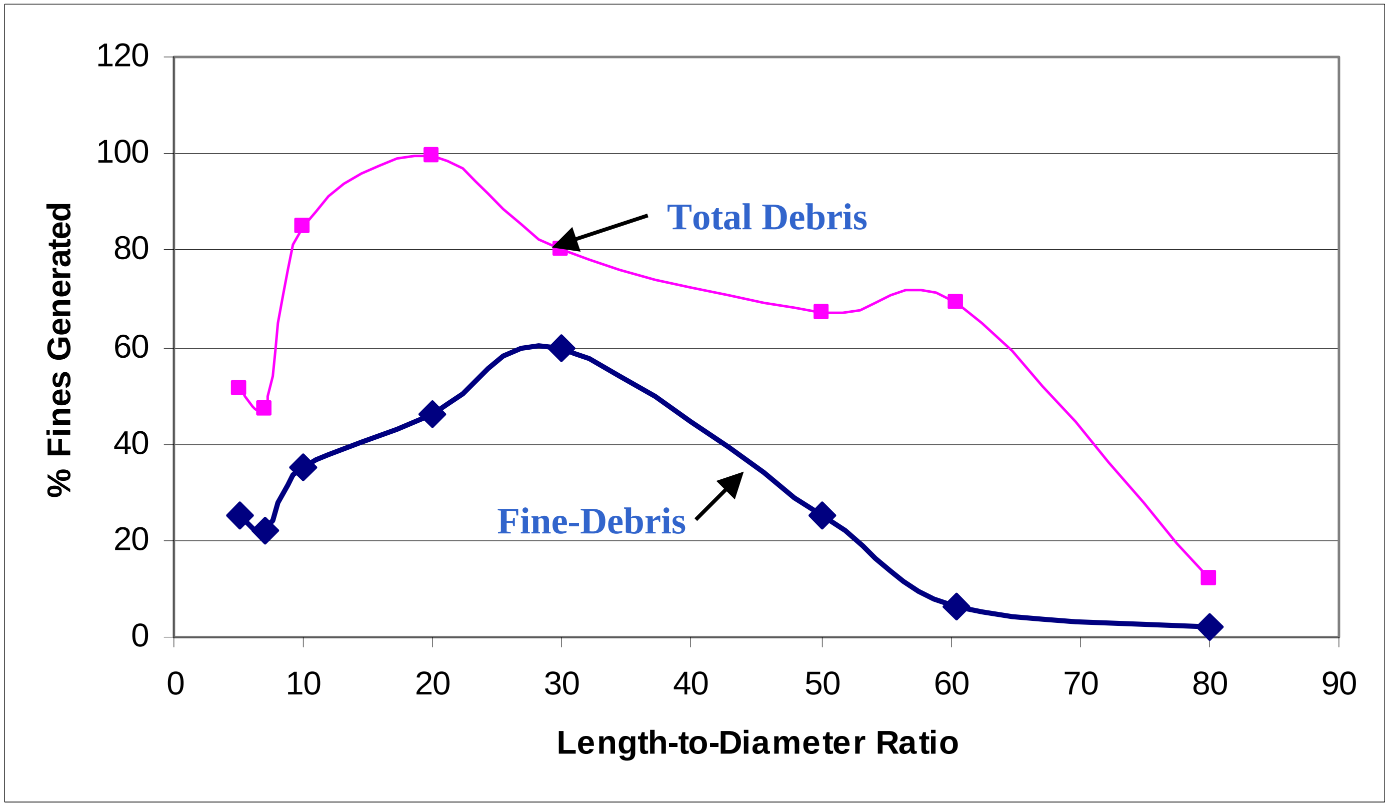
- Jet stagnation pressure of 1100 psia
- Jet pipe diameter 3 inches
- Target pipe diameter 12 inches
- Medium of expansion: air

BWROG Results: Damage Pressures

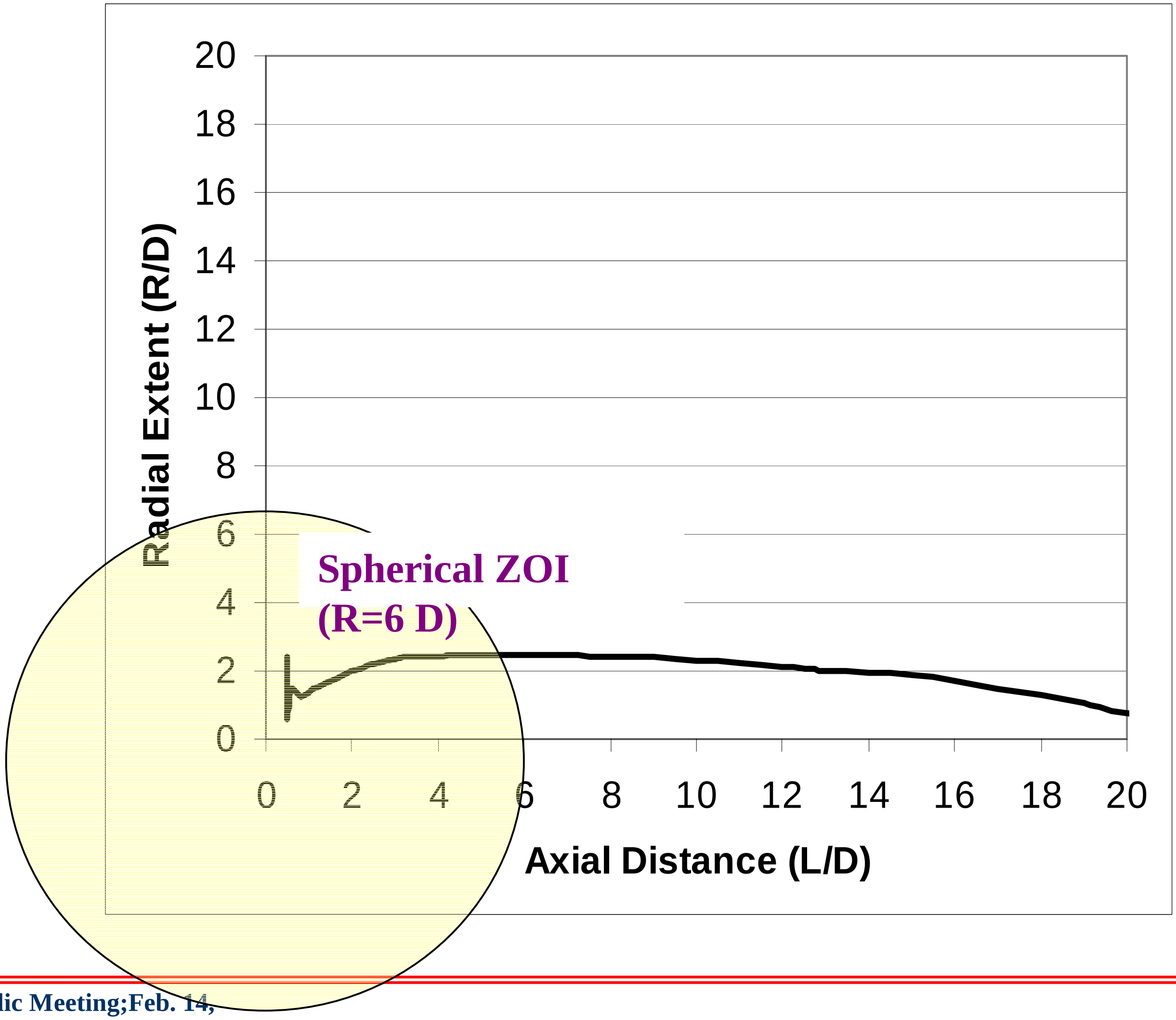


- Debris generation likely farther away from the break location
- Potential for generating more debris than USI A-43 Models

BWROG Tests: Size Distribution of Nukon



Use of BWROG Test Data: Define BWR ZOI



Use of BWROG Test Data:

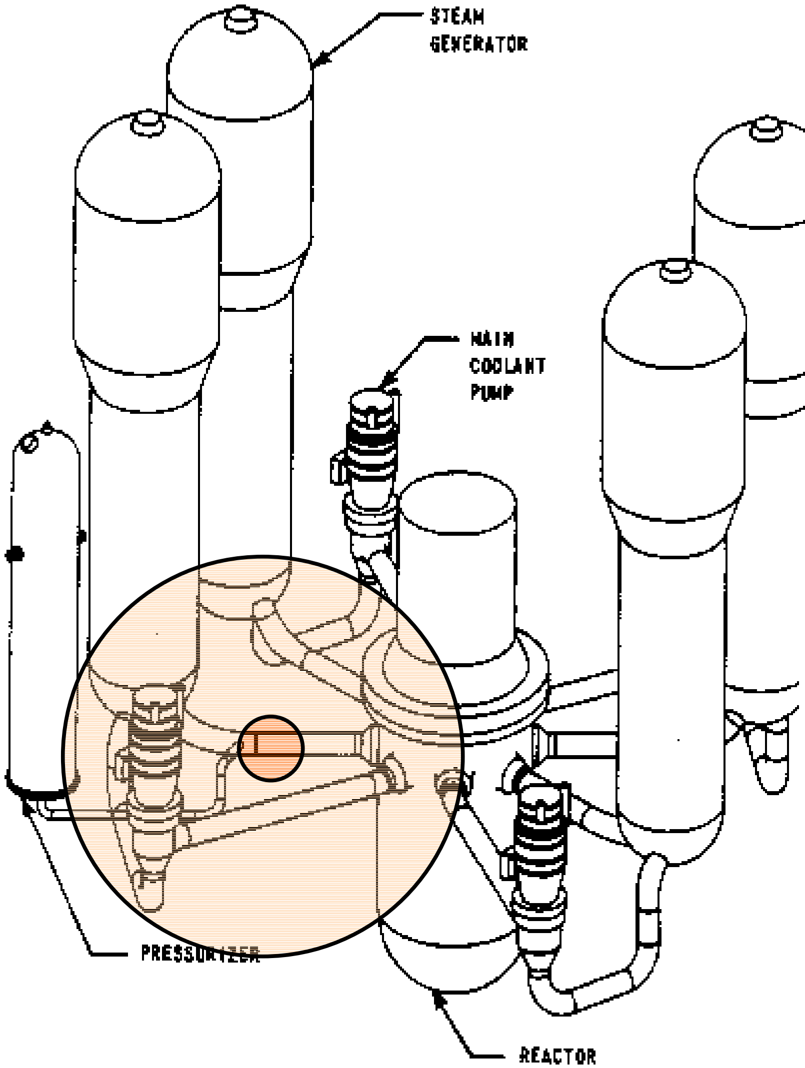
Dimensions of Spherical ZOI for BWRs

Insulation Type	P_{damge} (psig)	Radius of Sph. ZOI	
		X (D_{pipe})	ft
Transco RMI/Al Jacket Cal-Sil	150	6.0	12.0
K-Wool	25	7.8	15.5
TempMat	17	9.0	18.0
Nukon (fiber glass)	10	10.2	20.3
Mirror RMI (ss & Al)	4	11.7	23.3
Min-K	4	12.3	24.7

- The dimensions of the ZOI for BWRs are much larger than the USI A-43 ZOI values for PWRs
- Use of BWROG data in the GSI-191 study has the following uncertainties
  - Do the differences in operating conditions impact debris generation?
  - No conclusive data exist to answer this question

Need for Additional Test Data:

Differences in Reactor Operating Conditions



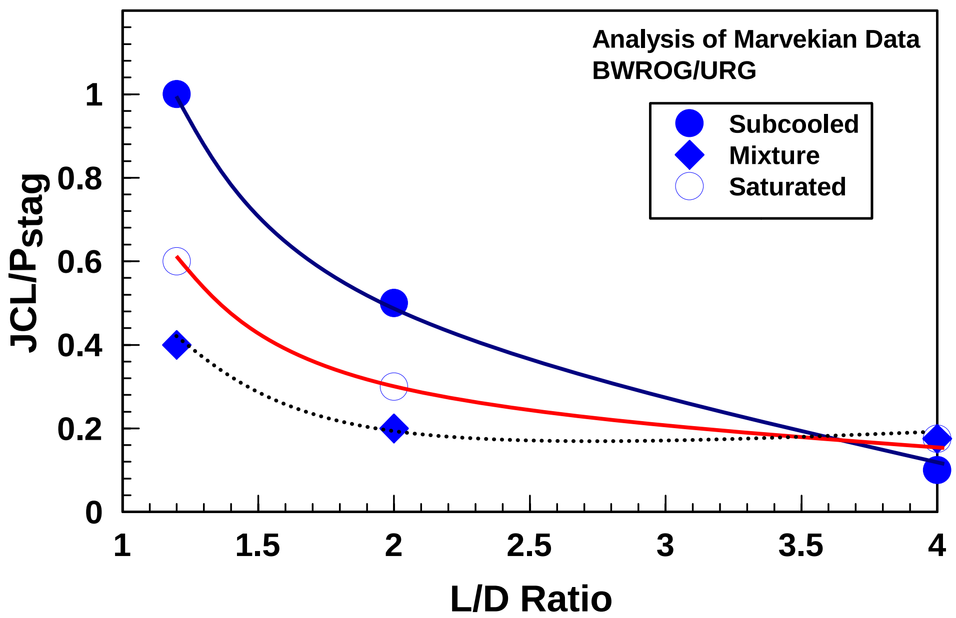
Operating Conditions

	PWR	BWR
Pressure (psi)	2235	1035
Cold-Leg Temp (F)	550	420 (FW)
Hot-Leg Temp(F)	620	530 (RCL)
Sat. Temp (F)	651	550

- PWRs are predominantly sub-cooled. During blowdown, steam venting may occur at low pressures.
- PWRs operate at much higher pressures.
- Do these differences impact debris generation, debris size, or debris shape? Limited European data. Need additional data.

Need for Additional Data:

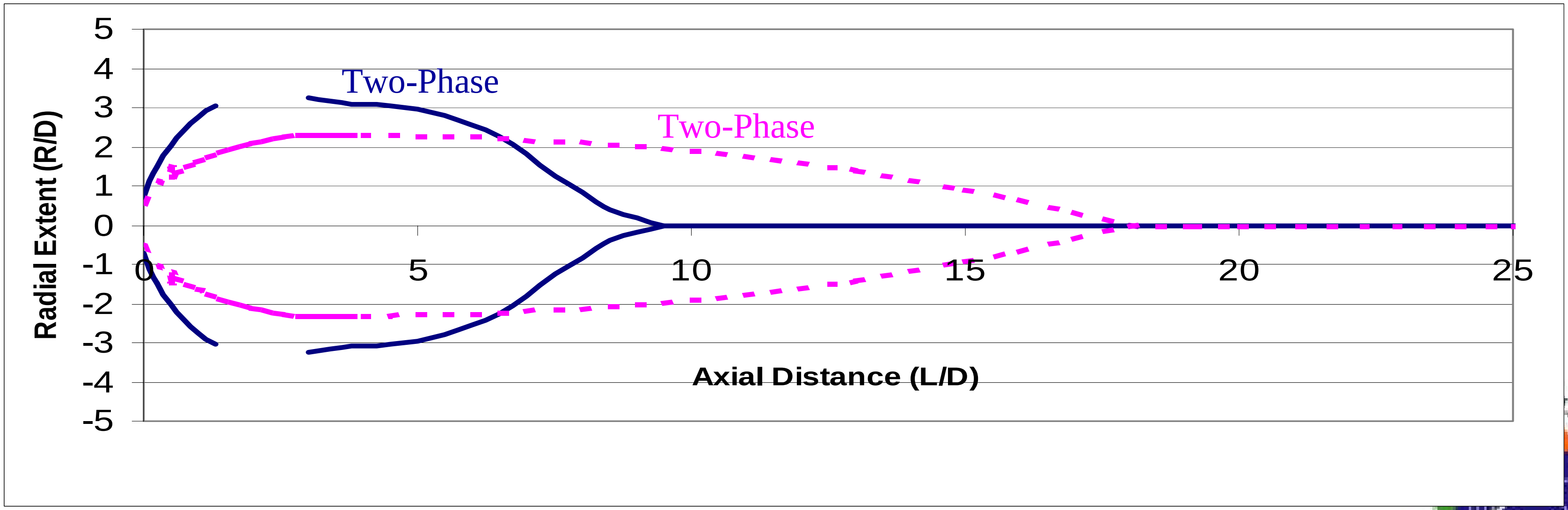
Insights from Marvekan Jet Tests



- **The jet center-line pressure in the subcooled two-phase jets tends to decay faster than saturated and/or steam jets**
- **Nomenclature**
  - Subcooled Jets: Jets are subcooled at the nozzle entry. They flash into steam-water mixtures as they expand.
  - Saturated: Jets are near saturation at the nozzle entry.
  - Steam: Jets are steam at the nozzle entry (condensation causes water).
- BWROG concluded that recirc lines (slightly subcooled to saturated) would have approximately the same ZOI)

Need for Additional Data:
Implications of Differences in Operating Conditions

- **Sub-cooled/saturated blowdown jet expansion different**
  - The subcooled jets are known to expand wider and not penetrate as far.
  - These jets are vapor continuum with large quantities of water in droplet suspension (droplets are 10 micrometers).
- **Use of BWROG Test data for PWRs without validation may not be appropriate.**
  - BWROG test data are lagging for certain insulation types (e.g., cal-sil, coatings).

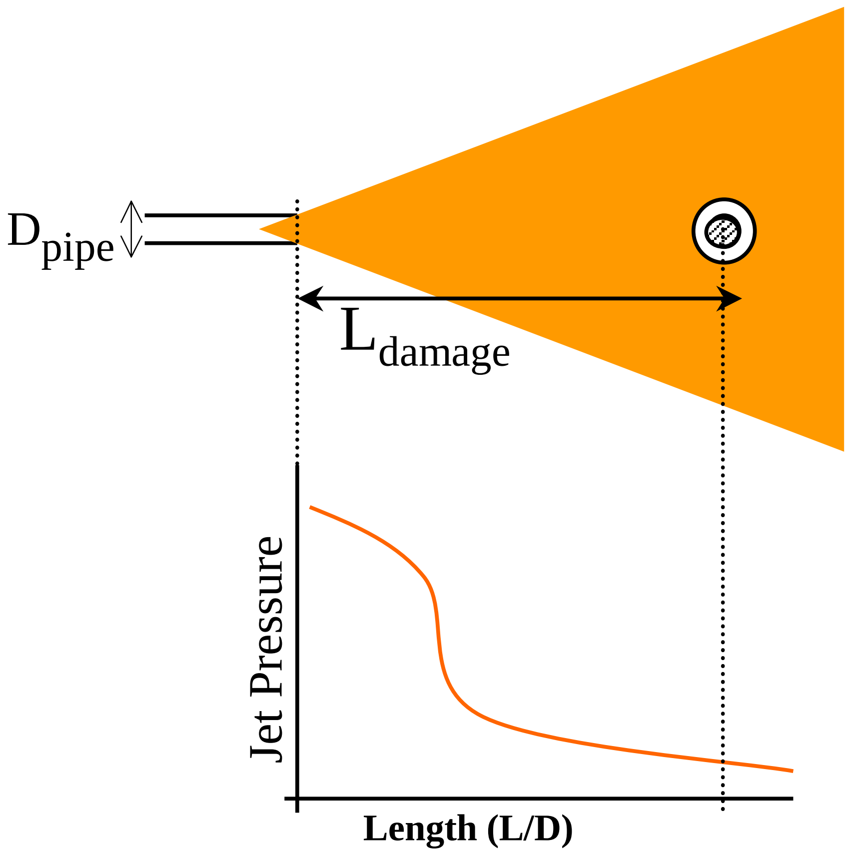


Plans for Obtaining Test Data:

Key Elements of NRC/LANL Approach

- **Participate in Ontario Power Generation (OPG) Test Program.**
- **Perform Computer Simulations and Analyses to Identify Additional Testing Necessary to Obtain Data for US PWR Use.**
  - RELAP Simulations of US PWRs and OPG test setup. Identify differences and modifications necessary to address these differences (e.g., duration of blowdown and steam-quality during blowdown).
  - Jet models to simulate expanding jets and validate them using test data.
- **Identify Insulations and Materials for Testing.**
- **Use Data Together with Models and Computer Simulations to Define the ZOI for PWRs.**
  - Validated jet models together with destruction pressures from testing
  - Generally follow the technical approach developed for BWRs

Debris Generation Testing: OPG Program



Elements of Testing Program

- Determine location of incipient damage for different orientations.
- Estimate jet pressure corresponding to that location.
- Measure size distribution of generated debris.

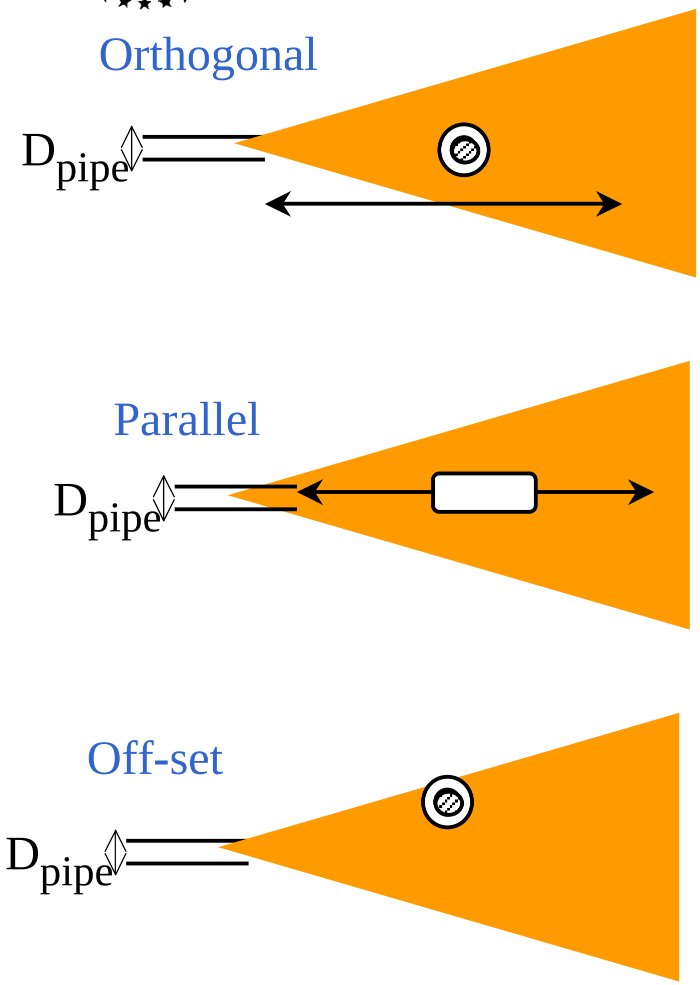
Operating Parameters

- Jet Stagnation Pressure: 1600 psia
- Jet Pipe Diameter: 3 inches (2.86 inches)
- Target Diameter: 4 inches
- Test Medium : Two-Phase Blowdown

Test Materials

- Calcium-Silicate
- Fiber Glass

Debris Generation Testing: OPG Program

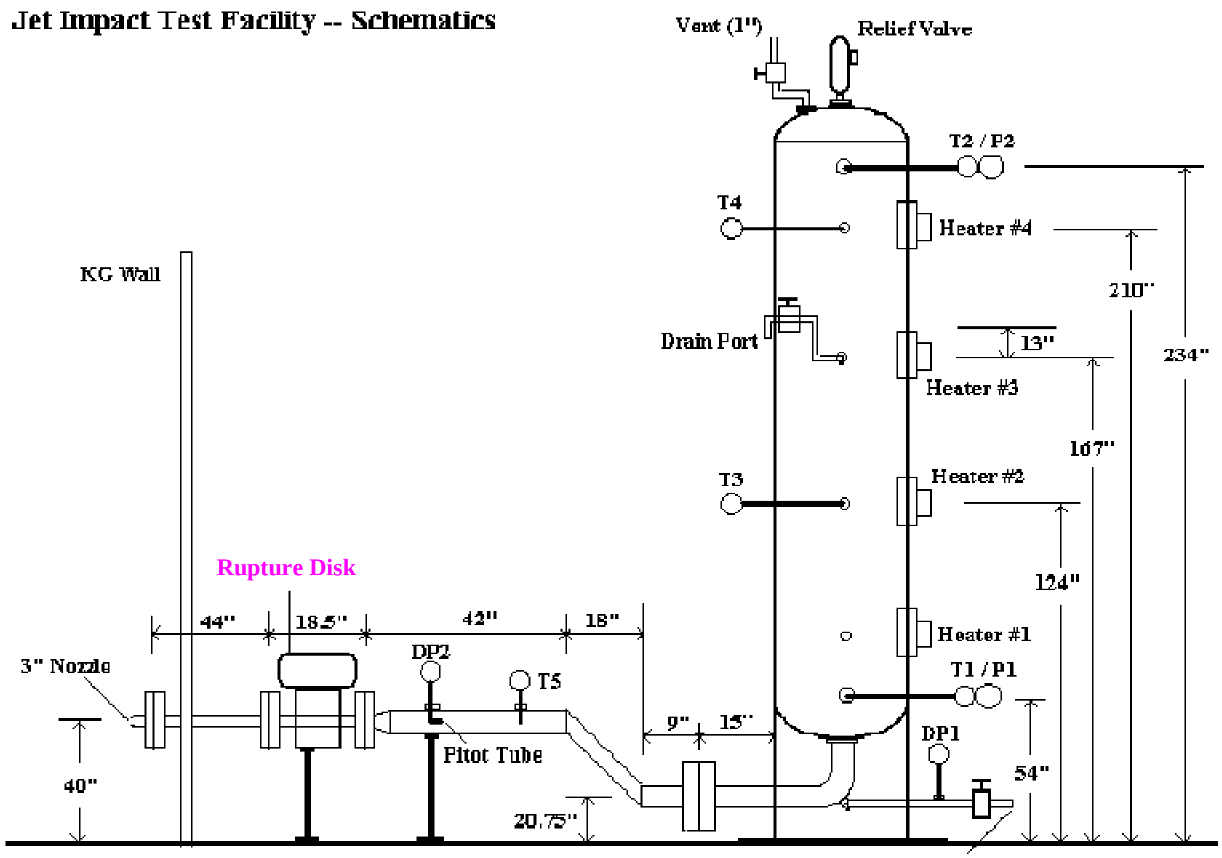


Insulation Mounting Schemes
- Orthogonal
- Parallel
- "Wall" Deflected

Use of Data
- Similar to that proposed by NRC
- Data resolution to support ZOI reduction from the present value of 10D
- Emphasis on particulate debris

LANL Role
- Participation and access to test data
- Provide results of jet modeling and work together with OPG Engineers on data interpretation

OPG Debris Generation Testing: Test Setup



OPG Debris Generation Testing: Test Results

Details
- Insulation: Calcium-Silicate
- Nozzle Diameter: 3 inch nominal
- Target Diameter: 3 inch nominal

Debris Gen. Testing: LANL Modifications

Objective: Obtain data necessary to develop and validate a defensible ZOI model that can be used in the GSI-191 study.

- Fundamental understanding of the debris generation mechanisms and how they are impacted by jet conditions
- Data necessary to validate jet models and other models to be developed
- Data for Insulations of interest
- Parametric studies

Elements of Testing Program

- Measure jet pressures at the location of incipient damage
- Quantify the impact of blowdown duration
- Quantify the impact of nozzle diameter
- Obtain Data for Additional Insulations

Hardware Modifications

- Instrument upstream of nozzle for pressure and temperature (useful for RELAP)
- Instrument the target pipe with transducers to measure radial and axial impingement pressure distribution (jet model validation)
- Change nozzle diameter
- Double reservoir volume

Test Materials

- Fiberglass, mineral-wool, RMI
- Paints and coatings

Debris Generation Testing: NRC/LANL Baseline

- **Total of 14 tests (option to increase to 20)**
- **4 to 5 instrumented tests (no insulation; pressure measurement)**
- **Remaining (10-11) insulation tests**
  - Test matrix to be finalized as OPG testing nears completion
- **Collected debris to be used in UNM transport testing**

LANL Use of Test Data: Technical Approach

❶ Understand damage mechanism and factors that effect damage.

❷ Develop appropriate scaling rationale. Derive “destruction pressure” for each insulation of interest.

❸ Translate “destruction pressures” into ZOI applicable to PWRs.

❹ Estimate fraction of debris that is “fines.”

❺ Use the ZOI and fraction of “fines” in reference plant analyses.

LANL Use of Test Data:
Understand Damage Mechanism

- **Mechanisms for peeling-off metal jackets (or encapsulation)**
  - Total drag force
  - Deformation of jacket and/or the bands to increase projected area

- **Mechanisms for destruction of insulation**
  - Erosion (e.g., Calcium-Silicate and nonencapsulated fiberglasses)
  - Penetration of nylon or canvas clothing

LANL Use of Test Data: Rationale

- **Is the damage directly attributable to local jet impingement pressures?**
  - Independent of medium of expansion
  - Use jet models (and pressure measurements) to compare local impingement pressures for various media and how they are related to damage
- **If yes, impingement pressure to scale destruction pressures.**
  - Use jet models to layout contours of destruction pressure isobars
  - Address various stages of PWR blowdown:

    (1) subcooled blowdown (2000 psi and 60 ^{o}F Subcooled)

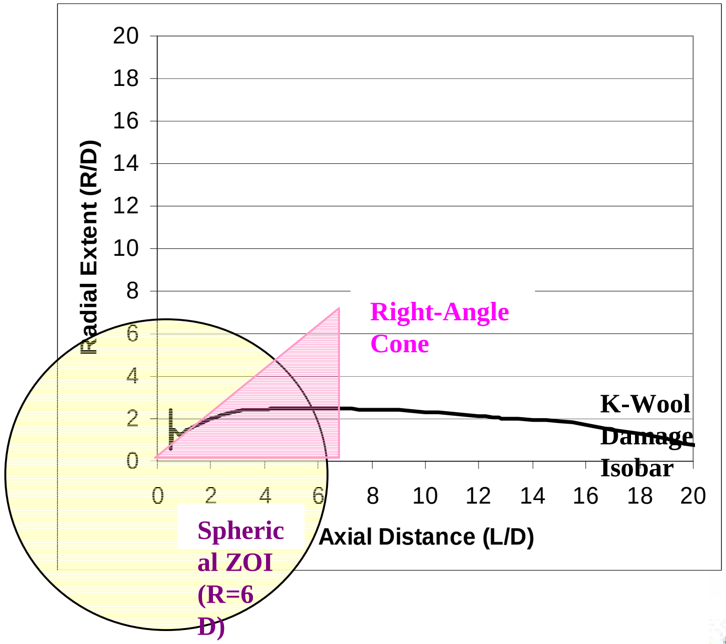
    (2) saturated blowdown (1500 psi and $x = 0.1$)

    (3) steam blowdown (1000 psi and $x = 0.4$)
- **If no, explore other means for scaling destruction pressures.**
  - Address issues using conservative interpretation of data
  - We must know damage mechanisms before we know how we would scale

Zone of Influence Model: PWR Study

- Conserves volume beneath a destruction pressure isobar
- Explore two different shapes
  - Conical (Non-congested)
  - Spherical (congested)
  - Other ?? (SG compartment)
- Use reference plant analyses to select
  - Debris generation parameterics
  - CFD analyses

NRC or LANL has not finalized. These are preliminary ideas.



Estimate Debris Generated in Reference Plants

- **Application to Reference Plants**
  - LANL developed an automated approach
  - Reference Plants #1 and #2 CAD models already coded in
  - Numerous parametrics planned

DEBRIS TRANSPORT TEST PROGRAM

Arup K. Maji
University of New Mexico

EXPLORATORY TESTS: JUN ‘99 - FEB ’00

PARAMETRIC FLUME TESTS: FEB ‘00 - SEP ‘00

3-D TANK TESTS: OCT ‘00 - PRESENT

TYPES OF DEBRIS EVALUATED

A. NUKON
B. ALUMINUM RMI
C. CALCIUM SILICATE
D. STAINLESS STEEL RMI
E. THERMAL-WRAP
F. KAOWOOL
G. MARINITE BOARD
H. SILICONE FOAM

SCREENING TESTS

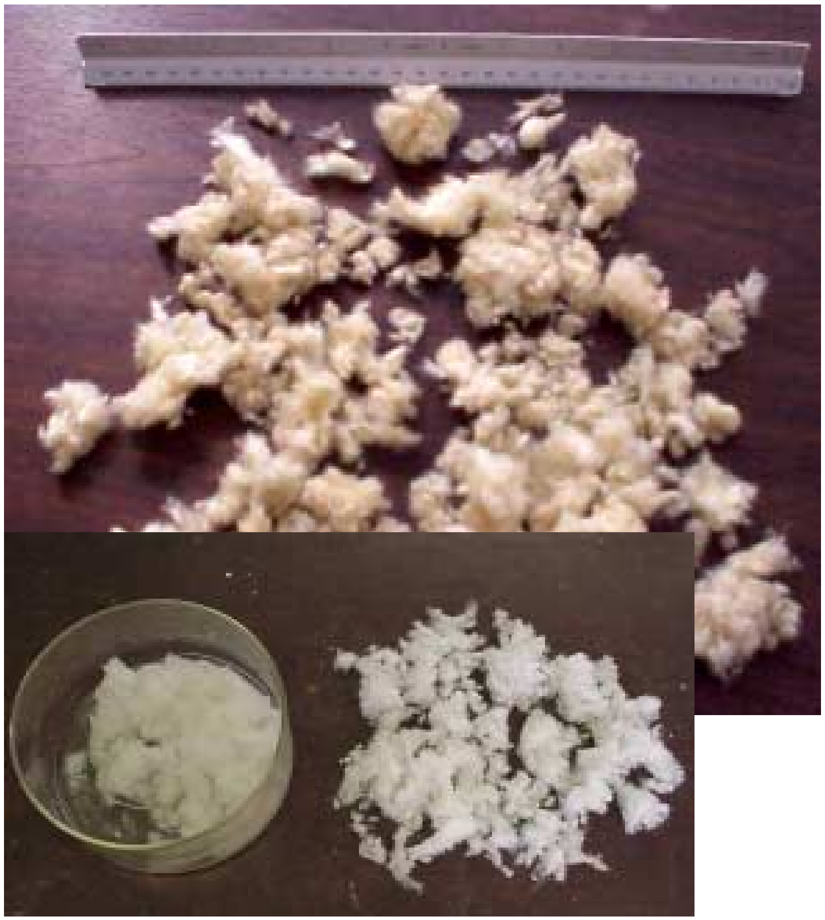
C. Calcium silicate
G. Marinite board
H. Silicone foam
D. E. Large size (1')

FULL TEST MATRIX

A. Nukon
E. Thermal-wrap
F. Kawool
B. Aluminum RMI
D. Stainless Steel RMI

FIBERGLASS INSULATION

Nukon: Airjet processing

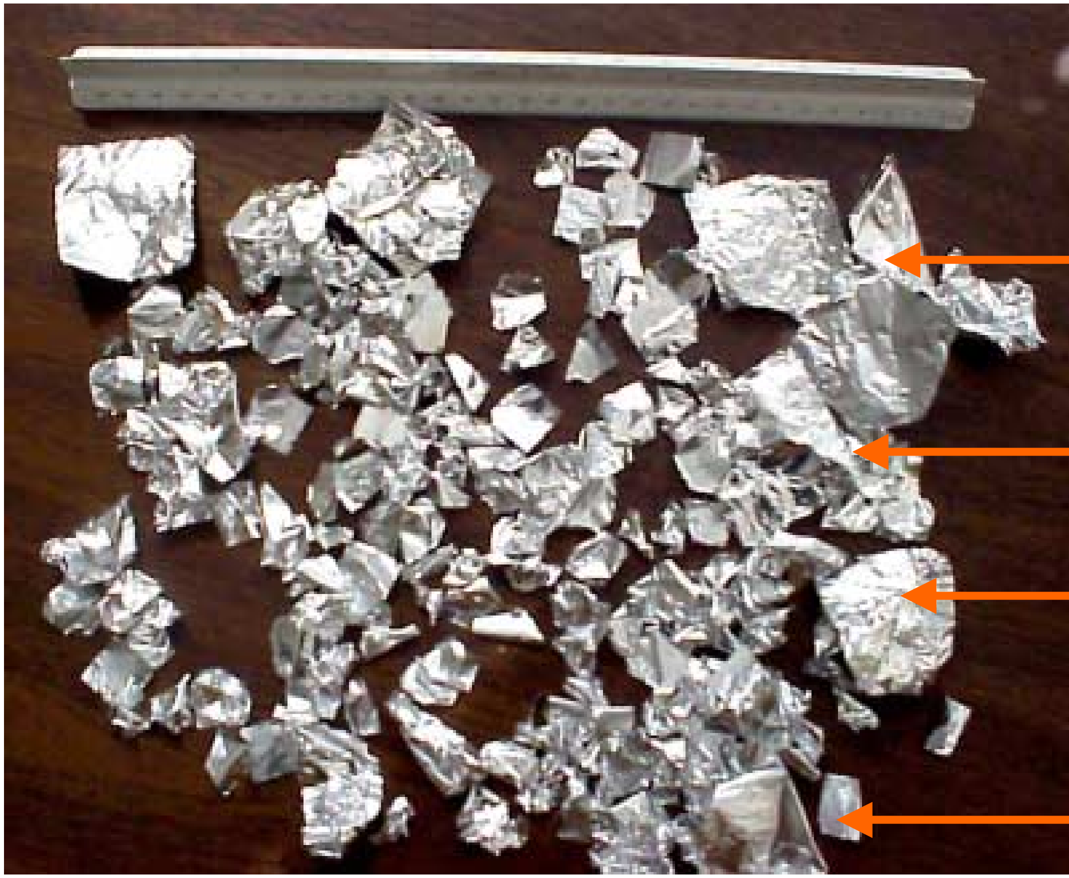


Kawool & Thermal Wrap: Leaf Shredder

All Fiberglass debris treated in 80°C water

REFLECTIVE METALLIC INSULATION
Aluminum & Stainless Steel

Al RMI: Airjet processing, 1 mil thick
S.S. RMI: Hand processing, 2 mil thick



Semi-crumpled

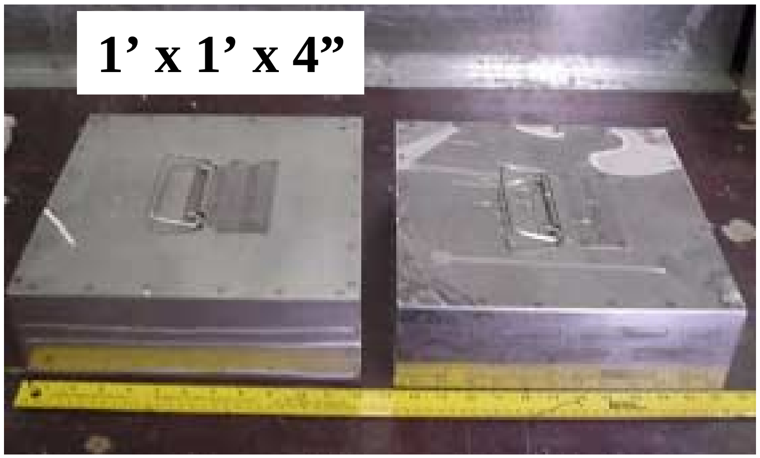
Crumpled

Flat 2" square

Flat 3/4" square

LARGE SIZE DEBRIS (EXPLORATORY)

Stainless Steel RMI Cassettes



Marinite Boards

Thermal Wrap Blankets

Silicone Foam

FINAL TESTS

DEBRIS TYPES

Nukon
Thermal-wrap
Kawool
Aluminum RMI
Stainless Steel RMI

TEST TYPES

Screen Accumulation
Incipient Motion
Lift Over Curb
Converging Flow
Drop Transport

SCREEN ACCUMULATION TESTS

Diffuser on, no curbs, inlet above surface
18" water height.
Debris dropped 3" below water, 3" from screen

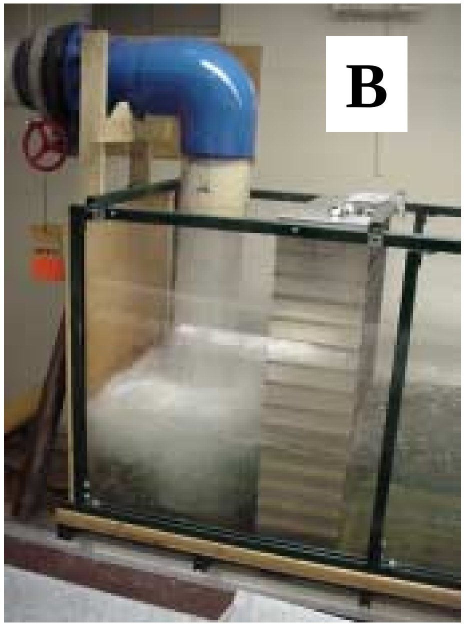
NUKON	**0.05 ft./sec**
THERM. WRAP	**0.04 ft./sec**
STEEL RMI	**0.12 ft./sec**
AL RMI	**0.11 ft./sec**

INCIPIENT MOTION TESTS

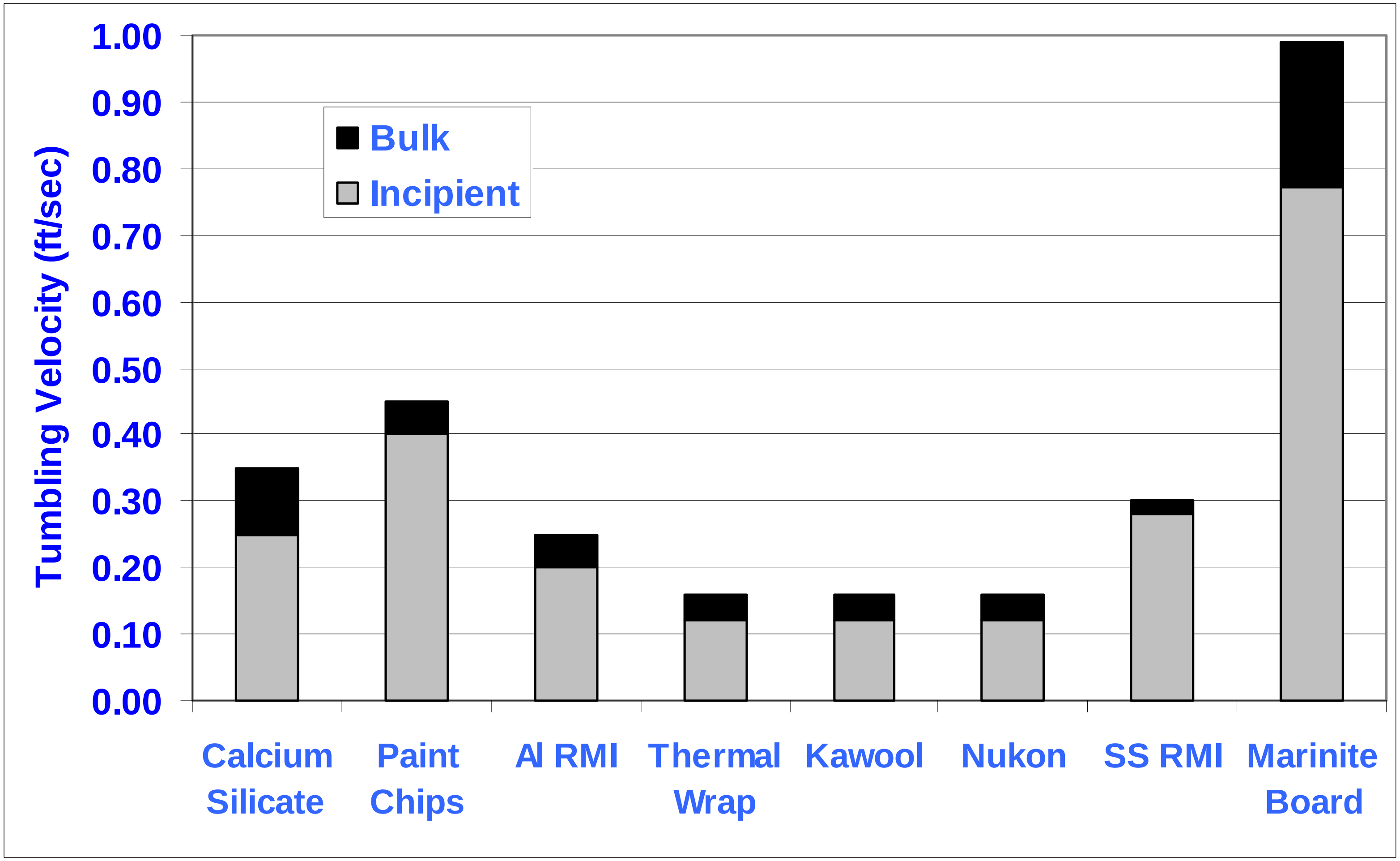
Water height = 18” ± 1”

Debris introduced 4’ 7” from the upstream screen

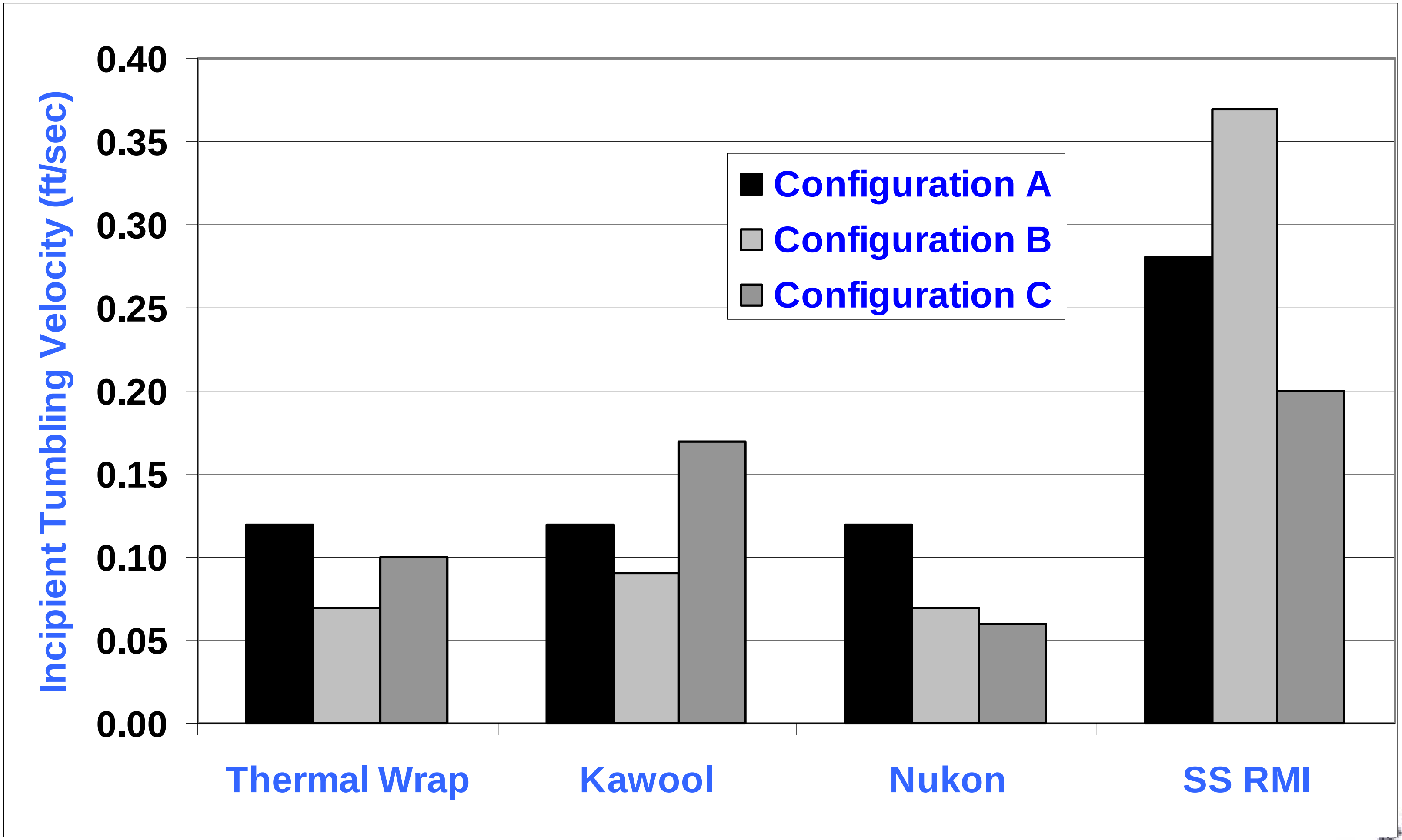
- **Configuration A: Diffuser on, 10” dia. Pipe above surface**
- **Configuration B: Diffuser off, 10” dia. Pipe above surface**
- **Configuration C: Diffuser off, 6” dia. Pipe 1’ above floor**



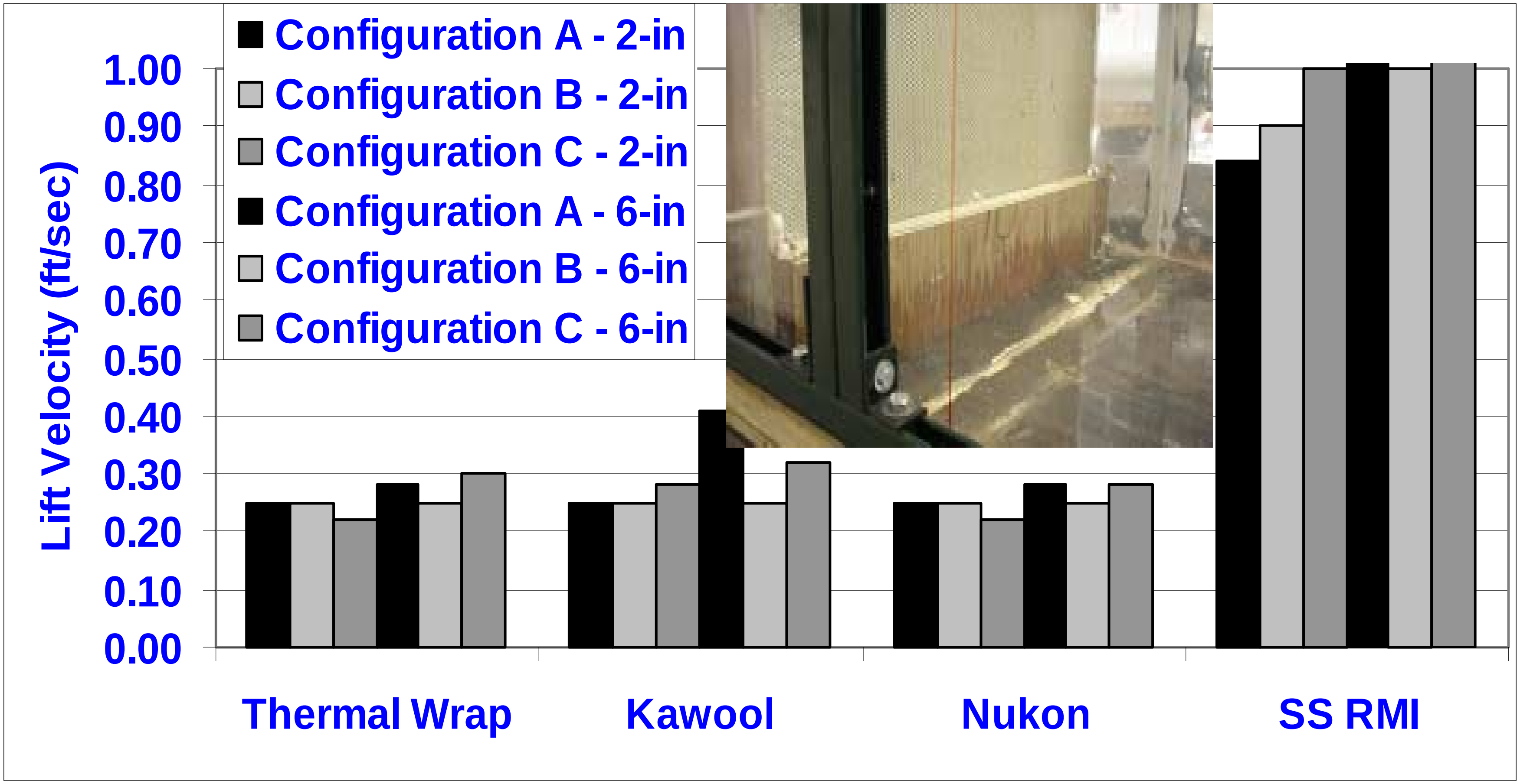
INCIPIENT MOTION (A)



INCIPIENT MOTION (A,B,C)



LIFT OVER 2” & 6”CURB



TRANSPORT DISTANCE (DROP TEST)
(Configuration A - nonturbulent)

Debris Type	Size	Measured Distance (in.)	Distance based on Vterm (in.)
AL RMI (2”)	Crumpled	10-16	24-30
	SemiCrumpled	16-28	17-21
	Flat	15-20	14-15
RMI(1/2”)	Crumpled		
	Semicrumpled		
	Flat		
Nukon	Small (1 gm.)	15-30	17-21

TRANSPORT DISTANCE (DROP TEST)

ALL DEBRIS TYPE TESTED UNDER TEST Configuration: A (TBD), B, and C, (5 different Q)

EXAMPLE: NUKON, TEST Configuration B Velocity = 0.19 ft./sec, Height = 18”

Time (sec.) to bottom (seconds)	Distance Traveled (inch)	Distance = Time x Vel. (inch)
11	15	25
6	29	13.7
8	26	18.2
5	20	11.4
6	18	13.7

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Title: **DEBRIS TRANSPORT CHARACTERISTICS**

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Department of Energy Training Complex
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DEBRIS TRANSPORT CHARACTERISTICS

by

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February 2001

DEBRIS TRANSPORT CHARACTERISTICS

INTRODUCTION

In the unlikely event of a Loss of Coolant Accident (LOCA) in a pressurized water reactor (PWR), break jet impingement would dislodge thermal insulation from nearby piping, as well as other materials within the containment, such as paint chips, concrete dust, and fire barrier materials. Steam/water flows induced by the break and by the containment sprays would transport debris to the containment floor. Subsequently, debris would likely transport to and accumulate on the suction sump screens of the emergency core cooling system (ECCS) pumps, thereby potentially degrading ECCS performance and possibly even failing the ECCS.

In 1998, the U. S. Nuclear Regulatory Commission (NRC) initiated a generic study (Generic Safety Issue-191) to evaluate the potential for the accumulation of LOCA related debris on the PWR sump screen and the consequent loss of ECCS pump net positive suction head (NPSH). Los Alamos National Laboratory (LANL), supporting the resolution of GSI-191, was tasked with developing a method for estimating debris transport in PWR containments to estimate the quantity of debris that would accumulate on the sump screen for use in plant specific evaluations.

The analytical method proposed by LANL, to predict debris transport within the water that would accumulate on the containment floor, is to use computational fluid dynamics (CFD) combined with experimental debris transport data to predict debris transport and accumulation on the screen. CFD simulations of actual plant containment designs would provide flow data for a postulated accident in that plant, e.g., three-dimensional patterns of flow velocities and flow turbulence. Small-scale experiments would determine parameters defining the debris transport characteristics for each type of debris. The containment floor transport methodology will merge debris transport characteristics with CFD results to provide a reasonable and conservative estimate of debris transport within the containment floor pool and subsequent accumulation of debris on the sump screen. The complete methodology will, of course, include a means of estimating debris generation, transport to the containment floor, transport to the sump screen, and the resulting loss of NPSH.

A panel was convened to identify the important phenomena associated with debris transport on the containment floor. This panel produced a table known as the phenomena identification and ranking table (PIRT). Based on the PIRT combined with preliminary CFD analyses, LANL determined the physical processes governing the transport of debris on the containment floor. These processes include: the settling of debris in turbulent pools, tumbling/sliding of settled debris along the floor, re-entrainment of debris from the containment floor, lifting of debris over structural impediments, retention of debris on the vertical screens, and the destruction of debris due to sump pool dynamics, thermal, and chemical effects.

The experimental program described herein was designed to gather data on these transport processes. These tests were conducted at the University of New Mexico (UNM) Open-Channel Hydrology Laboratory. The ranges of experimental parameters and the types of insulation that needed testing were based on a survey of the U. S. PWR plants and CFD simulations of volunteer plants. Potential debris in U. S. PWR plants include various combinations of fibrous, particulate, or metallic thermal insulations, fire-barrier materials, and miscellaneous debris, such as paint chips, concrete dust. The specific materials selected for testing at UNM included: Nukon, Thermal Wrap, Kawool, calcium silicate, aluminum and stainless steel RMI, paint chips, silicone foam and Marinite board.

TEST APPARATUS

LARGE FLUME

The primary test apparatus used to conduct these tests was a relatively large linear flume. The large flume was designed as a separate-effects test apparatus to simulate a variety of flow conditions and to study debris transport under these conditions. The flume consisted of a sturdy open-top box 20-ft long, 3-ft wide, and 4-ft high with Plexiglas side panels for viewing the transport of debris. The large flume rested on two sturdy 6-in. by 6-in.

aluminum I-beams that in turn rested on the UNM 50-ft long tilting table where hydraulic jacks were used to level the table. The first 6 ft of the flume was reserved for the water inlet and flow conditioning apparatus and the final 4 ft section was reserved for a debris catcher screen and the outlet drain. This left a central 10-ft section available for testing. The water surface was a free flowing surface. The floor of the flume was coated with an epoxy liner to obtain a surface roughness comparable to an epoxy coated PWR floor and the flume was wide enough to negate wall-effects. The wall and floor sections were held together with a sturdy steel framework. A variable speed centrifugal pump capable of 2200 GPM pumped water from the sump to overhead piping to the test apparatus. At the rear of the flume, water drained through an outlet pipe back into the sump. The flow velocity was thus variable to velocities up to and beyond 1.5 ft/s. The large flume is shown in Photo 1.

A range of pool flow dynamics would likely exist in a containment floor pool following a postulated LOCA accident, i.e., from quiescent or nearly still water to extremely turbulent water. A goal of the large flume testing was to explore the effect of inlet flow patterns and fluid residual turbulence on the transport of debris. To achieve this goal, flow straighteners and diffusers were used to condition the flow prior to its entering the test section. The conditioning method depended upon the type of test being conducted. Three methods of inlet flow conditioning were used in the large flume tests. These methods were: 1) Configuration A: Diffused Flow Entry, 2) Configuration B: Free Fall Flow Entry, and 3) Configuration C: Immersed Pipe Flow Entry. An extensive effort was devoted for understanding types of flow patterns established in the flume for these different operating conditions, both experimentally and using CFD simulations of the large flume.

Using Configuration A to condition the flow, flow turbulence was extensively dampened to provide a uniform quiescent flow throughout the test section. Therefore, the local flow velocities were unidirectional and well represented by the average flow velocity. In this manner, the local conditions affecting the transport of individual pieces of debris were well known, i.e., debris transport could be correlated with the flow conditions affecting that piece of debris. On the other hand, Configuration Methods B and C provided two different types of three-dimensional inlet flow conditioning that retained both non-uniformities and turbulence affecting debris transport. In this manner, the impact of flow turbulence could be realistically assessed. With non-uniform flow conditioning, the local flow velocity affecting an individual piece of debris was not necessarily represented by the average flow velocity.

Using Configuration A, the diffused flow entry was achieved by implementing a series of damping pads followed by a flow straightener. The damping pads were actually synthetic air-conditioning humidifier pads held in place by #4 wire mesh attached to wooden frames. A dampening section consisted of a total of five wooden frames holding four humidifier pads in-between. The sheet-metal lattice-structured flow straightener furthered straightened the flow. The dimensions of the straightener assembly were 3-ft by 4-ft to fit within the flume cross-section, and 1-ft thick with 3-in. square lattice cells. The flow conditioner section, for Configuration A, is shown in Photo 2.

Considerable flow visualization/characterization testing was done to develop this hardware configuration. Conventional techniques such as dye injection and tracer particle tracking were used to visually establish that flow patterns were straight and that no visible eddies existed in the test section. In addition local flow velocities were measured at several horizontal and vertical locations to ensure that flow entering the test section was straight and that no unusual flow patterns existed. These measurements relied on ‘neutrally buoyant water balloons’ at low flow rates and ‘pigmy’ type turbine flow meters at the higher flow rates through the flume.

In addition, CFD modeling of the flume flow patterns was also undertaken to further assure that flow patterns were as intended. These models also confirmed that flow patterns expected for this configuration were uniform, although slightly faster flow occurred near the top surface. For example, a CFD simulation for diffuse flow entry is shown in Fig. 1, which illustrated uniform flow in the test section even though the inlet section and, to a lesser extent, the outlet section were highly non-uniform and turbulent. The CFD analytical results were in good qualitative agreement with the experiment flow-visualization results.

Finally, experiments conducted in the large flume to measure tumbling velocity of regularly cut pieces of low-density fibrous insulation were compared with data obtained in other USI A-43 studies for similar pieces and test data obtained from the small flume. These comparisons further established that flow patterns in the flume corresponding to Configuration A were calm, straight and free of eddies.

Photo 1. Large flume test apparatus.

Photo 2. Diffuse flow entry flow conditioning section.

When conditioning flow with Configuration B and C, the series of dampening pads were removed leaving only the flow straightener to condition the flow, however, their method of introducing water to the inlet section differed. In Method B, the water was allowed to freefall from the pipe exit located approximately 2 ft above the water surface. Flow measurements suggested that a fast moving water layer existed at the bottom and further that the flow field was dominated by large-scale eddies. The location and extent of these eddies appeared to shift closer to the sump as flow rate was increased. Qualitatively at least it could be stated that the flow patterns were in agreement with those predicted by the CFD analyses. They also appeared to capture many of the important aspects of the flow patterns predicted by the CFD analyses for 'exposed sump' geometry. In Configuration C, the inlet water pipe was extended to exit 1 ft from the flume floor and the pipe diameter was reduced from 10 in. to 6 in. Thus, Configuration C provided a different three-dimensional flow pattern than that of Configuration B.

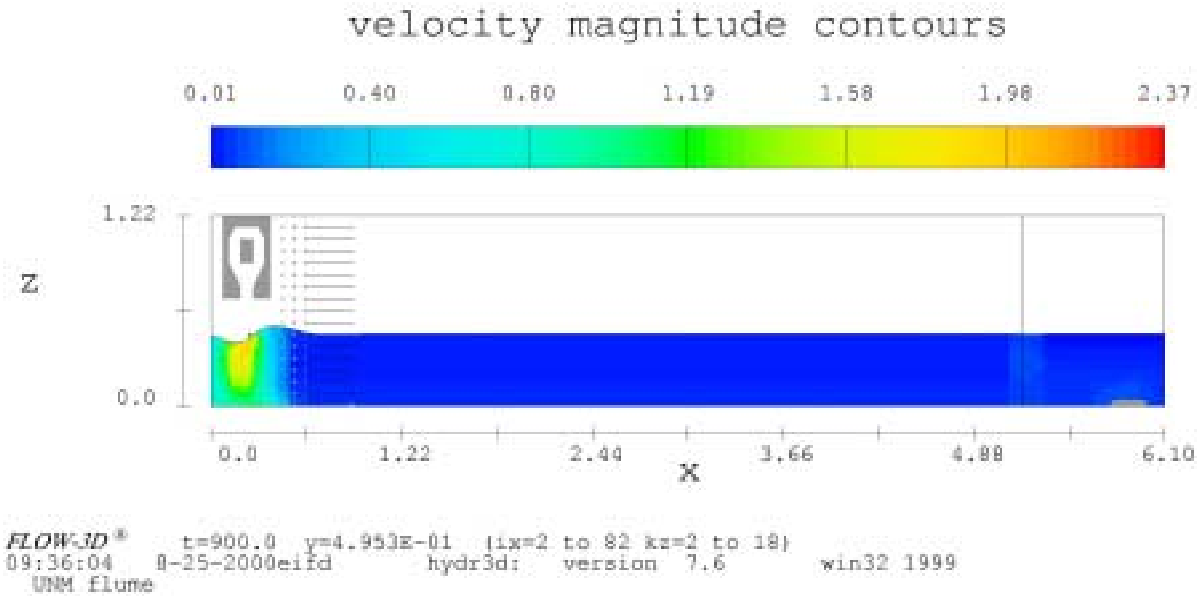


Fig. 1. Example CFD result for the diffuse flow-conditioning configuration.

A screen filtered the water flow leaving the large flume test section. This screen both filtered the water before it was returned to the sump and provided a means of measuring head loss associated with debris buildup on a screen. This screen was constructed from commercially available screening material. The weave of this screen created diamond shaped cells that were approximately 1/4-in. wide by 1/8-in. height[1]. The screen was supported by a section of standard-use grating located directly behind the screen.

Floor obstructions in the form of 'curbs' were attached to the flume floor in selected tests to simulate curbs found in nuclear power plants. These curbs were placed just in front of the screen, were about 2-in. thick, and either 2 in. or 6 in. in height. Photo 3 shows a typical curb in the standard test section along with the lower portion of the debris catch screen.

In selected tests, the flow cross section was altered to force the flow to accelerate by converging the sidewalls to examine the impact, if any, that accelerating water velocities had on debris transport. The channel width decreased from 3 ft down to 1 ft at the downstream screen over a length of 8 ft, thus the cross-sectional flow area was linearly decreased. The converging channel apparatus is shown in Photo 4.

<u>SMALL FLUME</u>

In addition to the large linear flume, a smaller flume, previously operated by UNM was available and used in selected tests. The dimensions of the small flume were 1-ft wide, 1.5-ft deep, and 10-ft long. The small flume was capable of testing insulation debris transport at full-scale transport velocities. The primary advantages of the small flume were 1) a uniform, calm and well-characterized flow throughout its length, 2) the debris were more visible

[1] Note that features of the screen (e.g., clearance size) were immaterial to the experiments conducted. Screen facial roughness was somewhat important because it influenced debris detachment velocity. From that point of view, the selected screen resembled PWR screens closely in that it offered a smooth surface without observable dimples or other such geometrical features that induced unrealistic friction.

due to the narrowness of its test section than was the wider large flume, and 3) it was relatively easy to clean fine debris, that could not be effectively filtered, from the flume and its sump (e.g., calcium-silicate dust). The small flume is shown in Photo 5.

Photo 3. Test obstruction curb (6-in.) and debris catch screen.

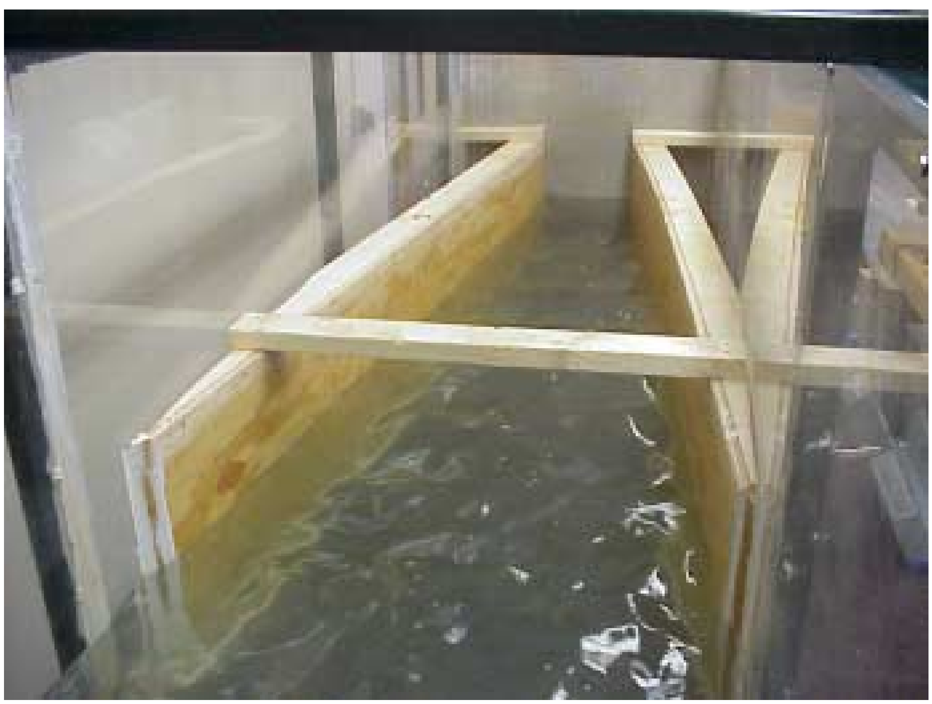


Photo 4. Converging test section.

Photo 5. Small flume test apparatus.

The flume had two pumps with the combined flow capacity of approximately 100 GPM. Water was pumped from a small collection volume underneath the flume into the flume entrance and then allowed to drained back into the collection volume at the flume exit. Front and rear control gates were used to control flow height and velocity through the flume test section. The slope of the flume could also be varied. Conventional flow visualization/measurement techniques were used to assure that calm, uniform and straight flow patterns existed through out the flume length.

The small flume was used extensively in the exploratory testing phase 1) to establish the importance of flume water height on debris transport, and 2) to develop test procedures that were ultimately used in the large flume. Comparison of small flume test data with the large flume test data also added a measure of quality assurance to the overall test data.

STILL WATER APPARATUS

Tests of selected debris behavior in still water were conducted to augment the flume debris transport tests. These tests included the measurement of the terminal settling velocity in still water and the dissolution behavior of calcium silicate insulation material. The effect of calcium silicate in the water on the settling velocity of other debris was also investigated with this apparatus. Specifically, the test apparatus was designed to provide insights into the following aspects of debris transportability:

1. How long does it take for the fibrous shreds to become fully saturated with water? And is that affected by water temperature?
2. Do Calcium-Silicate, Marinite or other such particulate insulations disintegrate in water? If so, how long does it take for the fragments to become dissolved in water? And is that affected by water temperature and/or turbulence?
3. What is the terminal velocity of each type of debris type and size being tested in the flume? And does temperature or the heights of water affect that?

This apparatus was used extensively during the exploratory phase 1) to evaluate the need for conducting transport testing at elevated temperatures and 2) to develop procedures for pre-treating the insulation debris. During the parametric testing phase the test apparatus was primarily used for debris characterization.

The terminal settling velocity measurements were performed by dropping pieces of pretreated debris of various types in a column of water and then timing their fall through a prescribed distance (10 to 30 in. below the water surface). The water column, shown in Photo 6, was constructed of Plexiglas and was 10 in. in diameter and 34 in. in height. As confirmed by exploratory testing, the height of the settling column was sufficient to ensure that terminal velocity is reached before debris reaches the bottom half of the test apparatus. A small water heater, located adjacent to the water column, was available to supply 80°C water to the column.

The dissolution behavior of calcium silicate, marinite and silicone-foam insulation fragments in water was investigated by dropping pre-characterized (mass and size measured) pieces into a large plastic cylinder (approximately 2 ft in diameter and 1.5 ft in height), filled with water to a height of 1 ft. Calcium silicate that did not disintegrate into the water settled into the tray placed in the bottom of the cylinder. This apparatus is shown on Photo 7.

Photo 6. Plexiglas water column.

Photo 7. Plastic cylinder used in dissolution tests.

EXPLORATORY TESTING

An exploratory test program was conducted to develop test procedures and to identify important parameters for detailed testing, i.e., eliminate further testing of parameters shown to have little impact on debris transport. Thus exploratory testing examined: 1) the impact of water temperature, 2) the interdependency of mixed debris, i.e., the influence of one debris type on another, 3) the impact of flume height, 4) the importance of floor surface roughness, 5) the uniformity of the flow and the influence of non-uniformities on debris transport, 6) rather or not, vertical mixing was possible at higher velocities, and 7) repeatability of test data.

Because post-LOCA temperatures, ~80^{o}C, would be considerable warmer than the room temperature, water used in flume operation, the impact of water temperature was examined to determine the validity of conducting debris transport testing at room temperature. The temperature affects water density, surface tension, and viscosity and the saturation and potentially structural stability of the debris.

Water temperature can dramatically affect the time required to saturate debris placed in water. At room temperature, Nukon for example typically continued to float on the surface for more than a day. However, if the Nukon was placed in 80^{o}C water, it readily sank and remained submerged in as little as 2 min. Therefore, it was determined that debris would in general have to be pretreated before transport testing. That is, debris was soaked in hot in 80^{o}C water for a period of time before undergoing testing. A period of 5 min was found adequate.

Terminal settling velocities were measured in both 22^{o}C and 80^{o}C water for a variety of debris types and sizes. Exploratory tests determined that water temperature did not significantly impact the terminal settling velocity measurements; therefore all remaining measurements of settling velocities were conducted using room temperature water.

Water temperature was found to significantly influence the rate of dissolution of calcium silicate in water, therefore water temperature was retained as a test parameter in those tests.

Selected transport tests involving two different kinds of debris were exploratory tested to look for possible synergistic effects. Specifically, the transport characteristics of Nukon debris were examined to determine if the presence of fine calcium silicate particulate could alter either the terminal settling velocity or the tumbling velocity of pieces of Nukon. The presence of calcium silicate did not detectably affect either the terminal settling velocity or the tumbling velocity of Nukon.

The height of water in the flume was examined in both the small and the large flumes to determine if the water height needed to be retained as a test parameter. These exploratory tests led to the conclusion that the height of the water above the debris does not introduce a sufficient variation in the test results to warrant its inclusion as a test variable. Therefore, further floor transport tests were done with 18-inches of water height in the large flume.

A series of exploratory tests were performed to examine the impact, if any, of floor surface roughness, within the range of typical roughness for PWR surfaces, on floor debris transport. The transport of Nukon was tested for transport across both Plexiglas and plywood surfaces. The surface roughness did not have a statistically significant effect on floor debris transport for the conditions tested. Therefore, surface roughness was not retained as a test parameter.

The uniformity of the flow and the influence of non-uniformities on debris transport were examined with exploratory tests to develop an adequate method of dampening flow turbulences and non-uniformities. As dampening methods were tested, the uniformity of the flow was studied using both visual observations and qualitative measurements. Techniques included: 1) the tracking of dye injections, tracer particles, and air bubbles, 2) the measurement of local flow velocities using calibrated tracer balloons (calibrated in the small flume), and comparing debris transport results with data obtained by past investigators. Surface waves and large eddies observed prior to the use of dampeners and straighteners, were, for example, completely eliminated.

The question of rather or not debris could be vertically re-entrained by fast flowing water, i.e., the vertical mixing velocity, was examined during exploratory testing. Testing on both the small and large flumes using Nukon and aluminum RMI demonstrated conclusively that once the debris was on the floor and the flow conditions were uniform, the debris would not re-suspend itself into the flow. The debris remained close to the floor; therefore no further testing was conducted attempting to determine the vertical mixing velocities.

Exploratory testing was conducted to verify repeatability of debris transport data. Incipient motion tests were conducted for Nukon and steel RMI. These tests led to the decision to define incipient motion as movement of 6-inches or more in the first two minutes following an incremental change in flow velocity.

PARAMETRIC TESTING

Substantial quantities of test data were accumulated. The transport data was collected for the flow conditions of uniform flow velocities and low levels of flow turbulence. This data was collected in the small flume and a large flume configured for diffused flow entry, i.e., turbulence dampeners and straighteners in place (Configuration A). Summary diffused flow entry debris transport data is shown in Table 1.

A range of debris characteristics were found in the debris types tested; these characteristics ranged from the buoyant behavior of silicone form (silicone was found to always float) to Marinite board, which readily sank. The terminal settling velocities for the types of debris tested are compared in Fig. 2. Here the ranges of settling velocities, determined by timing the fall of pieces of debris through a specified distance in the water column, are shown as black bars. Of course, the heavier debris settled faster than the lighter debris. It should be noted that sizes and forms of debris different from the debris tested, might not fit within these ranges, for example, individual fibers of Nukon tend to settle very slowly, if at all.

The transport of debris moving along a floor was characterized by the flow velocity required to move the debris across the floor, referred to as the tumbling velocity, and the velocity required to cause the debris to jump an obstruction (curb), referred to as the lift velocity. These velocities were measured for onset of movement, i.e., incipient motion, and for bulk or mass movement of debris. The transport characteristics of incipient debris tumbling along the floor and the incipient lift velocities for transport of debris over an obstacle are compared in Fig. 3. Again, these data are for flow conditions of uniform flow velocities and low levels of flow turbulence. The general rule was that it took a higher velocity to lift debris over a curb than to simply move the debris across the floor and the higher the curb, the faster the flow had to move to lift the debris over the curb. The heavier the piece of debris, the higher the velocity required for transport and the larger the difference between the tumbling velocity and the lift velocity. SS RMI, for example, took a substantially faster flow to lift the debris over a curb than to simply move it across a flat floor.

Table 1. Summary Data for Diffused Flow Entry Inlet Conditions

Debris Type	Terminal Settling Velocity	Tumbling Velocities		2-in. Curb Lift Velocity		6-in. Curb Lift Velocity		Screen Retention Velocity
		Incipient	Bulk	Incipient	Bulk	Incipient	Bulk	
Calcium Silicate	0.13 to 0.17	0.25	0.35	No Data	No Data	No Data	No Data	No Data
Paint Chip	0.08 to 0.19	0.40	0.45	0.50	> 0.55	No Data	No Data	No Data
Al RMI	0.08 to 0.21	0.20	0.25	0.30	No Data	0.37	No Data	0.11
SS RMI	0.23 to 0.58	0.28	0.30	0.84	No Data	> 1.0	No Data	0.12
Nukon	0.13 to 0.41	0.12	0.16	0.25	No Data	0.28	0.34	0.05
Thermal-Wrap	0.08 to 0.22	0.12	0.16	0.25	0.25	0.30	No Data	0.04
Kawool	0.15 to 0.30	0.12	0.16	0.25	0.25	0.41	0.41	No Data
Marinite Board	0.44 to 0.63	0.77	0.99	No Data	No Data	No Data	No Data	No Data
Silicone Foam	Always Floats	N/A	N/A	N/A	N/A	N/A	N/A	N/A

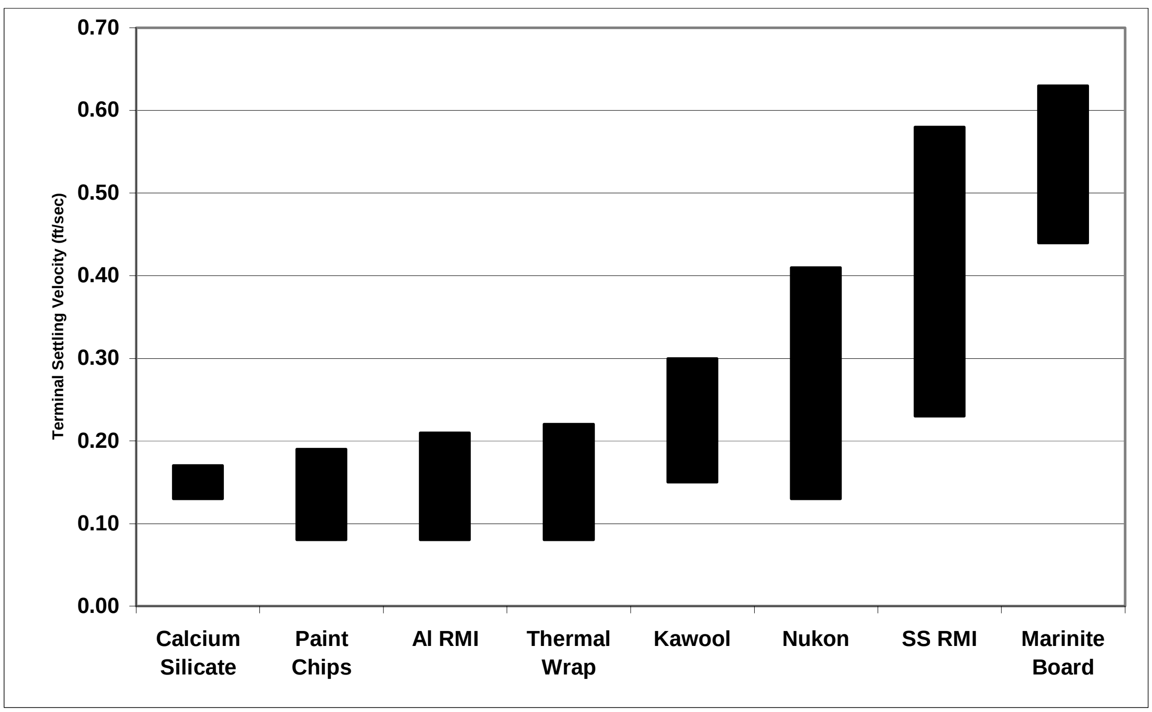


Fig. 2. Comparison of terminal settling velocities.

For most debris, the velocity differences between incipient and bulk motion were not substantial, that is, once the debris started to show movement (incipient), a relatively modest increase in velocity induced bulk movement of debris. This point is illustrated in Fig. 4, which compared the incipient tumbling velocity to the bulk tumbling velocity for the different types of debris tested.

The flow velocity needed to keep a piece of debris on the screen was less than the velocity needed to initiate transport of the debris to the screen. In general, the measured screen retention velocities, listed in Table 1, were less than half the incipient tumbling velocities. Therefore, once debris arrives at the screen, it can in general be expected to stay on the screen.

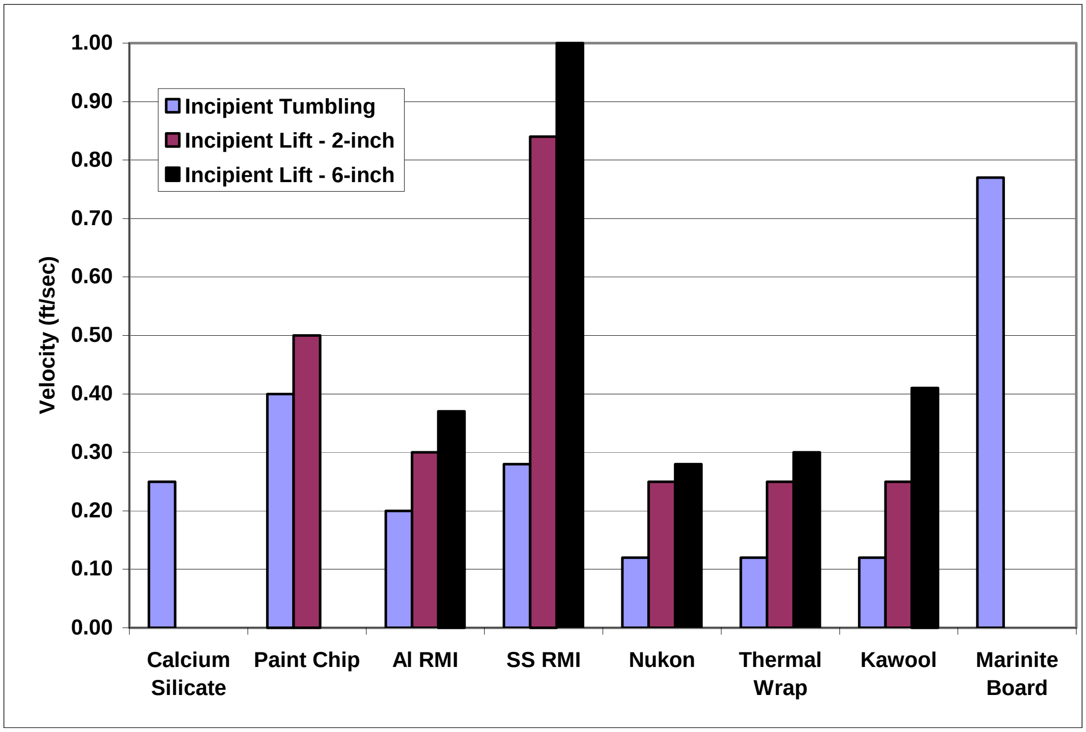


Fig. 3. Comparison of transport velocities.

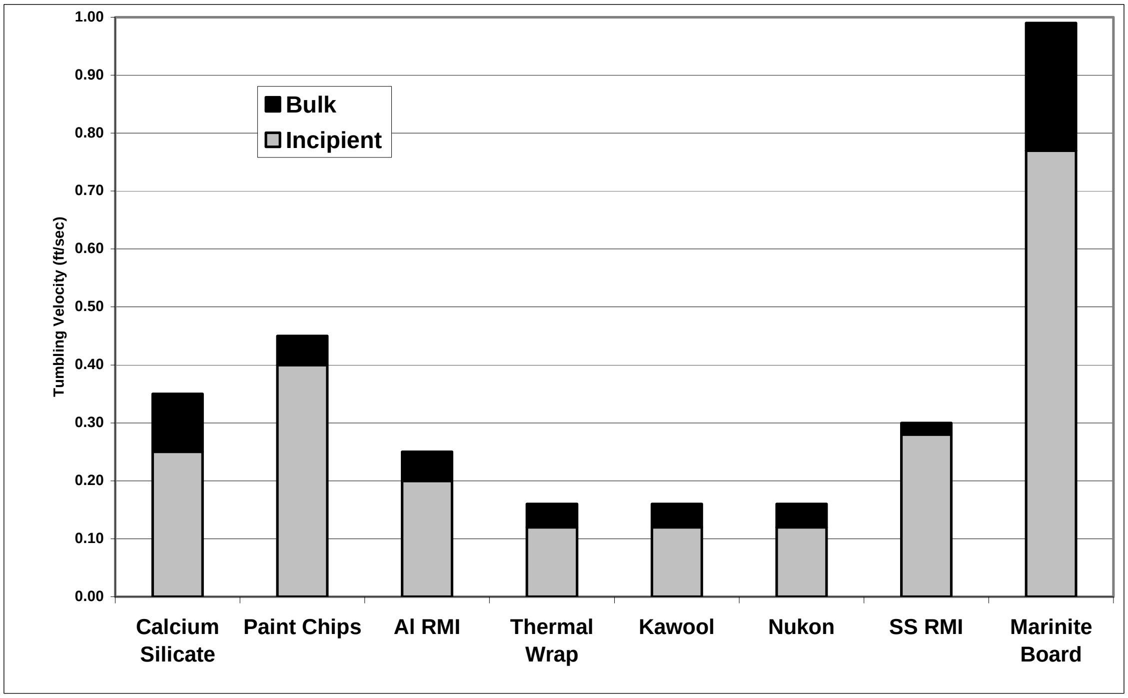


Fig. 4. Comparison of incipient and bulk tumbling velocities.

Debris transport was also tested for alternate inlet flow conditioning configurations to examine the impact of turbulence and non-uniform flow condition on debris transport. The summary debris transport data shown in Table 2 compares incipient transport velocities of debris tested in the large flume for each of the inlet flow conditioning Configurations A, B, and C. These data are compared graphically in Figs. 5 and 6, for the tumbling and lift velocities, respectfully.

It was difficult to draw conclusions regarding the impact of inlet flow conditioning configurations. It is important to keep in mind that these measured velocities were flume averaged flow velocities.

Table 2. Summary Velocity Data Comparing Turbulence and Non-Uniform Flow Effects

Debris Type	Incipient Tumbling			Incipient Lift–2" Curb			Incipient Lift-6" Curb		
	A	B	C	A	B	C	A	B	C
Thermal-Wrap	0.12	0.07	0.10	0.25	0.25	0.22	0.28	0.25	0.30
Kawool	0.12	0.09	0.17	0.25	0.25	0.28	0.41	0.25	0.32
Nukon	0.12	0.07	0.06	0.25	0.25	0.22	0.28	0.25	0.28
Steel RMI	0.28	0.37	0.20	0.84	0.90	1.0	>1.0	1.0	>1.0

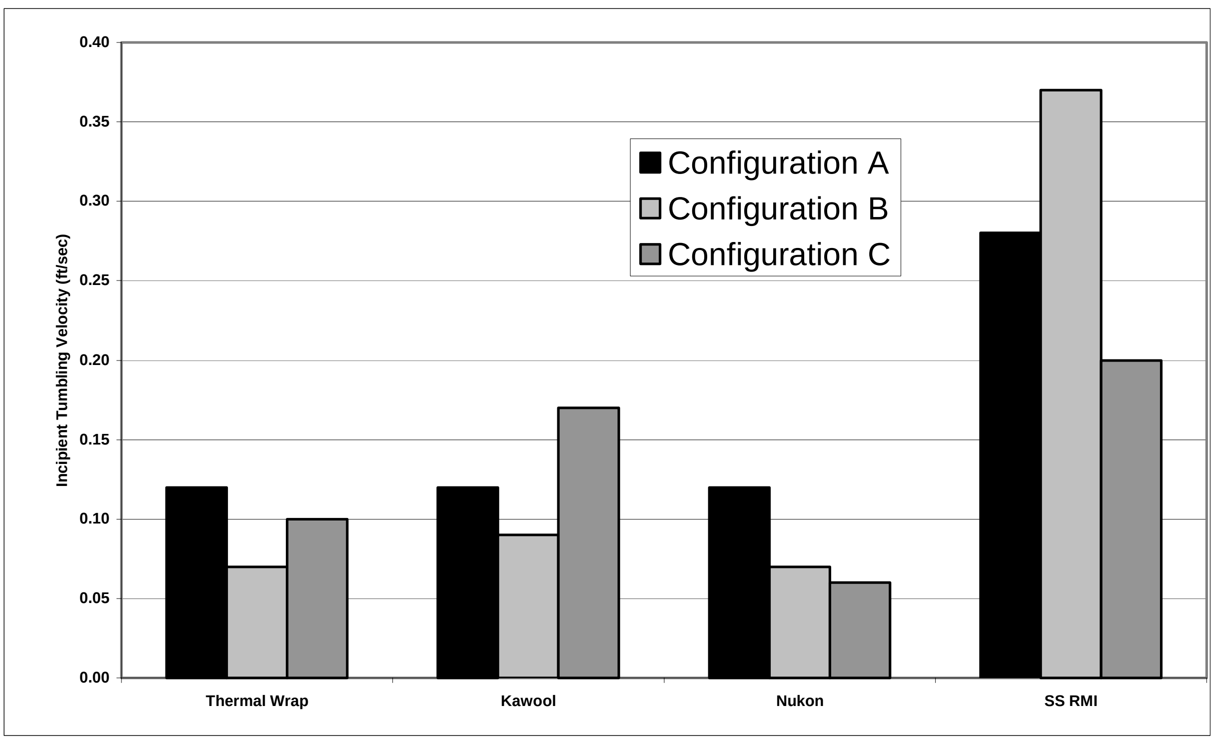


Fig. 5. Comparison of tumbling velocities vs inlet flow configurations.

Only in Configuration A did the average flow velocities reasonably reflect the local flow velocities, i.e., the flow velocity around the individual pieces of debris under study. With Configurations B and C, the local flow velocity were likely either somewhat faster or somewhat slower than the average velocity. Given this situation, it should be expected that trends associated with Configurations B and C would be somewhat erratic. For example, the incipient tumbling velocity for Kawool was slower at 0.09 ft/s in Configuration B than the 0.12 ft/s for Configuration A. But Configuration C was faster at 0.17 ft/s than was Configuration A.

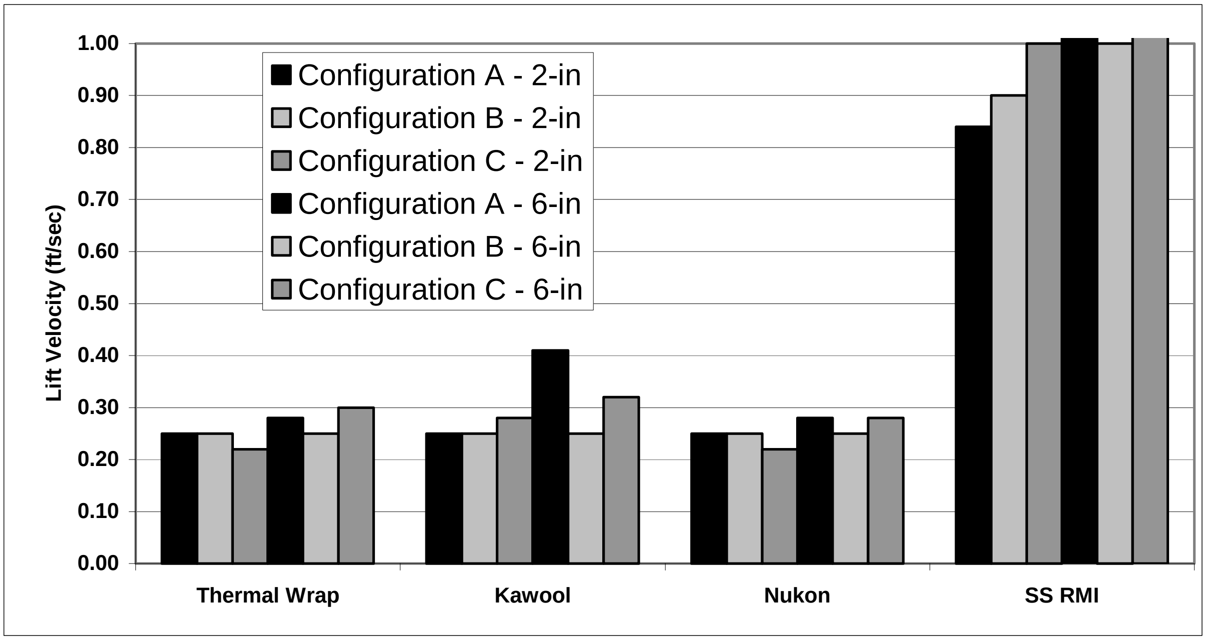


Fig. 6. Comparison of lift velocities vs inlet flow configurations.

In converging flume tests, where the flow cross-section was altered to force the flow to accelerate by converging the sidewall, debris transport was tested for selected conditions. Tests were conducted using steel RMI, aluminum RMI, and Nukon. Debris was dropped at a number of locations along the converging flume. Data suggests that the act of accelerating the water did not impact the transport of the debris. Rather, debris transport behaved according to the flow velocity at its current debris location.

The only debris tested for which substantial decomposition behavior was noted, was calcium silicate. Substantial quantities of calcium silicate debris were found to disintegrate when dropped into water and the degree of disintegration increased with water temperature. This disintegration data (the averages and the ranges) is shown in Fig. 7.

Debris dropped into was allowed 20 min to disintegrate. The water temperature was either room temperature or heated to 80^{o}C. In some of the 80^{o}C tests, the water was stirred by hand. Just dropping the debris in 80^{o}C water, approximately 50% of the debris mass was suspended in the water within 20 min. Stirring the water increased the disintegration process. It must be concluded that calcium silicate dropped into a hot containment floor pool for extended time and possibly undergoing turbulent churning will most likely disintegrate into fine particulate that easily remains suspended.

While not disintegrating, pieces of Marinite board became soft and with a rubbery texture on the exposed surfaces when submerged in boiling water for 30 min. A very small amount of milky whitish substance was released when the wet material was rubbed. Small pieces of material, smaller than 1/4 in., could be pulled from the wet surfaces. These small pieces readily sank. Considering the amount of plastic deformation required to pull these rubbery pieces apart, the disintegration of Marinite into smaller fragments due to flow turbulence is highly unlikely.

Silicone foam was obtained after it had been mixed and foamed in a 5-gallon bucket by the supplier. Irregular pieces, roughly 2-in. cube, were cut from the buckets for testing. Foam pieces were forcefully immersed in 80^{o}C water for 10 min, boiling water for 15 min, squeezed under water to force out remaining air, then re-submerged and kept submerged for 3 days in room temperature water. After all this, the pieces of foam always continued to float.

Intact steel RMI cassettes were tested to determine the time required for a cassette to sink and the flow velocity required to push a cassette across the floor. A slotted cassette sank in 5 min and a cassette with solid closures sank in 13 min. No floor transport was observed at the flow velocity of 0.5 ft/s but some transport was observed at 1.0 ft/s.

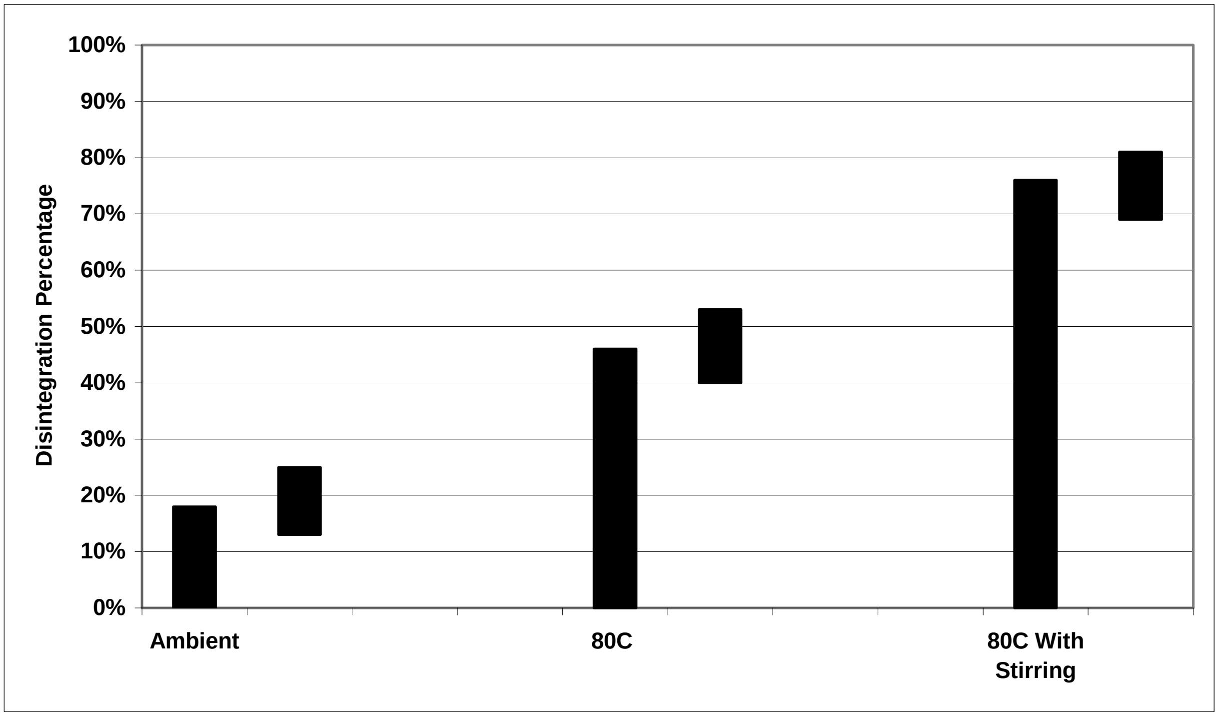


Fig. 7. Disintegration data for calcium silicate.

Five intact pillows of thermal-wrap insulation were tested to determine their terminal settling velocity after forcibly soaking them for 24 hr. The settling velocities ranged from 0.25 to 0.54 ft/s.

A substantial quantity of basic debris transport data was accumulated in these tests, thereby fulfilling the experimental objectives. It is anticipated that an overall methodology can now be developed that will combine this database with CFD analyses to predict debris transport within a containment floor ECCS pool.

APPENDIX A: MATERIAL DESCRIPTIONS

This appendix describes the materials tested.

CALCIUM SILICATE INSULATION

Calcium Silicate insulation is widely used to insulate steam generators and other special components of PWR primary system. It was procured from the vendor(s) in two basic shapes: 1) medium pieces (typically inches in length and width) and 2) small debris (simulated LOCA debris, which basically consists of approximately 1-in. chunks, attached to powdery-fibrous erosions). Representative samples of these size classes are shown in Photo A-1. The major emphasis of the Calcium Silicate tests was to collect data on disintegration and transport characteristics of smaller debris; very few tests were conducted using the larger pieces.

Photo A-1. Calcium silicate.

PAINT CHIPS

Epoxy based Paint Chips ranging in size from 1-in. x ½-in. to 1/8-in. x 1/8-in. were manufactured for testing, as shown in Photo A-2. These chips had a median thickness of approximately 15 mil but ranged between 13 and 16 mil.

Photo A-2. Paint chips.

ALUMINUM REFLECTIVE METALLIC INSULATION

Aluminum Reflective Metallic Insulation (RMI) was obtained from an insulation vendor in small fragments (1/2-in. and 2-in. square pieces). Thickness of these fragments was confirmed on-site to be approximately 1.5-mil. These pieces were subjected to air-jets by the vendor to produce crumpled samples. In order to distinguish their transport properties, the Aluminum RMI was categorized into Crumpled, Semi-Crumpled, and Flat. The insulation fragments can be qualitatively characterized as flat, crumpled or semi-crumpled. A sampling of this debris is shown in Photo A-3.

MARINITE FIRE-BARRIER MATERIAL

The Marinite Fire-Barrier debris comes in the form of solid blocks (rectangular and curved pieces), as shown in Photo A-4. Simply dropped in water, the material readily sinks to the bottom. Pieces of Marinite (1/2-in. thick) were submerged in boiling water (100°C) for 30 min. As a result, the material becomes soft, with a rubbery texture on the exposed surface. This rubbery material remains intact (does not disintegrate). Very small amount of a milky whitish substance is released when the wet material is rubbed. Small amount (pieces smaller than ¼ in.) of the soft rubbery material, shown in Photo A-5, can be pulled from the soft wet surface. These small pieces also sink readily. Considering the amount of plastic deformation needed to pull these small rubbery pieces apart, the disintegration of Marinite into smaller fragments due to turbulence is highly unlikely.

Photo A-3. Aluminum RMI.

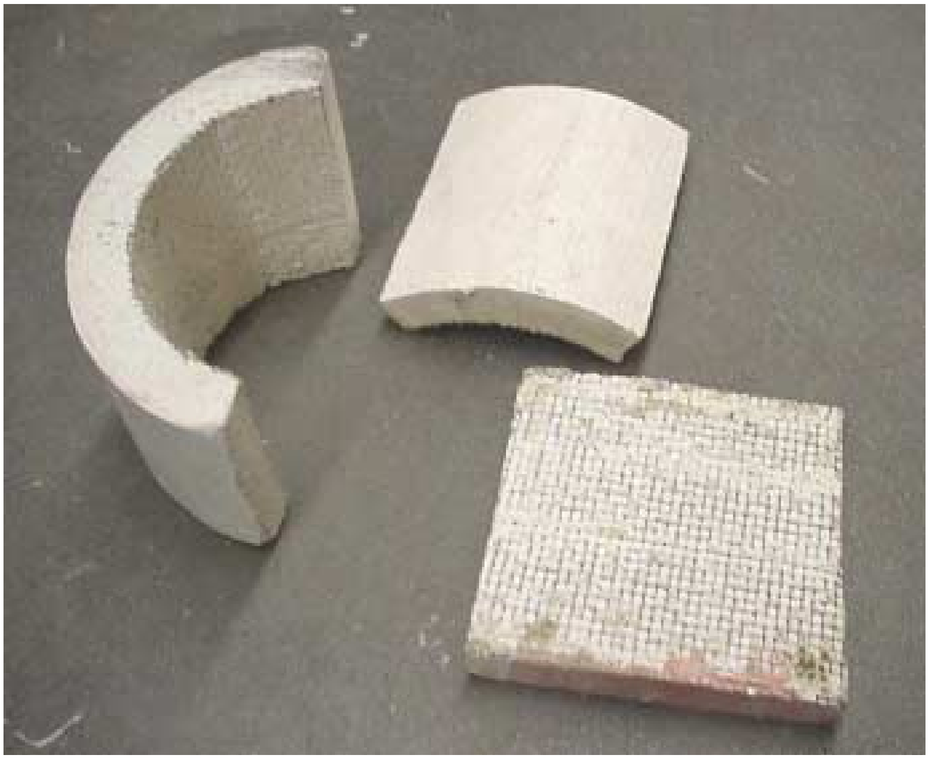


Photo A-4. Marinite fire-barrier material (dry and soaked block).

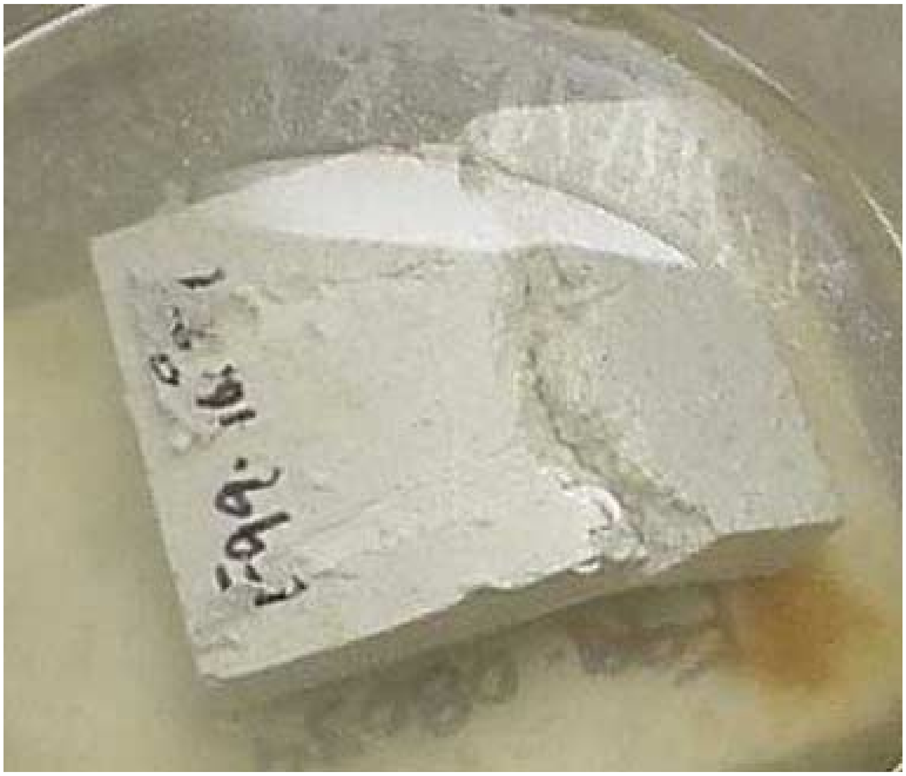


Photo A-5. Wet broken piece of Marinite.

SILICONE FOAM INSULATION MATERIAL

The silicone foam was obtained after it had been mixed and foamed in 5 gal. buckets by the supplier. Photo A-6 shows the Silicone Foam material. Irregular pieces (roughly 2 in. on one side were cut from these buckets and subjected to testing.

Photo A-6. Silicone foam insulation material (as foamed and pieces tested).

STAINLESS STEEL REFLECTIVE METALLIC INSULATION

Stainless Steel RMI (Reflective Metallic Insulation) was obtained in the following forms from the manufacturer:

Two 1 ft x 1 ft x 4 in. cassettes; one with slotted closures fabricated with 24 gage 304 SS and one with solid closures fabricated with 22 gal. 304 SS, as shown in Photo A-7.

24 gage, 304 SS foil sheets, 2 ft x 4 ft were cut into 2-in. square and ½ in. square pieces. These pieces were processed by hand to make three categories of SS RMI debris; crumpled, semi-crumpled and flat, similar to that shown in Photo A.3.

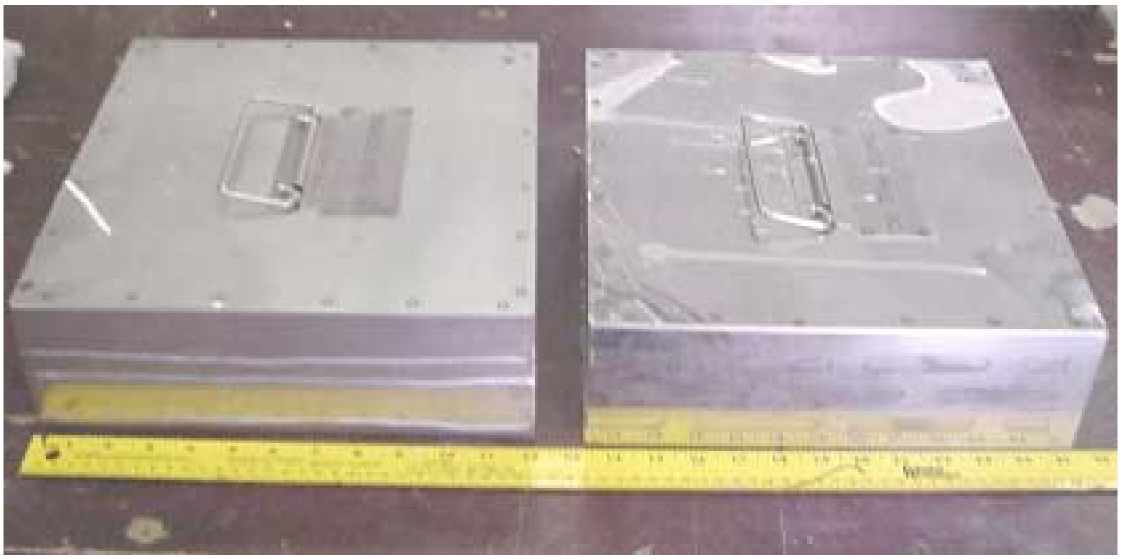


Photo A-7. SS RMI cassettes (solid and slotted closure).

LOW DENSITY FIBERGLASS NUKON INSULATION

Nukon is a low-density fiber-glass material and used as insulation in several of the operating PWRs. The vendor manufactured the Nukon base-wool following their usual methods, and then fragmented the blanket using air-jets to form the debris that was supplied to UNM. Visually the debris resembles size classes 3 and 4, as described in the NUREG/CR-6224 and shown in Photo A-8. Some large (4 in. and 6 in.) pieces of Nukon were also tested for settling velocity to demonstrate the effect of the size of the material.

LOW DENSITY FIBERGLASS THERMAL-WRAP INSULATION

This fiberglass material is similar to the Nukon insulation. Thermal wrap comes in 2-ft x 4-ft blanket form that is approximately 4 in. thick, shown in Figure A-9. These blankets were initially cut into 4-in. by 6-in. pieces with scissors. These smaller pieces were subsequently shredded with a leaf shredder to produce the material shown in Photo A-10. Some large (4-in. x 6-in.) pieces were also tested to demonstrate the effect of the size of the material. For each of the tests, the samples used are soaked in 80°C water for at least ten minutes. The blanket comes apart during handling after soaking. Five additional pillows (1 ft x 1 ft x 4 in.) of the Thermal-Wrap insulation were also obtained. The pillows were tested for terminal velocity after forcibly soaking them in water for 24 h.

Photo A-8. Typical NUKON fiberglass insulation.

Photo A-9. Thermal-wrap fiberglass insulation in bulk form.

Photo A-10. Shredded thermal-wrap.

KAOWOOL FIBERGLASS INSULATION

Kaowool insulation was obtained from Radiant Energy Shield (RES) samples in 4-ft x 3-ft pieces. The white Kaowool (1-½ in. nominal thickness) is enclosed inside the fire-blanket. The white Kaowool from these blankets were initially cut into 4 in. by 6-in. pieces with scissors, as shown in Photo A-11. These smaller pieces were subsequently shredded with a leaf shredder to produce the debris shown in Photo A-12. For each of the tests the samples used are soaked in 80°C water for at least ten minutes. Some large (4 in. x 6 in.) pieces (Fig. 4.8a) were also tested to demonstrate the effect of the size of the material.

Photo A-11. Kaowool insulation cut into 4-in. x 6-in. pieces.

Photo A-12. Shredded Kaowool.

APPENDIX B: RESULT DATA TABLES

This appendix contains tables of test results.

CALCIUM SILICATE INSULATION

Table B-1. Disintegration Characteristics of Calcium Silicate Fragments
(Initial Weight of Each Calcium Silicate Fragment is 10 gm)

Trial No	Weight of Calcium-Silicate Retained as Fragment (gm)		
	Ambient Water	80^{o}C Water	80^{o}C Water + Stirring
1	8.7	5.23	2.25
2	7.5	4.70	3.1
3	8.3	6.05	2.4
4	8.16	5.0	2.2
5	8.4	6.0	1.9
Average	**8.2**	**5.4**	**2.4**

Table B-2(a). Calcium Silicate Transport Data from Small Flume Tests (11/1999)
Between 5–10 chunks (each about 1in. in size) were placed on the flume floor.

Run	Debris Types	Flume Velocity (ft/s)	Observation
1	Cal-Sil	0.05	No movement
2		0.10	No movement. Dust and fibers detached.
3		0.15	No movement. Dust and fibers move away
4		0.20	Slight movement
5		0.25	Slight movement of smaller chunks. Not significant movement.
6		0.30	Larger pieces are ready to move. But very hesitant. Movement can ‘start’ and ‘stop.’ Appears as though this is the threshold for bigger chunks.
7		0.35	All debris moved to the screen.

Table B.2(b). Calcium-Silicate Transport Data from Large Flume Tests

<table>
<tr><th>Debris Type</th><th>Q (gal/min)</th><th>Height (in.)</th><th>Velocity (ft/s)</th><th colspan="4">Observation</th></tr>
<tr><td rowspan="7">Nukon and Calcium Silicate</td><td rowspan="7">1000

(1000-1025 gpm)

49 Hz</td><td rowspan="7">24</td><td rowspan="7">0.40</td><td colspan="4">Debris rolled on the floor and reached the screen. They moved over the curb.</td></tr>
<tr><td>Drop Test #</td><td>Horz. Dist.</td><td>Time (s)</td><td>V_{set} (ft/s)</td></tr>
<tr><td>1</td><td>53 in.</td><td>16.2</td><td>0.13</td></tr>
<tr><td>2</td><td>57 in.</td><td>15.9</td><td>0.13</td></tr>
<tr><td>3</td><td>43 in.</td><td>12.0</td><td>0.17</td></tr>
<tr><td>4</td><td>47 in.</td><td>14.2</td><td>0.15</td></tr>
<tr><td>5</td><td>57 in.</td><td>15.4</td><td>0.14</td></tr>
<tr><td rowspan="7">Nukon and Calcium Silicate</td><td rowspan="7">500

(490-515 gpm)

41 Hz</td><td rowspan="7">24</td><td rowspan="7">0.20</td><td colspan="4">All pieces rolled to the screen. None got over the curb.</td></tr>
<tr><td>Drop Test #</td><td>Horz. Dist.</td><td>Time (s)</td><td>V_{set} (ft/s)</td></tr>
<tr><td>1</td><td>27 in.</td><td>12.6</td><td>0.16</td></tr>
<tr><td>2</td><td>34 in.</td><td>15.6</td><td>0.13</td></tr>
<tr><td>3</td><td>28 in.</td><td>15.6</td><td>0.13</td></tr>
<tr><td>4</td><td>26 in.</td><td>12.7</td><td>0.15</td></tr>
<tr><td>5</td><td>27 in.</td><td>13.5</td><td>0.15</td></tr>
<tr><td rowspan="7">Nukon</td><td rowspan="7">500

(490-515 gpm)

41 Hz</td><td rowspan="7">24</td><td rowspan="7">0.20</td><td colspan="4">Debris rolled on the floor and reached the screen. They moved over the curb.</td></tr>
<tr><td>Drop Test #</td><td>Horz. Dist.</td><td>Time (s)</td><td>V_{set} (ft/s)</td></tr>
<tr><td>1</td><td>20 in.</td><td>12.5</td><td>0.17</td></tr>
<tr><td>2</td><td>28 in.</td><td>14.2</td><td>0.15</td></tr>
<tr><td>3</td><td>26 in.</td><td>12.0</td><td>0.17</td></tr>
<tr><td>4</td><td>31 in.</td><td>13.0</td><td>0.16</td></tr>
<tr><td>5</td><td>32 in.</td><td>15.4</td><td>0.14</td></tr>
<tr><td rowspan="7">Nukon</td><td rowspan="7">1000</td><td rowspan="7">24</td><td rowspan="7">0.40</td><td colspan="4">All pieces rolled to the screen. None got over the curb.</td></tr>
<tr><td>Drop Test #</td><td>Horz. Dist.</td><td>Time (s)</td><td>V_{set} (ft/s)</td></tr>
<tr><td>1</td><td>40 in.</td><td>11.7</td><td>0.18</td></tr>
<tr><td>2</td><td>61 in.</td><td>18.7</td><td>0.11</td></tr>
<tr><td>3</td><td>67 in.</td><td>15.1</td><td>0.13</td></tr>
<tr><td>4</td><td>71 in.</td><td>16.3</td><td>0.13</td></tr>
<tr><td>5</td><td>51 in.</td><td>14.9</td><td>0.14</td></tr>
</table>

PAINT CHIPS

Table B.3. Terminal Velocity Measurements for Epoxy Paint Chips

ID	Sample Size	Drop Distance (in.)	Time (s)	Terminal Velocity (ft/s)
1	Large (1-in. x ½-in.)	10	6	0.14
2	Medium (¼-in. – ¾ in.)	20	15	0.11
3	Small (1/8-in. – ¼-in.)	20	9	0.19
4	Small (1/8-in. – ¼-in.)	20	11	0.15
5	Small (1/8-in. – ¼-in.)	10	5	0.17
6	Small (1/8-in. – ¼-in.)	10	10	0.08
7	Large (1-in. x ½-in.)	20	13	0.13
8	Medium (¼-in. – ¾ in.)	20	10	0.17
Median Terminal Velocity				**0.15 ft/s**

TableB.4. Paint Chips Transport Data from Small Flume Tests (November 24, 1999)
Chips used ranged from 1/8 in. to 1 in. with few larger than 1 in.
Between 20 and 25 chips or 50 ml in volume were placed on the flume floor.

Run	Debris Types	Flume Velocity (ft/s)	Observation
		Paint Chip Transport	
1	Paint-Chips	0.10	No movement
2		0.15	No movement
3		0.20	No movement
4		0.25	No movement
5		0.30	Slight movement of particles
6		0.35	Still no movement (flutter)
7		0.40	1 piece moved
8		0.45	All pieces started to move
9		0.50	All pieces moved immediately to screen
		Paint Chip and Nukon Debris Transport	
10	Paint + Nukon	0.05	No transport/movement
		0.10	Some fluttering (Nukon fines move)
		0.15	≈10% Nukon transport/no paint movement
		0.20	≈50-75% Nukon transport/no paint movement
		0.25	100% Nukon transport/no paint movement
		0.45	Paint-chips move slowly; may go to screen
		0.50	All pieces reached screen instantaneously

Table B.5. Paint Chips Transport Data from Large Flume Tests

Chips used ranged from 1/8-in. to 1-in. with few larger than 1-in.
Between 20 and 25 chips or 50 ml in volume were placed on the flume floor.

<table>
<tr><th rowspan="2">Diffuser Status</th><th rowspan="2">Q (gal./min)</th><th rowspan="2">Height (in.)</th><th rowspan="2">Velocity (ft/s)</th><th colspan="4">Observation</th></tr>
<tr></tr>
<tr><td rowspan="7">Diffuser on
Calm flow.
No eddies.</td><td rowspan="7">1000

(1000–1025 gpm)</td><td rowspan="7">24</td><td rowspan="7">0.40</td><td colspan="4">Paint chips dropped at the top surface settled down to floor. No movement thereafter. Debris added on the floor did not move. Occasional fluttering did not result in movement.</td></tr>
<tr><td>Drop Test #</td><td>Horz. Dist.</td><td>Time (s)</td><td>V_{set} (ft/s)</td></tr>
<tr><td>1</td><td>37.5 in.</td><td>13</td><td>0.16</td></tr>
<tr><td>2</td><td>30 in.</td><td>12.5</td><td>0.17</td></tr>
<tr><td>3</td><td>29 in.</td><td>13.2</td><td>0.16</td></tr>
<tr><td>4</td><td>38 in.</td><td>11.5</td><td>0.18</td></tr>
<tr><td>5</td><td>25 in.</td><td>12.9</td><td>0.16</td></tr>
<tr><td>Diffuser on</td><td>1150</td><td>24</td><td>0.45</td><td colspan="4">About 10–15% traveled to the curb, but none went over. The rest moved from initial location. But in about 20 min they did not reach the curb.</td></tr>
<tr><td>Diffuser on</td><td>1150</td><td>19</td><td>0.55</td><td colspan="4">All debris reached the curb, all most instantaneously. Only very curled up ones and larger debris made it over the curb. The rest stayed put on the floor.</td></tr>
<tr><td>Diffuser off</td><td>1150</td><td>19</td><td>0.55</td><td colspan="4">All pieces moved to the curb and more go over it, but not all.</td></tr>
<tr><td>Diffuser off</td><td>1000</td><td>24</td><td>0.40</td><td colspan="4">All most all pieces moved to curb. None over it.</td></tr>
<tr><td>Diffuser off</td><td>850</td><td>24</td><td>0.31</td><td colspan="4">Several pieces moved towards the curb. Not all reached the curb. Significant hesitance during movement.</td></tr>
</table>

ALUMINUM REFLECTIVE METALLIC INSULATION

Table B-6(a). Terminal Velocity Measurements for Al-RMI Fragments

ID	Sample Shape	Drop Distance (in.)	Time (s)	Terminal Velocity (ft/s)
1	Flat (2-in. square)	20	12	0.14
2	Flat (2-in. square)	20	11	0.15
3	Flat (2-in. square)	20	12	0.14
4	Crumpled (2-in. square)	20	20	0.08
5	Crumpled (2-in. square)	20	19	0.09
6	Crumpled (2-in. square)	20	21	0.08
7	Semi-Crumpled (2-in. square)	20	16	0.10
8	Semi-Crumpled (2-in. square)	20	17	0.10
9	Semi-Crumpled (2-in. square)	20	14	0.12
Median Terminal Velocity (measured)				**0.11 ft/s**

Table B.6(b). Aluminum RMI Transport Data from Small Flume Tests (11/1999)

75 fragments consisting of flat, crumpled, semi-crumpled were placed on the flume floor.

Run	Debris Types	Flume Velocity (ft/s)	Observation
1	Aluminum RMI	0.05	No movement
2		0.10	No movement.
3		0.15	One piece out of approximately 25 transported. This also moved only few inches.
4		0.20	Several pieces traveled on the flume floor. Most of these pieces tended to be crumpled with large projected area facing the flow. Movement is sliding.
5		0.25	All most all the pieces traveled to the screen. Few very flat pieces (three out of 25) did not move.
6		0.30	All debris transported.
7		0.35	Another 25 pieces were added and all 25 pieces made it to the screen. Debris accumulated preferentially on the floor. But with arrival of newer debris the fragments moved upwards.

MARINITE FIRE-BARRIER MATERIAL

Table B-7. Drop Tests on Aluminum RMI with Inlet Flow Configuration A

Type of Al RMI	Measured Distance (in.)	Calculated Distance (in.)
Crumpled	10–16	24–30
Semi Crumpled	16–28	17–21
Flat	15–20	14–15

Table B-8. Marinite Settling Velocity

Curved 4 in. x 4 in.	
Sample	V (ft/s)
1	0.45
2	0.44
3	0.48
4	0.42
5	0.47

Flat 4 in. x 4 in.	
Sample	V (ft/s)
1	0.60
2	0.60
3	0.57
4	0.55
5	0.49

Flat 1 in. x 1 in.	
Sample	V (ft/s)
1	0.63
2	0.54
3	0.60
4	0.59
5	0.59

Table B-9 Marinite Floor Transport

Velocity (ft/s)	4 in. x 4 in. Curved	4 in. x 4 in. Flat	1 in. x 1 in. Flat
0.66	Rocked but did not travel	No movement	No movement
0.70	Moved a small distance	No movement	No movement
0.73	No movement	No movement	Move 2–4 in. over 5 min
0.77	Moves slowly toward screen	No movement	Moves slowly toward screen
0.99	Traveled easily to screen	No movement	Traveled easily to screen

STAINLESS STEEL REFLECTIVE METALLIC INSULATION

Table B-10. SS RMI Settling Velocity

Steel 1/2 in. x 1/2 in. semi-crumpled		
No.	18 in.	0 in.
1	NA	8.16
2	NA	9.25
3	2.97	8.00
4	3.29	8.15
5	4.06	10.91
6	2.50	7.50
7	2.75	7.84
8	NA	5.47
9	2.30	6.18
10	NA	6.53
Ave. Velocity (ft/s) =		**0.32**

Steel 1/2 in. x 1/2 in. crumpled		
No.	18 in.	0 in.
1	1.68	5.28
2	2.41	6.22
3	air bubble	
4	NA	6.32
5	NA	4.60
6	NA	7.62
7	1.97	6.10
8	2.19	6.53
9	1.87	5.87
10	2.69	6.75
Ave. Velocity (ft/s) =		**0.41**

Steel 2 in. x 2 in. semi-crumpled		
No.	18 in.	0 in.
1	1.90	5.46
2	2.21	5.78
3	NA	5.13
4	2.53	6.47
5	2.38	6.56
Ave. Velocity (ft/s) =		**0.43**

Steel 2 in. x 2 in. crumpled		
No.	18 in.	0 in.
1	1.84	4.28
2	1.59	4.65
3	1.66	4.44
4	1.53	NA
5	2.25	5.34
Ave. Velocity (ft/s) =		**0.53**

Table B-11. Floor Transport of SS RMI

Inlet Flow Conditioning: Configuration A

Type of Insulation	Velocity (ft/s)	Observation
SS RMI ½ in. x ½ in.	0.19	No movement
SS RMI 2 in. x 2 in.	0.19	No movement
SS RMI ½ in. x ½ in.	0.23	No movement
SS RMI 2 in. x 2 in.	0.23	No movement
SS RMI ½ in. x ½ in.	0.28	20% moves
SS RMI 2 in. x 2 in.	0.28	20% moves
SS RMI ½ in. x ½ in.	0.30	>50% moves
SS RMI 2 in. x 2 in.	0.30	>50% moves
SS RMI ½ in. x ½ in.	0.37	No further testing
SS RMI 2 in. x 2 in.	0.37	No further testing
SS RMI ½ in. x ½ in.	0.41	No further testing
SS RMI 2 in. x 2 in.	0.41	No further testing

Inlet Flow Conditioning: Configuration B

Type of Insulation	Velocity (ft/s)	Observation
SS RMI ½ in. x ½ in.	0.23	No movement
SS RMI 2 in. x 2 in.	0.23	No movement
SS RMI ½ in. x ½ in.	0.28	No movement
SS RMI 2 in. x 2 in.	0.28	Moves a little
SS RMI ½ in. x ½ in.	0.30	No movement
SS RMI 2 in. x 2 in.	0.30	No movement
SS RMI ½ in. x ½ in.	0.37	No movement
SS RMI 2 in. x 2 in.	0.37	Moves to screen
SS RMI ½ in. x ½ in.	0.41	Moves to screen
SS RMI 2 in. x 2 in.	0.41	No further testing

Inlet Flow Conditioning: Configuration C

Type of Insulation	Velocity (ft/s)	Observation
SS RMI ½ in. x ½ in.	0.10	No movement
SS RMI 2 in. x 2 in.	0.10	No movement
SS RMI ½ in. x ½ in.	0.17	No movement
SS RMI 2 in. x 2 in.	0.17	No movement
SS RMI ½ in. x ½ in.	0.20	1/3 moves
SS RMI 2 in. x 2 in.	0.20	Scattered in flume
SS RMI ½ in. x ½ in.	0.22	Moves to screen
SS RMI 2 in. x 2 in.	0.22	Moves to screen
SS RMI ½ in. x ½ in.	0.25	No further testing
SS RMI 2 in. x 2 in.	0.25	No further testing

Table B-12. Lift-at-Curb Velocity

Inlet Flow Conditioning: Configuration A

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
SS RMI	0.77	Stayed at the curb	Stayed at the curb
SS RMI	0.81	Stayed at the curb	Stayed at the curb
SS RMI	0.84	Some jumped over	Stayed at the curb
SS RMI	0.90	Most jumped over	Stayed at the curb
SS RMI	0.99	All jumped over	Stayed at the curb

Inlet Flow Conditioning: Configuration B

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
SS RMI	0.12	Stayed at the curb	Stayed at the curb
SS RMI	0.19	Stayed at the curb	Stayed at the curb
SS RMI	0.25	Some pieces moved upstream. None jumped over the curb	Some ½-in. pieces moved upstream. None jumped over the curb
SS RMI	0.28	Most pieces moved upstream. None jumped over the curb	Most pieces moved upstream. None jumped over the curb
SS RMI	0.30	All jumped upstream	All moved upstream

Inlet Flow Conditioning: Configuration C

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
SS RMI	0.50	Stayed at the curb	Stayed at the curb
SS RMI	0.73	Stayed at the curb	Stayed at the curb
SS RMI	1.0	Half of the 2-in. pieces jumped over. All ½-in. pieces stayed at the curb	Stayed at the curb

Table B-13a. Drop Tests: Inlet Flow Conditioning Configuration B

1/2 in. x 1/2 in. SS RMI

Vel. (ft/s)	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)
0.15	3	1	4	10	6	17	5.4	16	5	17
0.22	9	-6	6	6	6	7	5	2	5	9
0.27	4	2	8	4	3	20	4	7	5	6
0.36	5	-10	4	15	3	21	5	16	5	15
0.42	3	3	3	7	7	21	5	14	6	11

2 in. x 2 in. SS RMI

Vel. (ft/s)	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)
0.15	4	12	2.35	6	5	7	4.4	18	4.6	12
0.22	4	22	5	3	3	2	4	2	4	3
0.27	4	-6	4	12	5	6	4	-8	3	2
0.36	5	-10	4	15	3	21	5	16	5	15
0.42	4	7	12	50	7	15	3	5	8	-9

Table B-13b. Drop Tests: Inlet Flow Conditioning Configuration C

1/2 in. x 1/2 in. SS RMI

Vel. (ft/s)	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)
0.31	5.8	47	6.2	36	7.5	51	4.8	23	7.8	46
0.33	5.0	43	5.0	6	5.1	16	9.0	78	7.4	69
0.45	6.5	62	4.1	39	3.2	31	7.3	84	7.7	77
0.54	7.4	57	4.4	33	5.3	29	6.0	71	7.0	66
0.57	4.9	46	6.6	68	3.4	29	5.5	44	3.7	30

2 in. x 2 in. SS RMI

Vel. (ft/s)	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)
0.31	3.7	21	5.8	43	4.9	30	3.6	23	10.1	81
0.33	4.1	7	5.2	45	4.9	23	5.6	44	4.9	45
0.45	1.3	15	3.6	42	4.4	50	4.5	34	8.8	82
0.54	4.6	24	4.3	16	3.8	40	4.5	35	3.2	30
0.57	8.3	57	5.5	26	2.7	28	9.3	63	4.6	32

LOW DENSITY FIBERGLASS NUKON INSULATION

Table B-14. Nukon Settling Velocity (ft/s)

	6 in. pieces	4 in. pieces	1 in. pieces
Sample #1	0.41	0.41	0.13
Sample #2	0.41	0.33	0.16
Sample #3	0.41	0.41	0.15
Sample #4	0.41	0.41	0.16
Sample #5	0.41	0.41	0.14
Ave. vel (ft/s)	**0.41**	**0.40**	**0.15**

Table B-15. Floor Transport of Nukon

Inlet Flow Conditioning: Configuration A

Type of Insulation	Velocity (ft/s)	Observation
Nukon	0.11	No movement
Nukon	0.12	10–50% moves in different tests
Nukon	0.16	80% moves
Nukon	0.19	100% moves

Inlet Flow Conditioning: Configuration B

Type of Insulation	Velocity (ft/s)	Observation
Nukon	0.06	No movement
Nukon	0.07	50% moves
Nukon	0.09	100% moves
Nukon	0.11	No further testing

Inlet Flow Conditioning: Configuration C

Type of Insulation	Velocity (ft/s)	Observation
Nukon	0.06	0–10% movement in different tests
Nukon	0.07	10–20% moves in different tests
Nukon	0.10	80% moves
Nukon	0.11	100% moves

Table B-16. Lift at Curbs – Nukon

Inlet Flow Conditioning: Configuration A

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
Nukon	0.22	Stayed at the curb	Stayed at the curb
Nukon	0.25	Some jumped over	Stayed at the curb
Nukon	0.28	No further testing	<5% jumped over (very small, pieces)
Nukon	0.34	No further testing	20–30% over curb
Nukon	0.37	No further testing	100% over curb

Inlet Flow Conditioning: Configuration B

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
Nukon	0.19	Stayed at the curb	Stayed at the curb
Nukon	0.25	Small pieces jumped over Most moved upstream	Small pieces jumped over Most moved upstream
Nukon	0.28	No further testing	No further testing

Inlet Flow Conditioning: Configuration C

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
Nukon	0.19	Stayed at the curb	Stayed at the curb
Nukon	0.22	Small pieces jumped over	Stayed at the curb
Nukon	0.25	No further testing	Stayed at the curb
Nukon	0.28	No further testing	Small pieces jumped over

LOW DENSITY FIBERGLASS THERMAL-WRAP INSULATION

Table B-17. Drop Test of Nukon

Inlet flow conditioning: Configuration A

Q (gal/min)	Velocity (ft/s)	Water Height (in.)	Horizontal Distance (in.)	Time (s)	Theoretical Distance (in.)
490	0.23	19	19.0	8.1	22.3
			19.0	N/A*	N/A
			18.5	7.5	20.7
			18.0	8.2	22.6
			18.0	N/A	N/A
			19.0	6.8	18.8
531	0.24	19.75	20.75	8.9	25.6
			20.0	8.3	23.9
679	0.33	18	23.75	6.8	26.9
			21.5	7.0	27.7
			24.0	9.0	35.6
			27.0	8.0	31.7
			20.0	5.9	23.4
820	0.37	19.5	36.0	5.7	25.3
			60	8.8	39.1
			41	6.9	30.6
			22	7.5	7.5
			20	6.8	6.8
			15	5.5	5.5
1107	49	19.25	35	8.2	8.2
			37	8.0	8.0
			36	8.2	8.2

Inlet flow conditioning: Configuration B

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
Vel. (ft/s)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)
0.15	11	15	6	29	8	26	5	20	6	18
0.22	25	34	5	23	5	16	10	10	6	26
0.27	11	35	7	33	7	29	7	16	18	40
0.36	9	31	7	15	5	28	8	45	13	12
0.42	13	58	11	26	15	34	9	40	5	1

Inlet flow conditioning: Configuration C

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
Vel. (ft/s)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)	Time (s)	Dist. (in.)
0.31	6.8	35	12.1	75	10.9	78	36.3	*	10.6	79
0.33	5.1	31	11.6	55	19.5	*	7.1	29	13.7	71
0.45	13.1	40	20	*	10.4	55	15.9	*	12.5	*
0.54	13.3	*	17.6	*	4.2	21	12.1	28	18.5	82
0.57	4.8	29	11.8	*	13.8	*	6.4	40	14.4	*

* Measurement not taken.

Table B-18. Thermal-Wrap Settling Velocity

Thermal Wrap (1 in. x 1 in. clumps)		
No.	**18 in.**	**0 in.**
1	NA	13.47
2	6.78	14.37
3	7.06	17.56
4	6.97	15.78
5	4.91	12.56
6	6.84	19.22
7	6.53	16.12
8	5.6	17.36
9	NA	NA
10	NA	NA
Ave. Velocity (ft/s) =		**0.16**

Thermal Wrap 2 in. x 2.5 in. (clumps)		
No.	**18 in.**	**0 in.**
1	5.97	14.59
2	7.91	17.19
3	7.72	19.88
4	NA	23.41
5	6.97	11.25
6	11.04	26.06
7	5.88	12.69
8	10.56	29.37
9	9.37	28.16
10	NA	16.65
Ave. Velocity (ft/s) =		**0.13**

(The terminal velocity of the five 1 ft x 1 ft x 4 in. pillows was determined to be 0.25 to 0.54 ft/s.)

Table B-19. Floor Transport of Thermal-Wrap

Inlet flow conditioning: Configuration A

Type of Insulation	Velocity (ft/s)	Observation
Thermal-wrap fragments	0.11	No movement
Thermal-wrap 4 in. x 6 in.	0.11	No movement
Thermal-wrap fragments	0.12	No movement
Thermal-wrap 4 in. x 6 in.	0.12	50% moves
Thermal-wrap fragments	0.16	Some movement
Thermal-wrap 4 in. x 6 in.	0.16	50% moves
Thermal-wrap fragments	0.19	100% moves
Thermal-wrap 4 in. x 6 in.	0.19	100% moves

Inlet flow conditioning: Configuration B

Type of Insulation	Velocity (ft/s)	Observation
Thermal-wrap fragments	0.06	No movement
Thermal-wrap 4 in. x 6 in.	0.06	No movement
Thermal-wrap fragments	0.07	Some movement
Thermal-wrap 4 in. x 6 in.	0.07	No movement
Thermal-wrap fragments	0.11	100% moves
Thermal-wrap 4 in. x 6 in.	0.11	No movement
Thermal-wrap fragments	0.19	No further testing
Thermal-wrap 4 in. x 6 in.	0.19	Some movement
Thermal-wrap fragments	0.23	No further testing
Thermal-wrap 4 in. x 6 in.	0.23	100% moves

Inlet flow conditioning: Configuration C

Type of Insulation	Velocity (ft/s)	Observation
Thermal-wrap fragments	0.06	No movement
Thermal-wrap 4 in. x 6 in.	0.06	No movement
Thermal-wrap fragments	0.10	Some movement
Thermal-wrap 4 in. x 6 in.	0.10	Some movement
Thermal-wrap fragments	0.11	100% movement
Thermal-wrap 4 in. x 6 in.	0.11	No movement
Thermal-wrap fragments	0.17	50% moves
Thermal-wrap 4 in. x 6 in.	0.17	Some movement
Thermal-wrap fragments	0.20	100% moves
Thermal-wrap 4 in. x 6 in.	0.20	100% moves

Table b_20. Lift-at-Curbs for Thermal-Wrap

Inlet flow conditioning: Configuration A

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
Thermal Wrap fragments	0.22	Stayed at the curb	Stayed at the curb
Thermal Wrap 4 in. x 6 in.	0.22	Stayed at the curb	Stayed at the curb
Thermal Wrap fragments	0.25	Jumped over the curb	Stayed at the curb
Thermal Wrap 4 in. x 6 in.	0.25	Jumped over the curb	Stayed at the curb
Thermal Wrap fragments	0.28	No further testing	Some jumped over
Thermal Wrap 4 in. x 6 in.	0.28	No further testing	Stayed at the curb
Thermal Wrap fragments	0.30	No further testing	Some jumped over
Thermal Wrap 4 in. x 6 in.	0.30	No further testing	Some jumped over

Inlet flow conditioning: Configuration B

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
Thermal Wrap fragments	0.19	Stayed at the curb	Stayed at the curb
Thermal Wrap 4 in. x 6 in.	0.19	Stayed at the curb	Stayed at the curb
Thermal Wrap fragments	0.25	Small fragments jumped over Most moved upstream	Moved upstream
Thermal Wrap 4 in. x 6 in.	0.25	Stayed at the curb	Moved upstream
Thermal Wrap fragments	0.28	No further testing	No further testing
Thermal Wrap 4 in. x 6 in.	0.28	Moved upstream	No further testing
Thermal Wrap fragments	0.30	No further testing	No further testing
Thermal Wrap 4 in. x 6 in.	0.30	No further testing	No further testing

Inlet flow conditioning: Configuration C

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
Thermal Wrap fragments	0.20	Stayed at the curb	Stayed at the curb
Thermal Wrap 4 in. x 6 in.	0.20	Stayed at the curb	Stayed at the curb
Thermal Wrap fragments	0.22	Small fragments moved over	Stayed at the curb
Thermal Wrap 4 in. x 6 in.	0.22	Moved over	Stayed at the curb
Thermal Wrap fragments	0.28	No further testing	Stayed at the curb
Thermal Wrap 4 in. x 6 in.	0.28	No further testing	Stayed at the curb
Thermal Wrap fragments	0.30	No further testing	Moved over
Thermal Wrap 4 in. x 6 in.	0.30	No further testing	Moved over

Table B-21. Drop Tests with Thermal-Wrap Debris

Inlet flow conditioning: Configuration B

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
Vel. (ft/s)	**Time (s)**	**Dist. (in.)**	**Time (s)**	**Dist. (in.)**	**Time (s)**	**Dist. (in.)**	**Time (s)**	**Dist. (in.)**	**Time (s)**	**Dist. (in.)**
0.15	8	29	8	23	10	29	9	29	11	12
0.22	8	21	5	8	9	27	7	18	8	16
0.27	15	67	16	24	10	28	8	-10	28	80
0.36	8	35	10	68	6	15	5	6	14	58
0.42	18	66	10	45	14	75	3	2	8	44

Inlet flow conditioning: Configuration C

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
Vel. (ft/s)	**Time (s)**	**Dist. (in.)**	**Time (s)**	**Dist. (in.)**	**Time (s)**	**Dist. (in.)**	**Time (s)**	**Dist. (in.)**	**Time (s)**	**Dist. (in.)**
0.31	10.4	31	10.4	58	18.0	88	8.7	46	25.2	29
0.33	9.6	28	15.7	77	21.7	79	7.6	36	17.9	91
0.45	4.9	61	7.0	19	10.3	*	17.4	-9	11.9	*
0.54	5.0	35	13.5	71	12.1	*	10.3	38	14.6	92
0.57	12.4	*	8.8	45	13.0	91	17.6	*	13.8	90

KAOWOOL FIBERGLASS INSULATION

Table 4B-22. Kaowool Settling Velocity

Test #	Velocity (ft/s)
1	0.15
2	0.19
3	0.25
4	0.23
5	0.19
6	0.19
7	0.19
8	0.30
9	0.19
10	0.22
Ave. Vel (ft/s)	**0.21**

Table B-23. Floor Transport of Kaowool

Inlet flow conditioning: Configuration A

Type of Insulation	Velocity (ft/s)	Observation
Kaowool pieces	0.11	No movement
Kaowool 4 in. x 6 in.	0.11	No movement
Kaowool pieces	0.12	No movement
Kaowool 4 in. x 6 in.	0.12	50% moves
Kaowool pieces	0.16	Some movement
Kaowool 4 in. x 6 in.	0.16	50% moves
Kaowool pieces	0.19	50% moves
Kaowool 4 in. x 6 in.	0.19	50% moves

Inlet flow conditioning: Configuration B

Type of Insulation	Velocity (ft/s)	Observation
Kaowool fragments	0.07	No movement
Kaowool 4 in. x 6 in.	0.07	No movement
Kaowool fragments	0.09	Some movement
Kaowool 4 in. x 6 in.	0.09	No movement
Kaowool fragments	0.11	No further testing
Kaowool 4 in. x 6 in.	0.11	No movement
Kaowool fragments	0.23	No further testing
Kaowool 4 in. x 6 in.	0.23	no movement
Kaowool fragments	0.25	No further testing
Kaowool 4 in. x 6 in.	0.25	Moves to screen

Inlet flow conditioning: Configuration C

Type of Insulation	Velocity (ft/s)	Observation
Kaowool fragments	0.10	No movement
Kaowool 4 in. x 6 in.	0.10	No movement
Kaowool fragments	0.17	Some movement
Kaowool 4 in. x 6 in.	0.17	Some movement
Kaowool fragments	0.20	50% movement
Kaowool 4 in. x 6 in.	0.20	Some movement
Kaowool fragments	0.22	100% moves
Kaowool 4 in. x 6 in.	0.22	100% moves

Table B-24. Lift-at-Curbs Velocity - Kaowool

Inlet flow conditioning: Configuration A

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
Kaowool fragments	0.22	Stayed at the curb	Stayed at the curb
Kaowool 4 in. x 6 in.	0.22	Stayed at the curb	Stayed at the curb
Kaowool fragments	0.25	Stayed at the curb	Stayed at the curb
Kaowool 4 in. x 6 in.	0.25	Jumped over the curb	Stayed at the curb
Kaowool fragments	0.28	Stayed at the curb	Stayed at the curb
Kaowool 4 in. x 6 in.	0.28	No further testing	Stayed at the curb
Kaowool fragments	0.30	Jumped over the curb	Stayed at the curb
Kaowool 4 in. x 6 in.	0.30	No further testing	Stayed at the curb
Kaowool fragments	0.37	No further testing	Stayed at the curb
Kaowool 4 in. x 6 in.	0.37	No further testing	Stayed at the curb
Kaowool fragments	0.41	No further testing	50% moved over
Kaowool 4 in. x 6 in.	0.41	No further testing	Stayed at the curb
Kaowool fragments	0.43	No further testing	No further testing
Kaowool 4 in. x 6 in.	0.43	No further testing	Stayed at the curb
Kaowool fragments	0.47	No further testing	No further testing
Kaowool 4 in. x 6 in.	0.47	No further testing	Moved over curb

Inlet flow conditioning: Configuration B

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
Kaowool fragments	0.19	Stayed at the curb	Stayed at the curb
Kaowool 4 in. x 6 in.	0.19	Stayed at the curb	Stayed at the curb
Kaowool fragments	0.25	Small pieces jumped over Most moved upstream	Moved upstream
Kaowool 4 in. x 6 in.	0.25	Stayed at the curb	Moved upstream
Kaowool fragments	0.28	No further testing	No further testing
Kaowool 4 in. x 6 in.	0.28	Moved upstream	No further testing
Kaowool fragments	0.30	No further testing	No further testing
Kaowool 4 in. x 6 in.	0.30	No further testing	No further testing

Inlet flow conditioning: Configuration C

Type of Insulation	Velocity (ft/s)	2 in. Curb	6 in. Curb
Kaowool fragments	0.24	Stayed at the curb	Stayed at the curb
Kaowool 4 in. x 6 in.	0.24	Stayed at the curb	Stayed at the curb
Kaowool fragments	0.28	Small pieces moved over	Stayed at the curb
Kaowool 4 in. x 6 in.	0.28	Stayed at the curb	Stayed at the curb
Kaowool fragments	0.30	No further testing	Stayed at the curb
Kaowool 4 in. x 6 in.	0.30	Moved over	Stayed at the curb
Kaowool fragments	0.32	No further testing	Moved over
Kaowool 4 in. x 6 in.	0.32	No further testing	Stayed at the curb
Kaowool fragments	0.34	No further testing	No further testing
Kaowool 4 in. x 6 in.	0.34	No further testing	Stayed at the curb
Kaowool fragments	0.39	No further testing	No further testing
Kaowool 4 in. x 6 in.	0.39	No further testing	Moved over

Table B-25. Kaowool Drop Tests

Inlet flow conditioning: Configuration B

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
Vel. (ft/s)	**Time (s)**	**Dist. (s)**	**Time (s)**	**Dist. (s)**	**Time (s)**	**Dist. (s)**	**Time (s)**	**Dist. (s)**	**Time (s)**	**Dist. (s)**
0.15	5	17	6	20	8	4	4	14	6	15
0.22	4	19	5	13	7	17	4	9	7	7
0.27	6	6	5	17	5	3	8	16	7	-16
0.36	5	6	6	-10	7	-15	7	26	6	23
0.42	4	12	5	34	4	0	16	49	19	43

Inlet flow conditioning: Configuration C

	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
Vel. (ft/s)	**Time (s)**	**Dist. (s)**	**Time (s)**	**Dist. (s)**	**Time (s)**	**Dist. (s)**	**Time (s)**	**Dist. (s)**	**Time (s)**	**Dist. (s)**
0.31	7.8	36	5.9	36	6.8	47	7.3	42	5.6	26
0.33	4.3	33	3.2	16	8.3	45	5.1	22	10.5	59
0.45	10.3	87	12.3	90	3.0	42	7.0	51	8.2	70
0.54	17.2	89	4.2	33	5.6	46	6.0	56	4.5	14
0.57	4.7	59	12.7	91	5.4	49	7.7	73	41	25

PWR Sump Blockage Study:
Integrated Tank Testing of Debris Transport

Arup Maji

Department of Civil Engineering

University of New Mexico

Objectives of Tank Testing

- **Observe debris transport in regimes of turbulent and rotational flow comparable to the complexity of PWR containment floors**
  - Linear flume characterized separate effects of settling and incipient motion
- **Develop approximate method for fractional debris transport during pool fill and recirculation phases of LOCA in combination with Computational Fluid Dynamics (CFD) calculations**
- **Experimentally validate approximate transport method for various debris locations and source conditions**
- **Provide validation for CFD calculations of water velocity patterns**

These objectives can be met using somewhat arbitrary flow conditions because plant-specific calculations will be performed for actual analyses

Apparatus for Tank Testing

- **Initial debate regarding geometry:**
  - Mock plant-floor arrangement suggests a dimensionally scaled experiment when in fact they are not intended to be
  - Arbitrary obstacles could be used to create complex flows
- **Final configuration:**
  - 15-ft diameter cylindrical tank, 24 inches deep (large as practical)
  - Obstacles that resemble Volunteer Plant #2 (large-dry)
    - No instrumentation room or reactor cavity detail
    - No raised floor in steam generator compartments
- **Construction:**
  - 3/8-inch rolled steel welded in quarters with flanges on all sides
  - Flanges bolted at 1-inch intervals with rubber compression gaskets
  - 1-ft x 2-ft sump box with two 8-in drains with coarse and fine valves
  - Interior floor spread with self-leveling hydraulic cement
  - Painted with epoxy paint, sanded and painted second time

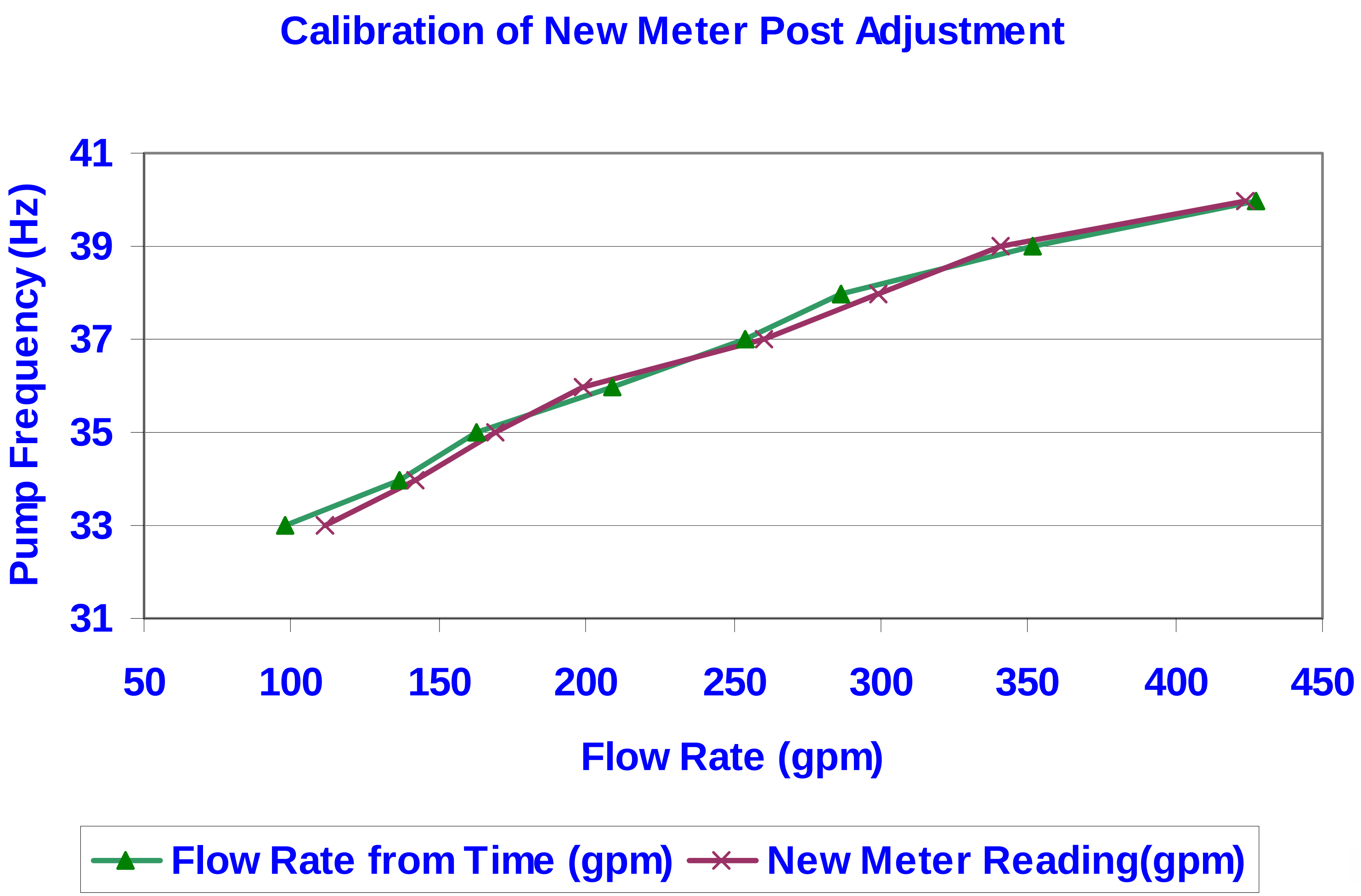
3-D Tank Features

2 valves for coarse & fine adjustment

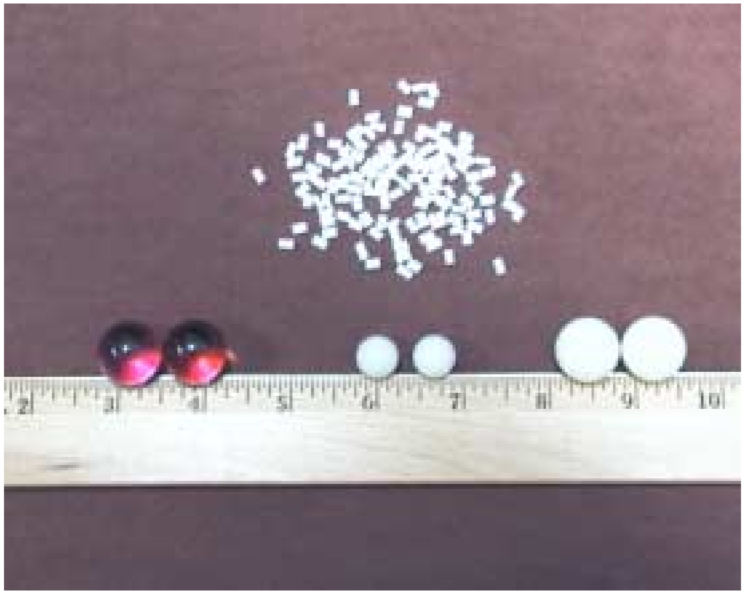
2970 gallon 13' diameter x 2.5'

Epoxy Painting

Flowmeter Calibration



Surrogate Flow Tracers



Rationale for Use

Uniformity in Property
Easy to Use and Clean
Easy to Visualize

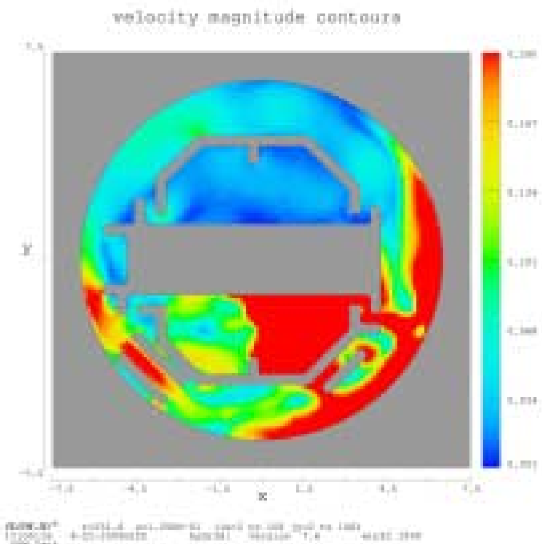
Material	Sp. Gravity	Incipient Motion (ft/sec)	Terminal Velocity (ft/sec)
Nylon	1.14	0.20	0.61 (0.55-0.66)
Acrylic	1.39	0.20	0.80 (0.75-0.88)
Glass	2.0	0.40	1.42 (1.26-1.56)
Polystyrene	1.04		

Test Configurations

CONFIGURATION #1
Source in Annulus,
Opposite to Sump

CONFIGURATION #2
Source Inside
Close to Sump

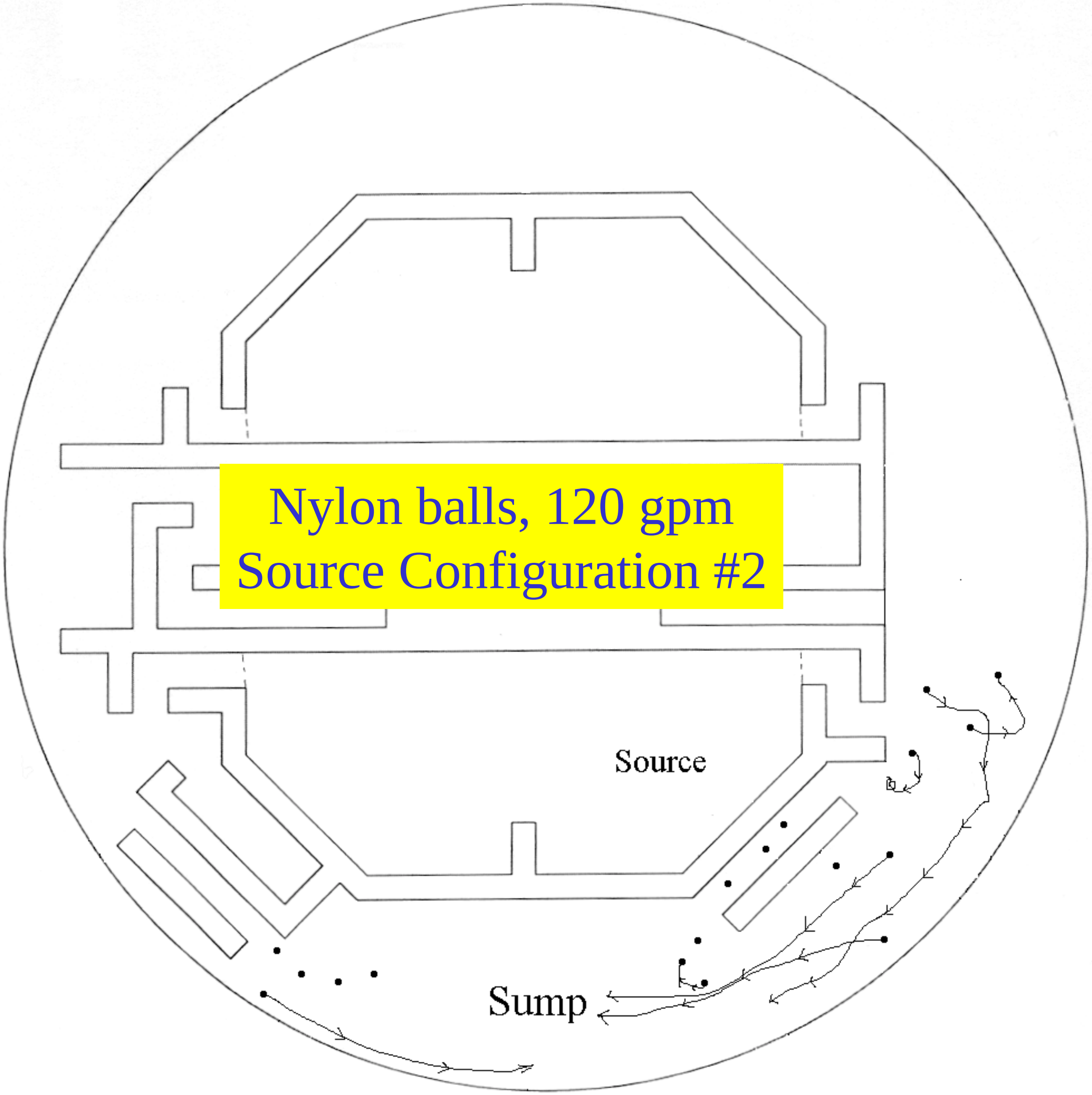
Rationale for Tank Tests



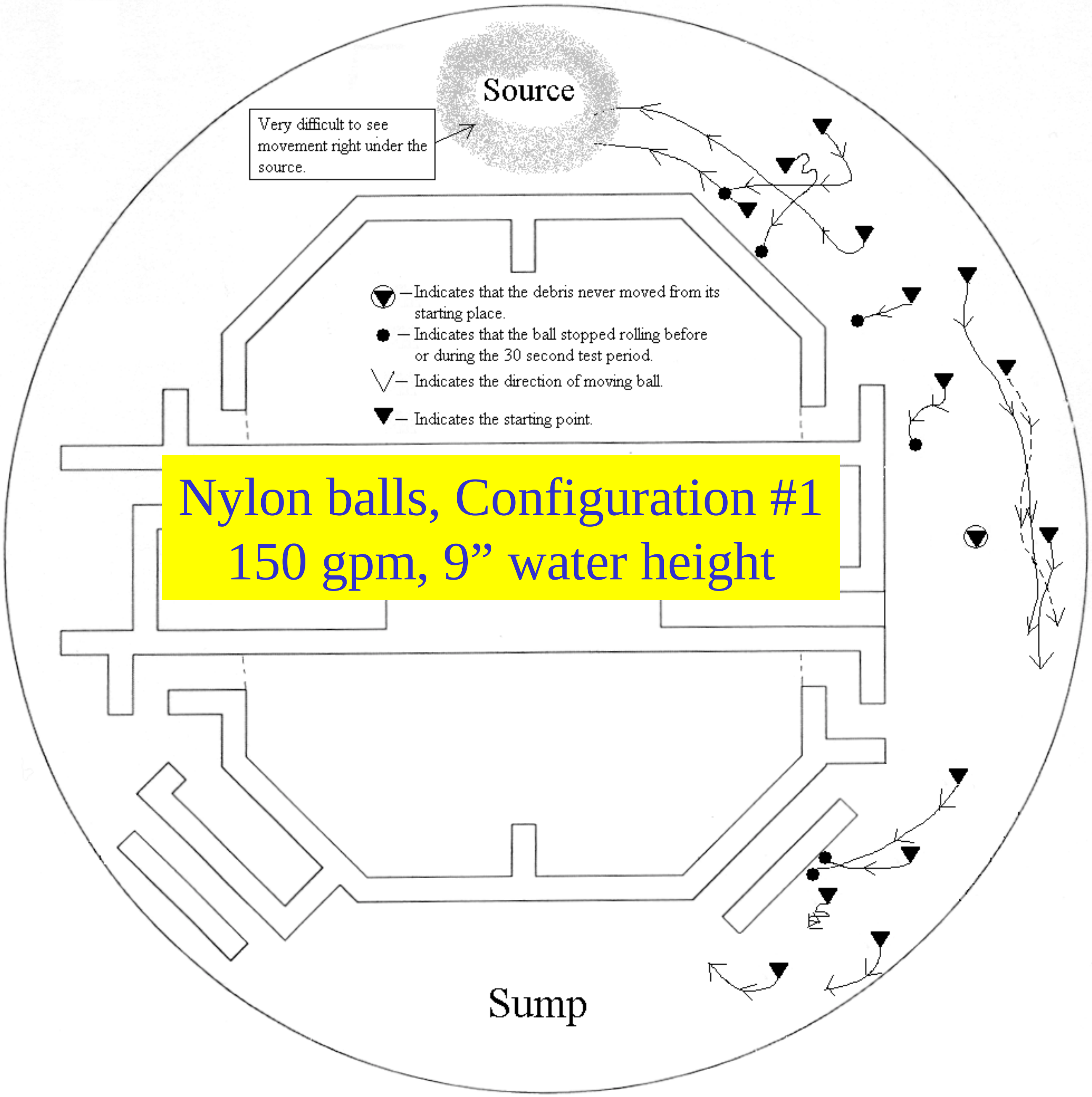
Flow Velocities from CFD

Incipient Motion
Linear flume Test Data

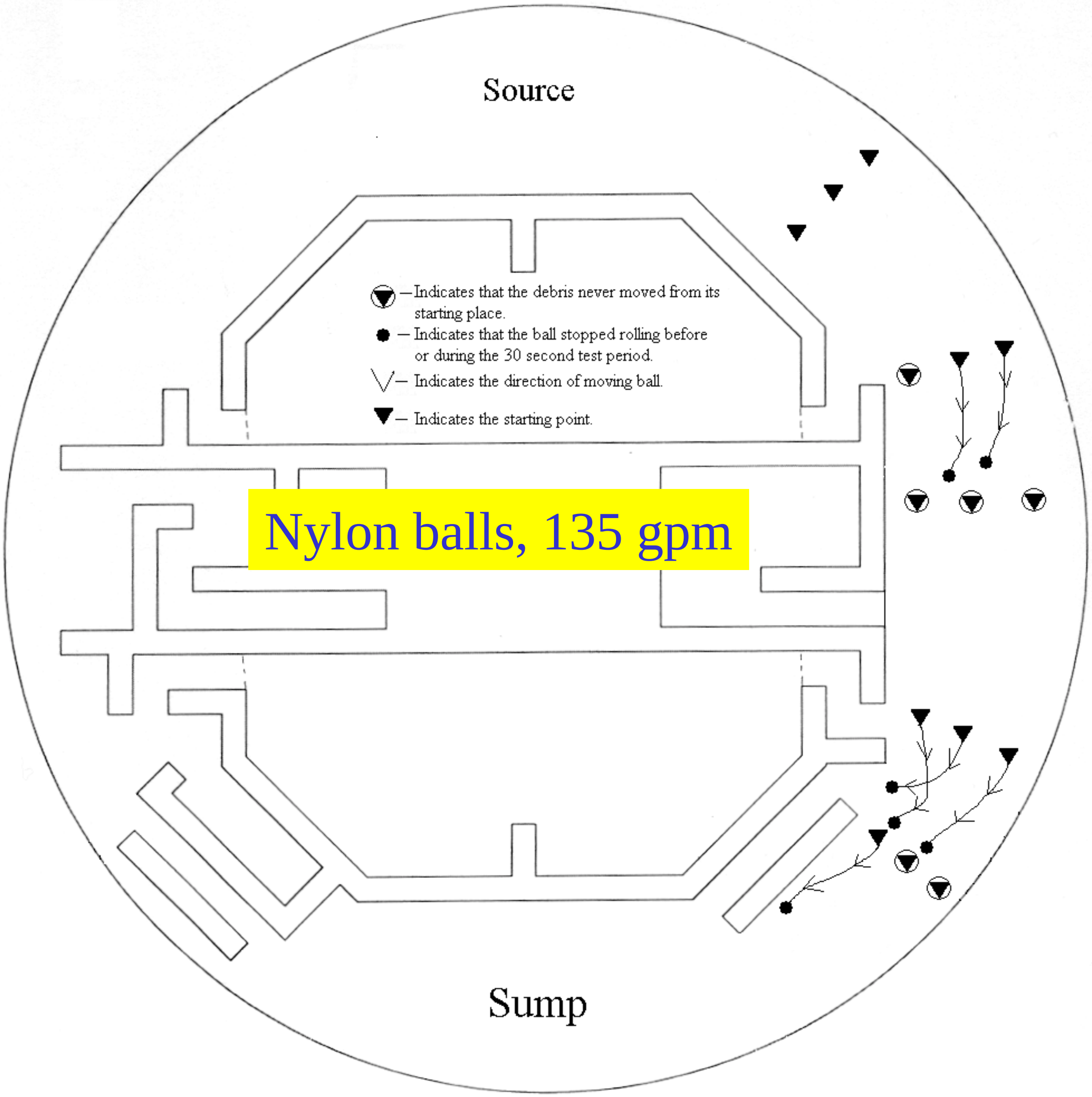
Determination of Transport Fraction



Nylon balls, 120 gpm
Source Configuration #2
Source
Sump



Nylon balls, Configuration #1
150 gpm, 9" water height


Source
Indicates that the debris never moved from its starting place.
Indicates that the ball stopped rolling before or during the 30 second test period.
Indicates the direction of moving ball.
Indicates the starting point.
Nylon balls, 135 gpm
Sump

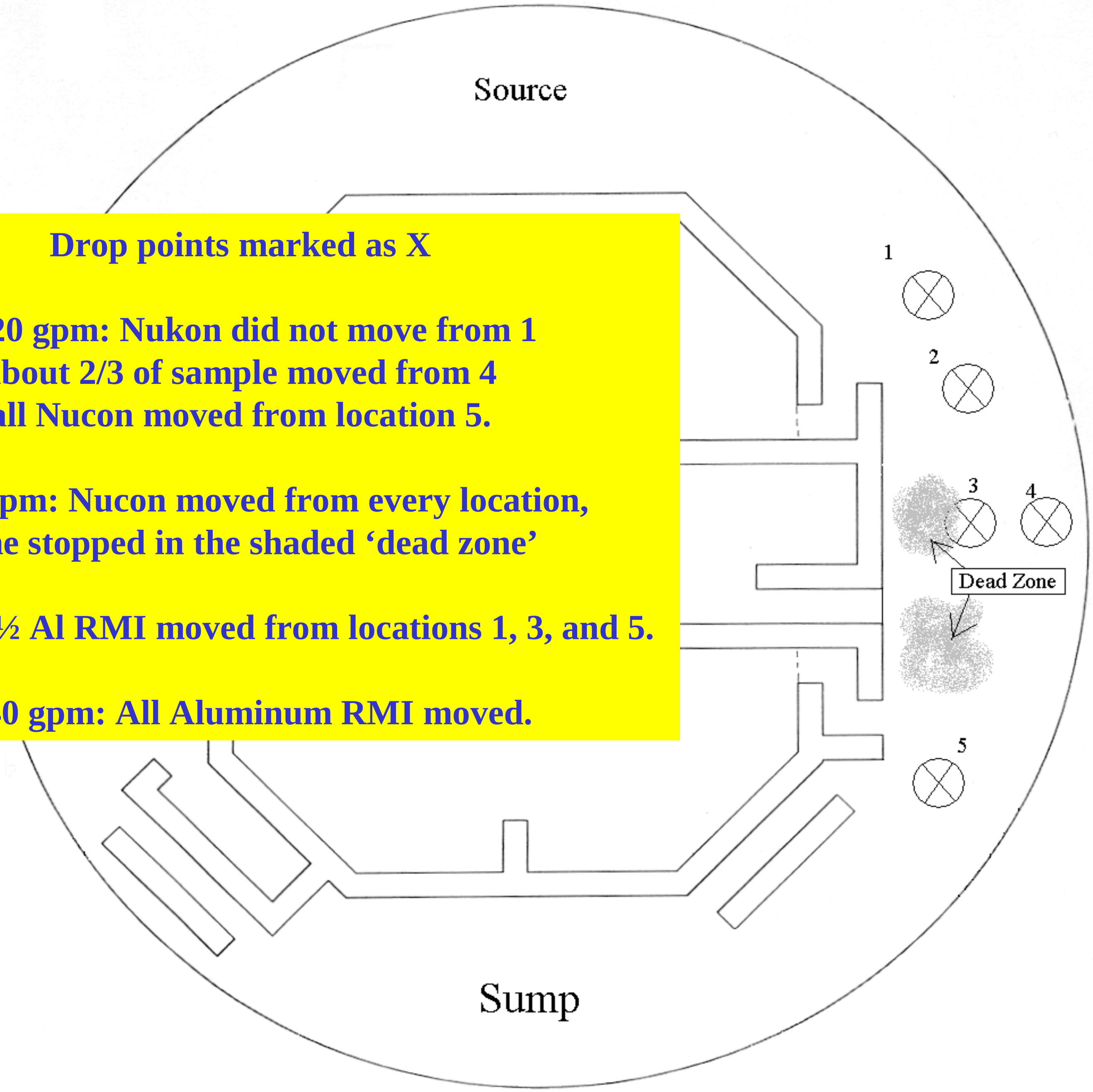
Drop points marked as X

~ 120 gpm: Nukon did not move from 1
about 2/3 of sample moved from 4
all Nucon moved from location 5.

~ 145 gpm: Nucon moved from every location,
some stopped in the shaded 'dead zone'

~230 gpm: ½ Al RMI moved from locations 1, 3, and 5.

~440 gpm: All Aluminum RMI moved.



Completed Test Matrix

3 TEST CONFIGURATIONS
(One in the annulus, two inside regions)

TWO FLOW VELOCITIES
(Close to incipient motion of Nukon & Nylon Marbles)

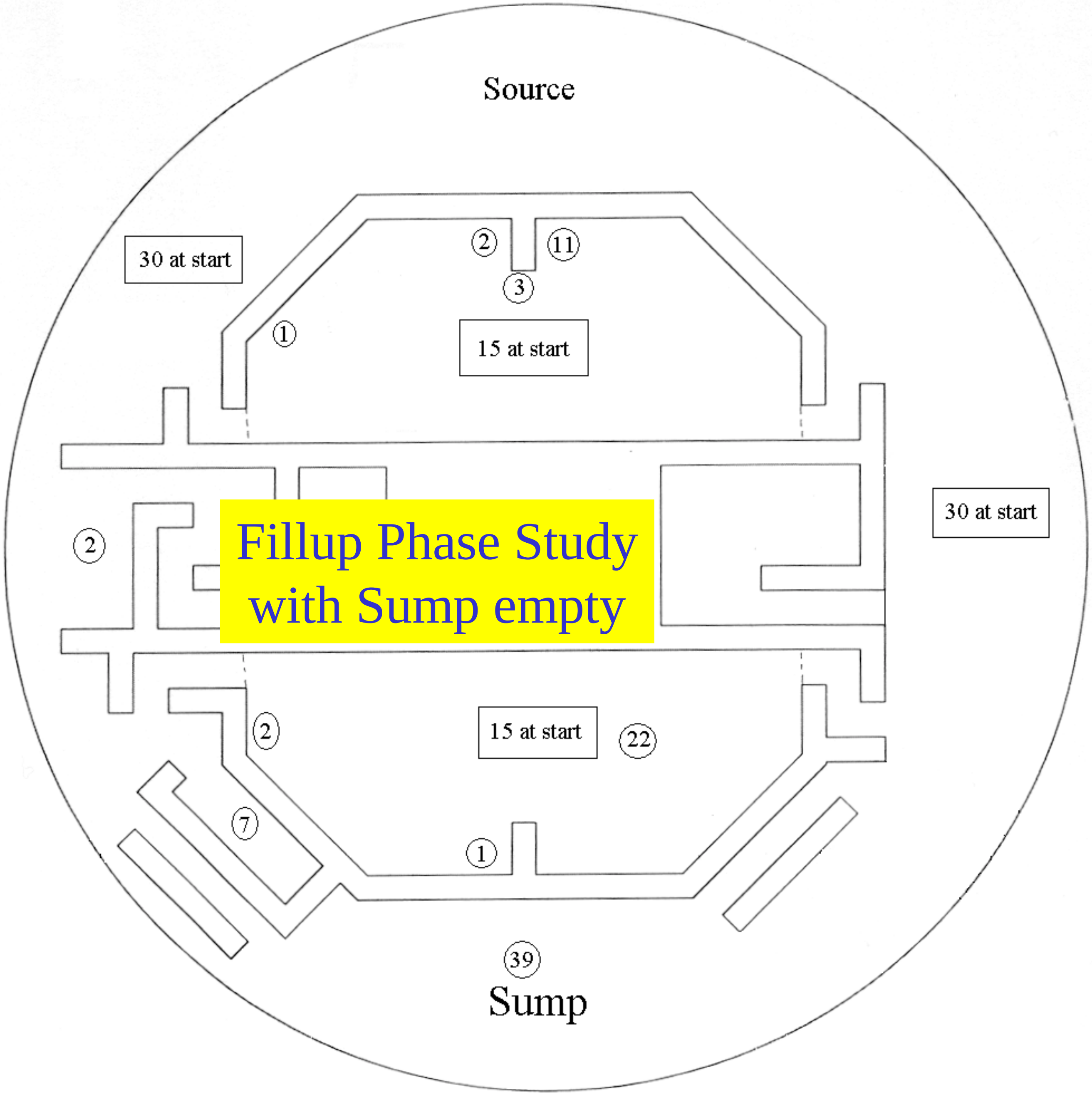
FLOW MAPPING WITH NYLON MARBLES
(Separate active and inactive zone)

DETERMINATION OF NUKON TRANSPORT FRACTION
(Short term and long term)

Fillup Phase Studies

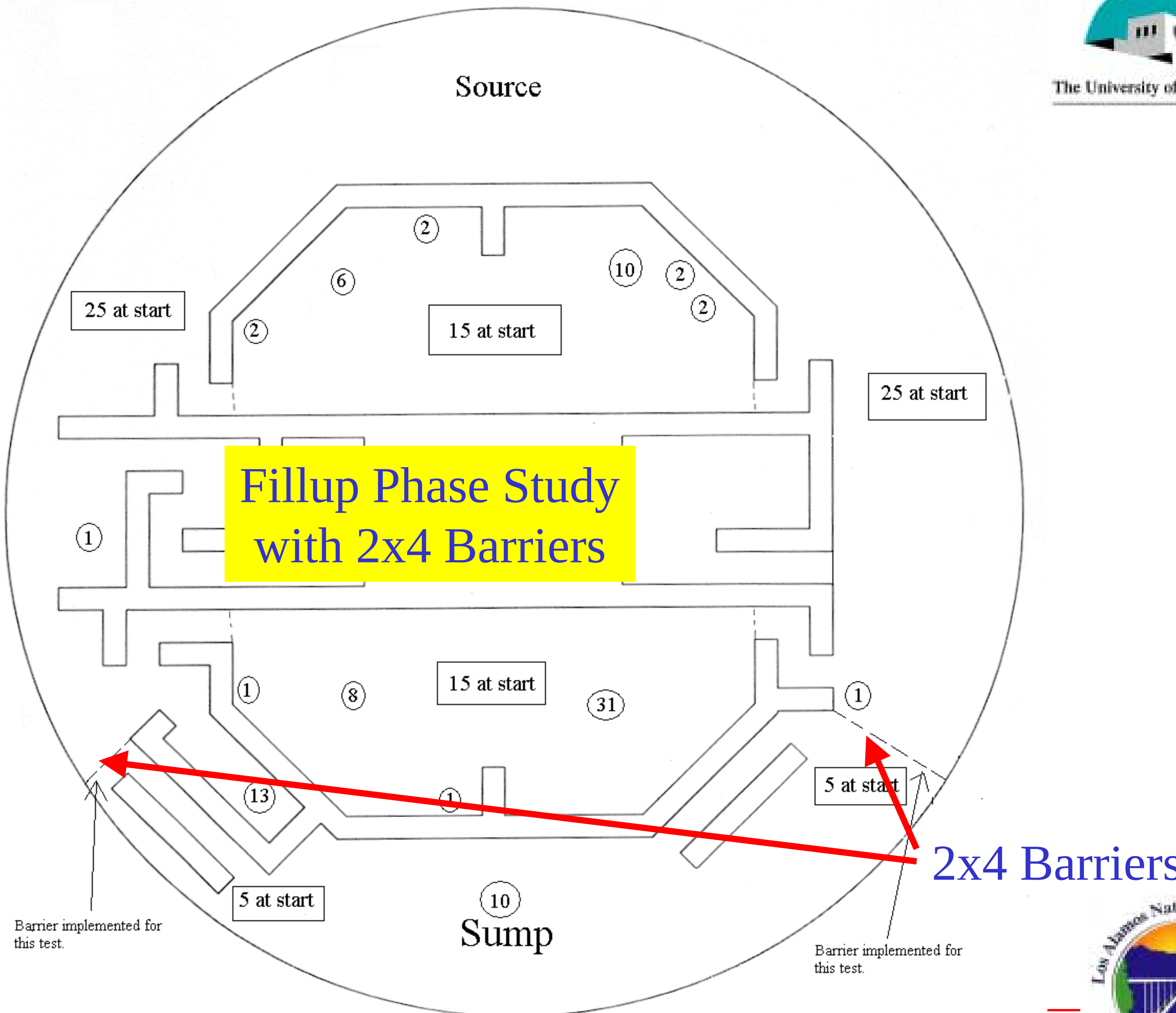
Debris Distributed Inside the Tank
Nylon, Al RMI
(Sump Initially Full or Empty)

2x4 Barrier
to Redirect Debris

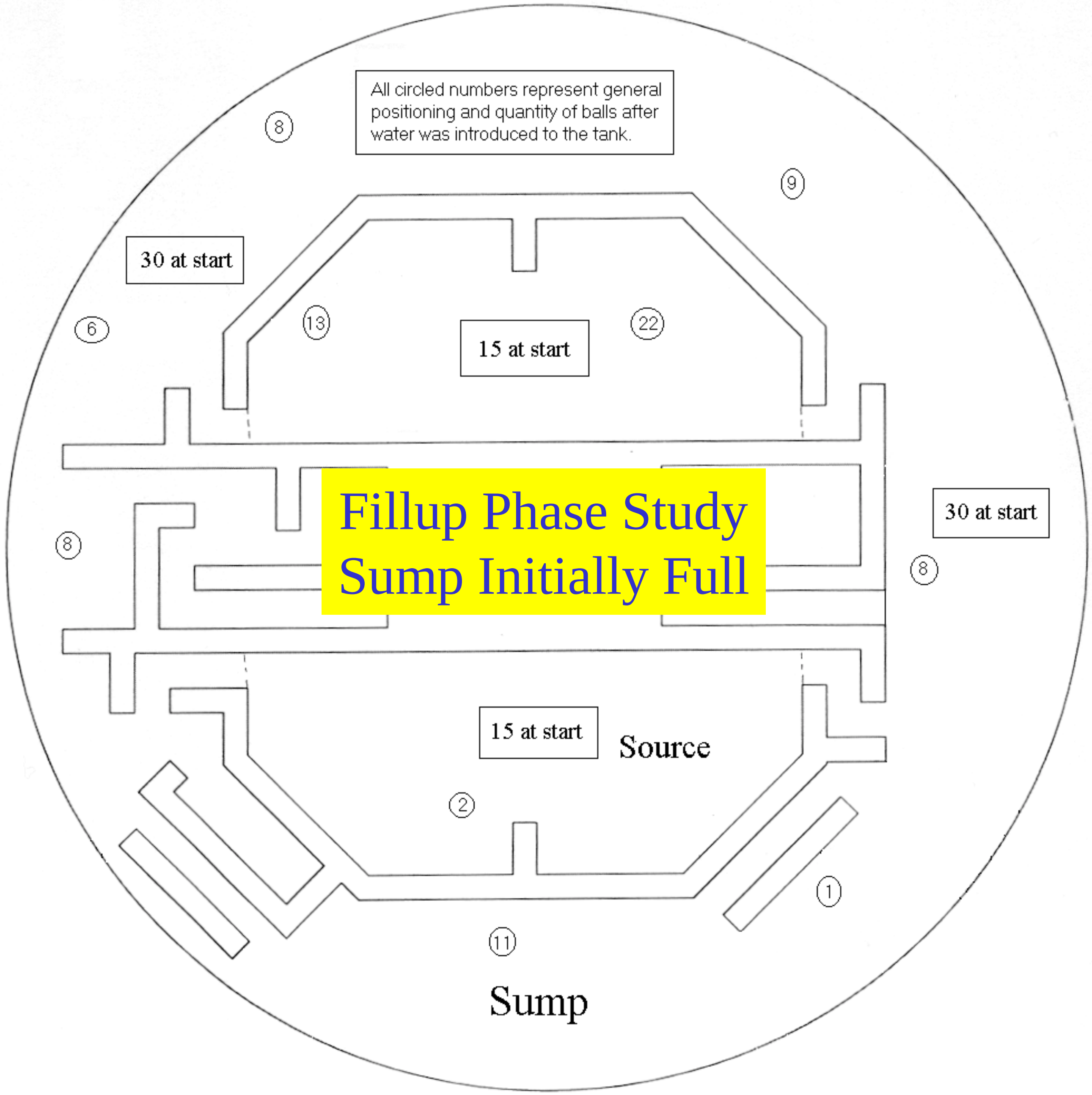


Source
30 at start
2
11
3
1
15 at start
30 at start
2
Fillup Phase Study
with Sump empty
2
15 at start
22
7
1
39
Sump

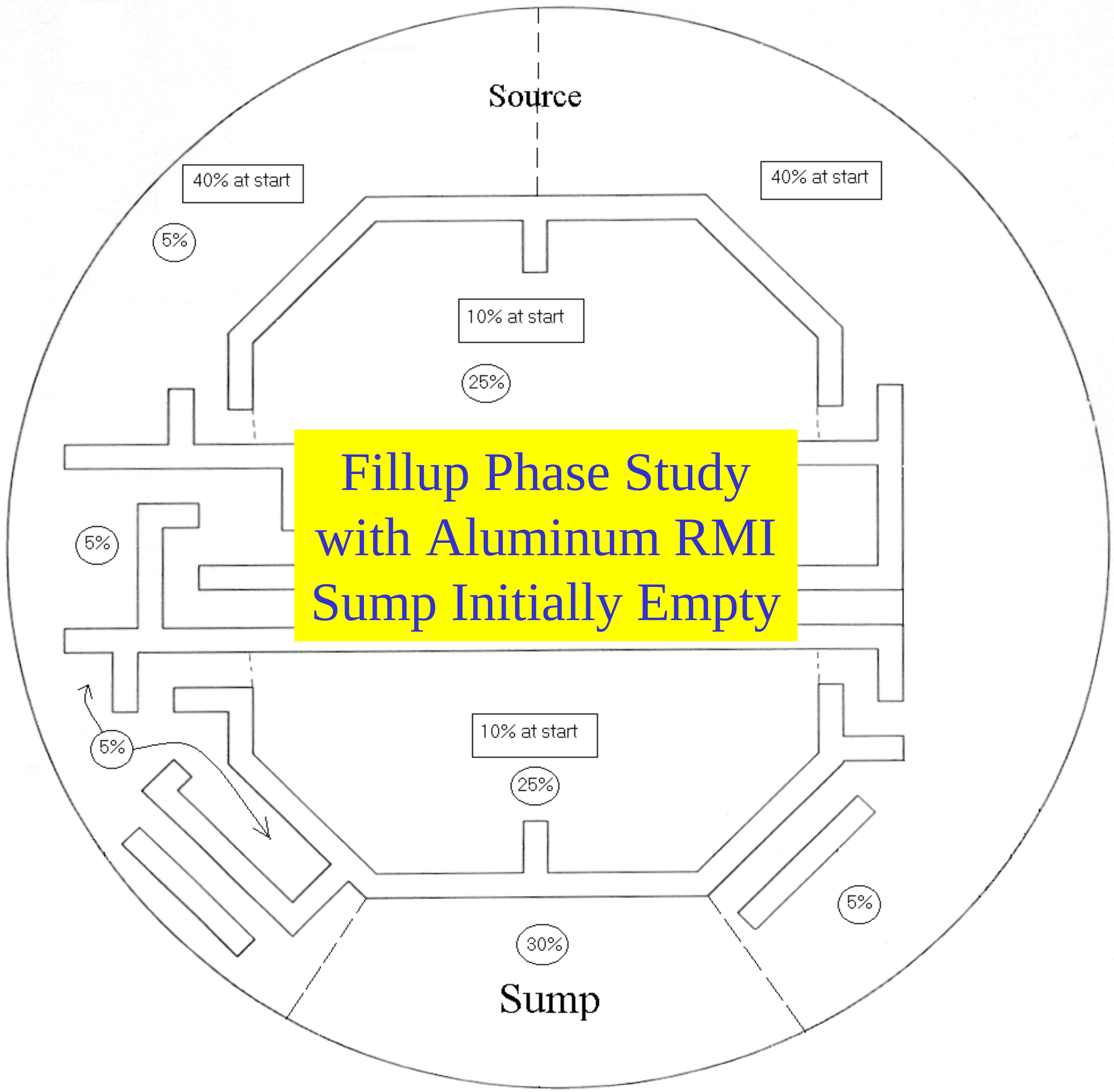
Fillup Phase Study with 2x4 Barriers



Fillup Phase Study
Sump Initially Full



Fillup Phase Study with Aluminum RMI Sump Initially Empty



PWR Sump Blockage Study:
Integrated Tank Testing of Debris Transport

Bruce Letellier

Probabilistic Risk and Hazards Analysis Group (D-11)

Decision Applications Division

Los Alamos National Laboratory

Los Alamos, NM

Integral (Bulk) Transport Tests

Generic Procedure:

1. 200 g of dry Nukon boiled 10 min and stored saturated
2. Introduced to a region of empty tank or at steady state with 9-inches of water
3. Nested top screen used to collect transport fraction at end of test (15 to 30 min)
4. Nested bottom screen used to collect non-transport fraction as tank is swept and washed
5. All contents dried overnight and reweighed

Integral (Bulk) Transport Tests (cont.)

Tank-Test Results

15-min Video of Debris Transport in Tank

Important Tank-Test Observations

- **Geometry of primary walls relative to break affects water flow patterns**
- **Dead sumps (large rooms, shafts, cavities) significantly affect transport during fill up and permanently hold some debris**
  - May move debris of all sizes at high velocity
  - Only important for debris fraction that is already on the floor
- **Fluctuations in pump flow and pool depth increase the uncertainty between tank measurements and CFD calculations**
- **Shreds of non-friable debris (RMI, marbles, polystyrene pellets) can accumulate in recirculation eddies close to break**
  - May only be stable if break flow is nearly constant
  - Fibrous debris can gradually decay out of eddies but small pockets remain stable for up to 5 hours

Important Tank-Test Observations

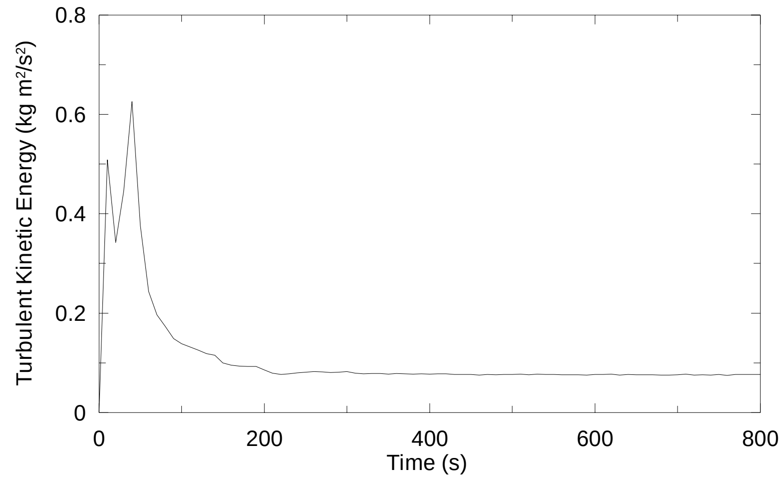
- **Approx. transport method must account for initial size/character of debris, initial location, time of introduction to floor level**
  - Fibrous debris introduced near falling water can degenerate to individual fibers
- **Although current flow regimes separate the “sump zone” from the “break zone” at a 0.2 ft/s velocity criteria, recalibration and testing is needed at lower flow volumes**
  - Ratio of plant volume to tank volume suggests tests flows ≤50 gpm
  - Long-term disposition of individual fibers and very small flocks should be tested
- **Ancillary water cascades representing containment spray return paths should be estimated and tested**

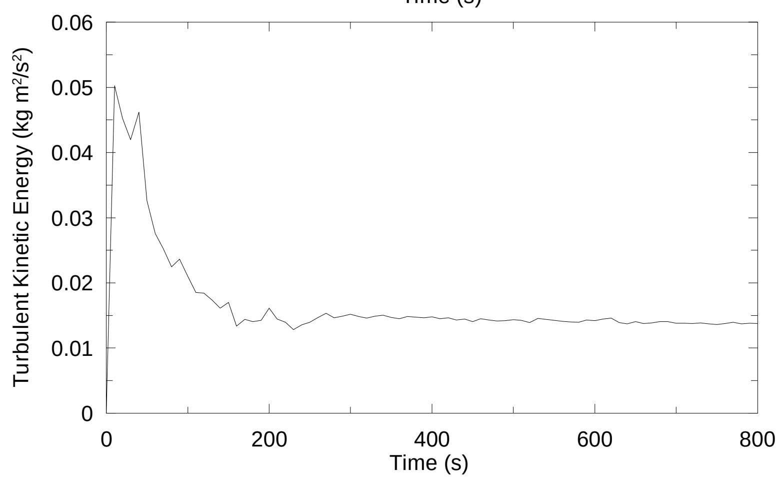
CFD Modeling of Tank Transport

- **Objectives:**
  - Reproduce observed flow patterns for various tank conditions
  - Provide quantitative predictions of local velocities that support approximate transport methodology
- **Mechanics:**
  - Flow-3D still preferred for free-surface treatment and convenient access to local support at LANL
  - Approx 300,000 cells give spatial resolutions ~1.5 in^3 and calculation times between 50 and 70 hours from fill up to steady state (950 MHz desktop PC)
  - Velocity patterns under "steady-state" recirculation often fluctuate due to eddy collapse and regrowth
  - Steady state identified by stable or oscillating turbulent kinetic energy and bulk kinetic energy

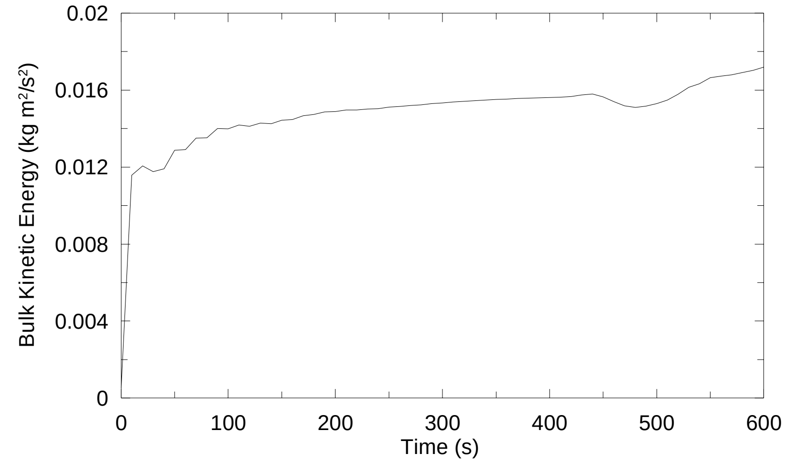
Convergence Criteria for CFD Calculations

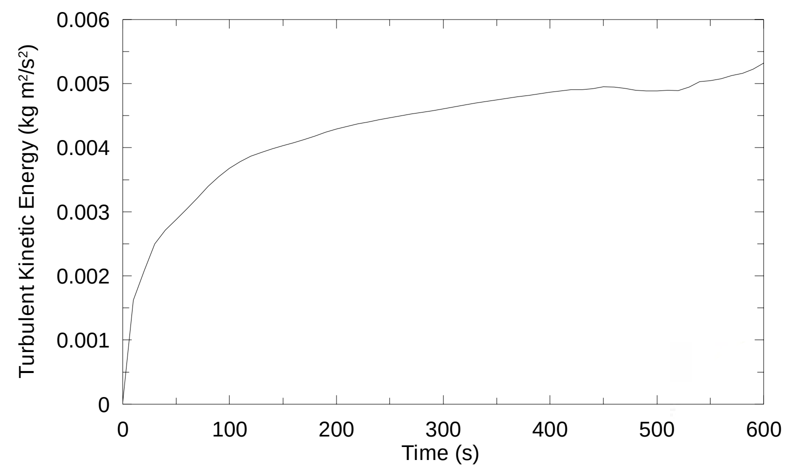
Upper Quadrant Break

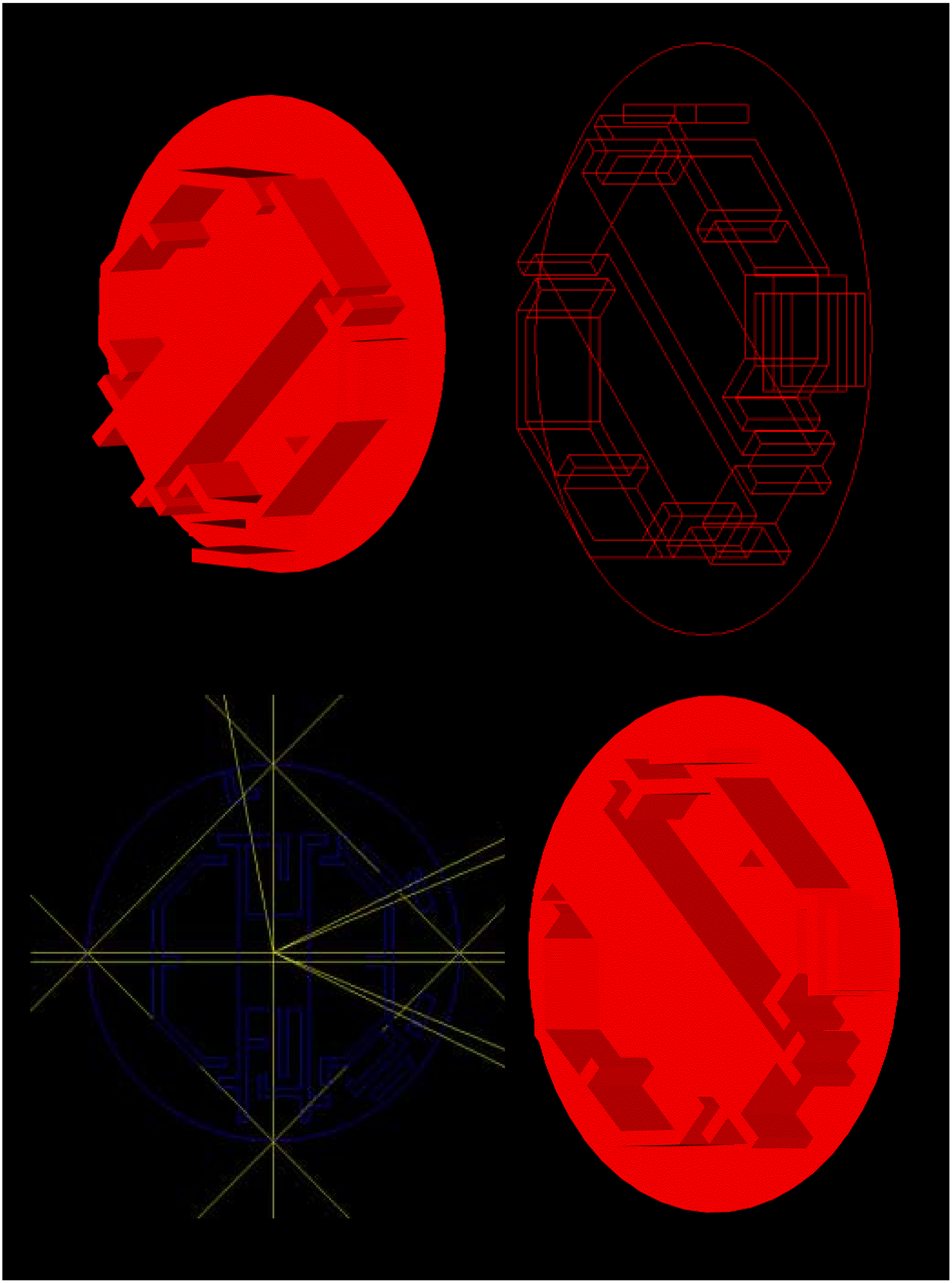




Lower Quadrant Break



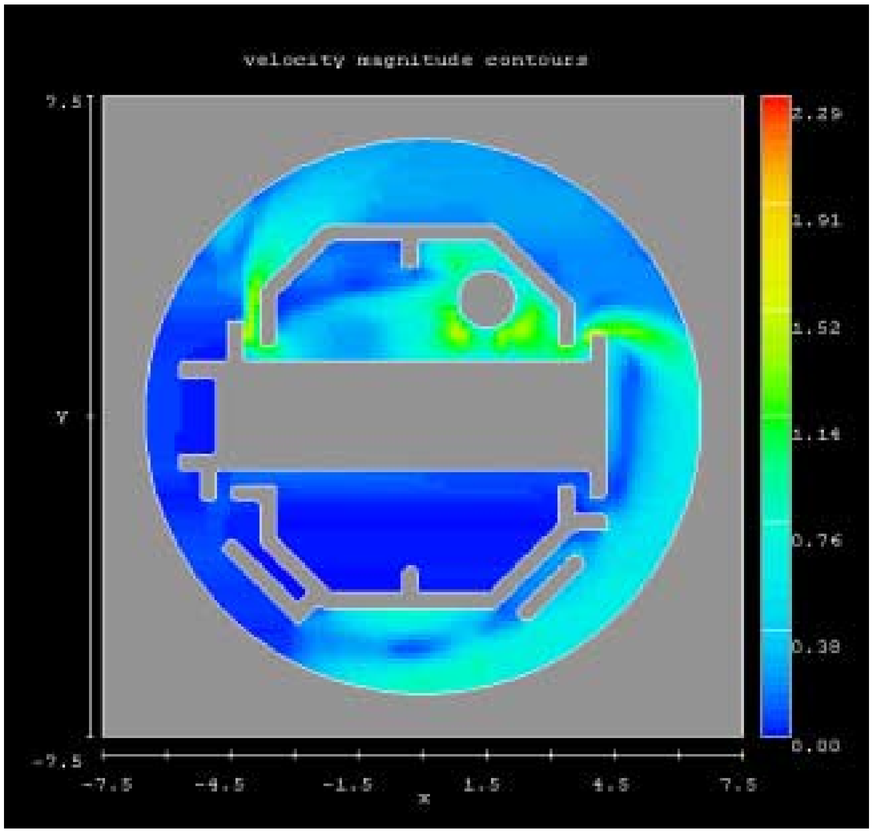




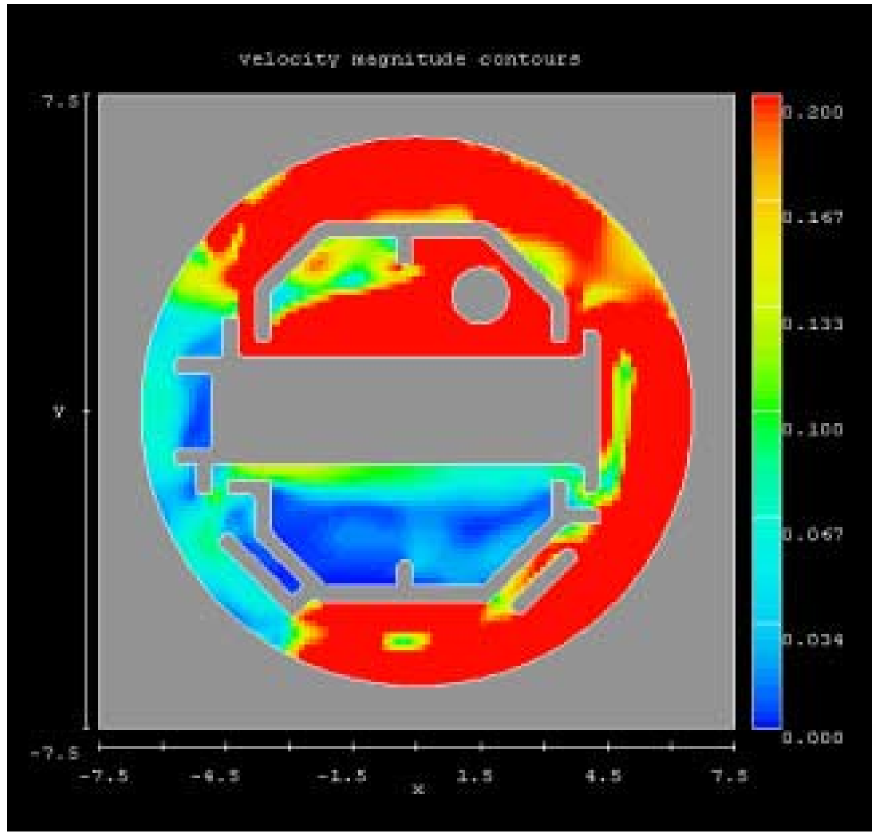
Steady-State Velocity Maps (Upper Quadrant)

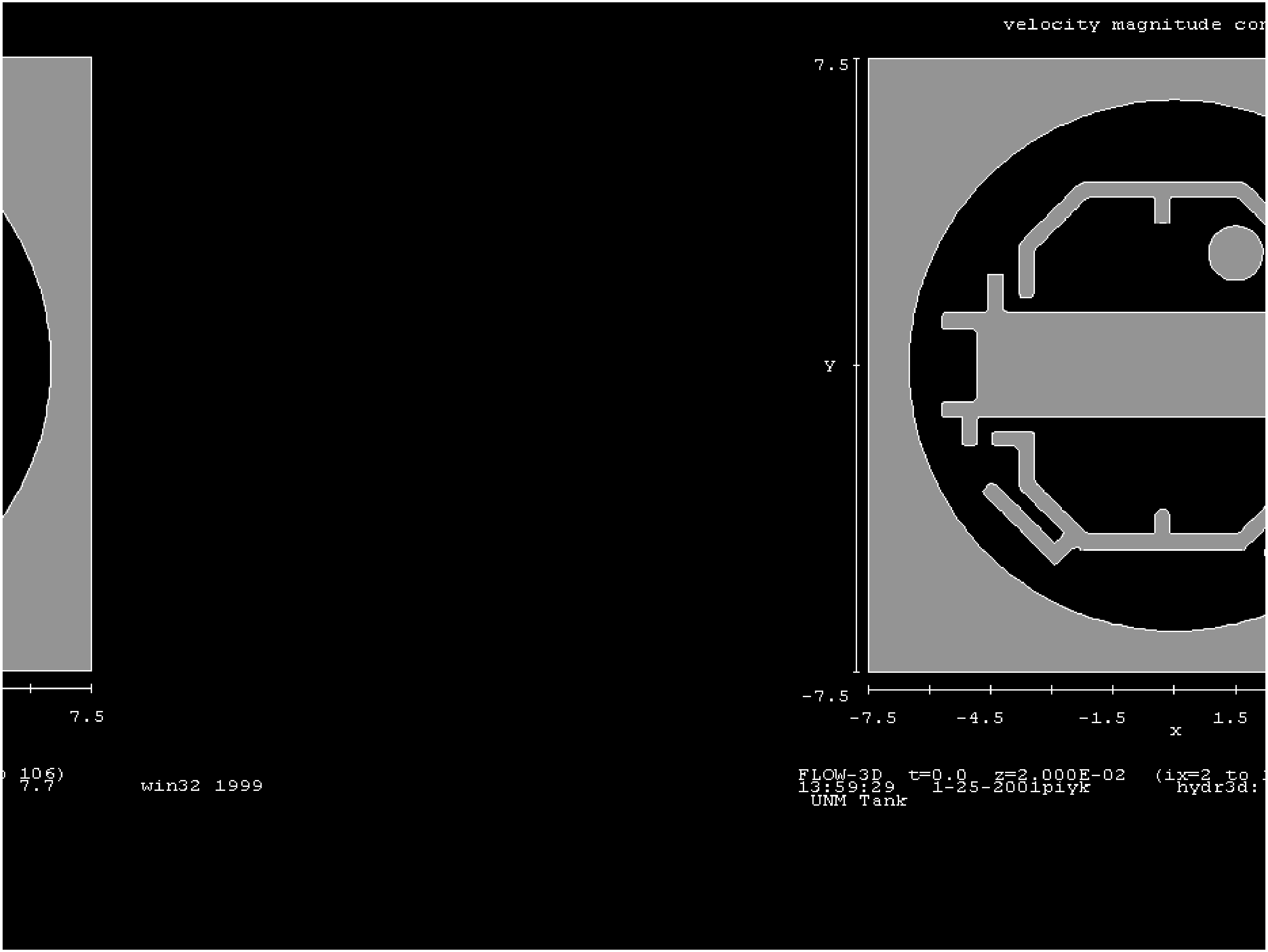
(Both Shown as Animations)

Auto Scale Max Velocity



Max Velocity 0.2 ft/s





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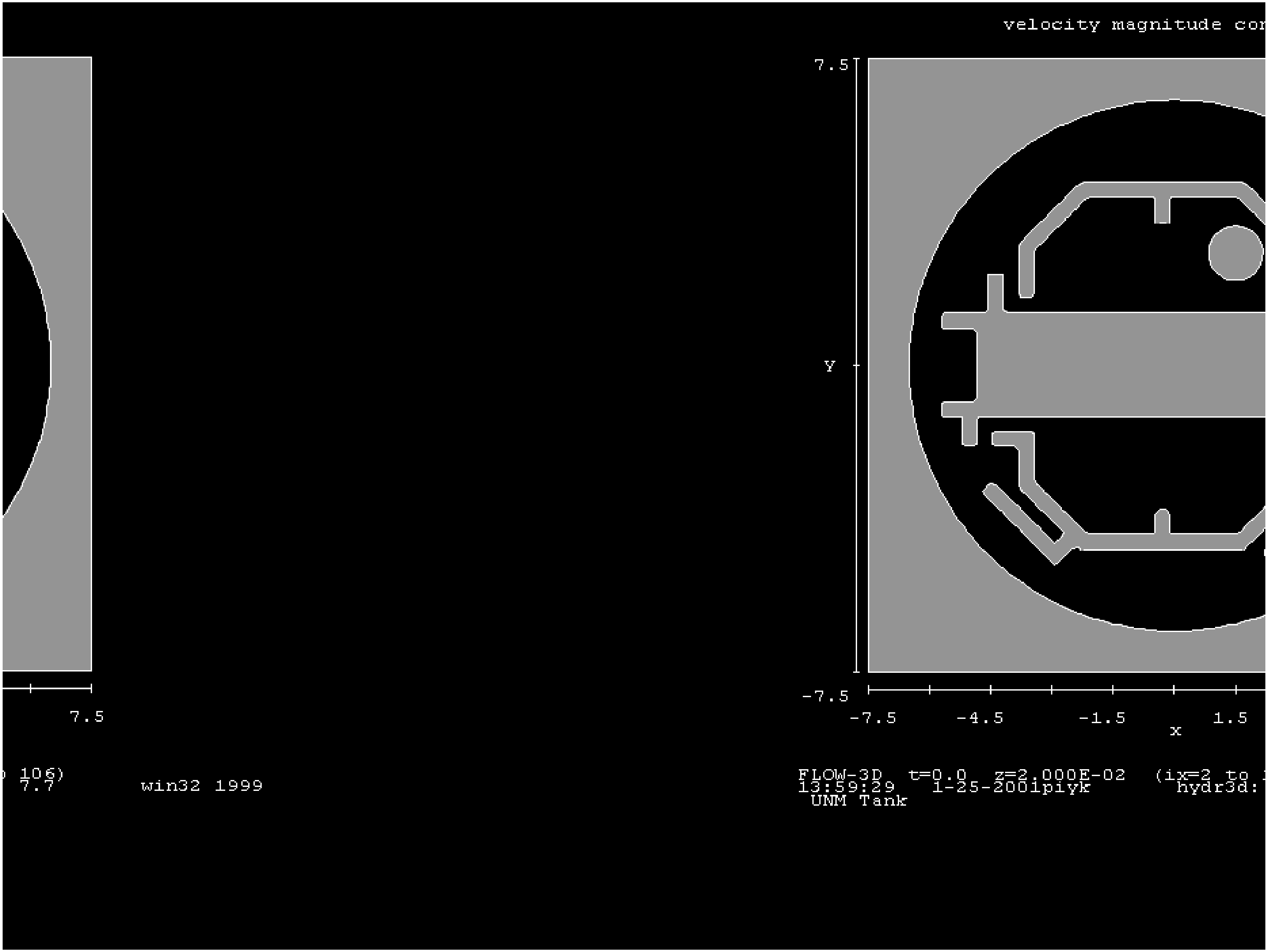
hydr3d:
UNM Tank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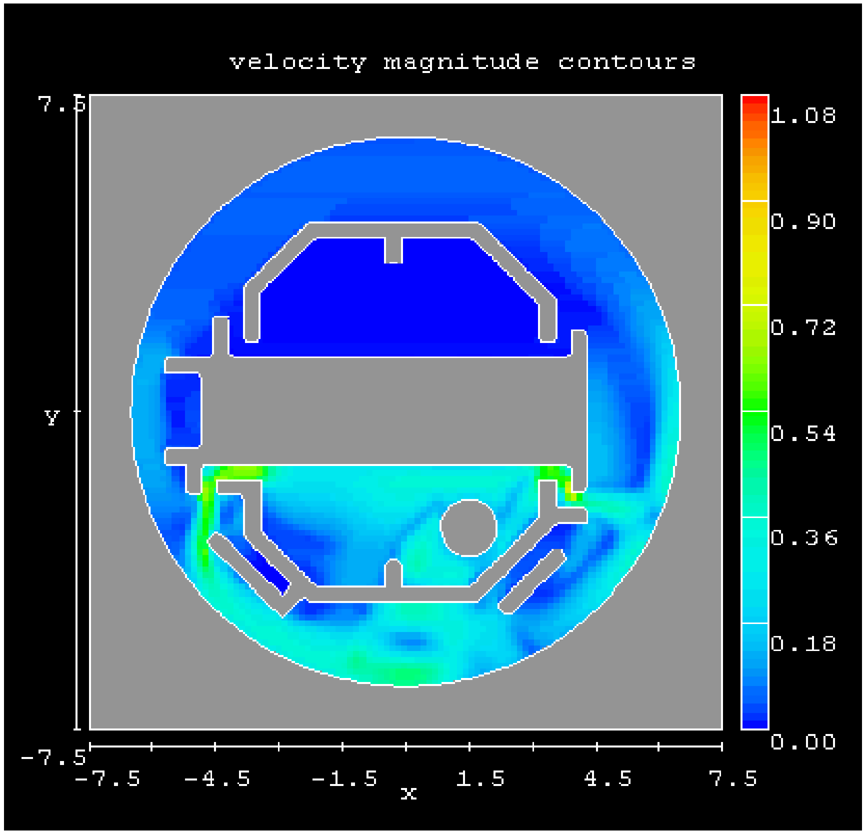
hydr3d:
UNM Tank

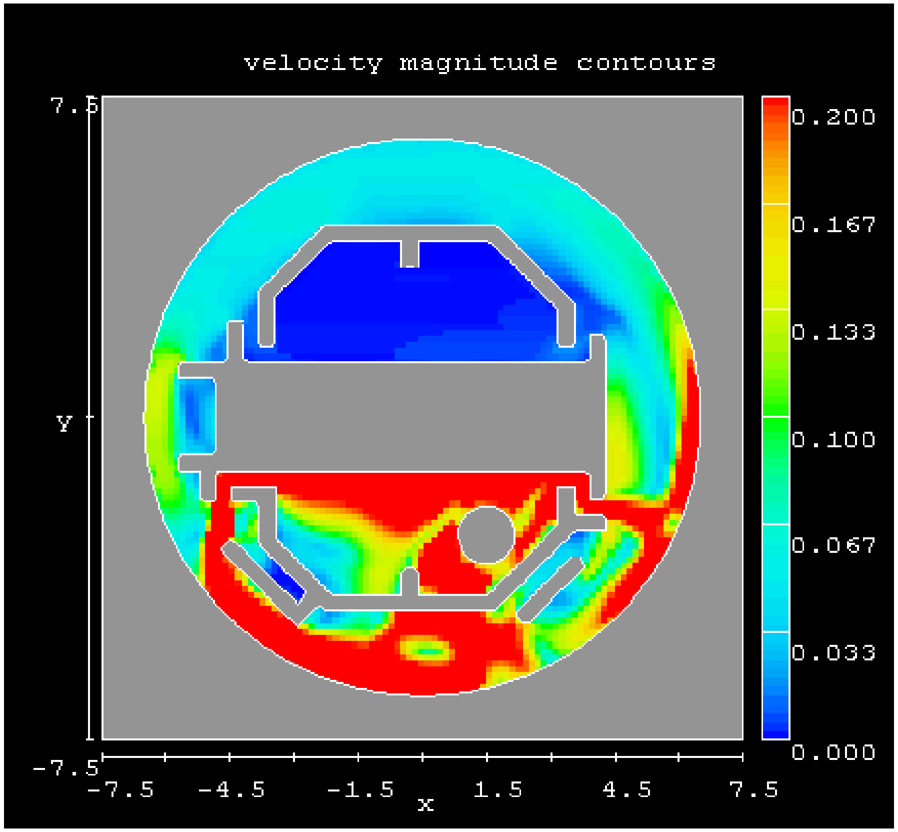
Steady-State Velocity Maps (Lower Quadrant)

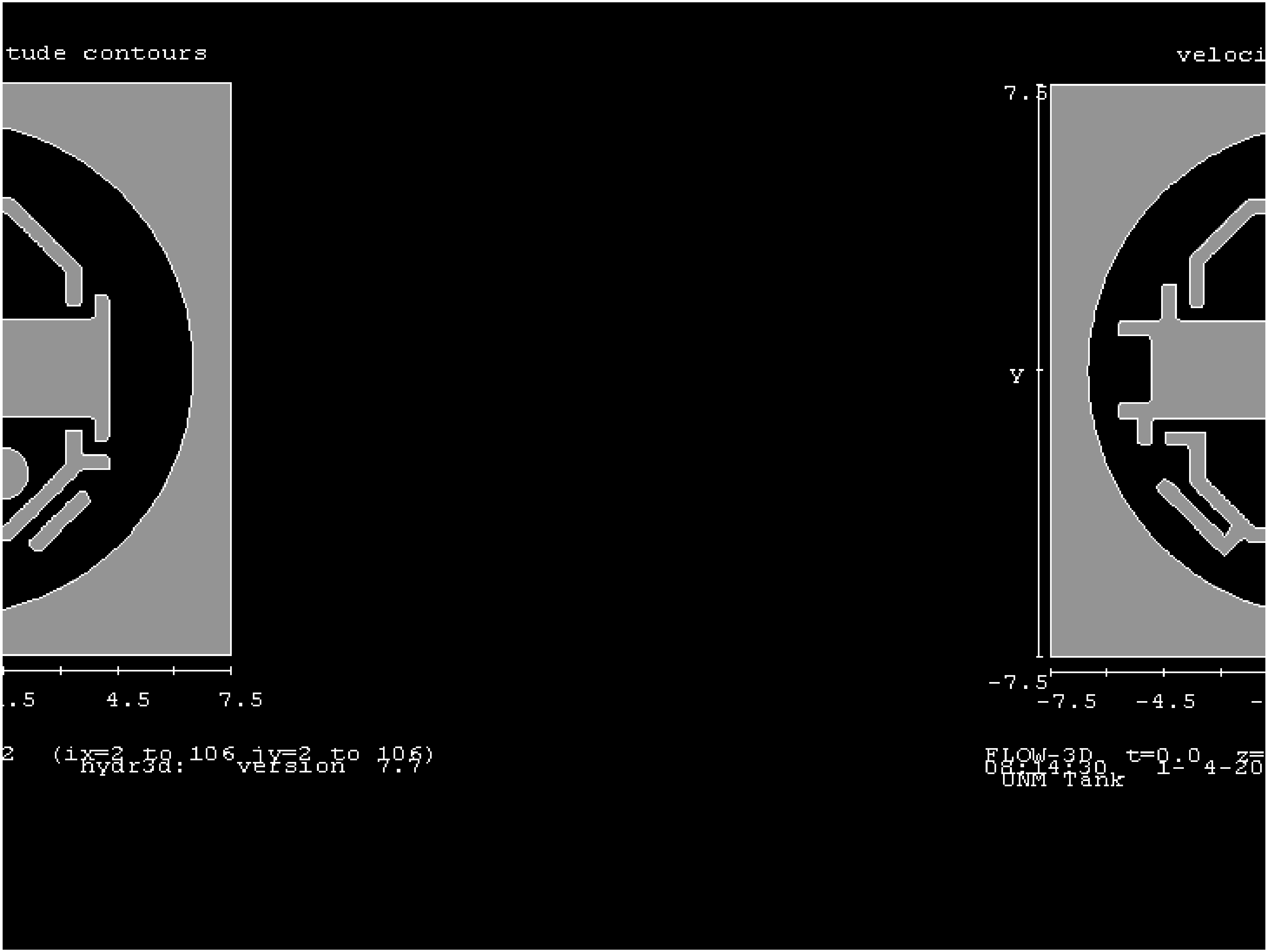
(Both Shown as Animations)

Auto Scale Max Velocity



Max Velocity 0.2 ft/s





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FLOW-3D t=0.0 z=
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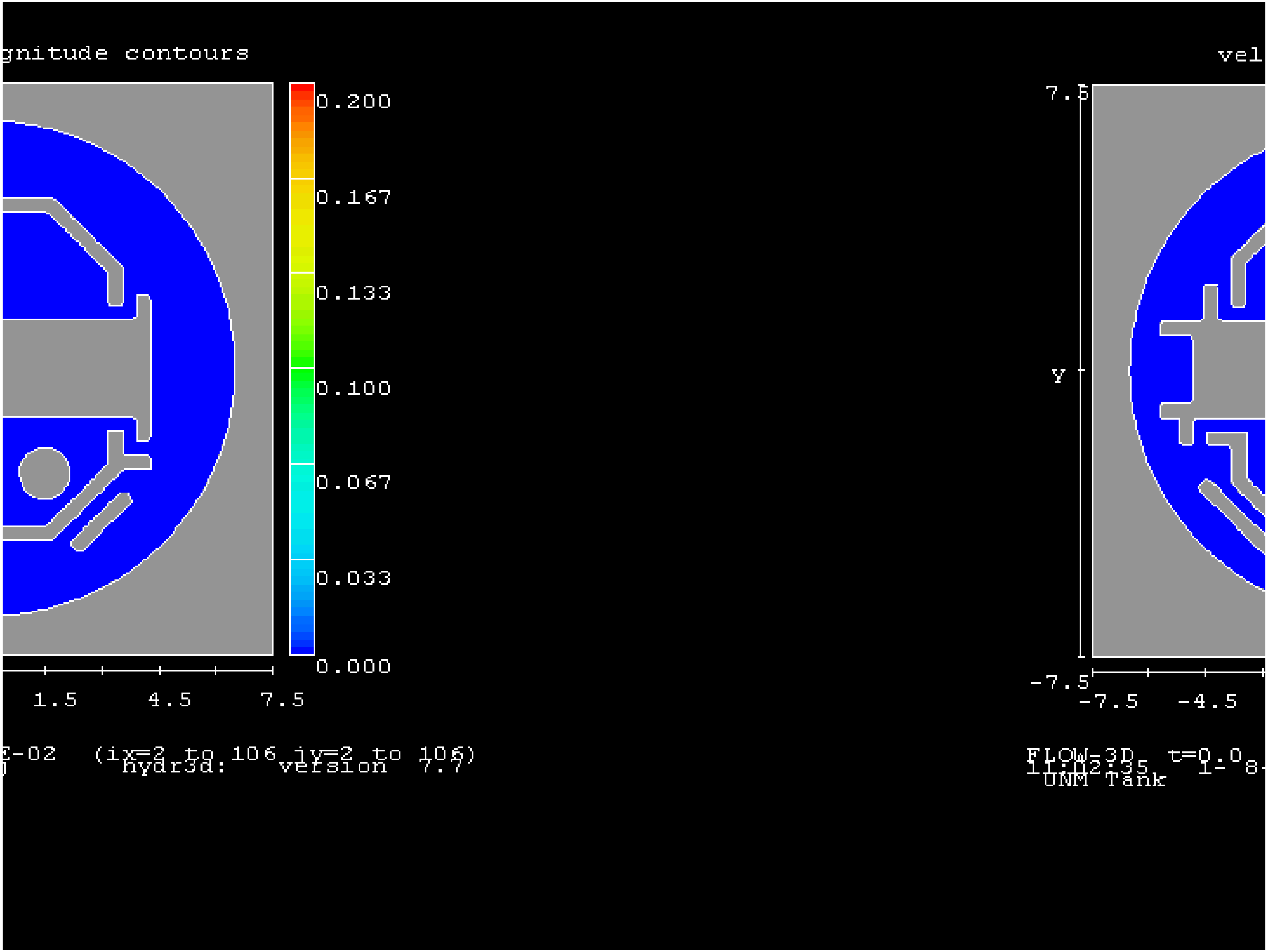
UNM Tank



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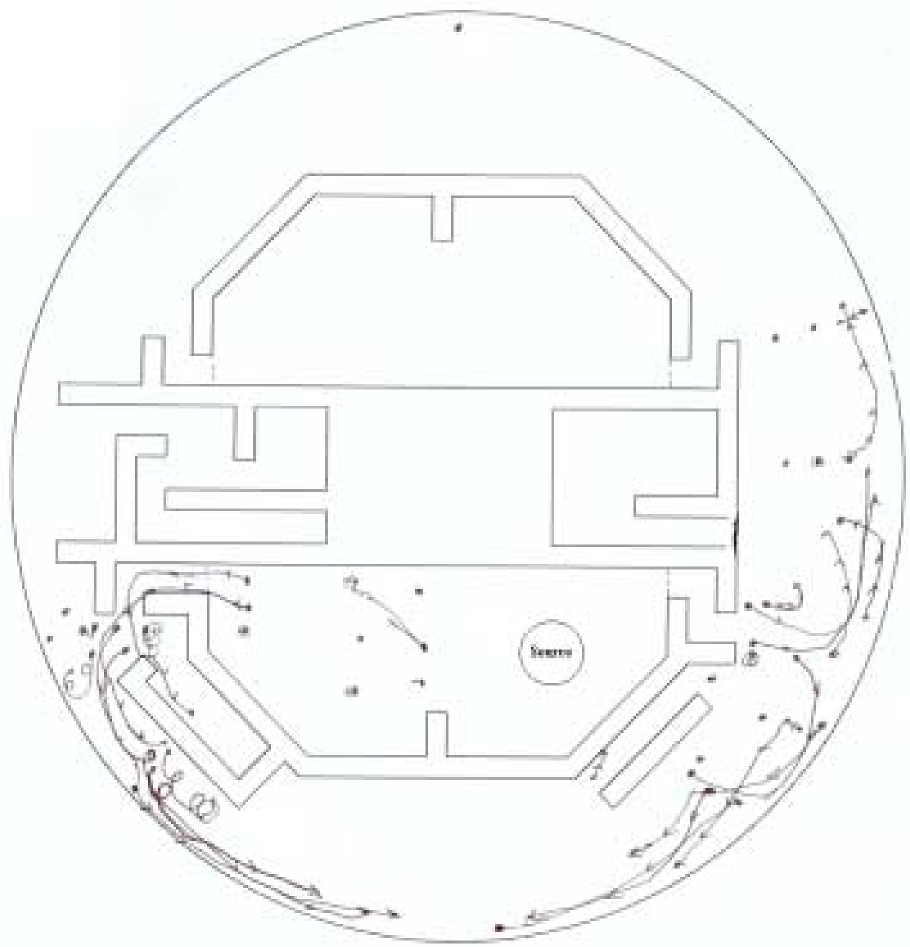
-7.5
-7.5
-4.5
E-02 (ix=2 to 106 iy=2 to 106)
hydr3d: version 7.7
FLOW-3D t=0.0
11:02:35
UNM Tank

120 gpm With 30-s Observation Times



Conceptual Model of Debris Transport

Migration to the sump can be viewed as the interaction of two functions: Pool Transport and Debris Source Description

$$I = \int S(m,\vec{r},t)T(m,\vec{r},t)d\xi$$

<u>Source Function, *S(m,r,t)*</u>

m = material type, size, character, etc.

r = spatial location *(x,y,z)* introduced

t = time when introduced to pool

• Describes all aspects of the debris that enters the pool.

• Analysis of blow down and water return paths needed to define the source term.

<u>Transport Function, *T(m,r,t)*</u>

m = material type, size, character, etc.

r = spatial location *(x,y,z)* in pool

t = time during accident event

• Describes all aspects of water flow and the interaction of velocity field with the debris particles/pieces.

• Predicted by CFD calculations

Preliminary Statement of Transport Method

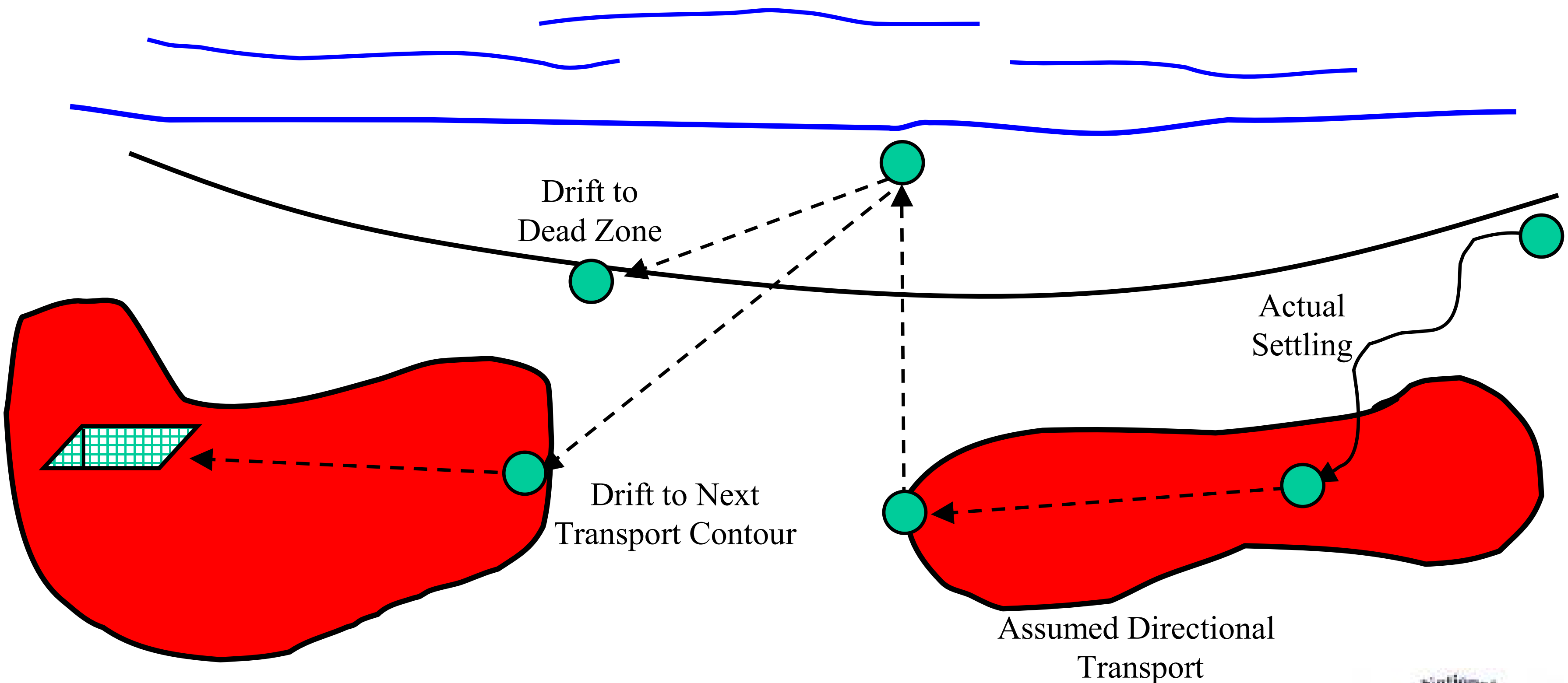
Basic Assumptions:

1. Linear flume tests characterized the incipient flow and settling velocities of various debris types and sizes
2. CFD can predict local water velocities (speed and direction)

Approach: (for a given debris size and initial location)

1. Consider contiguous areas with velocities higher than incipient velocity as regions susceptible to transport
2. Conservatively assume migration to boundary of the incipient velocity contour and release from pool surface
3. Consider settling time from surface as an opportunity to drift into another contour or into a stagnant zone (velocity < incipient)
4. Any debris reaching the contiguous contour surrounding the sump (sump zone) is assumed to eventually collect on the screen

Schematic of Approx Transport Method



Observations Regarding CFD Modeling

- **Good qualitative agreement between CFD models of fill/steady-state velocities and Tank Experiments**
- **Ancillary sources representing containment spray return paths should be added**
  - Particular interest in effect of annular wash down of walls at the pool level
- **Current suite of desktop PCs will permit ~10 break simulations per volunteer plant**
- **Quantitative flow maps provide access to an approximate, yet tractable estimate of transport fraction**
  - Logic maps and engineering judgment will be needed to consider fractions and characteristics of debris returned to the pool via various paths

Summary of Industry At-Power Radiation Dose Rates Survey

Presented by:
Tim Andreychek
Westinghouse Electric Co., LLC
andreyts@westinghouse.com
Albuquerque, NM
February 14, 2001

Overview

- Purpose
- Background
  - SRTC Coatings Failures
  - Industry Response
- Industry Action
- Summary of Survey Results
- Conclusions

Purpose

This Industry Initiative directed at supporting the NRC research being conducted under GSI-191in the following topical areas

- Coatings failure research
- Probabilistic risk assessment

by voluntarily providing operating plant data to support closure of this issue

SRTC Coatings Failures

September 26, 2000 Public Meeting

- Coatings failure observations from SRTD tests noted
- Data suggests that coatings failures driven by
  - Total radiation dose
  - Radiation dose rate
  - Oxygen in environment
- Applicability of test data to plant operation questioned
  - Plant dose rate and total dose compared to test conditions
  - Time for off-gassing gaseous products of radiolysis
  - Submersion sequence; dose, pressure and temperature
- NEI letter dated 10/19/2000 communicated concerns

SRTC Coatings Failures

Coatings failures summary

- Phenoline® 305 coating tested
  - Concrete substrate, Starglaz® 2011S epoxy surfacer
  - Test conditions:
    - Irradiated at $1x10^6$ rads / hr for $1x10^9$ rads total dose
      - ASTM D3911-95 DBA : NO DEBRIS
      - "Plant specific" DBA : No debris, disbondment / blistering
      - Submergence in 200° F water : Flocculent debris
    - Irradiated at $1x10^6$ rads / hr for $1x10^7$ rads total dose
      - Submergence in 200° F water : NO DEBRIS
    - Pre-1987, $1x10^8$ rads / hr for $1x10^9$ rads total dose
      - ANSI 101.2-1972 DBA : NO DEBRIS
- Data suggests behavior driven by dose and dose rate

Industry Action

Address applicability of test conditions to operating plants

- Dose rates at full power operation
- 60 years of effective full power operation
- Dose rate for postulated LOCA

Industry Action

Approach

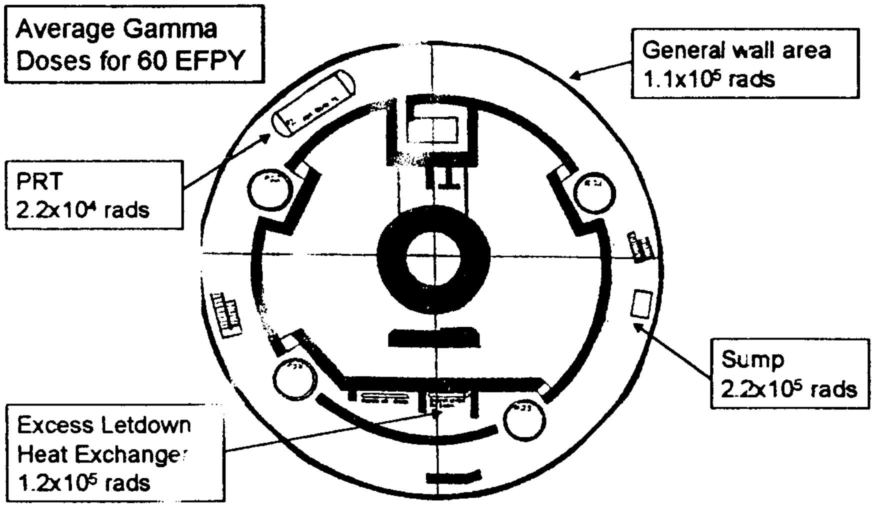
- Sites requested to provide available at-power dose survey information
  - No request made to obtain additional information
  - Data is historical in nature
  - Available information varies from plant to plant
  - Dependent upon site-specific at power containment entries
  - Survey development lead by WOG
  - Participation agreed to by all three PWR OG's
- Excellent initial cooperation;additional responses coming

Industry Action

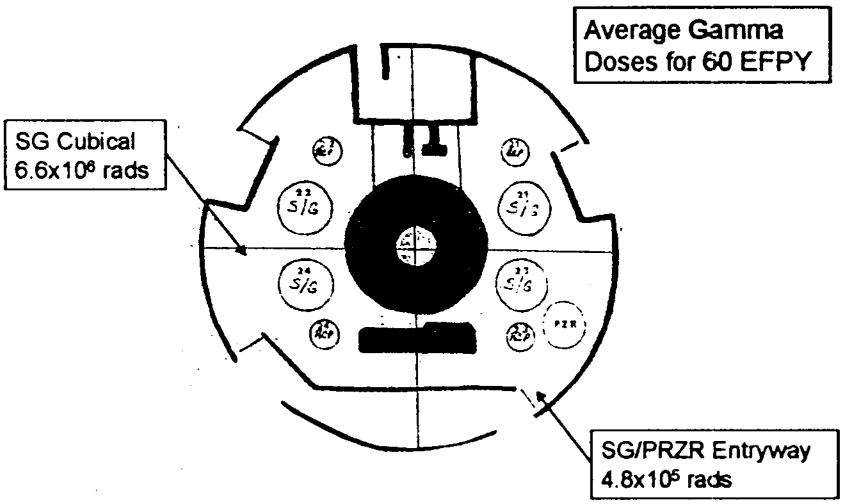
Operational Doses

- Only locations with four or more plants reporting used
- Reported dose rates extrapolated to total integrated dose after 60 Effective Full Power Years (EFPY)
- Average, Max and Min values calculated
  - Dose rates
  - Total integrated dose extrapolated to 60 EFPY of operation
- Total of fourteen locations reported here

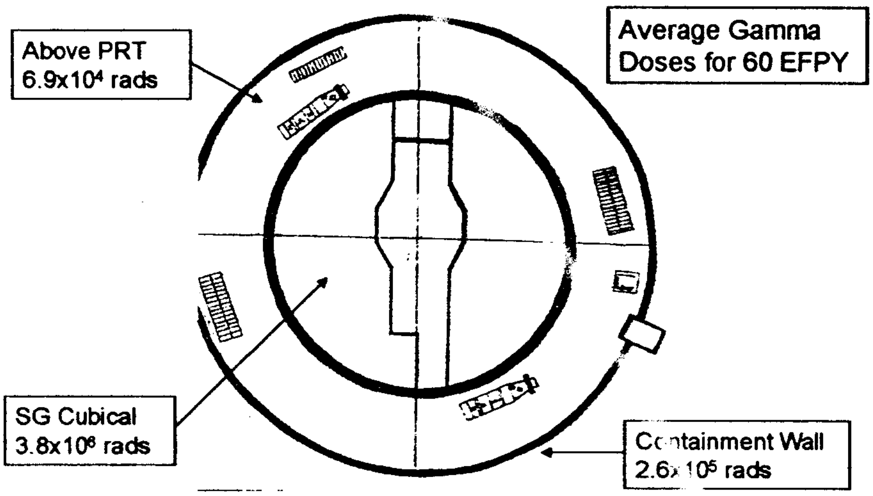
Containment Sun ip Level



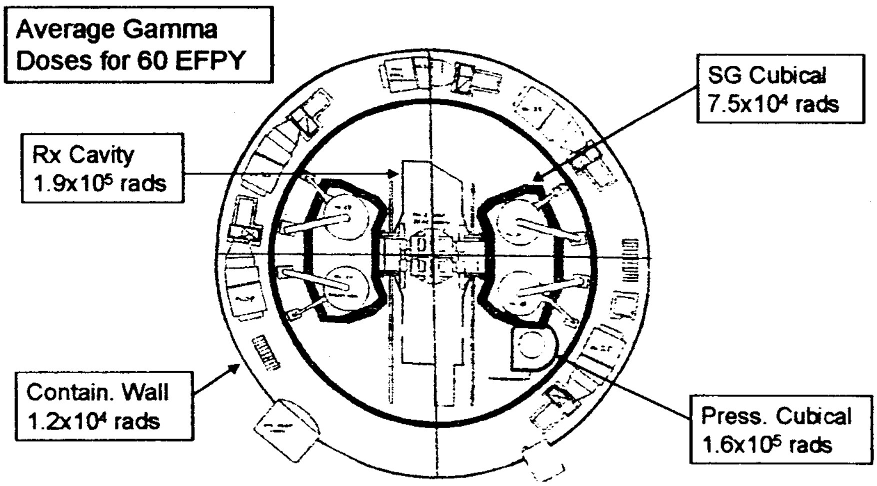
Containment Floor, Sump Level



Containment Intermediate Deck



Containment Operating Deck

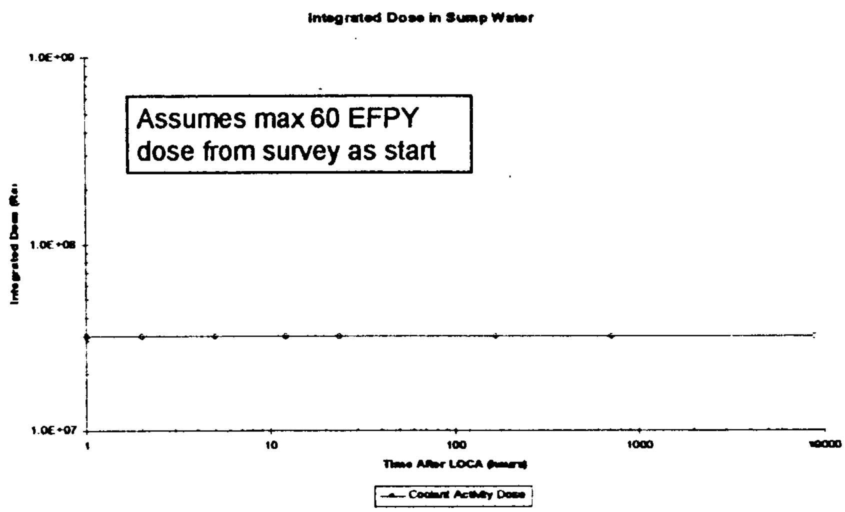


Industry Action

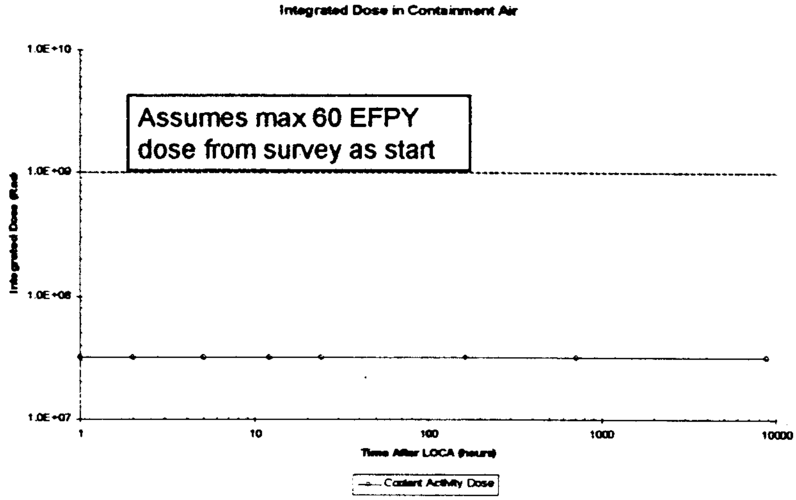
Accident Scenario

- Total integrated dose at initiation of LBLOCA is less than $5.0x10^7$ rads
- LOCA postulated to occur
  - Pressure and temperature transient occurs
  - Then flooding of containment floor
- Per 10 CFR 50.46, ECCS function is successful
  - Beta dose from coolant
  - Gamma dose from core

Total Accident Dose for Sump Water



Total Accident Dose for Air



Summary

- Concern of applicability of test conditions to plant conditions raised at September 26, 2000 public meeting
- Concern formally transmitted to NRC via NEI letter of October 19, 2000
- Industry survey initiated to address concerns
- Survey results suggest radiological pre-conditions leading to coatings failures presented at September 26, 2000 public meeting do not exist at plants
- Reported at-power dose rates and total integrated dose suggest no additional coatings testing warranted
- Request NRC comment on Industry survey information

Consideration for Additonal Coatings Research

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Division of Engineering Technology
Engineering Research Applications Branch

Contact:
Michael Marshall, 415-5895

Public Meeting
Alburquerque, NM
February 14, 2001

Why Did NRC Start a NPP Protective Research Program?

- Failed coatings represent an undesirable debris source which could impede long-term recirculation following a loss-of-coolant accident.
- Clear evidence of failure of **qualified** coatings during "design life" plant operating conditions (see GL 98-04)

☛ The explanation given for most of the failures was poor surface preparation or improper application.

What were the Goals of NRC-Sponsored Reserach?

- ! Determine failure mechanisms of coatings system
- ! Estimated time to failure
- ! Identify coating debris characteristics

✳ Also, the findings would help identify failure mechanisms that may not be identified during normal qualification testing. In other words, where qualified coatings failed because of some other reason than poor application or improper surface preparations.

What Are The Major Findings of Program?

! During testing under various conditions, debris was produced

- Chips
- Particulates

Test Conditions	Non-Defected		Defect Type 1		Defect Type 2	
	Non-Aged	Aged	Non-Aged	Aged	Non-Aged	Aged
ASTM D3911 DBA Curve	N	N	**NOTE:** SRTC did not check for powder-like debris during early testing.			
ASTM D3911 DBA Curve w/ Water Immersion	N	Y				
Plant Specific Curve	N	Y				
Plant Specific Curve w/ Water Immersion	N	Y				
200°F Water Immersion	N	Y				

! Particulate debris failures occurred between 10 and 60 minutes

What Additional Work Will Be Completed?

- **Complete Testing of Plant Samples**
  - epoxy epoxy on steel (snubber plate and handrail)
  - epoxy epoxy on steel (plate)
  - epoxy phenolic with IOZ (chips)

- **Complete Particulate Debris Characterization**
  - Amount per area
  - Size distribution
  - Degree of “stickiness”
  - “Float”

How Will The Findings Be Applied?

Other Research

- Findings will be used to define an additional debris source in PWR Sump Screen Blockage Study.

- NRC staff is considering using findings to develop a new research effort.

Regulatory

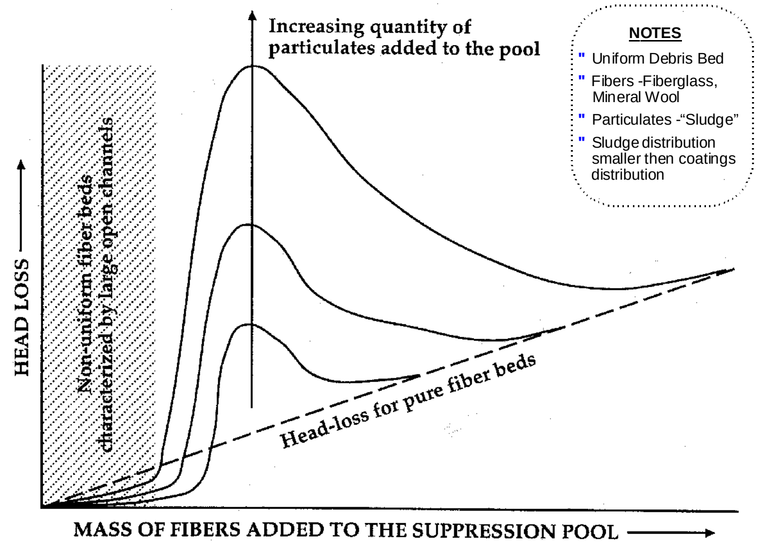
- Regulatory implication will be assessed.

How Will The Findings Be Applied?

Continued

- Of the two types of coating debris generated during the testing, particulate debris is the more problematic.

- Particulate debris (like sludge) when combined with fibrous debris creates very high head loss across sump screens.



SOURCE: "Knowledge Base for Emergency Core Cooling System Recirculation Reliability," February 1996

What Elses Needs to Be Done?

Findings will be used to define an additional debris source in PWR Sump Screen Blockage Study

- Particulate coating debris will be included in reference plant analyses.

Particulate

Curled Chips

- Only flat chips have been used in transport tests.

What Elses Needs to Be Done?

NRC staff is considering using findings to develop a new research effort.

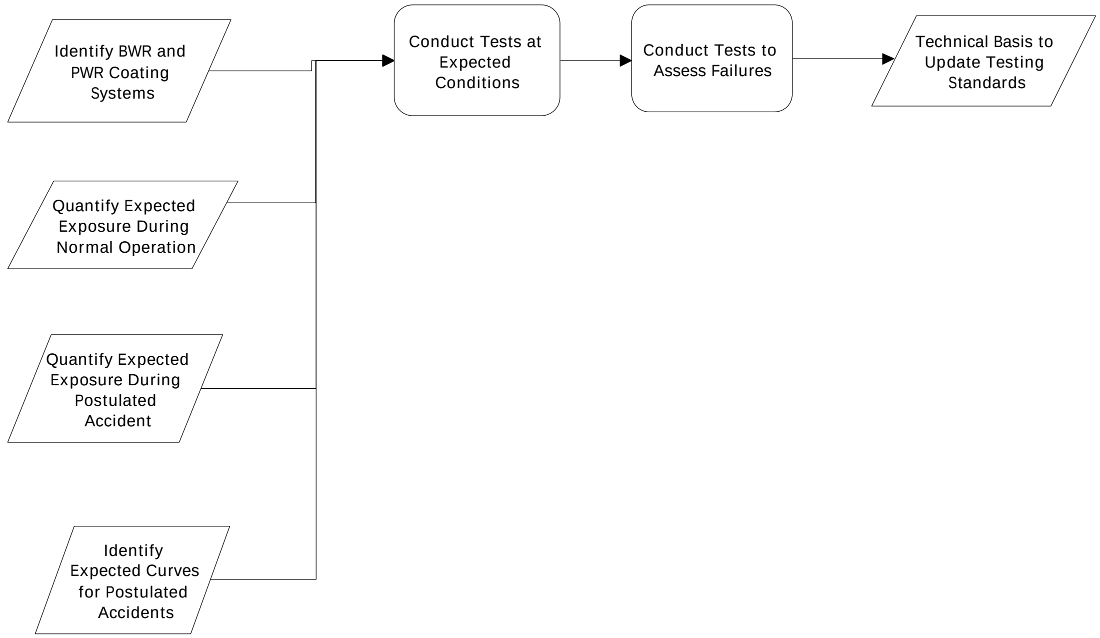
- Current NRC-sponsored coating research, which uses ASTM qualification standards, is sufficient to identify failure but not to conclusively identify failure mechanism.

- NRC proposes that a joint NRC and industry research effort be started to develop technical basis to make changes to testing of protective coatings.

What Elses Needs to Be Done?

Continued

NRC staff is considering using findings to develop a new research effort.



Potential Changes to RG 1.82

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Division of Engineering Technology
Engineering Research Applications Branch

Contact:
Michael Marshall, 415-5895

Public Meeting
Alburquerque, NM
February 14, 2001

Background

- Title

  - "Water Sources for Long-Term Recirculation Cooling Following A Loss-of-Coolant Accident"

- Purpose

  - "..... This guide describes methods acceptable to the NRC staff for implementing these requirements with respect to the sumps and suppression pools performing the functions of water sources for emergency core cooling, containment heat removal, or containment atmosphere cleanup. The guide also provides guidelines for evaluating the adequacy of the sump and suppression pool for long-term recirculation cooling following a loss-of-coolant accident (LOCA)....."

Background
Continued

! Changes in Guidance

" Regulatory Guide 1.82, Rev. 0 (1974)
- 50% Blockage of Screen or Sump

" Regulatory Guide 1.82, Rev. 1 (1985)
- Referenced in Generic Letter 85-22

" Regulatory Guide 1.82, Rev. 2 (1996)
- Referenced in NRC Bulletin 96-03

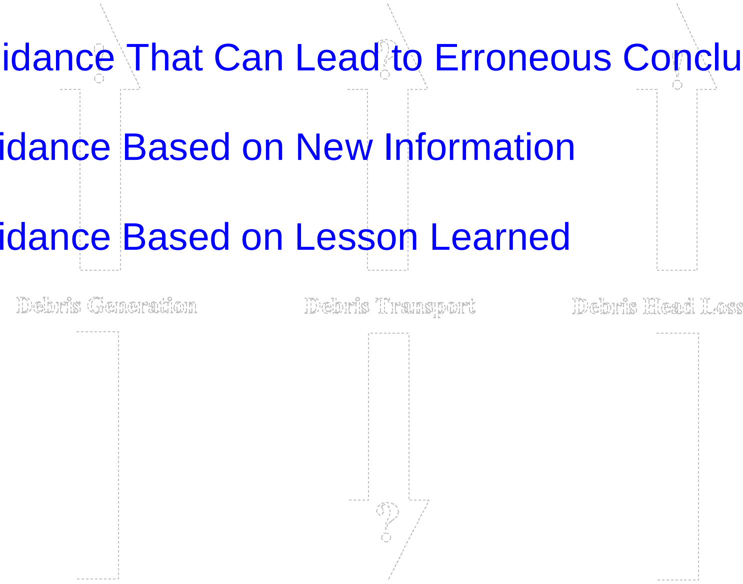
Background
Continued

! Reason for Changes

" Remove Guidance That Can Lead to Erroneous Conclusions

" Improve Guidance Based on New Information

" Improve Guidance Based on Lesson Learned



Scope of Changes

! No changes are being considered for the air ingestion sections of the regulatory guide.

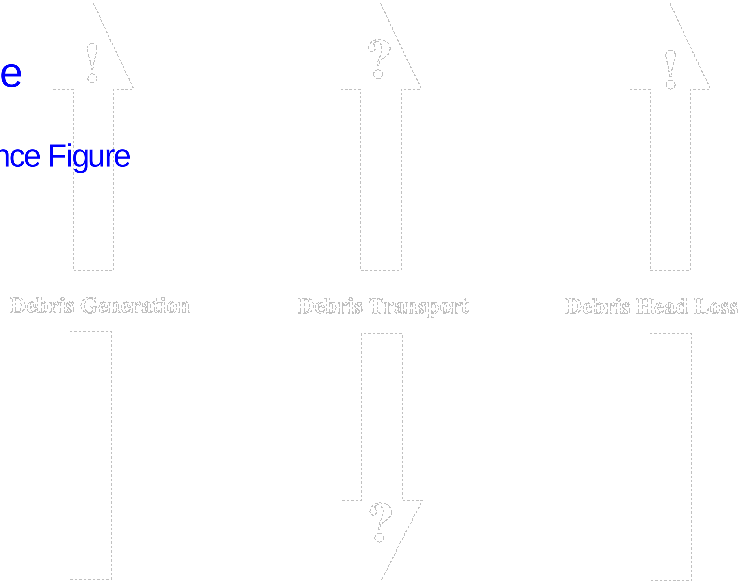
! Significant changes are considered for the debris blockage sections of the regulatory guide.

- **Extensive changes will be considered for the guidance concerning pressurized water reactors.**
- **Limited changes will be considered for the guidance concerning boiling water reactors.**

! Consideration is be given to adding new sections providing general guidance on estimating the available net positive section head during recirculation.

Types of Content Changes Being Considered

- Remove Guidance That Can Lead to Erroneous Conclusions
- For Example
  - 0.2 ft/s
  - Zone of Influence Figure

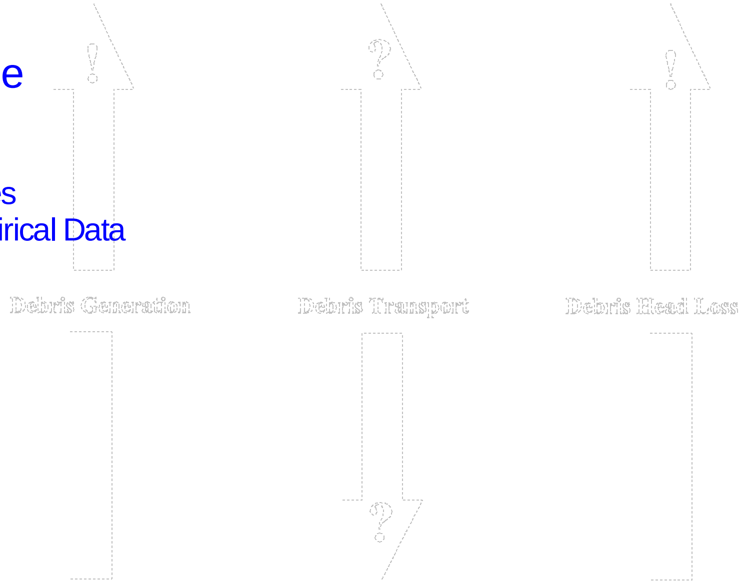


Types of Content Changes Being Considered

Continued

- Improve Guidance Based on New Information

- For Example
  - Filtration
  - Destruction
  - Debris Sources
  - Need for Empirical Data

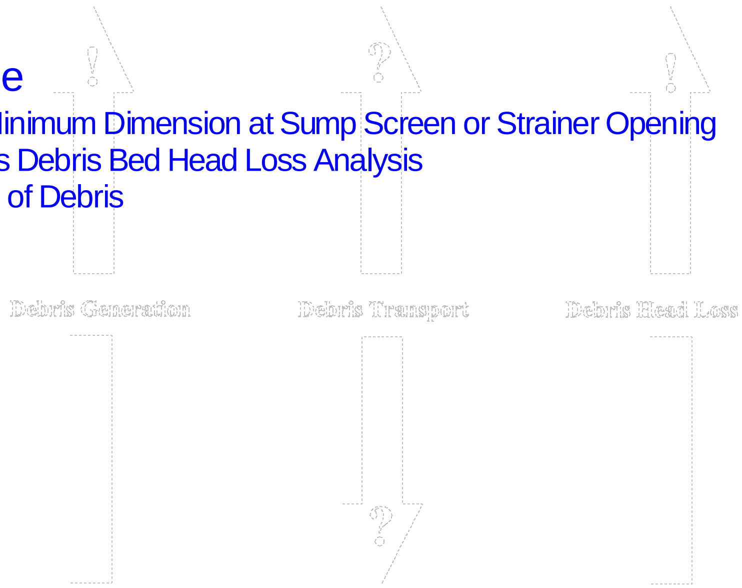


Types of Content Changes Being Considered

Continued

- ! Improve Guidance Based on Lessons Learned

- ! For Example
  - Definition of Minimum Dimension at Sump Screen or Strainer Opening
  - Single Species Debris Bed Head Loss Analysis
  - Minimum Size of Debris



NRC FORM 549 (9-94) NRCMD 3.5 — U. S. NUCLEAR REGULATORY COMMISSION

PUBLIC MEETING ANNOUNCEMENT DATA INPUT

(Fields with shaded headings are mandatory)

MEETING	
x	NEW
	REVISED

MEETING NOTICE NUMBER (FOIA/LPDR BRANCH WILL COMPLETE)

NRC MEETING CONTACT

NAME	COMMERCIAL TELEPHONE *(Include Area Code)*	FACSIMILE TELEPHONE (Include Area Code)
Michael Marshall	301-415-5895	301-415-5151

MEETING DATE(S) AND TIME(S) (up to three entries)

MEETING DATE(S) *(Use MM/DD/YY format)* FROM	TO	MEETING TIME(S) *(Circle a.m. or p.m.)* BEGINNING	ENDING
February 14, 2001		9:00 a.m.	5:00 p.m.
February 15, 2001		9:00 a.m.	10:30 a.m.
		a.m. p.m.	a.m. p.m.

MEETING LOCATION

BUILDING: DOE Energy Training Complex	STREET ADDRESS: 1401 Maxwell Street
ROOM NUMBER: TBD	CITY AND STATE: Albuquerque, NM

PURPOSE OF MEETING (96 characters available)

Inform external stakeholders of status of ongoing research and analyses concerning NRC's assessment of debris blockages of sump screens in pressurized water reactors.

COMMENTS *(96 characters available)*

Verify meeting status. Please call (301-415-5895) or e-mail (mxm2@nrc.gov) if plan to attend because an attendance list must be provided to meeting facility.

MEETING *(CHECK ONE)*	
x	PUBLIC
	NON-PUBLIC

DOCKET OR PROJECT NUMBER	and/or FACILITY NAME
n/a	n/a

ORGANIZATIONS IN ATTENDANCE

NRC OFFICES/REGIONS *(Offices only -- DO NOT use Divisions, Branches, etc.)*	OUTSIDE PARTICIPANTS *(Company/Licensee/Agency Names -- avoid abbreviations)*
Office of Nuclear Regulatory Research	Nuclear Energy Institute
Office of Nuclear Reactor Regulation	Westinghouse Owner's Group
Los Alamos National Laboratory	Combustion Engineering Owner's Group
University of New Mexico	Babcock and Wilcox Owner's Group

APPROVAL -- *(Required for fewer than 10 calendar days advance notice)*

SIGNATURE -- BRANCH CHIEF	DATE
n/a	n/a

RETURN THIS FORM TO: MEETING NOTICE COORDINATOR, MAIL STOP T-6 D8
FACSIMILE (301) 415-5130, TELEPHONE (301) 415-7092, E-MAIL: PMNS

MEETING ATTENDANCE

Please Sign Attendance Sheet

DATE: Wednesday, February 14, 2001

TIME: 9:00 am to 5:00 pm

PLACE: Conference Room: T-10A1
U.S. Department of Energy - Energy Training Complex
1401 Maxwell St., KAFB West
Albuquerque, NM 87118

SUBJECT: Public Meeting Between NEI and NRC re Selected Aspects of GSI-191 Study

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Bruce Letellier	LANL	Los Alamos National Laboratory D-Division (D-11) PO Box 1663, MS K557 Los Alamos, NM 87545	(505)665-5188	(505) 667-5731	bcl@lanl.gov

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