NRC FORM 658
(9-1999)

U.S. NUCLEAR REGULATORY COMMISSION

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Do not include proprietary materials.

DATE OF MEETING
3/22/00

The attached document(s), which was/were handed out in this meeting, is/are to be placed in the public domain as soon as possible. The minutes of the meeting will be issued in the near future. Following are administrative details regarding this meeting:

Docket Number(s): n/a

Plant/Facility Name: n/a

TAC Number(s) (if available): n/a

Reference Meeting Notice: 2000 - ?

Purpose of Meeting (copy from meeting notice): address concerns expressed by UEI and PWROOn re selected aspects of GSI-191 study....

NAME OF PERSON WHO ISSUED MEETING NOTICE: Michael Marshall

TITLE: mechanical engineer

OFFICE: RES

DIVISION: DET

BRANCH: ERAB

Distribution of this form and attachments:
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DF03

Agenda for March 22, 2000 Meeting

Time	Topic	Speaker
8:30 - 8:45	Opening Remarks	Michael Marshall, NRC Kurt Cozens, NEI
8:45 - 9:30	Debris Transport Tests Progress To Date	DV Rao, LANL
9:30 - 10:15	PWROG's Approach to Assessing Risk of Debris Blockage of Sump Screens	Karl Jacobs, WOG Michael Canton, W
10:15 - 10:30	---- BREAK ----	
10:30 - 11:15	LANL's Approach to Assessing Risk of Debris Blockage of Sump Screens	John Darby, LANL
11:15 - 11:45	~~Use of Risk To Date in GSI-191 Study~~	~~John Darby, LANL~~
11:45 - 1:00	---- LUNCH ----	
1:00 - 1:45	Debris Generation Modeling	Bruce Letellier, LANL
1:45 - 2:30	Response to PWROG's Concerns	Michael Marshall, NRC
2:30 - 3:30	Open Discussions	

An Industry Proposed Risk-Informed Approach to Post-Accident Sump Performance Evaluation

Karl Jacobs and Michael Canton
Westinghouse Owners Group
March 22, 2000

Overview

- Generic Safety Issue GSI-191
- Purpose
- Approach
- Examples of Other Risk Informed Applications
- Program Definition Inputs
- Methodology
- Conclusions and Summary

Generic Safety Issue 191: "Assessment of Debris Accumulation on PWR Sump Performance"

Results of research on BWR ECCS suction strainer blockage identified new phenomena and failure modes that were not considered in the resolution of Unresolved Safety Issue (USI) A-43. In addition, operating experience identified new contributors to debris and possible blockage in PWR sumps, such as degraded or failed containment paint coatings. Thus, this new issue was identified in Footnotes 1691 and 1692 of NUREG-0933 by NRR to address an expanded research effort to address these new safety concerns.

Purpose

NRC invited Industry to discuss methodology to:

- Conduct a risk-informed assessment of potential unacceptable containment sump blockage following an accident requiring ECCS operation in the recirculation mode, to determine if there are significant associated risks
- Use the results of this assessment to provide insights into determining what, if any, measures may be appropriate to address this issue in a risk-informed manner, within the existing regulations, while maintaining adequate safety margins and defense in depth

Approach

Determines if GSI-191 has risk significance that warrants plant actions

- Use of an integrated decision-making approach allows an assessment of the risk-significance of unacceptable sump blockage
- If there is a risk significance,
  - Provides insights to allow emphasis to be placed on the risk-significant aspects of the issues under GSI-191, and,
  - Focuses attention on actions that, if required, assure plant safety

Examples of Other Risk Informed Applications

- Operational improvements
  - ISI / IST
  - Technical Specifications
- Technical issues
  - CRDM Housing Cracking
  - Baffle Barrel Bolts
  - Risk-informed approach used for Environmental Fatigue, GSI-190
  - PTS, revision of 10 CFR 50.61

Program Definition Inputs

- Regulatory Guide 1.174
  - Defines an acceptable integrated risk-informed decision-making process
  - Provides guidance on evaluation of acceptable risks
- Use of Latest NRC information
  - Pipe break initiating event frequencies (NUREG/CR-5750)
  - NRC Research into Sump Debris Phenomenology
    - Results of NRC debris transport tests
    - Results of NRC coatings failure testing
- PWR-applicable industry documentation
- Other PWR-specific information needs

Methodology

Seven step approach defined:

Phenomenological (deterministic) tasks

- Identification of events and sequences that can cause debris generation
- Assessment of debris generation by these events
- Assessment of debris transport with respect to plant geometry/features
- Accumulation of debris on sump screens
- Assessment of susceptibility to potential unacceptable sump blockage

Risk evaluation tasks

- Assessment of risk impact due to potential unacceptable sump blockage
- Define plant actions to maintain sump functionality

Methodology (continued)

Step 1: Identification of events and sequences that can cause debris generation

- Form expert panel, for example:

Engineering	Safety Analysis	Maintenance
Operations	PRA	EOP

- Consider a comprehensive set of initiating events; identify which result in recirculation from containment sump
- Identify and document the following:
  - Events and sequences that can cause debris generation
  - Contributors to debris transport and screen blockage

Methodology (continued)

Step 2: Assessment of debris generation by events from Step 1

- Expert panel to assess amounts and characteristics of actual debris generation:
  - Plant scenarios
  - Plant containment characteristics
  - Debris characteristics: insulation, coatings, fire barriers, combinations
  - Location of high-energy areas relative to the sumps and to sources of debris
  - High energy line zones of influence
  - Containment Spray
- Document the assessment

Methodology (continued)

Step 3: Assessment of debris transport with respect to plant geometry/features

- Inputs include, but are not limited to the following:
  - The NRC debris transport PIRT report(s)
  - NRC debris transport test data
  - International Working Group report on ECCS Recirculation
  - TMI-II Coatings Post-accident Inspection - Draft EPRI Report
- The following factors will be considered:
  - Flow patterns inside containment; sump approach velocities
  - Obstacles in flow paths; sump configuration
  - Combinations of Materials
- Document the assessment

Methodology (continued)

Step 4: Assess accumulation of debris

- Consider factors relating to debris bed morphology, including:

Debris material	Debris shape
Flow patterns	Screen configuration
Debris bed compression	Pressure drop

- Document the assessment

Methodology (continued)

Step 5: Assess susceptibility of sump to unacceptable blockage

- Define containment attributes that would preclude excessive sump blockage

Sump design	Screen design	Redundant sumps
Curbs	Trash racks	Plant layout
Debris types	Debris quantities	Break location
Multiple independent systems		

- Screen out non-susceptible plants from further consideration based on information from previous steps
- Group remaining plants into "susceptibility" categories
  - For example, NRC characterization of three PWR sump designs: Remote sumps, Exposed sumps, Intermediate sumps

Methodology (continued)

Step 6: Determine risk impact due to unacceptable sump blockage

Specific steps in the risk-informed assessment process include:

- Definition of an appropriate measure of risk (e.g. internal events at power CDF) and success criteria
- Selection of risk models representative of plants in the susceptibility groups
- Definition of initiating event frequencies for events identified in Step 1
- Identification of event sequences resulting in potential unacceptable sump blockage conditions
- Quantification of incremental risk due to unacceptable sump blockage, including a process for assigning blockage probabilities
- Evaluation of variations of model to cover all plants in a given group
- Evaluation of uncertainties associated with the analysis, sensitivities to input assumptions, risk contribution at other operating modes, etc.

Methodology (continued)

Step 7: Define plant actions to maintain sump functionality

- Identify options to mitigate the effects of unacceptable sump blockage
  - Investigate suitability and risk significance as part of the risk evaluation
- Identify guidance and strategies for reducing the likelihood of unacceptable sump blockage

Conclusions and Summary

- Guidance of Regulatory Guide 1.174 should be applied to evaluating post-accident sump performance issues
  - Use NRC Guidance as a basis
  - Incorporate recent NRC / Industry experience
  - Identify additional information needs
- Industry interested in working with NRC to properly utilize this approach to achieve a better understanding of this topic
- Industry requests NRC feedback on this proposed methodology

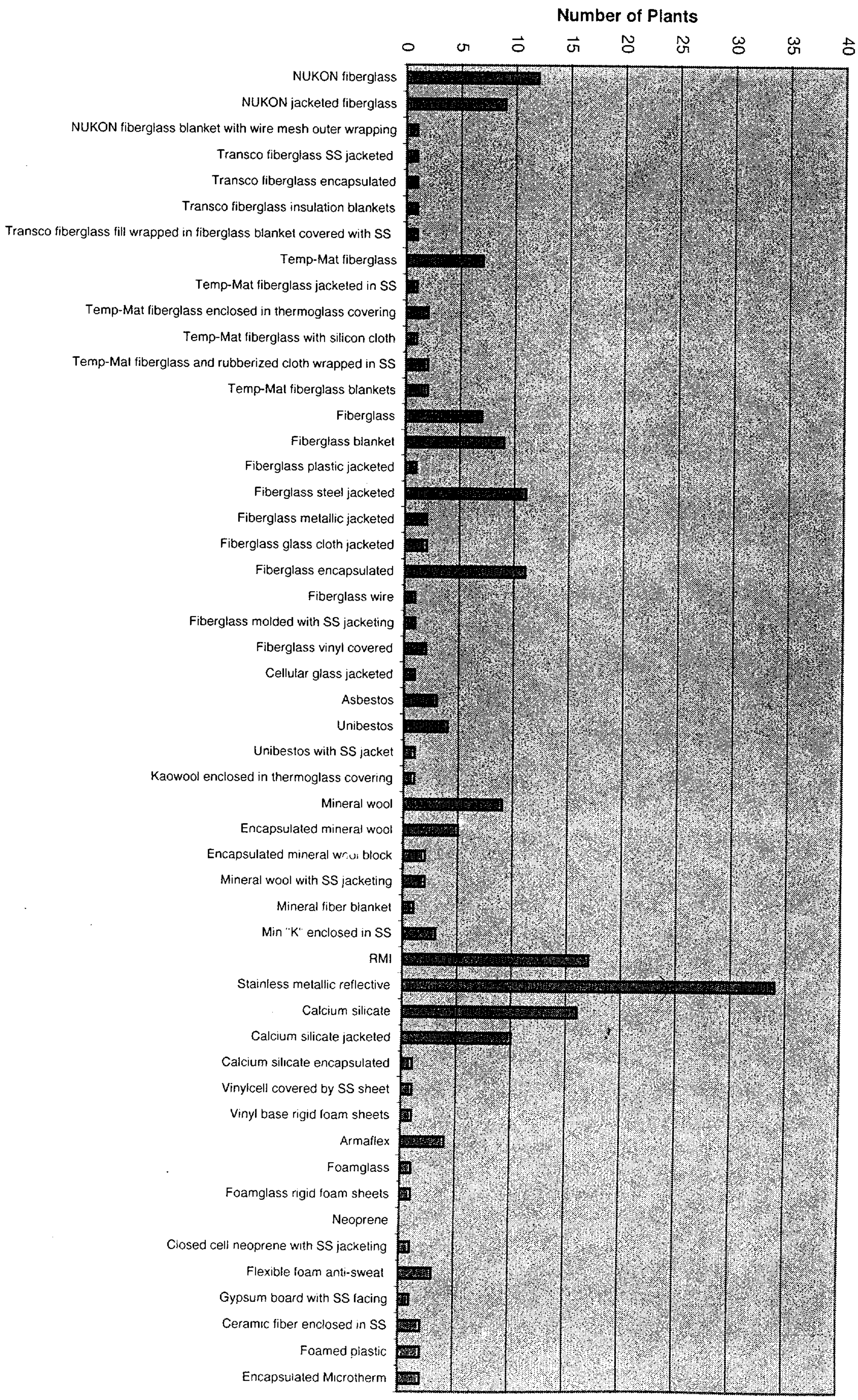

Figure 2-8. Number of Plants with Each Reported Type of Insulation

MEETING ATTENDANCE

Please Sign Attendance Sheet

DATE: March 22, 2000

TIME: 8:30 am to 3:30 pm

PLACE: Conference Room: T-10A1
Two White Flint North Building
11545 Rockville Pike
Rockville, MD USA

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

Name	Organization	Business Address	Phone Number	Fax Number	Email Address
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Craig Harrington	TXU	PO Box 1002 Glen Rose, TX 76043 MZ-019	254-897-6705	254-897-0530	charrin1@txu.co
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Nick Saltos	NRC/NRR/SPSB	USNRC - O10H4 Washington DC 20555	(301) 415-1072		NTS@NRC.GOV

Generic Safety Issue (GSI)-191:
Assessment of Debris Accumulation on PWR Sump Performance

United States Nuclear Regulatory Commission

Los Alamos National Laboratory
Science Serving Society

NRC Public Meeting

Rockville, Maryland

March 22, 2000

The University of New Mexico

Generic Safety Issue (GSI) -191, "Assessment of Debris Accumulation on Pressurized Water Reactor Sump Performance."

Introductory Remarks

Michael L. Marshall, Jr.
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Division of Engineeering Technology
Engineering Research Applications Branch

301-415-5895
mxm2@nrc.gov

Public Meeting with NEI, et. al.
Rockville, Maryland
March 22, 2000

Purpose of Public Meeting

- **Discuss NRC-Sponsored Debris Transport Test Results to Date**
  - data only, no analysis
- **Discuss Approach to Assessing Risk**
- **Discuss Debris Generation Work Completed to Date**
- **Discuss NEI's Concerns with Study**

Meeting Agenda

Agenda for March 22, 2000 Meeting

Time	Topic	Speaker
8:30 - 8:45	Opening Remarks	Michael Marshall, NRC Kurt Cozens, NEI
8:45 - 9:30	Debris Transport Tests Progress To Date	DV Rao, LANL
9:30 - 10:15	PWROG's Approach to Assessing Risk of Debris Blockage of Sump Screens	TBD
10:15 - 10:30	--- BREAK ---	
10:30 - 11:15	LANL's Approach to Assessing Risk of Debris Blockage of.Sump Screens	John Darby, LANL
11:15 - 11:45	Use of Risk To Date in GSI-191 Study	John Darby, LANL
11:45 - 1:00	--- LUNCH ---	
1:00 - 1:45	Debris Generation Modeling	Bruce Letellier, LANL
1:45 - 2:30	Response to PWROG's Concerns	Michael Marshall, NRC
2:30 - 3:30	Open Discussions	

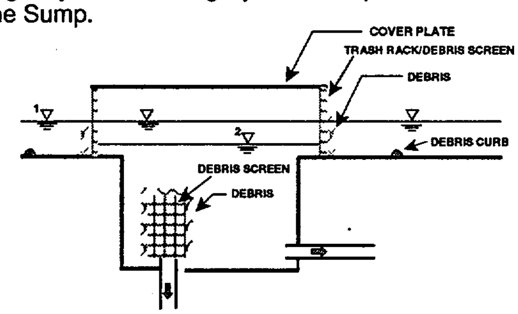
Overview of GSI-191 Study

• Potential Safety Concern

- The Accumulation of Debris on Sump Screens (or Strainers) Will Increase the Resistance Across the Screen (or Strainer) and Thus Reduce the Net Positive Suction Head Avlaible to the Emergency Core Cooling System Pumps Drawing Suction From the Sump.
- The Accumulation of Debris at the Sump Screen or Along the Fowpaths on the Containment Floor May Form Dams That Prevent or Impede the Flow of Water Into thje Sump and Thus the Water in the Sump Can Be Drawn Down Which Will Reduce the Net Positive Suction Head Available to the Emergency Core Cooling System Pumps and Effectively Reduce the Water Inventory in the Sump.

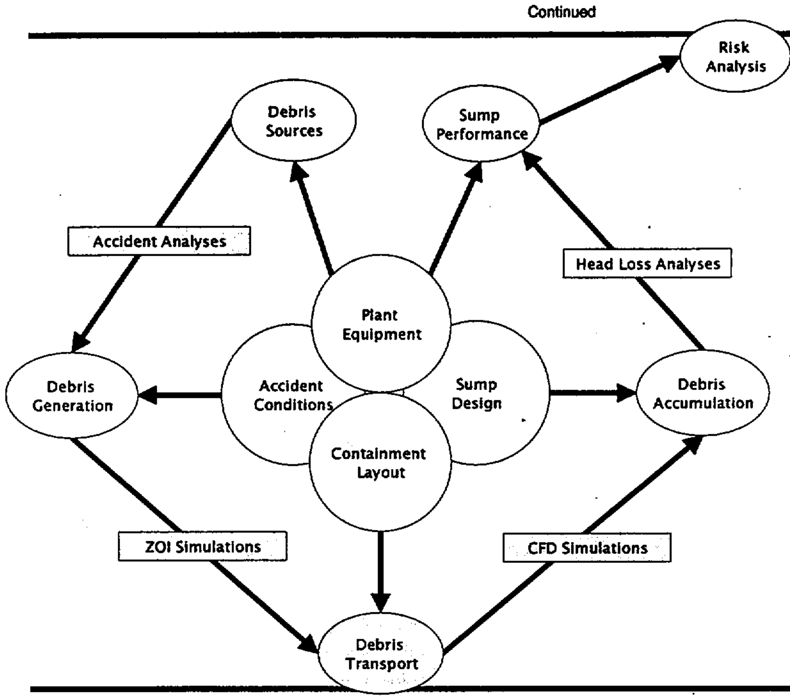
• Purpose of Study

- Detemine if Have a Safety Problem
- If a Safety Problem is Confirmed, Then Identify Resolution



Overview of GSI-191 Study

Continued



NEI'S CONCERNS

Michael L. Marshall, Jr.
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Division of Engineering Technology
Engineering Research Applications Branch

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Public Meeting with NEI, et. al.
Rockville, Maryland
March 22, 2000

NEI's CONCERNS

- Letter Dated September 30, 1999
  - "The lack of discussion about how the PWR debris generation will be characterized using a scaled BWR debris generation source."
  - "Whether the integrated tank test 10:1 ration permits a reliable scaling to the full-sized plant application without introduction [of] unnecessary conservatisms."
  - "The NRC staff intention to use engineering judgement to compensate for the inability of a computational fluid dynamics model to characterize debris transport along the floor."
  - "The development of a risk-informed approach is moving forward a a much slower pace than the experimental portions of the NRC research program."
  - "The relationship of leak-before-break assumptions to the sump performance issue."

NEI's CONCERNS
Continued

- "The lack of discussion about how the PWR debris generation will be characterized using a scaled BWR debris generation source."

Clarification is Needed
Why is this a concern?

Response
Work on how to apply debris generation data produced by BWROG will not begin, in earnest, until late this FY and early next FY. No detailed presentations will be made on this subject until meaningful work has begun.

NEI's CONCERNS
Continued

- "Whether the integrated tank test 10:1 ration permits a reliable scaling to the full-sized plant application without introduction [of] unnecessary conservatisms."

Clarification is Needed
What is meant by "unnecessary conservatisms?" In other words, how do you make a determination that conservatism is unnecessary?

Response
The integrated tank tests are not intended to be scaled to full-sized plant. One of the main points of the test program presentation in Albuquerque was to state that scaled tests could not be conducted. The integrated tank test will be used to demonstrate that combining the results of flume tests with CFD calculations can produce reasonable predictions of transport.

NEI's CONCERNS
Continued

- "The NRC staff intention to use engineering judgement to compensate for the inability of a computational fluid dynamics model to characterize debris transport along the floor."

Response
Engineering judgement will not be used to estimate tumbling transport. The amount of transport along the floor will be based on transport tests currently being conducted.

NEI's CONCERNS
Continued

- "The development of a risk-informed approach is moving forward a a much slower pace than the experimental portions of the NRC research program."

Clarifications are Needed
What is meant by "risk-informed approach?"
Why is this a concern?

Use of Risk to Date
Risk has been used to select the postulated accidents being modeled. Various T/H calculations were conducted based on the postulated accidents selected based on risk insights. The results of these calculations form part of the bases for selecting test conditions.

Future Use of Risk
After all the "deterministic" modeling and calculations are completed, CP of ECCS Failure due to sump blockage, CDF, ΔCDF, LERF, and ΔLERF. These metrics will be used by regulatory arm of the NRC to help decide how to apply findings of study. Since no crediblé operational or other data exist to estimate the unavailability of the sump, these metrics cannot be calculated today with any reasonable confidence.

NEI's CONCERNS

Continued

- "The relationship of leak-before-break assumptions to the sump performance issue."

Clarification is Needed
What are the leak-before-break assumptions?

Response
A small-small loss-of-coolant accident has been included in the spectrum of postulated accidents being to address LBB. It should be noted that LBB was not used to eliminate postulated accidents, such as the double ended guillotine break, from the spectrum of postulated accidents.

GSI-191 Debris Transport Tests
Progress To Date

Dasari V. Rao
Technology and Safety Assessment Division
Los Alamos National Laboratory

A. Maji, B. Marshall and R. Heggen
Dept. of Civil Engineering
University of New Mexico
Albuquerque, NM

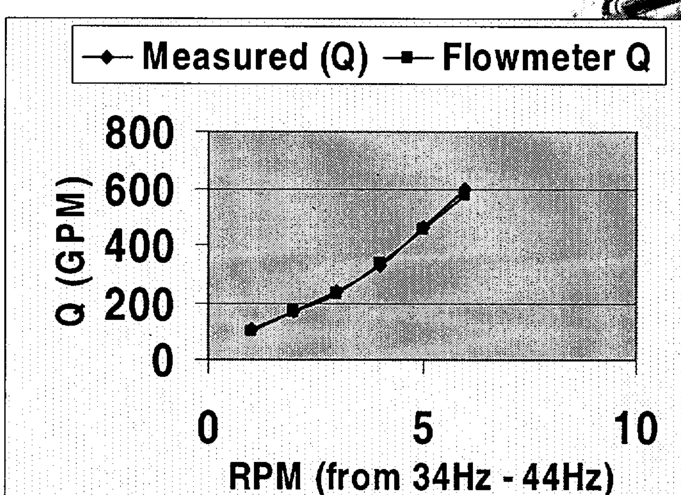
Introduction

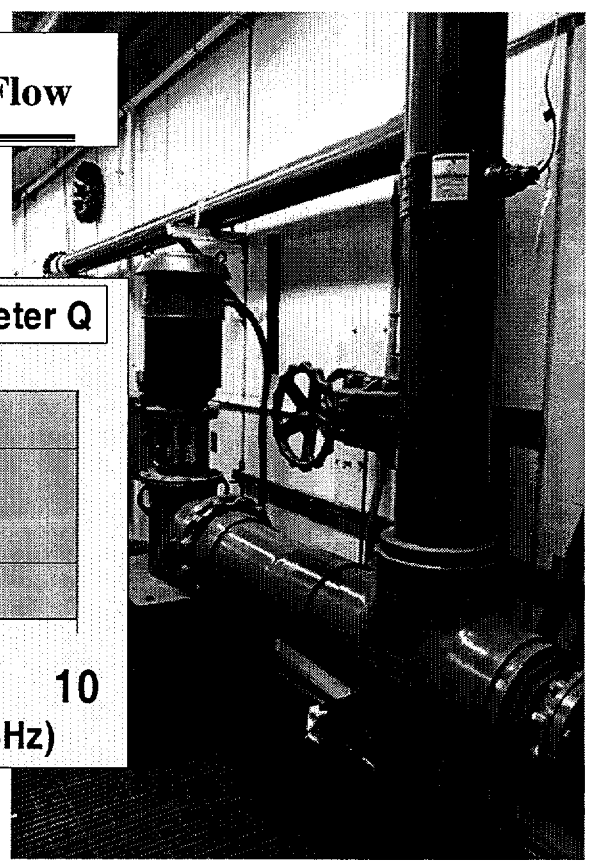
- Overall Test Program (Ref: GSI-191 Debris Transport Test Plan, Rev. 0)
  - Debris Characterization and Linear Flume Testing
  - Integrated Tank Testing
  - Head Loss Testing
- Focus of the Presentation
  - Debris Characterization/Flume Testing
  - Test Matrix and Procedures for Testing
    - Selection of Parameters and Insulations for Testing

Outline of the Presentation

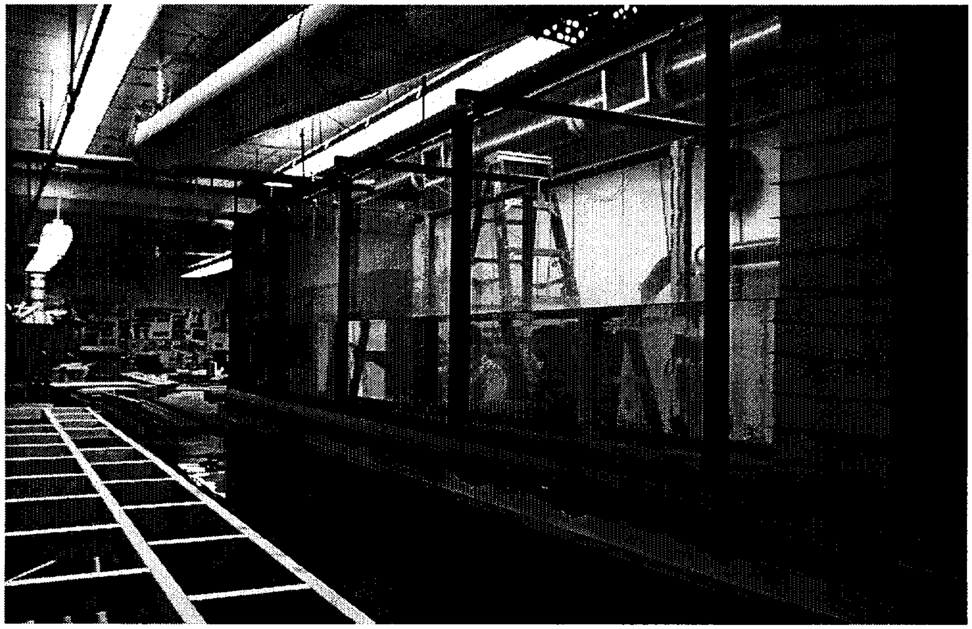
- Facility Description
- Exploratory Testing
- Review of Exploratory Test Data and Conclusions
- Parametric Testing
  - Rationale for the selection of parameters and Insulations
- Review of Parametric Test Data
- Schedule for Completion of Testing

Facility Description -- Pump/Flow



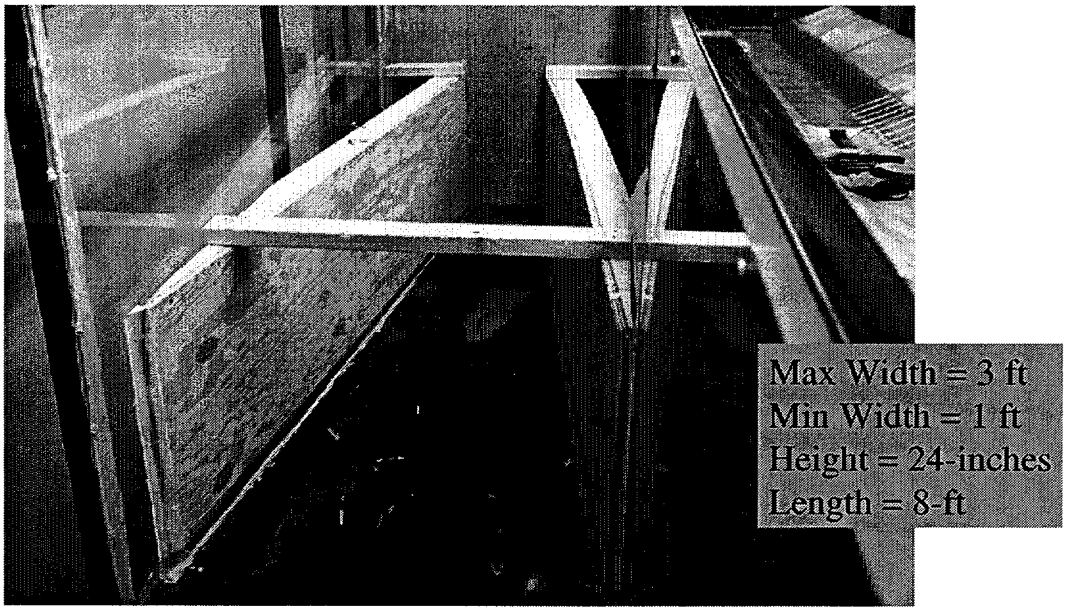


Facility Description -- Large Flume

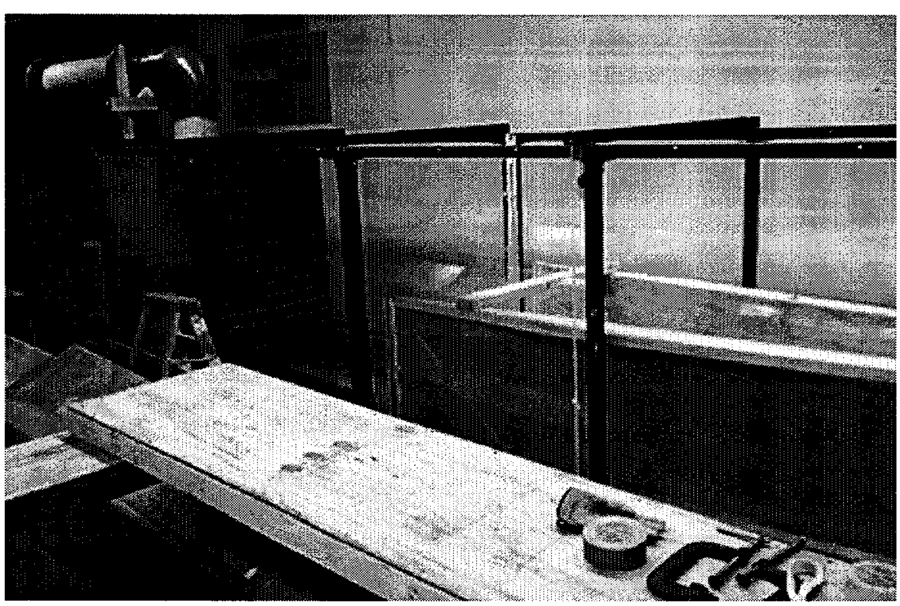


Facility Description: Large Flume (Diffusers)

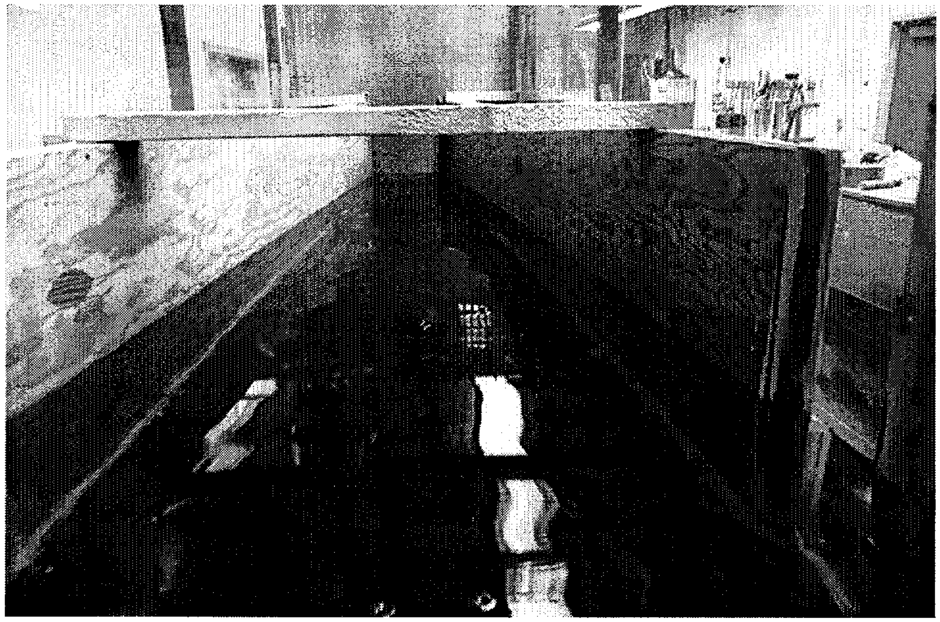
Facility Description: "Pie-Channel"



Facility Description: "Pie-Channel"



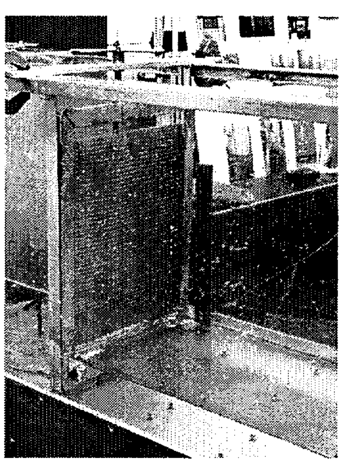
Facility Description: "Pie-Channel"



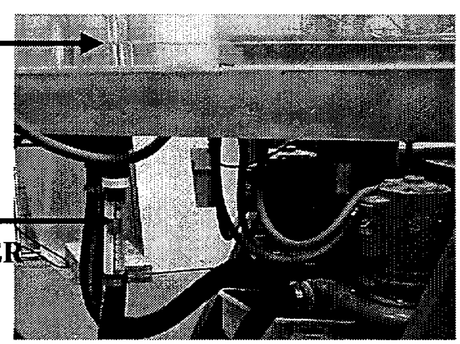
Facility Description -- Small Flume

12" flow height (max)

Outflow control GATE

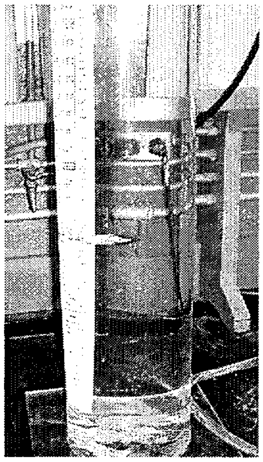


40 GPM
FLOW METER

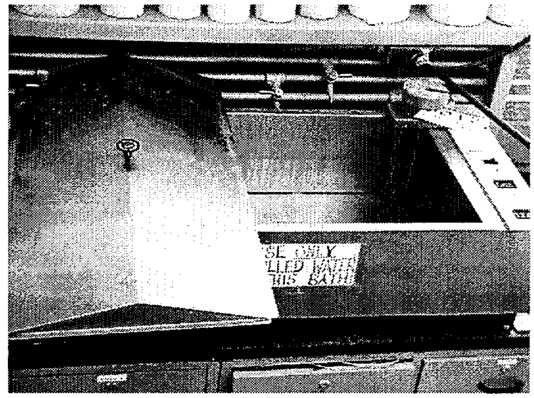


- Discharge and Gate control flow height and velocity
- Small recirculation water volume (heating and cleaning is easy, if needed)
- Debris introduced at the floor

Facility Description -- Settling Column



Settling column
4'long X 1" diameter



WATER HEATER

Exploratory Testing

<u>Test Objectives</u>:

- Dissolution and Saturation of debris in Water versus Temperature
- Examine if transport of a particular debris type is influenced by presence of other debris type(s) in the flume at the same time.
- Establish or eliminate the need to vary flume height as an experimental parameter.
- Establish or eliminate the need to measure transport distance.
- Explore turbulence impact on debris transport and determine if the test set-up and instrumentation is sufficient to capture this impact.
- Explore importance of Floor roughness, Curb Height and and the need to test various geometrical layouts.
- Identify and Screen out non-problematic debris materials.

Results of Exploratory Testing

Saturation of Nukon Debris by Water

- Room Temperature water does not 'penetrate' Nukon debris. They float for several hours
- 'Treating' small and medium Nukon fragments for several minutes at 80°C is sufficient to saturate† them.

Nukon Terminal Velocities (Likely applicable to all Low-Density FG)
- 5 and 10 gm. pieces treated in 80°C water for 20 min: 0.36-0.43 ft/s
- 5 and 10 gm. pieces treated in 80°C water for 10 minutes: 0.36-0.43 ft/s
- 5 and 10 gm. pieces treated in 80°C water for 5 minutes: 0.36-0.43 ft/s
- 1 gm. pieces, treated for 5 minutes: 0.13-0.18 (0.15)
- 1 gm. Pieces treated for 20 minutes: 0.13-0.18 (0.15)

† Saturation is indicated by no measurable change in terminal velocity with treatment time

Results of Exploratory Testing

Dissolution† of Cal-Sil Debris in Water

- Room Temperature water does not readily 'dissolve' ~~Nukon~~ Cal Sil debris.
- 'Treating' Cal-Sil fragments for several minutes at 80°C is sufficient to dissolve them. In 20 minutes most of "fluffy" stuff dissolves leaving solid fragments.

22°C water

Test #	On Tray
1	87%
2	75%
3	83%
4	82%
5	84%

80°C water

Test #	On Tray
1	52%
2	47%
3	65%
4	50%
5	60%

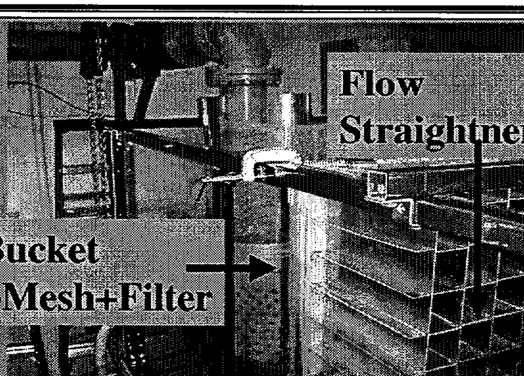
†Cal-Sil is not solvable in water. A more accurate description is suspension of cal-sil particles in water.

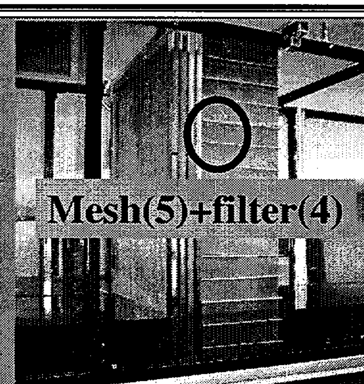
Results of Exploratory Testing

- Debris settles via inertial means. No measurable viscosity or temperature effects.
  - Performing terminal velocity and transport velocities at room temperatures is acceptable for Nukon and RMI fragments
- Presence of other debris does not impede transport
  - Nukon settling or tumbling properties are not effected by Cal-Sil. Examined up to a Cal-Sil concentration of 100 g/litre.
  - Presence of RMI on the floor may impede movement of Nukon fragments. But it depends on the concentration of RMI.

Nukon Terminal Velocities (Likely applicable to all Low-Density FG)
•5 and 10 gm. pieces treated in 100 g/l water for 20 min: 0.36-0.43 ft/s
•5 and 10 gm. pieces treated in 10 g/l water for 10 minutes: 0.36-0.43 ft/s
•5 and 10 gm. pieces treated in 0 g/l water for 5 minutes: 0.36-0.43 ft/s
•1 gm. pieces treated in 100 g/l water for 20 min : 0.13-0.18 (0.15)
•1 gm. Pieces treated in 0 g/l water for 20 min : 0.13-0.18 (0.15)

Exploratory Tests: Boundary Effects





Buoyant balloons

V(balloon) (ft./sec.)	V (from Q) (ft./sec.)
0.13	0.15
0.22	0.21
0.19	0.20

Velocity Variation with Depth

Location	V (ft./sec.)	V(ft./sec.)
Top surface	0.50	0.57
Middle	0.44	0.50
Bottom	0.41	0.48
Vavg (Q)	0.42	0.54

Debris Characterization Test Matrix

Terminal Velocity†	√
Weight*	√
Size*	√
Time to Saturate	√
Qualitative Description	√

†All debris presoaked to saturation before terminal velocity measured.

† Used 85°C (≈ 185°F) water for presoak and 60 °F water in settling-column.

*Weight and size of dry debris only.

At least 20 samples in three batches will be used in the tests.

LiFT Test Matrix

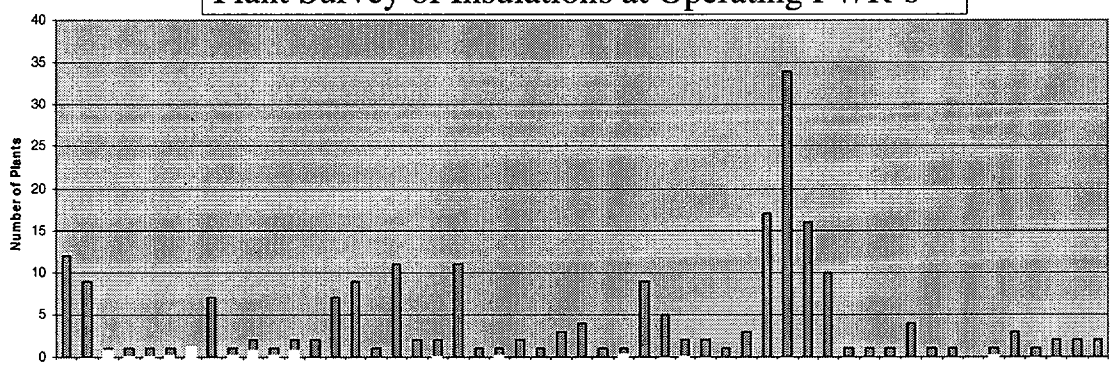
	Flume Height (in.)	Curb Height (in.)	Screen Orientation	Diffuser Status	Pump Discharge Point	Channel X-Section
Settling Velocity†				√	√	√
Tumbling Velocity-Incipient				√	√	√
Tumbling Velocity-Upper Bound				√	√	√
Accumulation Velocity-Incipient	√	√	√	√	√	√
Accumulation Velocity-Upper Bound	√	√	√	√	√	√
Transport Distance†				√	√	√

†At least 5 pieces will be used to measure the settling velocity and transport distance.

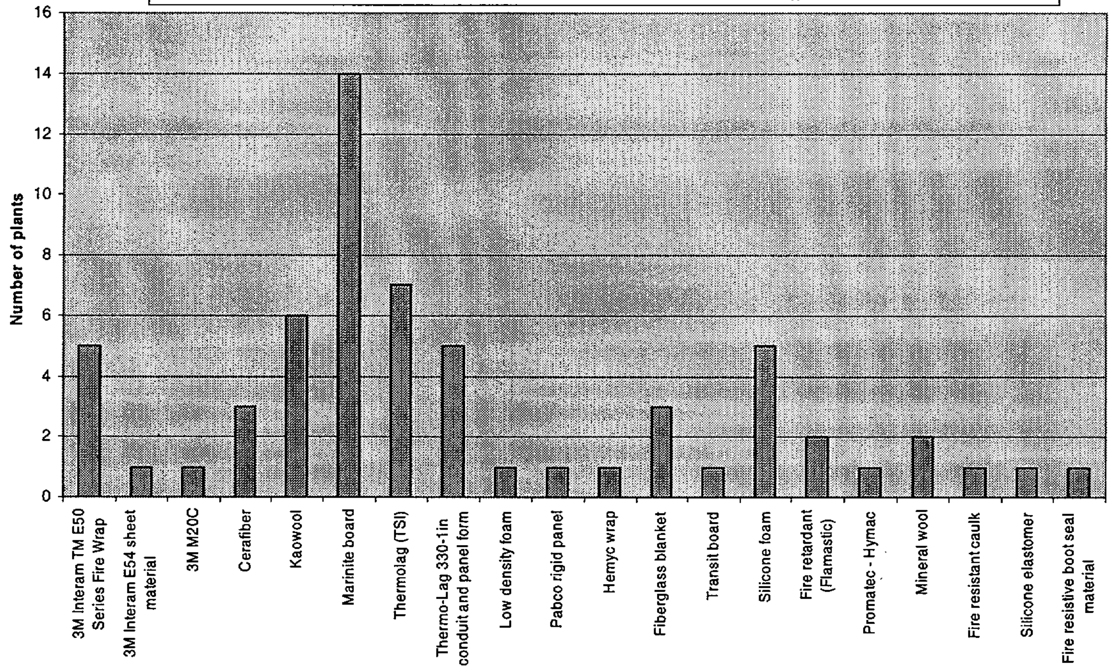
Rationale for Selecting Test Debris Materials

- Plant Survey of Insulations and Fire Barrier Materials
- Internal/Vendor Discussions on "Similarity" of Insulations
  - Reduction in Test Samples

Plant Survey of Insulations at Operating PWR's



Plant Survey of Fire-Barrier Materials at Operating PWRs



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Debris Type/Size Selected for Testing

	As-Manufactured Cassettes/Blankets	As-Manufactured Large Pieces	Smaller Fragments	Medium Fragments
RMI–S/S	◆	◆	◆	◆
Nukon–LDFG	▨		◆	
RMI–Al (1.5 mil)			◆	
Thermal Wrap–LDFG	◆	◆	◆	◆
Temp-Mat–HDFG	▨	▨	▨	▨
Mineral Wool	▨	▨	▨	▨
Cal-Sil		◆	◆	◆
Marinite Board		◆	◆	◆
Silicone Foam		◆	◆	◆
Thermo-Log	◇	◇	◇	◇
Kaowool	◇	◇	◇	◇
Min-K/Asestos/Unibestos	◇	◇	◇	◇

LEGEND

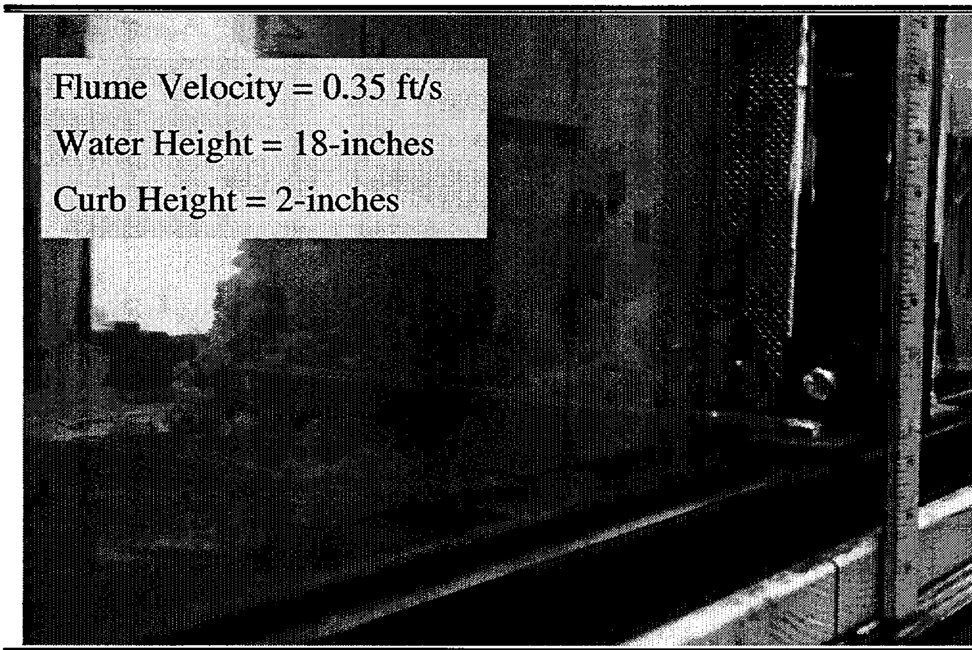
- ◆ Will test.
- ▨ May test them
- ◇ Like to Test. TBD

Preliminary Test Results

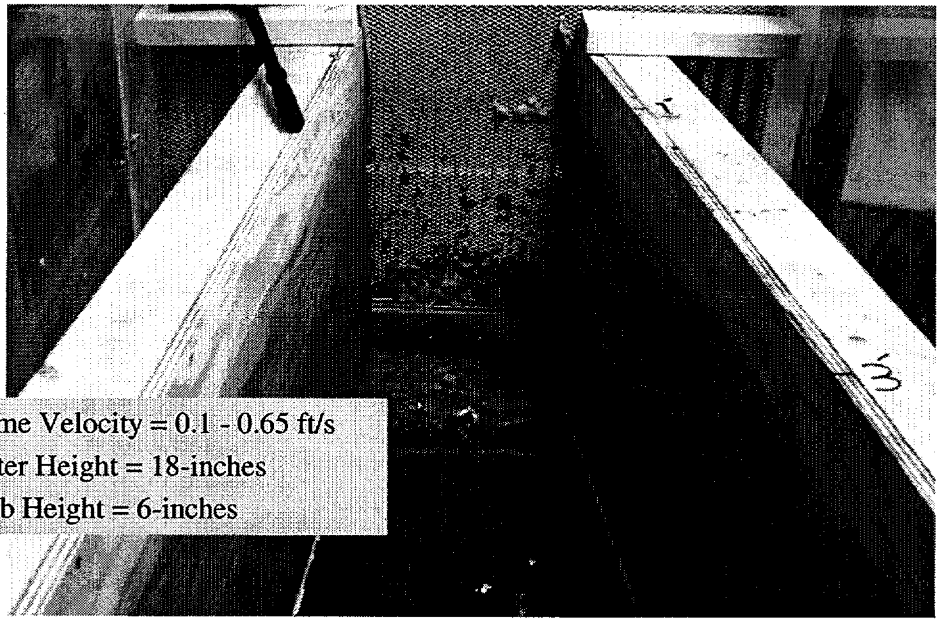
	Test ID	Debris Size	Flume Height	Flow Velocity	Flume X-section	Curb Height	Screen Orient	Diff Mats	Dis. Point
o	Nukon #0	Size 3&4	18-inch	0.05 - 0.5	Normal	0-inch	Vertical	Normal	Normal
o	Nukon #1	Size 3&4	18-inch	0.05 - 0.5	Normal	2-inch	Vertical	Normal	Normal
o	Nukon #2	Size 3&4	18-inch	0.05 - 0.5	Normal	6-inch	Vertical	Normal	Normal
o	Nukon #3	Size 3&4	24-inch	0.05 - 0.5	[illegible]	[illegible]	Vertical	Normal	Normal
o	Nukon #4	Size 3&4	24-inch	0.05 - [illegible]	[illegible]	[illegible]	Vertical	Off	Normal
	Nukon #5	Size 3&4	18-inch	[illegible]	[illegible]	12-inch	Vertical	Normal	Normal
o	Nukon #6	e 3&4+ Cal	[illegible]	[illegible]	Normal	6-inch	Vertical	Normal	Normal
o	Nukon #7	Size 3&4	[illegible]	0.05 - 0.5	Pie-Shaped	2-inch	Vertical	Normal	Normal
o	Nukon #8	Size 3&4	18-inch	0.05 - 0.5	Pie-Shaped	6-inch	Vertical	Normal	Normal
o	Nukon #9	Size 3&4	18-inch	0.05 - 0.5	Pie-Shaped	6-inch	Vertical	Off	Normal
	Nukon #10	Size 3&4	18-inch	0.05 - 0.5	Normal	6-inch	Vertical	Off	10-ft
	Nukon #11	Size 3&4	18-inch	0.05 - 0.5	Normal	2-inch	Lean-to	Normal	Normal
	Nukon #12	Size 3&4	18-inch	0.05 - 0.5	Normal	6-inch	Lean-to	Normal	Normal

- Several tests with Nukon insulation were completed. Others are in Progress
- RMI Tests are in progress.

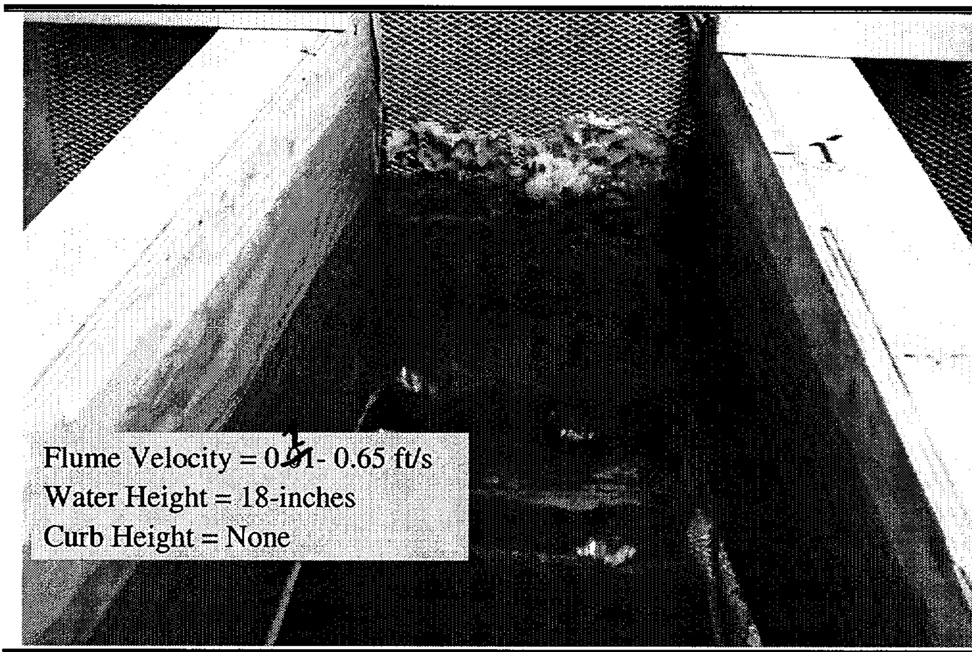
Debris Accumulation on the Screen (2-inch Curb)



Debris Accumulation on the Screen (Pie-Channel)



Debris Accumulation on the Screen (Pie-Channel)



Preliminary Conclusions

Characterization Test Data

- Low-Density fiber shreds (Nukon™) and large-pieces take several minutes of exposure to high temperature water (180 °F) to saturate.
- Terminal Velocities range between xx cm/s to yy cm/s. Shape, but not weight seem to control settling velocity.

Transport Test Data

- Settling and Transport Distance
  - For flume velocities < 0.35 ft/s, debris settling in the flume can be predicted without any consideration for "turbulence".
  - Large-scale eddies do retard settling. Even at flume velocities of 0.2 ft/s, debris settling is limited because of eddies

Draft Only

Results from this slide should not be used with out prior consultation with NRC. They may change as more data becomes available.

Preliminary Conclusions

Tumbling of Fiberglass Debris on the Floor

- Quiescent (or Remote) Flume
  - Incipience of tumbling at 0.15 ft/s. A small fraction of debris start to tumble at that velocity.
  - Bulk tumbling occurs between 0.2 and 0.25 ft/s. At 0.25 ft/s it can be stated that all the debris tumbles on the floor.
- Recirculative (or Exposed) Flume
  - Incipience of tumbling at 0.15 ft/s. A large fraction (up to 30-40%) moves.
  - At 0.2 ft/s most of the debris approaches the screen.

Draft Only

Results from this slide should not be used with out prior consultation with NRC. They may change as more data becomes available.

Preliminary Conclusions

Accumulation of ~~Debris~~ on the Vertical Screen

- Quiescent (or Remote) Flume
  - Incipience of lift at the curb at 0.25 ft/s. Only about 5% of debris start to accumulate at that velocity.
  - Bulk accumulation occurs between 0.3 and 0.35 ft/s. At 0.35 ft/s it can be stated that all the debris lifts at the curb and accumulates uniformly across the 2-ft height we used in the experiments.
- Recirculative (or Exposed) Flume
  - Incipience of tumbling at 0.25 ft/s. A larger fraction (up to 30-40%) moves.
  - At 0.3 ft/s most of the debris lifts-up and deposits on the vertical screen.

Draft Only

Results from this slide should not be used with out prior consultation with NRC. They may change as more data becomes available.

Schedule for Completion of Testing

- LiFT
  - Completion of Testing (May/22/2000)
  - Draft Report (July/21/2000)
- Integrated Tank Test
  - Construction of Test Setup (April/15/2000)
  - Completion of Testing (August/27/2000)
  - Draft Report (Sept/15/2000)
- Head Loss Tests
  - Start (Jan/01)
  - Finish (June/01)

Risk Analysis for PWR Sump Blockage

Presenter:

John Darby

Los Alamos National Laboratory

Technology and Safety Assessment Division

Topics of Presentation

- Scope of Risk Analysis Task
- Technical Approach for Evaluating Risk
- Interface with Debris Phenomenological Studies

Scope of Risk Analysis Task

- Frequency of Initiating Events
- Each Volunteer Plant
  - Core Damage Frequency (CDF, ΔCDF)
  - Large Early Release Frequency (LERF, Δ LERF)
  - Conditional Probability of ECCS Failure as a Result of Debris Accumulation ($CP_{ECCS\ FAIL\ DEBRIS}$)
- Sensitivity/Parametric Analyses
  - Capture Plant Design Differences
  - Evaluate importance of Assumptions Related to Plant Response

Specifications for the Risk Analysis Model

- Objectives
  - Estimate CDF, ΔCDF, LERF, ΔLERF, and $CP_{ECCS\ FAIL\ DEBRIS}$
  - Differentiate Among Plant Designs
  - Include Quantification of Effects of Debris
  - Be Probabilistically Based
  - Be Able to Quantify Numerous Accident Sequences at Systems Level
  - Be Extensible to the Component Level
  - Consider Mitigation Strategies
  - Be Quantifiable with Both Licensing Assumptions and 'Most Likely' Plant Response
  - Be Able to Quantify the Impact of Debris in the Sump

Specifications for the Risk Analysis Model

- Desired Attributes
  - State of the Art
  - Fast (Computerized)
  - Flexible, Extensible, Proven
  - Acceptable to NRC
  - Easy to Understand Conceptually
  - Includes Sensitivity and Uncertainty Analysis Capabilities

Proposed Approach for Evaluating Risk

Components of the Approach (Other than Debris Phenomena)

- Selection of Accident Sequences
- Identify Possible Mitigation Strategies
- Estimate Frequency of Initiating Events
- Account for Licensing vs 'Most-Likely' Plant Systems Response
- Account for Plant Design Differences
  - Sensitivity/Parametric Analyses

Selection of Accident Sequences

- Selection Criteria
  - Importance of Sump to Mitigate the IE
    - Metric: F_{sump} = Frequency of Accident Initiating Event x Conditional Probability Sump Required for ECCS Recirculation
    - Used existing PRAs and databases to estimate sump importance
  - Potential for Debris Generation
    - As a Result of Preferred Strategy
    - As a Result of Alternate Strategy

The selection process did not address likelihood that the sump would be 'blocked' by debris

Accident Sequences Selected for Evaluation

- Loss of Offsite Power with Loss of Auxiliary Feedwater
- Medium Loss-of-Coolant Accident (MLOCA)
- Small Loss-of-Coolant Accident (SLOCA)
- Large Loss-of-Coolant Accident (LLOCA)
- Transient with Stuck-Open PORV
- Small-Small LOCA (SSLOCA), within Capacity of Normal Makeup System
- Break in Pressurizer Surge Line

Possible Mitigation Strategies

- All Require Evaluation of Emergency Operating Procedures (EOPs)
- Refill Source of Injection and Continue Injection
  - Require Borated Water
  - Concerns over Overfill of Containment
- Depressurize Reactor Coolant System and use Shutdown Cooling System
  - Limits on Rate of Cooldown/Depressurization
- Throttle Flow through Pumps Pulling from Sump
  - Counter to Safety Philosophy to Inject as Much as Possible
  - Requirements to Maintain Subcooling Margin

Sources of Information
- PWR Plant Survey for Mitigation Strategies
- Selected Plant EOPs

Frequency of Initiating Events

- Licensing
  - All Design-Basis Accidents Equally Likely
- 'Standard' Probabilistic Risk Assessments
  - Basically the WASH-1400 Reactor Safety Study Values from 1974 through the IPEs
- 'Newer' Risk Assessment Values
  - Leak-Before-Break (LBB) considerations lower the frequency of Large and Medium breaks

Table 3. Calculations Used to Estimate Frequency That Sump Will Be Required

Debris Concern Category (from Table 2)	Accident Condition Type	Accident Condition Frequency (per year)				Conditional Probability of Requiring Sump w/o Special Strategy		F_{sump}, Frequency of Accident Condition Times Conditional Probability of Requiring Sump (per year); (all sequences potentially generate debris)		Characterization of Potential Source of Debris
		IPE	Basis	Updated	Basis	Value	Basis, Notes	IPE	Updated	
A	Large LOCA	5E-04	a	5E-06	b	1		5E-04	5E-06	C1
A	Medium LOCA	1E-03	a	4E-05	b	1		1E-03	4E-05	C2
A	Small LOCA	1E-03	a	5E-04	b	1		1E-03	5E-04	C3
A	ISLOCA inside containment	1E-04	c			1		1E-04		C2
A	Transient that transitions to RCP seal LOCA	4E-05	d			1		4E-05		C3
A	Transient involving RCS valves opening and failing to reclose	4E-04	e			1		4E-04		C4
B	Small-small LOCA	1.3E-02	a			1E-03	h, 1, 2	1.3E-05		C4
B	Transients involving RCS valves opening and reclosing	1E-1				1E-03	h, 1, 2	1E-04		C4
B	Transients that discharge fluid into containment but do not evolve into LOCAs (e.g. MSLB, MLFB)	2.16E-03	a			1E-03	h, 1, 2	2.16E-06		C1
B	ATWS transients in which RCS valves reclose	1.3E-04	f			0	3			
C	(None identified at present time)									
D	Transients that do not discharge fluid into containment	8.4	a	1.2	b	1E-03	h	8.4E-03	1.2E-03	C4
D	SGTR	1E-02	a	7E-03	b	1E-03	h	1E-05	7E-06	C4
D	ISLOCA outside containment	2E-06	g			0	3	0		

Basis: (a) Indian Point 3 IPE list of generic values, IPE Table 3.3.1.1 (b) "Rates of Initiating Events at U. S. Nuclear Power Plants: 1987 – 1995, NUREG/CR-5750, February 1999. (c) based on estimated failure rate of inboard RHR shutdown cooling line isolation valve (see text for additional details) (d) based on estimated frequency of station blackout (SBO) and non-recovery of AC electrical power within 1 hour (see text for additional details) (e) based on demand probabilities of PORV operation following a transient, along with probability that an open PORV will fail to reclose (see text for additional details) (f) based on Indian Point 3 IPE estimate of RPS failure probability of 1.6E-05 (see text for additional details) (g) Indian Point 3 IPE list of plant-specific values, IPE Table 3.3.1.1 (h) based on Indian Point 3 IPE loss of secondary cooling (see text for additional details)

Notes: (1) loss of steam generator cooling for decay heat removal (2) debris from feed and bleed (potential) (3) cannot mitigate with sump

Characterization of potential source of debris: (C1) large (C2) medium (C3) small (C4) debris from feed and bleed; quench tank rupture disk is source of fluid

Licensing-vs "Most-Likely" Plant Response/Conditions

- Licensing
  - Limiting Case is a Result of Single-Failure Criterion:
    - One Train of ECCS and Containment Spray; Lower Sump Water Flow Maximum Water Temperature in $NPSH_{Margin}$ Evaluation
  - RG 1.1: May Not Credit Containment Over-Pressure $NPSH_{Margin}$ Evaluation

- Most Likely Scenario
  - Both Trains of ECCS for Core Cooling
  - Containment Pressure Higher Than What Is Credited in the Licensing-Basis Evaluations
  - Containment Spray May Not Be Actuated for Certain Scenarios if All Fan Coolers Function

The Licensing Basis Assumptions May Not Provide the Limiting Case.
- The "most likely" case may result in higher pressure drop (transport and flow) and thus outweigh conservatism introduced by the licensing-basis assumptions.

The licensing-basis assumptions may not provide a consistent description of accident progression.
- Resolution of these deficiencies may require more investigation into containment-core interface details.

Plant Design Differences

- Sump Characteristics and Pump Characteristics
- Use of Makeup Pumps as Part of High-Pressure Emergency Core Cooling System
- Use of Fan Coolers/Spray for Containment Cooling
- Different Containment Designs
- Reactor Coolant System Safety Valves Discharge: to Quench Tank or Directly to Containment
- Different Pressure Set Points for Spray Actuation

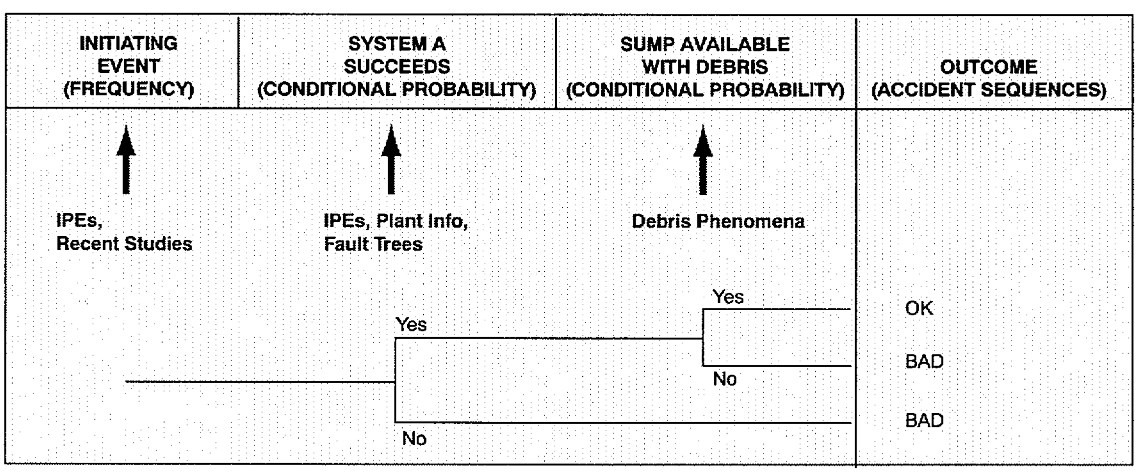
Plant Variability compared with volunteer plants and their impacts will be captured through sensitivity analyses.

The final results (ΔCDF, ΔLERF) will be expressed with a range.
- **This approach will quantify importance of plant differences.**
- **This approach will minimize number of plants that have to be modeled.**

Risk Model Description

- Model at the Event-Tree Level
  - Traditional PRA Data
  - Newer PRA Data
  - Plant-Specific Data
  - Extend to Fault Trees Only if Necessary
- Use the SAPHIRE Software

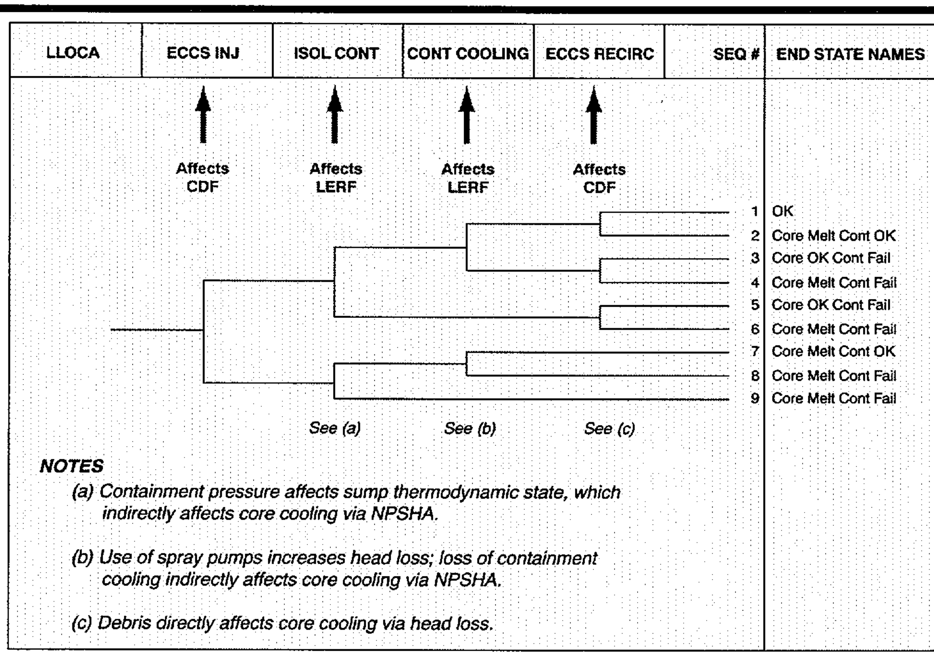
Use of an Event Tree



How Event Tree Meets Model Required Attributes

- Estimate CDF, LERF
  - Include Core Cooling and Containment State Information on the Event Tree
  - Explicitly Indicate Core and Containment States in Sequence End States
- Differentiate Among Plant Designs
  - Develop More Detailed Event Trees
  - Develop Supporting Fault Trees (if required)

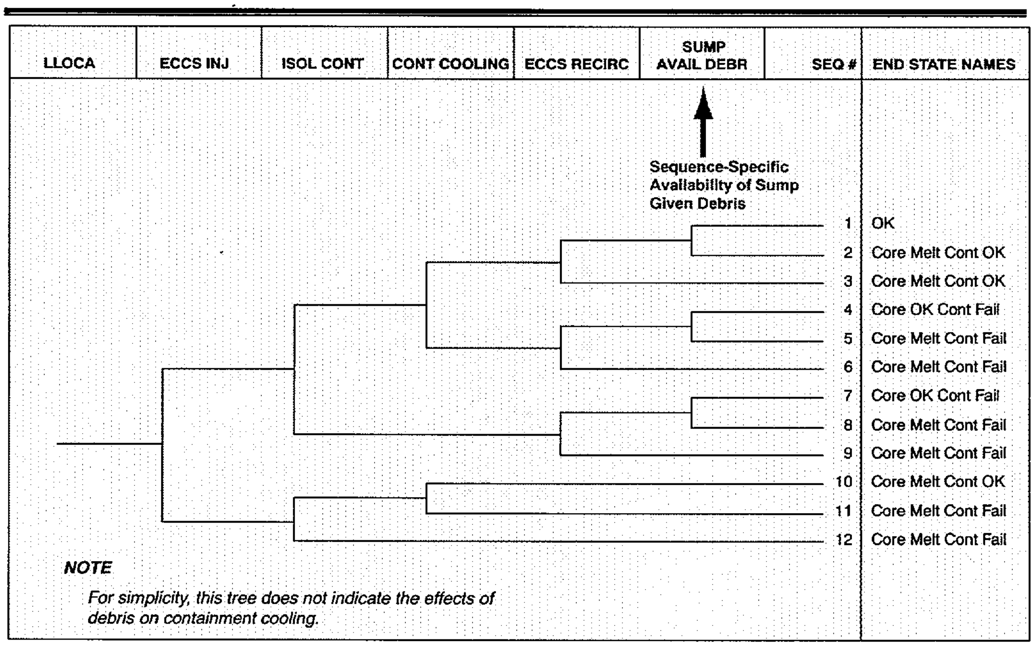
Estimate CDF, ΔCDF, LERF, ΔLERF
Explicit inclusion of containment events



How Event Tree Meets Model Required Attributes

- Includes Quantification of Effects of Debris
  - Conditional Probabilities for Core Cooling During Recirculation and for Containment Cooling
- Probabilistically Based
  - Quantifies Sequence Frequencies as Products of Initiating-Event Frequency and Systems-Level Conditional Probabilities of Failure/Success

Include Sequence-Specific Effects of Debris



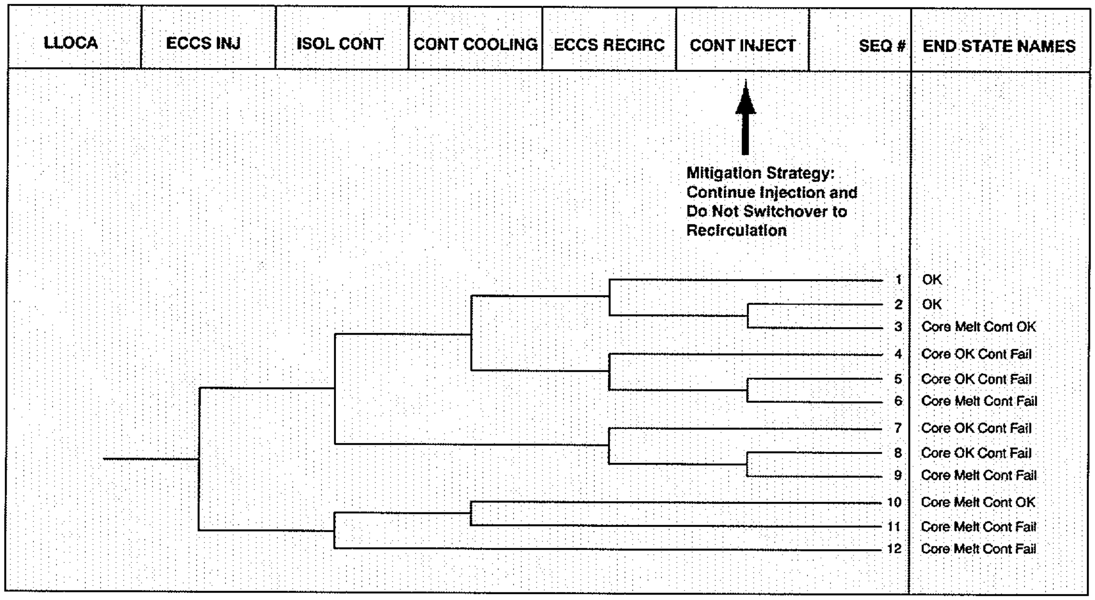
How Event Tree Meets Model Required Attributes

- Be Able to Quantify Numerous Accident Sequences at Systems Level
  - Each Initiating Event has a Unique Event Tree
  - Each Event Tree Delineates the Possible Accident Sequences (Combinations of Systems Successes/Failures)
- Be Extensible to the Component Level
  - Each Event Can Be Modeled as a Fault Tree
  - Analysis Tools (e.g., SAPHIRE Automatically Links the Fault Trees)

How Event Tree Meets Model Required Attributes

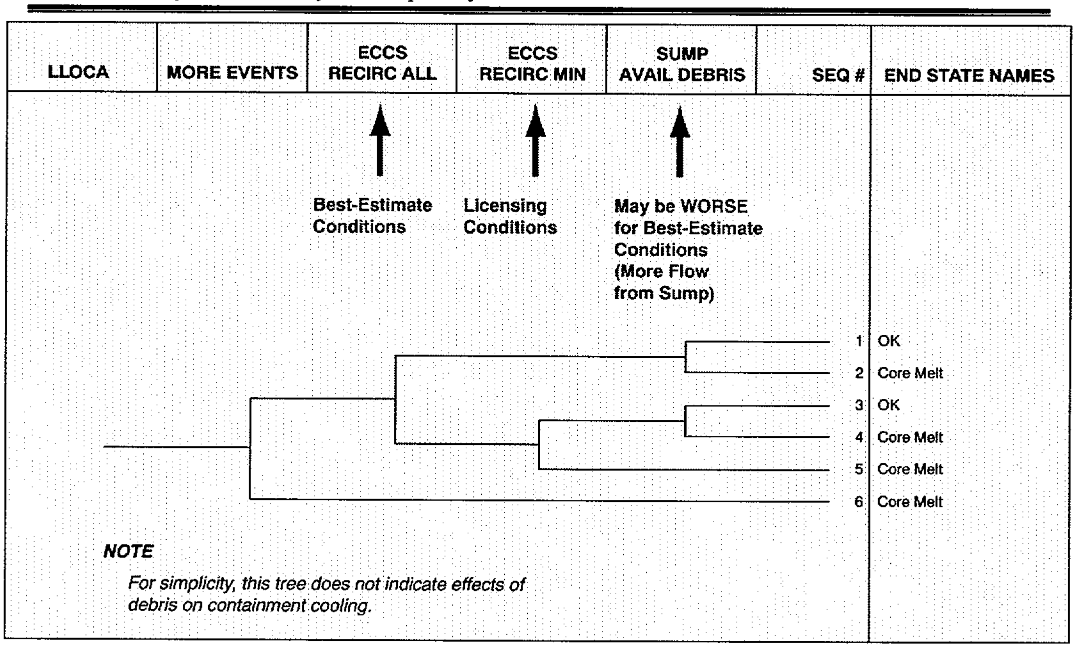
- Consider Mitigation Strategies
  - Explicitly via Additional Events in the Tree
- Be Quantifiable with Both Licensing Assumptions and Most Likely Response
  - Explicitly via Additional Events in the Tree

Account for Mitigation Strategies
Explicit inclusion of Operator Response Events



Account for Differences Between Licensing-Basis Assumptions and Most Likely Response

- Explicit inclusion of events that provide the distinctive success criteria
- Use system reliability data to quantify event failures



How Event Tree Meets Model Required Attributes

- Be Able to Quantify the Impact of Debris in the Sump
  - Interface with Phenomenological Studies to Assign Conditional Probability of Sump Not Available with Debris
    - Plant System Conditions as Indicated on Upstream Events in the Specific Accident Sequence on the Event Tree (e.g., Number of Pumps Pulling From Sump for Containment and Core Cooling)
    - Debris Phenomena Dependent on Size and Location of Break, Time when Sump Required, etc.

How Event Tree Meets Model Desired Attributes

- State of the Art
  - Implementation in the Latest SAPHIRE Framework
- Fast (Computerized)
  - SAPHIRE is a Computer Code
- Flexible, Extensible, Proven, and Acceptable to NRC
  - Event Trees Used Extensively for Reactor Safety Modeling Since the 1970s

How Event Tree Meets Model Desired Attributes

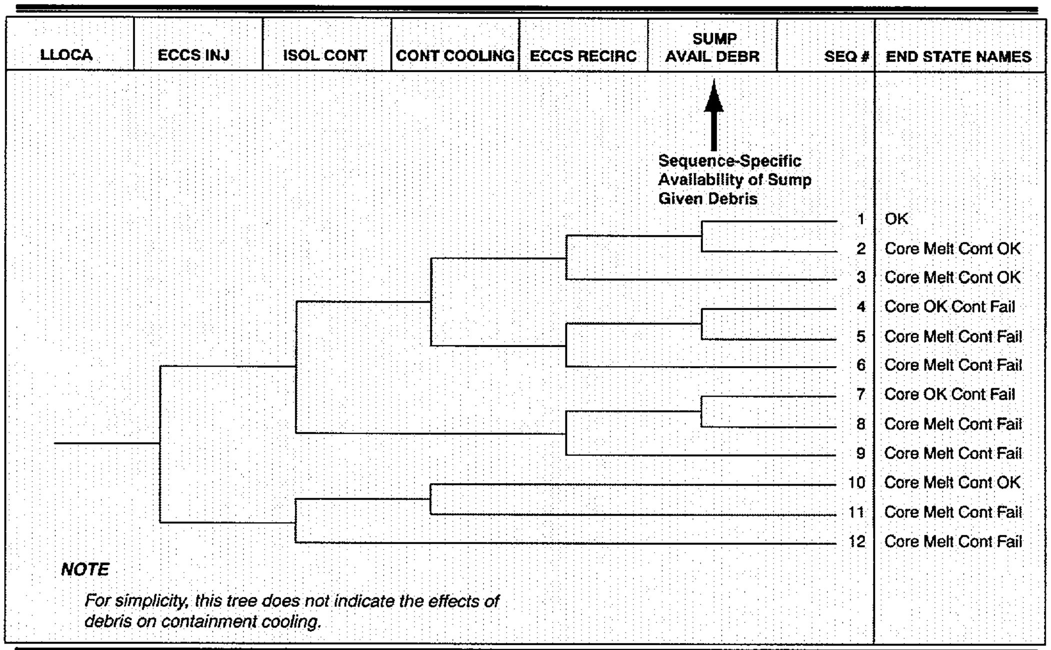
- Easy to Understand Conceptually
  - At the Top Level the Event Tree Provides a Clear Description of Accident Sequence Systems Level Successes/Failures
  - At the Top Level the Event Tree Shows Quantification as Product of Event Values (Frequency/Probability)
- Includes Sensitivity/Uncertainty Analysis Capabilities
  - Built into SAPHIRE

Interface with Debris Phenomenological Studies

$CP_{ECCS\ FAIL\ DEBRIS}$

- The Probability That the Sump is Not Available Because of Debris is Accident-Sequence Specific
  - Event-Tree Structure Does Delineate Individual Accident Sequences
    - Initiating Event (IE)
    - Subsequent Systems States (Number of pumps, etc., as Defined by Success/Failure of Events)
    - Effect of Debris on Sump Is an Explicit Event in the Event Tree SUMP_AVAIL_DEBRIS
      - Probability of SUMP AVAIL DEBRIS Depends on the Accident Sequence per the Event Tree
      - $CP_{ECCS\ FAIL\ DEBRIS}$ = 1 - Probability of SUMP_AVAIL_DEBRIS

Include Sequence-Specific Effects of Debris



Quantification of $CP_{ECCS\ FAIL\ DEBRIS}$ for a Specific Accident Sequence

- If Accident Sequence Uniquely Specifies all Variables, $CP_{ECCS\ FAIL\ DEBRIS}$ is 0 or 1
  - $CP_{ECCS\ FAIL\ DEBRIS} = 0$ if $NPSHA \geq NPSHR$
  - $CP_{ECCS\ FAIL\ DEBRIS} = 1$ if $NPSHA < NPSHR$

Calculation of Important Conditions

- Plant Design Characteristics (PDCs)
  - RELAP / MELCOR Calculations
- Plant System Conditions (PSCs)
  - Explicitly in Accident Sequence as Delineated on Event Tree
- Sump State (SS)
  - RELAP / MELCOR Calculations
- Debris Phenomena (DP)
  - Debris Phenomena Studies from Other Tasks

Roll-Up Process

- Specify PDC
- For Each Accident Sequence on Each Event Tree
  - Specify PSC, SS, DP
- Determine if NPSHA ≥ NPSHR for Each Accident Sequence
  - If Yes, $CP_{ECCS\ FAIL\ DEBRIS} = 0$
  - If No, $CP_{ECCS\ FAIL\ DEBRIS} = 1$

Can Event Trees Specify **All** Variables to Uniquely Determine $CP_{ECCS\ FAIL\ DEBRIS}$ as 0 or 1 for Each Accident Sequence?

Fidelity of Event-Tree Accident Sequences

- Will be Sufficient to Specify PDCs
- Will be Sufficient to Specify PSCs

Factors Complicating Specifying $CP_{ECCS\ FAIL\ DEBRIS}$ as 0 or 1 for Each Accident Sequence

- Fidelity of RELAP/MELCOR Calculations Affects Determination of Sump State (SS)
- Variety of Break Locations with Different Frequencies Affects Determination of Debris Phenomena (DP)
  - Even for a Specific-Size-Break Event Tree
  - Transients Are a Degenerate Case (Known 'Break' Location; e.g., PORV Failed Open)
- Uncertainty on Debris Phenomena (Volume, Transport, Settling, etc.) Affects Determination of Debris Phenomena (DP)

Include Sump State Results from RELAP/MELCOR Calculations in Accident Sequences

- Include Explicitly or Implicitly in Event-Tree Accident Sequences
  - Explicit via Additional Events
  - Implicit via Assignment of Event Failure Probabilities

Consideration of Debris Phenomena in Accident Sequences

- Not Feasible to Develop Accident Sequences to Sufficient Fidelity to Uniquely Model all Debris Phenomena
  - Too Many Parameters
- Use Composite Value Derived from Statistical Combination of Important Parameters

Approach

- Develop Accident Sequences on Event Trees in Sufficient Detail to Uniquely Specify all Parameters Required to Calculate $CP_{ECCS\ FAIL\ DEBRIS}$ <u>except</u> for Debris Phenomena, specifically
  - Specify Plant Design Characteristics (PDC)
  - Specify Plant System Conditions (PSC)
  - Specify Sump State (SS)

Approach

- Quantify Debris Phenomena for Each Accident Sequence as a Composite Value Derived from a Statistical Combination of Important Parameters

Parameters for Composite Debris Phenomena Quantification for a Given Accident Sequence

- 'Break' Size is Specified in the Accident Sequence
- Other Break Variables are Specified by a Break Set ≡ {Location, Pipe Size, System}:
  - Break Location (Not All Locations Have the Same Frequency of Break; E.G., Welds, Bends, etc.)
  - Pipe Size (Total Break in Smaller Pipe, or Hole in Larger Pipe)
  - System or Subsystem with Break (Credit for LBB or not)

Parameters for Composite Debris Phenomena Quantification for a Given Accident Sequence

- Variables Affecting Debris Generation and Transport to Sump Given a Specific Break Set Are Specified by a Debris Set ≡ {Source, Volume Transport, Settling}

Calculation Process

- For each Accident Sequence (AS) there will be a Specific $CP_{ECCS\ FAIL\ DEBRIS}$ (AS)
- $CP_{ECCS\ FAIL\ DEBRIS}$ (AS) is a Weighted Combination of a Set of 0/1 values
  - Each Element of the Set is $P_{Fail\ Sump\ Debris}(AS, BS, DS) = 0$ or 1
    - BS is a unique Break Set
    - DS is a unique Debris Set; DS is dependent on BS

Calculate $CP_{ECCS\ FAIL\ SUMP}$

- $CP_{ECCS\ FAIL\ DEBRIS}(AS) = \Sigma_{i\ Break\ Sets}\ W_i\ P_{Fail\ Sump\ Debris}(AS, BS_i)$
  - W_i is Weight Factor (to be determined)

- $P_{Fail\ Sump\ Debris}(AS, BS_i) = \Sigma_{k\ Debris\ Sets}\ W_{i,k}\ P_{Fail\ Sump\ Debris}(AS, BS_i, DS_{i,k})$
  - $W_{i,k}$ is Weight Factor (to be determined)
  - $P_{Fail\ Sump\ Debris}(AS, BS_i, DS_{i,k}) = 0$ or 1

GSI-191: PWR Sump Blockage by Debris
Plant-Specific Debris Generation Model

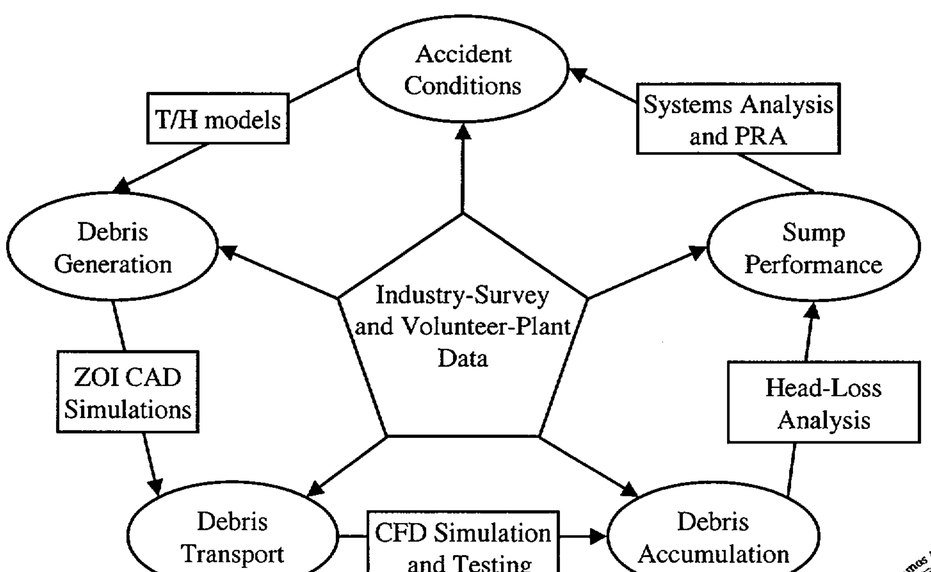
Bruce Letellier

Probabilistic Risk and Hazards Analysis Group

Technology and Safety Assessment Division

Los Alamos National Laboratory, NM

MultiComponent Analysis Plan



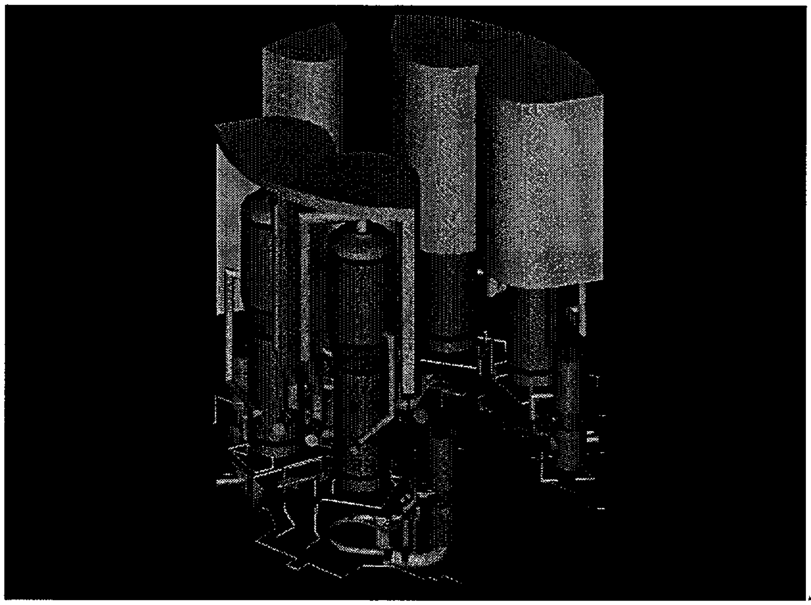
Spatial Plant Model Needed to Address All Debris Source Issues

- **Realistic spatial configuration of insulated piping and equipment is important:**
  - Proper distribution of potential break sizes **(debris volume)**
  - Defines regions of high insulation density **(debris volume and composition)**
  - Presence of structure and equipment offers confinement and sheltering **(debris volume)**
  - Spatial correlation between insulation types and break sizes **(debris composition)**
  - Break location relative to sump **(debris transport)**
- **A flexible, efficient model can be used for parameter studies: insulation type, effective damage volume, directional impingement, postulated break location, barriers, etc.**

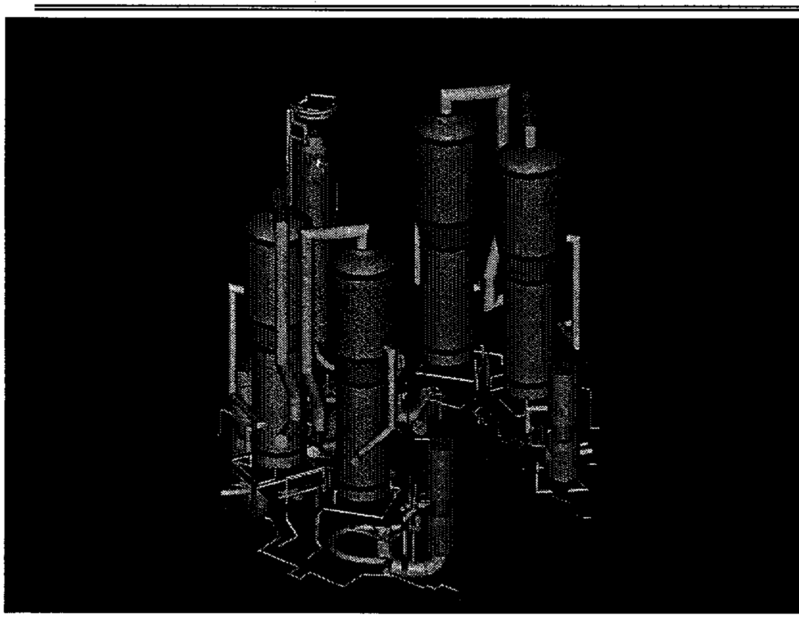
DEBGEN Source-Term Analysis Model

- **Debris Generation (DEBGEN) model:**
  - Accepts spatial pipe and equipment data cross referenced by reactor system, insulation type, and pipe diameter (ASCII data files)
  - Discretizes insulated pipes into linear segments that are then represented as point targets on the centerline
  - Discretizes equipment blankets into panels represented as point targets
  - Maps spherical damage pressure zones on spatial insulation data
    - BWR URG correlations specific to each insulation type and break diam.
  - Postulates Guillotine breaks at any set of locations
    - Table of welds correlated with specific pipe sizes and reactor systems
  - Performs CAD-like simulations and compiles statistics on break size, reactor system, debris volume, and debris composition.
  - Developed in MATLAB® 5.3 to run on a high-end desktop PC
    - Potential for standalone distribution, GUI development, C++ interface

Volunteer-Plant Layout



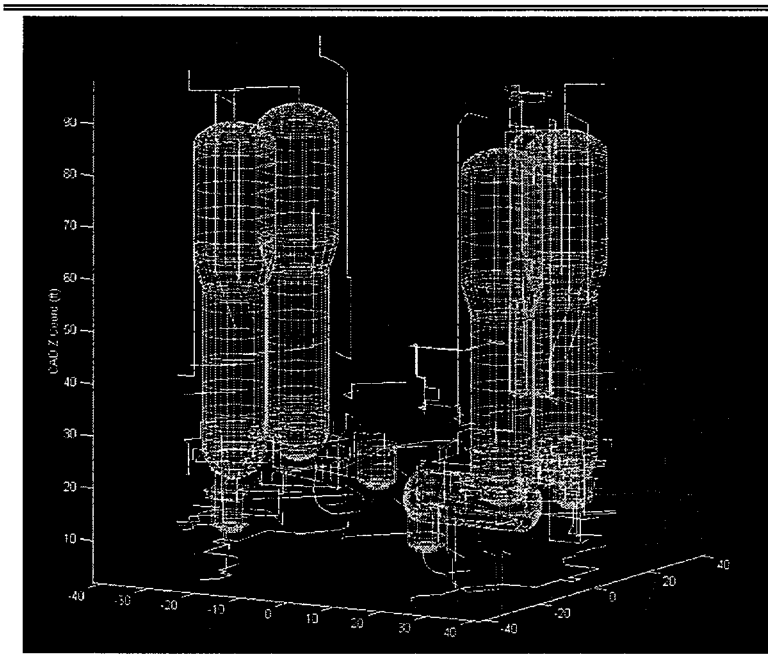
Volunteer-Plant Layout



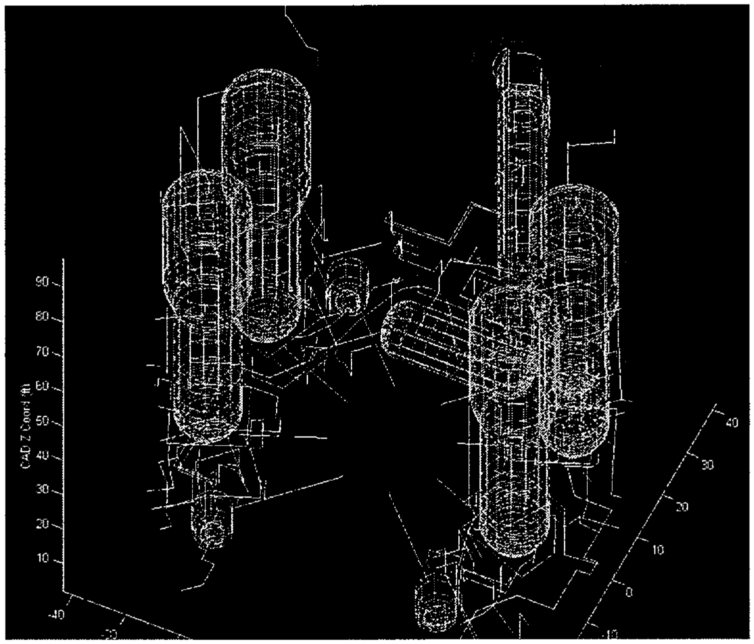
DEBGEN Input of Plant Features

- Current version strips pipe vertices and coordinates from an AutoCAD model
- Some thought has been given to scanning data directly from piping isometrics (labor intensive entry and validation)
- Prototype of DEBGEN was used with varied data formats in BWR audits (Excel spreadsheets, manual entry, etc.)
- DEBGEN visual model facilitates data validation

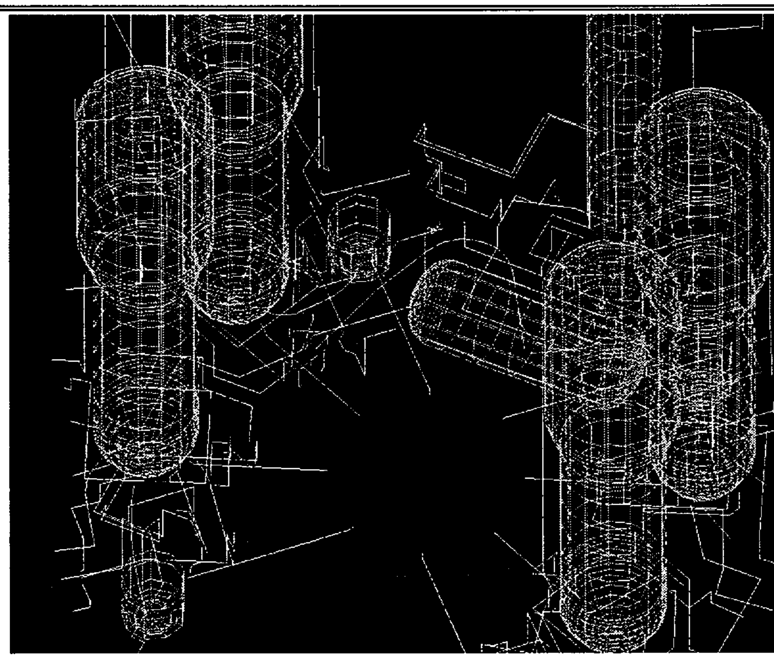
DEBGEN Debris Source Simulation



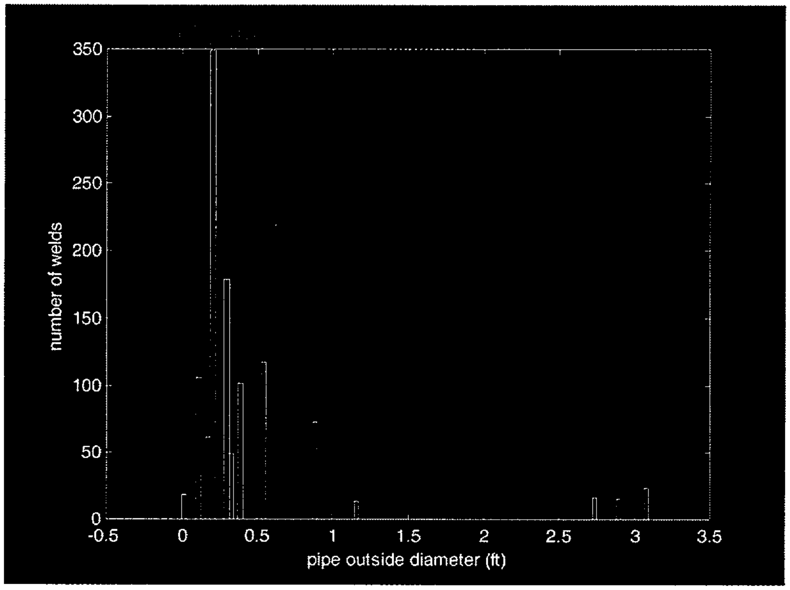
DEBGEN Debris Source Simulation



DEBGEN Debris Source Simulation



DEBGEN Summary Statistics



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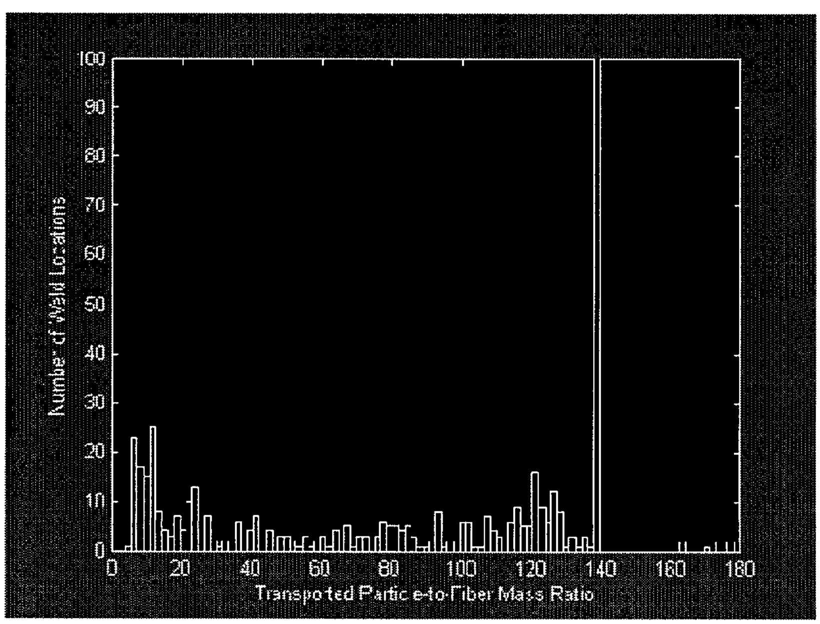

Future Work

- **Opposing conical damage volumes aligned with broken pipe**
- **Directional conical damage volume perpendicular to pipe**
- **Sampling scheme to choose breaks other than weld locations**
  - Uniformly per unit length
  - Weighted by reactor system
  - Preference for bends
- **Shadowing by major structures**
- **Output interface for risk assessment**