



Lessons Learned from Interim Volunteer-Plant (VP) ECCS Vulnerability Assessment

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Overview

- **Objectives of Volunteer-Plant Analysis**
- **Plant Description**
- **Sump-Screen Head Loss**
- **Pool Transport**
- **Blow Down/Wash Down Debris Transport**
- **Debris Generation**
- **Break Location**
- **Current Insights**



Objectives of Study

- **Volunteer Plant study integrates all phenomenology info and analysis methods using best available plant specific data**
- **Illustrates one possible implementation of the Reg Guide**
- **Provides NRC a detailed standard of comparison for reviewing future submittals and NEI ground rules**
- **May provide a template for content of plant assessments but with exaggerated detail needed for methodology insight**
- **Sets expectations for conservatism and application of data**
- **Will address all major accident scenario components BUT... will not analyze all industry conditions/configs**
- **'Best Available' info will still require approximation and engineering judgment. Will improve as condition assessment and further head-loss analyses are completed**



Required Plant Information

- **Water balance calculations**
 - Return flow locations and rates
 - Minimum pool depths for various break scenarios
 - ECCS flow rates for various break scenarios
- **ECCS pool geometry**
 - Flow velocity calculations
 - Identify dead sumps that can trap debris during fill up
 - Scope pool dynamics (regimes of fill up, spray return, steady-state)
- **Piping layout and insulation applications by type**
- **Sump-screen geometry**
- **Plant cleanliness characterization (Latent Debris)**

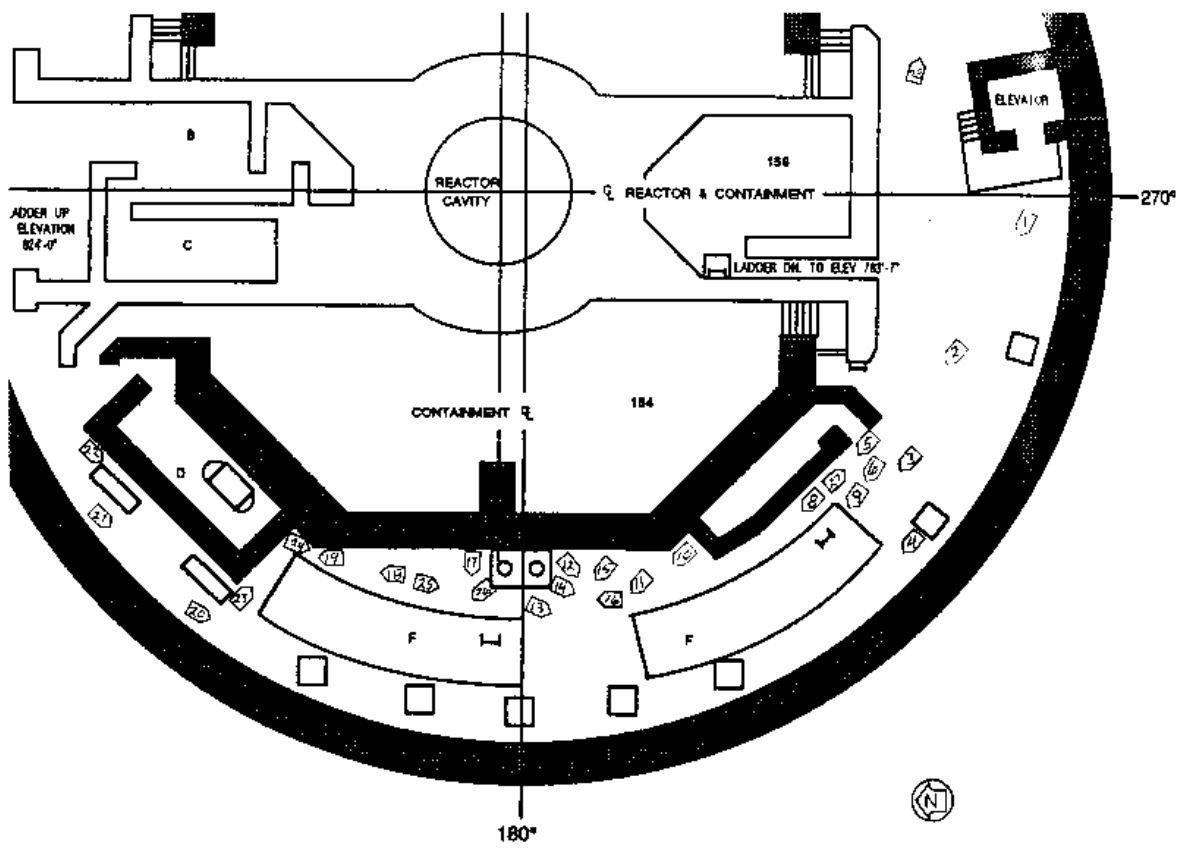


VP Geometry Features

- **Large dry containment (133 ft diam), four loop, 'remote' sumps**
- **Raised steam generator compartments**
 - Continual falling water sweeps compartment floor
 - Compartment opposite break cannot accept debris during fill phase
 - No damping of falling water. Momentum directed to annulus
- **Two adjacent roughly equivalent sump cages (260 ft² total)**
 - Very close to one steam generator compartment outlet
- **Sump-screen curb (4 in)**
 - Effective at stopping RMI debris unless severe piling occurs
 - Reduces effective pool depth
- **Nonsubmerged vertical sump screens 4.75 ft above curb**
 - Failure criteria ~1/2 pool depth above curb (ft H₂O)
- **Fall height from upper level drains ~10 ft**
- **Spray return drains adjacent to vertical sump screens**
- **Reactor cavity access has curb and partial steel-plate cover**



Sump Pool Plan View



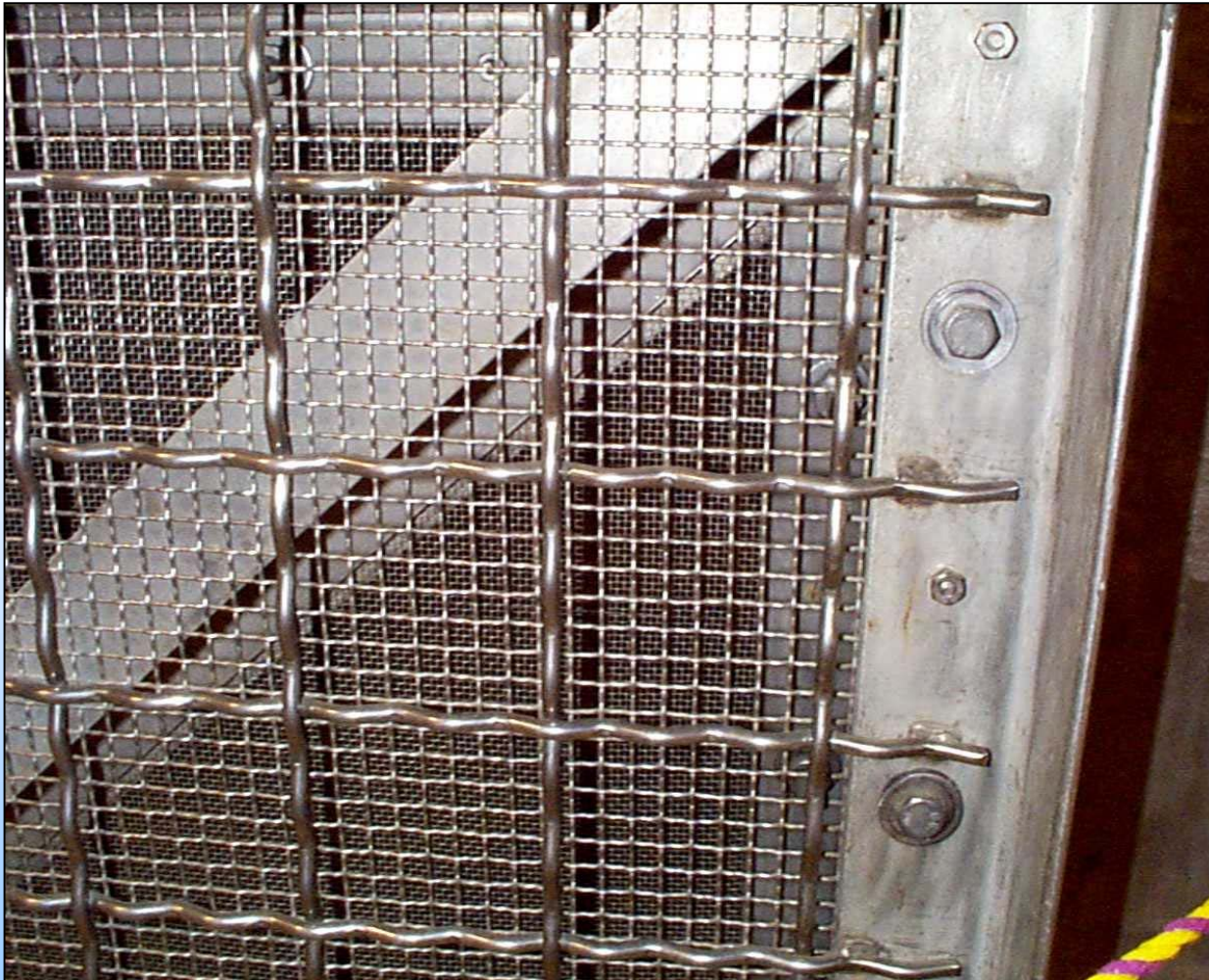


Sump Cages





Sump-Screen Construction





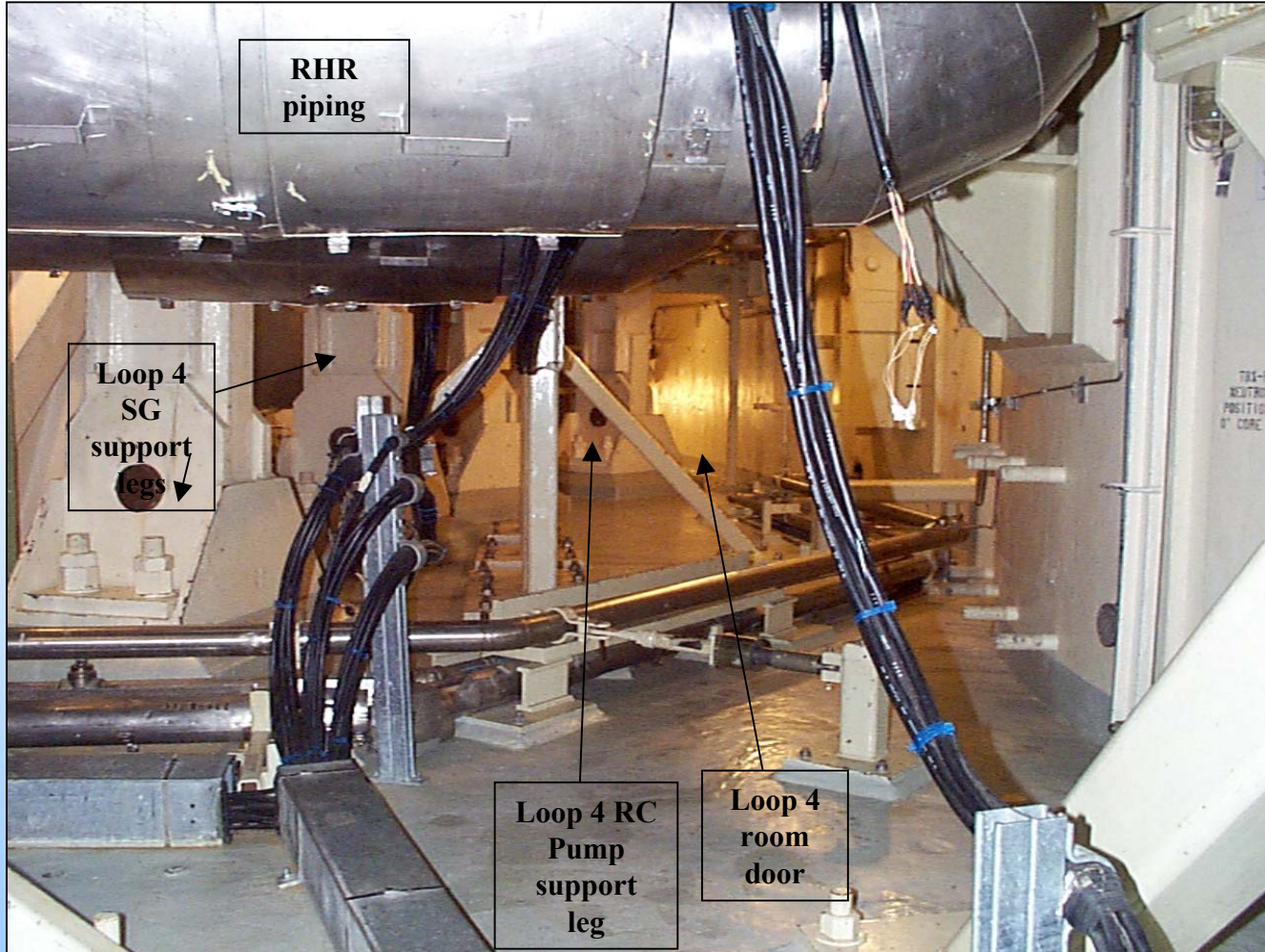
SG Compartment Entry



- Door closed during operation by radiation safety procedure
 - Intermediate debris trap or water flow blockage?
 - Both compartment doors must block to prevent flow yet large fraction of total debris may pass through these doors
 - Comparison of compartment fill up rate may show that structural failure loads are reached before switch over

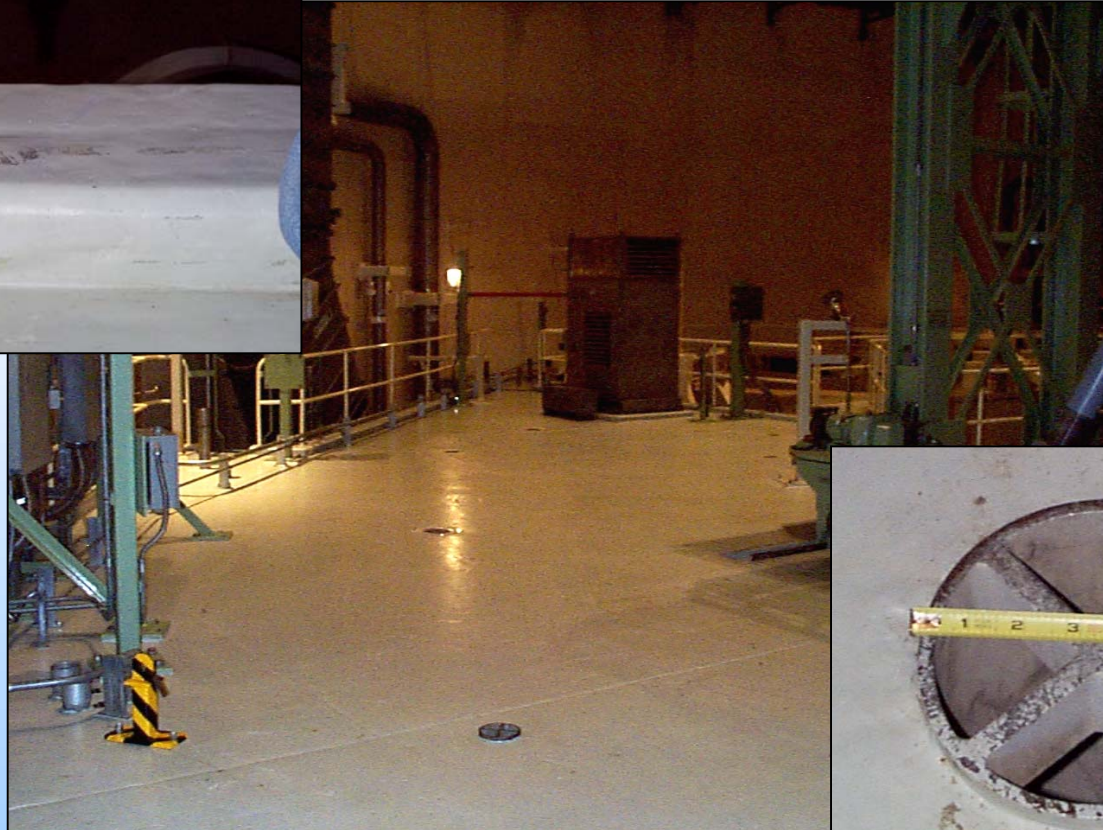
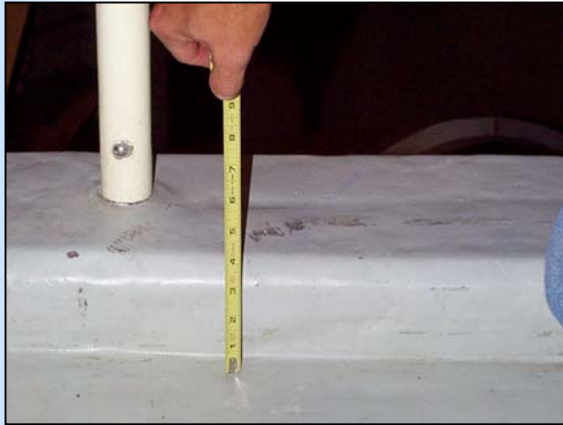


Steam Generator Compartment



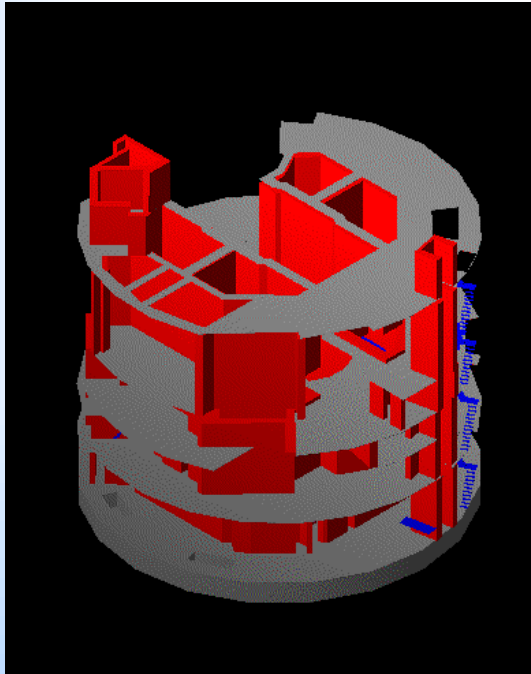


Floor Drains and Curbing

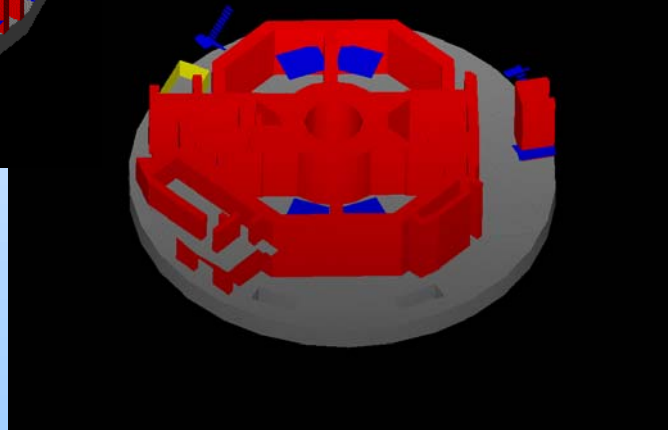
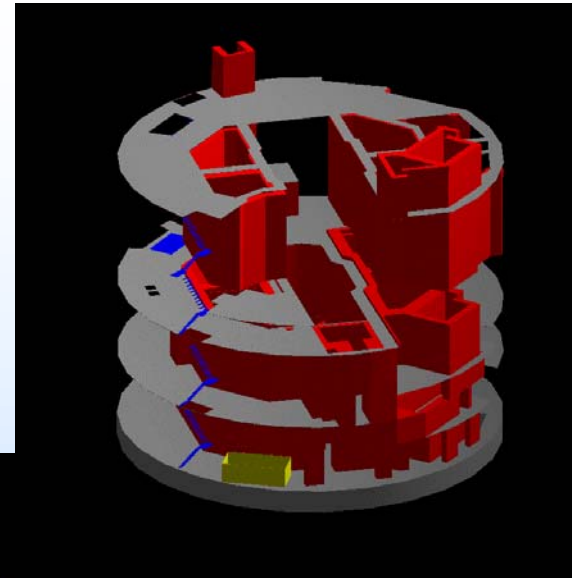




Concrete Structures

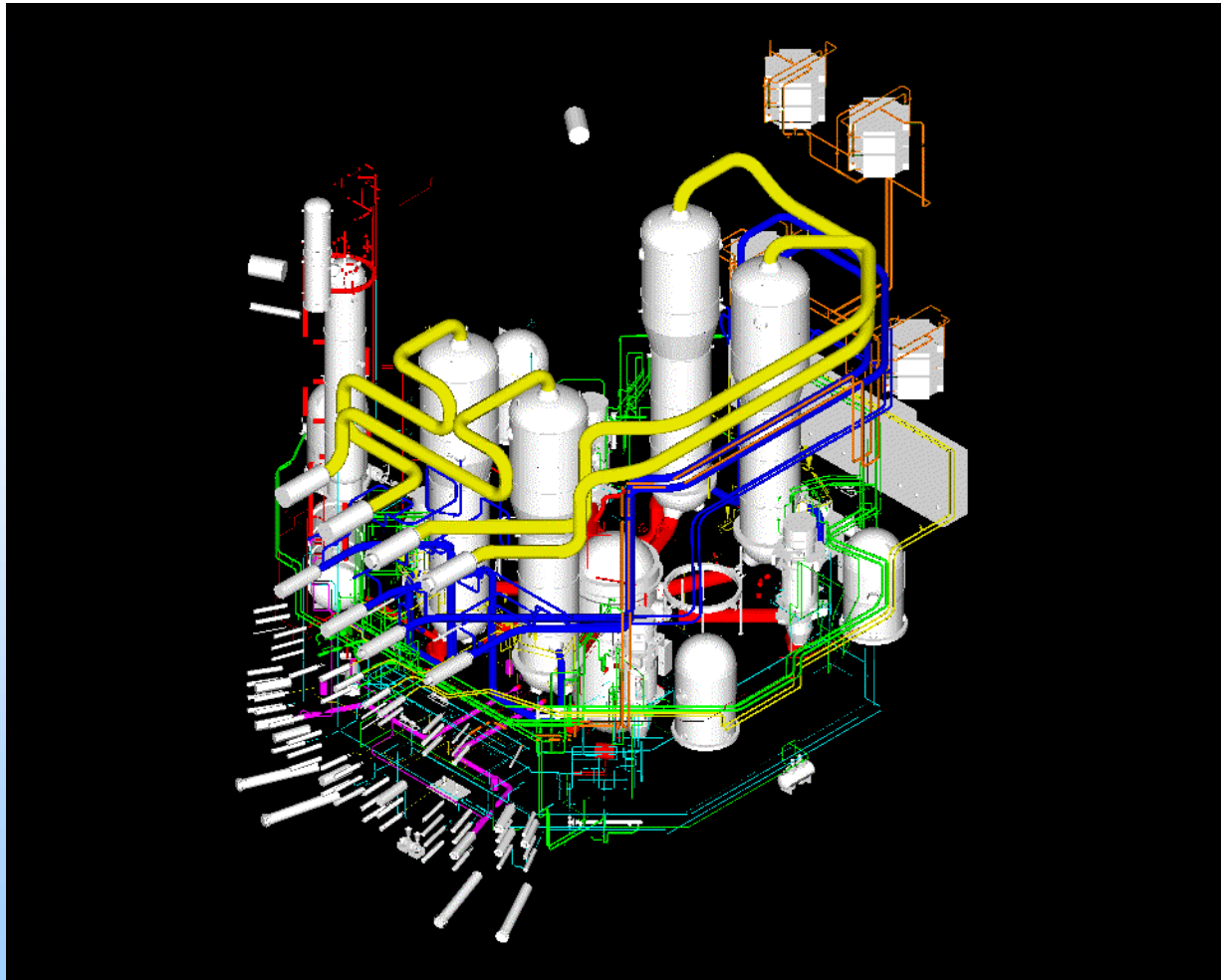


CAD model
constructed by
tracing plan view of
each level



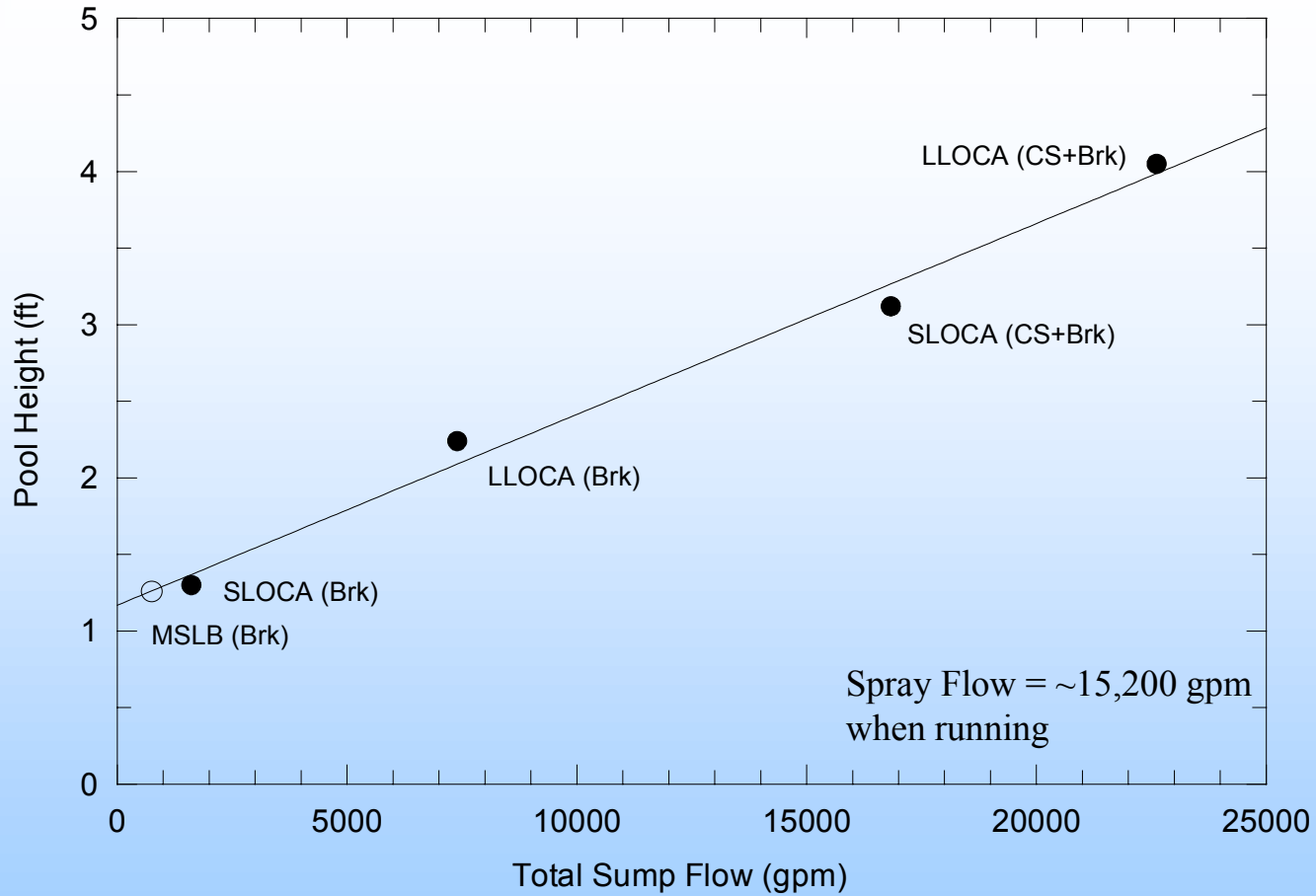


Piping and Equipment Model



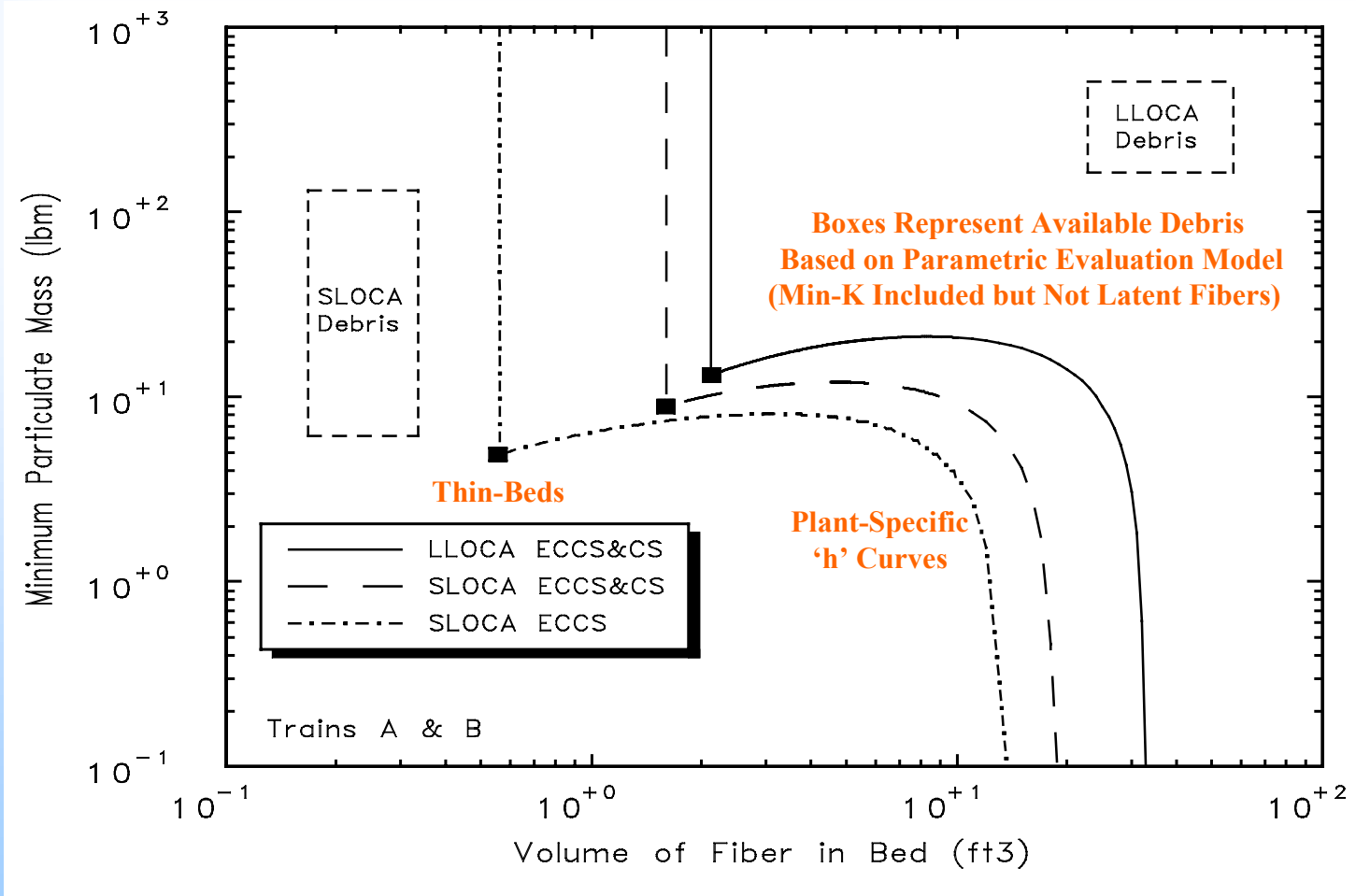


Ranges of Sump Flow





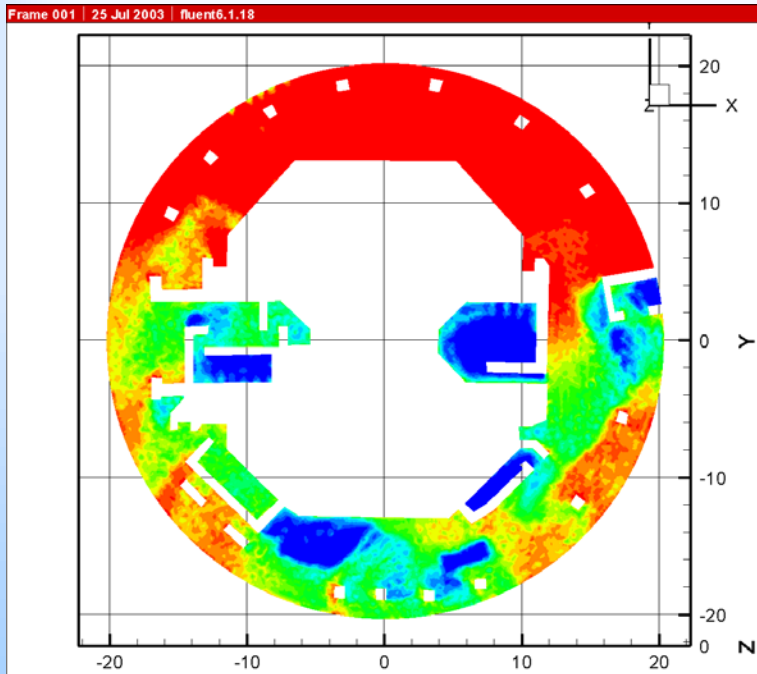
Head-Loss Vulnerability Assessment



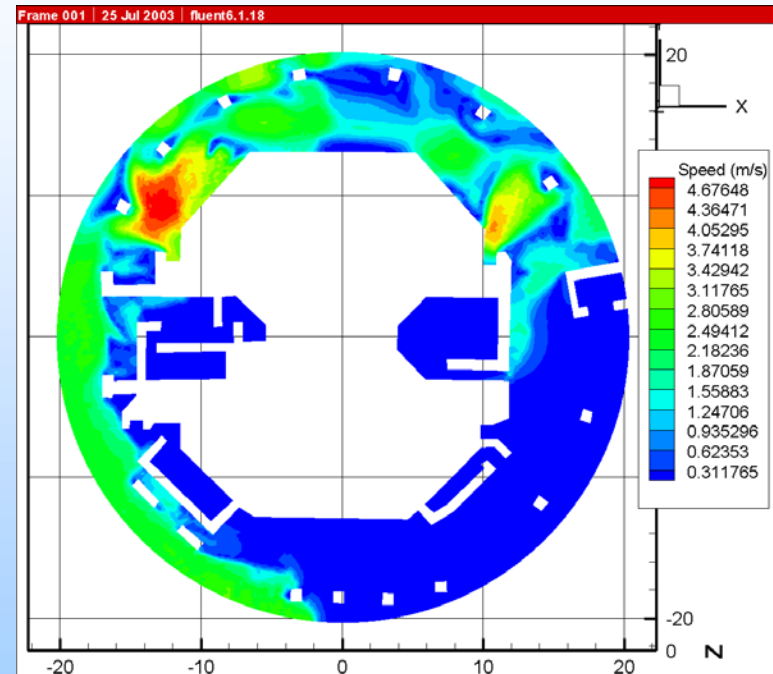


Containment Pool Flow Analysis

- Fluent fill up calculation with 7400 gpm break in upper left quadrant
- CS return cascades begin to hit pool at about 90s. Difficult to compute



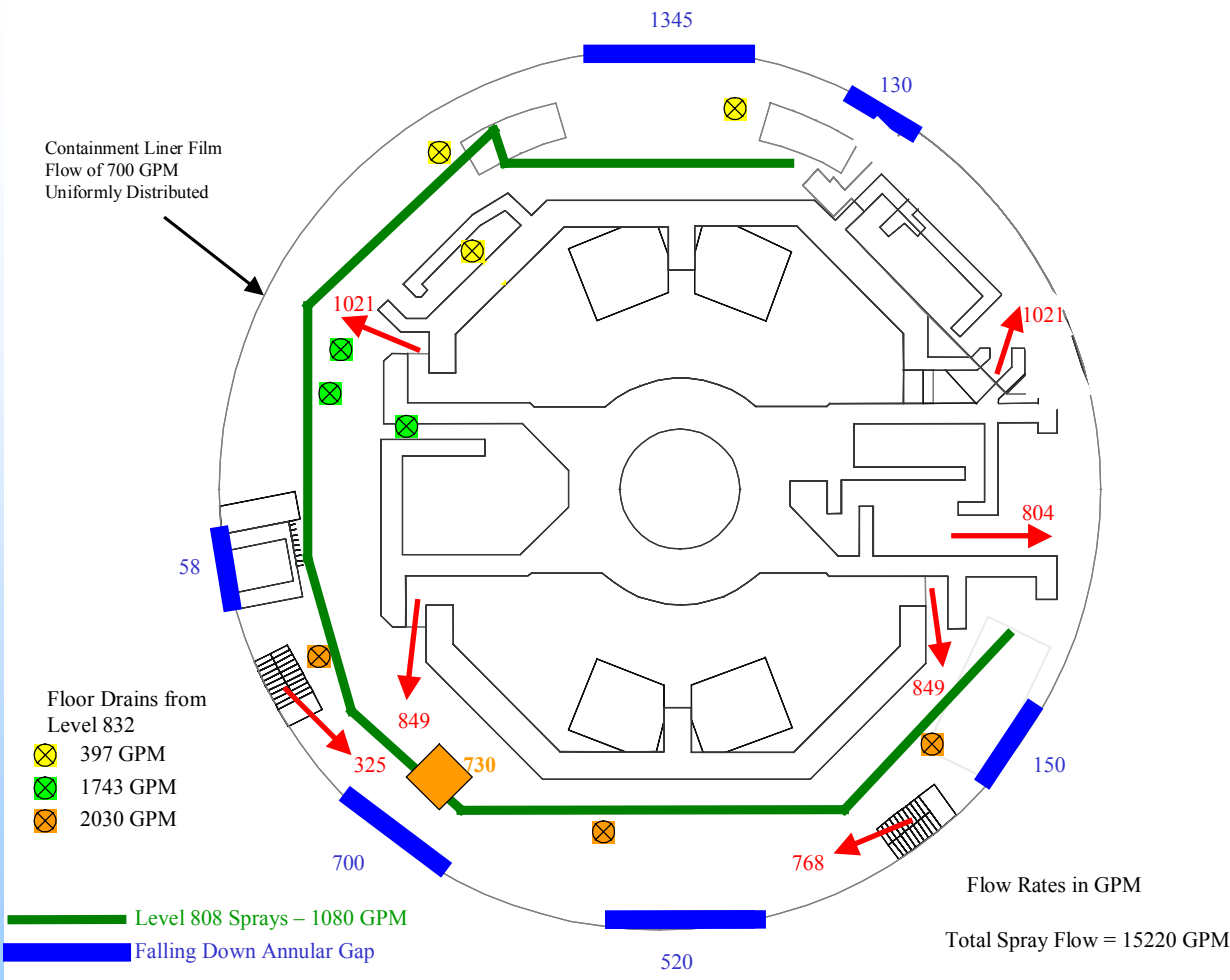
Volume fraction at 90 s and 0.1 m height



Velocities typical during fill up



Estimated Spray Return Cascades





Observations Regarding CFD

- **Good qualitative agreement between CFD models of fill/steady-state velocities and Tank Experiments**
- **Ancillary sources representing containment spray return paths can dominate pool activity**
- **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
- **Uncertainties in location and timing of debris entering pool limit the need for a high fidelity model of debris transport**

Area > threshold velocity proportional to degradation and transport for initial uniform distribution of fill-up phase debris



Transitional Pool Flow Sequence

Event

Characteristics

Break Occurs

Jet impingement, steam expansion, water to bare floor with sheet flow directed away from break. Highest transport velocities. Initial deposition pattern in dead areas and sumps.

Sprays Trip

Spray runoff accumulates and washdown begins, Sheet cover complete. Sumps fill via directed flow. Deposition pattern modified by splash zones

Max Spray Return

Maximum energy in minimum pool depth (~inches). No directed flow. Pool begins to fill. Max degradation. Pseudostable deposition pattern develops.

Lower Sumps Full

Directed flow begins to develop. Deposition pattern modified in vicinity of sump. Suspended debris collected very quickly. Steady-state flow pattern established.

Dead sump sheltering is only significant sequester

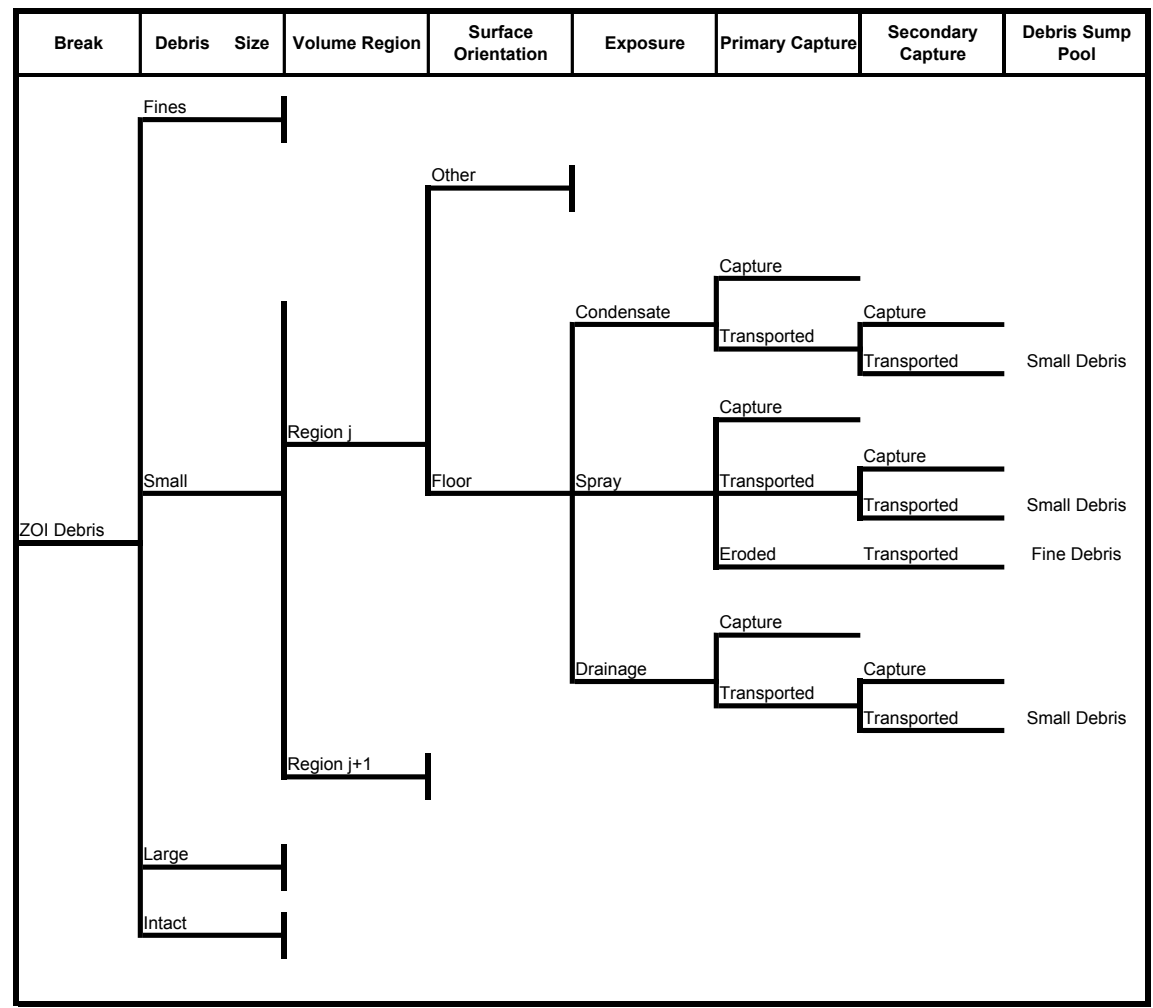


Key Transport Test Observations

- **Cal-Sil and fiber were able to form a thin bed on a 1/4-in mesh vertical screen at nominal approach velocity**
- **Fiber flocks that enter turbulent splash zones are effectively shredded to transportable sizes**
- **Individual fibers are suspended and continue to collect for many hours**
- **Shear forces between higher and lower pool velocity zones may be capable of slowly degrading piles of fiber flocks**

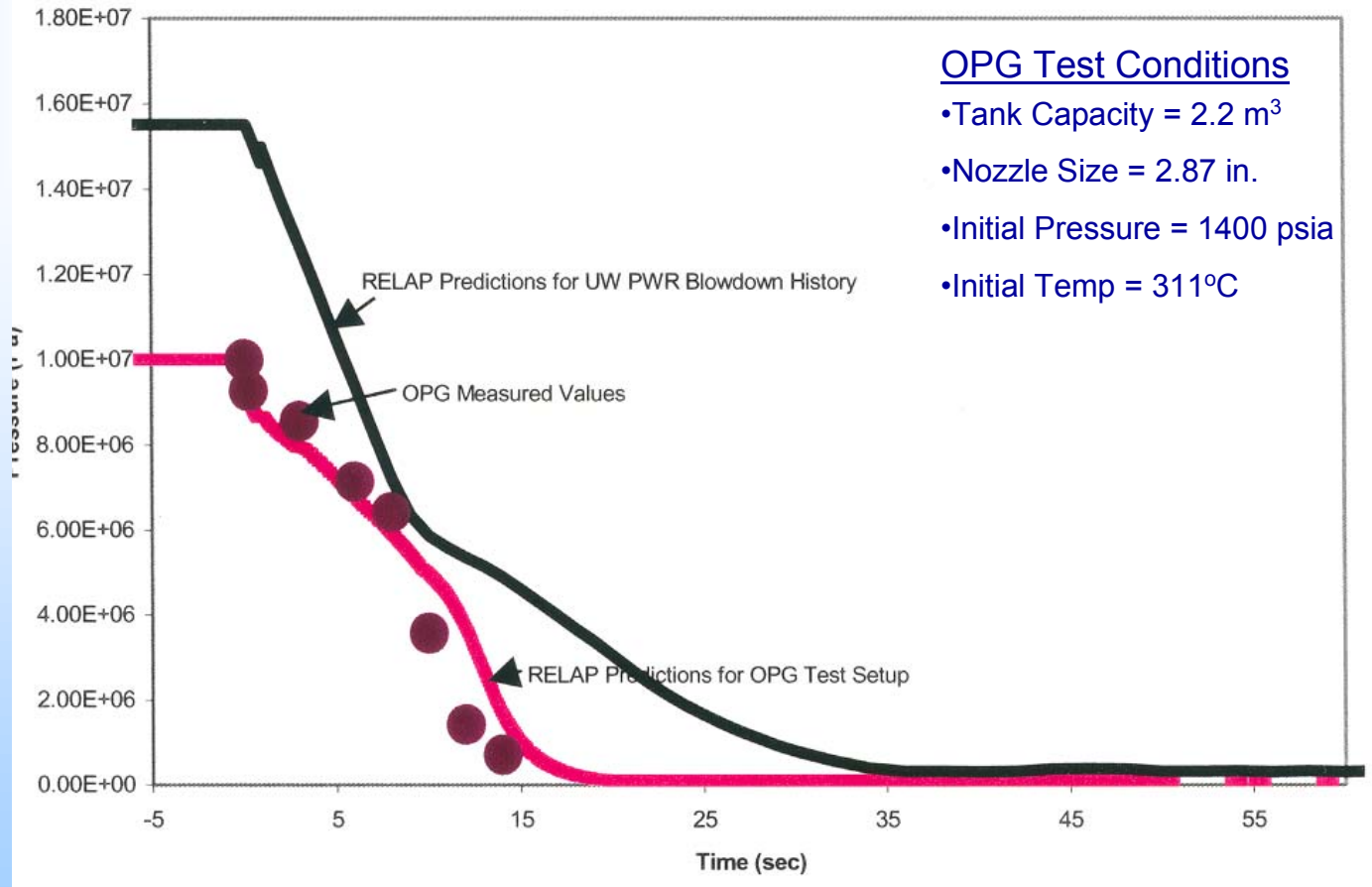


Containment Airborne/Washdown Debris Transport Logic Chart



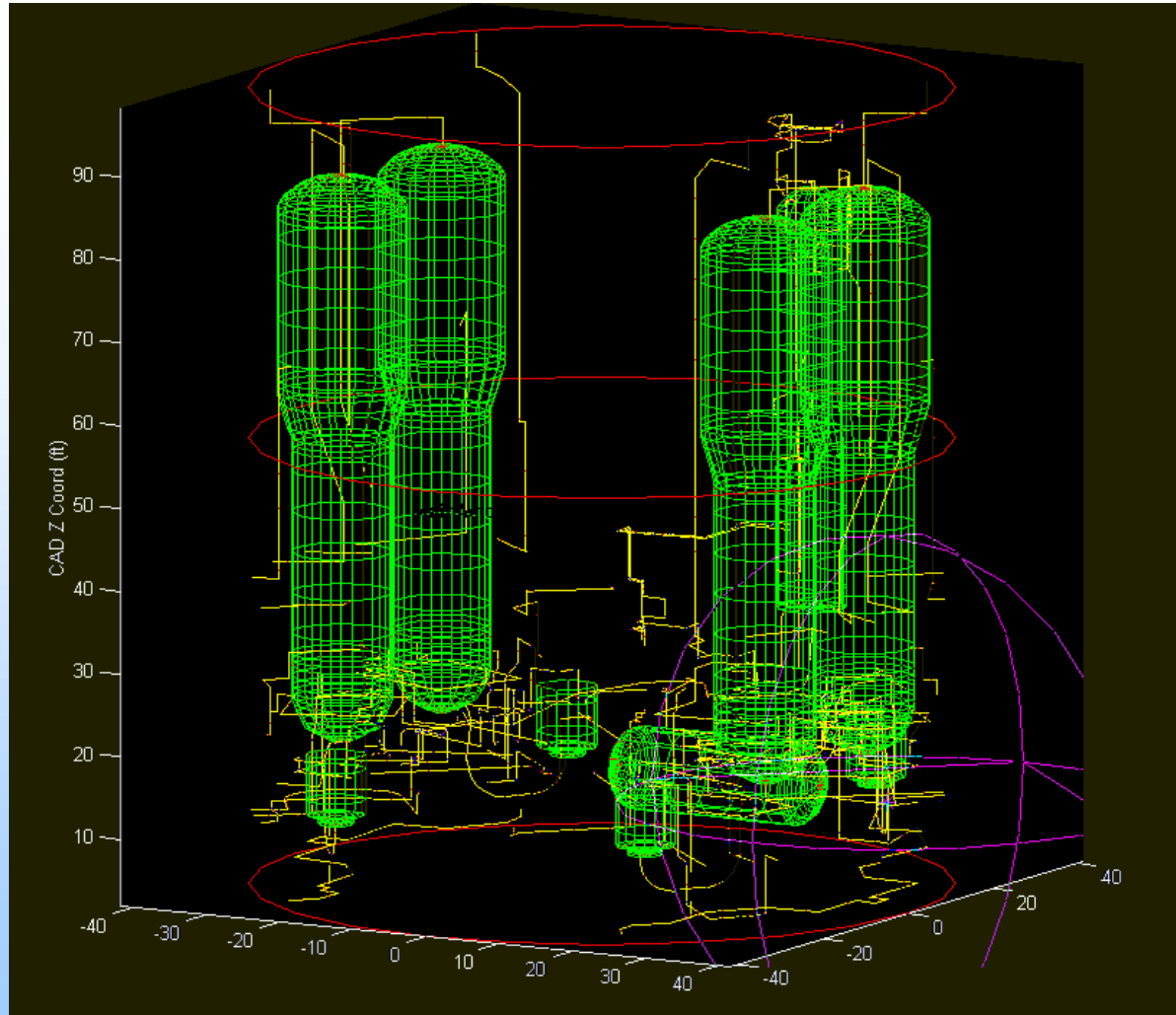


Two-Phase Debris Generation



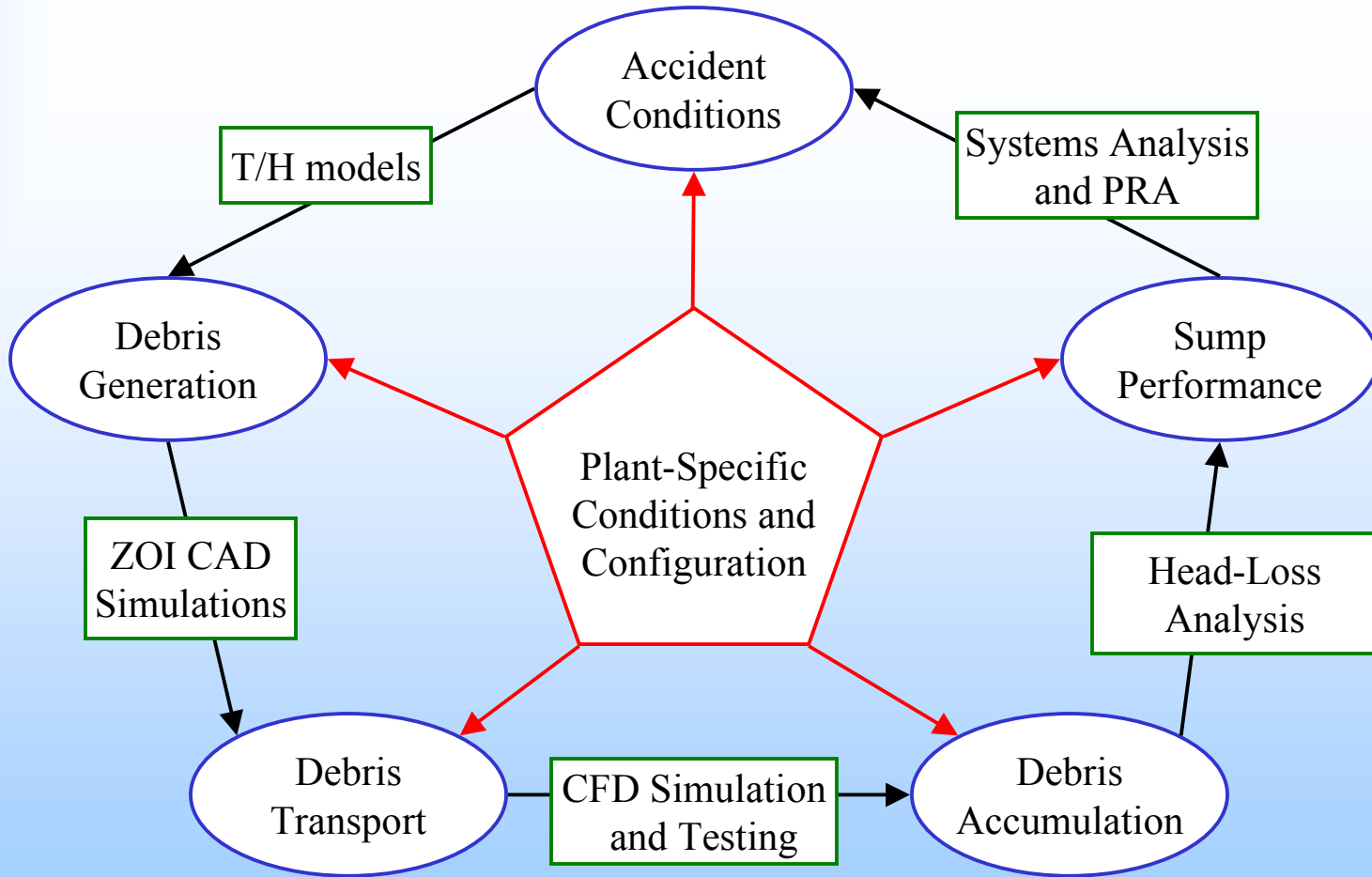


Survey of Break Locations





Integrated Vulnerability Assessment





Required Skill Set

- **Familiarity with containment**
 - Visual understanding of spray and floor water flow paths
- **Understanding of water levels and pump-flow rates as related to EOPs**
- **Competent application of BLOCKAGE or other implementation of NUREG/CR-6224 head-loss correlation**
 - All plants should start by understanding current sump vulnerability
- **Understanding of ZOD correlations to scope break locations**
- **Knowledge of applied insulation types and ability to query/manipulate electronic spatial information**
 - CAD models desirable, but not critical
- **Awareness of debris generation and head-loss data**
 - Identify unique materials and plan for characterization



Methodology Insights

- **Design/adapt screens to defeat thin-bed formation**
 - Transverse bulk and inlet flows to sweep or ‘self-clean’ surface
 - Stacked disks, crenulated plates, etc.
 - Complex filter surface to fragment fiber layer
- **Can mitigate to protect against large debris volumes**
 - Reducing insulation volume
 - Increase screen area with compact high surface modifications
 - Intermediate gates at pool level
 - Divert fill-up flow towards dead sumps/cavities
- **Always maximize pool depth**
 - Especially important for nonsubmerged screens
 - Run sprays for breaks of all sizes?
- **Special attention to cleanliness at pool level for small break/no spray**
- **Fill-up retention in dead sumps is perhaps the only important pool-transport reduction factor**



Mitigation Strategies

Preserve Integrated Safety Plan!

- **Submerge screens without compromising area**
 - Utilizes full NPSH margin of mechanical pumps
- **Avoid horizontal screens below grade**
- **Test and approve back-flush/throttle cycles to dislodge compacted debris**
- **Midstream debris screens to intercept steady-state flow channels**
- **Plant cleanliness programs**
- **Modification of insulation types**
 - With due care not to increase resident loading
- **Active mechanical sweep and collect concepts**
- **Innovative porous media designs on top of existing screens**
- **Multiple inclined screen surfaces that fall away to expose new area**