MELCOR Applications

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HDR V44 Assessment

Introduction

- Heissdampfreaktor facility (HDR)
  - PWR located near Frankfurt Germany
  - Used for a series of experiments
    - Selected for numerous International Standard Problems (ISPs)

- We'll be looking at the ISP-16 experiment
  - Gives us an opportunity to focus on some containment related modeling which isn't always discussed
  - Focus will be on Design Basis Accident (DBA) modeling methodology
  - Provide a comparison against experimental data

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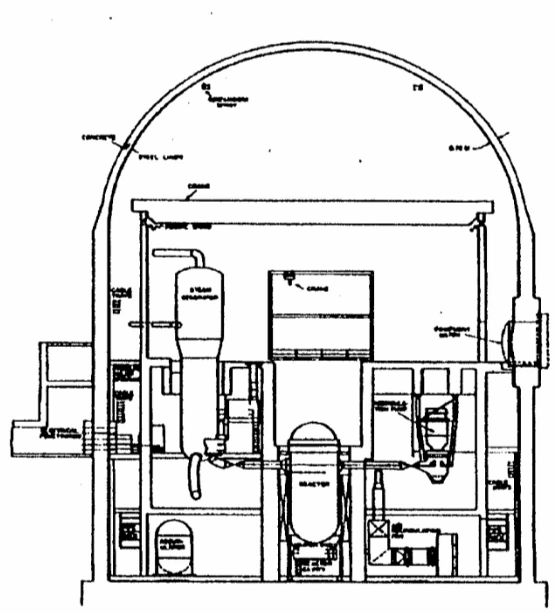
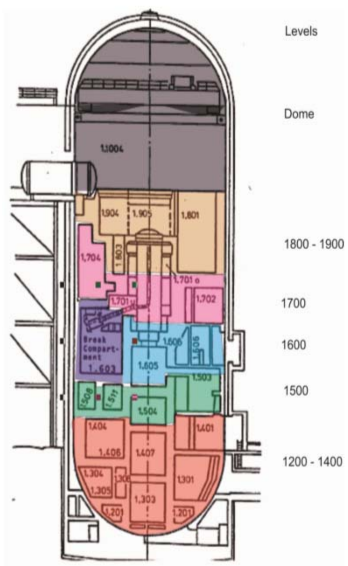
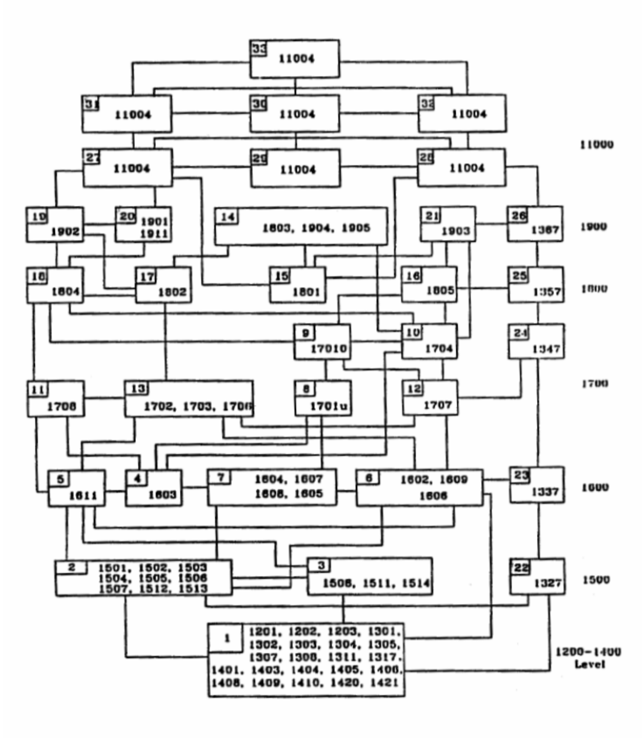
Introduction

- Heissdampfreaktor facility (HDR)
  - US PWR HDR facility Nodalization



Large Dry PWR





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Notable Differences from HDR to US PWRs

- Differences
  - Volume-to-height is smaller than domestic US PWR containment structures
  - Free volume is approximately 1/5th a conventional U.S. PWR containment
  - The break sources are introduced “higher” in HDR than coolant piping within domestic designs

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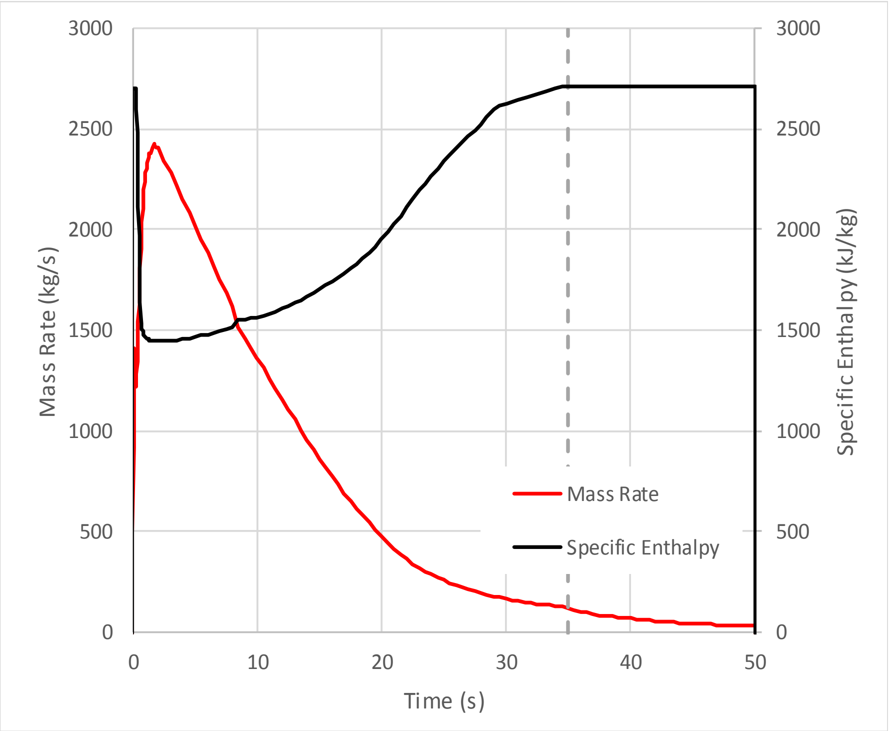
Intermediate Break Source Characteristic

- Intermediate break
- 50s injection source
  - 35s of two-phase
- Recipient volume is small (Cell#4 rm1603)



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Integral Phenomena of Interest

- Two-phase flashing
  - Discuss temperature versus pressure flashing models within MELCOR
- Choked flow
  - Default atmospheric choke flow compared two-phase (dispersed) choked flow for our analysis
- Heat transfer to structures
  - Comparison between the CONTAIN and MELCOR natural convection heat transfer correlation
  - Show sensitivity of peak results corresponding with the treatment of films

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Flashing Model

- Flashing fraction is the fraction of sourced water which becomes vapor
- Pressure Flashing (PF)
  - Record flow path flashing model (FL_FLSH) or water source using WM on CV_SOU
  - Explicit
- Temperature Flashing
  - Traditional CV_SOU Mass source
  - Implicit in pressure solution
  - Thermal equilibration of atmosphere determines whether water is vapor or liquid

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Choked Flow

- Default choked flow model neglects inertial mass of fog in its formation
- A new model for dispersed flow based on the homogeneous flow model (HFM) is available which account for fog mass
- If dispersed fog is important and at sufficient quantities, the maximum fog density term should be increase (SC_4406)

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Fog Allowance

- Fog may be permitted or disallowed
- As liquid water can readily impact the heat capacity of the atmosphere
  - Given the atmosphere field is at thermal equilibrium
- For DBA analysis, conservatism, is commonly imposed where uncertainty is present.
- NoFog option is investigated to demonstrate the effects Fog has on the peak conditions

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Heat Transfer – Convection Correlation and Film Treatment

- Convective Heat Transfer (Natural Convection)
  - CONTAIN: $Nu = 0.14*Ra^{1/3}$
  - MELCOR: $Nu = 0.10*Ra^{1/3}$
- Film Modeling
  - Impose a constant film depth model where depth exceeding value is drained
    - 50Micron
    - 100Micron
    - 500Micron
  - Dynamic film model
    - Dynamic film drainage

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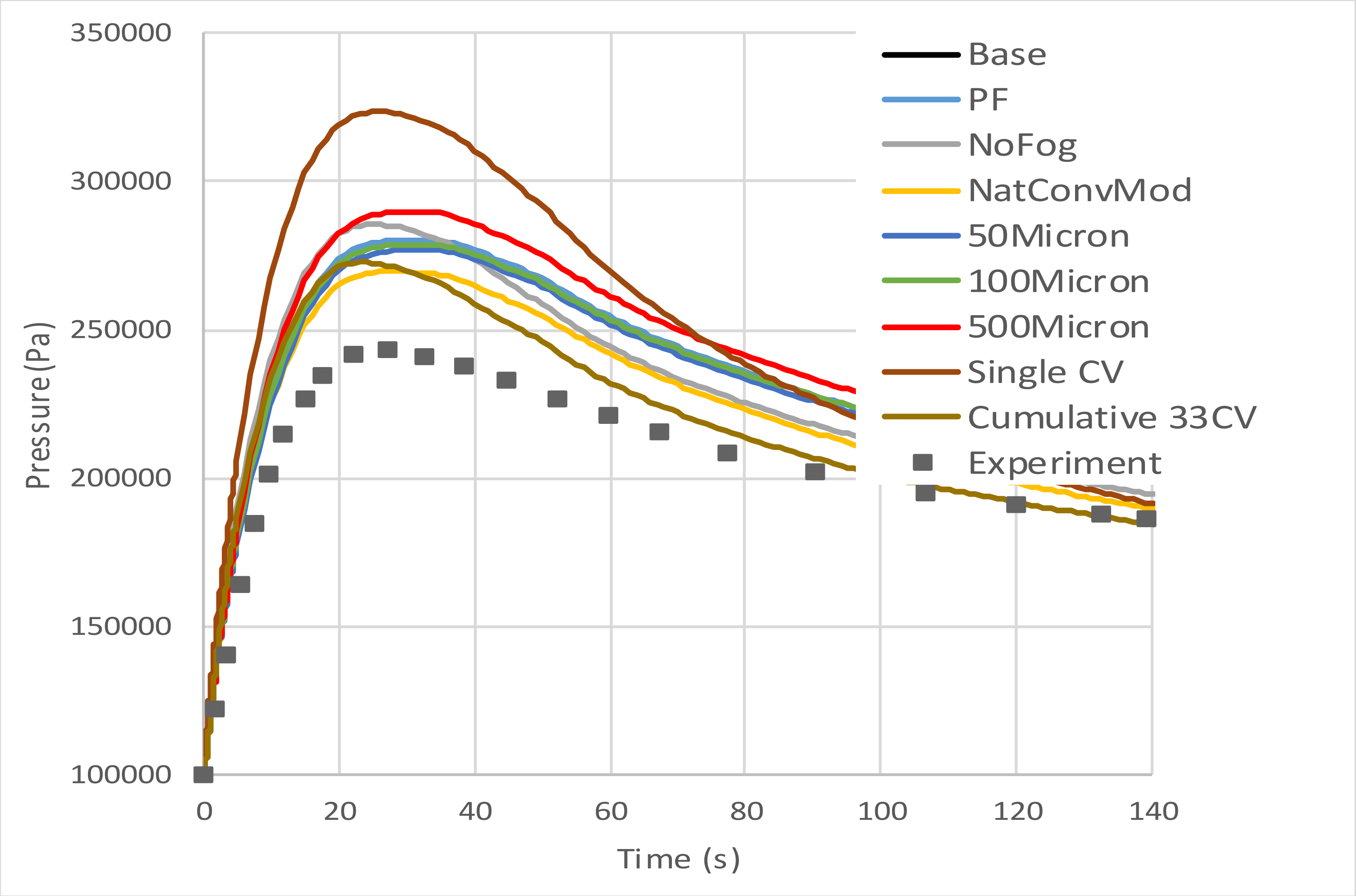
Senstivities – Pressure Response



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Pressure Results

- TF model in the Base Case is nearly identical to the PF sensitivity.
- NOFOG reduces the energy capacitance of the atmosphere and results in higher peak pressure.
- In depth review of the HFM sensitivity shows only a few more computational cycles were computed to have experienced choked flow than the Base Case resulting in no meaningful difference.
- Film depth varies the resistance for heat transfer to heat structures, thicker film is permits greater peak pressures.
- Adjustment of the natural convection heat transfer correlation to represent the CONTAIN implementation reduces peak condition given the 40% increase to the computed heat transfer coefficient.
- Single CV representation permits a very different treatment of local effects for various models. Flashing is impact by the well-mixed containment representation permitting greater disparity between the injected water and the local condition, increasing the flashing fraction. Condensation on heat structures must contend with ever present non-condensible gases in the single CV, whereas physically the rooms near the break site are readily evacuated by incoming steam and condensation is enhanced to heat structures.

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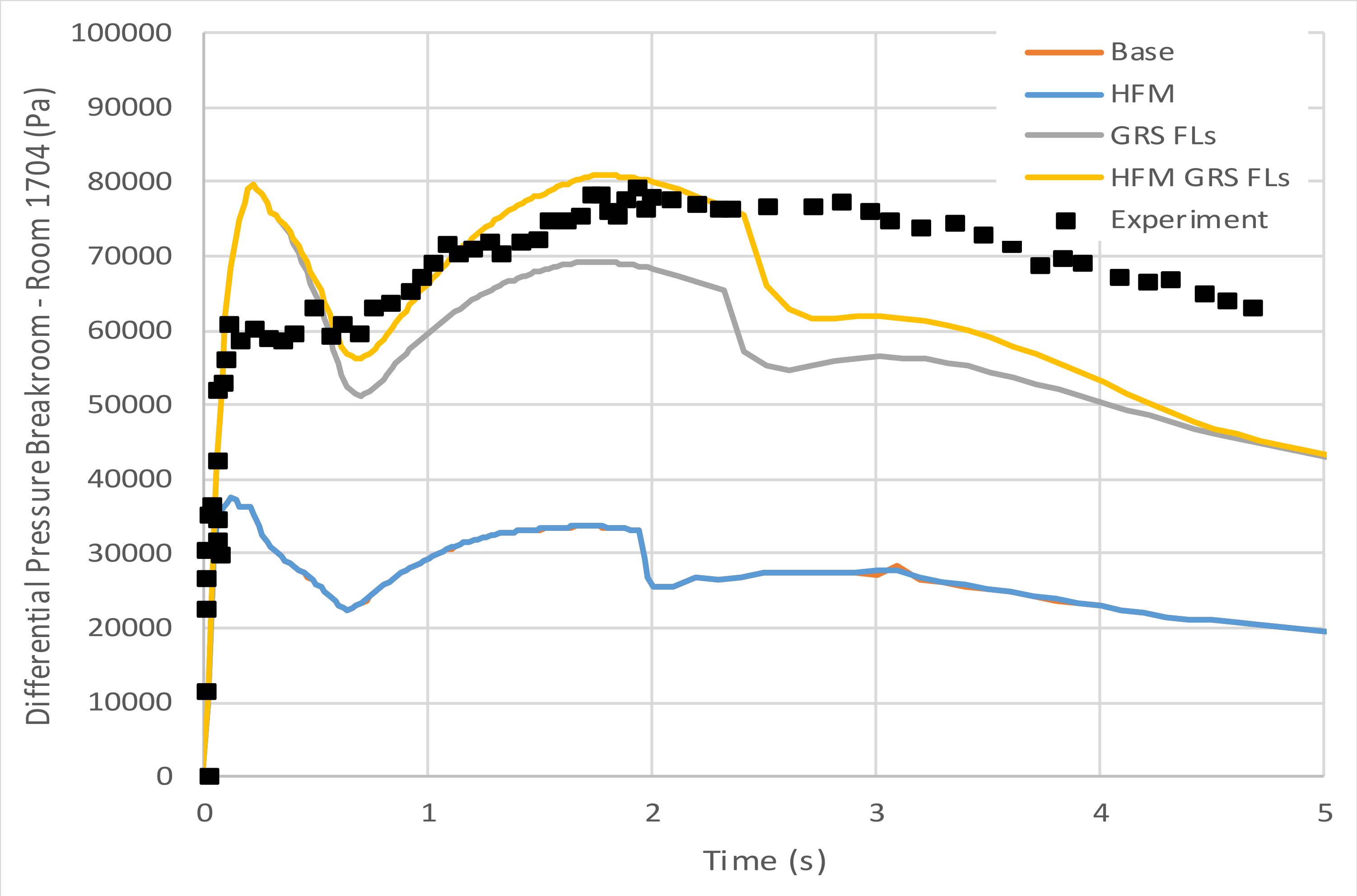
Sensitivities – Differential Pressure Response



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Differential Pressure

- Differential pressure between the break room and adjoining rooms is strongly related to the definition of the flowpaths as advection of material will limit peak differential pressure
- Sensitivity case utilizing the flowpath characteristics from Gessellshcaft fur Reaktorsicherheit (GRS) was imposed on the break room flowpaths to demonstrate better model response is possible using differing flowpath definitions
- Unlike the HFM sensitivity for the Base Case calculation, the duration of sonic flow is substantially longer with the GRS flowpath representation and the computation demonstrates a greater influence when the HFM model is enabled than the Base Case
- Observed discontinuity corresponds with the methodology used for mass transfer modeling. Condensation in MELCOR employs a heat-mass transfer analogy with a dependency on the non-condensible gases being present. The break room evacuates nearly all non-condensible gases. MELCOR changes to a pure steam condensation treatment when the partial pressure of vapor exceeds 99.95%. This results in condensation being limited by conduction, enhancing condensation rates. A more physical representation could smoothly transition this enhancement.

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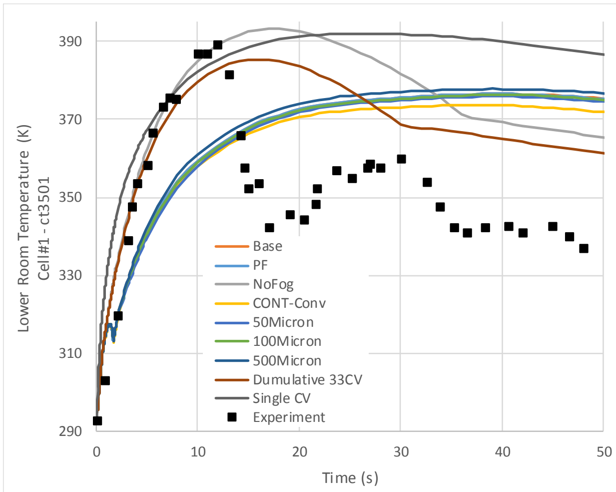
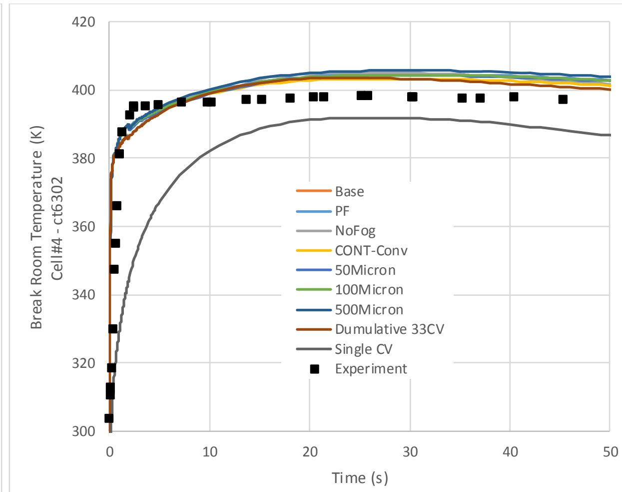
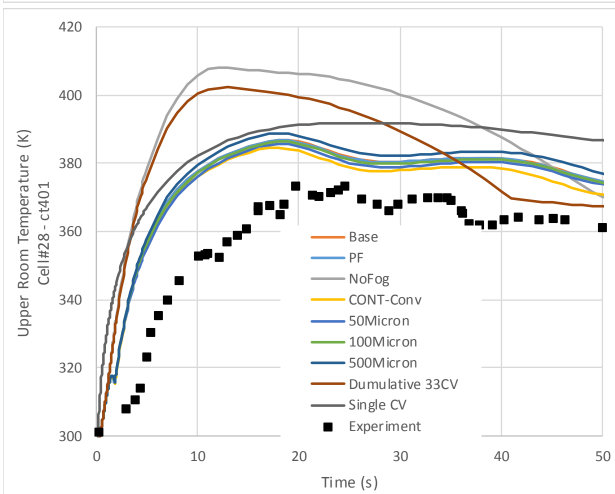
Sensitivities – Local Temperature Response







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Temperature Results

- When present, the discontinuities are a product of local superheat.
- The sensitivities which restrict fog formation enhance superheated atmospheres as a result
- Temperature profiles at various elevations give an indirect measure of the overall mixing in the computation
- Again, the HDR facility is not a “good” representation for U.S. PWRs
  - Stratification is promoted by the elevation of the break site near the mid-plane of the facility and enhanced by compartmentalization
  - U.S. PWRs may be anticipated to mix better given low break elevation for large break LOCAs and relatively open containment volumes

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HDR-Conclusions

- For DBA analysis the demonstration of conservatism, previously accept correlations, and adequate representation of the physical phenomena each play a role in the performance of the analysis
- Evaluation of the HDR ISP-16 experiment and common sensitivities provide insight into the imposed conservatisms common to DBA analyses as well as their effects
- This analysis also provided an opportunity to present some less common model adjustment and model behaviors relevant to containment analyses, which may be over-looked in integral power plant analysis

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ISLOCA Modeling Methodology

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Modeling Goals

Model the following aspects

- ISLOCA piping
  - Deposition within the injection piping
  - Revaporization from within the piping
  - Scrubbing of fission products released from ISLOCA break
    - If submerged?

- Ventilation system
  - Correct total volumetric flow rate through the system
  - Fan curve implementation/fan trip logic
  - Filtration models / data limitations / flow losses

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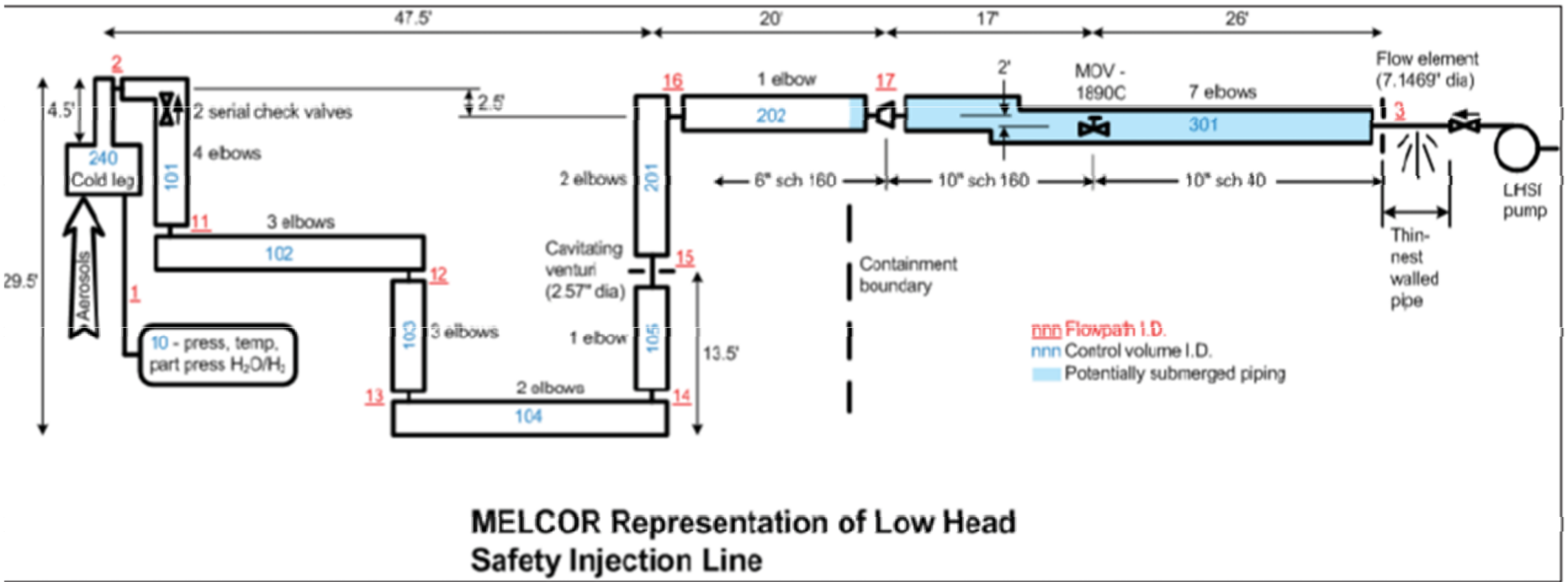
ISLOCA Piping

- Very detailed piping diagram was desired for “best estimate” turbulent deposition



ISLOCA Difficulties

- The piping has various areas, bend angles, orifices, venturis, valves, etc.
- Each reducing fission product inventories “in-series”
  - Detailed diagram representation could capture these local conditions and apply turbulent deposition modeling
- Chief limitation – Courant Limit
  - To properly perform heat and mass transfer, the total permissible volumetric flow rate through any control volume is limited to ½ the volume of a control volume within a timestep (RELAP can disable this limit at a cost to accuracy)
    - The pipe segments are relatively small and velocities within the pipe are high
  - The model runtime increased to unacceptable durations
    - Estimates were 1-month run times
    - Any modeling error found afterwards could cause a rerun

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ISLOCA Strategy

- How do we get the best of a detailed model, but with the speed of the single flowpath?
- We used the same strategy used for most lumped parameter / system level codes
  - Run a detailed model (usually a CFD), but in this case a more detailed MELCOR model
  - Use detailed model to determine the decontamination factors (DFs)
  - Impose these DFs onto the fast running model

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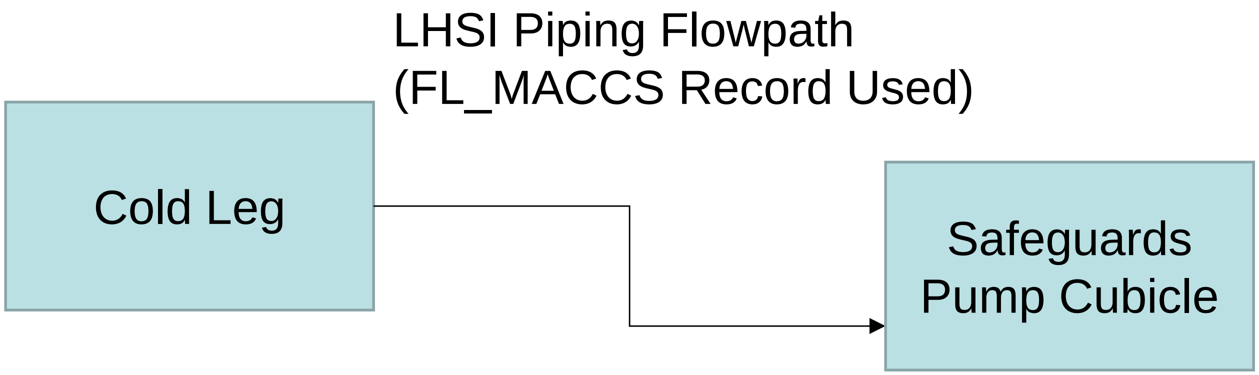
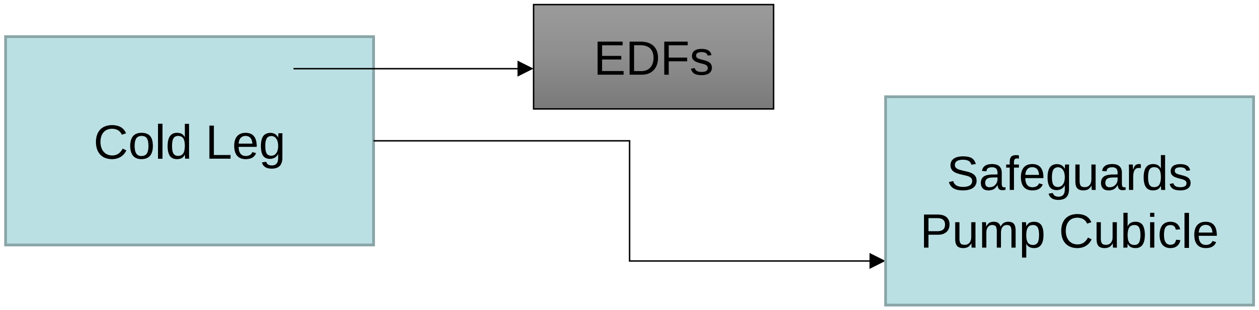
Detailed Plant Model Output to Detailed LHSI Model

- MACCS flowpaths were used in a unique way
  - The MACCS code needs aerosol size distribution to perform its analyses
  - MELCOR flowpath to environment are usually MACCS FLs
  - MACCS flow paths would permit tracking fission product mass and computing the decontamination factors (DFs)
  - However, complications with revaporization led to simplified class specific DFs, rather than size bin DFs



Detailed Plant Model Output to Detailed LHSI Model

- Cold Leg control volume details were written to an EDF
  - All necessary information to replicate the cold leg control volume thermal-hydraulics were written to an EDF
    - Pressure, temperatures, atms. composition, etc
  - We can now use the cold leg properties and the aerosol/vapor masses transported through the LHSI flowpath to support the detailed LHSI model



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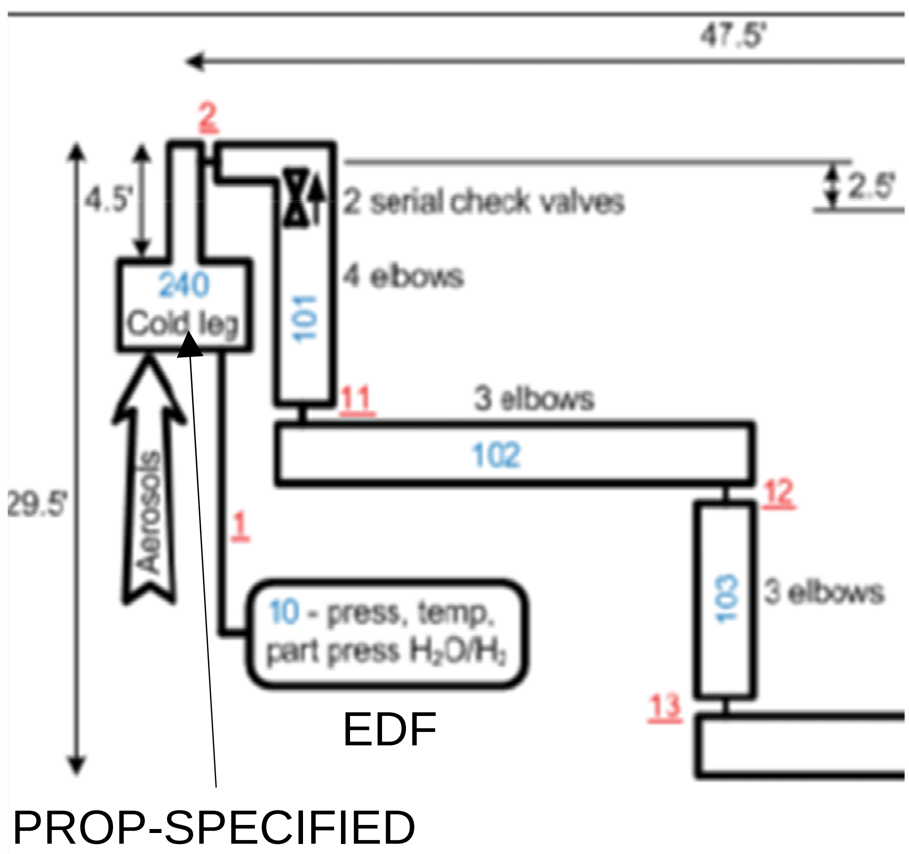
Controlling the Upstream Conditions of the Detailed LHSI Model

- EDF controls a 'prop-specified' control volume
- MACCS flowpath's integral RN classes are sourced into the LHSI model
  - RN1_AS and RN1_VS
- Non radioactive masses were sourced based on assumed distribution (MACCS doesn't track all classes)



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RN1_TURB/RN1_TDS

- Turbulent deposition model uses the following information: piping surface roughness, number of bends, and associated bend angles to determine deposition rates for aerosol size bins
- Model uses a specified heat structure and surface to determine the control volume with the fission products and by default the control volume velocity is used by the turbulent model
- Each control volume within the LHSI pipe model had the turbulent deposition model enabled

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Decontamination Factor

- Decontamination Factors (DFs) are not the ideal measure of removal rates
- DF = Mass In / Mass Out
  - DFs are good if mass removed can never re-enter
  - Mass deposited within the pipe can generate large amount of energy
  - Aerosol may revaporize as the piping temperatures increase and the result is:

  DF = Mass In / (Mass uncaptured + Mass of released material)

  - DF can therefore decrease below 1.0 (i.e., more mass is released than entering at late times)
  - Vaporizing aerosols from HS may begin to condense
  - Vapor condenses on existing aerosols and if the condensing mass exceeds the condensation rate to aerosols, remaining mass condenses into the smallest aerosol bin size

DFs Applied to Classes

- Vaporization and condensation caused instantaneous DFs to fall below one
- Integral size bin DFs demonstrated similar issues
- Integral class DFs were therefore used to approximate the total mass of fission products removed and limitation of the methodology was accepted
- Default decay heat deposition fractions (HS/CVH) assumes “large” control volumes not piping. Energy deposition within the pipe CVH may not be complete, allowing deposition into HS as radiation transverses the CV, and interacts with the other pipe wall. These were adjusted.

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In Summary

- The full plant model was ran so that the inlet conditions of the LHSI piping could be captured, as well as the fission products transporting through the LHSI piping. MACCS flowpaths and EDF writes of mass flow rates and CV conditions were used
  - Various ways to do this
  - Note MACCS flowpath report integral mass and only track radioactive FPs
  - Non radioactive FPs were sourced into the LHSI detailed model
- The separate effects model
  - Using these states parameters, flow rates, MACCS FP masses, we simulate flow through the detailed model
  - Detailed HSs, modified decay heat deposition constants for known geometry, submerged cooling, and turbulent deposition.
  - Based on mass of each class exiting the LHSI pipe integral DFs were determined.

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Rerun Full Plant Model

- Re-run full plant model with DFs
  - The determined DFs for each class were used as filters (RN2 input)
  - RN2_FLT – Allows for the definition of filters on the simple LHSI piping flowpath
  - RN2_CLS – Allows specific DFs to be define for each class
  - Also, water within safeguards building could promote aerosol scrubbing (see FL_JSW and RN2_PLS)
- This three run series took on the order of 5 days to perform
  - The detailed LHSI model still took the same timestep based on the same courant limit, but the LHSI model was still significantly simpler than the full plant deck running significantly faster than the full plant deck.
  - Much more labor intensive for analysts, but the turnaround time for testing and correcting input errors was far more acceptable

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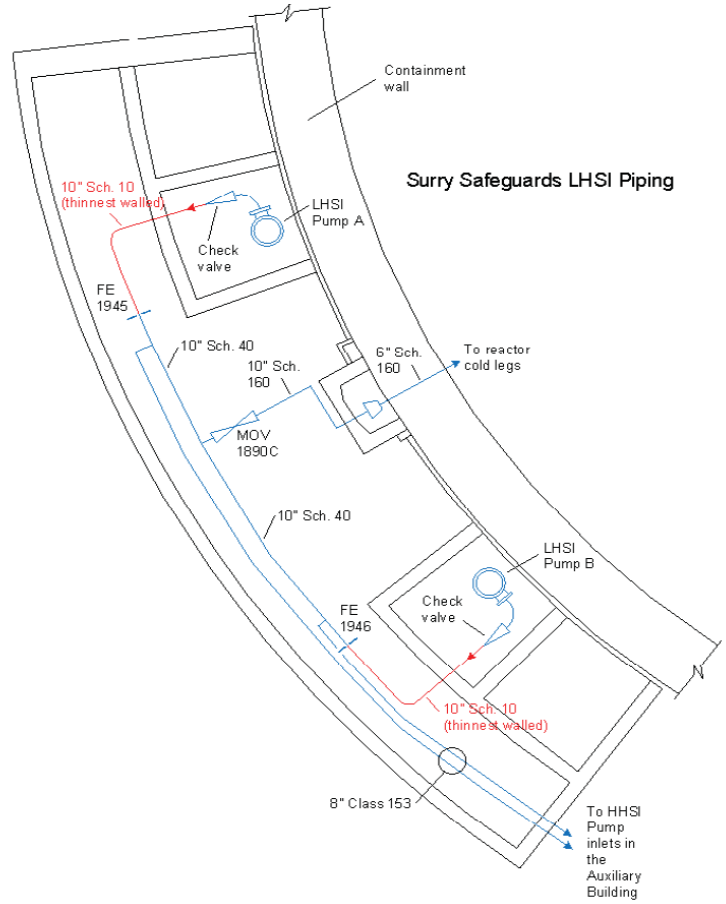
Safeguards Building

- The break site (only one) issued RWST inventory and RCS inventory filling compartments within the safeguards building.
- Operator’s performed simulations to time isolation of the LHSI pump.
  - Determined RWST inventory saved for RCS injection



Fission Products Entering the Safeguards Bldg

- Fission products not deposited within the LHSI piping nor scrubbed by pooled water within the pump cubicle were actively pumped through the safeguards building ventilation system
- Pool drainage within the safeguards building was very important. Since pool scrubbing had a large impact on the fission product available for release, careful attention and modeling practices should be performed
- Pooled water enhances pipe cooling helping to retain FPs by limiting vaporization

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Ventilation System Goals

- Given known system performance and dimensions (known or estimated) impose system performance
- Volumetric flow rates were given
- Total ventilation duct lengths were estimated
- Fan curve was provided
- Loss coefficient were specified to imposed known volumetric flow rates
  - Specified and the safeguard flow rates were then verified with known cubic feet per second for each compartment

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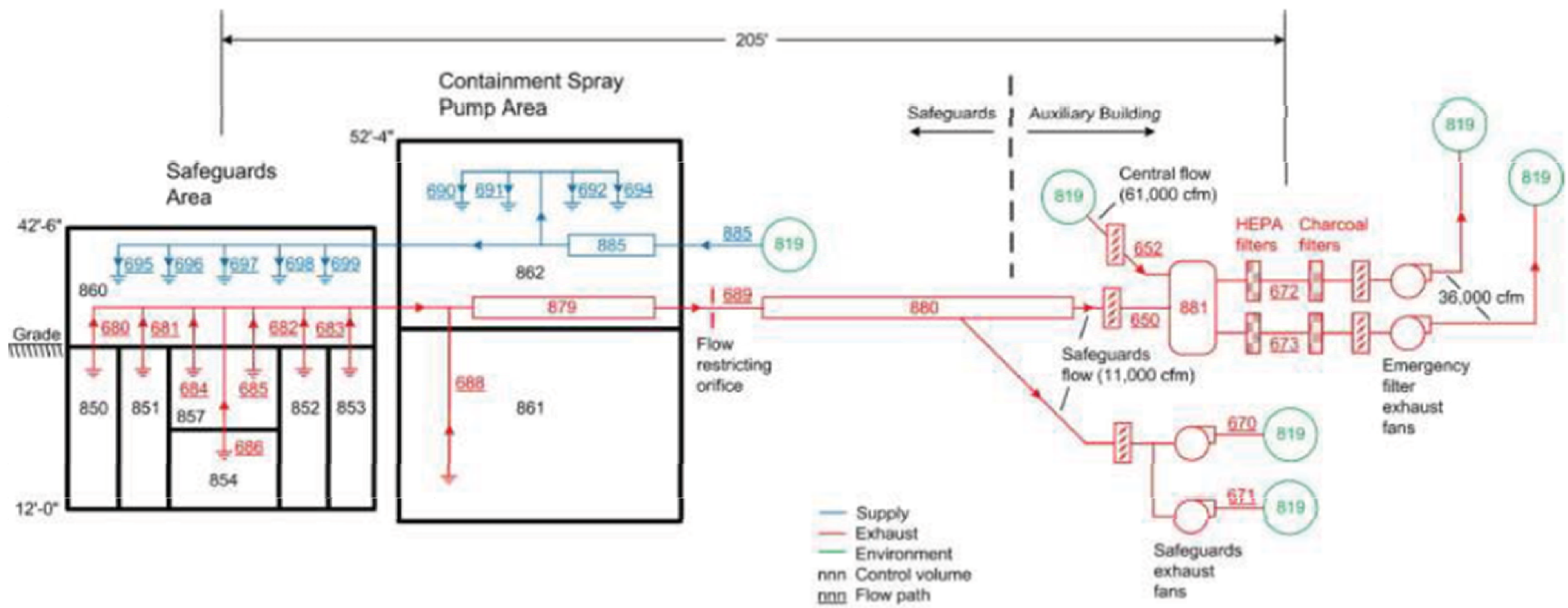
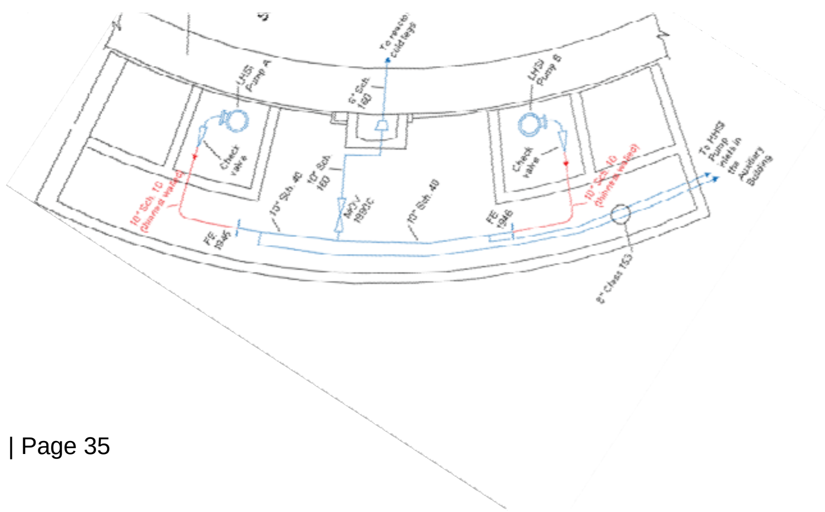
Ventilation System Model





Ventilation System Model

- Two Parallel Fan Set
  - Normal
    - Define but not terribly important
  - Safety
    - Safety train runs all exhaust “air” through the filter bank – comprised of pre-filters, HEPA filters, and charcoal filters
      - Pre-filter was ignored
      - HEPA Filters were model with a set constant DF representing 99.5% retention rate (DF = 200)
      - Charcoal filters captures iodine representing 99.0% (DF=100)
    - System was not design for the amount of fission products that will be introduced during the ISLOCA
    - Significant masses of FP and associate decay heat would load upon filters bank
    - Increasing deposited masses would increase the pressure drop across the filter bank

Filter/Fan Flow Path

- Standard pressure drop across of the filter bank was known as well as the flow rate
  - Flow within the filter bank is laminar. Using the known pressure drop, a supporting hydraulic diameter was determined
  - The laminar loss coefficient (commonly report (based on correlation) as 16 or 64) can be specified by a control function
  - Using a CF allowed for a mass loading correlation to be used to increase resistance as the filter becomes loaded

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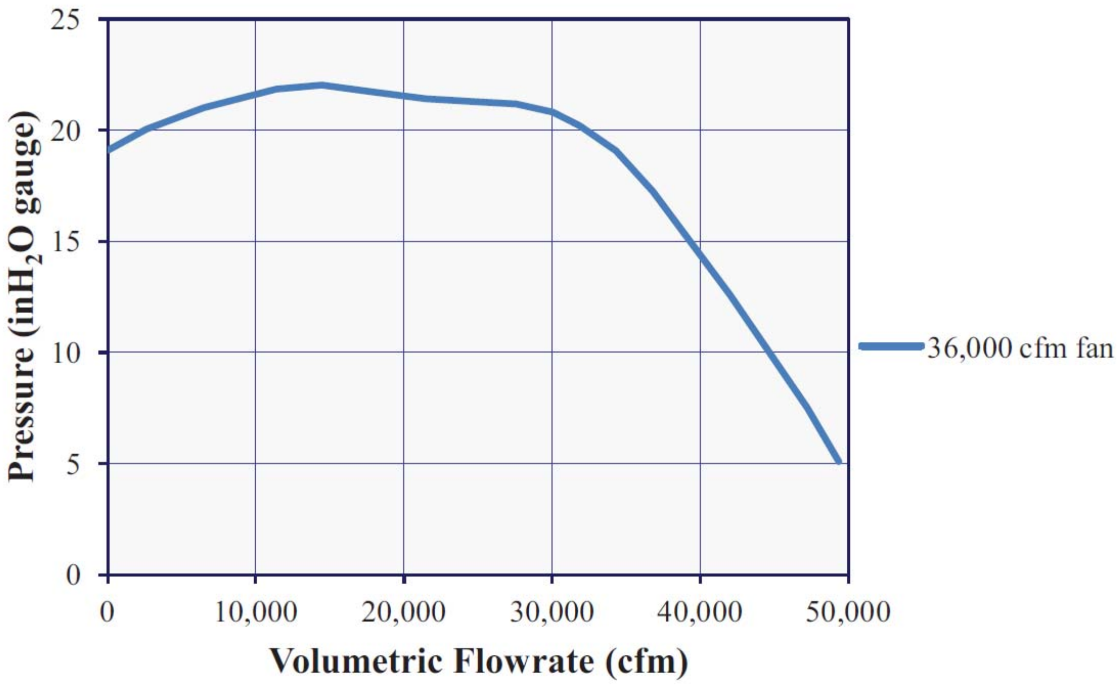
Filter/Fan Flow Path

- The fan curve was specified using a control function to produce the known pump head term



Filter/Fan Flow Path

- With the filter pressure drop, frictional pressure drops, and fan curve defined, the volumetric flow rates were balanced using form losses coefficients
- The ventilation system now appeared to match known performance metrics
- Fan trips were finally specified based on the following
  - Pressure drop across the filter back can not exceed a set value
  - Fan control trips the fan if this condition were to occur
  - This function was modeled using control function to would set the driving pressure from the fan to zero

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Deflagrations

- Given the fission products are exiting through the LHSI, the on going zirconium oxidation is producing hydrogen which is flowing into the building as well.
- No hydrogen controls are in place and local concentrations buildup may result in an explosion
- Deflagrations could destroy the building, destroy the ventilation system, rupture filters, etc.
- The code users need to decide the best approach for each of these possibilities

Conclusions

- Presentation offered an opportunity to discuss Design Basis Accident analysis in added to the Volume 3 of the manual
- Extend some of the workshop material on detailed RN modeling and how it was incorporated into the ISLOCA SOARCA analysis

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