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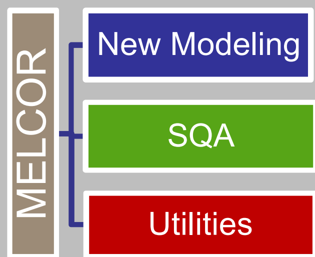

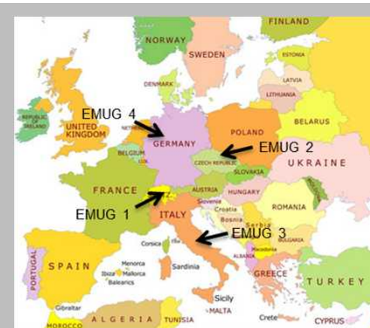

Recent Containment Design Basis Accident Analyses

Presented by Jesse Phillips

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Overview

- Present a review of some recent analyses concerning Design Basis Accidents (DBA).
  - Ice condenser performance
  - Testing new (CONTAIN) mechanistic fan cooler

Ice Condenser Modeling/Performance

- Comparison with CONTAIN results for the Watts Bar (PWR ice condenser containment) DBA analysis.
  - Watts Bar Unit 1 construction initiated built in 1973
    - Sister plant is being finalized for operation
  - Ice condenser containment
    - Stored ice performs passive pressure suppression during loss of coolant accidents
    - Smaller free volume than other PWR designs
    - Segregated containment regions (upper and lower containment regions)

Nodalization

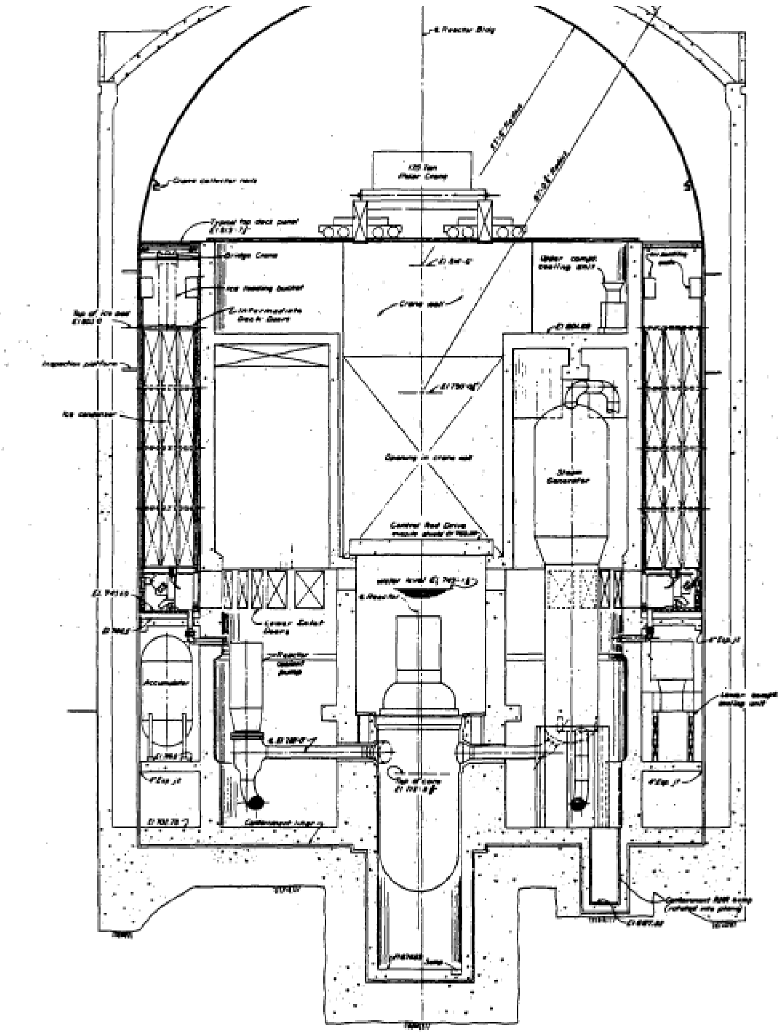

Figure 4.4-13. Section Views of the Watts Bar Ice Condenser Containment (Sheet 1 of 2)

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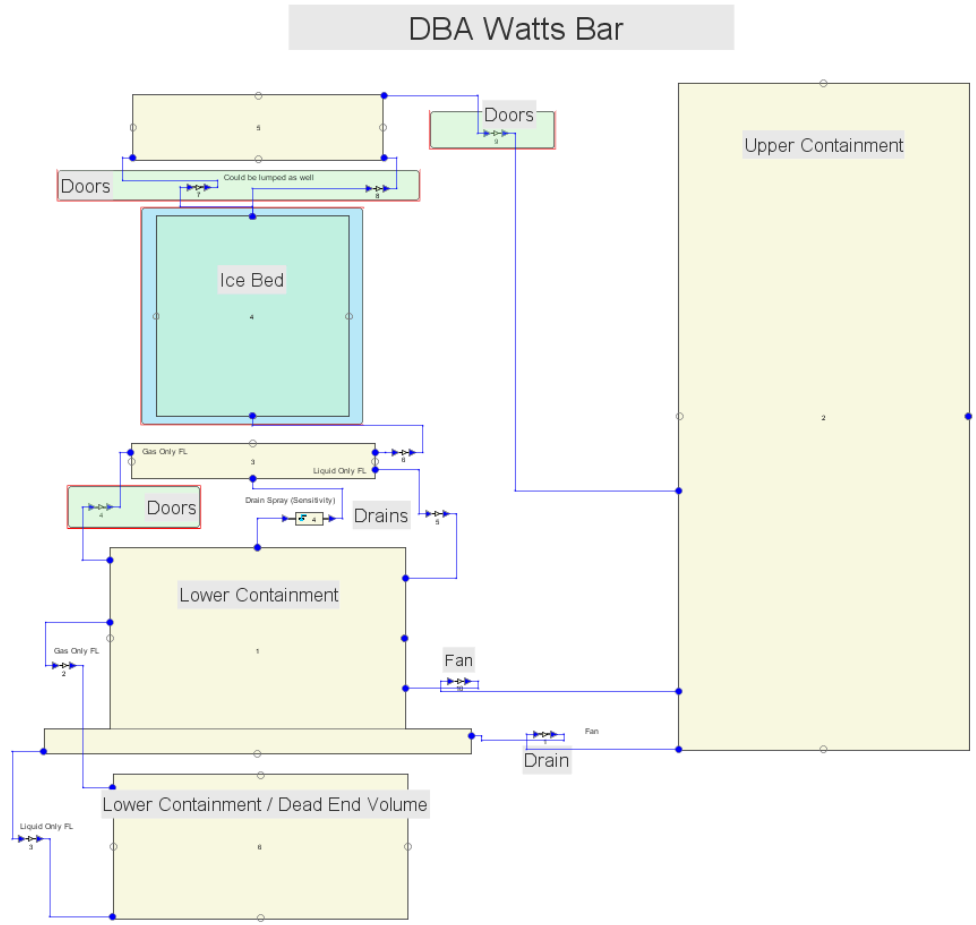


See NUREG/CR-5640

Modeling Ice in MELCOR

- Ice modeling in MELCOR uses the degassing model
  - Degassing model determines a mass source based on energy transfer to heat structures
    - Commonly used for concrete structures
    - Mass source is directed to the control volume
  - Simplified model
  - Requires specification of a “Reaction Temperature Range”
    - Specifies temperature range with which the mass source is released
      - The defined range should be greater than 273.15K to avoid water equation of state issues near the freezing point
    - Released mass observed to exit at the upper temperature from user specified range

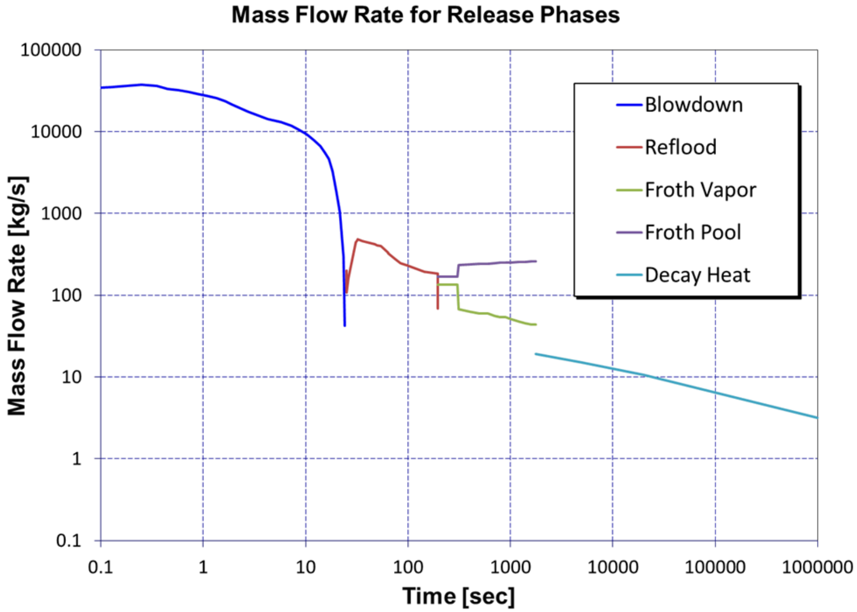
Modeling Ice for DBA

- Enhancements to heat and mass transfer for the ice in DBA study
  - Taken from prior recommendations/observations from the Waltz Mill ice experiments
    - Prototypic volume
      - Very good for peak pressure determination
    - Non-prototypic heat structures or surface areas
      - Introduces uncertain for long-term sequences
  - From experiment observations of the high gas flow through the ice condenser
    - Film entrainment into the gas
      - User input to limit film thickness at a depth of 5.0e-6m (New MELCOR model option added by development staff; EnforceMax on HS_LB/RB)
    - Gas flow induced turbulence within the film layer
      - User specified 10x multiples for the heat and mass transfer rates
    - These inclusions were determined and applied coincidently in early scoping analyses with the CONTAIN code.
      - Shown in CONTAIN analysis to produce conservative peak pressure conditions with these enhance heat and mass transfer enhancements

MELCOR Input

- Ice is blown into the ice baskets so density is less than solid ice
  - Use total ice mass and available basket volume to determine density
- CONTAIN's ice model allows user to specify exit temperature for water (def. 350K)
  - MELCOR melting range specified as 274-350K to be consistent
  - Reaction energy corresponds to sensible heat of water and latent heat of fusion across this range (+10K to heat the ice from 264K to 274K)
  - Heat capacity of the ice material reduced to negligible value
    - Reaction energy adjusts the user specified heat capacity of the structure
  - Increase the ice thermal conductivity greatly (heat transfer should be limited at the film)
- Numerous other modification were made to address general differences between the MELCOR and CONTAIN codes

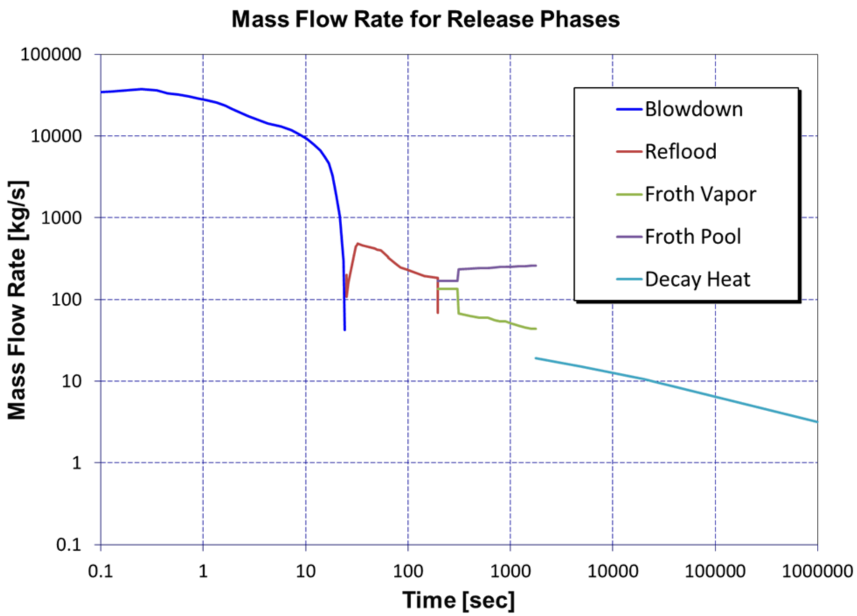
Pump Suction Line Rupture Sequence



Blowdown – Two-phase blowdown of the reactor coolant system

Event	Time, sec	Comment
Pump suction pipe rupture	0.0	Lower compartment break location in the open region
Accumulator flow starts	15.5	Water driven into core by nitrogen pressurized accumulation (nitrogen injection begins)
Assumed initiation of ECCS	24.0	
End of blowdown	24.0	
Assumed initiation of quench spray system	55.0	Spray water from RWST 135 seconds delay to reach full flow of 253 kg/s (linear ramp)
Accumulators empty	56.1	
End of reflood	195.0	
Froth injection from steam generators starts	195.0	Froth boiling in steam generator tubes after core has been quenched
Recirculation fans start	600.0	Flow rate of 18.88 m^3/s
End of Froth injection	1765	
Start of decay heating phase	1765	
End of quench spray water from RWST	2755	
Spray system suction aligned to lower compartment sump	2894	Flow rate approx. 253 kg/s from recirculation spray injection, heat exchanger cooled
Residual spray begins	3600	One RHR train switched over to recirculation spray mode, approx. 126.5 kg/s

Pump Suction Line Rupture Sequence



Reflood – Refilling the reactor pressure vessel generates superheated steam

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Accumulator flow starts	15.5	Water driven into core by nitrogen pressurized accumulation (nitrogen injection begins)
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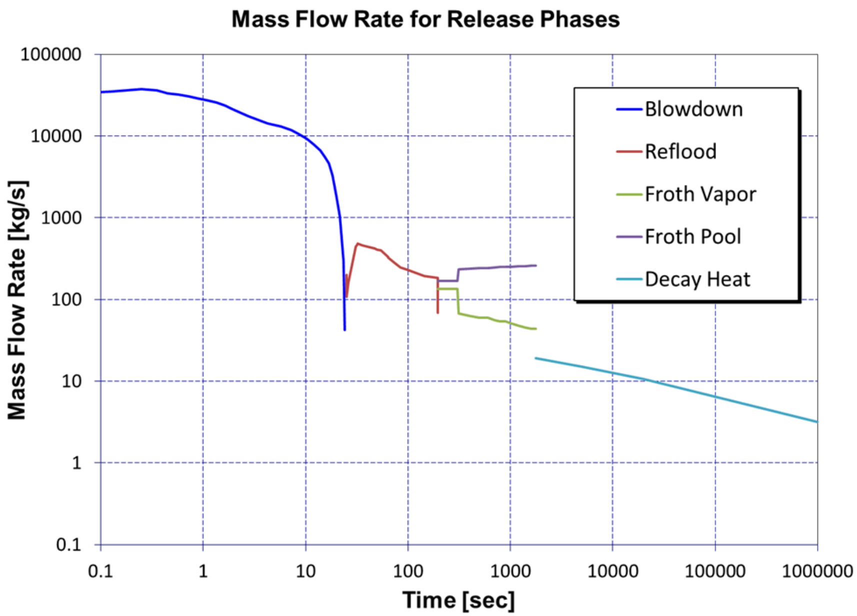

Froth – Reflooded RCS two phases released; energy rejected from steam generators superheats steam

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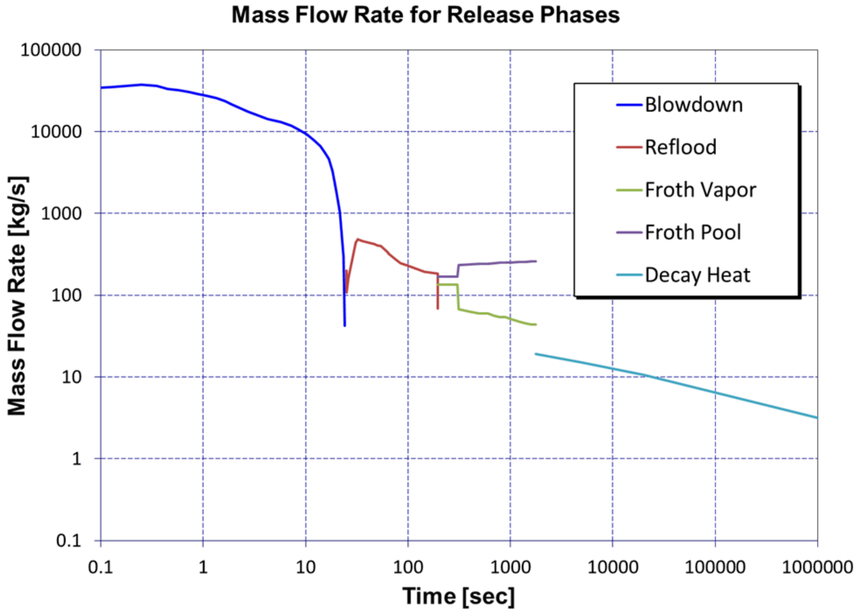

Decay Heat – Vessel level controlled, steam still issuing from RCS

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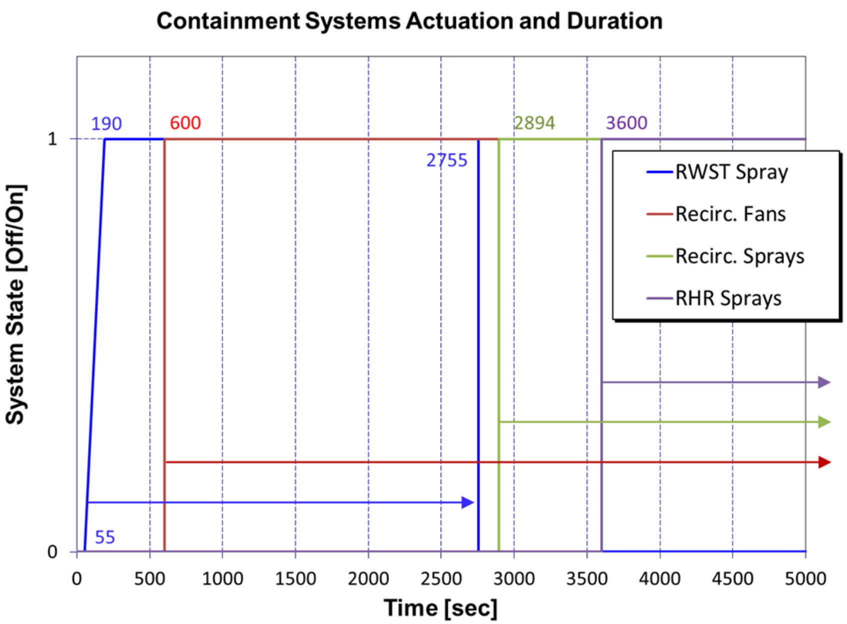

RWST – External spray to upper cont.
Fans – Force flow between upper and lower containment
Recirc/RHR – lower containment sump suction

Refueling water storage tank suction alignment (RWST)
Recirculation suction alignment (Recirc.)
Residual heat removal (RHR)

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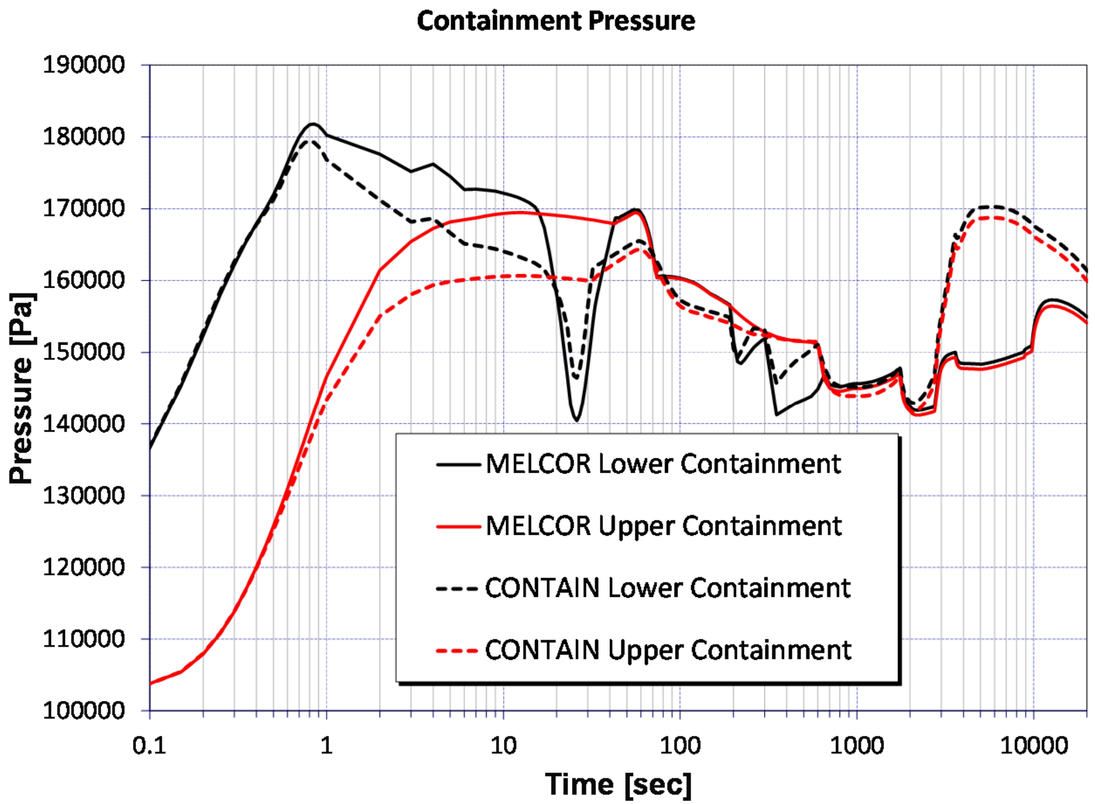
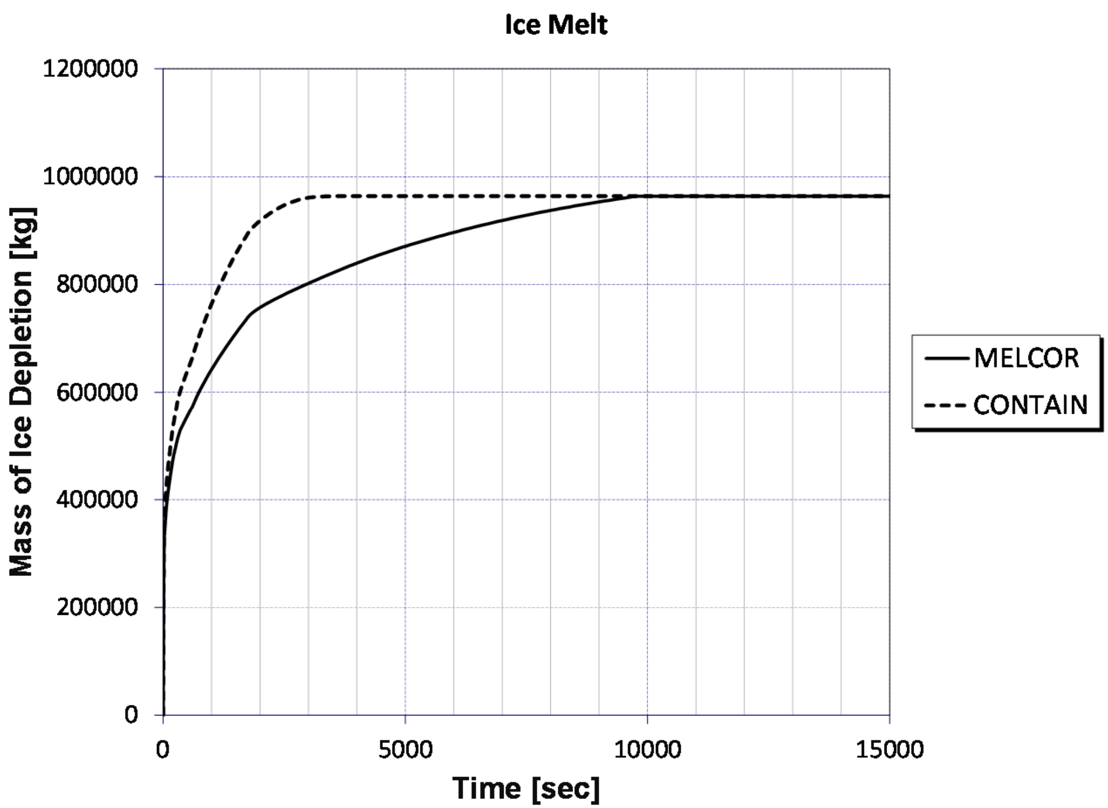
Key Figures of Merit



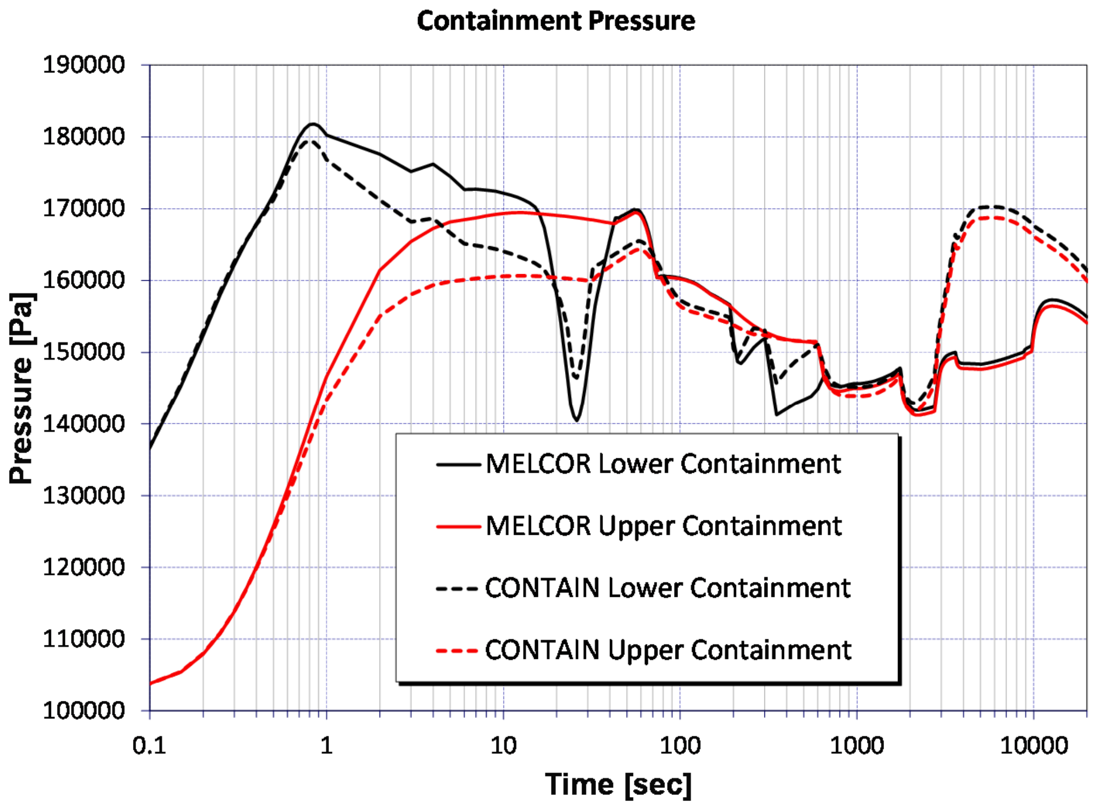
- Good agreement prior to RWST spray termination
  - Driven by total condensation being similar (sprays, heat structures, ice, pools)
- Intermediate door operations allow pressures to diverge

Key Figures of Merit



- More ice has melted in CONTAIN at the time of RWST spray actuation and is largely exhausted

Key Figures of Merit

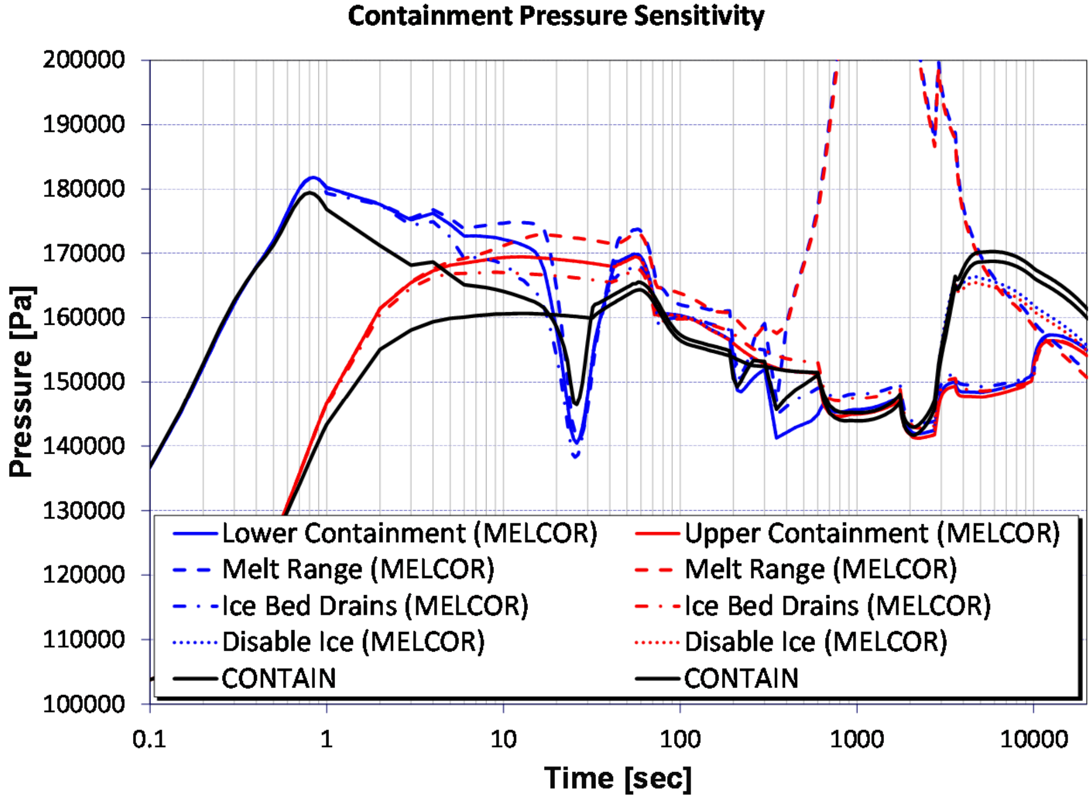


- After RWST spray termination
  - Late-term peak containment pressurization is occurring in CONTAIN
  - Remaining ice (~20%) in MELCOR continues to mute pressurization until melt out around 10,000s

Sensitivities

- Adjust melt range
  - Reduced to a range closer to the melting temperature of ice (274-277K)
    - Reaction energy was also adjusted, sensible heating of water
- Improve drainage from the Ice Bed control volume
  - CONTAIN directs ice melt to the lower plenum
  - MELCOR places it into the immediate volume allow level to build during the blowdown
- Disable ice heat transfer at the time of RWST spray termination

Sensitivity Cases



- Melt Range
  - Reduced heat capacity of the ice produce very early ice melt out and rapid pressurization
  - DBA analyses nominally disable or limit heat transfer to the pools so the exiting 277K water is not as meaningful to pressure suppression
- Ice Bed Drains
  - Improves the early containment pressure results, little other difference with base case
- Disable Ice
  - Emulates ice exhaustion at RWST spray termination allowing late-term pressurization to prevail until RHR/Recric sprays actuate

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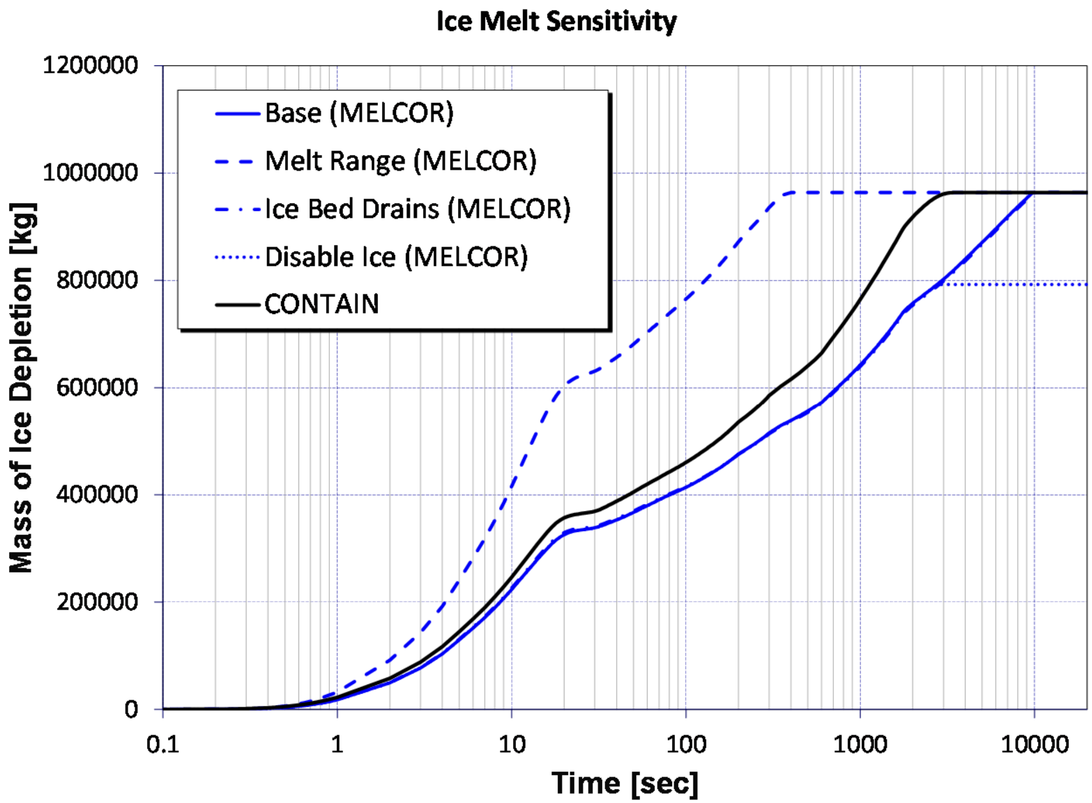

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Mechanistic Fan Cooler

- MELCOR Development Team recently added the mechanistic fan cooler from CONTAIN
- Uses heat and mass transfer analogy
- A simple FCL analysis (of some interest for small mass sources to large volumes…)

Mechanistic Fan Cooler

- Comparing CONTAIN and MELCOR FCL models
  - Accident sequence is a main steam line break in a large dry PWR (see SAND09-2858)
  - Nature of the problem
    - A very large single CV coupled with a slow formation rate of the pool caused an operating fan cooler.

Results of the old MARCH Model

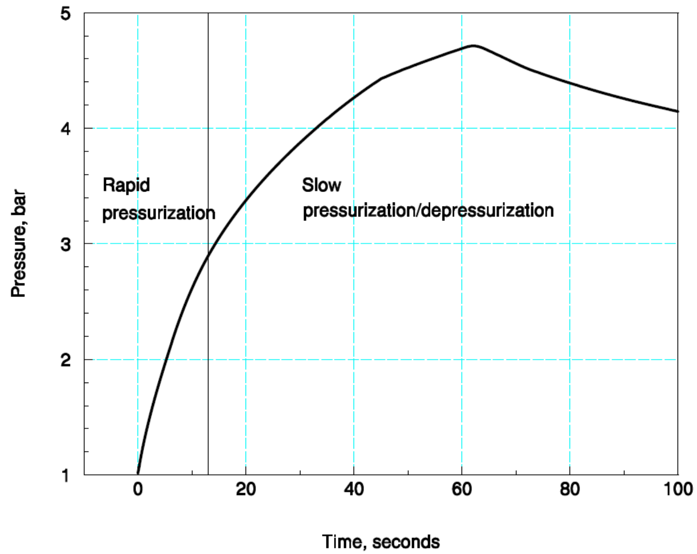


Figure 2.14 MELCOR-calculated containment gas pressure profile for an MSLB event in a large dry PWR containment.

These results were comparable to the CONTAIN Mechanistic models results

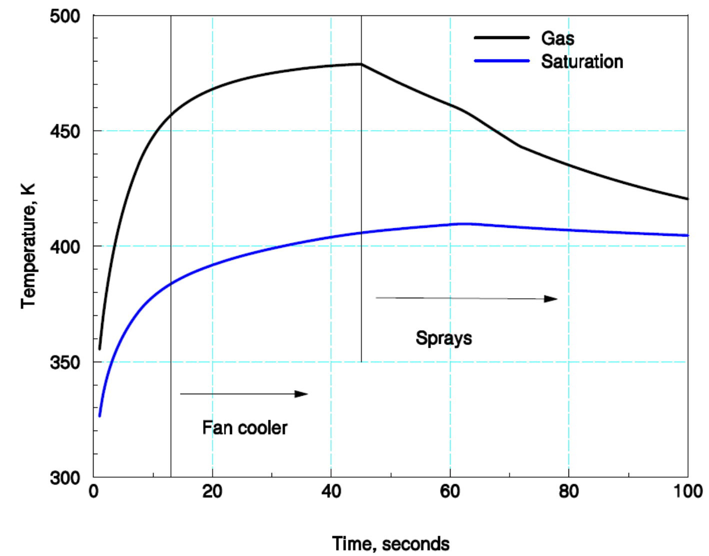
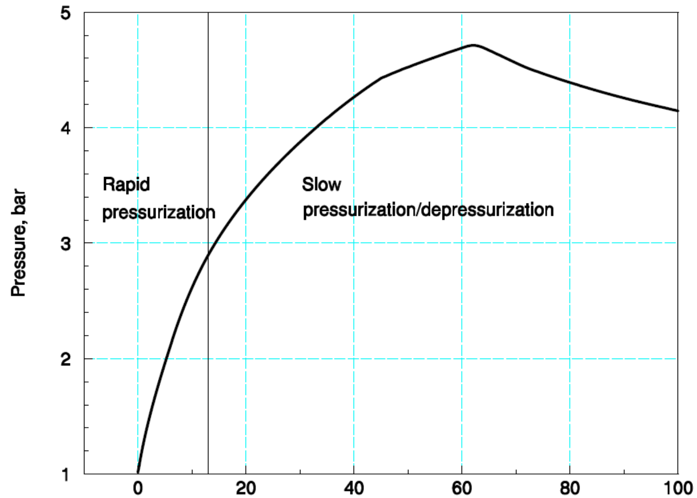
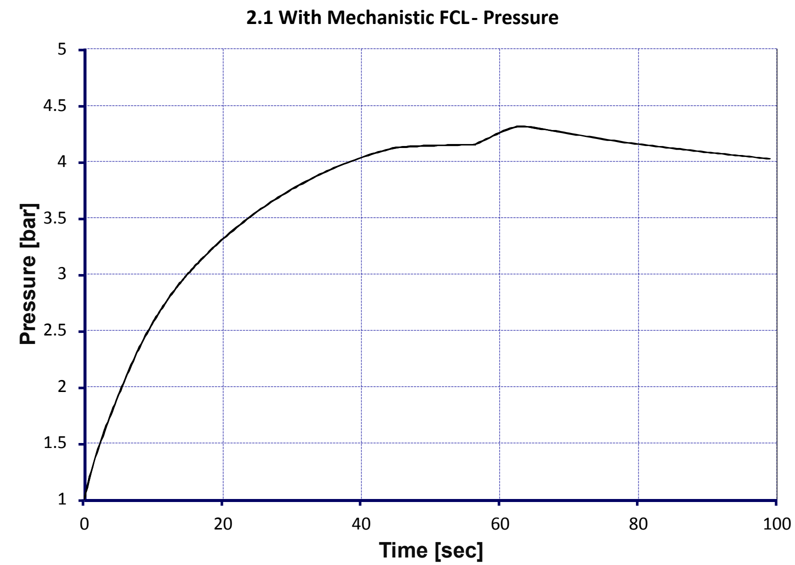
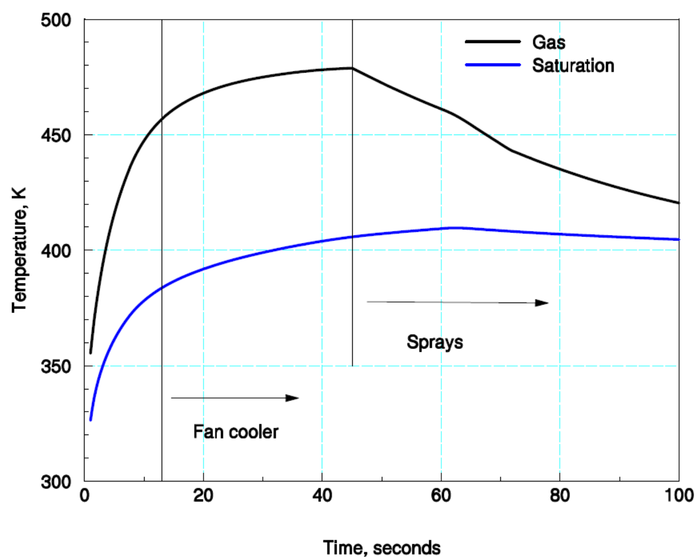


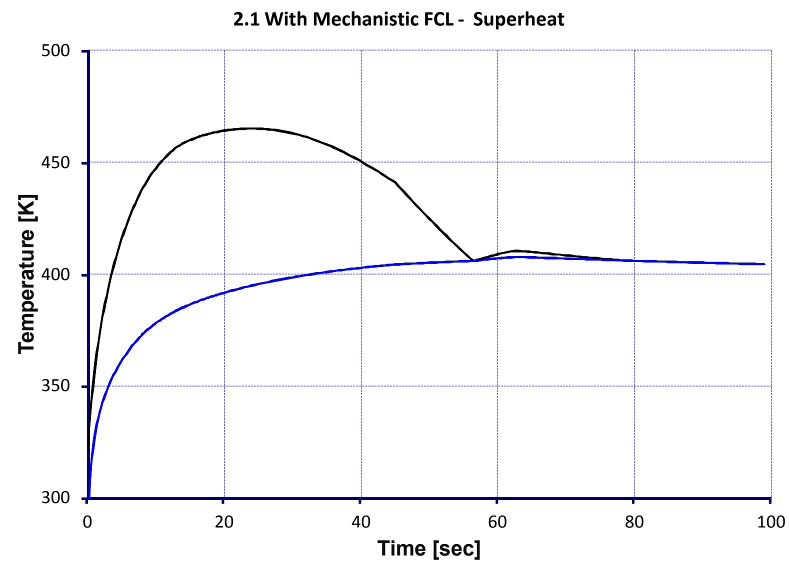
Figure 2.15 MELCOR-calculated containment gas temperature profiles for an MSLB event in a large dry PWR containment.

MARCH / Mechanistic Model





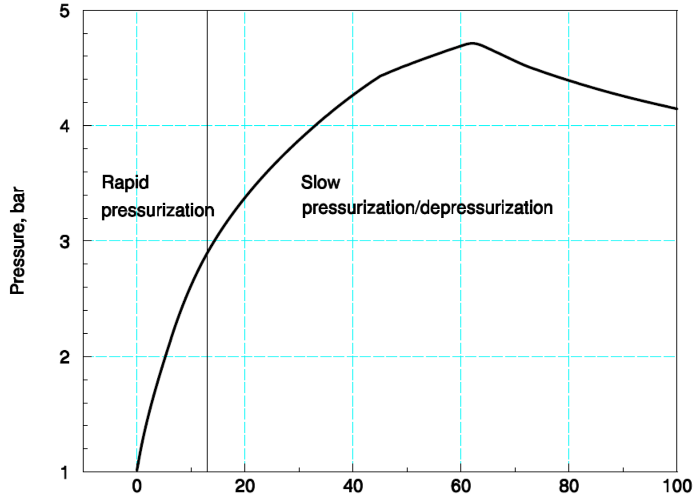




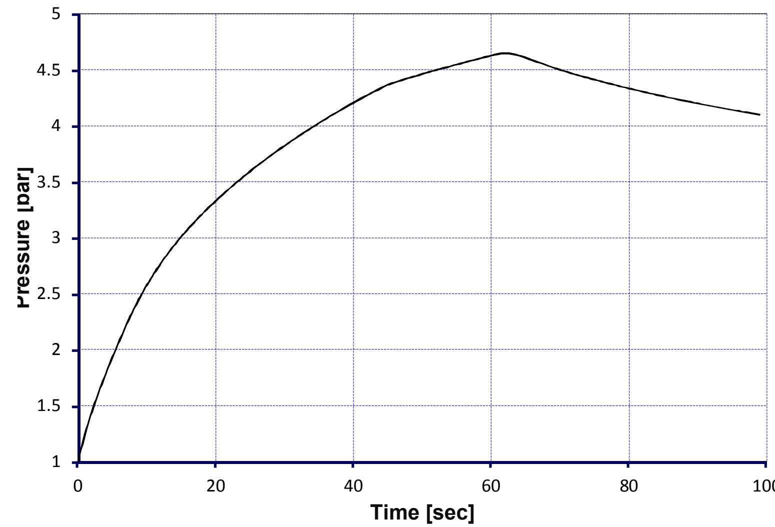
Equilibrium Model

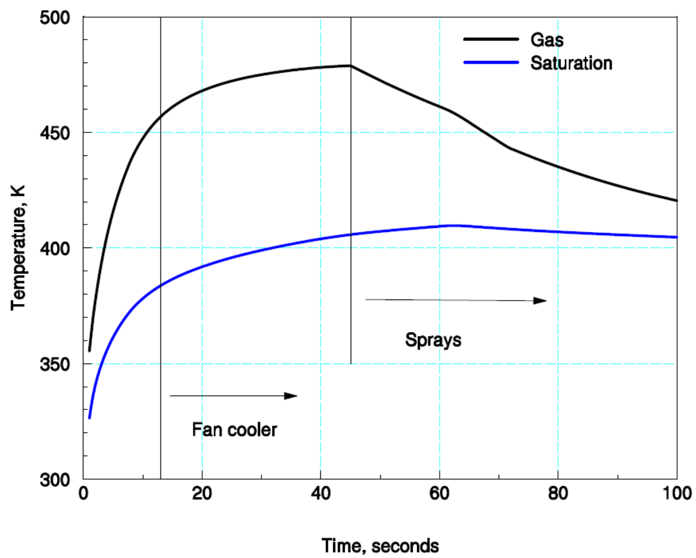
- If pool volume is less than the minimum pool volume fraction, then the equilibrium model is actuated.
  - The result, condensed water from the atmosphere is being added to a pool which is immediately brought to thermal equilibrium with the atmosphere.
  - Causing a forced cooling effect on the atmosphere
  - Analysis performed with the criterion set lower to avoid the equilibrium model (see SC4411(5))

MARCH / Adjusted Equil. Model and Mechanistic Model

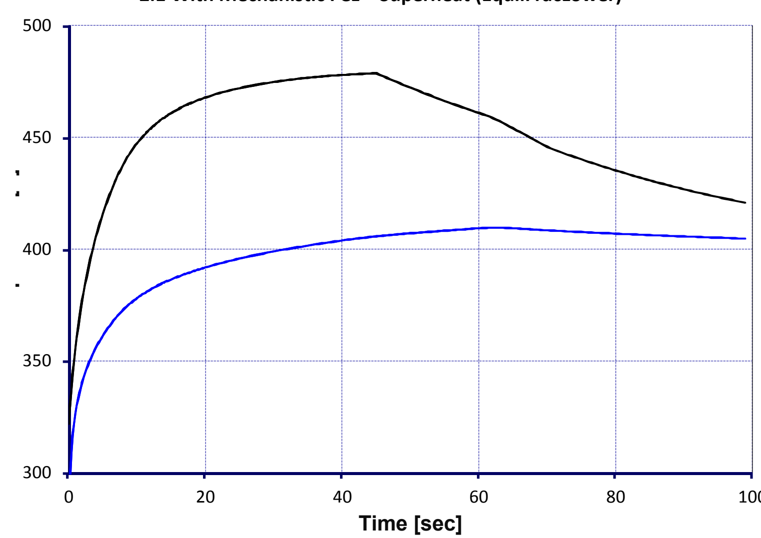


2.1 With Mechanistic FCL - Pressure (EquilFracLower)





2.1 With Mechanistic FCL - Superheat (EquilFracLower)



Questions?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