GOTHIC Overview Introduction

Dr. Nathan Carstens, Code Development Engineer

December 13, 2010

U.S. Nuclear Regulatory Commission
Pre-Application Meeting
Rockville, MD

NuScale Power

Safety Analysis Code: GOTHIC

- GOTHIC has been selected as the NuScale safety analysis code for licensing analyses
  - Some minor development is necessary
  - Through NAI, direct access to all legacy code documentation and assessments plus access to the code developers
  - Allows NuScale to focus on NuScale specific assessments and *not* on redoing and documenting legacy assessments for compliance with our QA program
- RELAP5 will continue to be used for some non-DCD referenced applications and as a reasonableness check of GOTHIC results

GOTHIC Overview

Dr. Tom George, Numerical Applications Inc.

December 13, 2010

U.S. Nuclear Regulatory Commission
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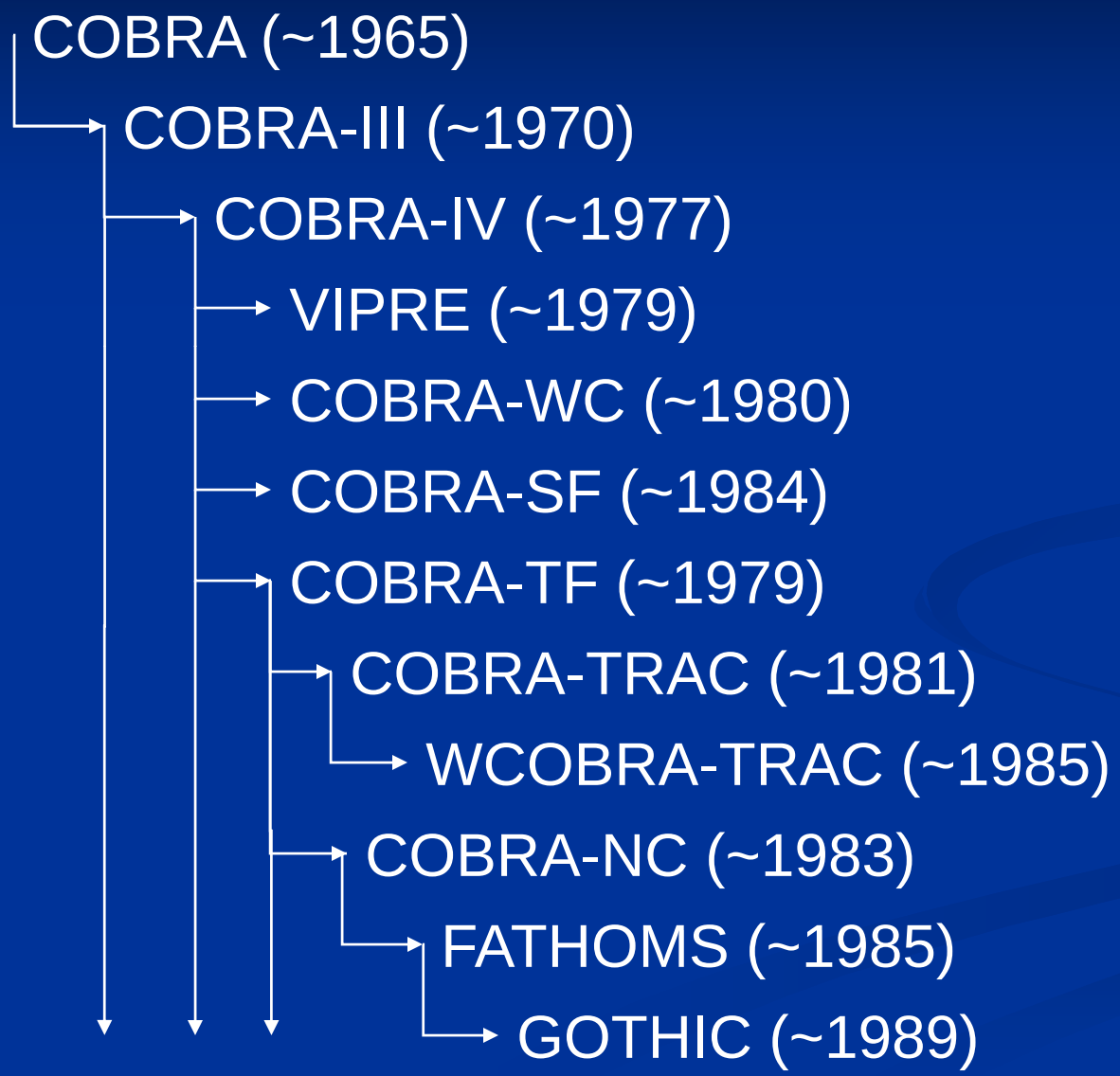
NuScale Power

GOTHIC

- General Purpose Thermal-Hydraulic Analysis
- Special Features for Nuclear Plant Modeling
- Ongoing Development and Maintenance Support by the EPRI GOTHIC Enhancement Project (since 1993).

Ancestry


COBRA (~1965)
COBRA-III (~1970)
COBRA-IV (~1977)
VIPRE (~1979)
COBRA-WC (~1980)
COBRA-SF (~1984)
COBRA-TF (~1979)
COBRA-TRAC (~1981)
WCOBRA-TRAC (~1985)
COBRA-NC (~1983)
FATHOMS (~1985)
GOTHIC (~1989)

GOTHIC Development

COBRA-NC

- Graphical Interface, Junction Model
- Components (pumps, HX, etc.)
- Separate Drop Energy Equation
- Design Review, QA

GOTHIC 4.0

- k-e Turbulence Model, Hydrogen Burn, Fan Coolers
- Improve Interphase Heat and Mass Transfer
- Control Variables, Radioactive Isotopes, Radiant Heat Transfer

GOTHIC 6.0

- Porous Body Model, Rectangular Coordinates, 3D Connectors
- DLM for Heat and Mass Transfer, Flow Networks, 2nd Order Numerics

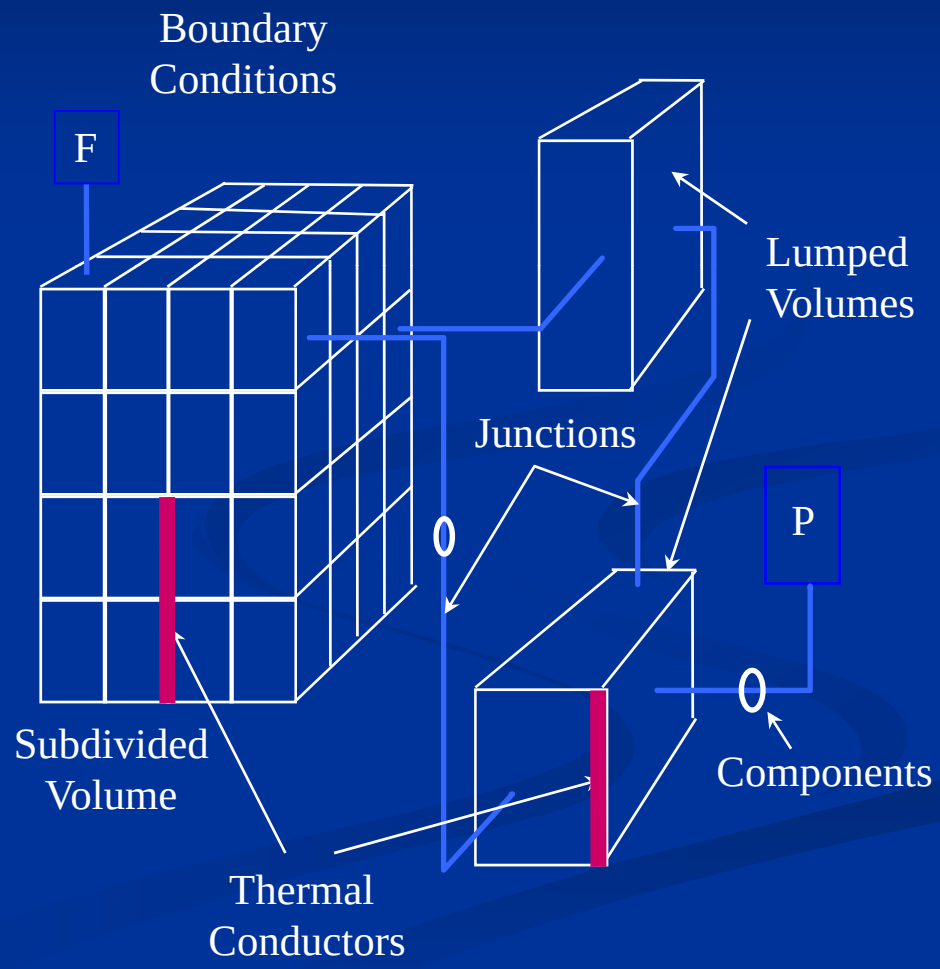
GOTHIC 7.0

- Dissolved Gases, Solid Particles, Freezing, 2D Conduction
- Multiple Drop Fields, Parallel Processing
- Improved Water Properties, Improved Interphase Drag

GOTHIC 8.0

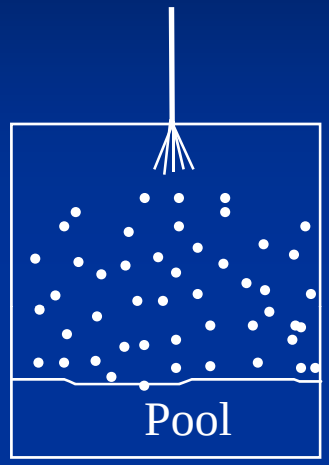
Multi-Zone Modeling

- Combine Lumped and Subdivided Volumes
- Superimposed Conductors
- Finite Volume Solution
  - Semi-implicit

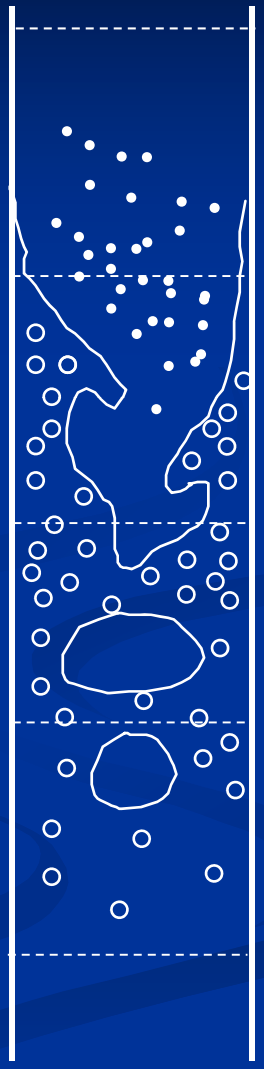


Multiphase/Multicomponent

- Vapor
  - Steam
  - N Gas Components
- Drops
  - N Fields
- Liquid
  - Films
  - Pools
  - Slugs
  - Stratified Flow
- Mist
- Ice



Lumped



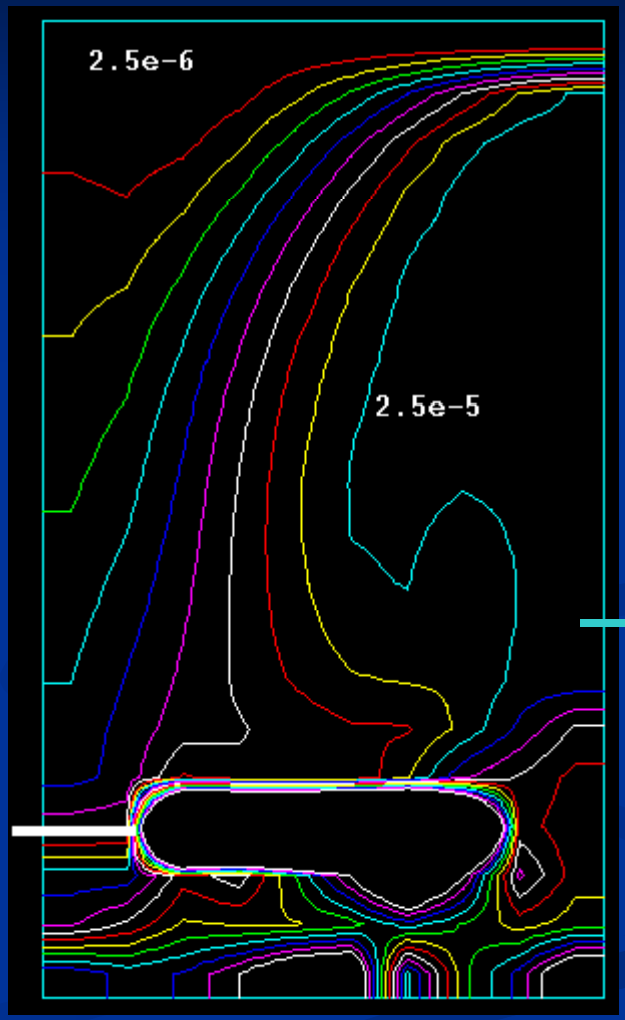
Subdivided

Equation Set

Phase	Description	Mass Balance	Energy Balance	Momentum Balance
Vapor	Steam, gas components in bubbles or free vapor	Steam, each gas component	Yes	Yes
Liquid	Continuous liquid in pools, films, slugs, bubbly flow	Yes	Yes	Yes
Drops	Water drops	Yes	Yes	Yes
Mist	Very Small Droplets	Yes	$T=T_{sat}$	$U=U_v$
Ice	Ice formation and melting on conductor surfaces	Yes	Yes	No

Comprehensive Drop Behavior Models

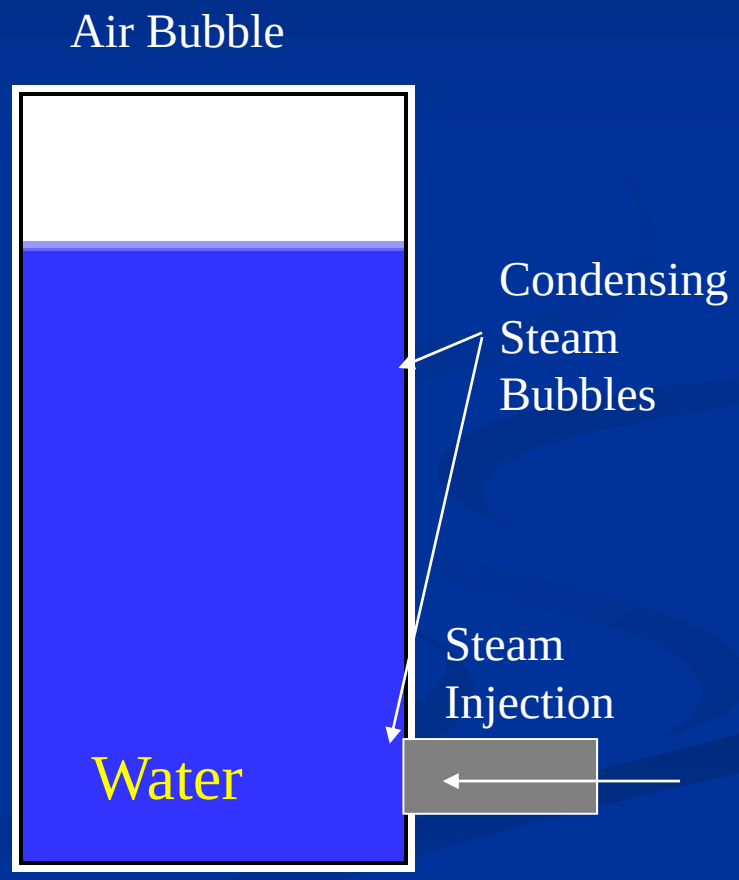
- Drop Breakup
  - Hydrodynamic Forces
  - Flashing
- General Entrainment Model
  - Relative Velocity
  - Film/Pool Thickness
  - Fluid Properties
- Depositions Models
  - Diffusion
  - Turbulent Impaction
  - Bends
  - Settling



WALE Test Drop Concentration

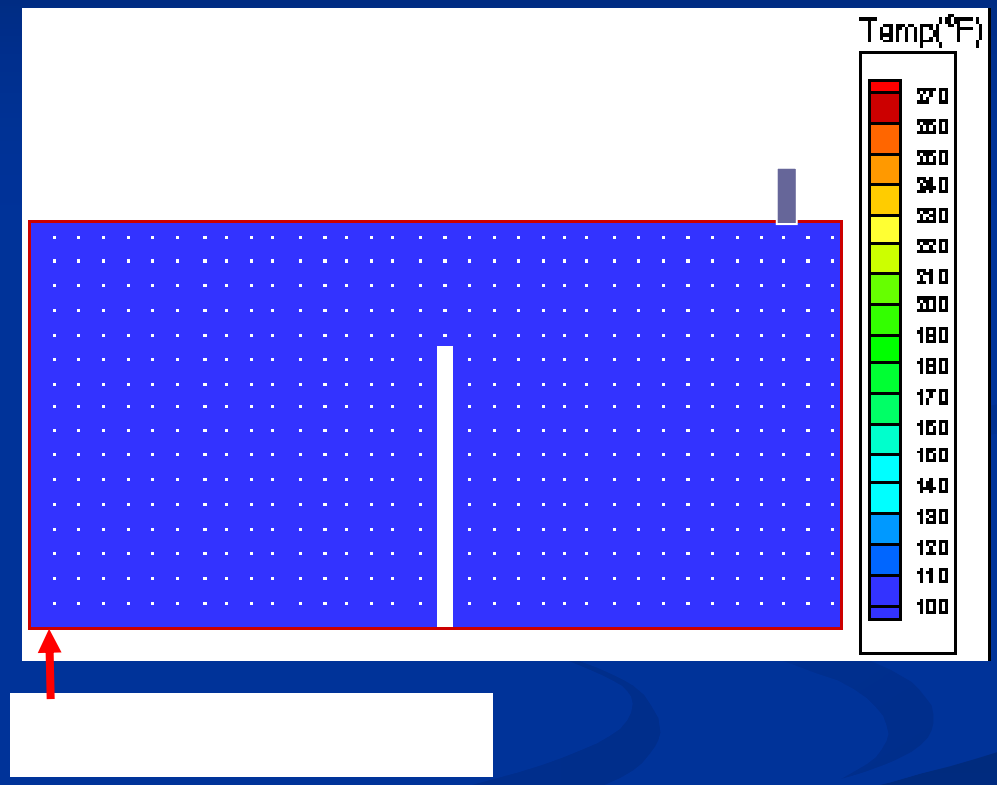
Interphase Heat, Mass and Momentum Transfer

- Drop/Vapor and Liquid Vapor Interfaces
- Evaporation
- Condensation
  - Diffusion Layer Model for Noncondensing Gas Effects
- Boiling/Flashing
- Drop Entrainment
- Drop Deposition
- Ice Formation and Melting



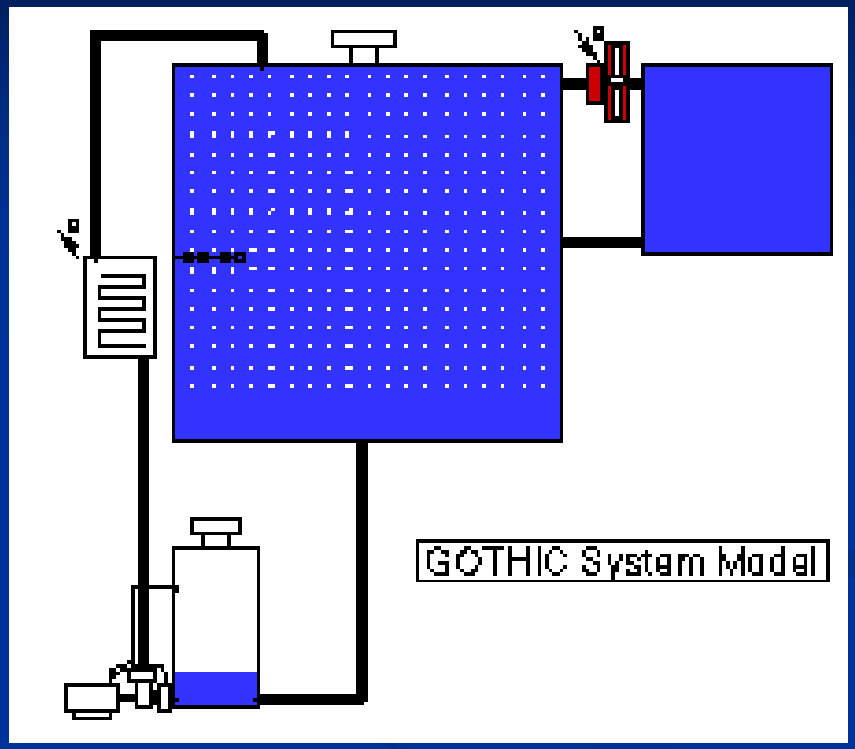
Mixing and Stratification

- Buoyant Flows
- Forced Convection
- Jet Induced Mixing
- Diffusion
  - Molecular
  - Turbulent - k-e Model
  - Mass Diffusion
    - Vapor and Liquid
  - Thermal Diffusion
    - Vapor and Liquid
  - Momentum Diffusion
    - Vapor and Liquid



Equipment Models

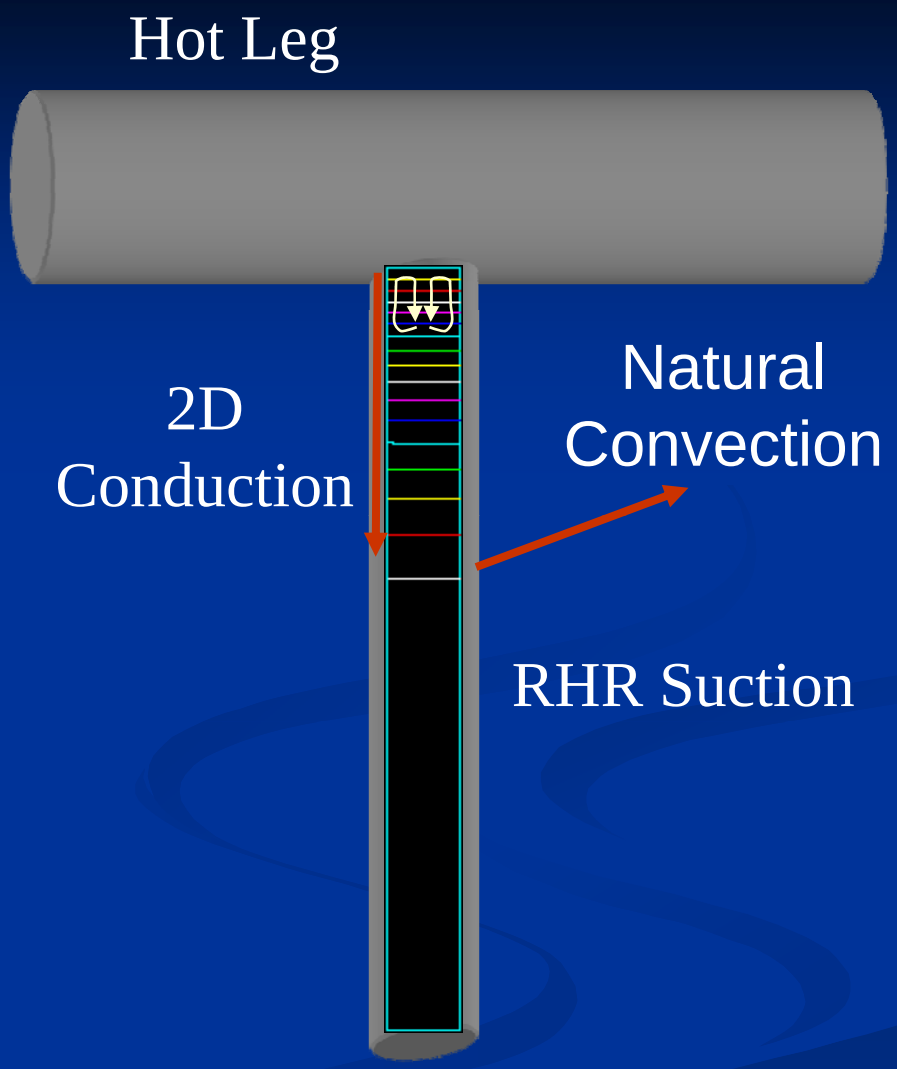
- Pumps/Fans
- Valves
- Vacuum Breakers
- Heat Exchangers
- Fan Coolers
- Igniters
- Recombiners
- Heaters/Coolers
- Spray Nozzles



- Controls
  - Trips
  - Forcing Function
  - Control Systems

Piping System Modeling

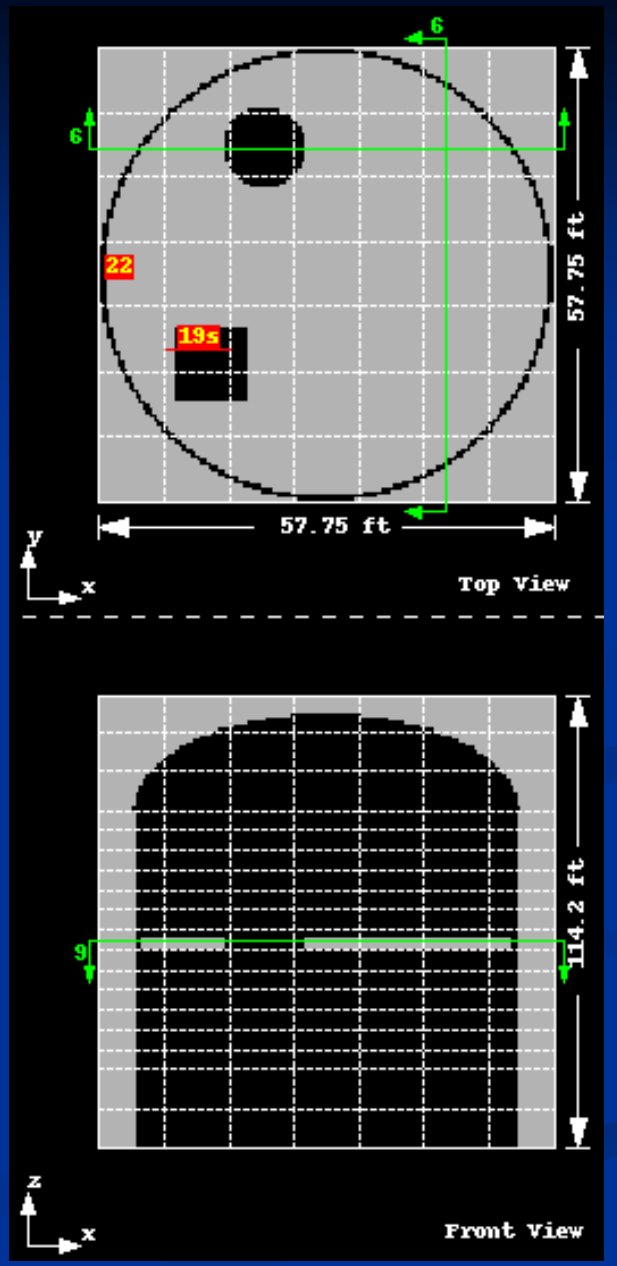
- Loop Performance
  - Pumps
  - Heat Exchangers
- Gas Transport
- Pressure Surge
- Water Hammer
- NPSH
- Thermal Mixing



Thermal Penetration in
Stagnate RHR Suction Line

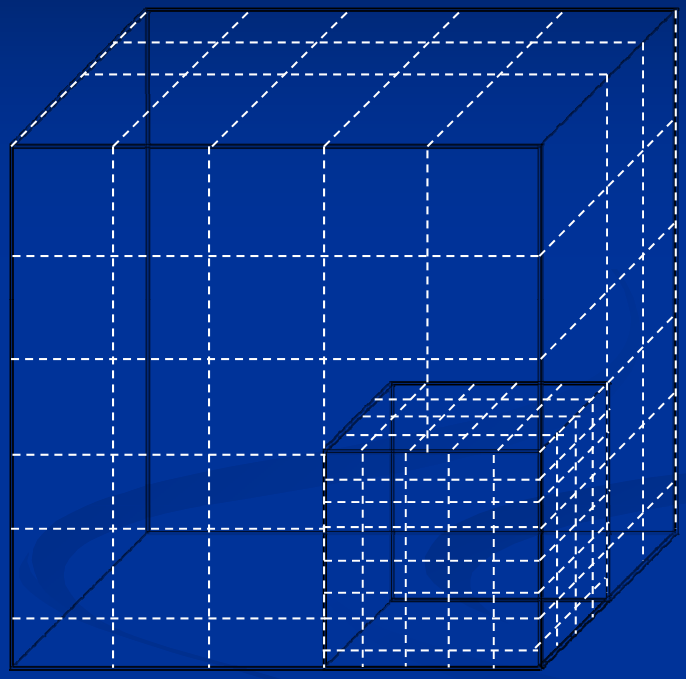
Subdivided Volumes

- Volume and Area Porosity Factors to Model Obstructions and Irregular Boundaries
- Slip/No-Slip Boundaries
- Easy User Interface



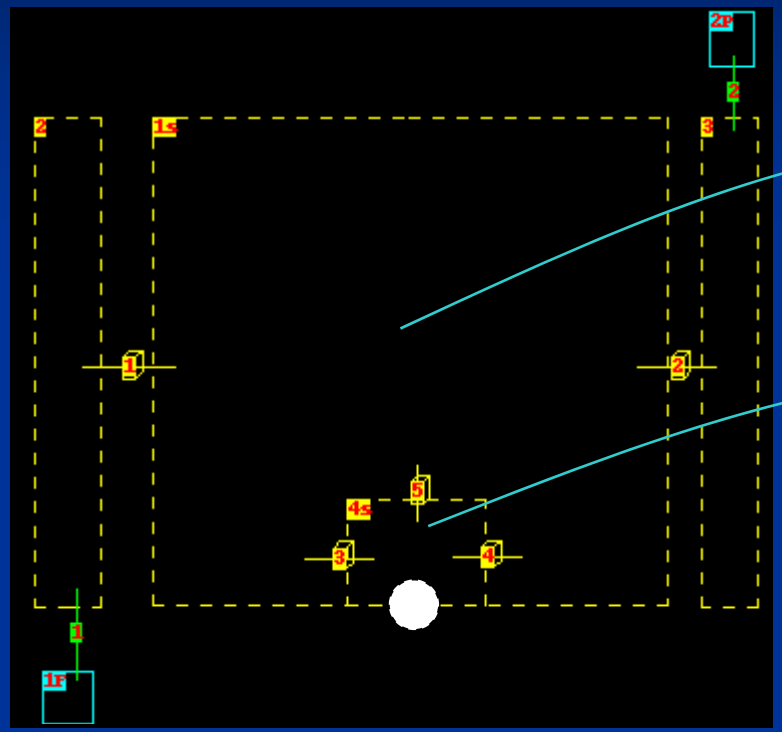
3D Connectors

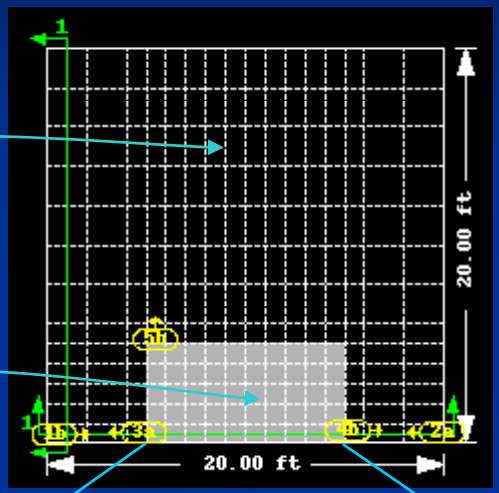
- Connect Subdivided Volumes to
  - Lumped Volumes
  - Subdivided Volumes
- Embedded Grids
- Full 3D Momentum Solution
- Diffusion Across Connection

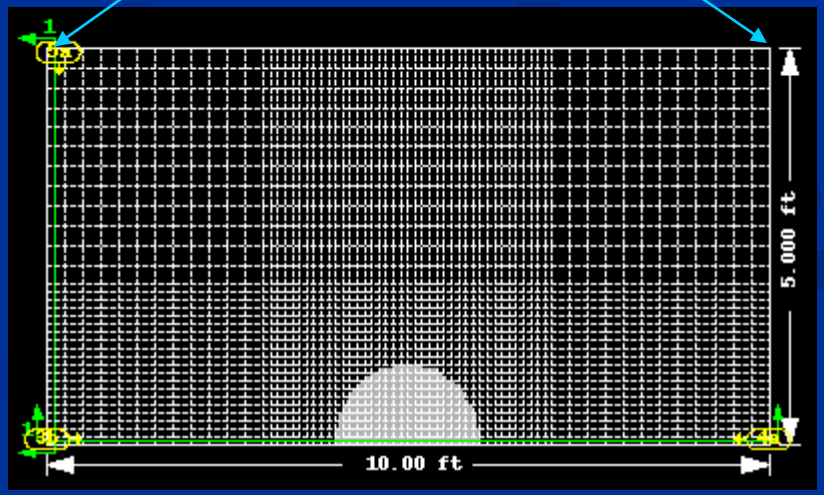


3D Connectors at interface between coarse and fine grids.

Multiple Detail Levels

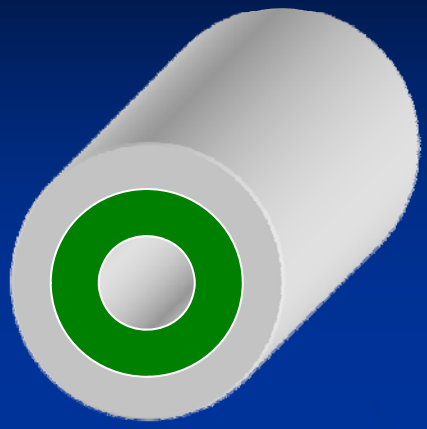


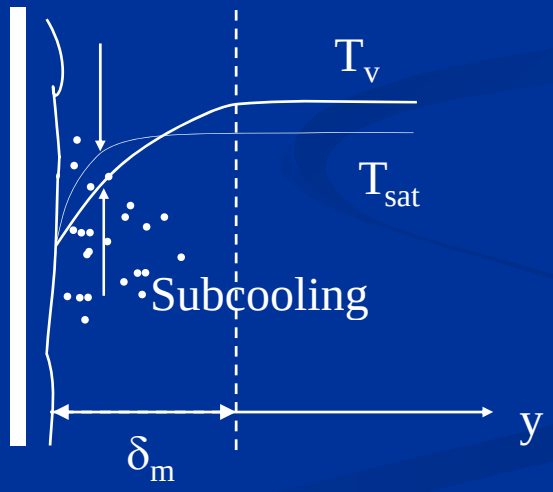




Wall Heat Transfer and Condensation

- Free Convection
- Forced Convection
- Radiation
  - Wall - Steam
  - Wall - Wall
- Condensation
  - Uchida
  - Tagami
  - Mist/Diffusion Layer Model





- 1D and 2D Conduction

Solution Methods

- Conductor Solution
  - Full implicit finite volume
- Fluids Solution
  - Semi-implicit finite volume
  - 1st and 2nd order upwind differencing options
  - Multigrid, Conjugate Gradient, Block Iterative and Direct Matrix solution options.
- Parallel Processing
  - Shared memory

Quality Assurance

- GOTHIC is maintained under NAI's QA Program.
- Conformance to 10CFR50 Appendix B requirements.
- Meets intent of ASME NQA-1
- Audited by NUPIC
- Built in QA features
  - Event Logging
  - File Comparison Utility

GOTHIC Qualification

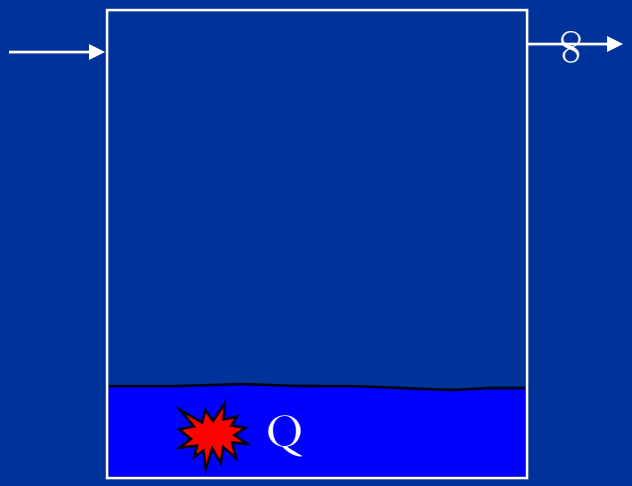
- Separate Effects Tests
  - Comparison with analytic solutions
  - Comparison with experimental data
  - Component functionality
- Combined Effects Tests
  - Comparison with experimental data

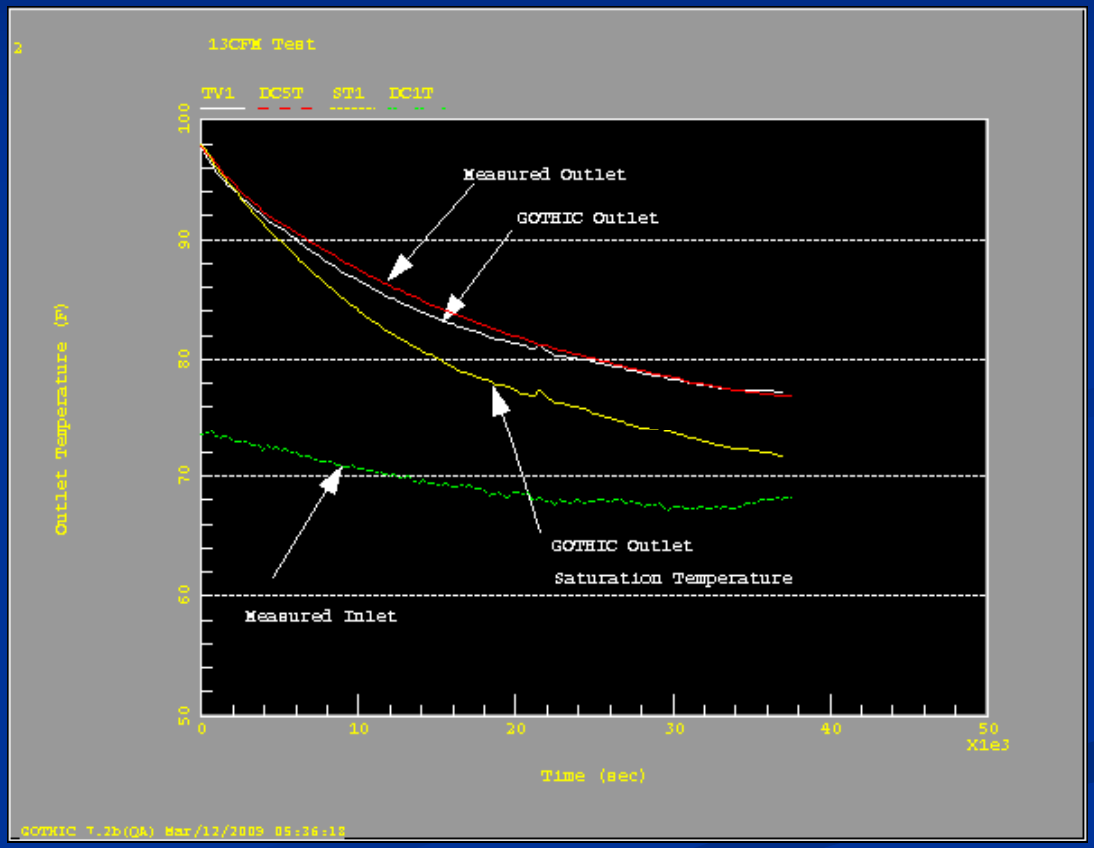
Basic Phenomena and Thermodynamics

- Compression and work
- Thermal and mass diffusion
- Buoyancy Driven Flows
- Multiphase phenomena
  - Interphase heat and mass transfer
    - Drop/Vapor
    - Liquid/Vapor
  - Interphase drag
    - Drop/Vapor
    - Liquid/Vapor
- Gas absorption and release

Interphase Heat and Mass Transfer
Free Convection for Pool

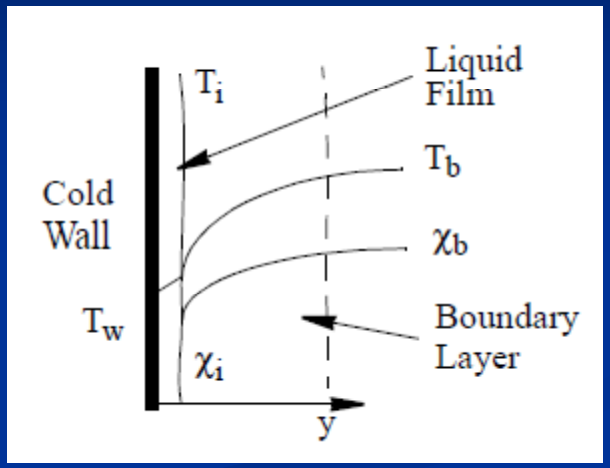
- PNL Grout Mold Evaporation Tests
  - Varied ventilation rate





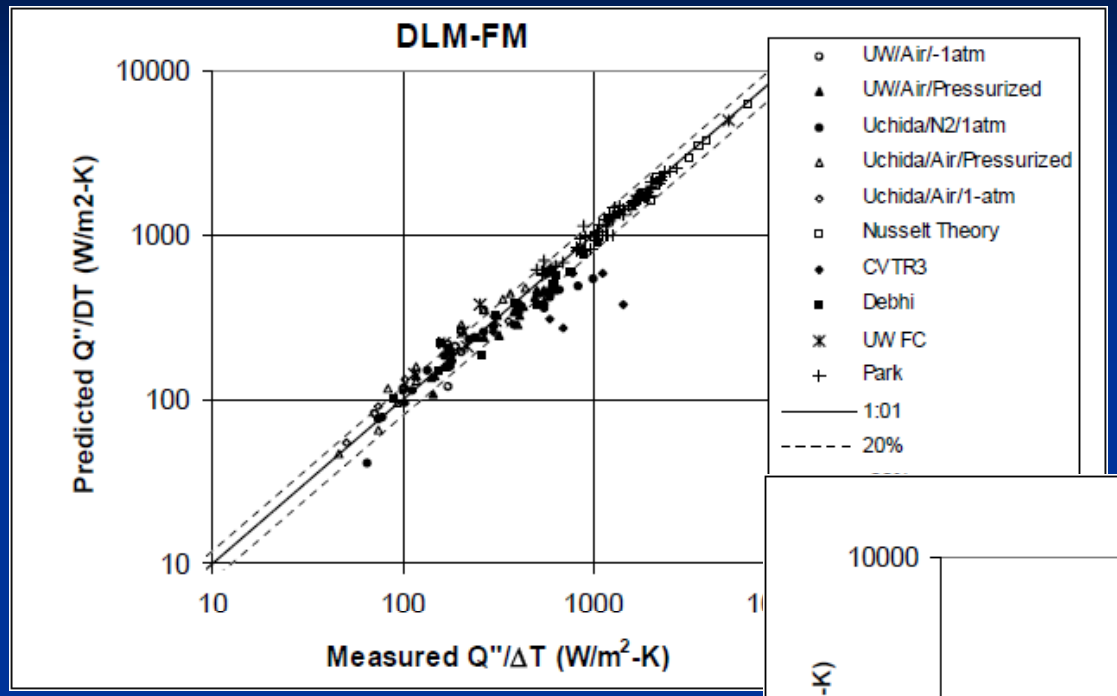
Diffusion Layer Model (DLM)
Wall Heat Transfer with Condensation

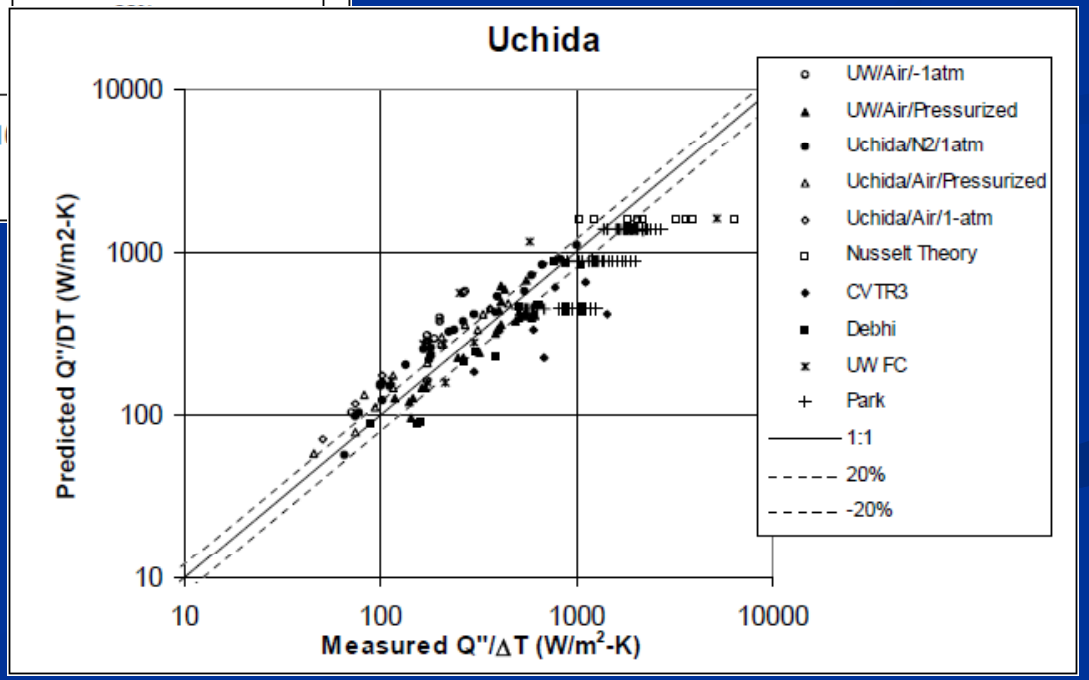
- Test range
  - Pressure, 1 – 4.5 atm
  - Steam Temperature, 47 – 139 C
  - Steam concentration, 0.1 – 1.0
  - Wall Temperature, 28 – 109 C
  - Wall Height, 0.3 – 18.3 m
  - Vapor Velocity, 0 – 7 m/s
- Film roughening effect
- Mist formation effect



- Data Sets
  - Uchida
  - U of W Vessel
  - U of W Plate Plate
  - MIT
  - Nusselt Theory
  - CVTR
  - Park Film Test

DLM for Heat and Mass Transfer

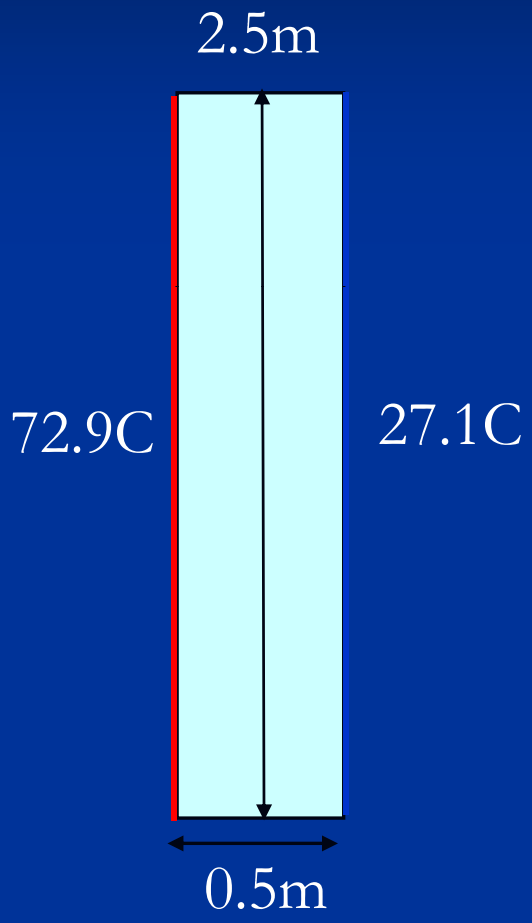


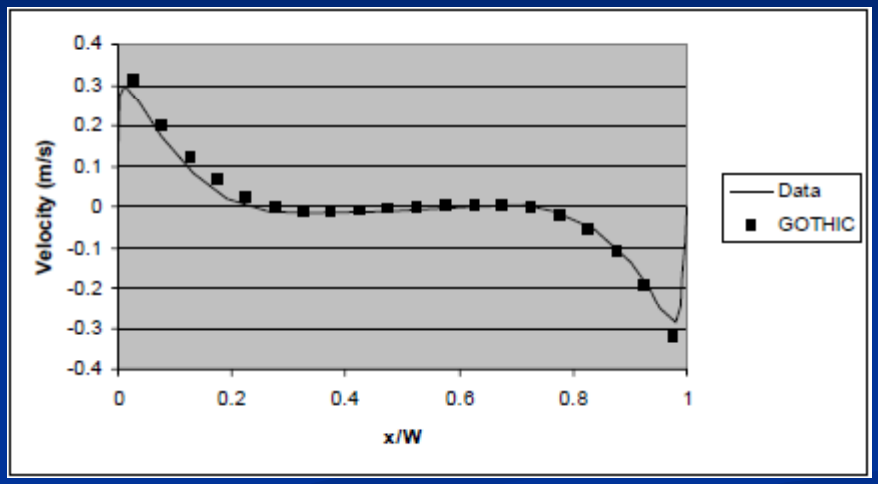


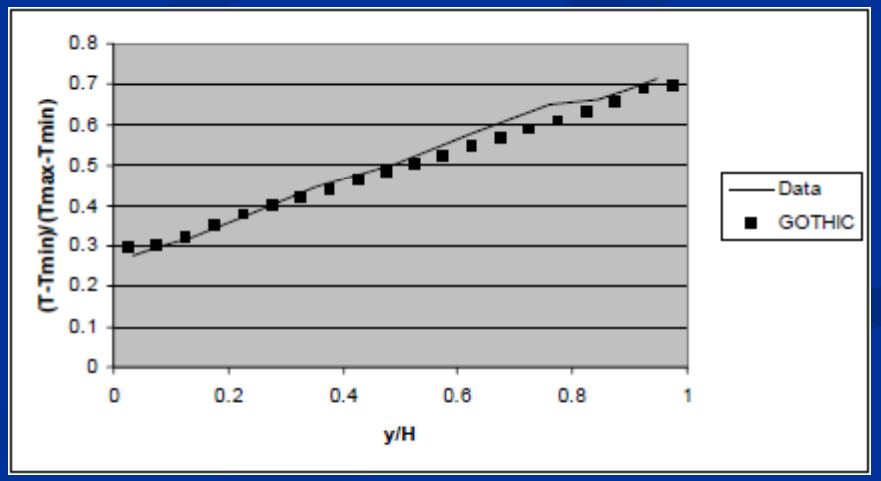
Buoyancy Driven Flow

- Mixing Analysis
- Room/Building Heatup
- Test
  - Analytic
  - Separate effects experiment
  - Large scale – single and multicompartment tests
    - HDR
    - Battelle Frankfurt Model Containment
    - MISTRA
    - TOSQAN
    - THaI
    - Others

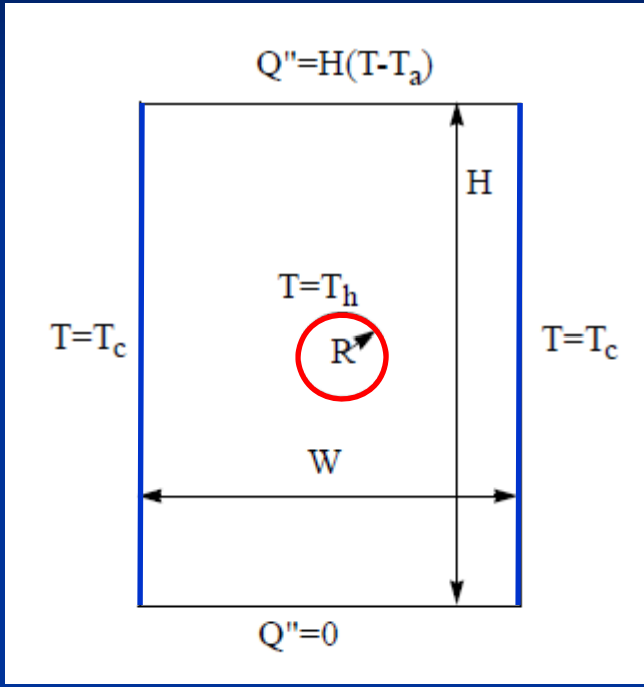
Buoyancy Driven Flow
Thermally Driven Cavity



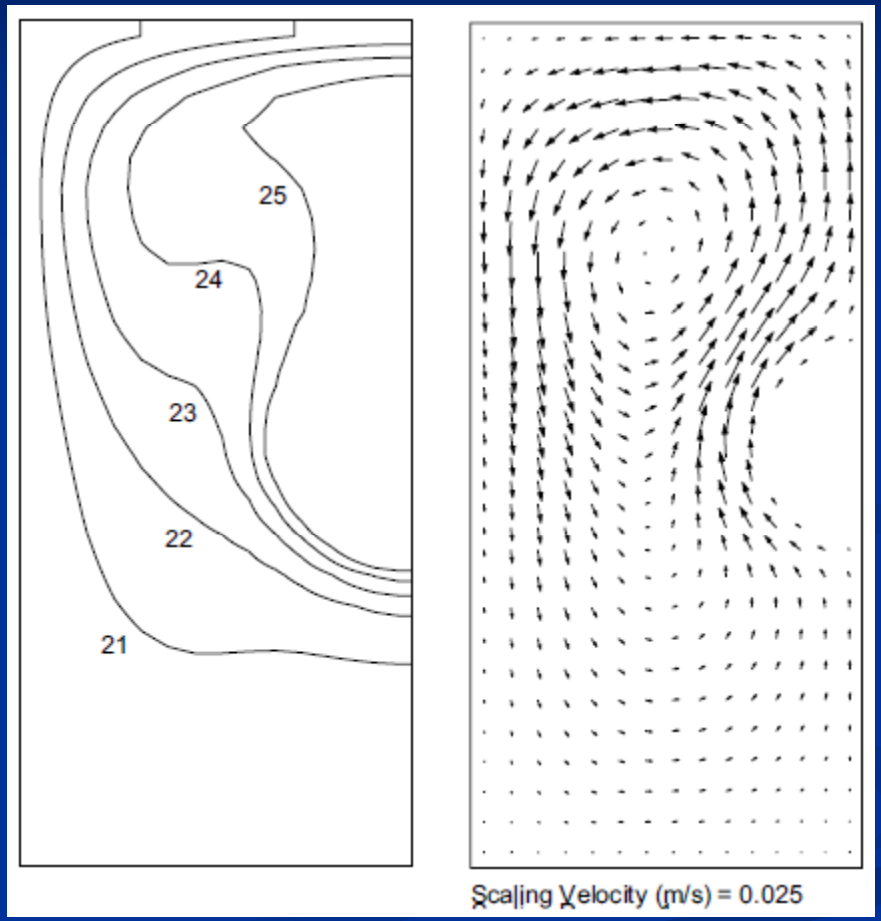




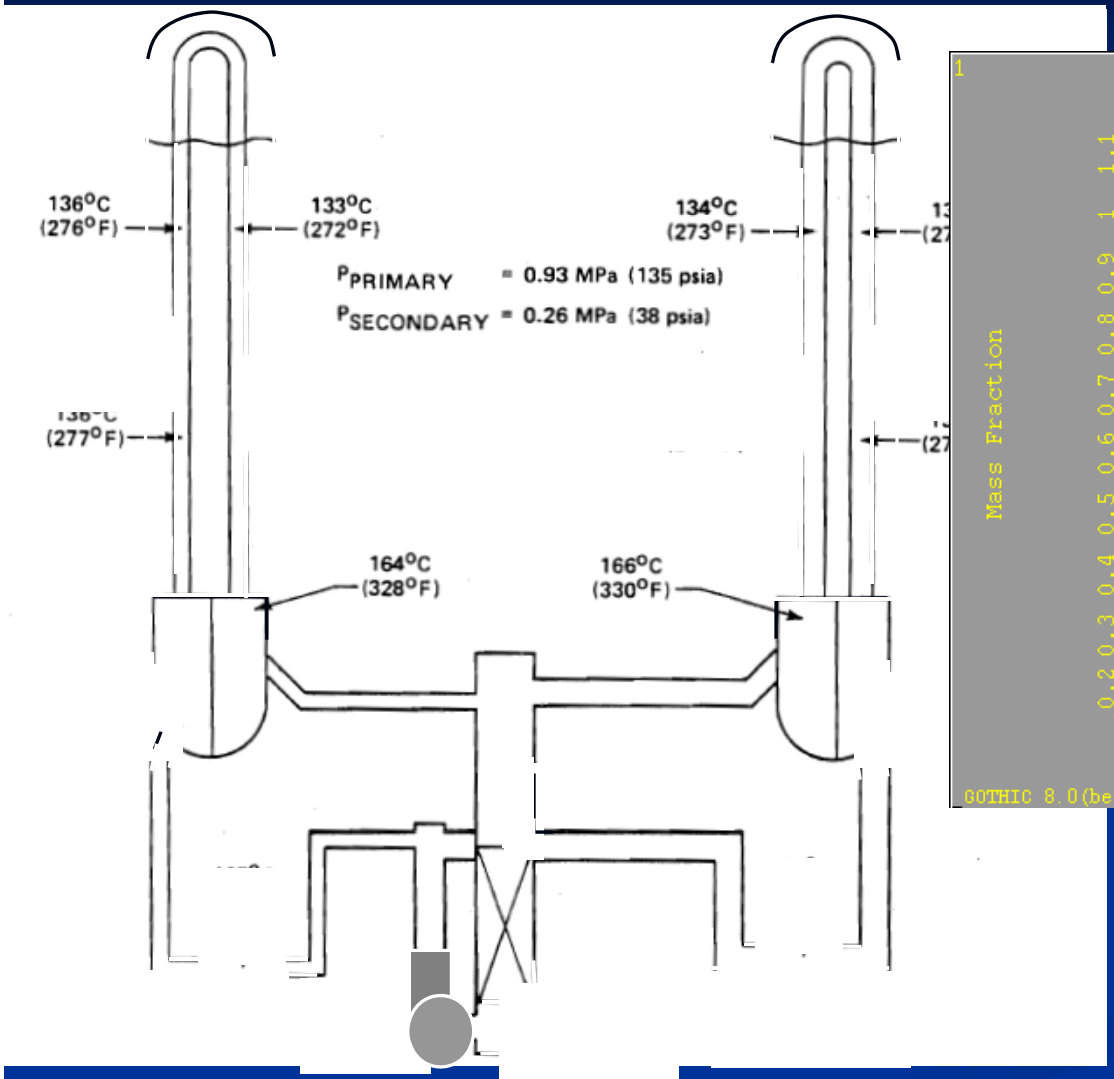
Natural Convection Heat Transfer

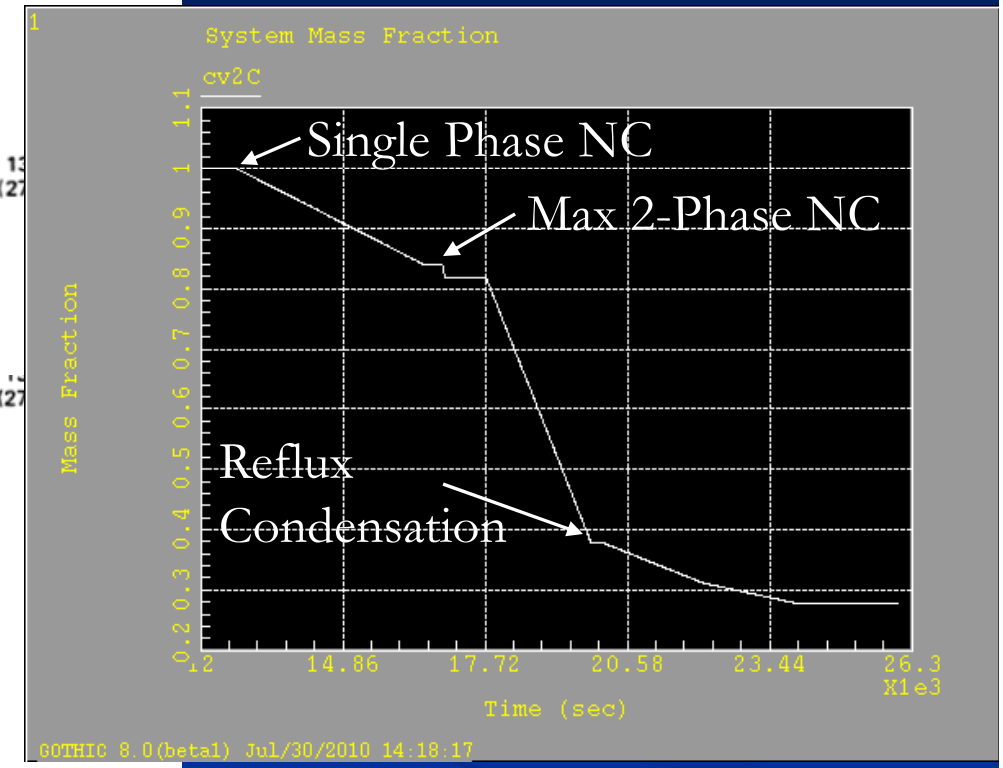


Raleigh No	Nu (Exp.)	Nu (GOTHIC)
1,300	2.35	2.52
2,400	2.79	3.06
3,400	3.06	3.38



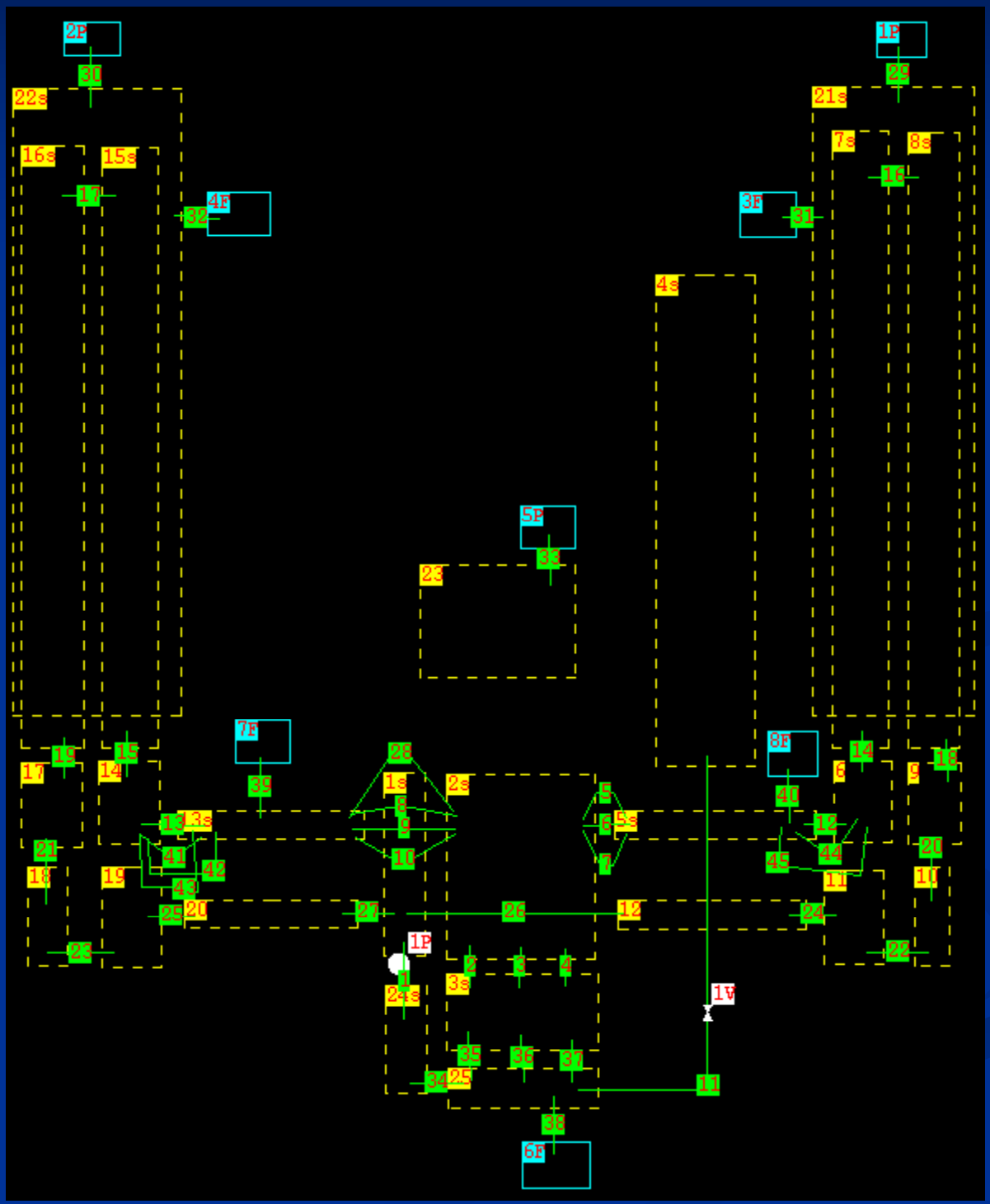
PWR FLECHT SEASET



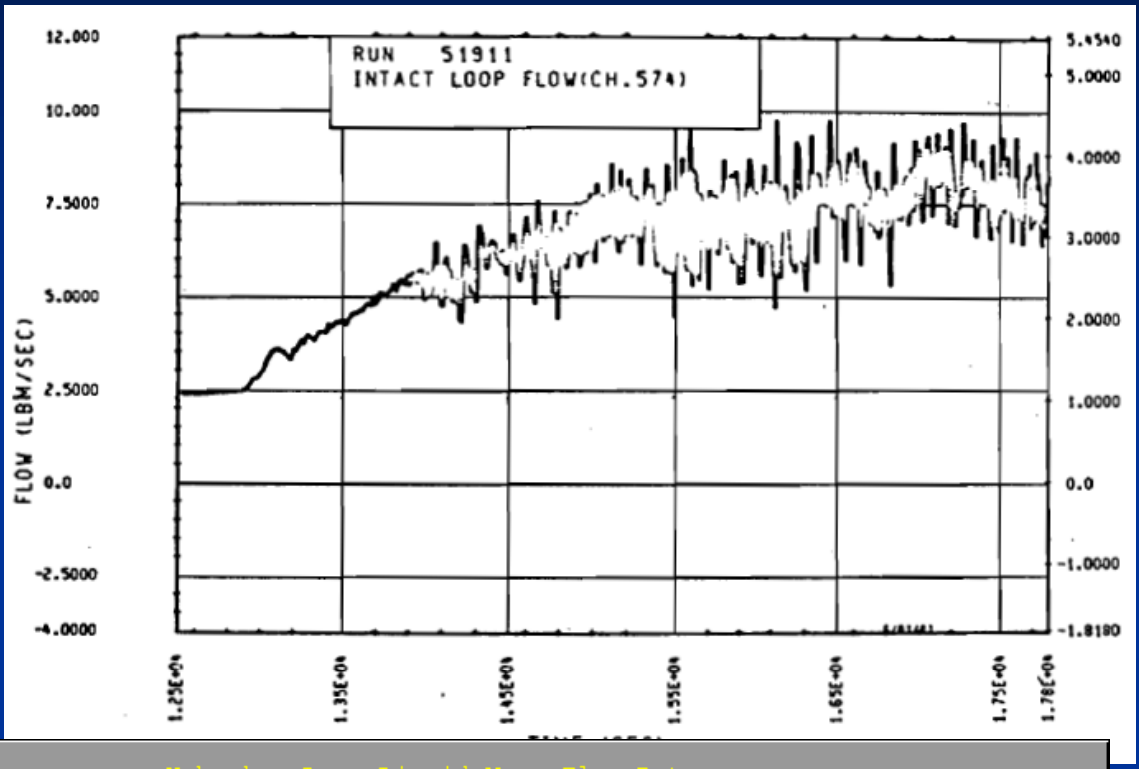


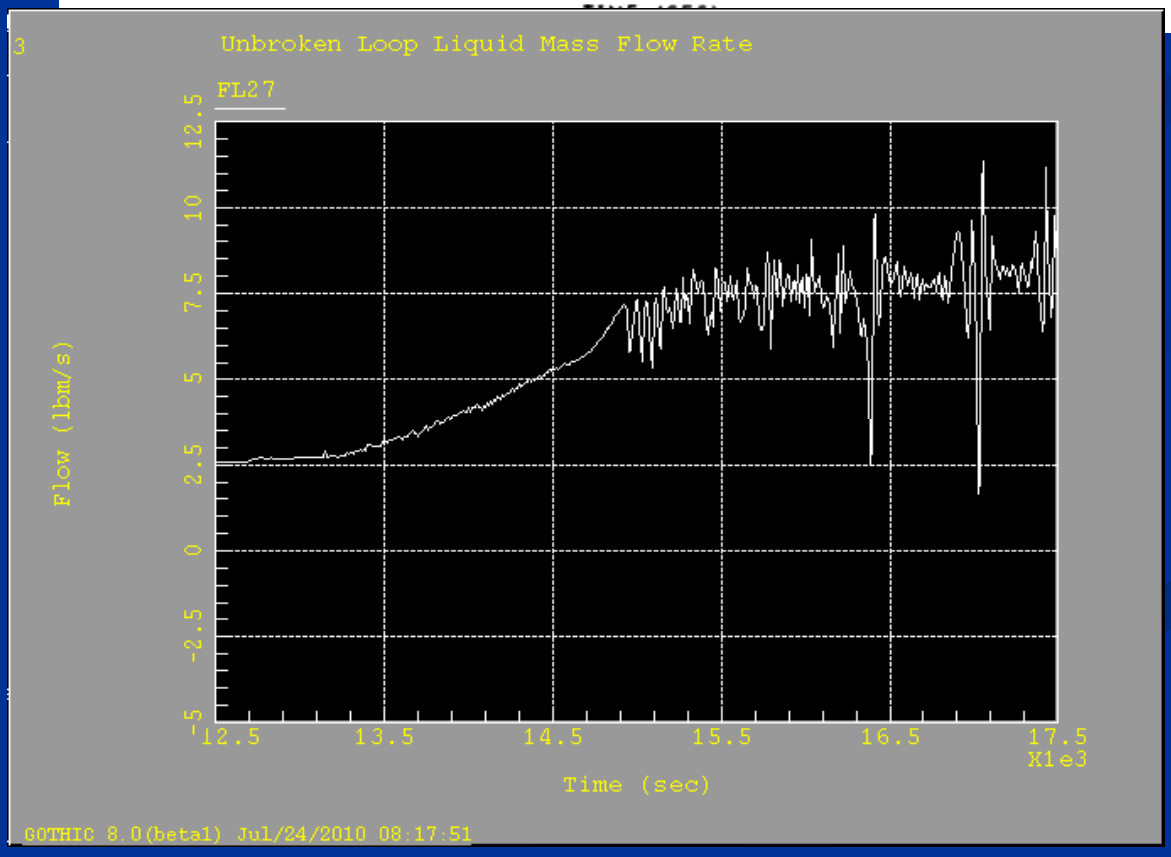
- **Data Comparisons**
  - Loop Flows
  - Steam Generator Performance

FLECHT-SEASET Noding

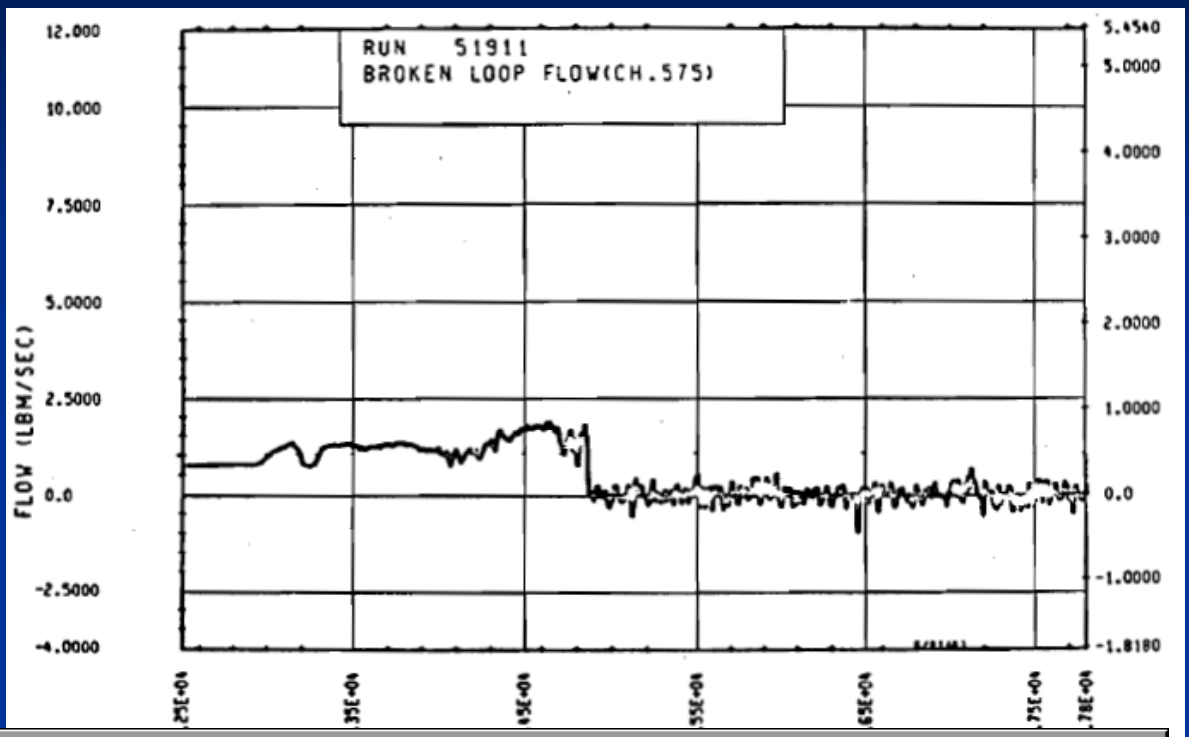


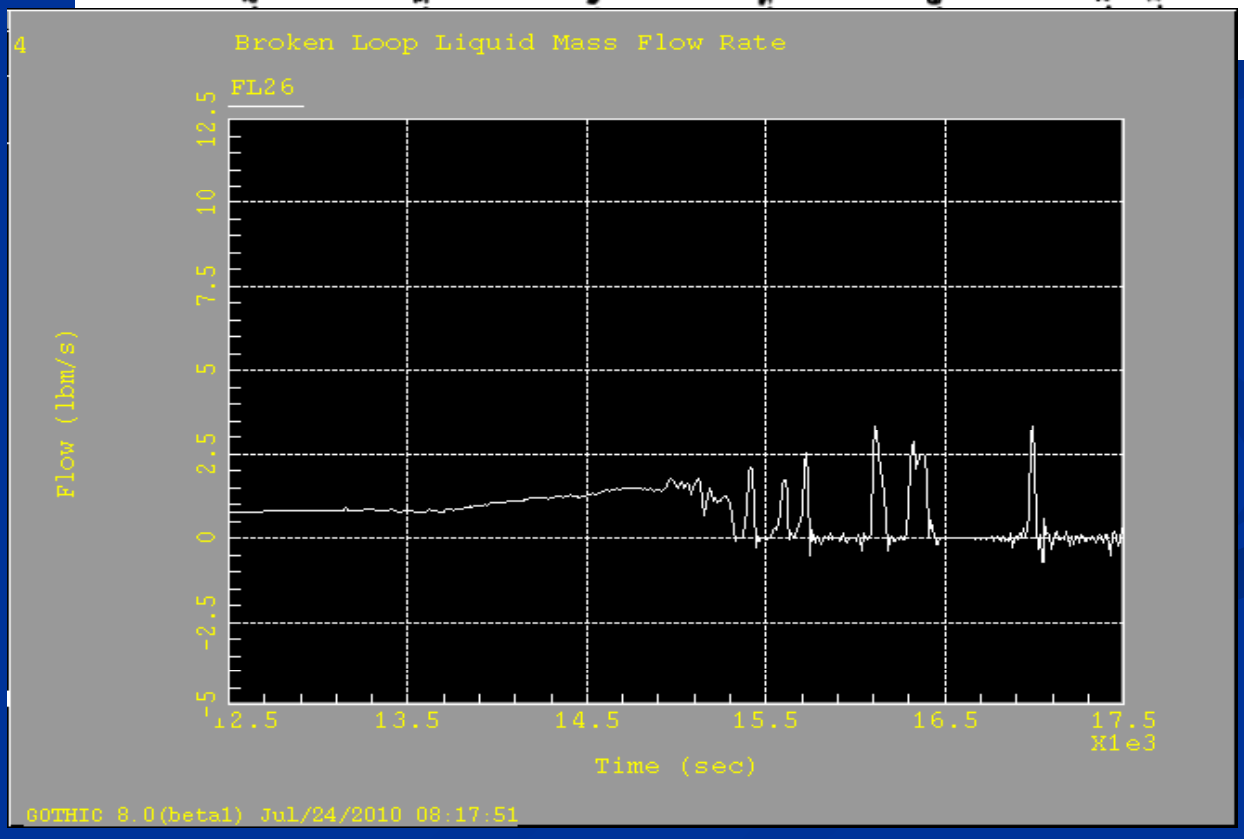
2-Phase Natural Circulation Intact Loop Flow



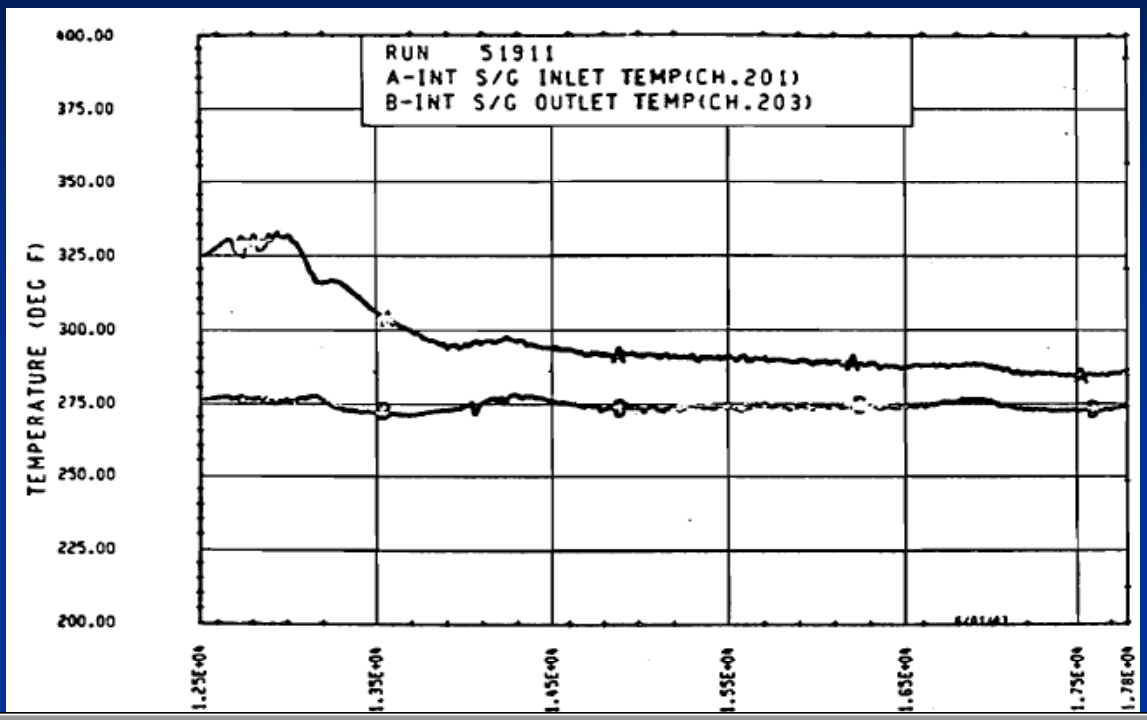


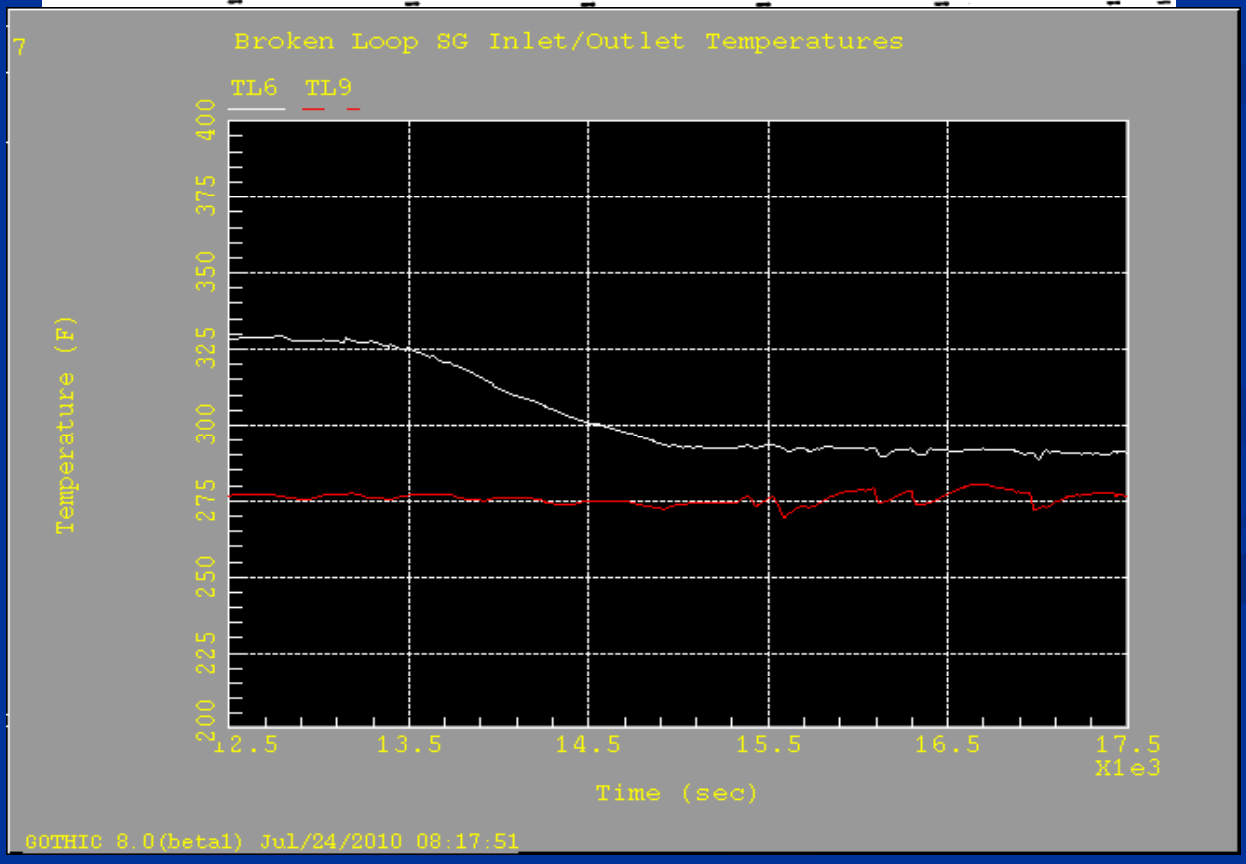
2-Phase Natural Circulation Broken Loop Flow



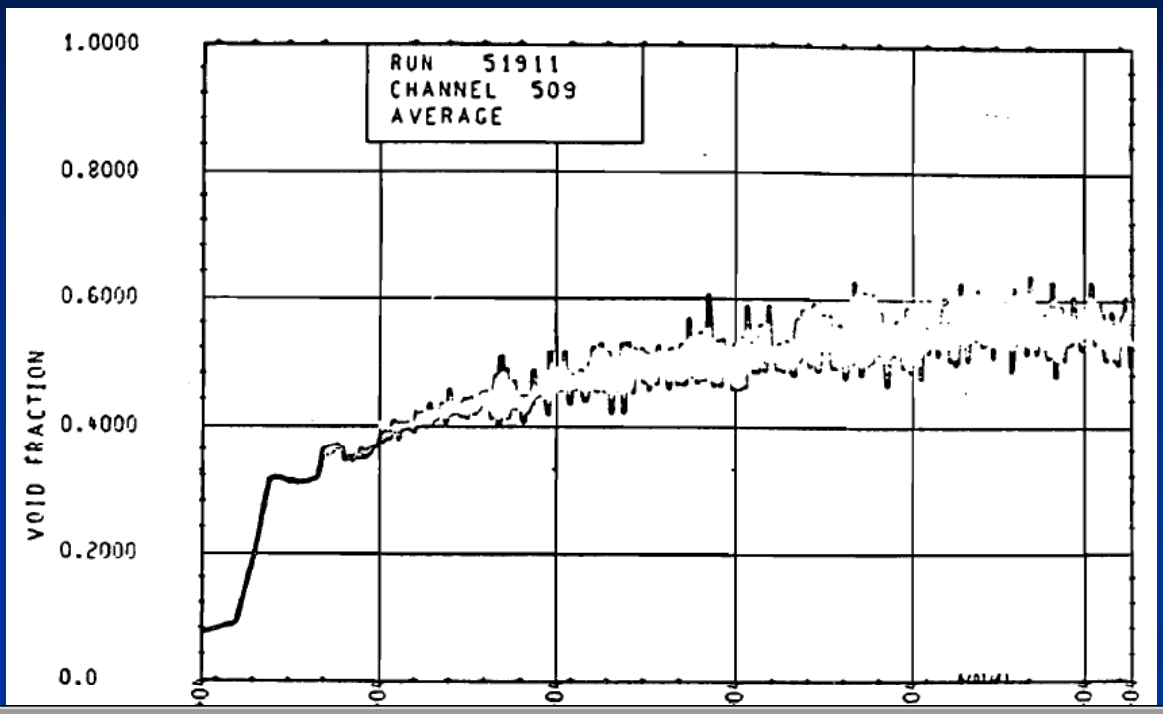


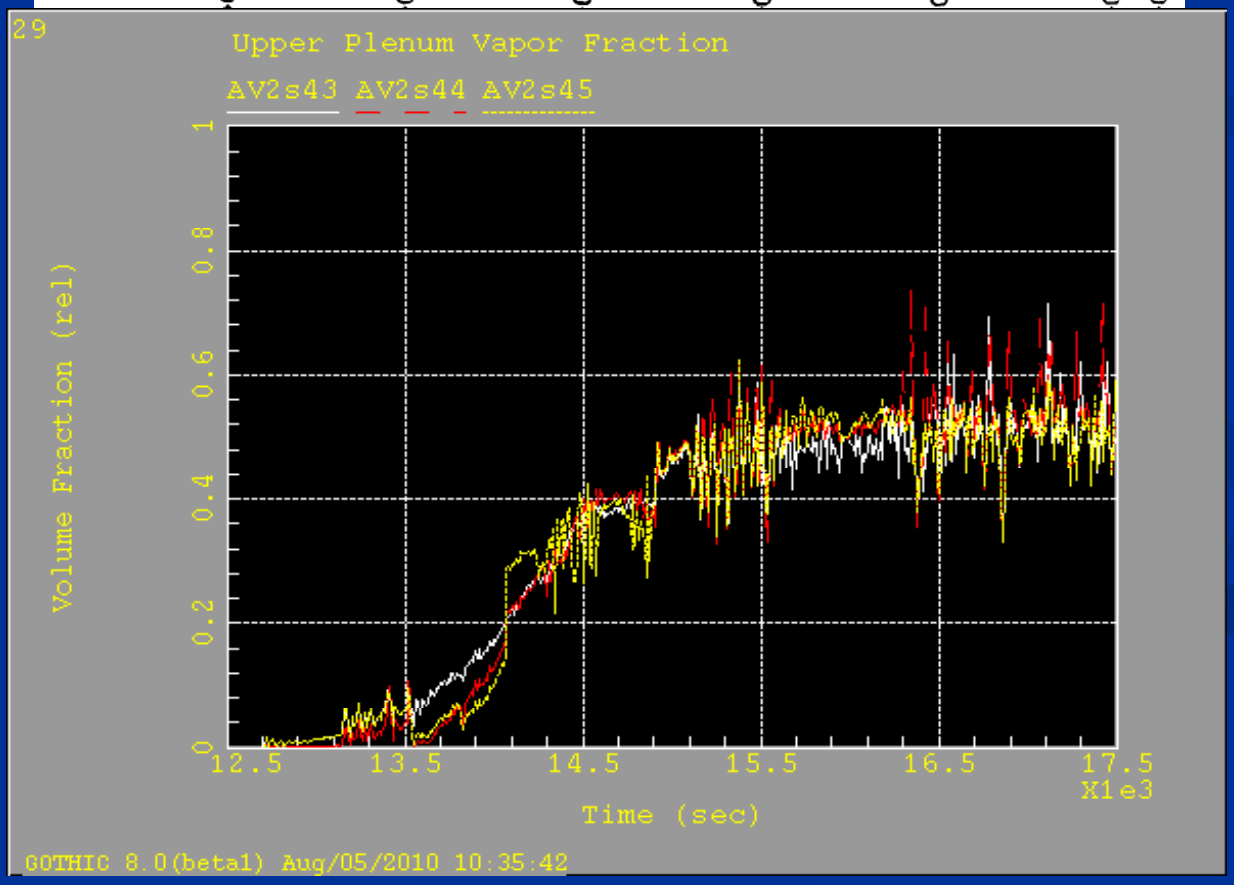
2-Phase Natural Circulation
Intact Loop SG Inlet/Outlet Temp.





2-Phase Natural Circulation Upper Plenum Vapor Fraction





Examples from NRC Submittals

- SER for Topical Report CPC-NE-3004-A, Duke Power, McGuire Nuclear Station Mass and Energy Release and Containment Response Methodology, 12/2000
- SER for Topical Report WCAP-16608-P, Westinghouse Containment Analysis Methodology, 1/27/09 (ML090230441)
- Acceptance Review Results for Topical Report WCAP-17065-P Rev. 0, Westinghouse ABWR Subcompartment Analysis Methodology Using GOTHIC Related to South Texas Project Units 3 & 4 Combined License , 6/2/10 (ML101530006)
- Approved Topical Report DOM-NAF-3 NP-A, “GOTHIC Methodology for Analyzing the Response to Postulated Pipe Ruptures Inside Containment” (ML063190467)

Summary

- GOTHIC solves fundamental equations for multiphase flow with basic models for interface and wall mass, momentum and energy transfer.
- Validation covers a wide range of single and two-phase flow situations
- Wide range applicability hinges on capability to simulate fundamental phenomena
  - Interphase and wall heat and mass transfer
  - Interphase and wall drag
  - Momentum dominated flow
  - Gravity dominated flow
- Code results are generally in good agreement with data
- Controlled code versions under NAI QA Program
  - Validation repeated for each code version

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