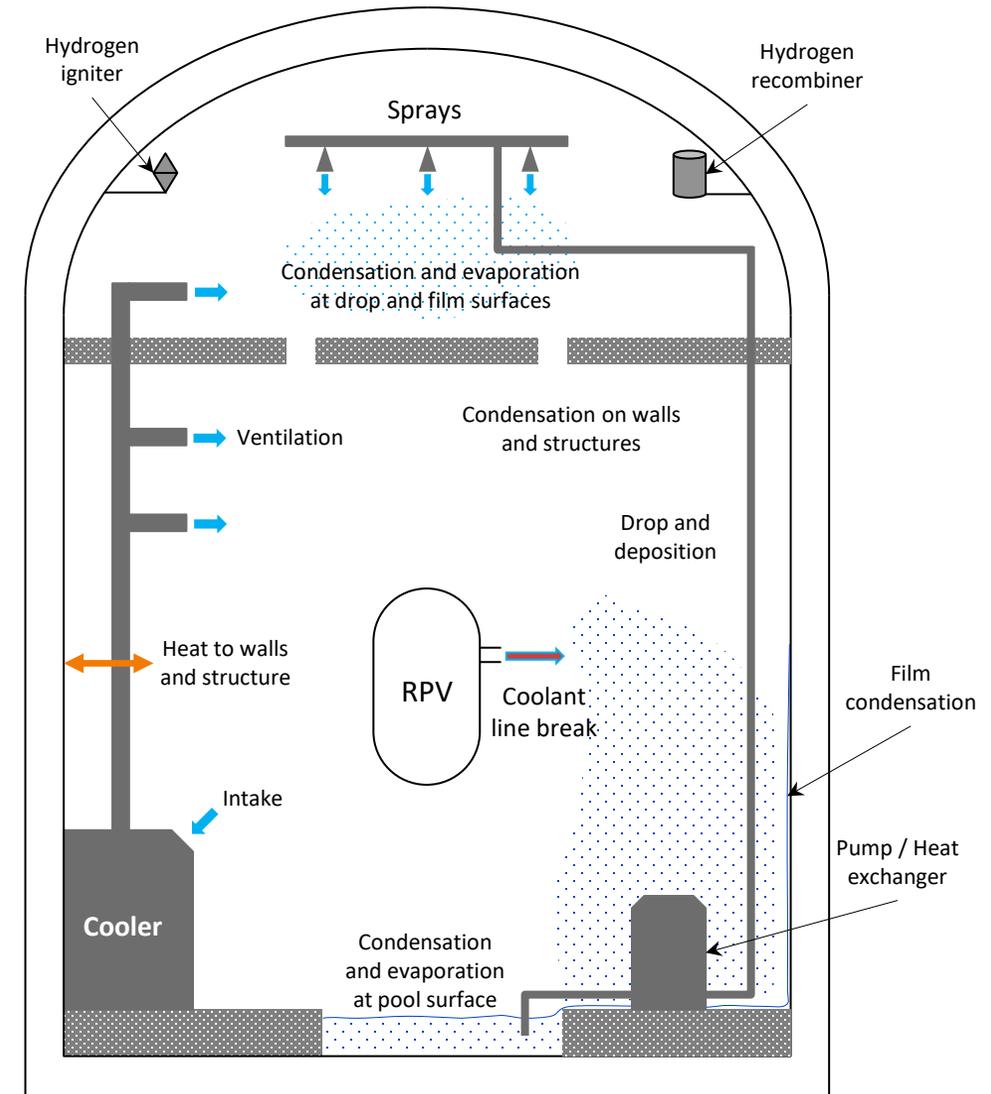# GOTHIC

## Thermal Hydraulics Analysis Code

YJ Choi, GOTHIC PM
(yjchoi@epri.com, gothic@epri.com)

Edition 2026

# Overview of GOTHIC

- GOTHIC is fully validated best-estimate nuclear thermal hydraulics (TH) analysis software
  - Coarse-mesh multi-phase CFD and system level nuclear TH
  - Originated from COBRA-TF subchannel analysis code 40 years ago
  - Strong user community supported by EPRI since 1993
- GOTHIC analyzes NPP containment TH, in principle
  - Analyze relative physics in NPP buildings and components
  - Applicable to both LWR and non-LWR designs
  - Versatile general-purpose multi-physics engineering tool
- GOTHIC supports licensing of NPP world widely
  - Compliance with U.S. 10CFR21, 10CFR50 Appendix B, ASME NQA-1
  - Extensive benchmark, validation and qualifications
- Latest version is GOTHIC v8.5(QA), released Oct. 2024
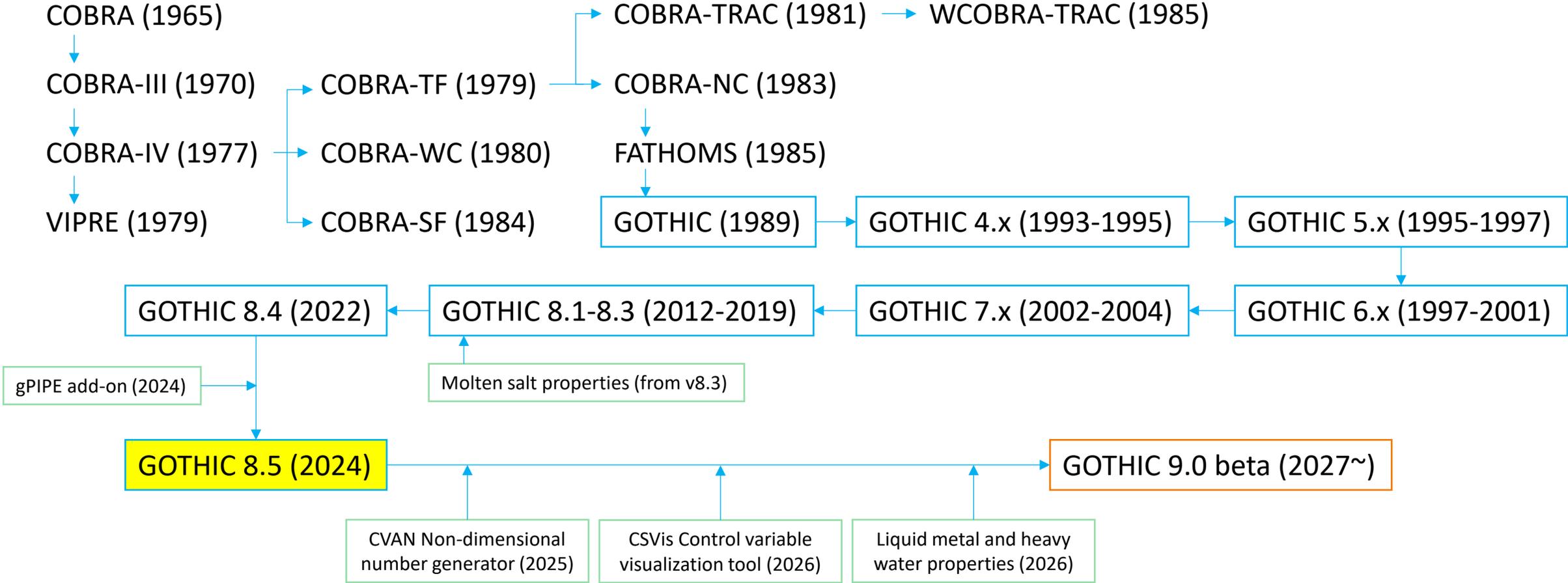  - Including molten salt property libraries



*Major phenomena of containment analysis*

## EPRI Controls Quality and License of GOTHIC

# GOTHIC Development History*

- GOTHIC is a descendant of the COBRA series which was originally developed for sub-channel analysis
  - Has been extensively modified, improved and validated to expand its range of applicability.

COBRA (1965) → COBRA-TRAC (1981) → WCOBRA-TRAC (1985)

COBRA-III (1970) → COBRA-TF (1979) → COBRA-NC (1983)

COBRA-IV (1977) → COBRA-WC (1980)

FATHOMS (1985)

VIPRE (1979) → COBRA-SF (1984)

GOTHIC (1989) → GOTHIC 4.x (1993-1995) → GOTHIC 5.x (1995-1997)

GOTHIC 8.4 (2022) ← GOTHIC 8.1-8.3 (2012-2019) ← GOTHIC 7.x (2002-2004) ← GOTHIC 6.x (1997-2001)

gPIPE add-on (2024)

Molten salt properties (from v8.3)

GOTHIC 8.5 (2024) → GOTHIC 9.0 beta (2027~)

CVAN Non-dimensional number generator (2025)

CSVis Control variable visualization tool (2026)

Liquid metal and heavy water properties (2026)

*YJ Choi et al., Completion of the GOTHIC v8.5 Multi-Physics Analysis Package Development, ANS 2025 Conference

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# Fundamental of GOTHIC

- Multiphase and multicomponent
  - Underlying conservation equations
  - Interphase heat, mass, and momentum transfer
  - Thermal conductors and wall heat transfer
- CFD-like capabilities
  - Coarse-grid CFD (CGCFD)
    - Combined lumped and subdivided volumes
    - Superimposed heat conductors
  - Semi-implicit finite volume discretization
    - Reynolds averaged Navier-Stokes equations
- Engineered equipment and components
  - Including control systems
  - Main and aux. buildings / Spent fuel storages
- User interface and post-processing
- Integrated training modules
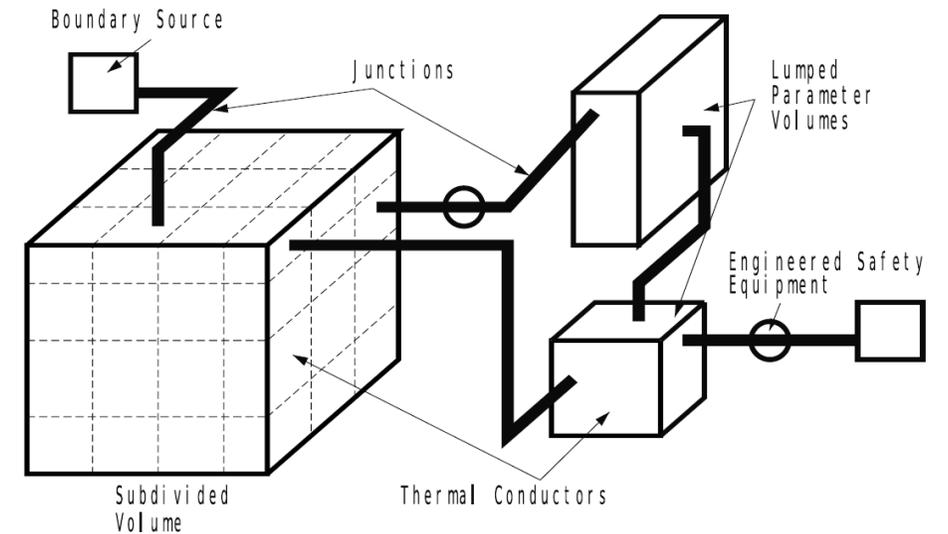


*Concept of coarse-grid analysis of GOTHIC*

| Feature | GOTHIC | CFD |
|---|---|---|
| Grid/Mesh | Rectangular with volume and area porosity | Body fitted |
| Molecular diffusion (Mass, energy, momentum) | Yes | Yes |
| Turbulent diffusion (Mass, energy, momentum) | Yes | Yes |
| Boundary layer wall effected | Correlations (heat transfer coefficient, friction factors) | Detailed |
| Phase change | Condensation, evaporation, boiling, gas dissolve | Limited |
| Equipment or component models | Yes | No |

*Feature comparison between GOTHIC and CFD*

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# Features of GOTHIC

- Multi-phase heat and mass transfer
  - Transient / Compressible / Separation / Jet / Buoyancy
  - Full 3D capabilities in turbulence and diffusion
  - Condensation and evaporation / Mixing and stratification

- Wide range of fluids
  - $H_2O$, $D_2O$, molten salts (e.g., FliBe, FLiNaK), sodium (Na, NaK), lead and lead-bismuth eutectic, gases (e.g., He, $H_2$)

- Specific component modeling
  - Piping, room, pool, tank, pump, fan, valve, door, heat exchanger, etc.

- Specific phenomena modeling
  - Combustion, drop, mist, aerosol, ice, dissolve gas, solid particle, fission products, etc
  - Point reactor kinetics and reactivity feedbacks

- Trip and control systems / Integrated code coupling

- Add-ons for specific features
  - gPIPE, Non-dimensional parameter, visualization tools, etc

- Fully integrated graphic user interphase
  - Flexible nodalization from lumped (0D) to 3D
  - Operating in Windows and Linux systems
  - Self-training modules and samples
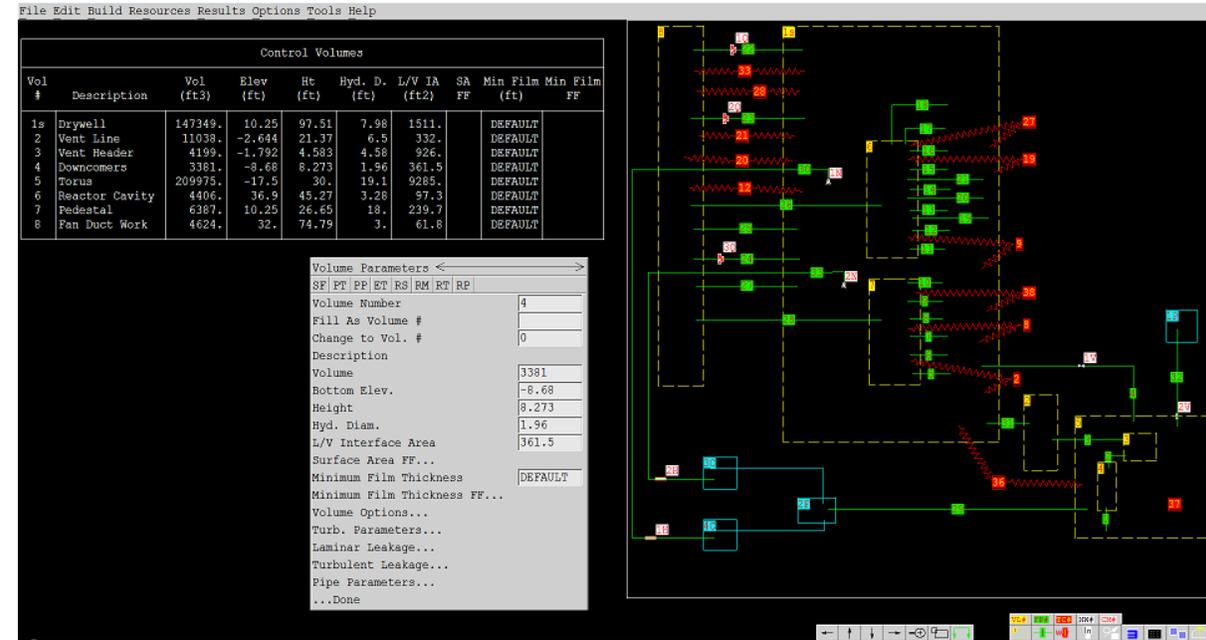


*GOTHIC graphic user interphase*
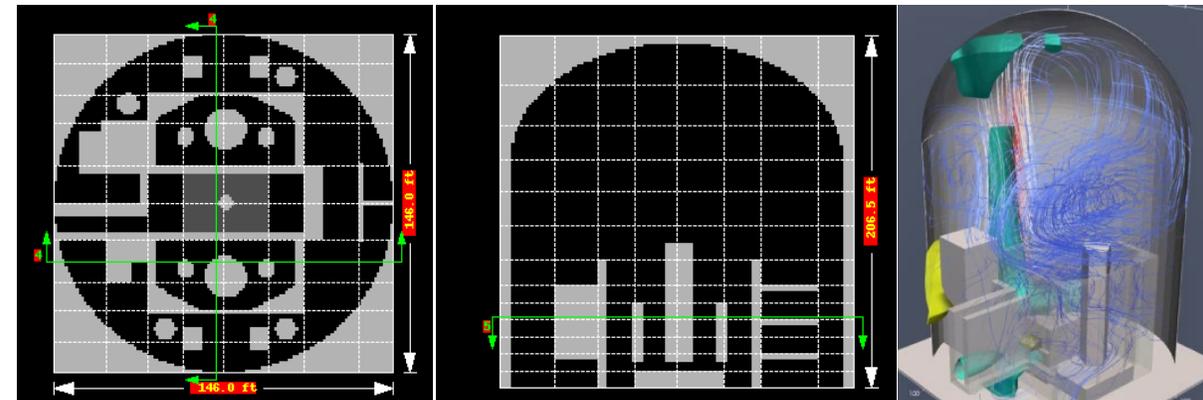


*Example of 3D containment analysis*

# User Interface of GOTHIC

- Graphical model construction
  - Fast, flexible creation
  - Simple nodalization diagrams
  - Structured tables for input
  - Tracks model element links

- User friendly features
  - Input error checking
  - Model comparison utility
  - Version sensitivity study
  - User action record and playback

- Post-processing
  - Graphical and tabular output
    - Line, vector and contour plot
    - AptPlot to read GOTHIC graphes
  - Output data compatible with other commercial tools
    - TECPLOT$^{TM}$, VisIt, ParaView



*
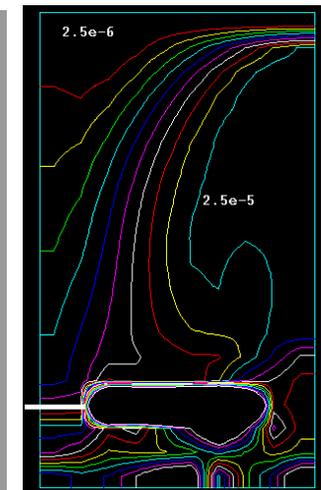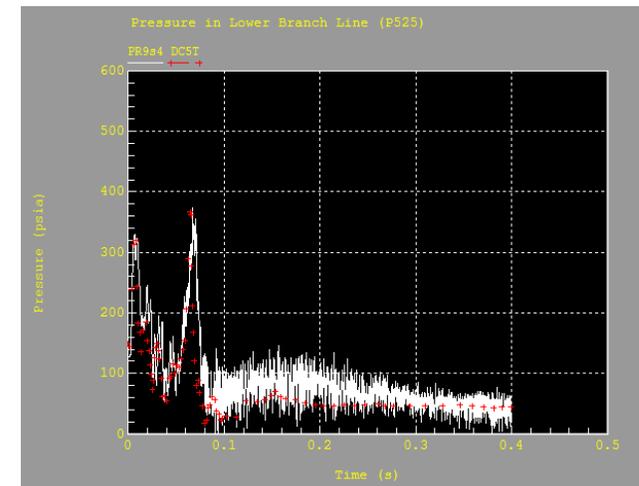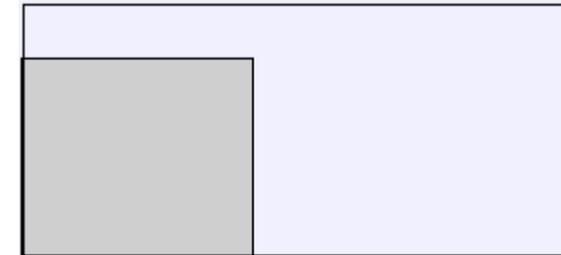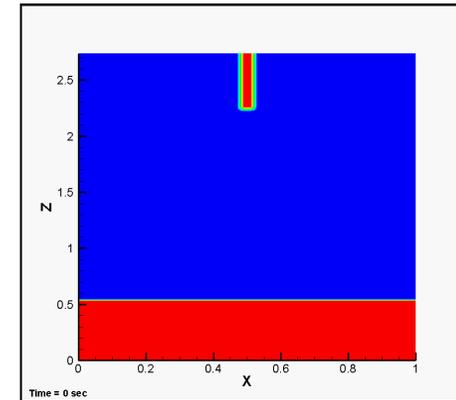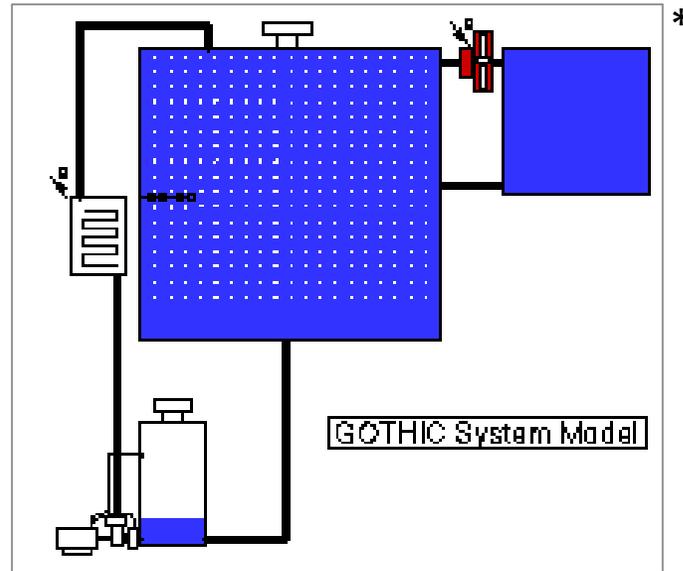
*GOTHIC post-processing examples*

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# Development of GOTHIC v9.0

- Major upgrade in GUI
  - Multiple tables and tree navigation
  - User friendly design and easy customization
  - Dynamic input data checking
  - Classic option also available
- New physics models
  - Drops and aerosol models / aerosol nucleation / spanned conductor, etc
- Uncertainty analysis capability
- GOTHIC launcher for multiple execution
- New benchmarks
  - Vattenfall condensation pool / Brown Ferry thermal stratification / GE level swell / Rancho Secor spray pond test / High Rayleigh or pressure condensation tests
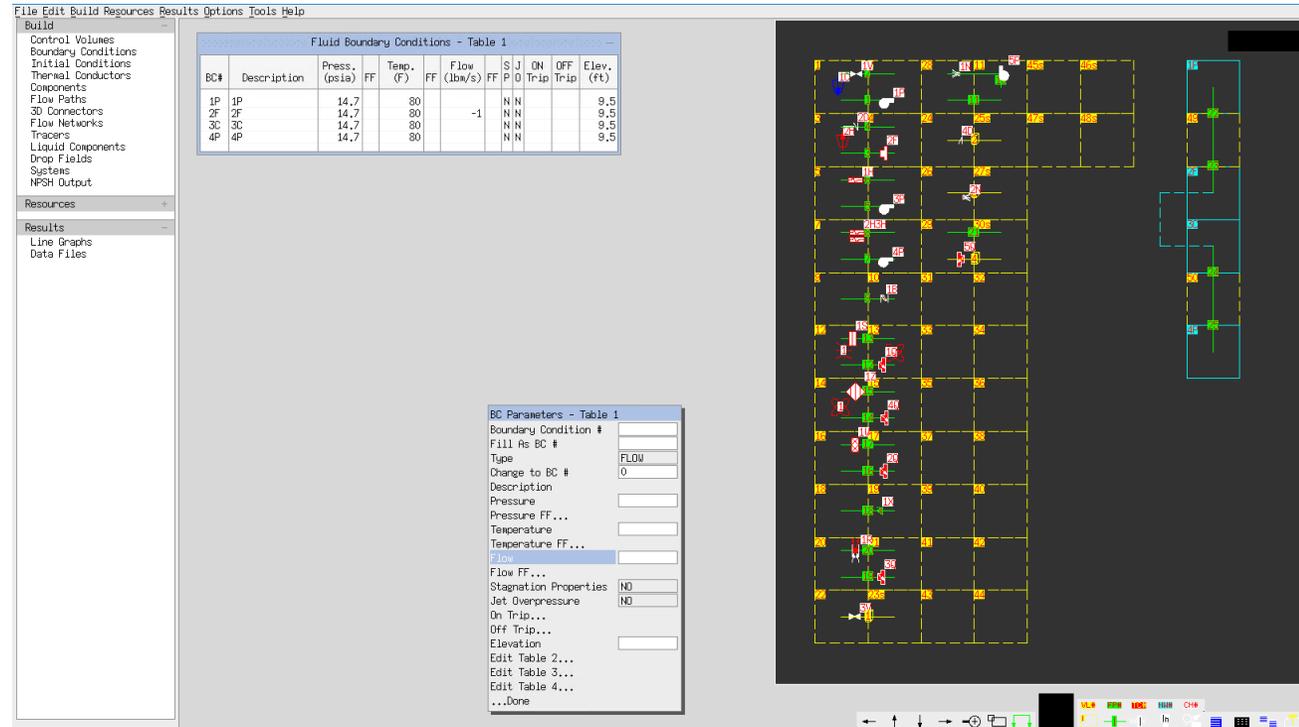


*Updated GOTHIC v9.0 GUI*

## GOTHIC v9.0 Beta version release in early 2027

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# GOTHIC Advisory Group

- EPRI supports GOTHIC users
  - Maintain code quality and provide technical support
  - Build worldwide network and collect feedback and error
  - Develop and release new versions and add-ons
  - Organize annual Safety Technology Week
    - **June 15-19, 2026, EPRI Charlotte office**
  - Provide training, webcast and workshop
  - Publish quarterly newsletter and error report
    - Events / User guide / Action items / Publications
  - Archive documents and previous versions
    - GOTHIC Wiki (https://gothic.epri.com)
  - Participate in various communities and conferences
    - Special session

**Please contact gothic@epri.com for the membership**

# GOTHIC Application Guide (EPRI Product 3002032029)

Edition 2025

- Containment integrity analysis
- Sub-compartment analysis
- Equipment qualification
- Minimum containment backpressure
- Analysis of HELBs outside containment
- Containment leakage
- Net positive suction head
- Primary system analysis

- Time to boil analysis
- Suppression pool analysis incl. pool stratification
- Piping system modeling
- Unwrapped geometries
- Charcoal filter
- Gas deflagation
- Dry fuel storage system modeling
- Uncertainty and sensitivity analyses

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2025 TECHNICAL REPORT

GOTHIC
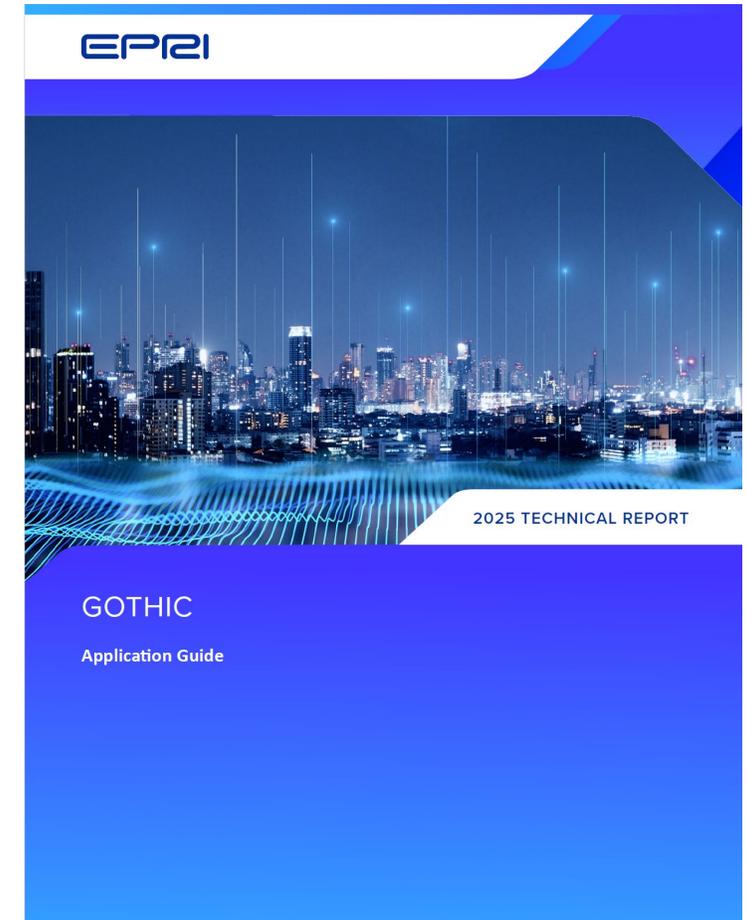
Application Guide

**Publicly available modeling guide examples**

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# GOTHIC Application to PWR

- 4-loop PWR shutdown cooling*
  - Loss of residual heat removal in 1-loop
  - Maximum inventory loss when relief valves open
  - Open vessel drain line
  - Analyze recovery time after operator action
- Modeling considerations
  - Buoyancy dominated flow from downcomer to reactor core
  - Cylindrical reactor, upper & lower plenum
  - SG and guide tubes and support structures
  - Uncovered reactor core and multi-phase flow
  - Leakage path and refueling pool
  - Heat source from decay heat
  - Heat conduction through guide tubes and structures
  - Film boiling option
  - See GOTHIC User Manual 28.1*
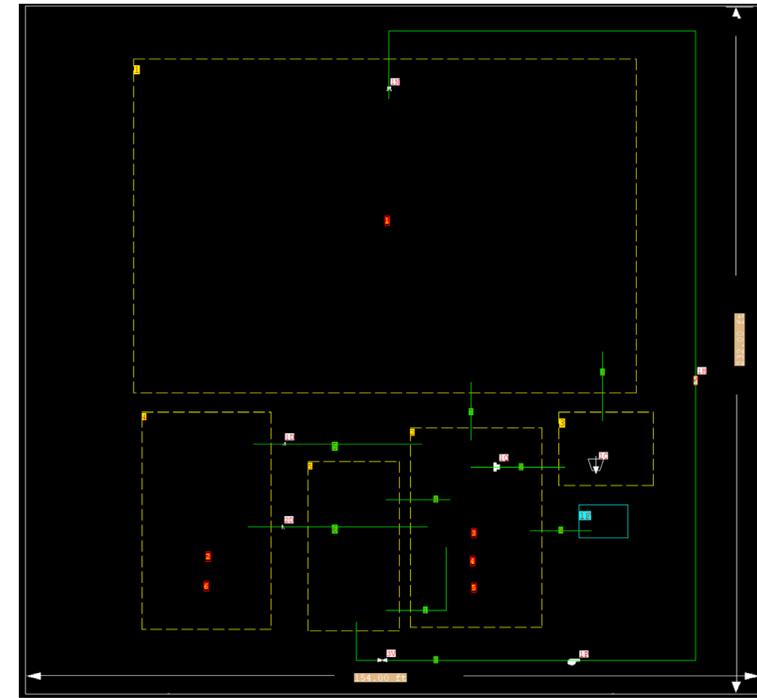


*GOTHIC nodalization of PWR containment**



*Compartment pressure (left) and temperature (right)*

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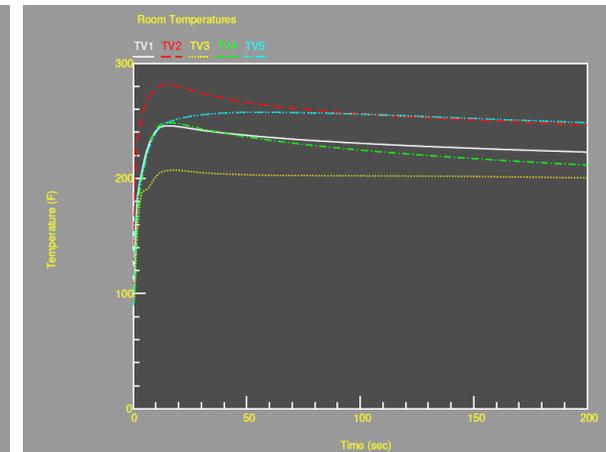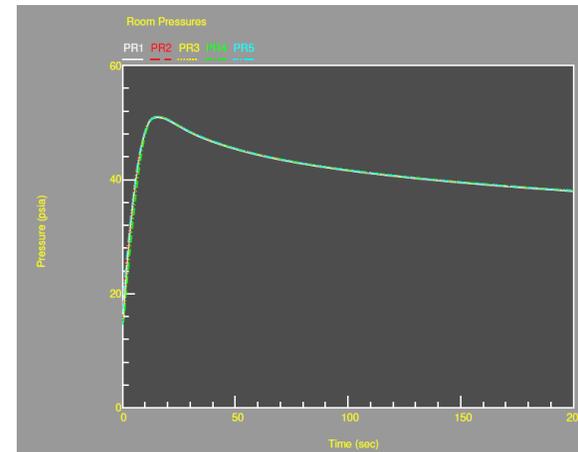
# GOTHIC Application to BWR



*GOTHIC nodalization of Mark I BWR containment\**

- Mark I BWR containment
  - Loss of containment cooling and heated up
  - Spray cooling water to drywell
  - Analyze containment thermal-hydraulics behavior
- Modeling considerations
  - Condensation and evaporation
  - Wetwell and drywell
  - Spray system
  - Ventilation ducts
  - Reactor cavity
  - See GOTHIC User Manual 28.2*



*Compartment pressure (left) and temperature (right)*

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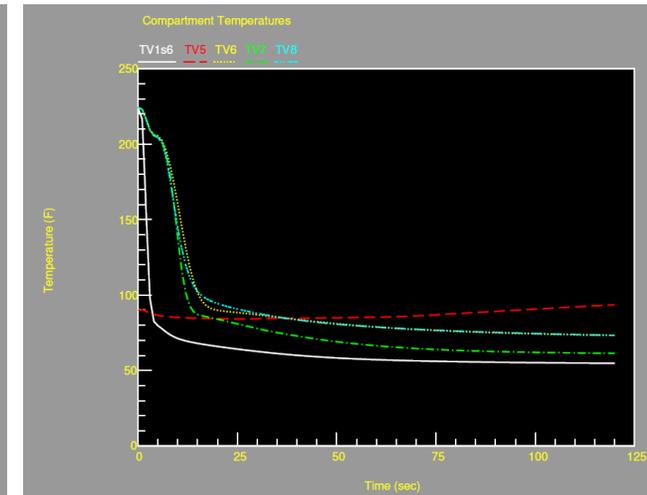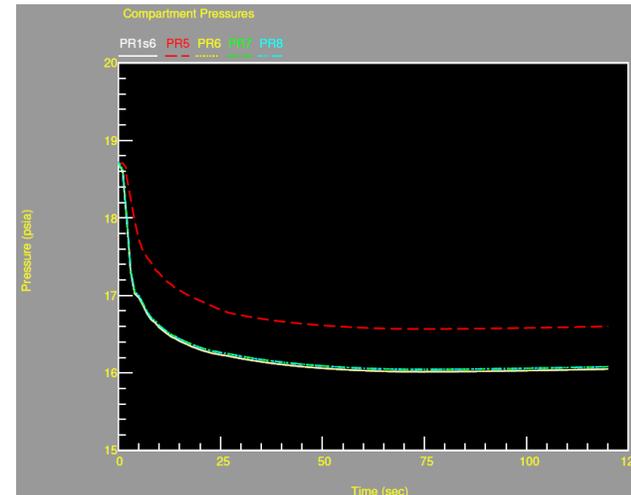
# GOTHIC Application to HTGR

- **Simplified pebble bed HTGR**
  - Models forced convection, natural circulation, buoyancy and stratification
  - Includes molecular and turbulent diffusion models
- **Modeling considerations**
  - Spherical conductors for pebble bed designs
  - Thermal conductivity model for simulating conduction cooldown events
  - Surface-to-surface radiative heat transfer
  - 2D conduction heat transfer in solids
  - Model transport, settling and resuspension of solid materials in the system such as graphite dust
  - See GOTHIC User Manual 28.3*
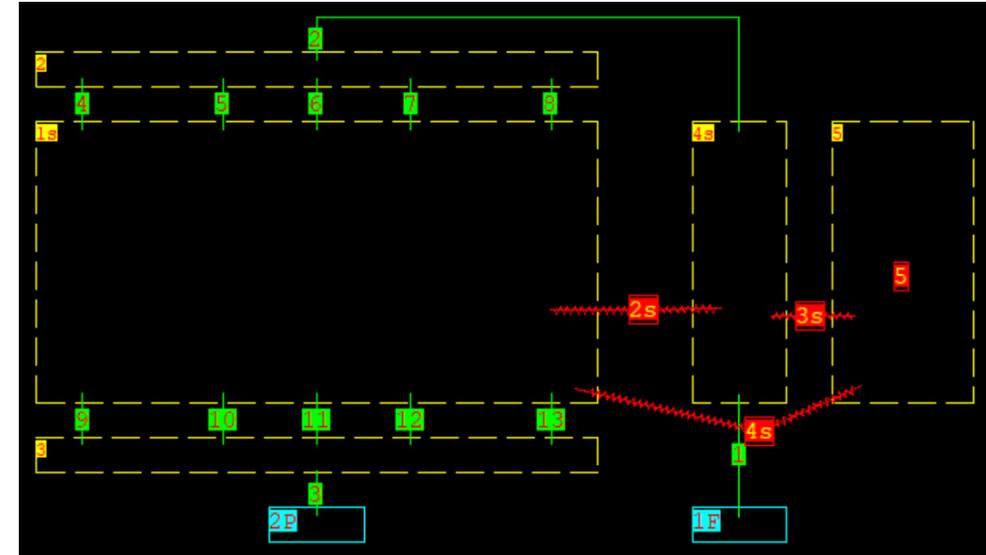


*HTGR GOTHIC example nodalization**

# GOTHIC Application to SFR

- Evaluation steady-state and transient response of an SFR design
  - Primary and intermediate systems using sodium
  - Secondary-side of steam generators using water
  - Direct reactor auxiliary cooling system (DRACS) using NaK
  - Sensitivity studies for design optimization
  - Sodium-Water reaction
  - Fluid hammer model
- Benchmark activities for the code validation
  - EBR-II SHRT-17 and 45R protected and unprotected loss of flow (LOF)*
  - EBR-II BOP-301/302 unprotected loss of heat sink (LOHS)
  - SHRT-25-26 reactivity feedback due to change in flow/temperature
  - FFTF loss-of-flow without scram test coordinated by IAEA
  - Sodium stratification using SUPERCAVNA (CEA France) and U. of Wisconsin tests
  - Speed of sound and fluid hammer using the large leak test rig (LLTR)
  - Natural convection shutdown heat removal test facility (NSTF)
  - Sodium freeze vent performance
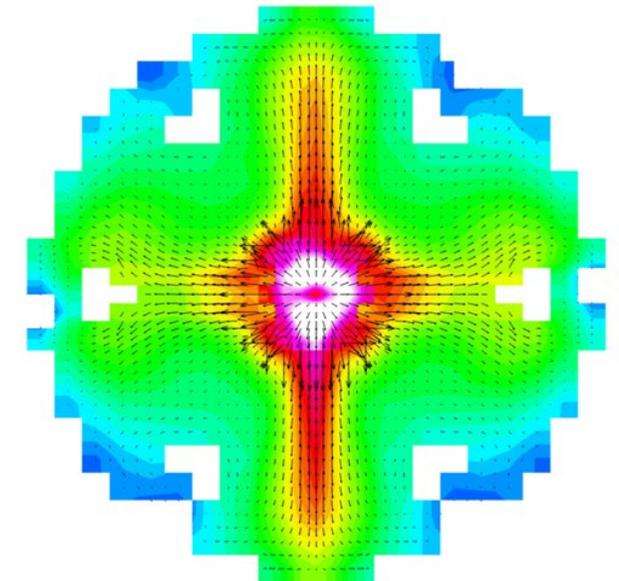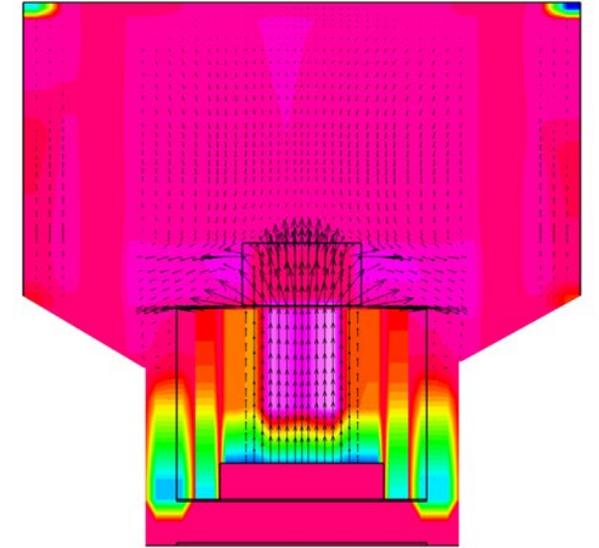


*SFR modeling example with GOTHIC*

*J. W. Lane et al., Benchmark of GOTHIC to EBR-II SHRT-17 and SHRT-45R Tests. Nuclear Technology 206, 2020

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# GOTHIC Application to MSR

- GOTHIC capability related to MSR analysis
  - Properties of six molten salts
    - NaCl-MgCl$_2$, LiF-BeF$_2$ (FLiBe), LiF-NaF-KF (FLiNaK), NaF-ZrF$_4$, KF-ZrF$_4$, and NaBF$_4$-NaF
  - Point neutron kinetics model considering delayed neutron precursor transit time
  - Additional features available*
    - Alternative friction factors
    - Heat transfer coefficients
    - For particular fluid or fuel rod design
    - Ice modeling for overcooling transient or freeze plug
    - Off-gas system model and source tracing
    - Corrosion or foreign object transportation
- Benchmark and related activities
  - Model validation through MSRE experiment**
  - Modeling support for Molten Salt Research Reactor (MSRR)
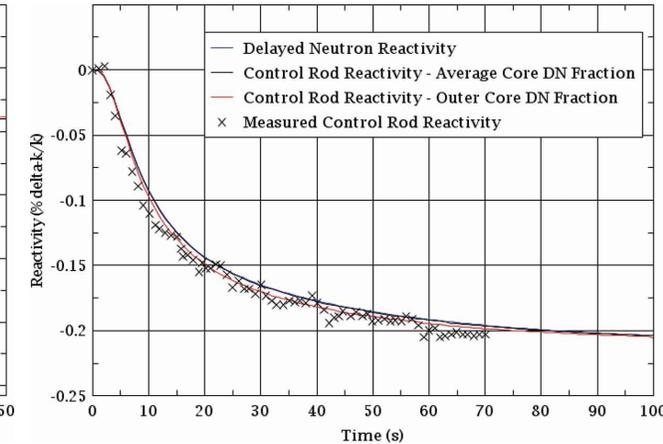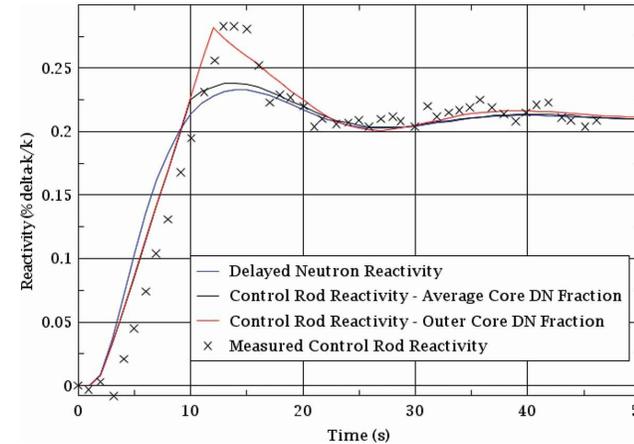


*Reactivity feedback of pump startup (left) and coast down (right)*
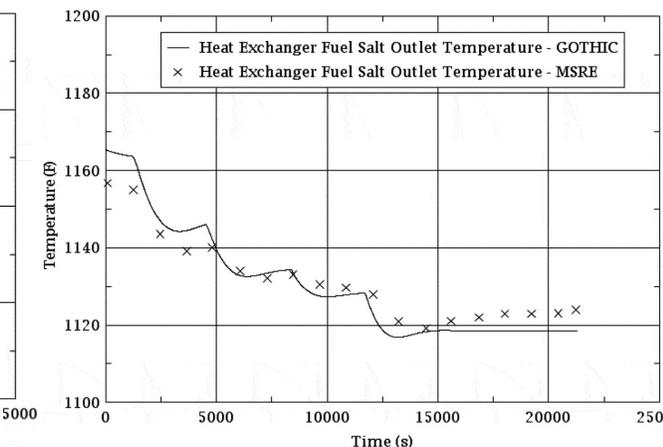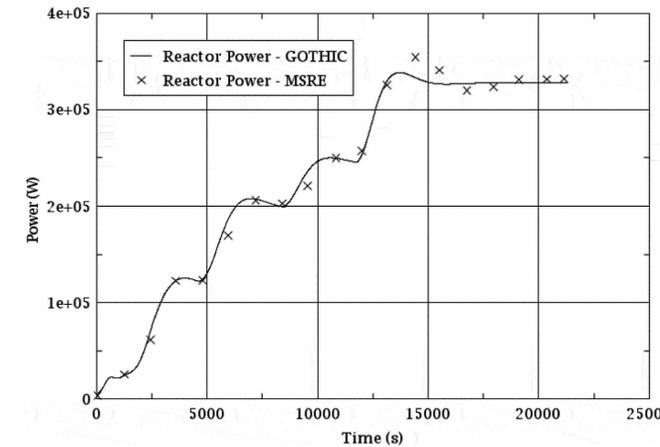


*Reactor power (left) and coolant temperature at HX outlet (right)*

* Available through NAS, **J.W.Lane et al., Steady-State and Transient Benchmarks of GOTHIC to the Molten Salt Reactor Experiment, Nuclear Technology, Vol. 208, 2022

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# GOTHIC Application to SMR

- Passive decay heat removal systems
  - Passive Containment Cooling System (PCCS)
  - Reactor Cavity Cooling Systems (RCCS)
  - Natural circulation (water cooled) or natural draft (air cooled) systems
- THAI+ experiment SMR2*
  - Submerged reactor containment as passive safety feature
  - Benchmark SMR2 LOCA experiment focus on containment simulator
  - Modeling considerations
    - Natural convection heat transfer
    - Very high Rayleigh numbers (>10E6) which exceeds range in safety codes
    - Pressure, temperature, velocity profile in pool
  - Result proposes modification of Churchill-Chu correlation
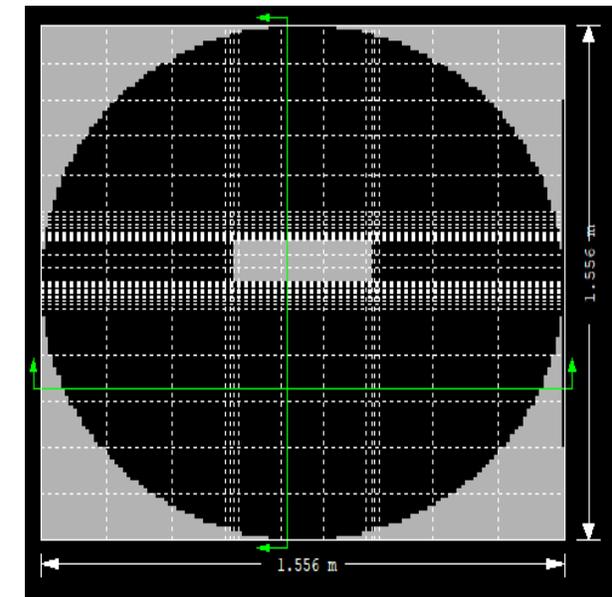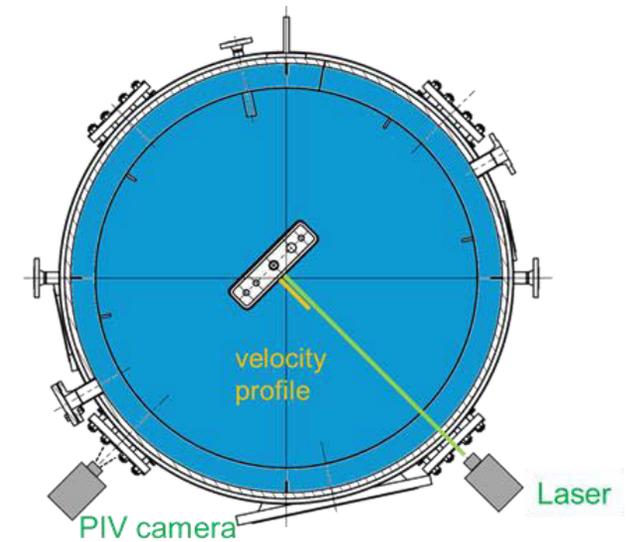




*Top view of THAI+ facility and GOTHIC nodalization*

*J. Lane et al, GOTHIC Benchmark to a Containment Vessel Passive Cooling Experiment, ANS Winter conference and expo, 2024

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# Benefit from GOTHIC

## Quality

- Over 40 years
- QA program
- Qualification
- Benchmark
- Full V&V
- Export Control

## Application

- Licensing tool
- Widely used
- Multi-physics
- Components
- GUI and post-process
- Academic use

## Support

- User group
- Stable funding
- Technical help
- Training
- EPRI and NAS
- Error tracking

**Using GOTHIC will establish cost-effective safety analysis**

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