

GOTHIC

Thermal Hydraulics Analysis Code

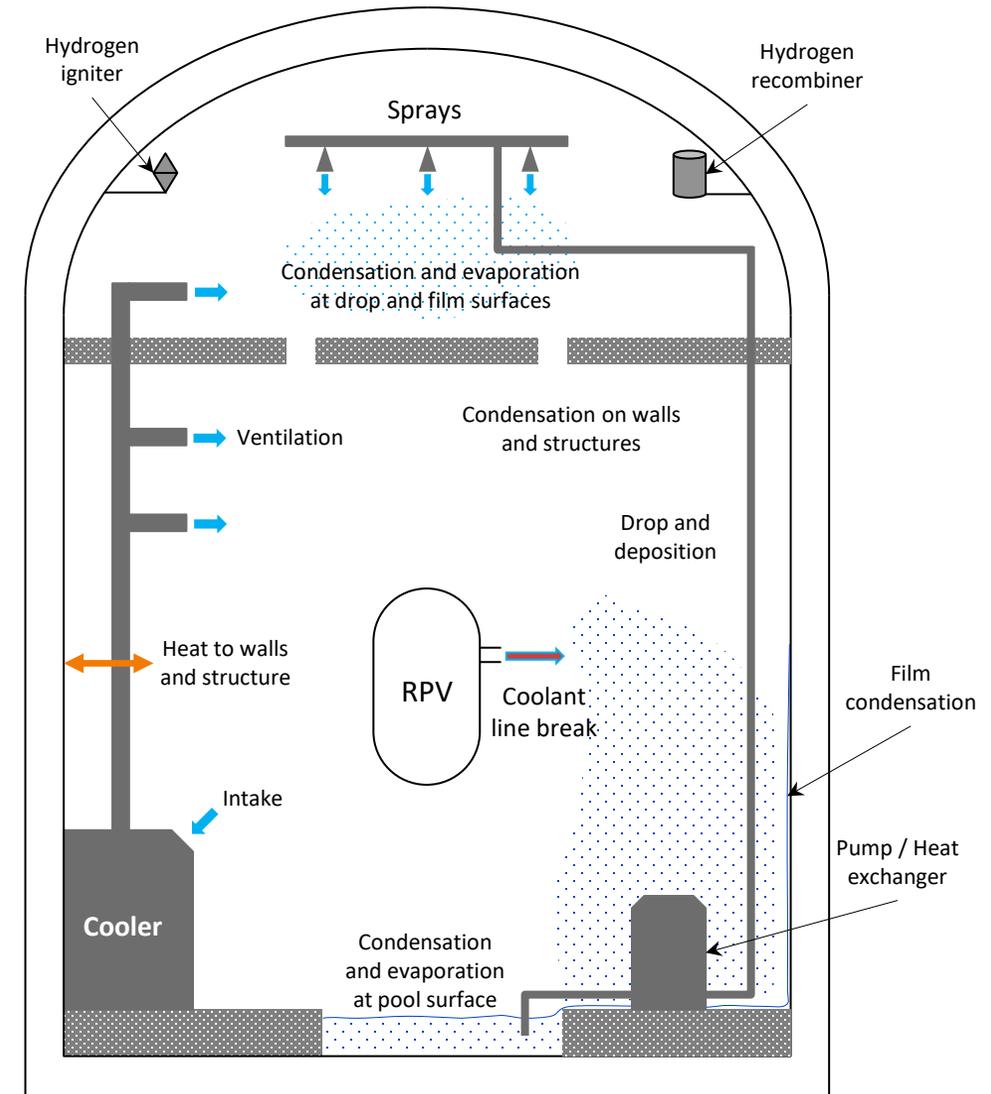


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Edition 2026

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

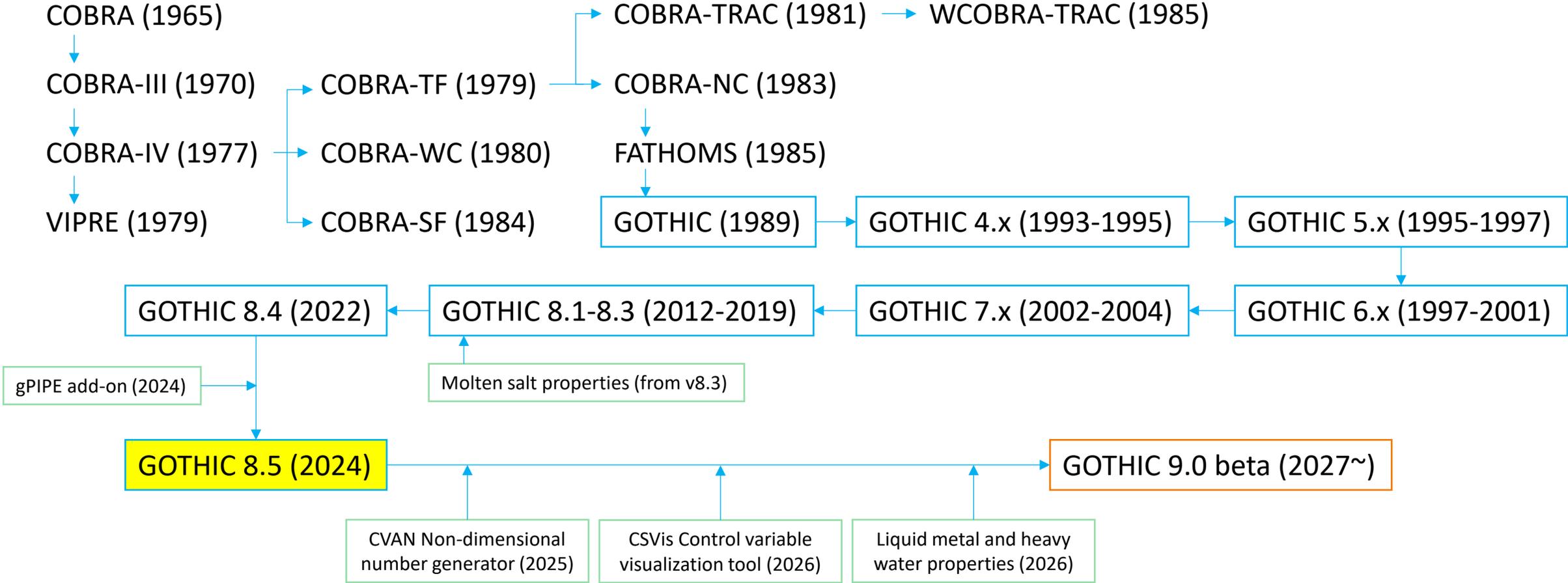


Major phenomena of containment analysis

EPRI Controls Quality and License of GOTHIC

GOTHIC Development History*

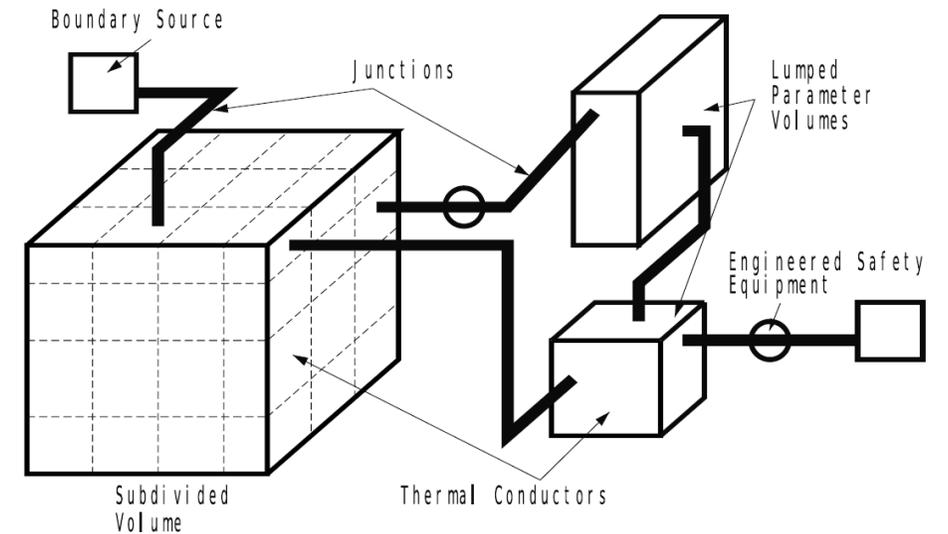
- GOTHIC is a descendant of the COBRA series which was originally developed for sub-channel analysis
 - Has been extensively modified, improved and validated to expand its range of applicability.



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

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



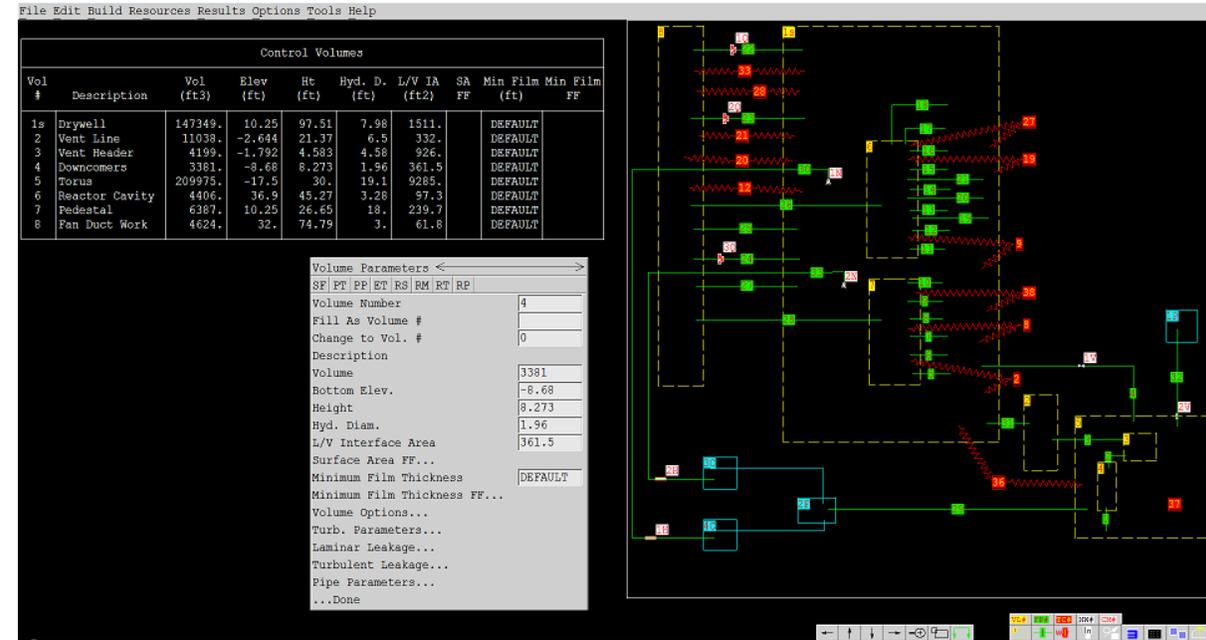
Concept of coarse-grid analysis of GOTHIC

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

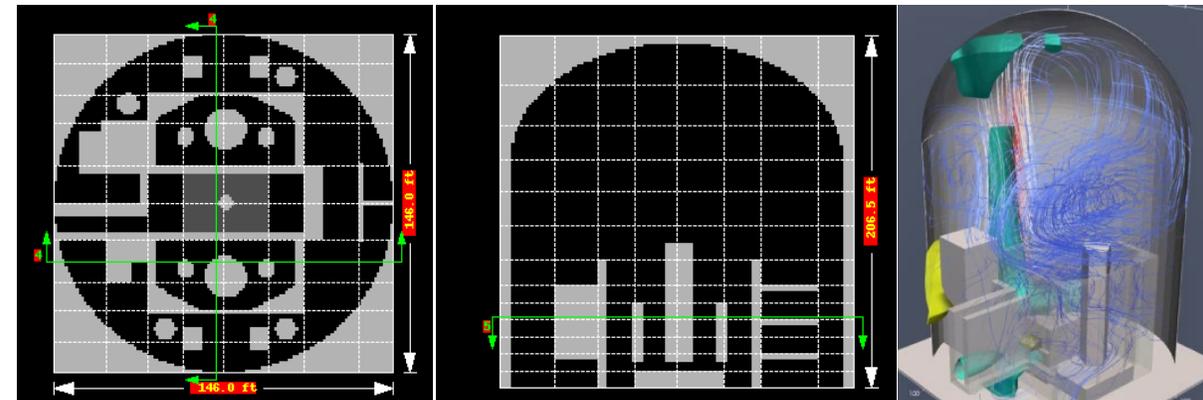
Feature comparison between GOTHIC and CFD

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
 - H₂O, D₂O, molten salts (e.g., FLiBe, FLiNaK), sodium (Na, NaK), lead and lead-bismuth eutectic, gases (e.g., He, H₂)
- 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



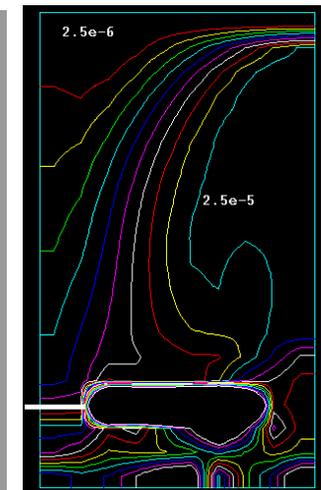
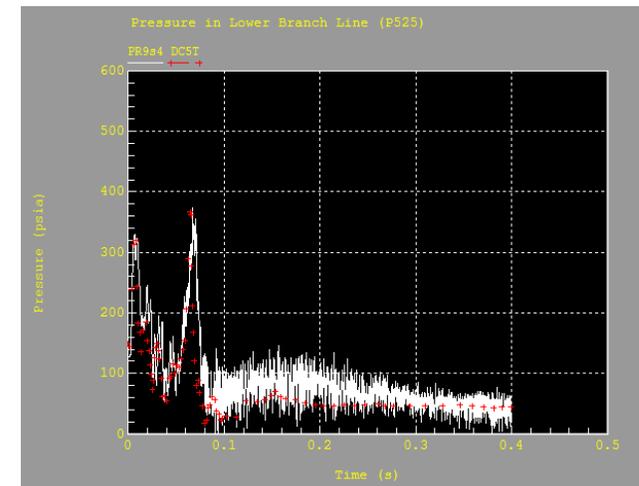
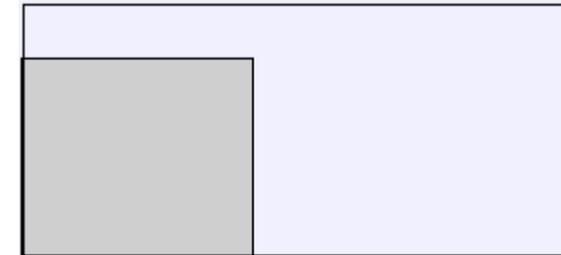
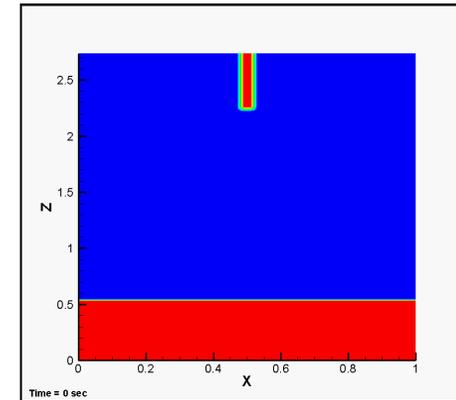
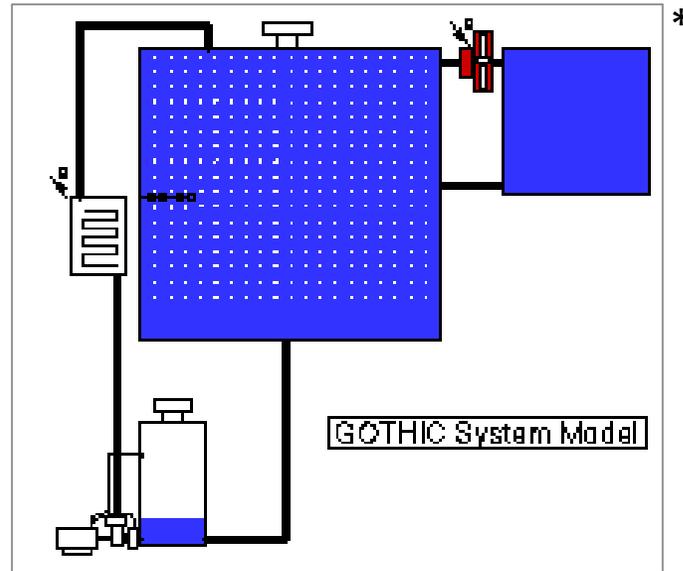
GOTHIC graphic user interphase



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™, VisIt, ParaView

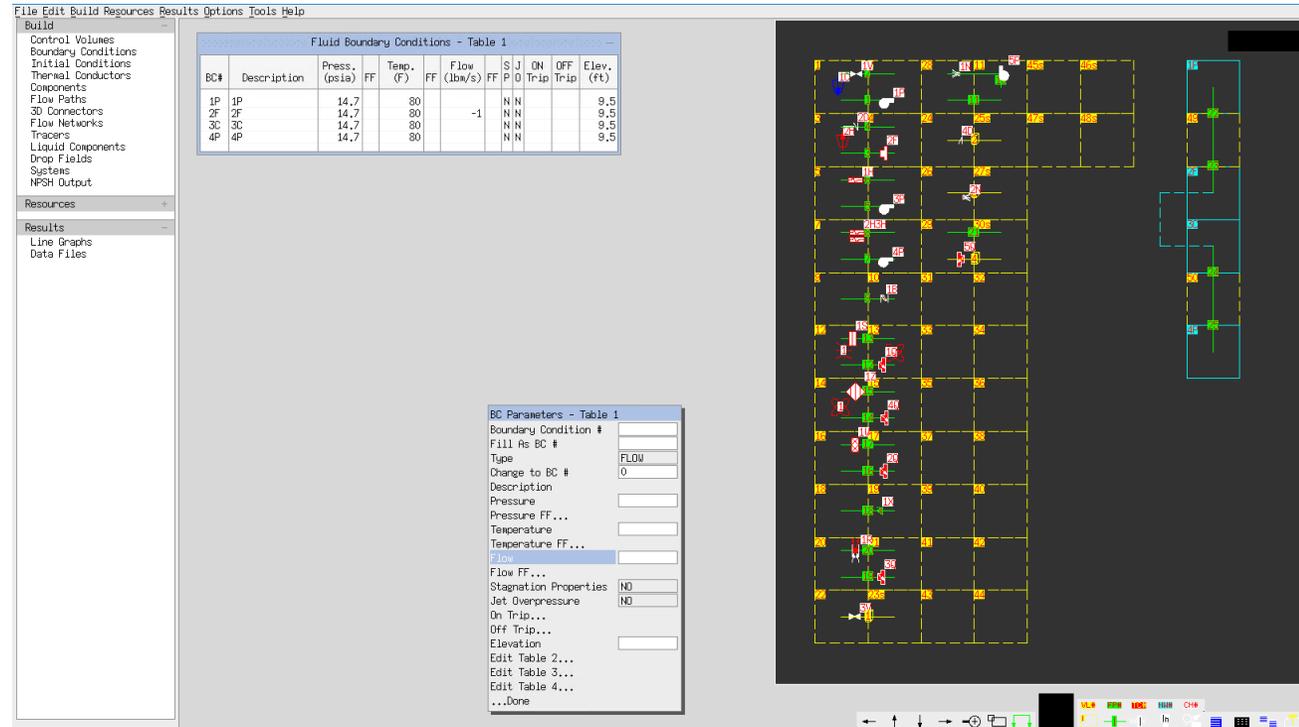


GOTHIC post-processing examples

*Figures from <https://www.numerical.com/software/gothic/>

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

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

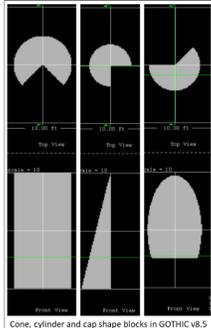
Please contact gothic@epri.com for the membership



October-December 2024

GOTHIC Advisory Group Newsletter

An EPRI Progress Report for the GOTHIC Advisory Group



Cone, cylinder and cap shape blocks in GOTHIC v8.5

About the Newsletter

This newsletter is published quarterly with input from both EPRI and NAS. Newsletters along with all GOTHIC Advisory Group materials throughout the year are posted on the advisory group [website](https://gothic.epri.com). If you have comments about the newsletter or need to be added to the EPRI GOTHIC distribution list, please contact EPRI's GOTHIC Project Manager, YJ Choi at yjchoi@epri.com, +1 (650) 855-2788

This GOTHIC Newsletter includes updates and information on the following topics:

- **Release of GOTHIC v8.5**
- **Upcoming Events**
- **4th Quarter 2024 GOTHIC Webcast**
- **Quick Tips:** Diagnose limiting locations with debug output option
- **User Guide:** Creating flipbook animation with vector and contour plots
- **Action Item**
 - A18.5-020: Mass error with volumetric fan option Action Items
- **Publications with GOTHIC Application**
- **GOTHIC Code Status**
- **Attachment 1:** Quarterly Error Summary Report

Reminder: Release of GOTHIC v8.5

The GOTHIC v8.5 thermal hydraulics analysis package is now available at EPRI Software Center products: [3002029326](#) (Windows), [3002029325](#) (Linux), and [3002029327](#) (Molten Salt Libraries).

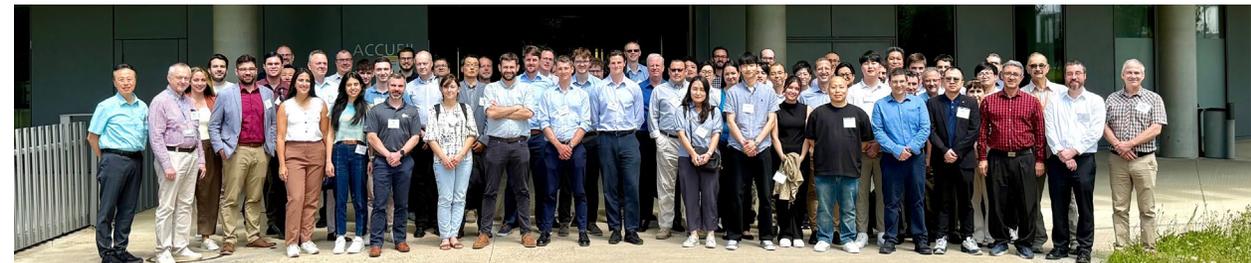
The GOTHIC v8.5 contains a variety of major new features and improvements that expand the range of applicability and make the software easier to use. Examples of new feature includes:

- Enhanced 3D simulation capability
- Update of pool scrubbing and spray nozzle models
- Development of multiple models for advanced nuclear reactor applications
- Various improvement of user interface and command file capability

GOTHIC Advisory Group Newsletter

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October-December 2024



Search GOTHIC

Main Page

Welcome to GOTHIC thermal hydraulics package support wiki page. This wiki provides comprehensive user guidance through application examples using real nuclear power plant data. If you have any question, please contact at gothic@epri.com

Developed by Electric Power Research Institute (EPRI) and Numerical Advisory Solutions LLC (NAS), GOTHIC is a comprehensive, versatile, multi-physics software package designed for the analysis, licensing, safety, and operational assessment of nuclear power plant containment, confinement buildings, and system components. It integrates coarse grid computational fluid dynamics (CFD) capabilities with system-level modeling functionalities. GOTHIC's applications encompass the evaluation of containment and sub-compartment response to a wide range of high-energy line breaks within design basis events. Additionally, it supports various system evaluations involving multiphase flow, heat transfer, gas mixing, and other thermal-hydraulic behaviors. Potential applications include, but are not limited to, determining pressure and temperature, establishing equipment qualification profiles, and analyzing inadvertent system initiations and the degradation or failure of engineered safety features. As a general-purpose tool, GOTHIC is suitable for a broad spectrum of plant operations support issues involving single and multiphase heat transfer and fluid flow, provided the application aligns with the underlying physical principles, assumptions, and code validation basis.

Figure 1 illustrates a schematic of the GOTHIC modeling concept. GOTHIC employs a domain decomposition approach, enabling the application of varying levels of fidelity from 0D to full 3D within a single model. This flexibility allows users to concentrate computational resources on specific regions of interest while still capturing the overall system response and critical feedback effects. Shown in Figure 2, GOTHIC has its own integrated graphical user interface (GUI) which makes model setup fast, accurate, and reliable with thorough error checking as well as generation of graphical output to allow the user to easily evaluate the simulation results.

The GOTHIC software package is developed and maintained under a quality assurance program that complies with U.S. 10 CFR 50, Appendix B, 10 CFR 21

GOTHIC Advisory Group

RISK AND SAFETY MANAGEMENT PROGRAM / GOTHIC ADVISORY GROUP

GOTHIC Advisory Group

Overview

The GOTHIC code enables users to analyze actual and simulated nuclear plant scenarios, with special features for the thermal-hydraulic response of containment buildings. GOTHIC is a general purpose thermal hydraulics computer program used to support the design, licensing, safety and operating analysis of nuclear power plants and other thermal-hydraulic systems. GOTHIC is used as an engine basis for a wide range of applications. A few specific applications for nuclear plant analysis include: containment pressure and temperature during design basis accidents (DBAs), environment profiles for equipment qualification (EQ), technical specifications (TS) evaluations, sub-compartment analysis to predict local temperatures and differential pressures, primary system response, and spent fuel pool modeling. The software is developed under 10CFR50 Appendix B, QA requirements for regulatory applications.

The GOTHIC Advisory Group provides user support and guides ongoing development and enhancement of the GOTHIC code. The Advisory Group is a community of U.S. and international utilities, and vendor experts within the fields of nuclear and thermal hydraulics. Application and expertise from use of the GOTHIC code is shared among members. Software updates as additional features and enhancements are added are distributed to members of the GOTHIC Advisory Group.

EPRI Contact
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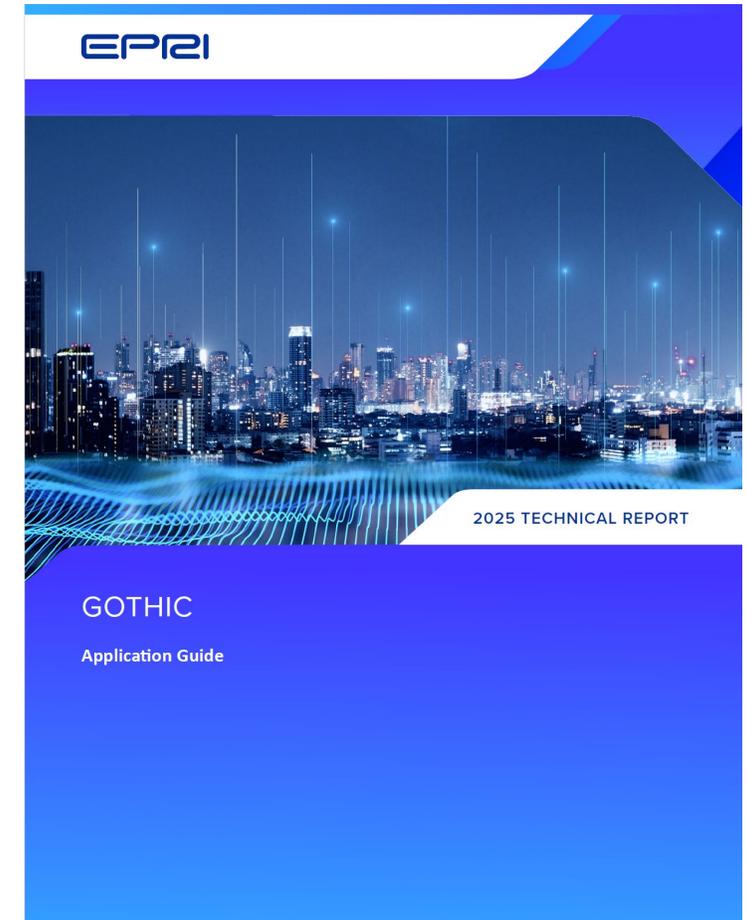
GOTHIC Advisory Group

Year	Issued
Legacy Information	Mon Jun 27 2022
2024	Fri Feb 08 2025
2023	Tue Jun 25 2024
2022	Thu Jun 9 2022
2021	Mon Oct 17 2022

GOTHIC Application Guide (EPRI Product [3002032029](#))

Edition 2025

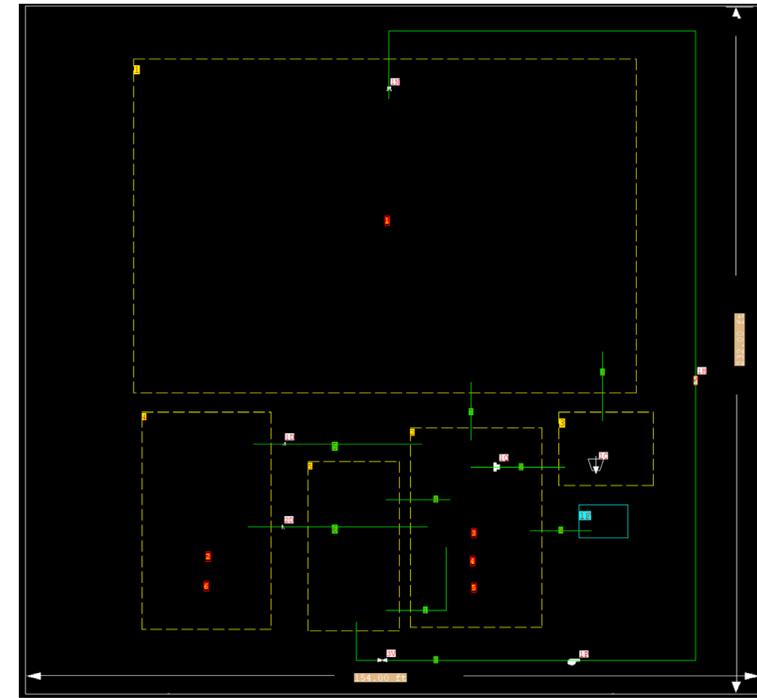
- Containment integrity analysis
- Sub-compartment analysis
- Equipment qualification
- Minimum containment backpressure
- Analysis of HELBs outside containment
- Containment leakage
- Net positive suction head
- Primary system analysis
- Time to boil analysis
- Suppression pool analysis incl. pool stratification
- Piping system modeling
- Unwrapped geometries
- Charcoal filter
- Gas deflagration
- Dry fuel storage system modeling
- Uncertainty and sensitivity analyses



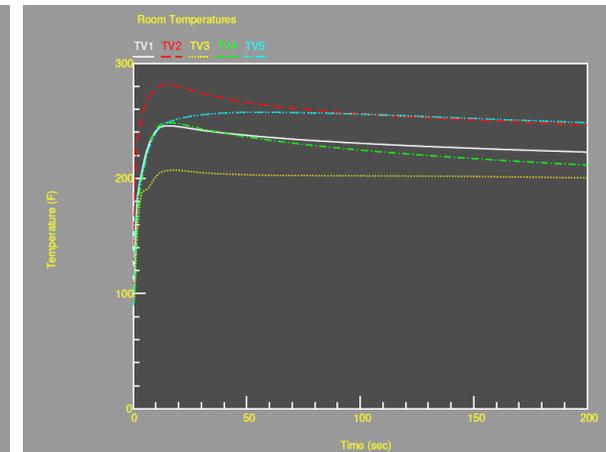
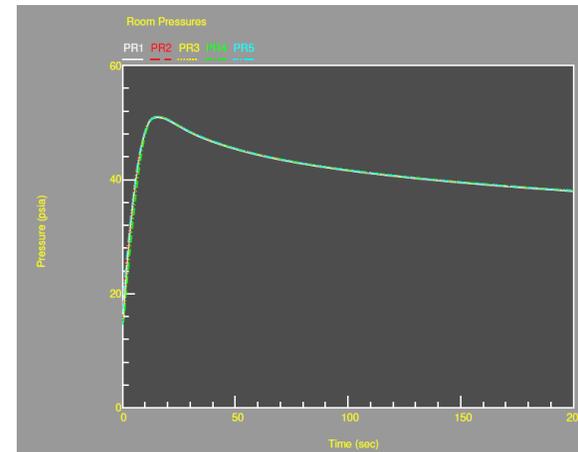
Publicly available modeling guide examples

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*



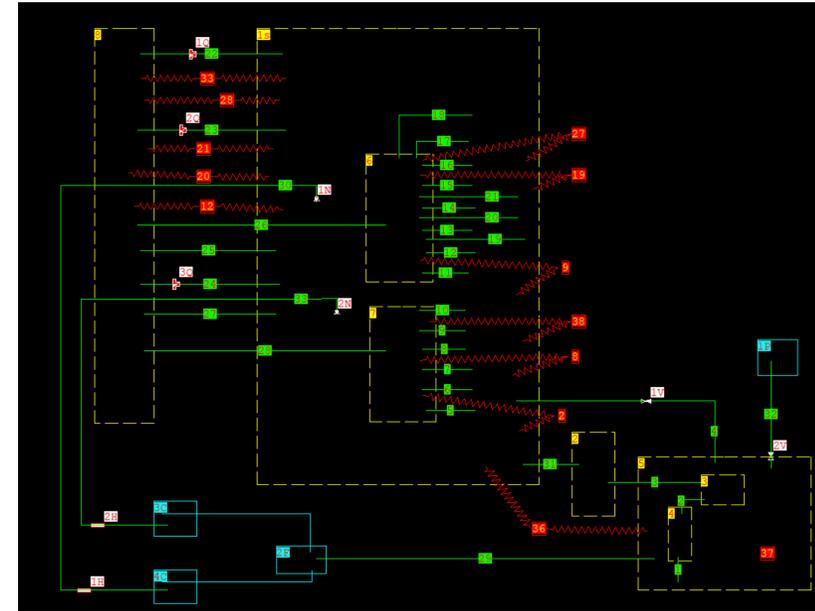
*GOTHIC nodalization of PWR containment**



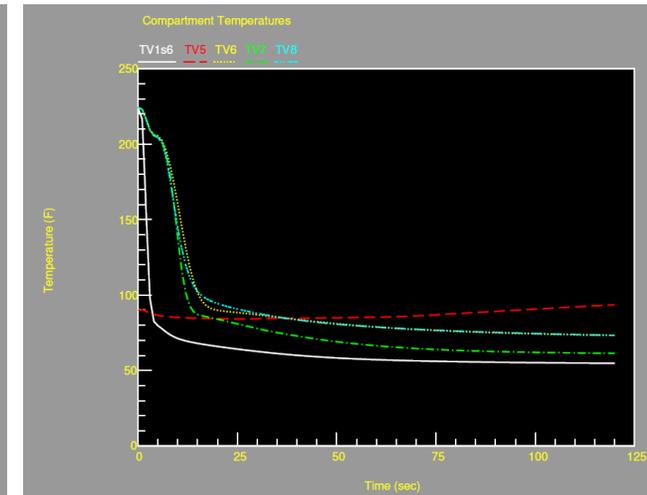
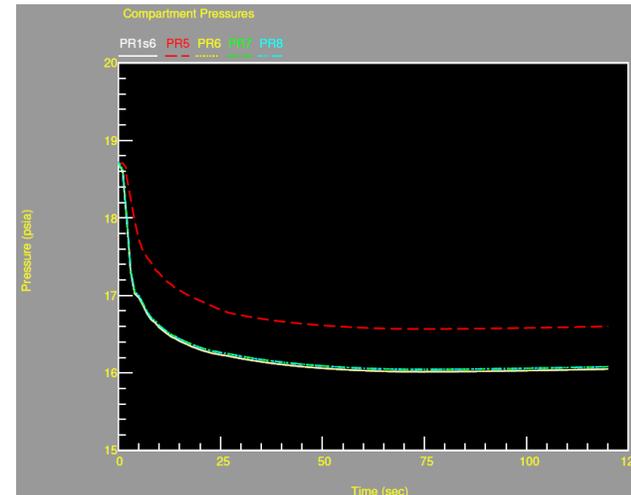
Compartment pressure (left) and temperature (right)

GOTHIC Application to BWR

- 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*



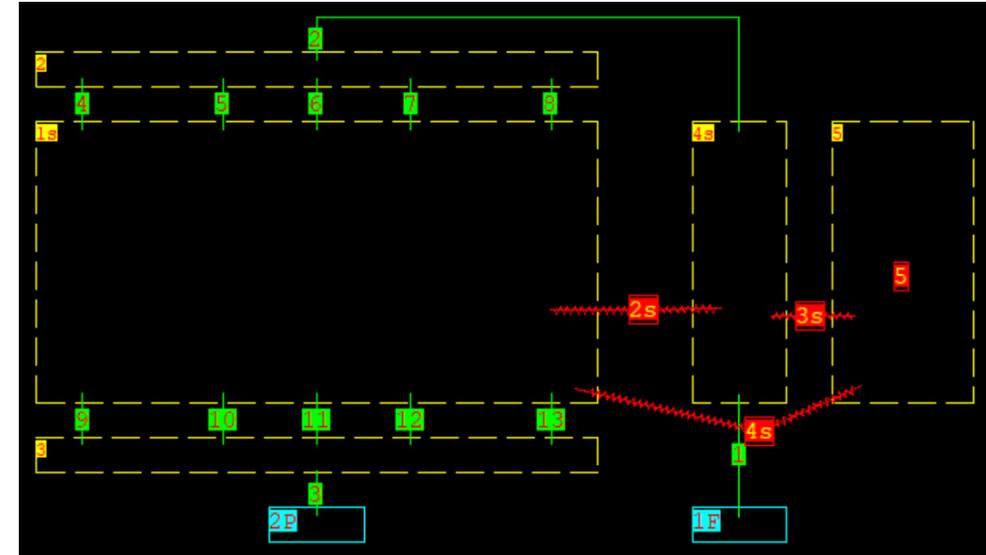
*GOTHIC nodalization of Mark I BWR containment**



Compartment pressure (left) and temperature (right)

GOTHIC Application to HTGR

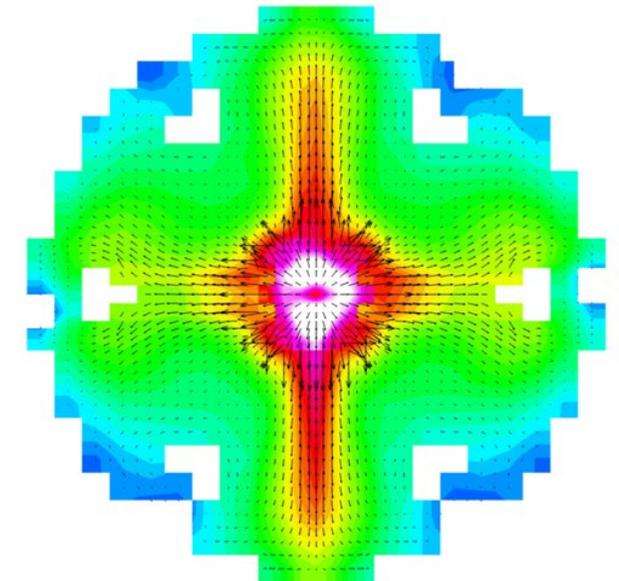
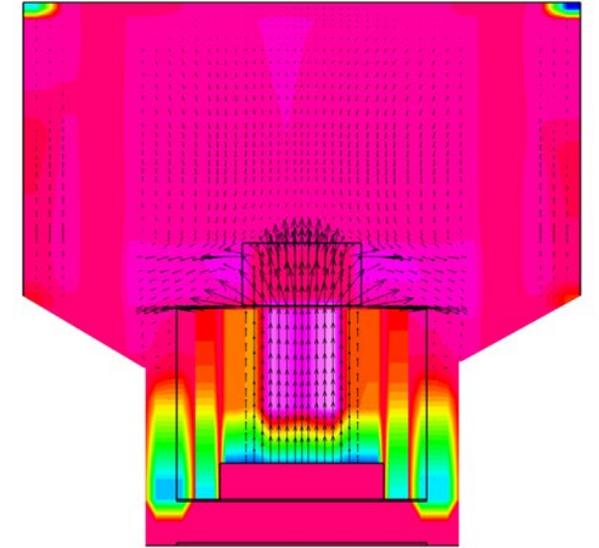
- Simplified pebble bed HTGR
 - Models forced convection, natural circulation, buoyancy and stratification
 - Includes molecular and turbulent diffusion models
- Modeling considerations
 - Spherical conductors for pebble bed designs
 - Thermal conductivity model for simulating conduction cooldown events
 - 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

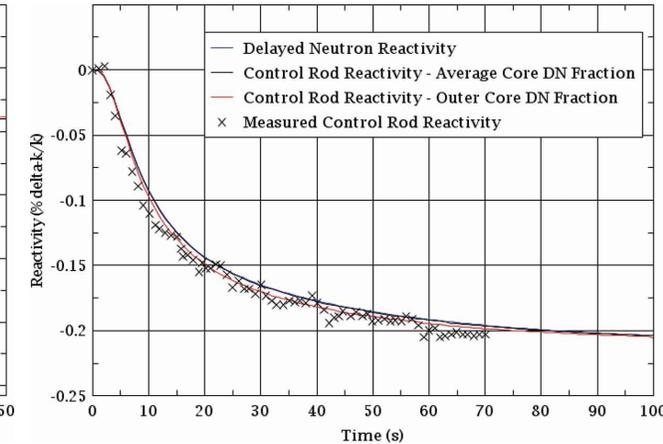
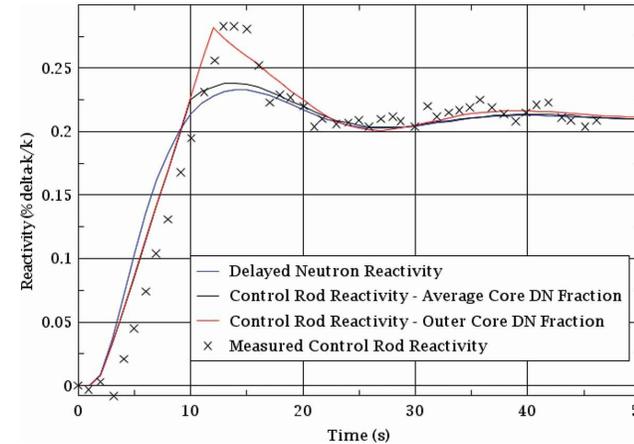


SFR modeling example with GOTHIC

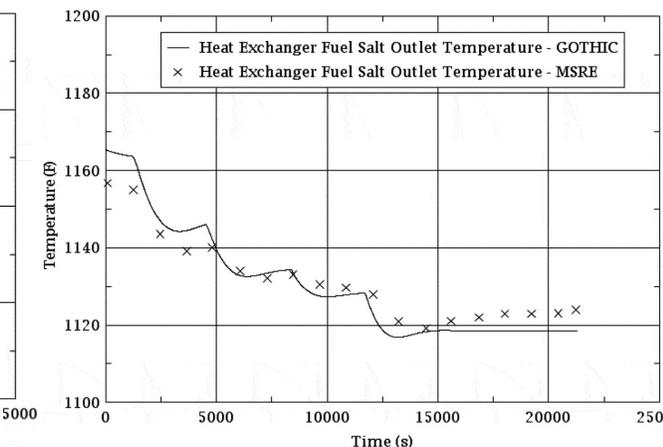
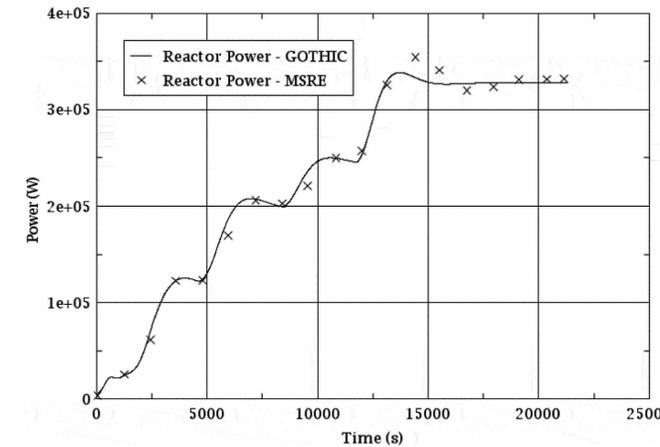
*J. W. Lane et al., Benchmark of GOTHIC to EBR-II SHRT-17 and SHRT-45R Tests. Nuclear Technology 206, 2020

GOTHIC Application to MSR

- GOTHIC capability related to MSR analysis
 - Properties of six molten salts
 - NaCl-MgCl₂, LiF-BeF₂ (FLiBe), LiF-NaF-KF (FLiNaK), NaF-ZrF₄, KF-ZrF₄, and NaBF₄-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)

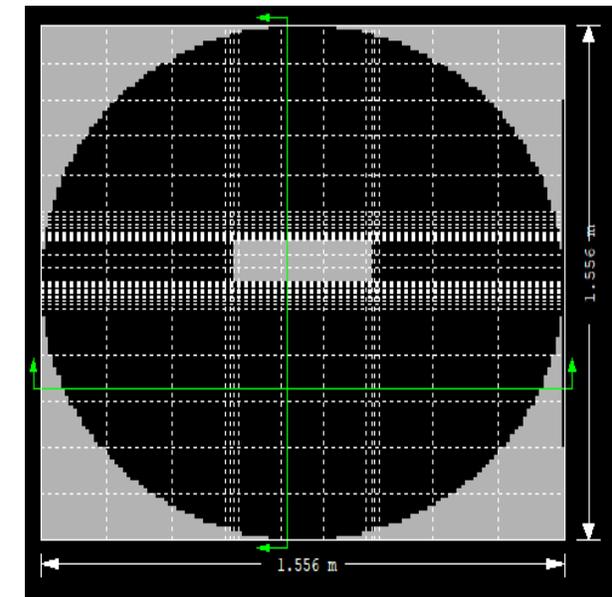
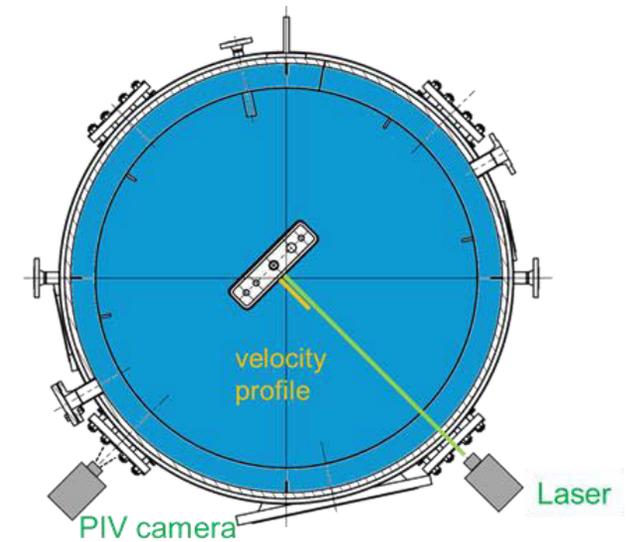


Reactor power (left) and coolant temperature at HX outlet (right)

* 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

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

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



TOGETHER...SHAPING THE FUTURE OF ENERGY®