Risk and Safety Management Program

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GAIN – EPRI Advanced Reactor Modeling and Simulation Workshop
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RSM Mission

RSM Program mission statement:

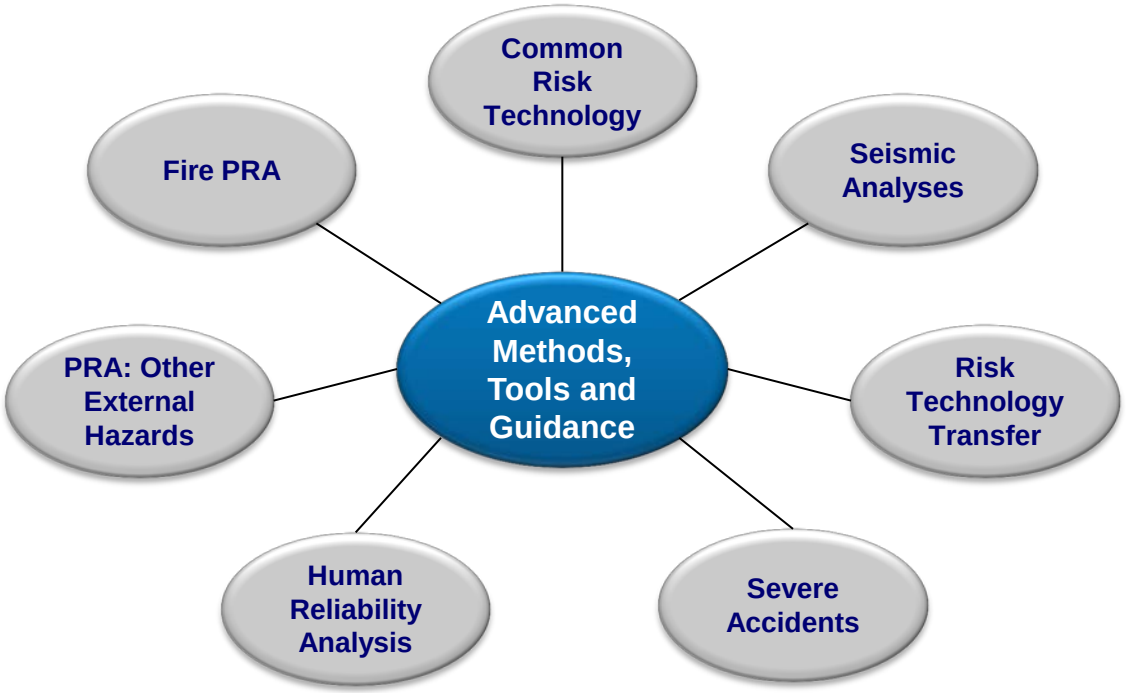
To equip members to implement a risk-informed framework to support

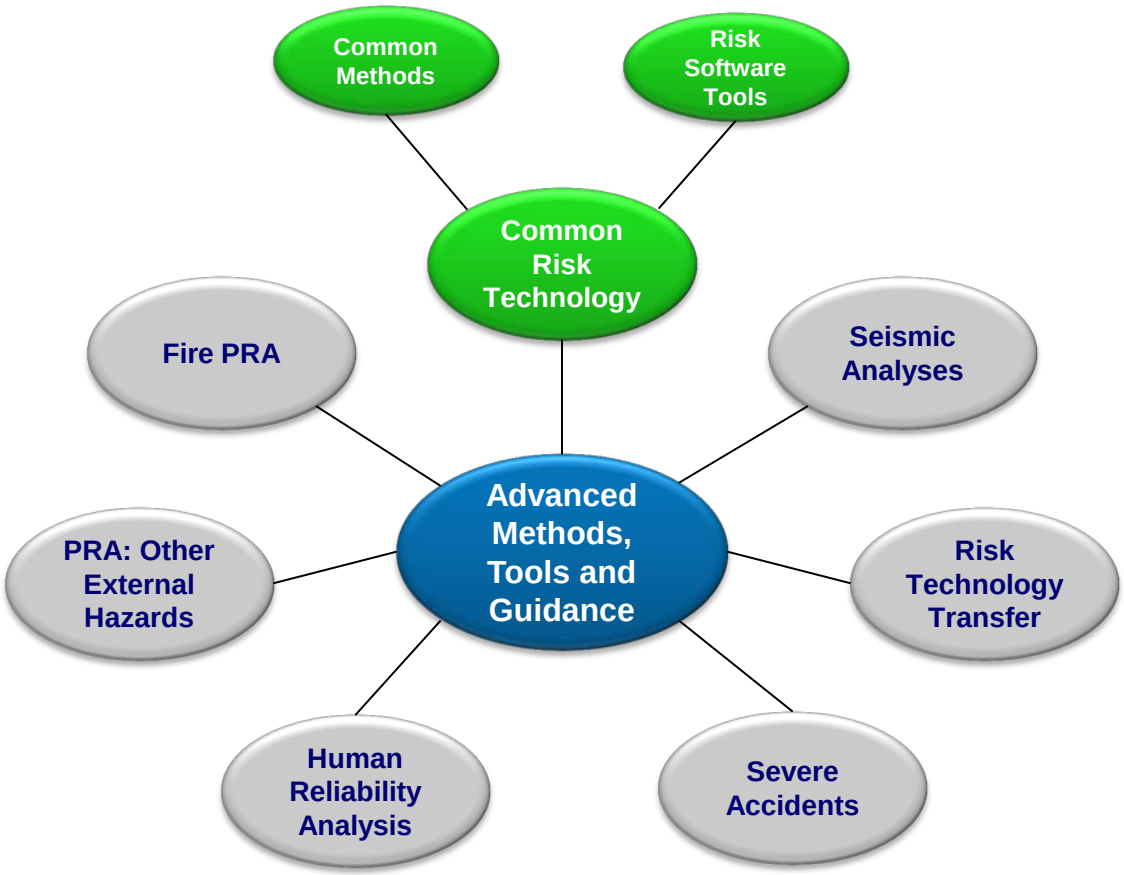
- Identifying cost-effective ways to improve ***safe operations***, *while also*
- Enhancing ***plant reliability and operational flexibility***

Mission achieved through

- Developing and improving ***technical methods*** and ***analysis tools***
- Providing ***guidance*** for effective use of methods and tools

Activities Organized into Seven *Research Focus Areas*





Common Risk Technology

- Methods developments relevant to internal events and across hazards

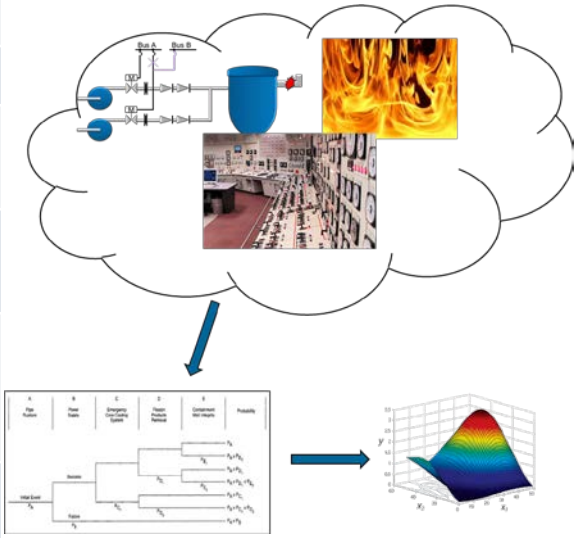
  Examples:
  - Reliability data analysis
  - Modeling of support-system initiating events
  - Methods for addressing low-power/shutdown conditions
  - Methods and frequencies for PRA of internal flooding
  - Detailed treatment of loss of offsite power and station blackout

- Software tools

Common Risk Technology (continued)

- Software tools

Software	Function
Integrated Risk Technology	
Phoenix	Advanced platform for constructing and applying PRA models, including for online risk management
CAFTA	Active legacy software for constructing PRA models
EOOS	Active legacy software for online management of risks
PRA DocAssist	Support for PRA documentation, with hyperlinks to drawings and procedures, etc.
FRANX	Software to facilitate modeling of spatial dependences (for seismic PRA, internal flooding, internal fire, etc.)
HRA Calculator	Modeling and documentation of human reliability analysis
FTREX	Powerful solution engine for large fault trees



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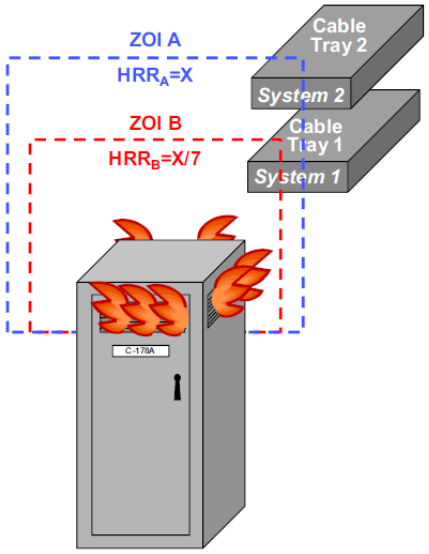
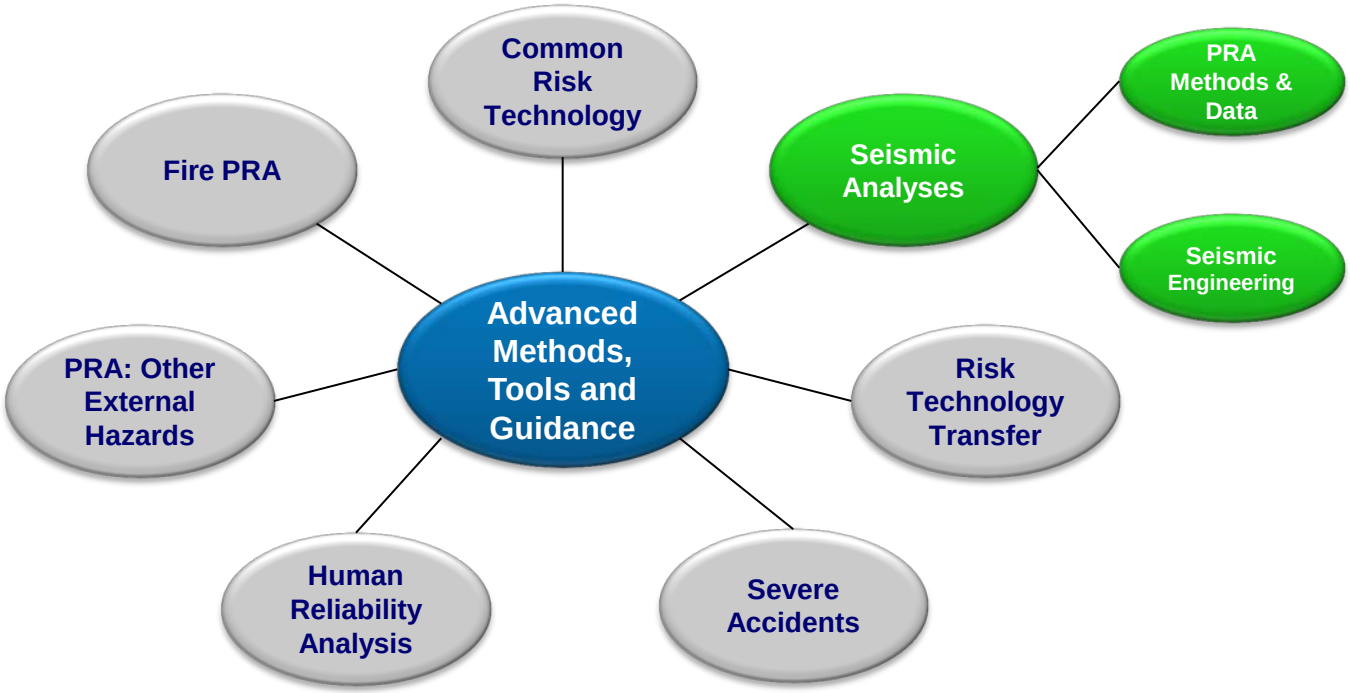
Fire Risk Assessment

- Fire PRA methods and data
  - Collection and analysis of data on fire occurrences
  - Modeling of fire development, growth, and damage potential
  - Incorporation of fire effects into PRA models
    - Accounting for fire damage
    - Incorporating operator interactions
- Fire PRA training – comprehensive set of courses covering all aspects of fire PRA



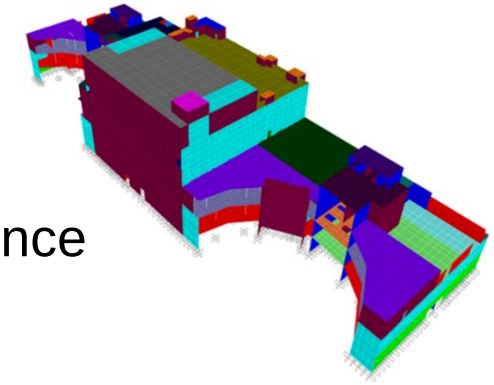


Seismic Analyses

- Seismic risk assessment
  - Advanced studies of seismic sources and ground motion
  - Plant response and seismic fragility analysis
  - Modeling and quantifying seismic impacts in PRAs
- Seismic engineering

Examples:

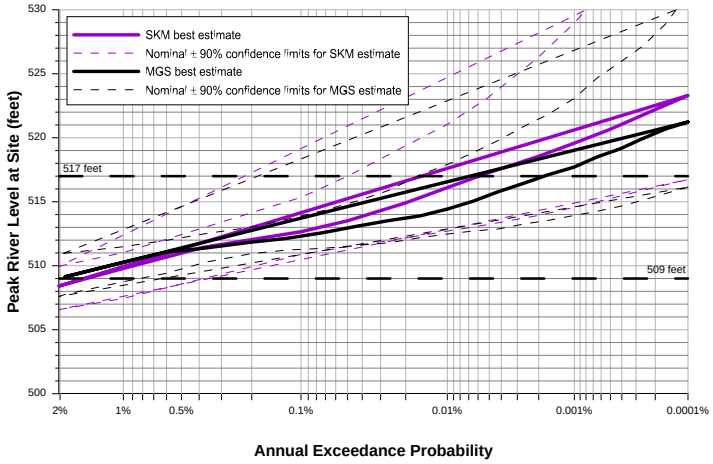
  - Seismic qualification by reviewing operating experience
  - Guidance for restarting plant after an earthquake
  - Seismic instrumentation



PRA for Other External Hazards

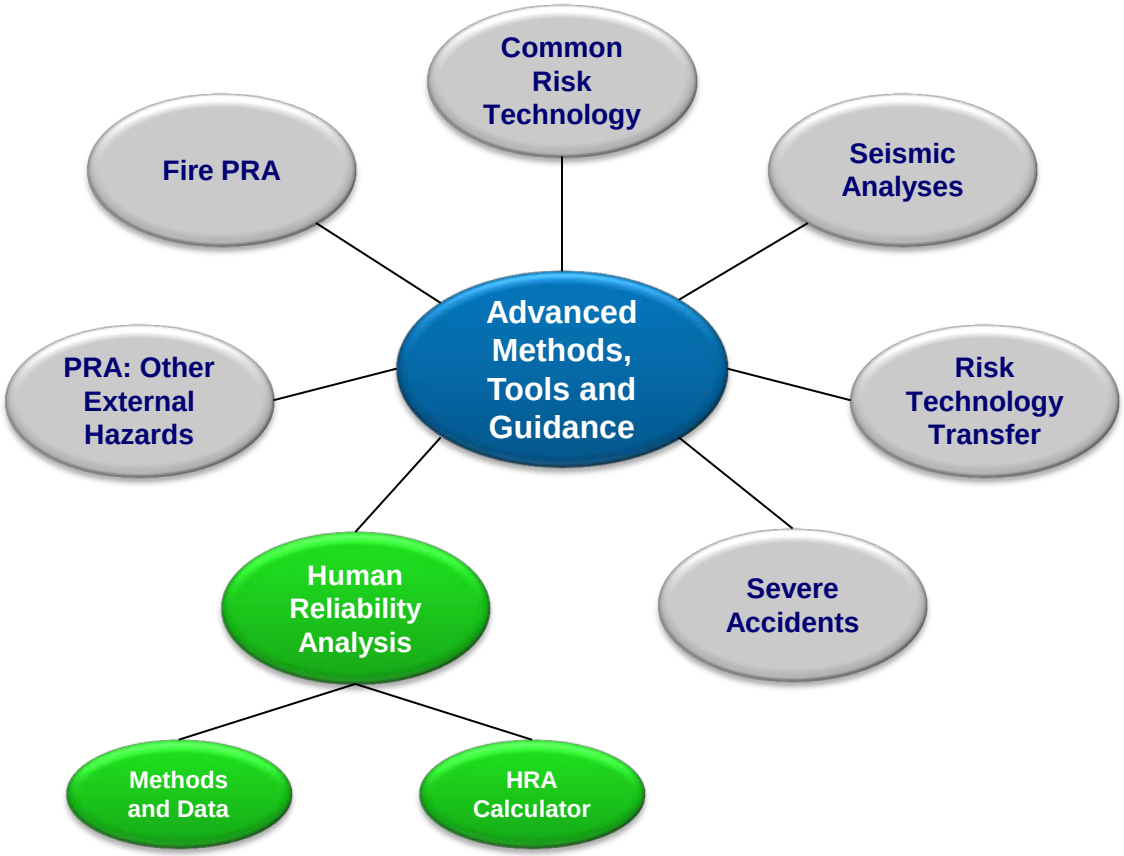
- Selection and screening
  - Identifying which hazards can be excluded for a particular site
  - Identifying which events merit detailed assessment in a comprehensive PRA

- Risk assessment for external flooding
  - Characterizing hazard for different types of floods
  - Evaluating plant impacts
  - Incorporating into PRA models



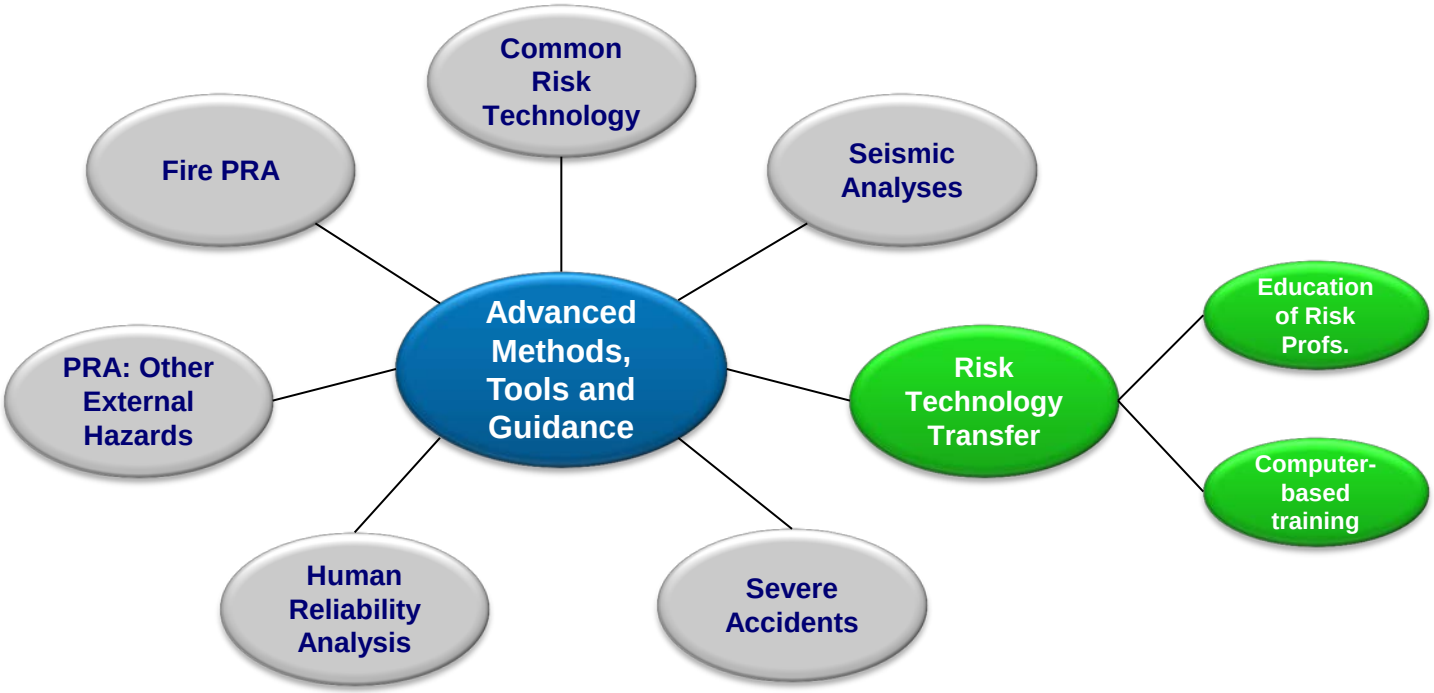
PRA for Other External Hazards (continued)

- Risk assessment for high winds
  - Characterizing hazard for straight-line and cyclonic winds
  - Evaluating impacts of wind loadings and missiles
  - Incorporating into PRA models
- Risk assessment for other external hazards
  - Generally, lower priority
  - To be addressed after external flooding and high winds



Human Reliability Analysis

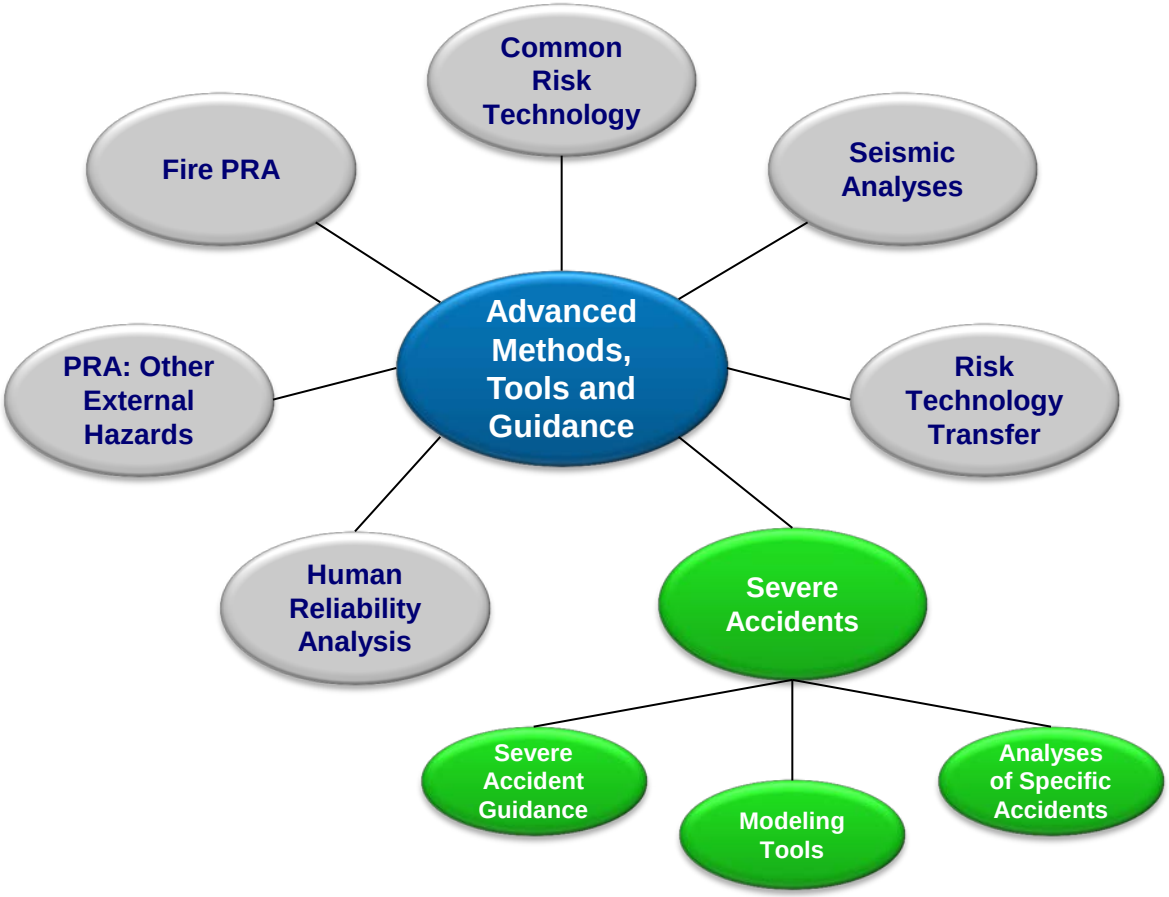
- HRA methods and data
  - Advanced common methods for evaluating human reliability in PRAs
  - Adaptations for specific conditions (challenging hazards, shutdown, severe accidents)
  - Benchmarking against experience and simulators
- HRA Calculator - widely used tool to facilitate performance and documentation of HRA



Risk Technology Transfer

- Education of Risk Professionals
  - Extensive six-week course to develop next generation of risk practitioners
  - Combines instruction by experts with innovative approaches
  - Completed nine times in US and once in Japan

- Computer-based training
  - Focused on non-PRA practitioners
  - Individual modules geared for needed level of familiarity
    - Executives and other management
    - Other functions (e.g., licensing, engineering design)



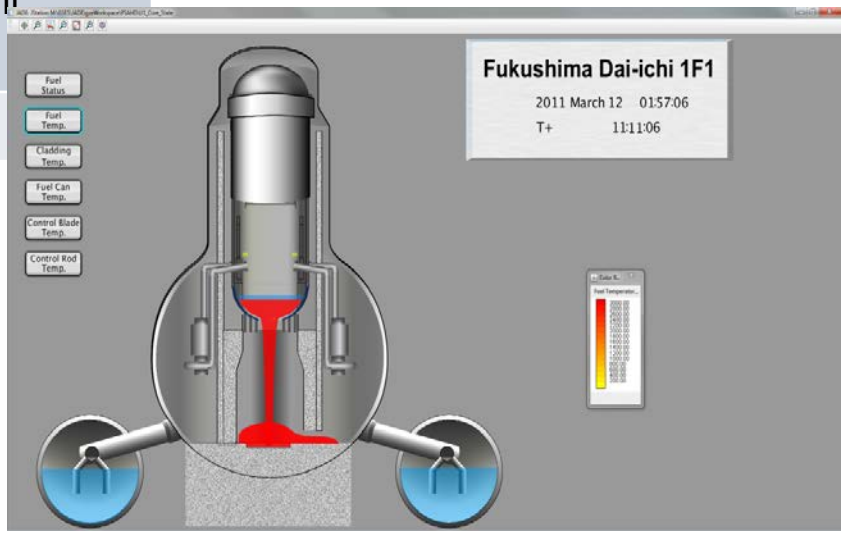
Severe Accident Analyses

- Severe-accident management guidance
- Analyses of specific accidents
  - In-depth technical investigation of the Fukushima accident
  - Evaluation of containment performance and mitigating strategies
  - Assessment of spent fuel pool risks
- Modeling tools
  - Evaluation of models for specific phenomena
  - Software codes

Severe Accident Analyses (continued)

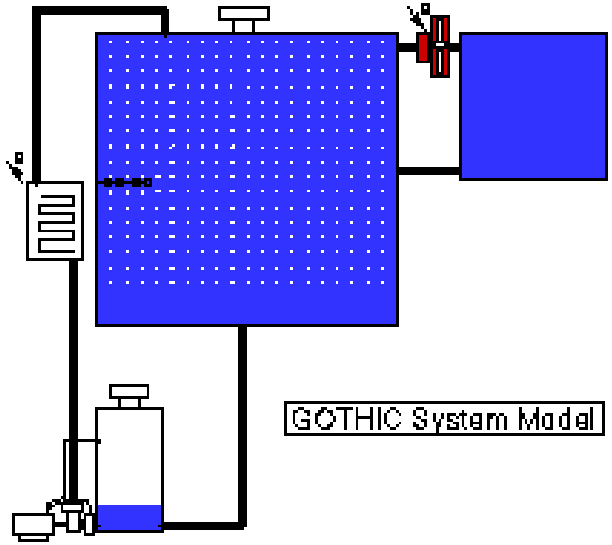
- Software codes

Software	Function
GOTHIC	Thermal/hydraulic modeling for containments and other compartments
MAAP	Severe-accident simulation
RETRAN	Thermal-hydraulic reactor/reactor coolant system simulation
VIPRE	Reactor core sub-channel analysis tool



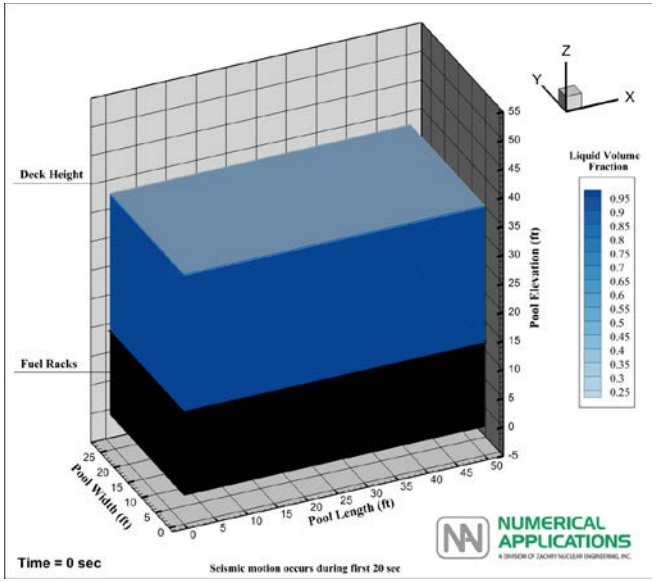
GOTHIC

- GOTHIC is a versatile thermal-hydraulics software package
  - Multiphase compressible flow with heat and mass transfer
  - Flexible nodalization (0-D to full 3-D)
  - Can represent complex geometries
  - Computationally efficient solutions for multi-scale applications



- Historically used for containment analysis, but is generally applicable to thermal hydraulic systems

- Integrated software containing:
  - graphical user interface (GUI)
  - solver
  - post-processor



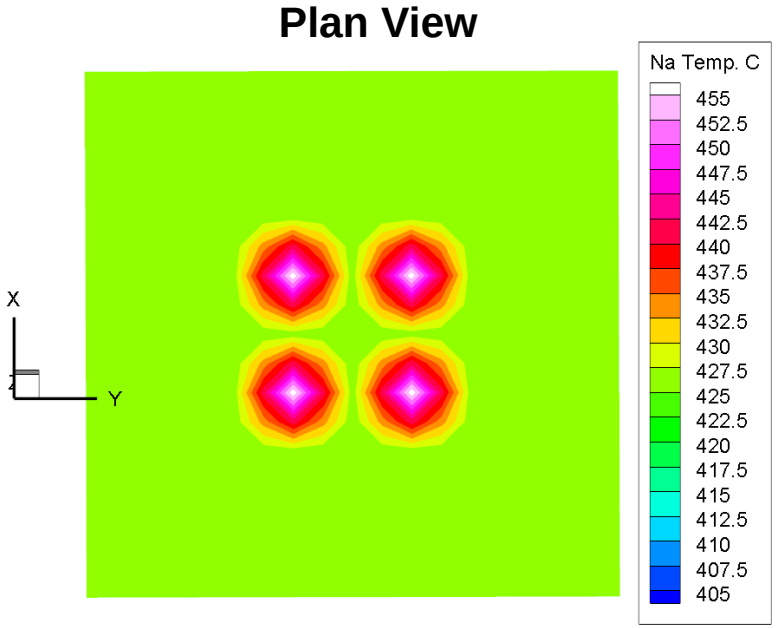
GOTHIC – RELEVENT ATTRIBUTES for non-LWRs

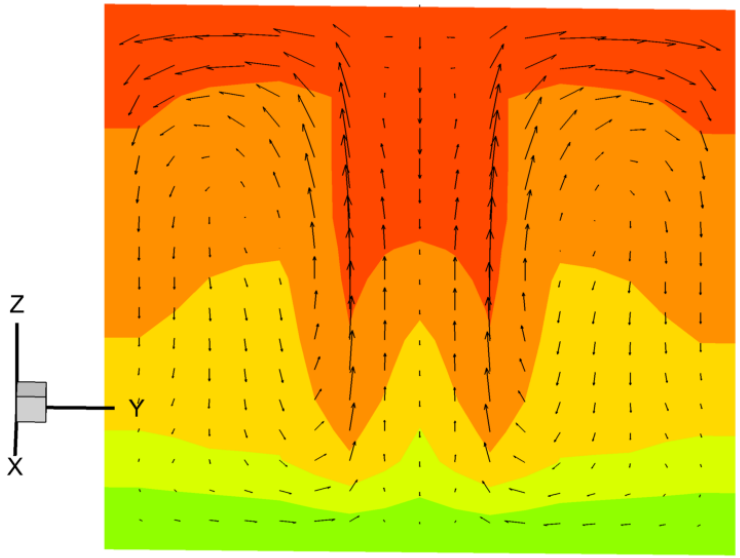
- Sodium properties are available for liquid metal reactor simulation
- Can model natural circulation, buoyancy and thermal stratification
- Offers parallel processing to decrease run time
- Includes molecular and turbulent diffusion
  - Turbulence model standard k-ε with variable PrT and ScT
  - Conduction in the fluid
- Includes 2nd order accurate advection schemes
- Offers 2D conduction heat transfer in solids
- Component models for engineered safety equipment (e.g., pumps, valves, heat exchangers, hydrogen recombiners, etc.)
- QA program that complies with 10CFR50, Appendix B

GOTHIC is a hybrid tool that bridges the gap between system level and CFD codes

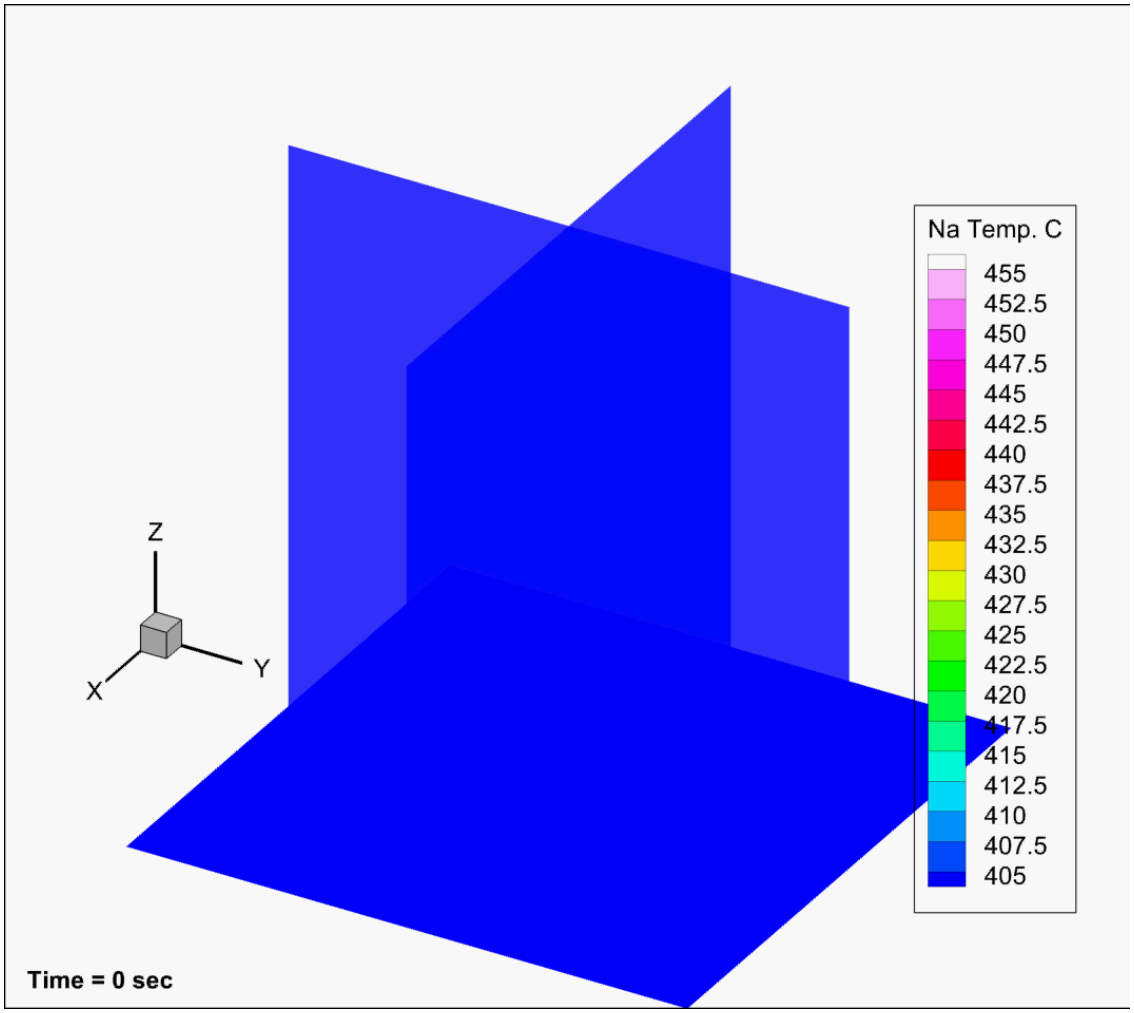
Example Sodium Simulation

- Liquid pool with 4 point heat sources near bottom
- Fluid conduction evident
- Convective currents show macroscopic recirculation
- Downflow between hot channels

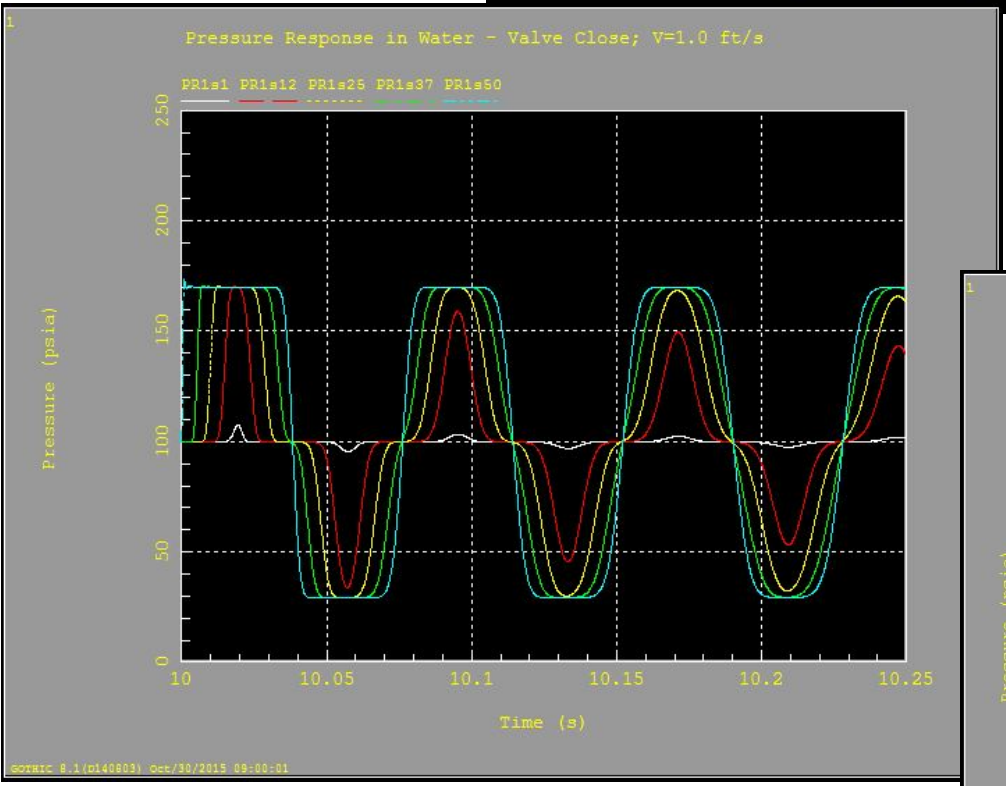




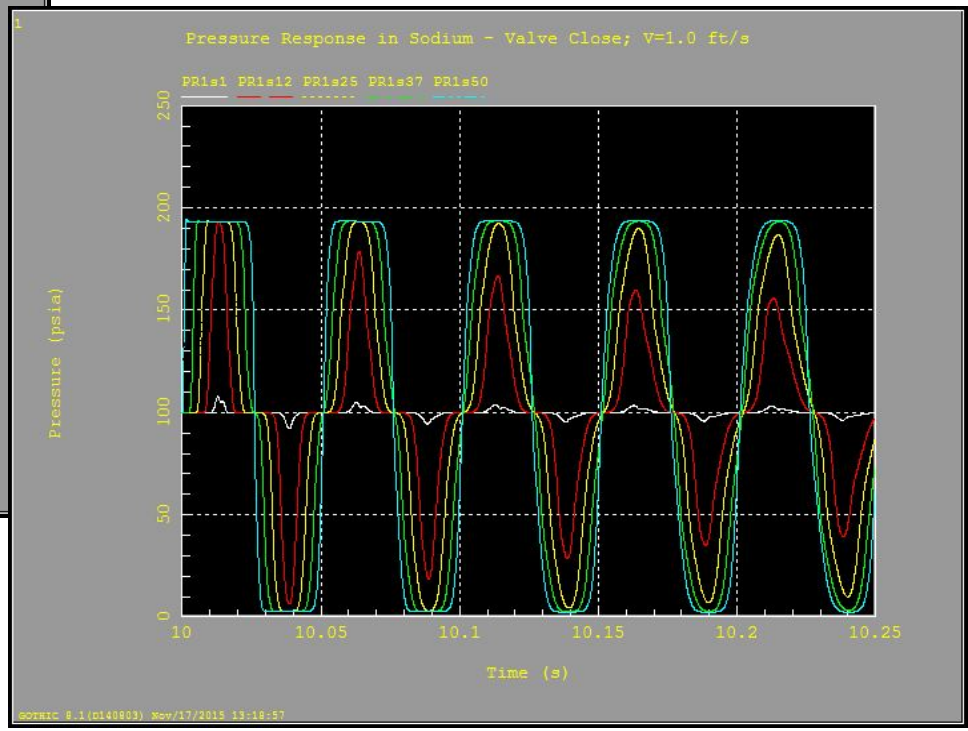
Example Sodium Simulation



Valve Closure Test



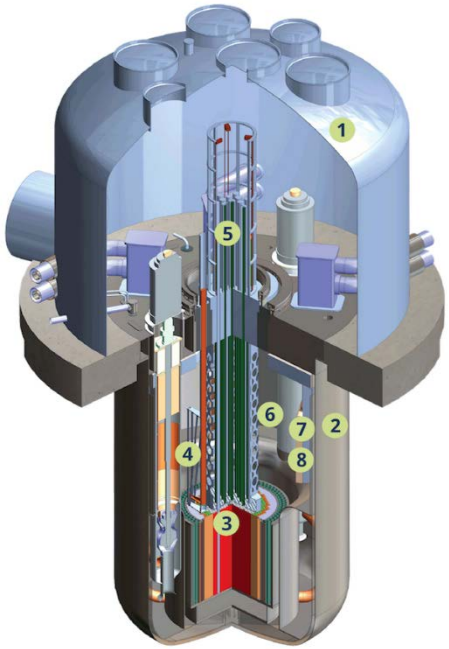
GOTHIC provides the expected pressure rise and speed of sound in both water and sodium.



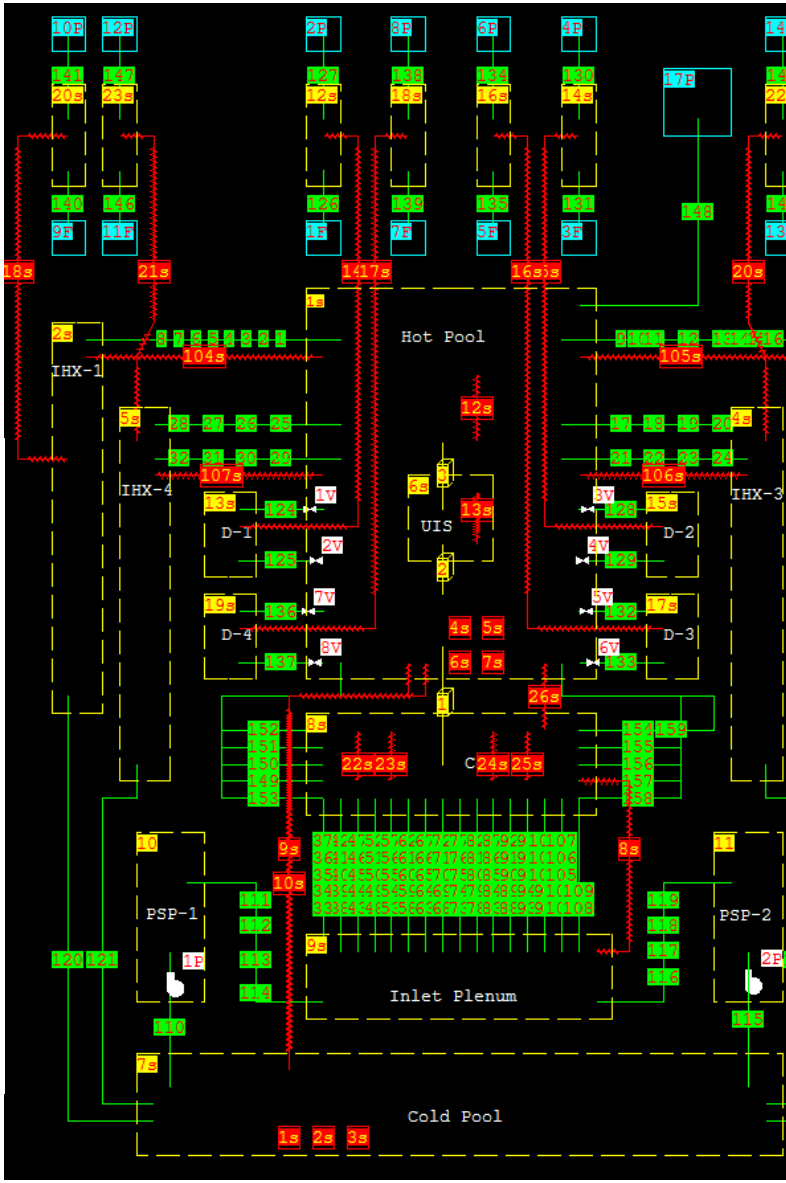
GOTHIC is being used to evaluate pressure pulse due to steam injection into sodium from a ruptured SG tube.

TWR-P Design and GOTHIC model

- **Objectives:**
  - Identify mixing and flow patterns
  - Predict local flow and temperature
  - Investigate various operating modes
- **3D GOTHIC model**
  - Almost 18,000 cells
  - Ratio of CPU/Sim. Time = 18.7

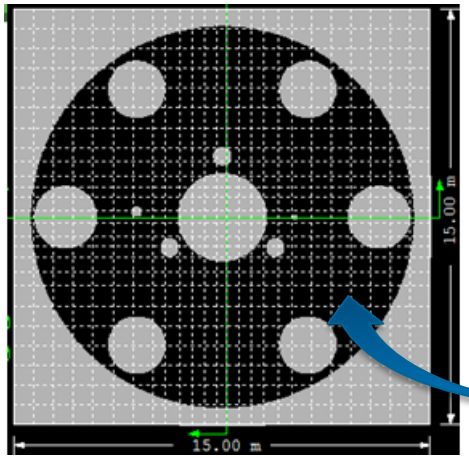


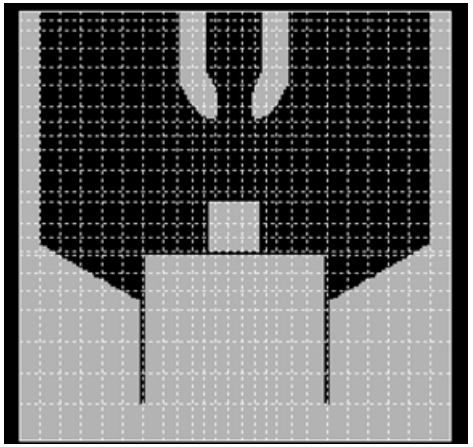
http://terrapower.com/pages/technology



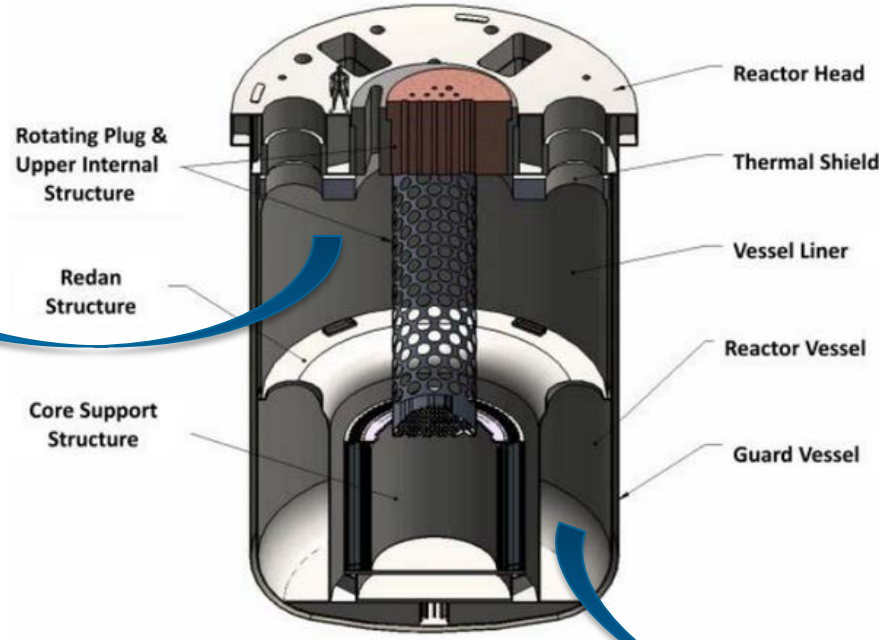
TWR-P Vessel Model

Hot Pool

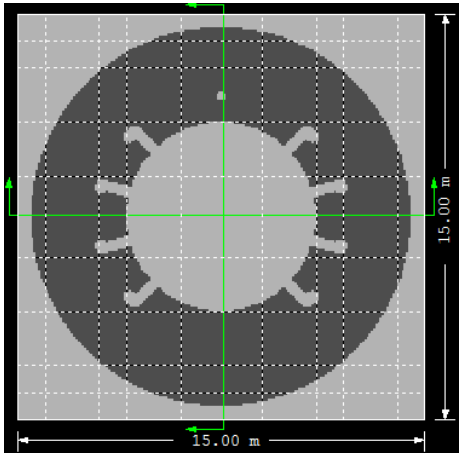


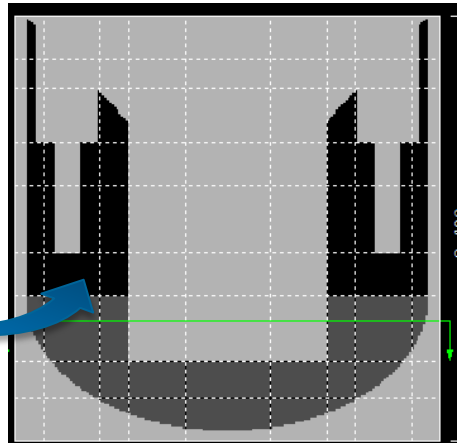


Vessel Design



Cold Pool

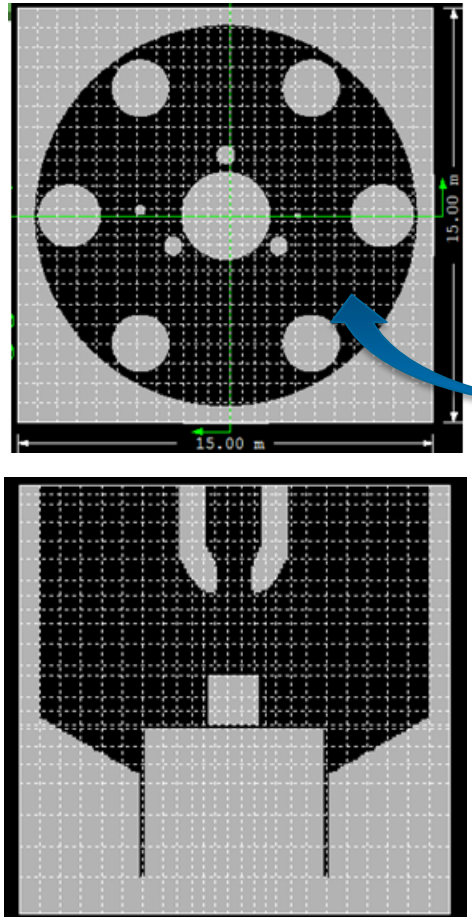




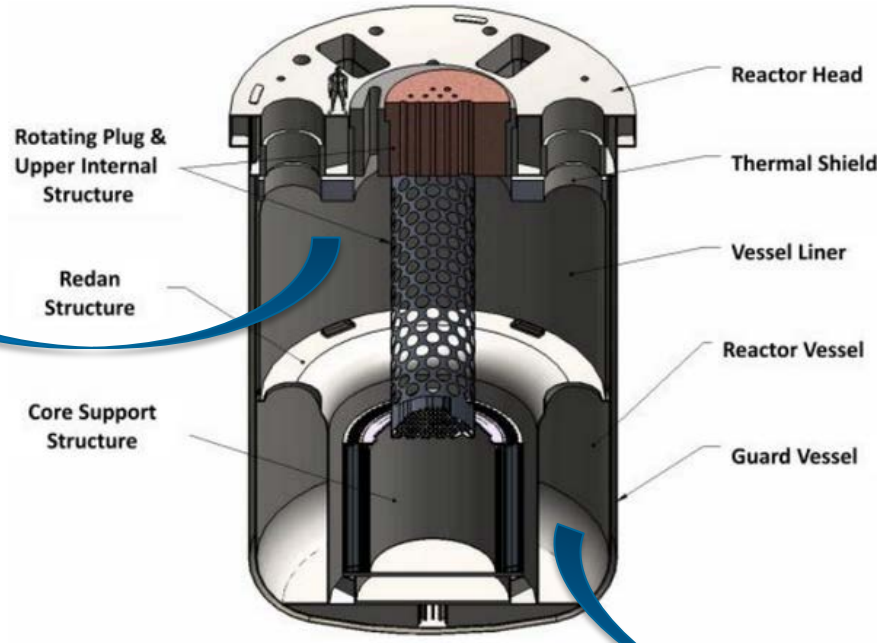
C. AHLFELD et. al., "Conceptual Design of a 500 MWe Traveling Wave Demonstration Reactor Plant," Proc. Int. Cong. Advances in Nuclear Power Plants (ICAPP), Nice, France, May 2-5, 2011, No. 11199 (2011).

TWR-P Vessel Model

Hot Pool



Vessel Design



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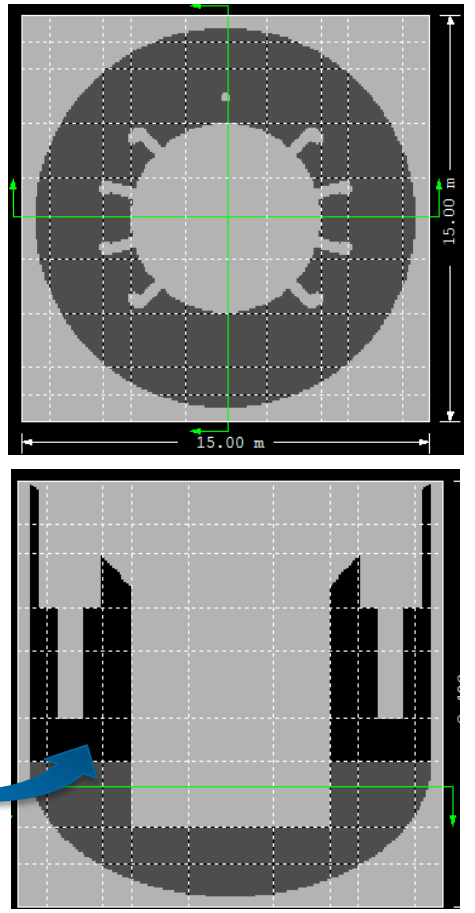

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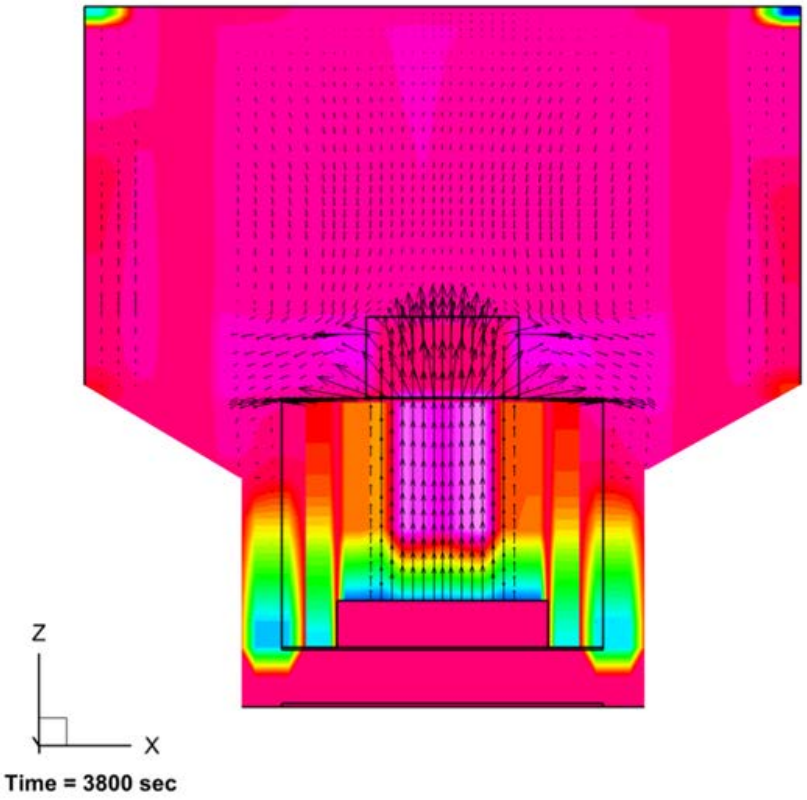
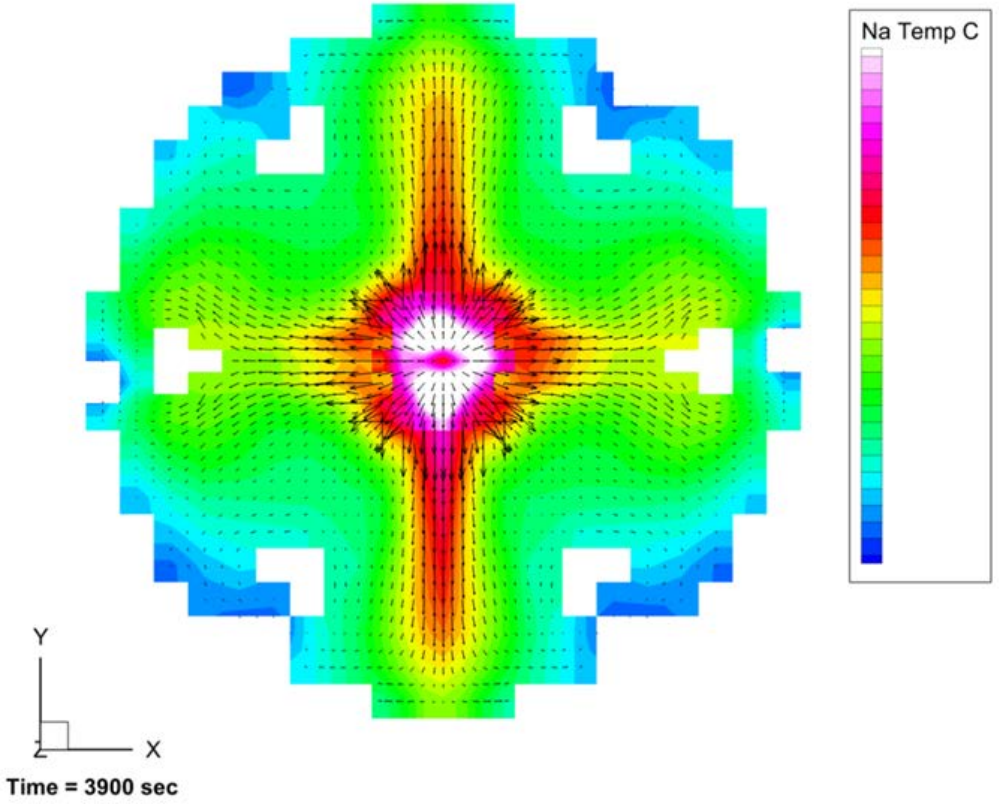
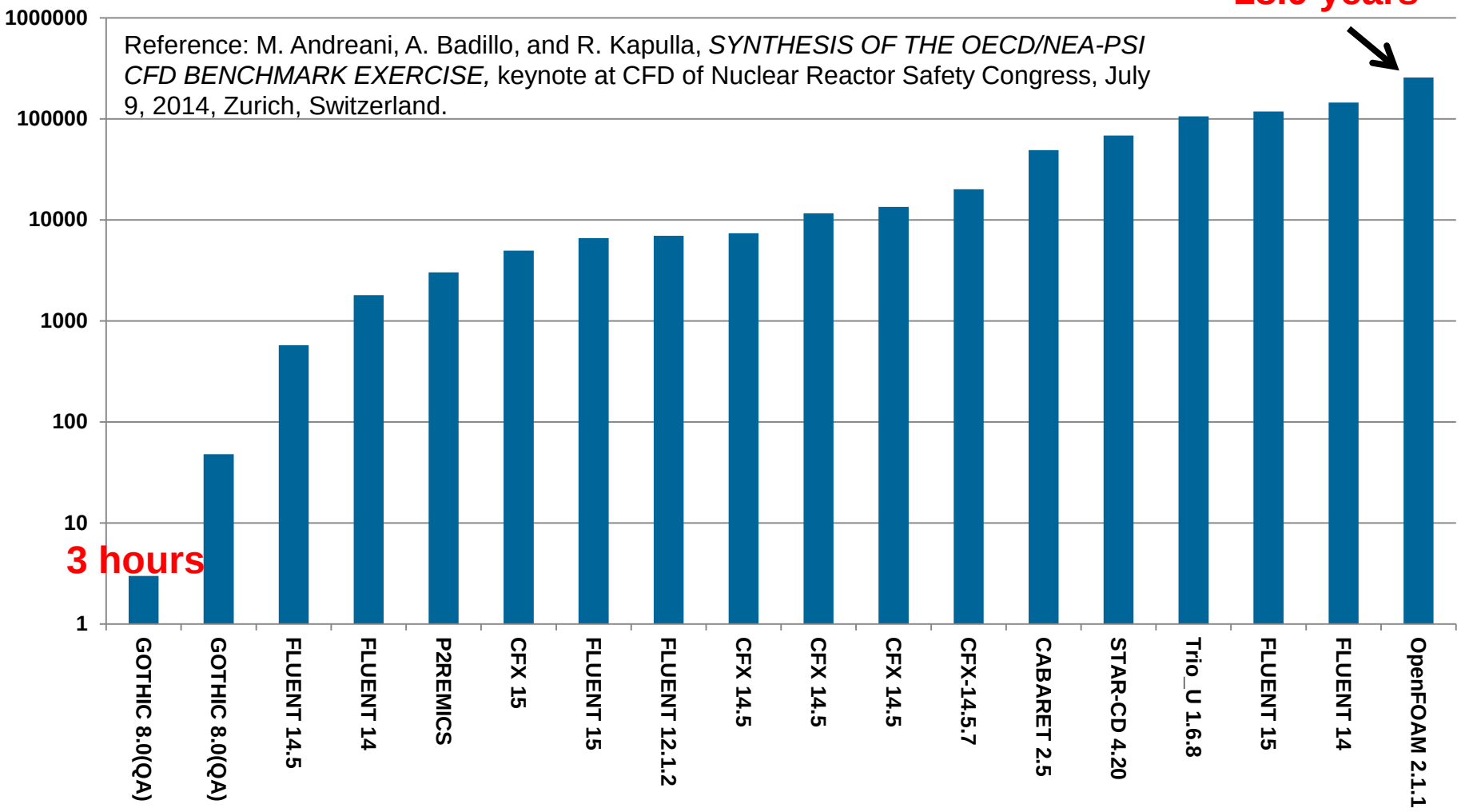
TWR-P Vessel Model - Results

- Results identified behavior that was not realized with other analysis tools being applied.





Computational Efficiency of GOTHIC



GOTHIC results comparable to CFD,
but obtained with a courser mesh and much shorter run times

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Current Status

- GOTHIC provides fundamental building blocks that can be combined to perform complex, multi-physics analyses
- Sodium properties being used by Zachry Nuclear Engineering to support TerraPower design
- TWR-P events simulated to date include:
  - Reactor transients
    - Natural circulation
    - Buoyancy induced mixing
  - Pressure pulse due to rupture of steam tube into sodium
    - Sodium/water chemistry
- Functional framework implemented in GOTHIC for generic fluid property tables
  - Can be extended to other working fluids in the future

GOTHIC's Capabilities For HTGR Modeling

- High temperature properties for steam and gases
- Real gas properties via gas property tables
- Primary and Secondary loop modeling
- Gas conductivity modeling
- Complex geometries
- Steady and transient analysis including compressibility effects
- Wall to Wall radiation heat transfer
  - Participating media modeling planned for version 8.3

GOTHIC

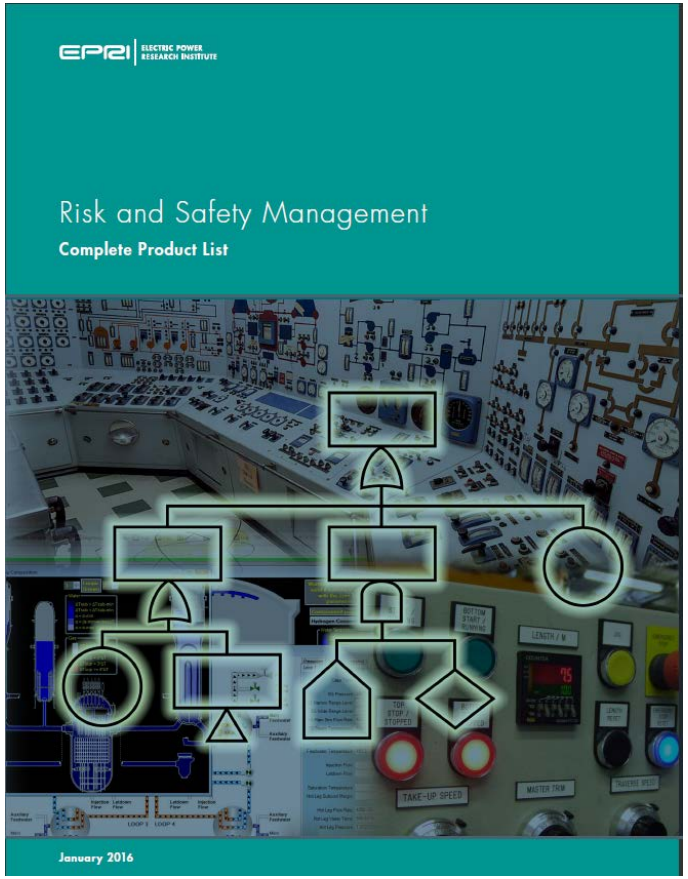
- GOTHIC is owned and managed by EPRI
- Zachry/Numerical Applications Division is the primary code developer under contract to EPRI.
- Zachry/Numerical Applications Dvision also performs a wide array of analytical services based on GOTHIC.
- Thank you Zachry for the examples and demonstration files for today's presentation.
- Contact: Jeff Lane, LaneJW@zachrygroup.com
  http://www.numerical.com/gothic.php

Resources – RSM Product Catalog

- Complete listing of available RSM research reports and software products
- Key references for new PRA analysts denoted (◆)

Probabilistic Risk Assessment (PRA) Methods			
Common-Cause Failures (CCF)			
	1015096	2007	Investigation of Inter-System Common-Cause Failures
◆	NP-5613	1988-98	Procedures for Treating Common Cause Failures in Safety and Reliability Studies, Volumes 1 and 2
	TR-100382	1992	A Database of Common-Cause Events for Risk and Reliability Applications
	NP-5777	1988-99	Defensive Strategies for Reducing Susceptibility to Common-Cause Failures, Volumes 1 and 2
Modeling			
	1016738	2008	Development of Declarative Modeling Applications
◆	1009187	2003	Treatment of Time Interdependencies in Fault Tree Generated Cutset Results
	TR-114880	2000	Use of KB3 to Develop System Fault Trees for the TMI-1 PRA
◆	NSAC-154	1991	ISLOCA Evaluation Guidelines
	NSAC-167	1991	ISLOCA Prevention and Mitigation Measures
	NP-5536	1987	Risk-Significant Functional Dependencies in PWRs

- Catalog available from www.epri.com as EPRI 3002007379



Summary – RSM Overview

- Broad range of risk-related research activities underway at EPRI

- The vast majority of EPRI's Risk and Safety products are technology neutral

- Engagement across all reactor design types

Questions or Follow-up

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