Risk and Safety Management Program

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GAIN – EPRI Advanced Reactor Modeling and Simulation Workshop
January 25, 2017
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
- Seismic Analyses
- Fire PRA
- Severe Accidents
- PRA: Other External Hazards
- Human Reliability Analysis
- Risk Technology Transfer

Advanced Methods, Tools and Guidance
Common Risk Technology

- Methods developments relevant to internal events and across hazards
  - 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

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

Methods and Data

Fire PRA Training

Common Risk Technology

Seismic Analyses

PRA: Other External Hazards

Advanced Methods, Tools and Guidance

Risk Technology Transfer

Human Reliability Analysis

Severe Accidents

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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)
Advanced Methods, Tools and Guidance

- Common Risk Technology
- Seismic Analyses
- Risk Technology Transfer
- Severe Accidents
  - Severe Accident Guidance
  - Analyses of Specific Accidents
- Modeling Tools
- PRA: Other External Hazards
- Human Reliability Analysis
- Fire PRA
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**

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<tr>
<td>GOTHIC</td>
<td>Thermal/hydraulic modeling for containments and other compartments</td>
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<tr>
<td>MAAP</td>
<td>Severe-accident simulation</td>
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<tr>
<td>RETRAN</td>
<td>Thermal-hydraulic reactor/reactor coolant system simulation</td>
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<tr>
<td>VIPRE</td>
<td>Reactor core sub-channel analysis tool</td>
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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 –
RELEVANT 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 $k-\varepsilon$ 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

TWR-P Vessel Model - Results

- Results identified behavior that was not realized with other analysis tools being applied.
Computational Efficiency of GOTHIC

PANDA Code Simulation Times: Log Scale


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

3 hours

28.9 years
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 Division 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 ( )

Catalog available from [www.epri.com](http://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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