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# Using the TRACE Code for Reactor Simulations

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# Presentation Overview

- Office of Nuclear Regulatory Research (RES)
  - Mission
  - How RES Accomplishes Its Mission :
    - The Evaluation Model Development and Assessment Process (EMDAP)
    - The User-Need Process
- Computer Codes Used in RES
  - TRACE Code
    - Overview
    - Code Characteristics
    - Limitations
    - Assessments
    - User needs
    - Future Code Development
- Summary

# The RES MISSION

- Provide technical advice, technical tools and information
  - for identifying and resolving safety issues, making regulatory decisions, and promulgating regulations and guidance.
  - to conduct independent experiments and analyses,
  - to develop technical bases for supporting realistic safety decisions by the agency,
  - to prepare the agency for the future by evaluating safety issues involving current and new designs and technologies.

- Develop programs with consideration of Commission direction and input from the program offices and other stakeholders.

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## The Evaluation Model Development and Assessment Process (EMDAP)

# RES uses the EMDAP in accomplishing its mission

An evaluation model (EM) is the calculational framework for evaluating the postulated behavior of a reactor system.

Therefore, the process of evaluating a T/H problem begins with the assessment of an existing EM or the development and assessment of a new EM (the EMDAP process).

- EMs can consist of a single computer code or multiple codes.
- RES uses the EMDAP to conduct its own research or to validate the use of its technical tools by the program offices

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- EMDAP Steps:
  1. Based on type of problem or reactor being considered, identify mathematical modeling methods, components, and phenomena needed to evaluate event behavior relative to figures of merit.
     » Phenomena Identification and Ranking Table (PIRT)
  2. Develop assessment base
  3. Develop the evaluation model.
     » Determine best calculational devices, e.g., TRACE code, CFD, Excel, MATLAB, etc.
  4. Assess the adequacy of the EM

# How RES Accomplishes Its Mission: The User-need Process

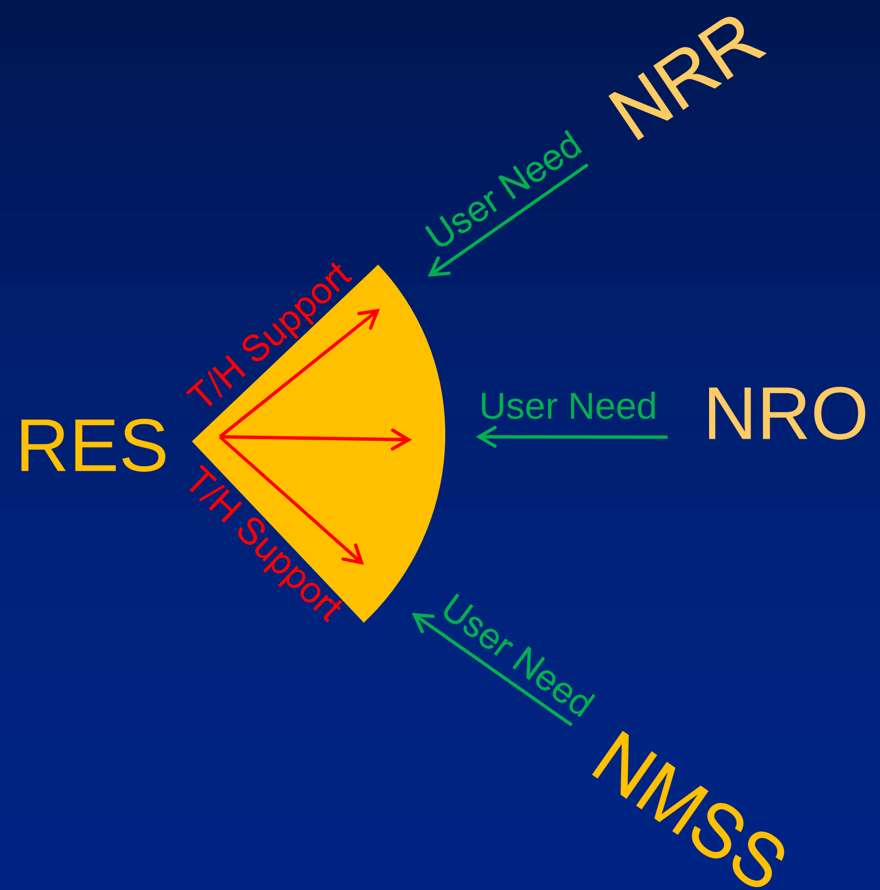
~80% of RES work involves responding to User-need requests for T/H analysis support.

Because of the complexity of T/H analyses, the bulk of this support involves the use, development, and assessment of computer codes

- Two-phase flows and heat transfer
- Complex single-phase fluid dynamics

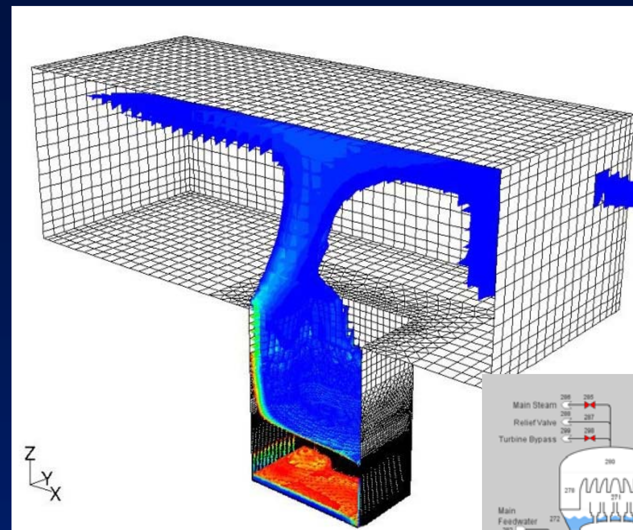
T/H analyses in support of user needs include the following:

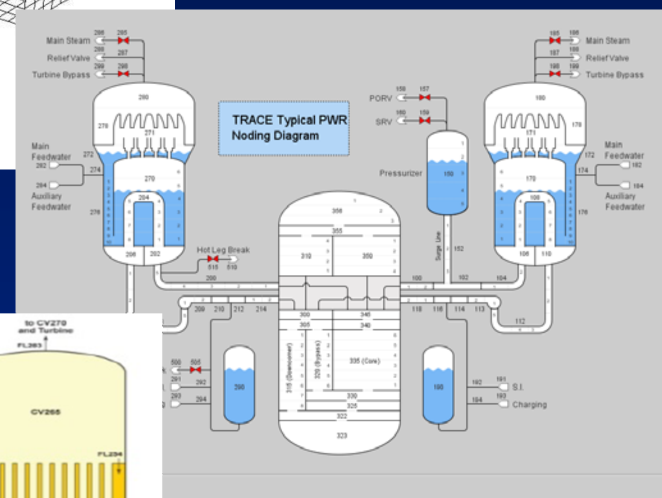
- Audit of licensee submittals for license amendments, power uprates, tech spec changes, and risk-informed plant changes
- New reactor design certification
- Resolution of generic safety issues
- Rulemaking
- Assessment of operating events

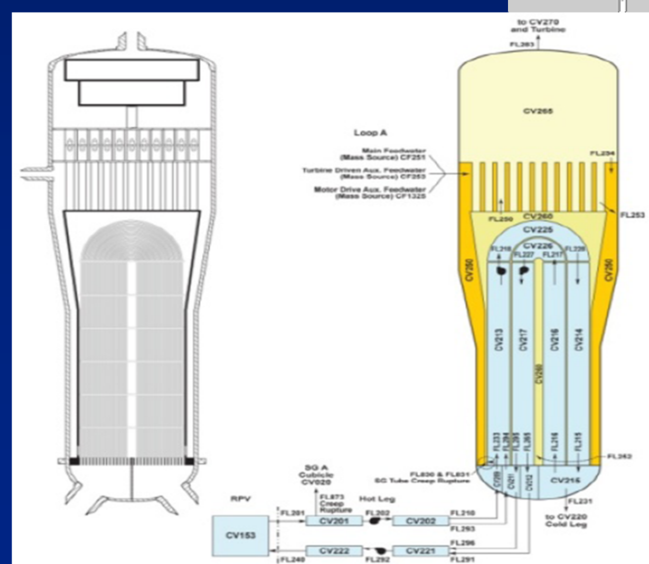


# Computer Codes Used in RES

- ***TRACE – T/H Systems Code***
- MELCOR - T/H Systems Code, used primarily for severe accident response and source term, and containment response
- ***FLUENT – Commercial CFD Code***
- CONTAIN – Reactor Containment Analysis Code
- FRAPTRAN – Fuels Code



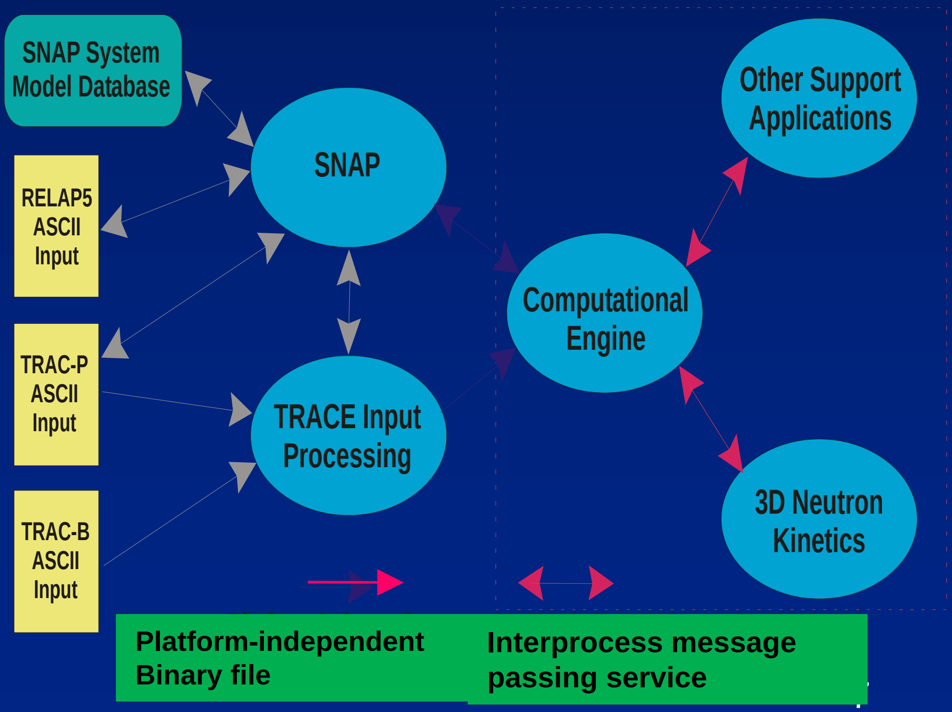


## Problems Involving Two-phase flows and Heat Transfer

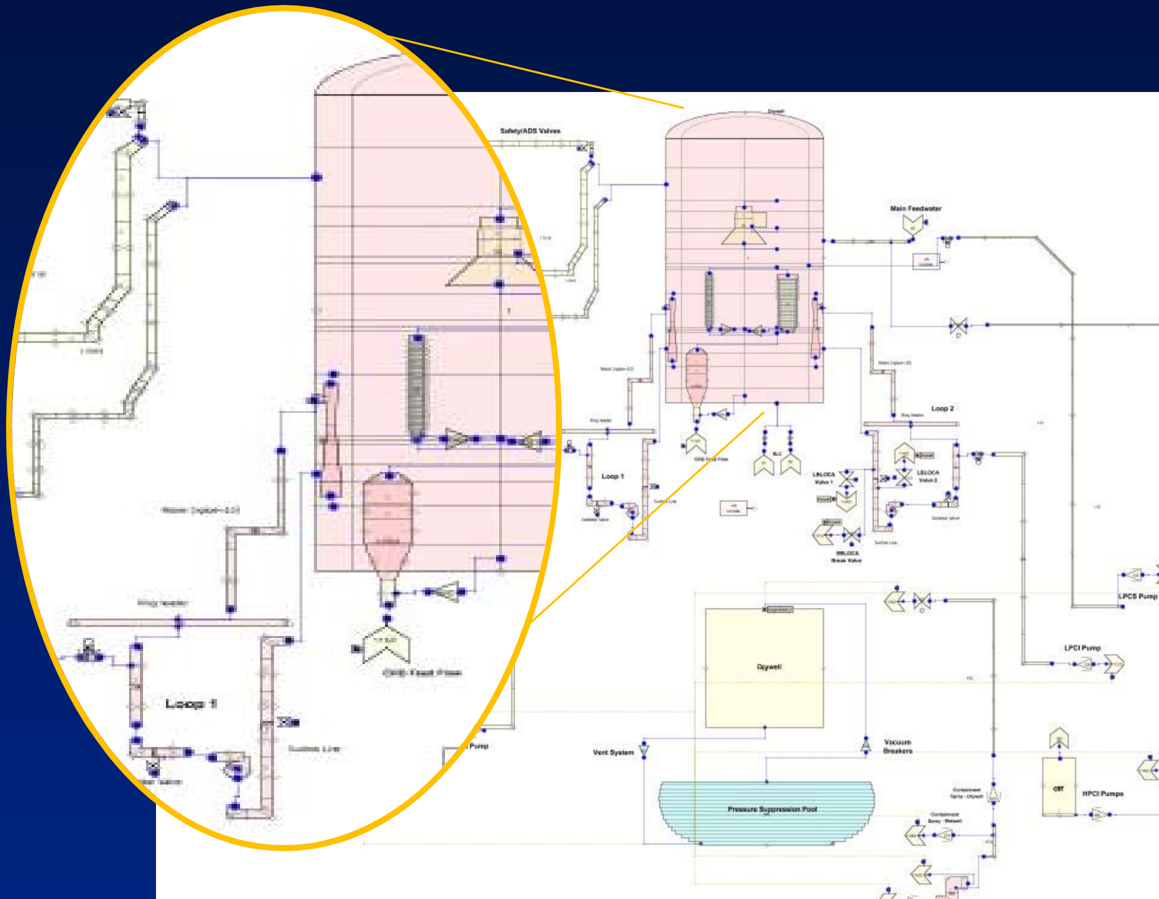
# TRACE
# TRAC/RELAP
# Advance Computation Engine

- Developed to simulate best-estimate transient and steady-state neutronics/thermal-hydraulic behavior in LWRs
- Combination of RELAP5,TRAC-B, TRAC-P, and RAMONA codes
  - Can run input models made using RELAP5 and TRAC-B,-P
- Dynamically coupled to the Purdue Advanced Reactor Core Simulator (PARCS) , which provides capability to calculate multi-dimensional time-dependent power distributions
- Can be used within the Symbolic Nuclear Analysis Program (SNAP) graphical user environment
  - Pre-processing
  - Runtime control
  - Database access and storage
  - Post-processing



# TRACE
# Modeling Environment

- Employs a component-based approach
  - Each physical piece of equipment in a flow loop can be represented using a TRACE component:
    - PIPE
    - Pressurizer
    - Jetpump
    - Vessel
  - Each component can be nodalized into volumes over which the fluid, conduction, and kinetics equations are averaged




SNAP View of plant model

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# TRACE Computing Environment

- Runs on most operating systems
  - Windows
  - LINUX
  - Mac OSX
- Modular coding (Fortran 95) makes TRACE portable, maintainable, and extensible
- Exterior Communications Interface allows for coupling with auxiliary codes:
  - MATLAB
  - CFD codes (future)
- Supports standard programming languages, network, and file formats:
  - Java, C, C++, PERL, Python
  - TCP/IP, BSD Sockets, PVM
  - XML, PDF, SVG, PNG

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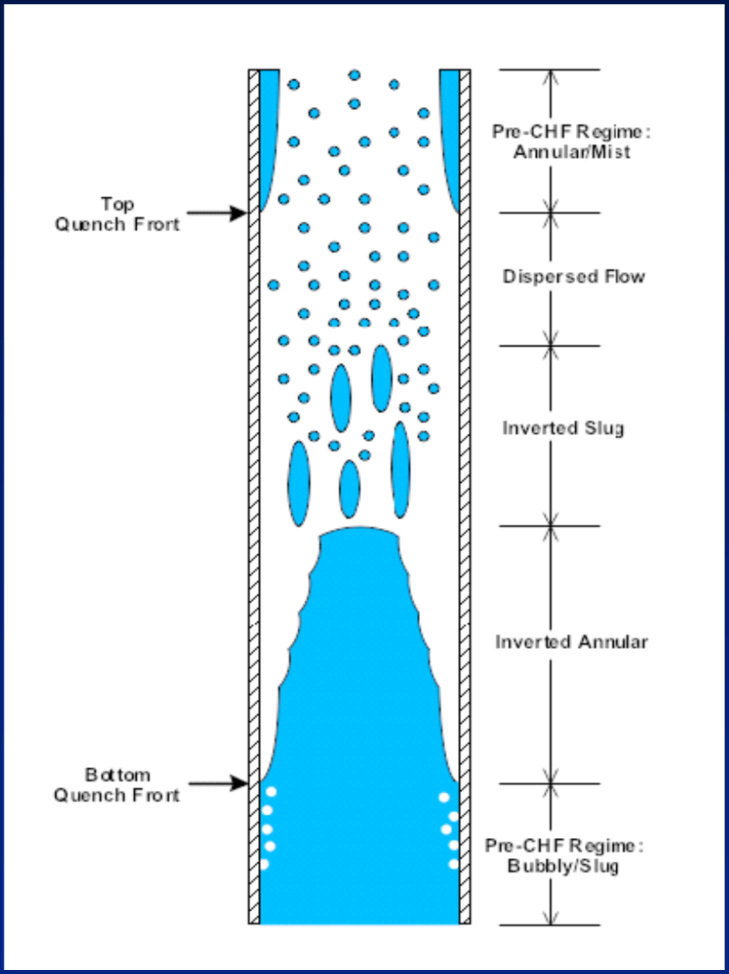
# TRACE
# Code Characteristics

- A finite-volume, two-fluid compressible flow code w/1-,2-,& 3-D flow geometry
  - Six-equation hydrodynamic model to evaluate liquid-gas flow
  - Additional mass conservation equations to track non-condensable gases and dissolved solute in the liquid field (Boron)
- Non-homogeneous, non-equilibrium modeling
- Static flow-regime-dependent constitutive equation package
- Comprehensive heat-transfer capability
  - 2-D treatment of heat transfer within structures
  - Flow-regime-dependent heat transfer coefficients from generalized boiling curve



# TRACE Limitations

## TRACE is not appropriate for modeling…

- Situations in which transfer of momentum plays an important role at a localized level.
- Transients in which thermal stratification of liquid in 1-D components is expected.
- Scenarios where viscous stresses are comparable to or larger than wall or interfacial shear stresses.
- In the evaluation of the stress/strain effects of temperature gradients in structures

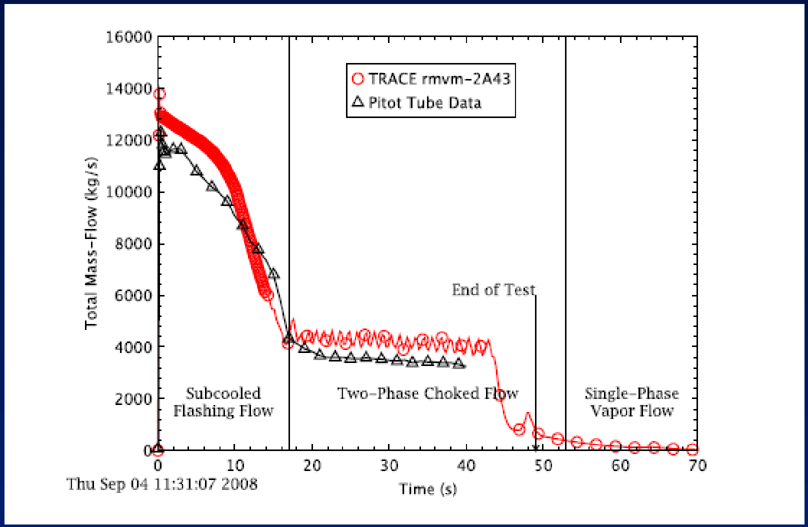
## Other Caveats

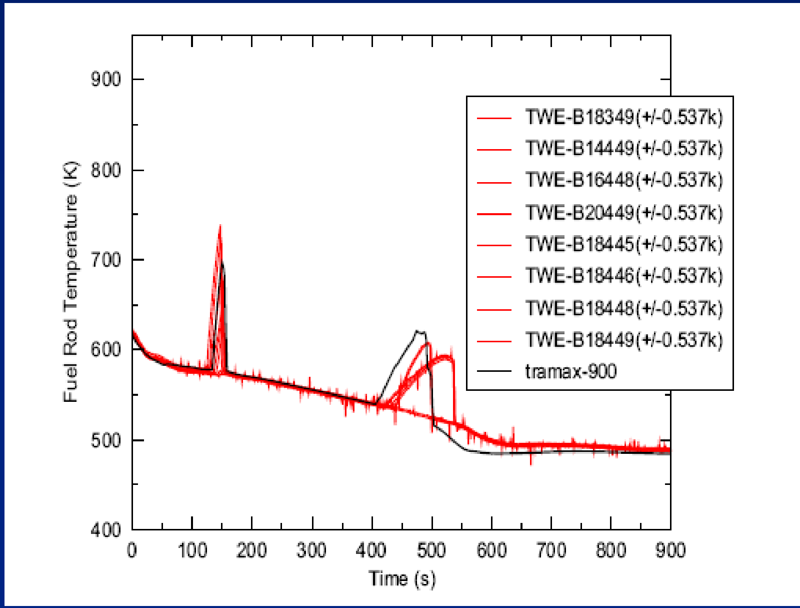
- Viscous heating within fluids is not generally considered; special model available to account for direct heating of fluid by pump rotor.
- Approximations in wall and interface heat flux terms affect accuracy

# TRACE Assessment

TRACE has to be assessed and demonstrated to be applicable over the range of intended uses.

- System-level codes like TRACE do not have “first principle” models; the models are semi-empirical or fully empirical in nature.
- As a result of extensive assessment and peer-review, TRACE V5.0 was found suitable for analyzing SBLOCA in currently operating LWRs and LBLOCA in operating plants that do not have upper-plenum injection.
- The current version of TRACE is V5.0 Patch 3; version V5.0 Patch 4 is expected in a few months.



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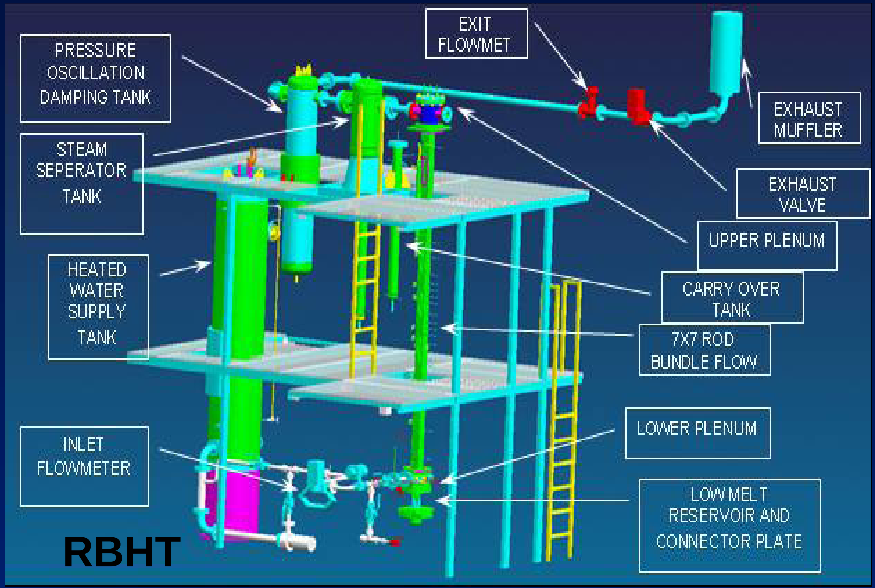
# Assessment Matrix for SBLOCA in PWRs

**Key:**
● = simulated
⊖ = partially simulated
\- = not simulated or measured

| Process | Blowdown | Natural Circulation | Loop Seal Clearance | Boil Off | Recovery | LOFT | ROSA-IV | BETHSY | Semiscale | SCTF | UPTF | THTF Mix Level and Uncovery | FRIGG | RBHT Mixture Level | RBHT Steam Cooling | UCB Condensation | Dehbi Condensation | U. Wisc. Condensation | Bankoff CCFL Tests | Single Tube Flooding |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oxidation (fuel rod) | - | - | - | ● | ● | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| Decay Heat (fuel rod) | ● | ● | ● | ● | ● | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| Local Power (fuel rod) | - | - | - | ● | ● | - | - | - | - | - | - | - | - | - | - | - | - | - | - | |
| 3-D Power Distribution (core) | - | - | - | ● | ● | - | ⊖ | ⊖ | - | ● | - | - | - | - | - | - | - | - | - | |
| Post-CHF Heat Transfer (core) | - | - | - | ● | ● | ⊖ | ● | ● | ● | ● | - | ⊖ | - | ● | - | - | - | - | - | |
| Rewet / Tmin (core) | - | - | - | ● | ● | ⊖ | ● | ● | ● | ● | - | - | - | ● | - | - | - | - | - | |
| Mixture Level (core) | - | - | ● | ● | ● | - | ● | ● | ● | ⊖ | - | ● | ● | ● | ● | - | - | - | - | |
| Hot Leg-Downcomer Gap Flow (UP) | - | - | ● | - | - | - | ● | ● | ● | - | - | - | - | - | - | - | - | - | - | |
| Counter-current Flow & CCFL (UP /Hot Leg Nozzle) | | ● | ● | - | - | - | ● | ● | ● | - | - | - | - | - | - | - | - | - | ● | |
| Primary side heat transfer / U-tube condensation (SG) | ● | - | ● | - | - | ● | ● | ● | ● | - | - | - | - | - | - | ● | ● | ● | - | - |
| CCFL / Tube Voiding (SG) | - | - | ● | - | - | ⊖ | ● | ● | ● | - | - | - | - | - | - | - | - | - | - | ● |
| Primary Flow Resistance / Two-Phase ΔP (SG) | - | - | ● | - | - | ● | ● | ● | ● | - | - | - | - | - | - | - | - | - | - | - |
| Entrainment/Flow Regime/Interfacial Drag (loop seal) | - | - | ● | - | - | - | ● | ● | ● | - | - | - | - | - | - | - | - | - | - | - |
| Horizontal Stratification (loop seal) | - | - | ● | - | - | - | ● | ● | ● | - | - | - | - | - | - | - | - | - | - | - |
| Condensation to stratified layer (cold leg) | - | - | - | ● | ● | - | ● | ● | ● | - | ⊖ | - | - | - | - | - | - | - | - | - |
| Horizontal Stratification/Flow Regime (cold leg) | | | ● | ● | ● | - | ● | ● | ● | - | ⊖ | - | - | - | - | - | - | - | - | - |

# Domestic Experimental Programs

- Rod Bundle Heat Transfer (RBHT) facility
  - Penn State Univ.
  - Spacer-grid rewet and droplet size during reflood
- T/H Institute
  - Numerous small- and large-scale experiments
    - Purdue Univ. Multi-dimensional Integral Test Assembly (PUMA)
    - Tests relevant to ESBWR
  - Interfacial area
  - Void fraction in large diameter pipes



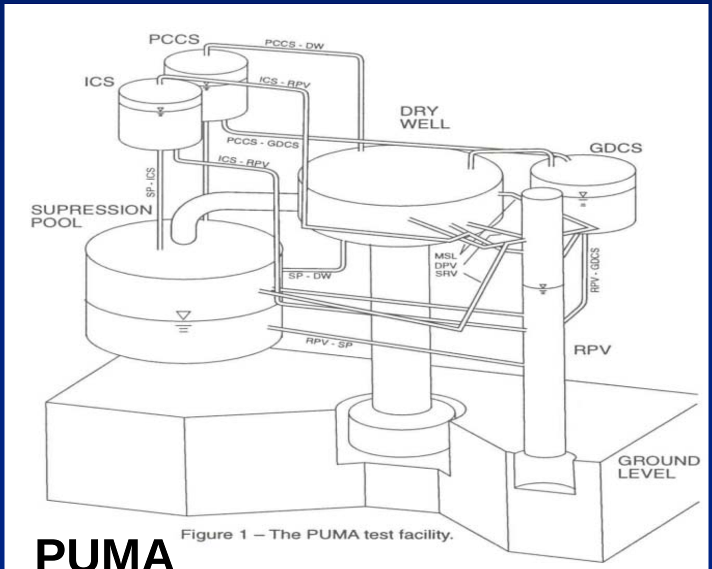
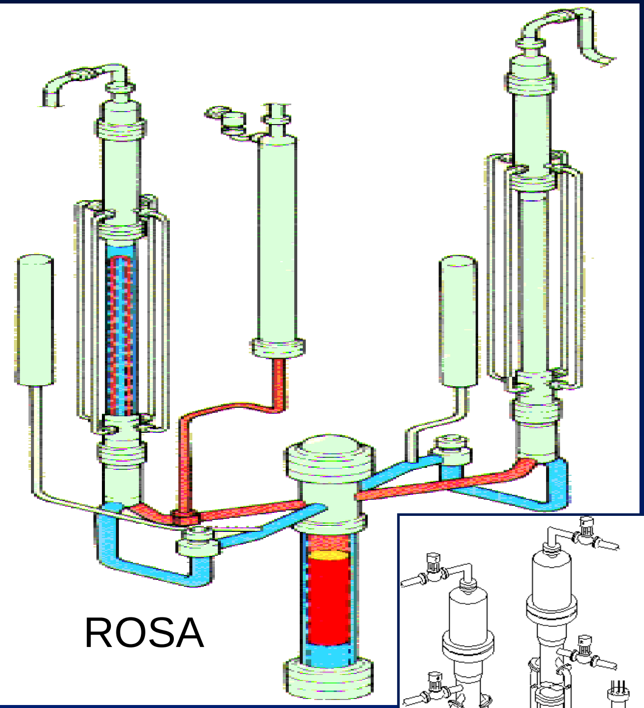
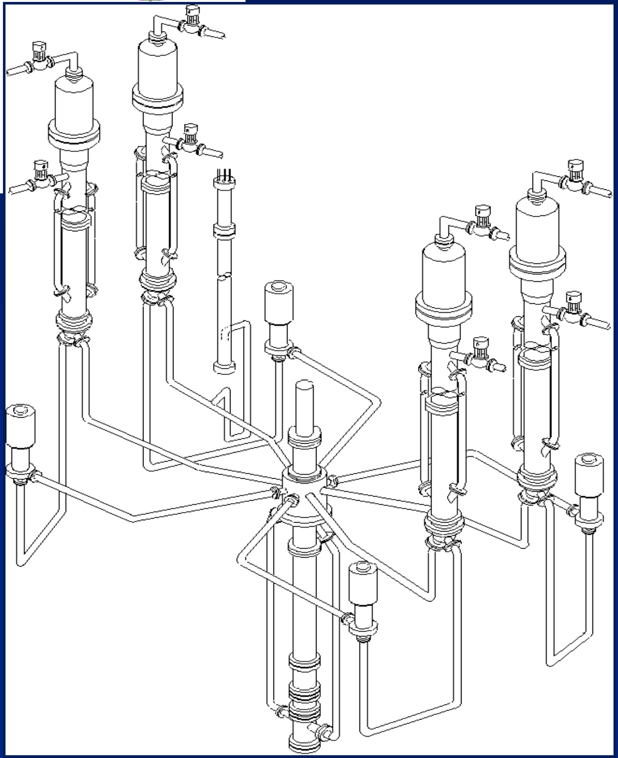




Figure 1 – The PUMA test facility.

# International Experimental Programs

- OECD/ROSA-2
  - Full-height, 1:48 scale model of PWR, 2-loops
  - Intermediate pipe breaks (>10 in)
  - Upper-head break
  - Thermal stratification during ECCS injection
- OECD/PKL-2
  - Full-height, 1:145 scale model of PWR, 4-loops
  - Boron precipitation
  - Steam generator parametric studies
  - Forced depressurization during LOCAs



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## USER-NEED TRANSIENT and ACCIDENT ANALYSIS

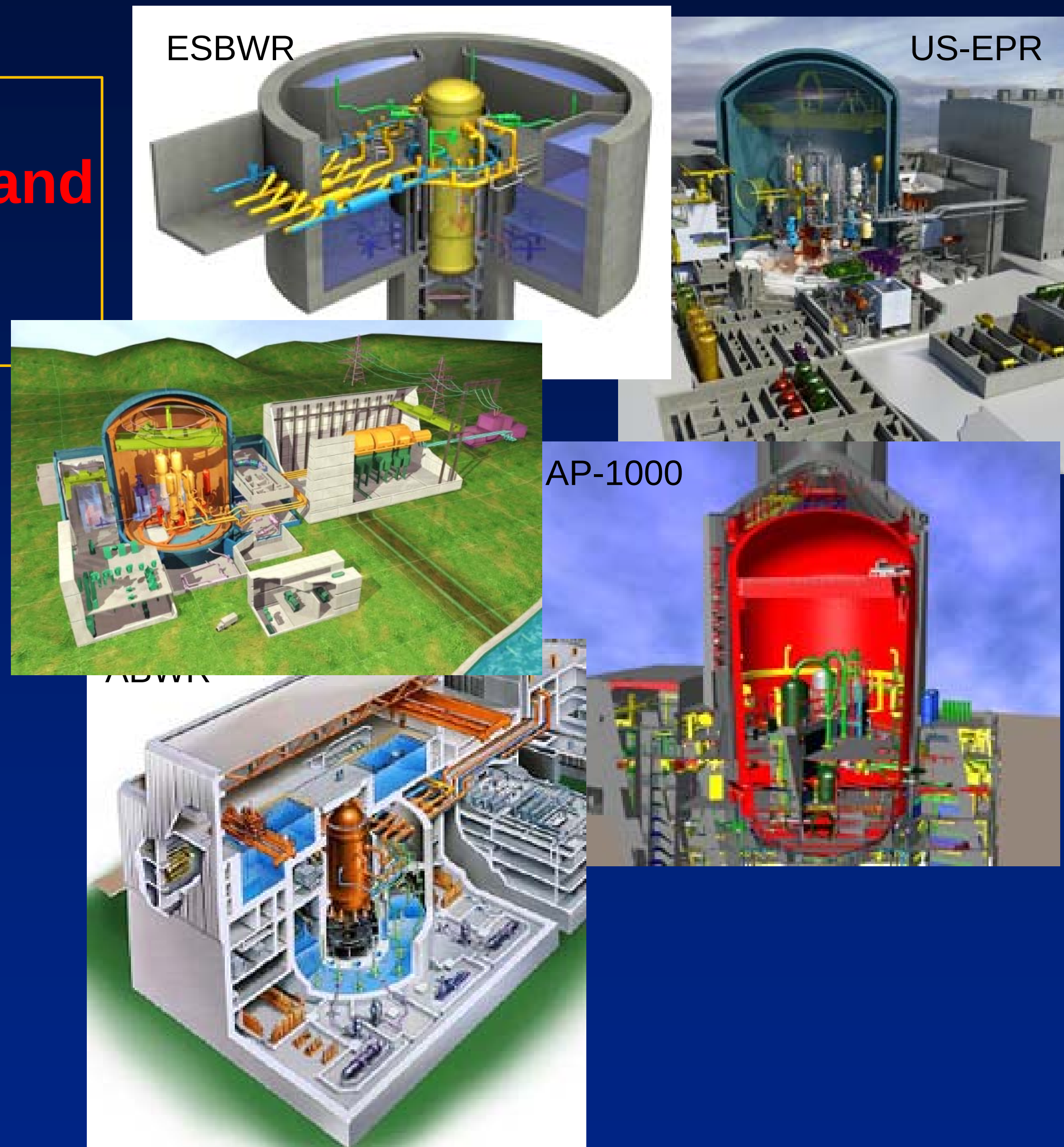
Licensees are required to use approved EMs to demonstrate compliance with NRC safety regulations:

- Therefore, as part of the RES mission of providing technical tools, RES develops TRACE input decks (EMs)
  - Receives plant-specific information from licensees during pre-application phase
  - TRACE input-deck library
    - BWR/3, /4, & /5
    - Westinghouse 2,3,& 4 loop PWR
    - C-E 2-Loop
    - B&W L-Loop
    - New BWR and PWR designs, e.g. ABWR, US-EPR, APWR, etc.

# New Reactor Designs

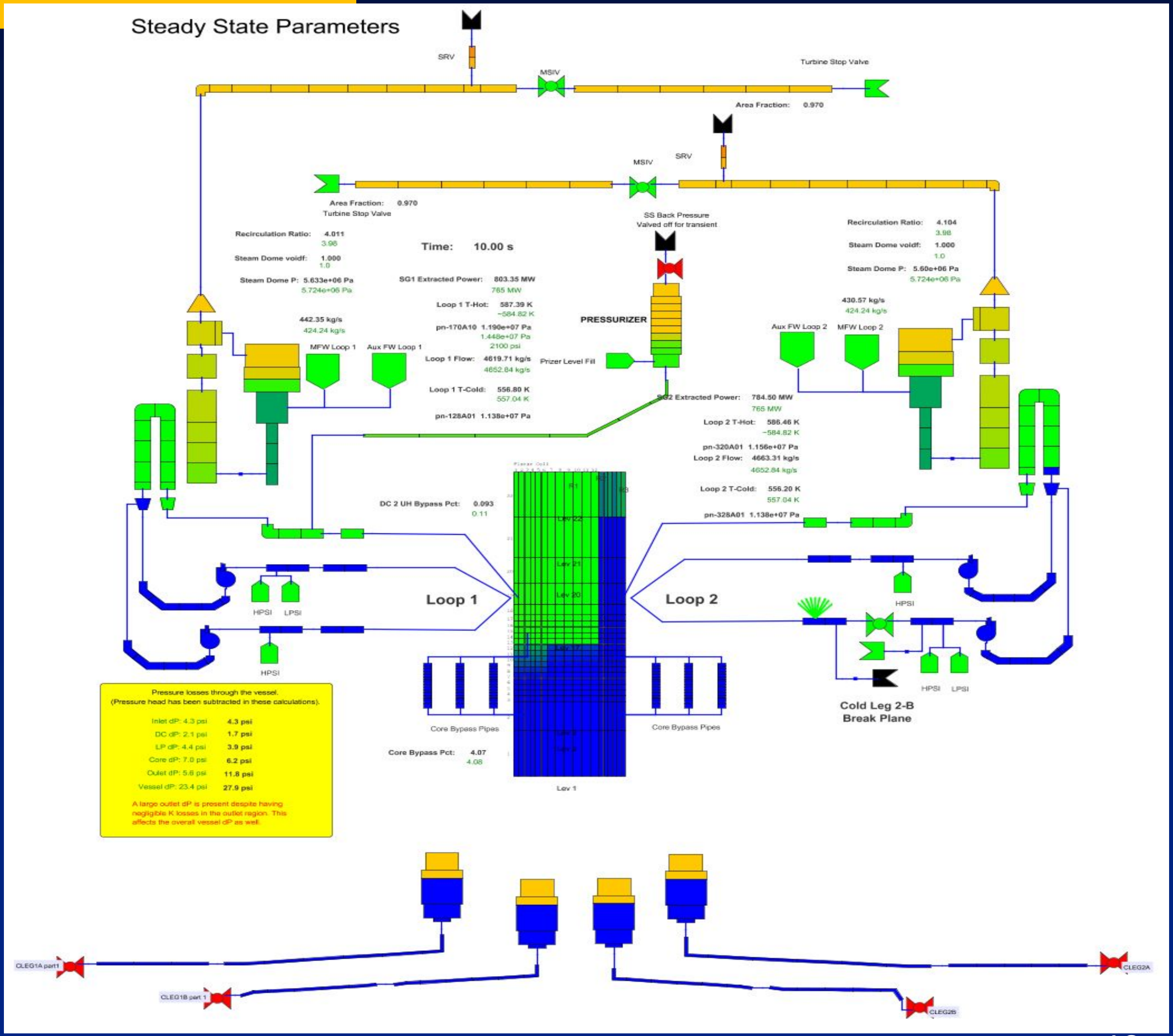
**User-need support for new-reactor licensing and design certification activities :**

- TRACE input deck development
- Assessment of TRACE applicability
  - Focus on major differences between new and currently operating reactors
    - Component/System innovations
    - Passive safety systems
    - Coupled T/H & 3D Kinetics



# SBLOCA Animation

*Will run an actual TRACE SBLOCA simulation and show the evolution of the transient using the animation.



# Future TRACE Assessment and Enhancement Needs

- Physical Models Currently Under Development:
  - Droplet Field
    - Allows for more mechanistic two-phase flow models
    - Increases accuracy in modeling droplet transport and interfacial heat transfer during reflood phase of LBLOCA
  - Grid Spacer Models
    - Increases accuracy of predicted temperature profiles downstream of grids
  - Containment modeling
    - Mechanistic models for film and droplet/spray condensation heat transfer are needed
- Improvements to Constitutive Relations:
  - Entrainment and de-entrainment
  - Subcooled boiling
  - Interfacial condensation

TRACE development and validation is driven by application needs

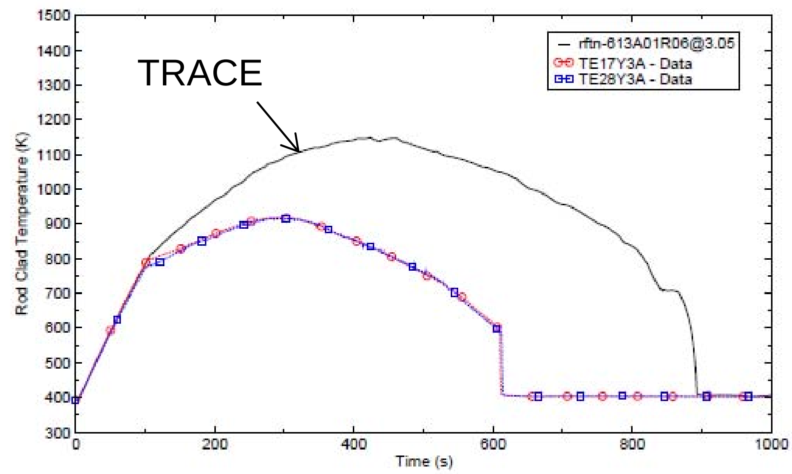



Figure C.2-39. Rod Clad Temperature Comparison at 3.05 Meters above the Bottom of the Heated Rods in the Medium Powered Region - Run 62.

Droplet field should improve clad-temperature predictions at upper bundle elevations

# Summary

- Most of the T/H work done in RES involves the use, development, and assessment of computer codes
- The primary codes used in RES for T/H analyses are TRACE, MELCOR, and FLUENT
- The enhancement of RES T/H codes is driven by application needs
- Code development and assessment will be continually needed to meet future challenges