

Nuclear Power Products and Services

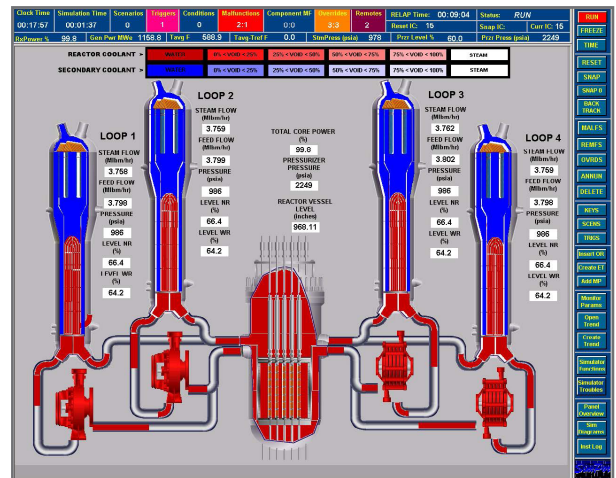


The Reactor Excursion and Leak Analysis Program (RELAP5) is an advanced, best-estimate, reactor thermal-hydraulic simulation code, developed at Idaho National Laboratory (INL). It has been exhaustively assessed and extensively applied for over 25 years by numerous companies, utilities, reactor vendors, and regulatory agencies throughout the United States and globally. The code models multi-phase flow of fluids in piping networks; heat transfer between the fuel, the fluid, heat sinks, and structural components; neutronic feedback effects between the fuel, the fluid, control rods, and soluble poisons in the reactor core. Its ability to mechanically predict behavior over the full range of normal, abnormal, and accident conditions, for an arbitrarily specified initial condition and time-varying boundary conditions, has been extensively benchmarked and is regarded as best-estimate.

NESTLE is a true two-energy group neutronics code that computes the neutron flux and power for each node at every time step. It provides this output by performing nodal diffusion calculations while assuming constant thermal-hydraulic conditions over the duration of the time step. The diffusion equations are solved in full two-group form using the nodal expansion method with a nonlinear iterative solution scheme. Control rods may be modeled individually or as groups, and may be of either partial or full length insertion.

As has been done with RELAP5 and NESTLE, WSC*, a legacy brand of Curtiss-Wright's Simulation Group, has adapted the Korea Atomic Energy Research Institute (KAERI) MARS code and severe accident codes to run in the 3KEYMASTER™ environment.

*: WSC, a legacy brand of Curtiss-Wright's Simulation Group, headquartered in Frederick, MD, is a global simulation and services company. Acquired by Curtiss-Wright in 2024, WSC is recognized for the quality and efficiency of their products and flexible team-oriented approach to serving its customers.



What is 3KEYRELAP5-RT™?

3KEYRELAP5-RT™ is Curtiss-Wright's adaptation of the RELAP5 and NESTLE codes to run in the 3KEYMASTER™ environment, in real-time mode with graphical visualization. Both codes provide best-estimate models for simulating nuclear reactors. 3KEYRELAP5 can be built with any version of RELAP5-3D under Microsoft Windows. Having RELAP5-3D source allows open source advantages and customization to one's specific needs.

3KEYRELAP5-RT™ Features

- Adapted to run in real-time mode
- Graphic representation of simulated system's internal structures to show model nodalization
- Extensive data visualization for nodal parameters, with user-specified nodal animation based on computed model parameters
- Nodal parameters are available for tabular and multi-variable trend chart displays

3KEYRELAP5-RT™ Real-Time RELAP5 & NESTLE

Thermal-Hydraulic and Neutronic Modeling

RELAP5 Thermal-Hydraulic Modeling Features

3KEYRELAP5-RT™ generates a non-equilibrium model for two-phase fluid systems, by solving the following for each node:

- Complete set of six conservation equations—consisting of the conservation of vapor mass, liquid mass, vapor energy, liquid energy, vapor momentum, and liquid momentum
- Transport equations for the conservation of non-condensable gas and material species (e.g., Boron)

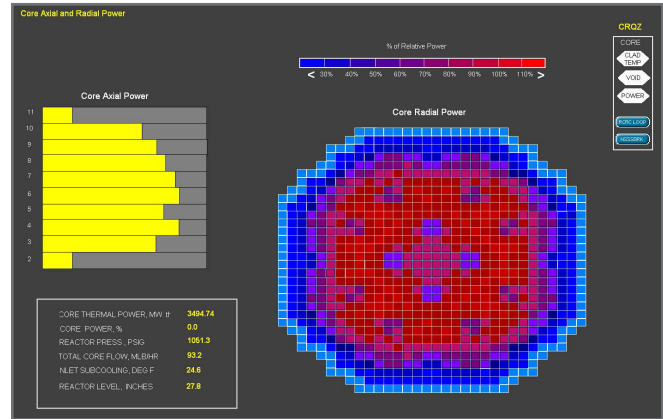
NESTLE Neutronics Modeling Features

- Complete 2-energy group neutronics model—greater accuracy throughout the core and in accident scenarios
- Explicit reflector modeling with 2-group cross-sections—more accurate accounting of neutron leakage across a wide range of conditions
- Model uses cycle-specific core design data from fuels group eliminating time-consuming cycle-specific tuning for non-equilibrium cycles
- Kinetics module is a subroutine within RELAP5 and provides tighter coupling between neutronics and thermal-hydraulics models
- Capable of parallel execution

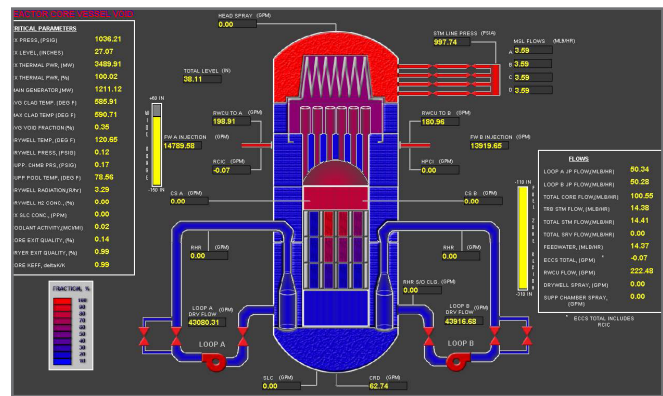
RELAP5 as a 3KEYMASTER™ Task

3KEYRELAP5-RT™ incorporates RELAP5 as a separate task within the 3KEYMASTER™ environment. This provides the following features:

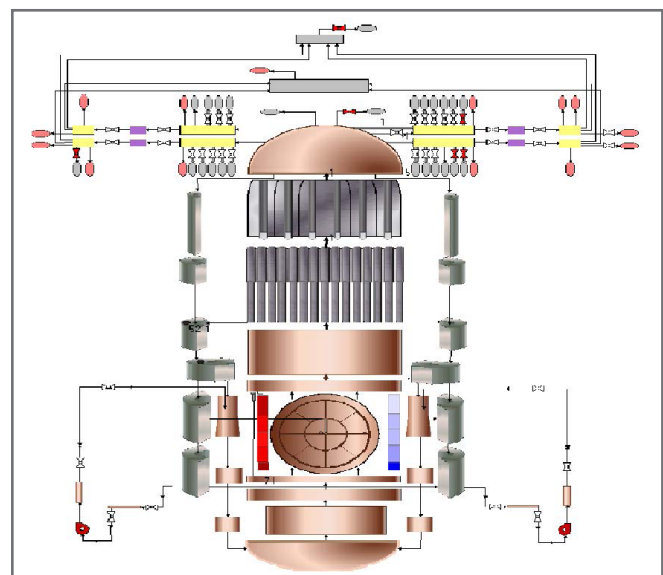
- Flexible RELAP5 time step adjustment
- Flexible RELAP5 task CPU assignment
- Run several RELAP5 real-time tasks simultaneously under the same simulation load
- Real-time change of boundary conditions
- Access to all RELAP5 memory variables
- RELAP5 data presentation in the form of tables, dynamic drawings, and trends
- Full control of RELAP5 via Graphical Engineering Station or Instructor Station
- Integration with other 3KEYMASTER™ models
- Run RELAP5 in standalone mode
- No need to change to RELAP5 source code
- Basis for further development and enhancements



Core and Axial Radial Power



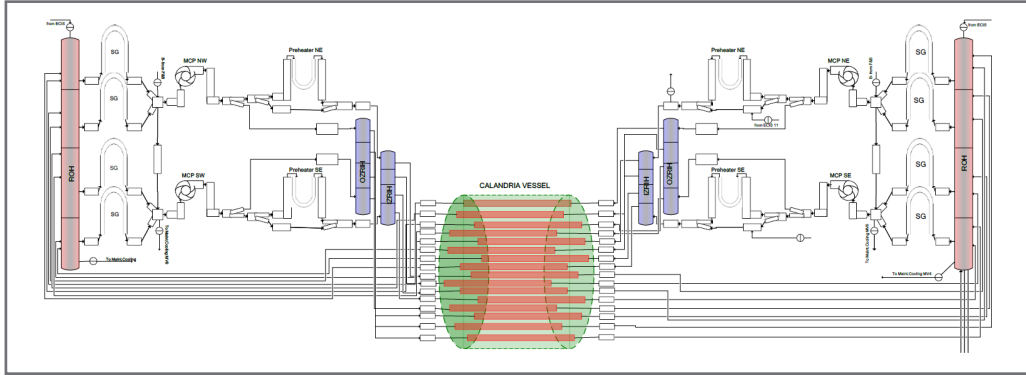
Reactor Core Vessel Void



BWR Relap Model Nodalization

3KEYRELAP5-RT™ Real-Time RELAP5 & NESTLE

Thermal-Hydraulic and Neutronic Modeling

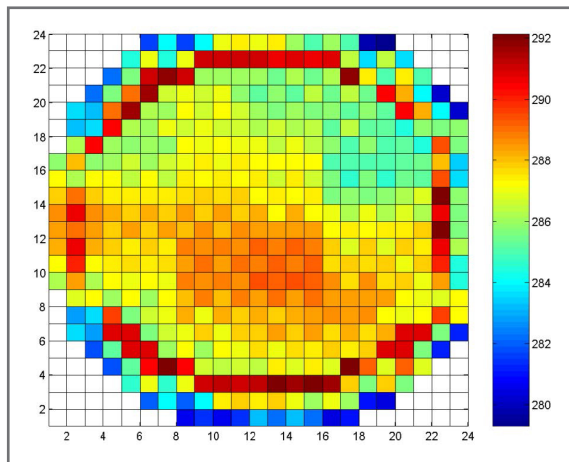


CANDU reactor Relap Thermohydraulic Model Nodalization

R3K Interface Layer & Execution Control

Communication between RELAP5-3D and the 3KEYMASTER™ environment is controlled via the R3K Interface layer developed by our Simulation Group. This provides the following functions and features:

- **Execution control functions:** setting-up parameters for RELAP execution control, including model time, making time-step advancements, managing snap / reset functions, reading and writing restart files
- **Performing setup mode functions:** this includes establishing steady state / transient modes, setting components to be run, printing major edits, and setting debug mode on/off
- Generating a list of memory variables and exporting specified variables. Note: shared memory is stored in 3KEYMASTER™
- Providing control over various model features, such as: input / output parameters, specifying heat capacity of materials, fouling factors, and form-loss coefficients at specified junction
- In addition, RELAP5 components can be replaced and model time changed after restart

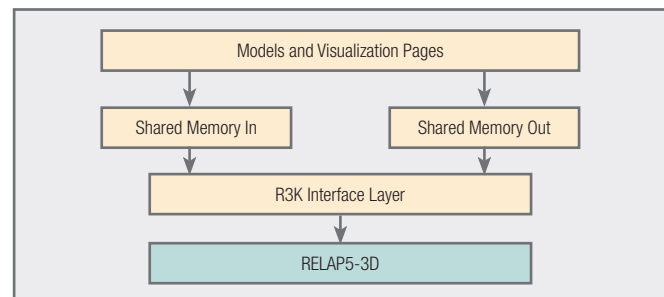


Core coolant temperature four (4) seconds after one (1) pump trip

3KEYRELAP5-RT™ Advantages

3KEYRELAP5-RT™ inherits the benefits provided by RELAP5 and NESTLE as proven industry-standard codes, and adds additional value provided by the 3KEYMASTER™ environment.

- **Proven across different types of reactors:** 3KEYRELAP5-RT™ installed base includes BWRs, PWRs, VVER, CANDU, and Naval reactors
- **Reduces tuning effort:** rigorous, physics-based modeling is accurate over a wider range of conditions and scenarios
- **Reduced integration effort:** leverages existing integration between the neutronics and thermal -hydraulics models
- **Extensive visualization:** provides insights into inner workings of systems and physical phenomena, providing in-depth training and knowledge
- **Greater credibility:** use of industry standard best-estimate modeling provides greater credibility for operator certifications and for simulator generated data to support licensing
- **Easy porting and integration:** based on the demonstrated success of RELAP5 and NESTLE implementation in 3KEYMASTER™, we offer this advantage to customers with a need to port other best-estimate and third-party models to a visual real-time environment
- Faithful and detailed modeling of systems and 3KEYMASTER™ features provides a valuable platform for analysis, design modification evaluations, operating procedure verification, etc.
- The thermal-hydraulic model can be extended to secondary systems



3KEYMASTER™ Environment

3KEYRELAP5-RT™ Real-Time RELAP5 & NESTLE

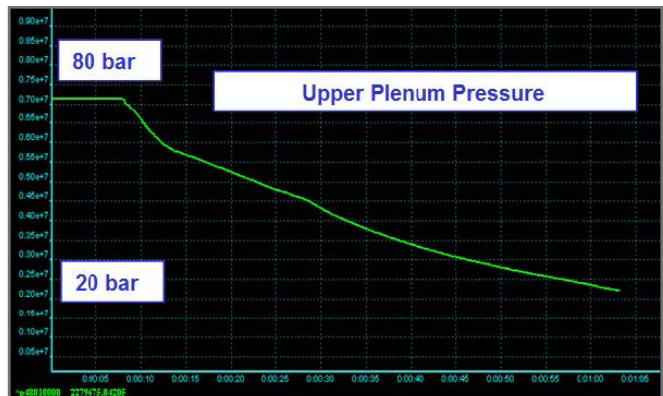
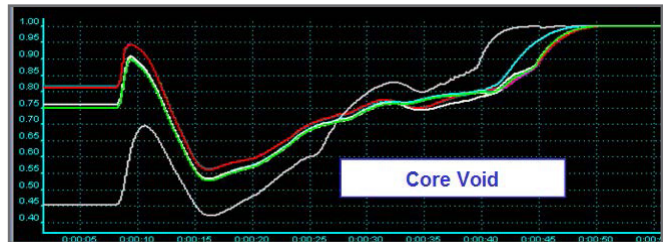
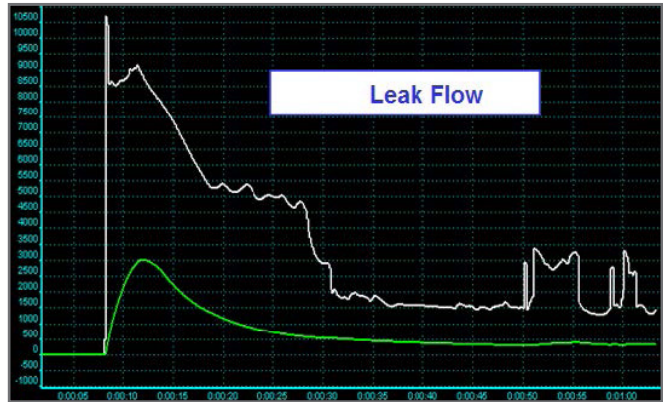
Thermal-Hydraulic and Neutronic Modeling

Benchmarking

- There is no change to the RELAP5 thermal-hydraulics or NESTLE neutronics models in 3KEYRELAP5-RT™; therefore, 3KEYRELAP5-RT™ inherits extensive benchmarking completed for RELAP5 and NESTLE against test facilities and other codes.
- Implementations of 3KEYRELAP5-RT™ are benchmarked against recorded plant evolutions and transient behavior at reference unit. This is performed as part of the implementation V&V or on an on-going basis.
- Benchmarking is also performed against other transient design analysis code results provided by reference units as part of the simulation V&V.

Trending Examples

The flexibility to choose any 3KEYRELAP5-RT™ variable that is available in shared memory allows the generation of trends and tabular displays for analyzing model response and benchmarking against available data.



Examples of trends from a BWR LOCA

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