Application of COMSOL Multiphysics® Pipe Flow Module to Develop a High Flux Isotope Reactor (HFIR) System Loop Model

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Abstract

ORNL's High Flux Isotope Reactor (HFIR) is the highest flux reactor-based source of neutrons for research in the United States. Thermal and cold neutrons produced by HFIR are used to study physics, chemistry, material science, engineering, and biology. HFIR is a beryllium-reflected, light-water-cooled and -moderated, aluminum-clad fuel plate, flux-trap-type reactor that utilizes highly enriched U-235. The HFIR core resides in an 8 ft diameter pressure vessel located in a pool of water. The core has two fuel elements, the inner fuel element (IFE) and the outer fuel element (OFE), consisting of 171 and 369 involute fuel plates, respectively, for a total of 540 fuel plates. These involute-shaped fuel plates are uniformly spaced in order to provide an equal coolant flow area for each plate within each element. The primary coolant enters the pressure vessel through two 16-in. diameter pipes above the core, passes downward through the core, and exits through an 18-in. diameter pipe beneath the core. The design total flow rate is 16,000 gal/min (1.0 m3/s) of which 13,000 gal/min (0.82 m3/s) flows through the fuel region and the remainder through the target, reflector, and control regions. The reactor is operated with an inlet pressure of 482.7 psi (3.33 MPa). The inlet temperature is 120 oF (48.9 oC), the core exit temperature is 157 oF (69.4 oC), and the pressure drop through the core is 105 psi (0.724 MPa).

Currently, RELAP5 code is the primary transient safety analysis tool used at HFIR to perform thermal-hydraulic system safety evaluations. RELAP5 is a 1D, best-estimate, single and two-phase flow capable, nuclear reactor systems analysis code that can analyze steady-state and transient system behavior in light water reactors under normal operating and off-normal accident conditions.

Recently, a Pipe Flow Module was added into the COMSOL Multiphysics® software for applications in fluid flow, heat and mass transfer, hydraulic transients, and acoustics in pipe and channel networks. This new module is suitable for modeling pipes and channels which have lengths large enough so that flow in them can be considered fully developed and represented by 1D approximation. Preset piping components such as bends, valves, T-junctions, contractions/expansions and pumps are also available to use. To verify and validate this new pipe flow capability in COMSOL, it was decided to develop a HFIR system model using this new module while keeping all the input parameters and model components exactly the same as the HFIR's existing RELAP5 model. All geometrical dimensions and other thermal-hydraulic data

for this model were obtained from the HFIR RELAP5 input deck and associated documentation. The system model consists of three primary coolant loops and a reactor vessel/core model as shown in Fig. 1.

Steady-state simulations and a postulated pump flow transient simulation were performed using this new COMSOL model and compared against the RELAP5 predictions. Overall, the COMSOL results yielded a good agreement with the RELAP5 results (see Fig. 2 and Table 1).

Figures used in the abstract

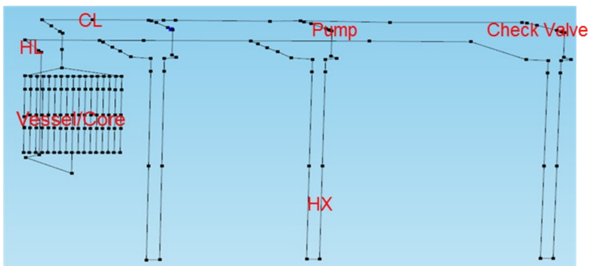

Figure 1: HFIR System Model using Pipe Flow Module

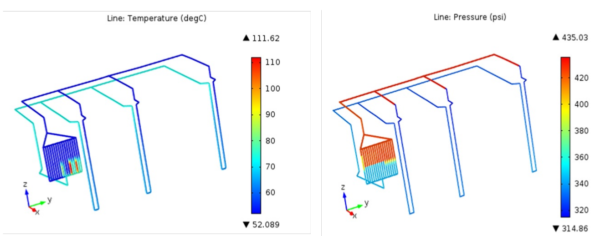

Figure 2: COMSOL Model Results

	COMSOL	RELAP5
Reactor power (MW)	86.6	
Total Loop flow rate (kg/s)	327.4x3	
RPV Inlet cold leg temperature (K)	325.56	325.48
RPV Exit Hot leg temperature (K)	346.8	347.2
RPV Inlet coolant pressure (MPa)	2.92	2.91
RPV exit coolant pressure (MPa)	2.31	2.20
Outer core hot fuel outlet coolant temperature (K)	385.08	386.2
Inner core hot fuel outlet coolant temperature (K)	380.1	381.1

Figure 3: COMSOL vs. RELAP5 – Steady-State Results