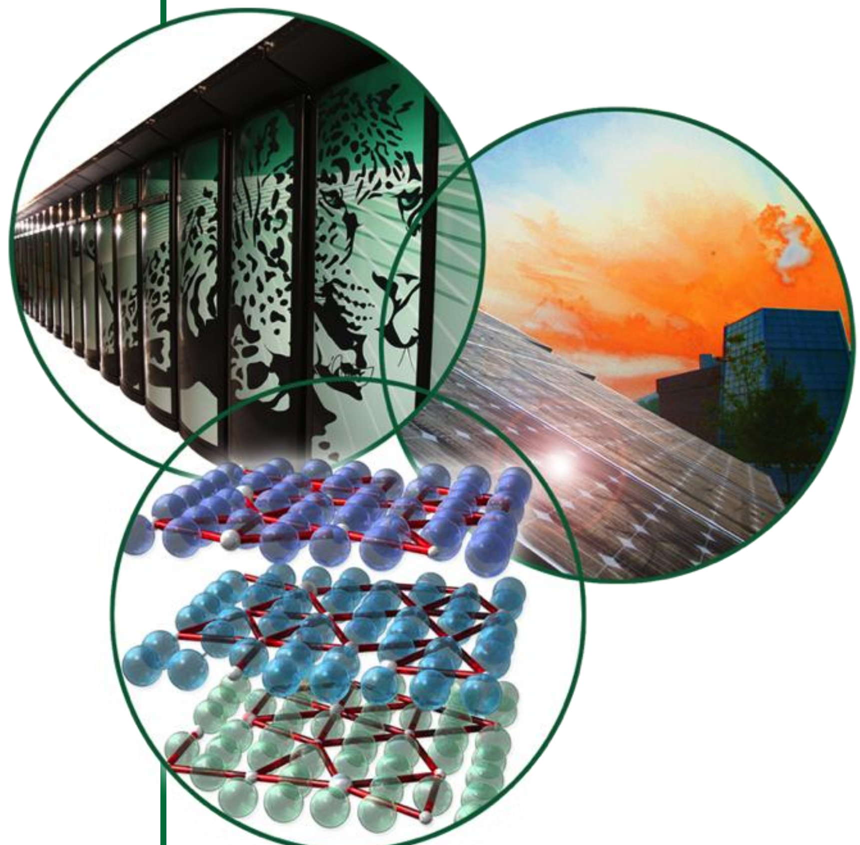
COMSOL CONFERENCE BOSTON2013

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



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COMSOL Conference 2013

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U.S. DEPARTMENT OF ENERGY

RNSD Reactor and Nuclear Systems Division

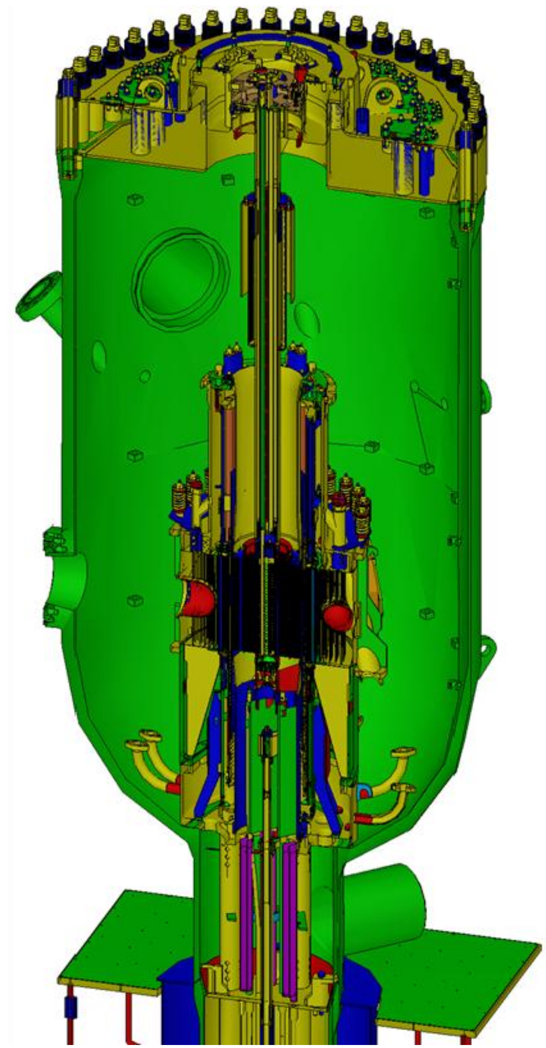
HFIR

OAK RIDGE NATIONAL LABORATORY

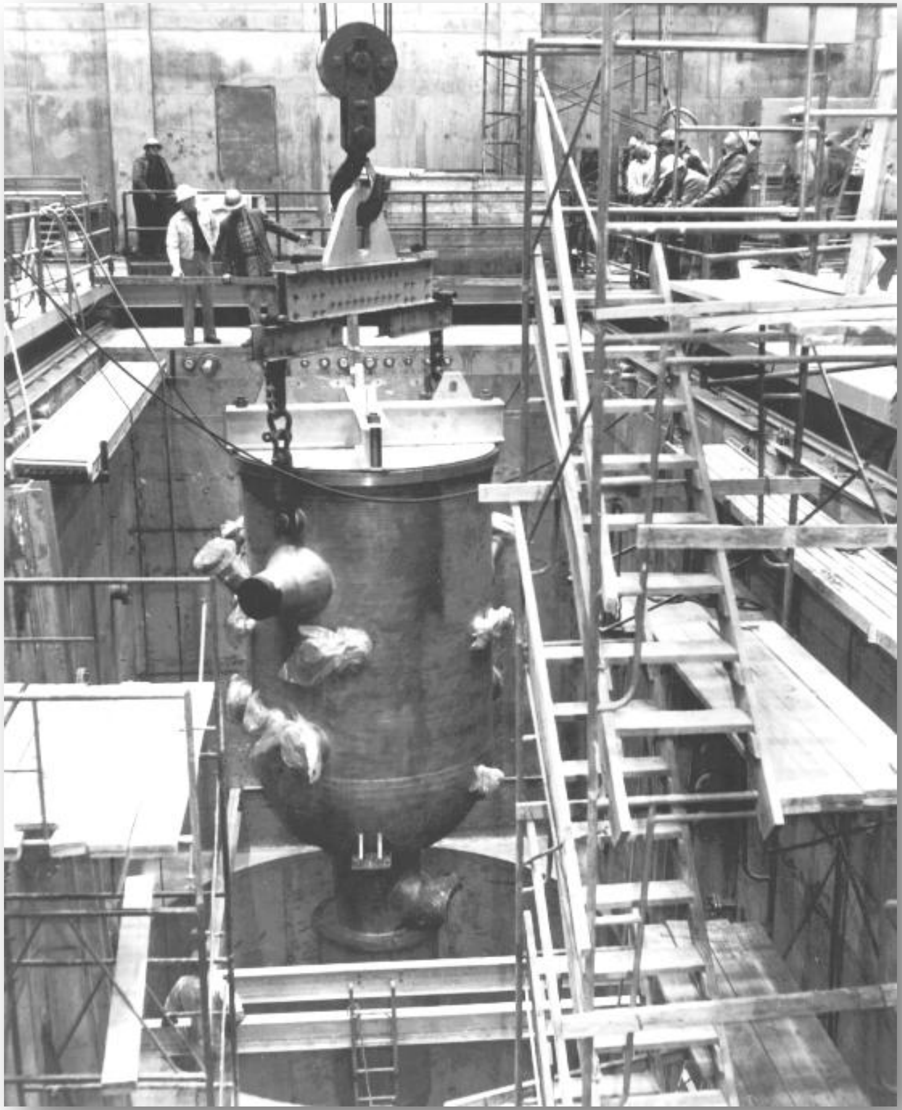
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

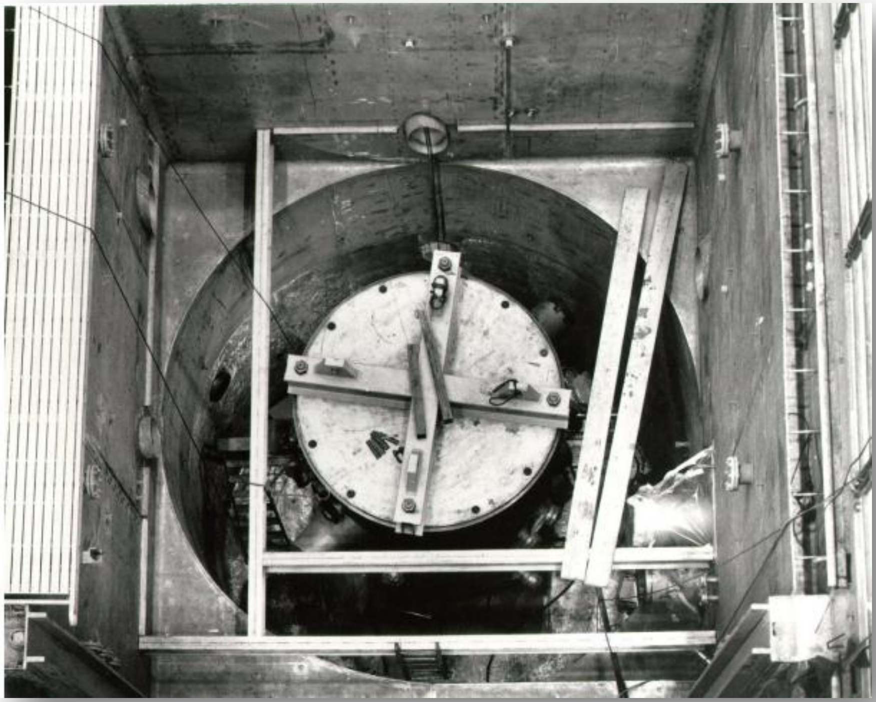
HFIR is a Multi-Purpose High-Performance Research Reactor

- Operated since 1966 with one of the world's highest thermal neutron fluxes ~2.5×10^{15} neutrons/(cm^2-s)
- Involute-shaped fuel plates, beryllium reflected, light water-cooled and –moderated, pressurized, flux-trap type research reactor
- Highly enriched uranium (~93% $^{235}U/U$) fuel embedded in aluminum-6061 clad
- Cold and thermal neutron scattering, materials irradiation, isotope production, neutron activation analysis



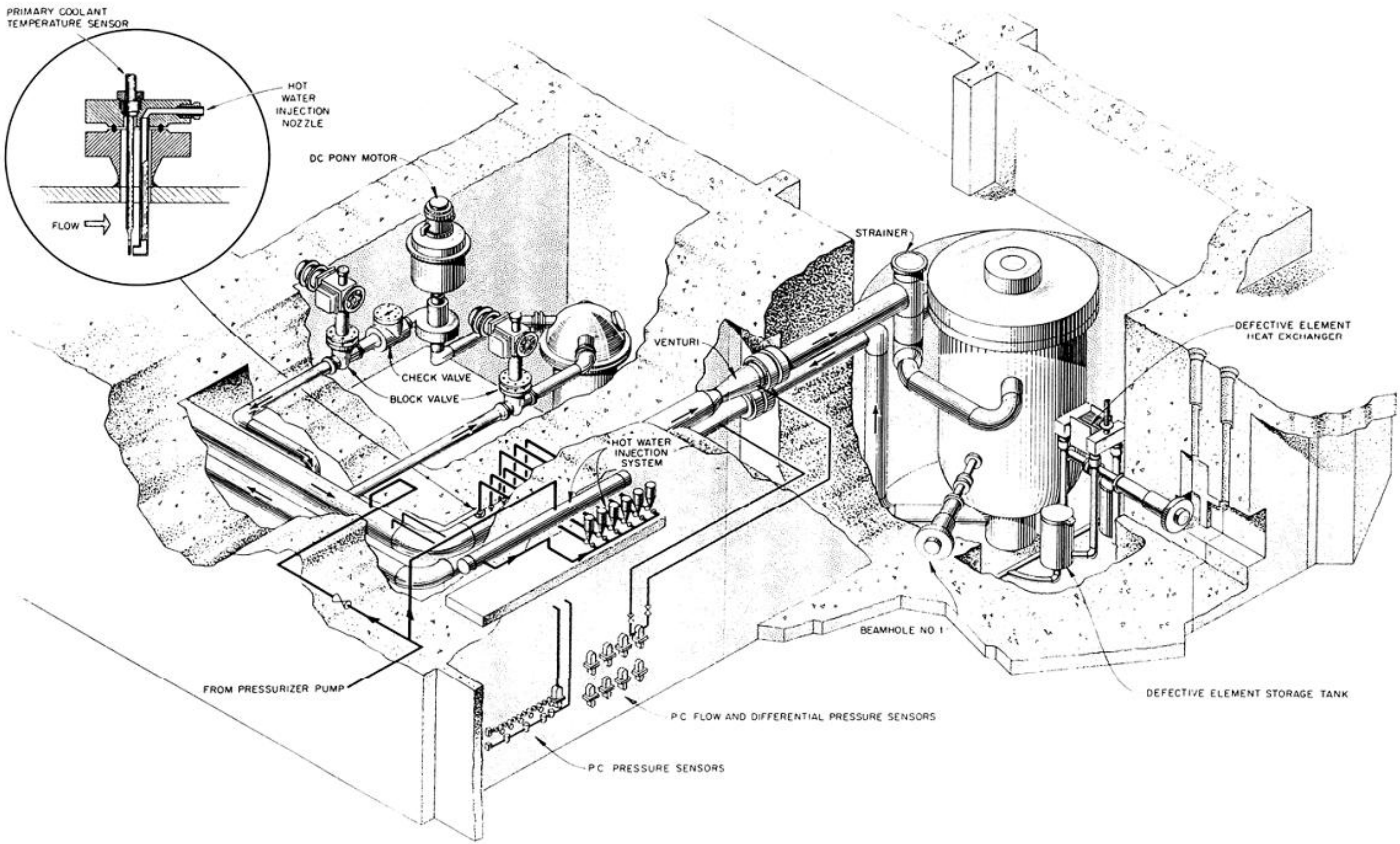
Sixties' Historical Photos of HFIR





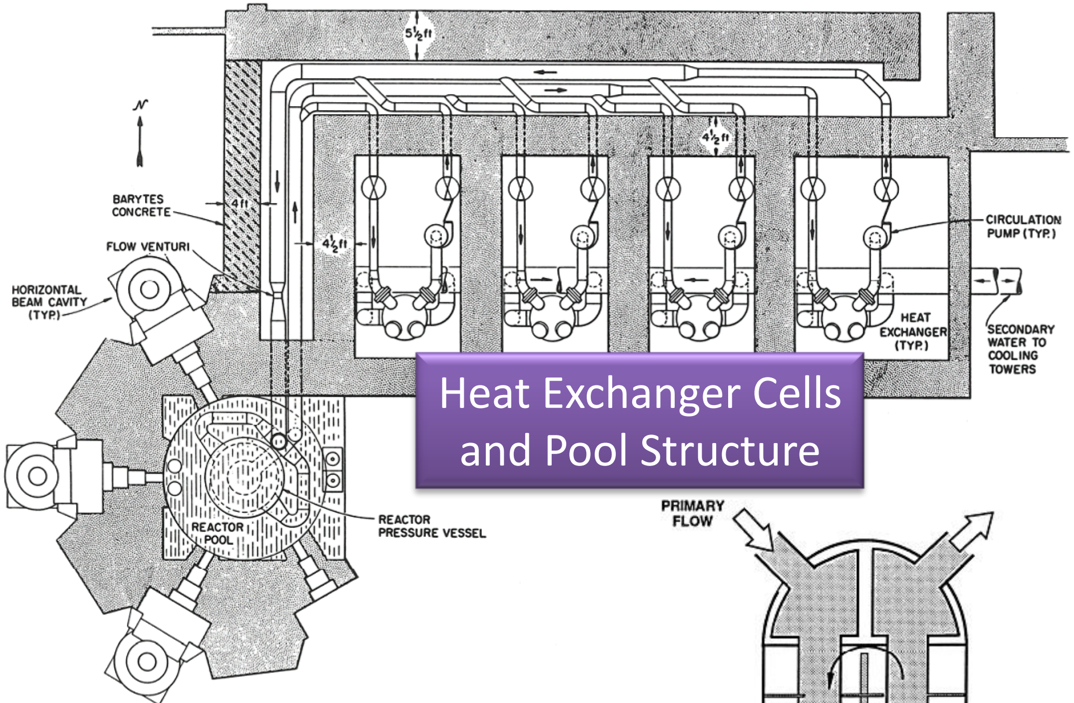
HFIR pressure vessel as being lowered into the pool cavity

HFIR Primary Coolant System

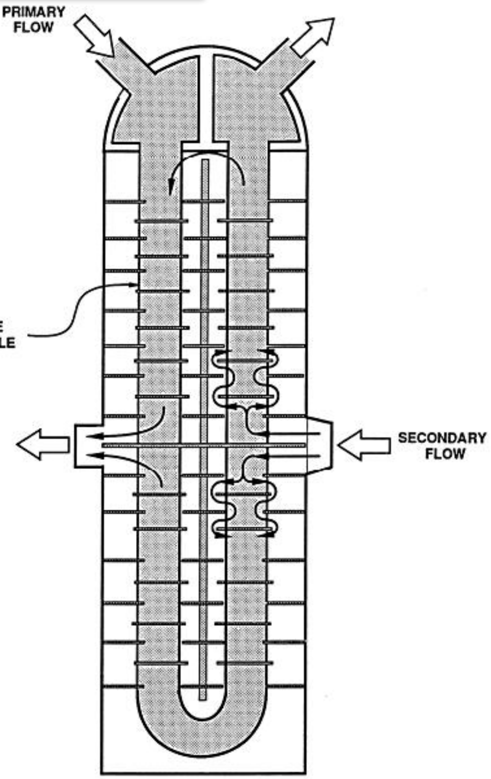


HFIR Primary Coolant System

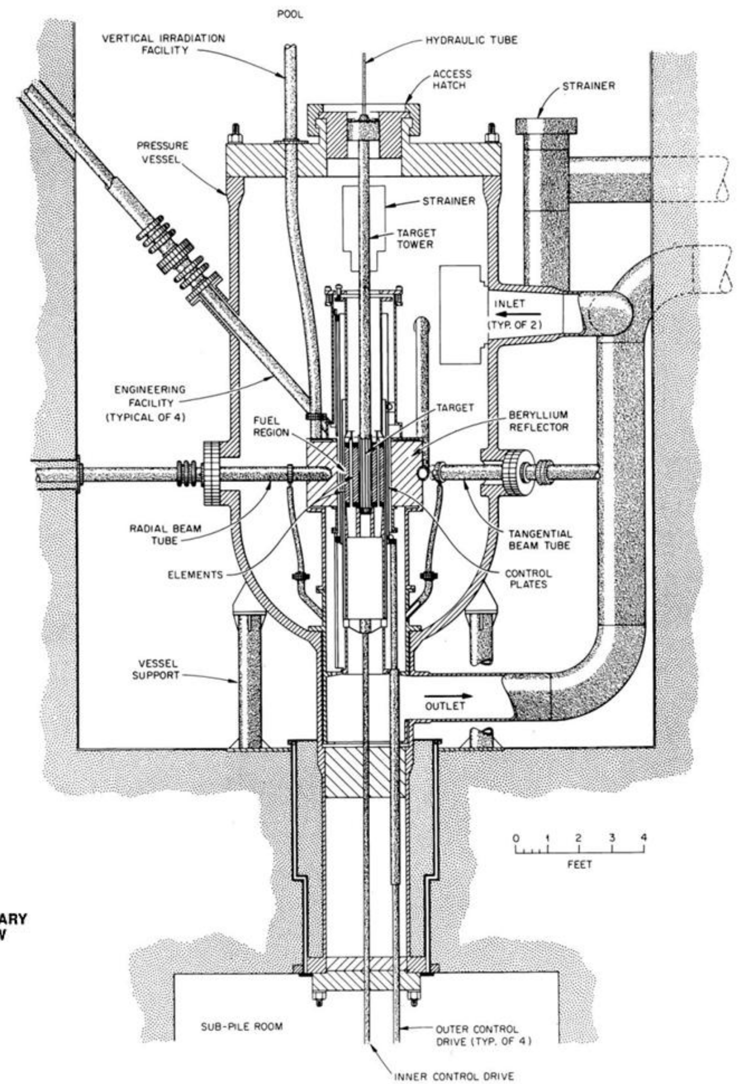
Schematics of HFIR System Components



Heat Exchanger Cells and Pool Structure

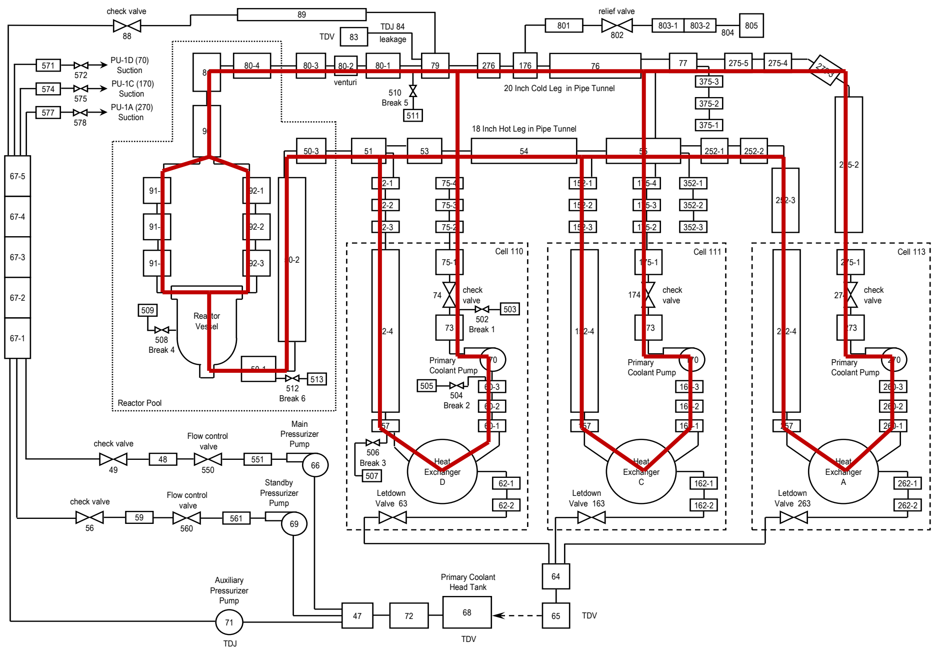


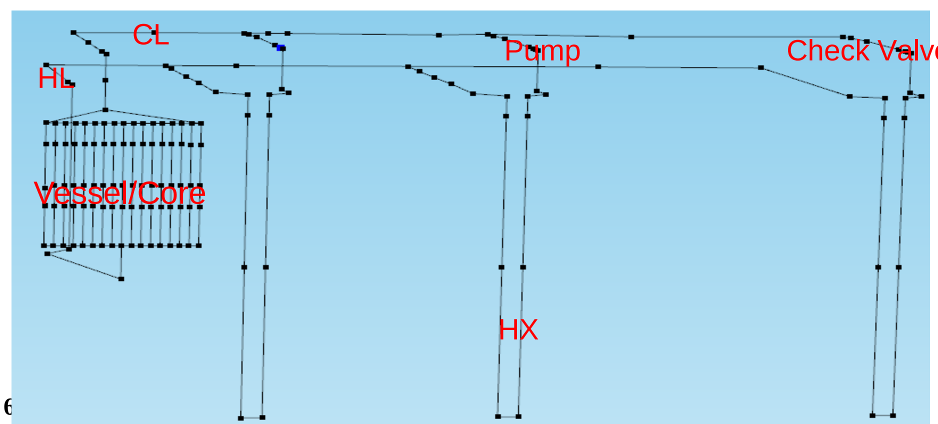
Heat Exchanger Flow Path



Vessel/Core Cross-section

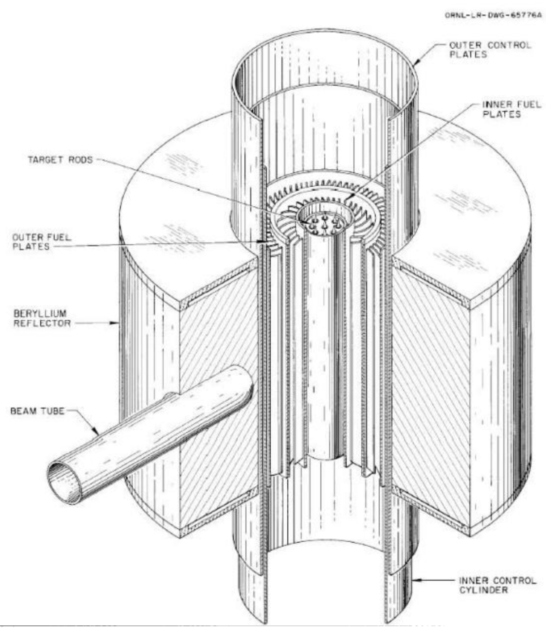
HFIR COMSOL System Model Based on the RELAP5 Model

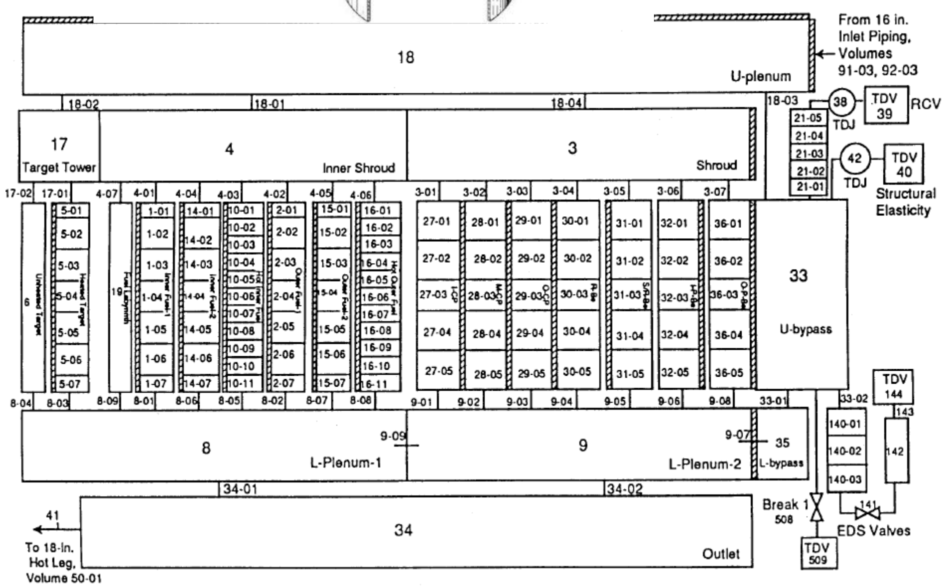




- Three primary loops modeled
- Reactor pressure vessel
  - Inner fuel region
  - Outer fuel regions
  - Target region
  - Reflector
- Primary coolant pumps
  - Modeled with COMSOL Pump component
  - Limited modeling capability: fixed flow, pressure increase, downstream pressure
  - Pump curves needed for flow transient
- Heat Exchanger
  - Modeled with COMSOL heat transfer component
  - Currently, the component cannot define effective heat transfer area

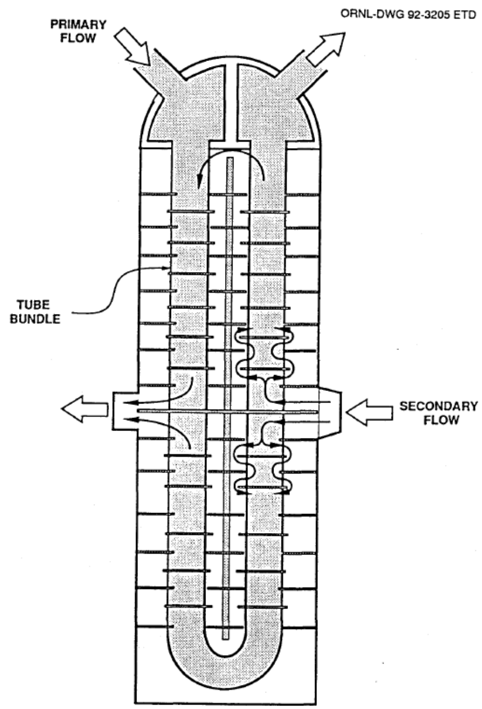
Vessel/Core Modeling

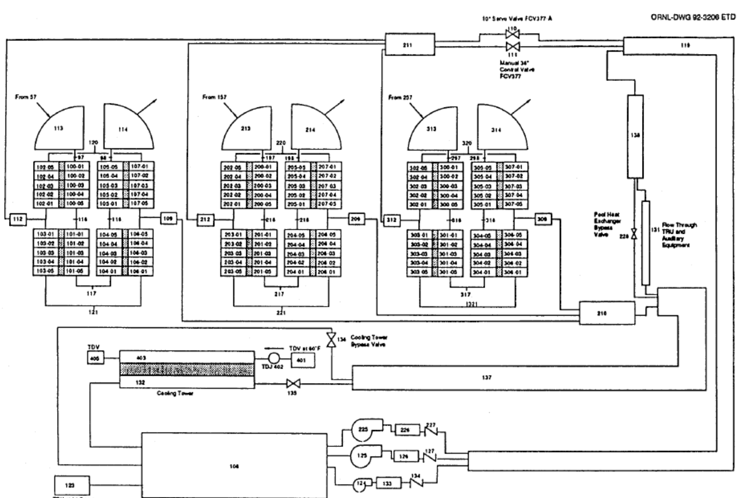




- Vessel/Core Components
  - Fuel element
  - Target
  - Control cylinders,
  - Reflector
  - Core bypass
  - Upper and lower plenum
  - Outlet
- Inner and outer hot fuel elements
- Core heat loads: 86MW
  - Distributed in fuel, target, cylinders, reflectors
  - Axial power shape
- Core heat structures needed for transients

Heat Exchanger Modeling





- HX bundle consists of 1200 SS tubes
  - Average tube length: 710.52 in.
  - Tube ID/OD: 0.555/0.625 in.
- The secondary side flow pattern is much more complicated.
  - HTC has to be estimated
- COMSOL lumped all tubes into one hydraulic pipe
  - User defined primary side Nu = f(Re, Pr)

Extra-Vessel Piping

- Lengths and elevations of the piping throughout the primary side were obtained from the RELAP5 deck/document
- Values of Hydraulic Diameter and K-loss were obtained from the RELAP5 model. Modifications were made when necessary.

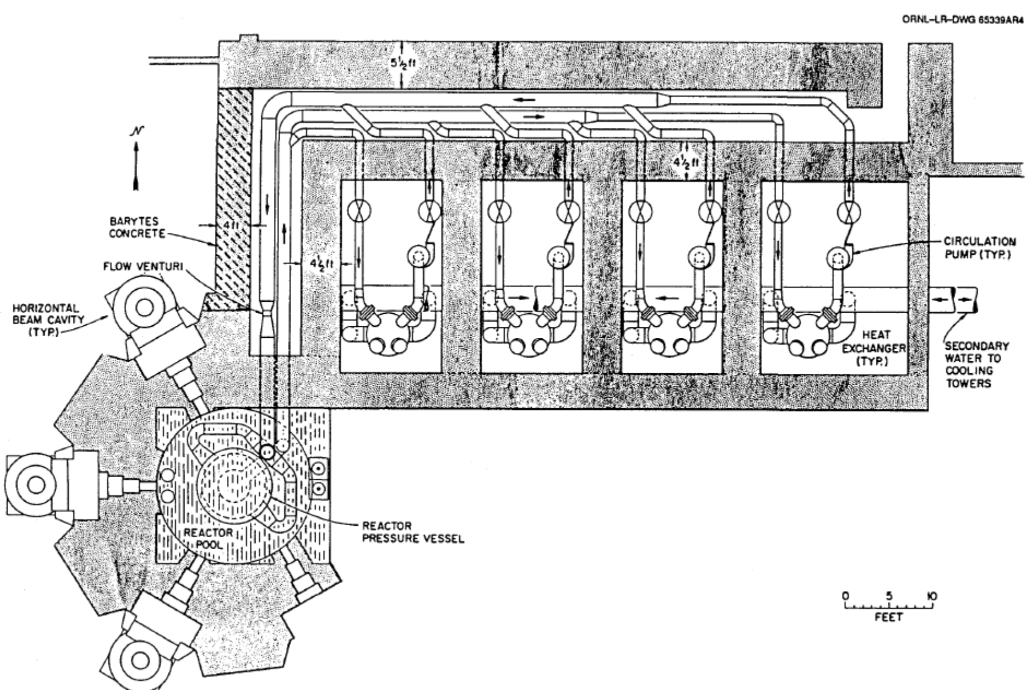


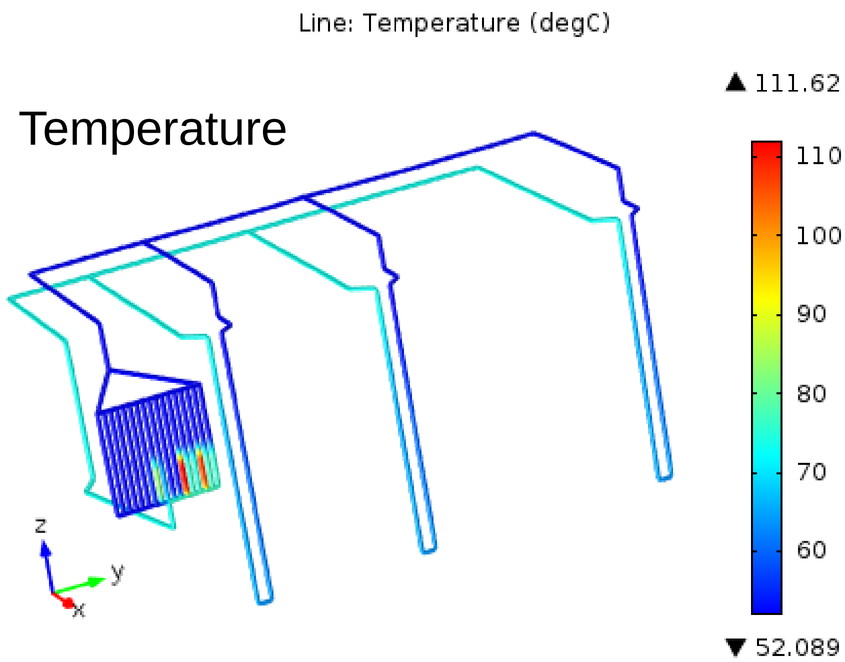
Table 39. Dimensions of steel pipe

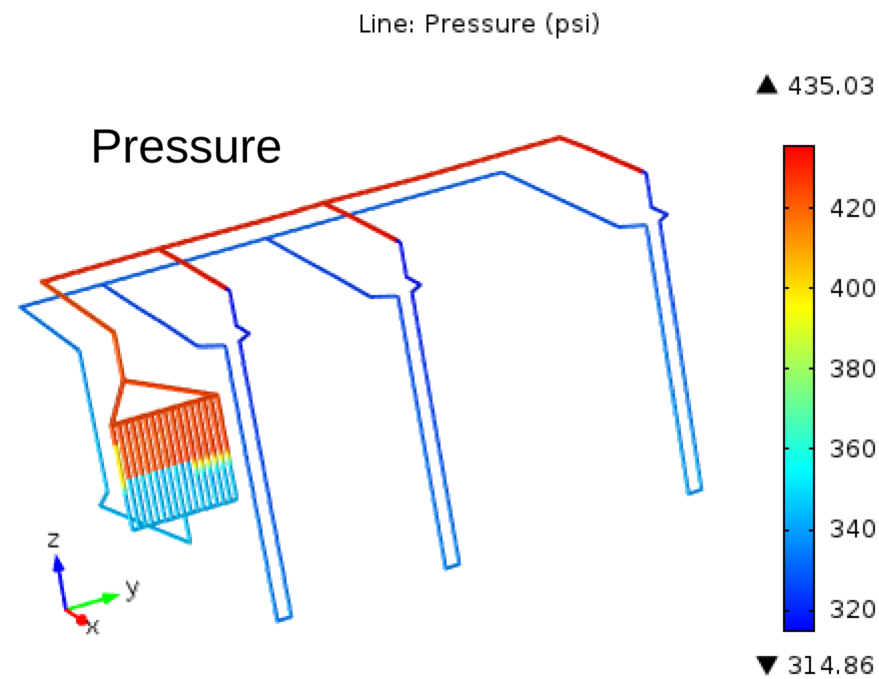
	Schedule	Nominal diameter (in.)	Indide diameter (in.)	Thickness (in.)
	40	2	2.067	0.154
	40	3	3.068	0.216
	40	4	4.026	0.237
	40	10	10.020	0.365
	40	14	13.126	0.437
	40	16	15.000	0.500
	40	18	16.876	0.562
HL	40	20	18.814	0.593
CL	80	10	9.564	0.593

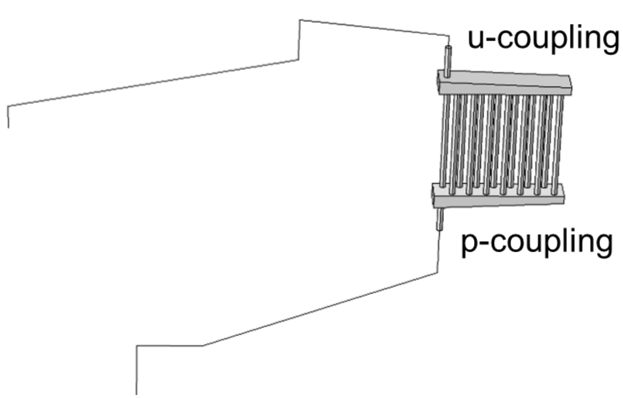
COMSOL vs. RELAP5 – Steady State Run

	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

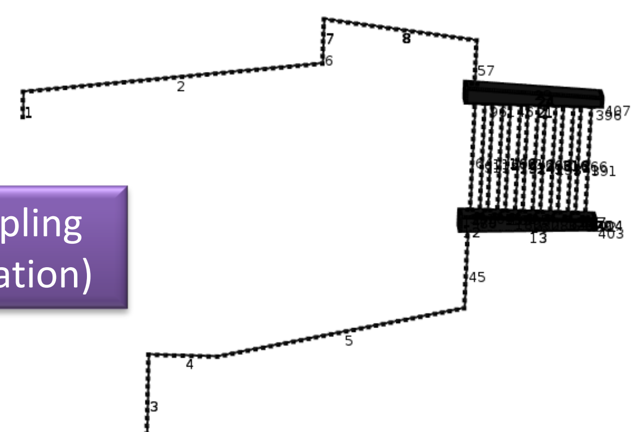
COMSOL Results – Steady State Run







1D-3D CFD Coupling (under investigation)



Advantages of COMSOL-based System Model of HFIR

- Coupling with same, higher or lower order physics, as needed
  - 1D-1D, 1D-2D, 1D-3D, 2D-3D…
  - "system-CFD-multiphysics" coupling
- Independent capability for reviewing calculations within the limited scope
- Enhanced interaction between transient and steady state analyses for different applications
- Easily tractable and portable (ease of user management)
- Modern user-interface (ease of model input management)
- More solver options/features (convergence, stability)
- Ease of handling for nonlinear (T,P)-dependent material properties
- Parametric and functional inputs (mathematical dependencies) could be easily implemented

Thank you for your attention.

Oak Ridge National Laboratory