A COMSOL Multiphysics® Software Analysis of Beam Tube Cooling in the High Flux Isotope Reactor of ORNL

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Abstract

Previous to the present work, a formal calculation was approved [1,2] to support the operation of the High Flux Isotope Reactor (HFIR) Horizontal Beam-Tube 1 of 4 (HB-1). The present calculation [3,4] repeats the previous work using COMSOL Multiphysics® software and extends the analysis to cover a broader range of coolant flow. In addition, this new calculation expands the analysis much further than the previous work to include (1) material properties as a function of temperature, (2) investigated available two-equation turbulence models, (3) investigated quadratic finite element basis functions, (4) included mesh-convergence studies, and (5) included a fully-coupled thermal-fluid-structure interaction due to the thermal expansion of the solid materials in the model. The analysis was performed at both normal power levels, and to address nuclear safety concerns, at extreme power levels. The purpose of the calculation was to allow the HB-1 system engineers to choose an extended operating range for the cooling water flow rate, and most importantly, assure that the aluminum components of HB-1 would not exceed a threshold temperature of 250 F [5] and cause undesirable changes in the temper properties of the aluminum components. And finally, in order to improve the analysis further, some additional recommendations are included for consideration.

HFIR Facility and HB-1 Component Description and Operating Constraint

Summary of the COMSOL® Model of HB-1

Development of an Innovative and Fully-Coupled Solver

Performance of the COMSOL® Software Solver on a Nuclear Qualified Linux Cluster

Discussion of Results

Conclusions and Suggestions for Further Improvement

References

Reference

[1] K. W. Childs, M. W. Wendel, and G. E. Giles. "Steady-State Thermal Qualification of HFIR HB-1 Beam Tube," C-HFIR-1998-038/R0, 4/5/1999 (available upon request from RRD of ORNL).

[2] CFX-4.2: Solver, AEA Engineering Software, Inc., Bethel Park. PA, December, 1997.

[3] J. D. Freels, M. W. Crowell, and P. K. Jain. "Extension and Improvements to the Steady-State Thermal Qualification of the HFIR HB-1 Beam Tube," C-HFIR-2015-041/R0, 2016, (available upon request from RRD of ORNL).

[4] COMSOL Software, a product of COMSOL, Inc., 100 District Avenue, Burlington, MA 01803 USA, info@comsol.com

[5] Farrell, K. and Richt, A. E. "Postirradiation Properties of the 6061-T6 Aluminum High Flux Isotope Reactor Hydraulic Tube," Properties of Reactor Structural Alloys After Neutron or Particle Irradiation, ASTM STP 570, American Society for Testing and Materials, 1975, pp. 311-325.

Figures used in the abstract

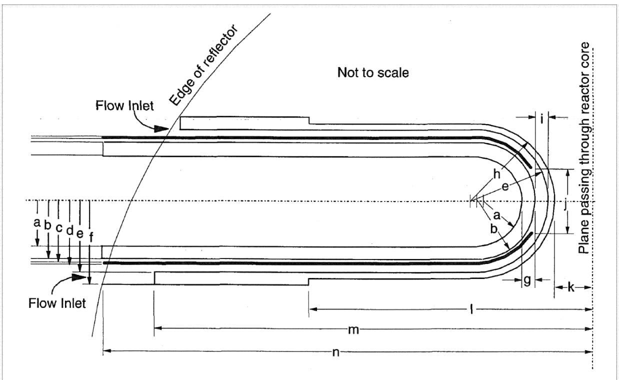

Figure 1: Schematic of horizontal cut through the middle of HB-1 from Ref. [1]

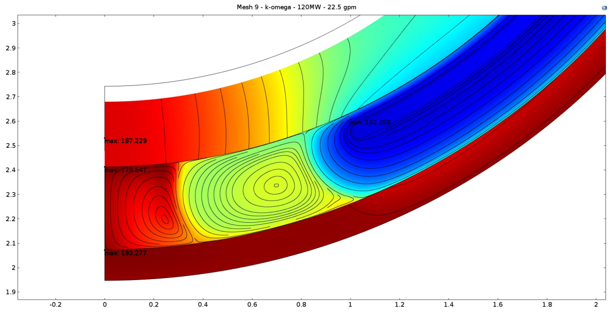

Figure 2: Solution view at beam tube nose detailing temperature contours and velocity streamlines for 22.5 gpm flow and 120 MW power using the k-ω turbulence model.

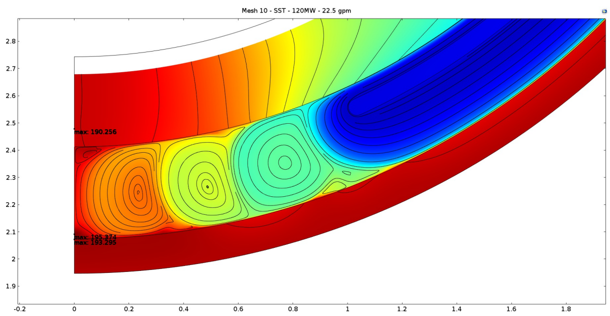

Figure 3: Solution view at beam tube nose detailing temperature contours and velocity streamlines for 22.5 gpm flow rate and 120 MW power using the SST turbulence model.

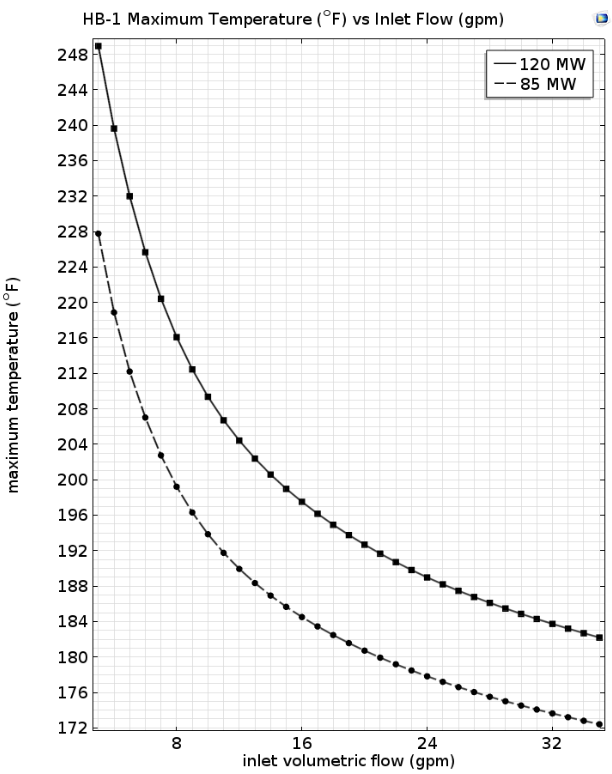

Figure 4: Maximum beam tube temperature (°F) as a function of HB-1 inlet flow (gpm) for conservative power level (120 MW; solid line and square symbols) and best-estimate power level (85 MW; dashed line and circle symbols).