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Application of the CATHENA Thermalhydraulics Code to MAPLE Research Reactor Safety Analysis

N.K. Popov, R. Kouyoumdjian, H. Sills, A.G. Lee, V. Langman
Atomic Energy of Canada Limited
2251 Speakman Drive
Mississauga, Ontario, L5K 1B2
E-mail: popovn@aecl.ca

ABSTRACT

MAPLE (Multipurpose Applied Physics Lattice Experiment) is a research reactor that was developed by Atomic Energy of Canada Limited (AECL) to be used as a key source of research and development in the nuclear industry. The MAPLE reactor can be used as a laboratory tool to test fuels and materials in support of power reactor design and development, a source of neutrons for scientific applications in physics, chemistry, biology and advanced materials science. The MAPLE reactor can serve as a teaching and training tool for development of essential nuclear expertise and licensing standards.

The MAPLE reactor is a low-pressure, low-temperature, open-tank-in-pool-type research reactor that can operate at power levels up to 35 MW_t. The compact light-water-cooled and -moderated core is surrounded by a heavy water reflector tank. The MAPLE core is deliberately undermoderated so that reactivity coefficients are negative.

The CATHENA code (Canadian Algorithm for Thermalhydraulic Network Analysis) [1] was developed by AECL, Whiteshell Laboratories, primarily for the analysis of postulated upset events in CANDU reactors. However, over the years, the code has been used in a variety of applications, including the MAPLE class of reactors. The CATHENA code has been developed as general as possible to enable a wide application range. Because of the generality of the input structure and heat transfer models, the code can be used for circuit thermalhydraulics analysis or detailed modelling of fuel channels. The code has also been used for the design and analysis of thermalhydraulic test facilities within AECL.

The thermalhydraulic model in CATHEHA [1] uses a one-dimensional, non-equilibrium, two-fluid model similar to that found in other current state-of-the-art reactor analysis codes. The basic thermalhydraulic model consists of six partial differential equations for mass, momentum and energy conservation—three for each phase. The conservation equations are coupled by flow-regime dependent set of constitutive equations defining the transport of mass, momentum and energy between the phases and the walls. The gas phase may consist of a mixture of up to four noncondensable gas components and the vapour. A generalised wall heat transfer package is used within CATHENA to model the heat transfer between the fluid and the wall consisting of four major components: wall-to-fluid heat transfer (covering all flow boiling regimes), wall-to-wall heat transfer (including solid-solid wall heat transfer and radiation heat transfer), heat conduction within wall models, and pressure tube deformation model. The two-fluid thermalhydraulic model forms a set of coupled, non-linear, first-order partial differential equations with non-linear source terms. These equations are solved by idealising the thermalhydraulic network by a system of discrete control volumes. The thermalhydraulic finite-difference approximations of the partial differential equations are based on semi-implicit first-order, donor-cell upwind differencing over the control volumes. The resulting system matrix is solved by the Harwell MA28 sparse matrix solution subroutine library.

A CATHENA model of the MAPLE primary cooling system has been used in the MAPLE safety analysis of the limiting accident scenarios including gross Loss of Flow (LOF) events, such as Loss of Class IV event, and Loss of Regulation (LOR) events. The model consists of a number of components specific to the MAPLE design, such as the Primary Cooling System (PCS) pump, the accumulator tank model, the PCS check valve model, etc., that are connected in a thermalhydraulic network by a number of pipe and volume components that represent the heat exchanger, reactor PCS piping, accumulator piping and the reactor pool. A number of system control models are used in the idealisation to model the reactor safety system trips and the reactor kinetics phenomena specific to the MAPLE reactor.

This paper briefly describes the essential features of the MAPLE core and PCS system, and safety system operation. The paper is focused on the description of the CATHENA model of the MAPLE PCS, and the specific CATHENA components that are used in the model. The paper presents selected results obtained from CATHENA simulations of LOF and LOR events that illustrate the code capabilities. Specific issues related to the code validation methodology and uncertainty analysis are discussed to demonstrate CATHENA applicability to research reactor modelling.

References

1. B.N. Hanna, "CATHENA: A Thermalhydraulic Code for CANDU Analysis," Nuclear Engineering and Design, Vol. 180, pp.113-131, 1998.