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RAMONA-4B CODE FOR BWR SYSTEMS ANALYSIS*

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ABSTRACT

The RAMONA-4B code is a coupled thermal-hydraulic, 3D kinetics code for plant transient analyses of a complete Boiling Water Reactor (BWR) system including Reactor Pressure Vessel (RPV), Balance of Plant (BOP) and containment. The complete system representation enables an integrated and coupled systems analysis of a BWR without recourse to prescribed boundary conditions.

INTRODUCTION

Historically, reactor systems codes were developed with primary emphasis on the RPV, while using prescribed boundary conditions to account for the effects of BOP. This renders a realistic simulation of plant transients difficult because the effects of BOP are not known a priori. The RAMONA-4B code[1] is the latest version of the RAMONA series of codes for a BWR and Simplified Boiling Water Reactor (SBWR) stability. It is an upgrade from a previous version, RAMONA-3B[2], with a view to eliminating the necessity of prescribing boundary conditions by an integrated approach for the RPV, BOP, and containment.

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The thermal conduction is based on a 1D transient heat conduction equation, the hydraulics is based on a 1D drift-flux model for non-equilibrium, non-homogeneous two-phase flow, and the neutronics is based on 1½ group, 3D neutron diffusion equations with feedback due to thermal-hydraulics, soluble boron, and control rod movement.

The integrated and coupled systems dynamic equations are solved by finite-difference methods in space and by implicit integration in time for thermal conduction and neutron kinetics, and by explicit integration in time for hydraulics.

The code has been used to simulate a variety of plant transients for a BWR and SBWR. It has also been assessed against FRIGG tests[2,3] for stability and void measurements, the Peach-Bottom 2 turbine trip tests[2,4], and Browns Ferry 1 recirculation pump trip tests[5].

This paper will describe the major developmental work of the code which are new and significant, and present some results which are of practical interest.

The Features of RAMONA-4B Code

The RAMONA-4B code was upgraded from the earlier version RAMONA-3B. The major upgrades are in the areas of two-phase flow modeling, level tracking, flow-dependent loss-coefficient, boron transport, steam separator modeling, motor-generator set dynamics, control systems, BOP, and containment. In addition, the code has heat slab models and many component models specific to the SBWR, thus making it a comprehensive system code for all BWRs (BWR, ABWR, and SBWR).

<u>Two-Phase Flow Modeling</u>

The principal upgrade in this area is a drift-flux mixture model instead of the old slip model. The technical basis of the drift-flux model is sound and well established[6]. It also facilitates the modeling of reverse flow. Other upgrade in this area is the two-phase form loss multiplier and flow-dependent loss-coefficient.

Two-Phase Level Tracking

The two-phase level tracking is based on a transient book-keeping of the mass inventory in the upper and lower downcomers. It involves first the detection of the mixture level in a local cell, followed by the calculation of the mixture and collapsed liquid levels in the cell. This is accomplished by a predictor-corrector iterative procedure[1].

Boron Transport

The old model in the earlier version was based on a very coarse-mesh tracking of boron. The new model in RAMONA-4B is based on local boron transport equations solved for every hydraulic cell in the RPV with boron flow reversal accounted for[1].

Mechanistic Steam Separator Model

A mechanistic steam separator model[1,7] was implemented in the code as an optional replacement for the old simplistic model based on an empirical correlation for L/A ratio. The new model calculates not only the effective L/A ratio, but also the steam carryunder, liquid carryover, and pressure drop across the separator.

BOP Models

The balance of plant is an important part of the BWR system. The operational transients and many anticipated plant transients depend upon the BOP. First-principle mechanistic BOP models[1,8] are implemented in the code to simulate the effects of BOP components such as turbines, generators, condensers, feedwater pumps and heaters, and steam lines with valves.

Motor-Generator Set Dynamics Models

The earlier version employed normalized homologous curves to represent the recirculation pump head and torque. In reality, most BWRs are equipped with a motor-generator set to control the recirculation pump. RAMONA-4B has incorporated a mechanistic model[1,8] to simulate the motor-generator set dynamics along with the recirculation loop model.

Control Systems Models

The earlier version has only a simplistic pressure regulator model and a feedwater control system model. The new code incorporated a genuine BWR pressure regulator model[1,8], feedwater control system model[1,8], and recirculation control system model[1,8]. This along with the BOP models makes possible realistic simulations of operational transients.

Containment Modeling

Containment is an important safety system of the BWR. The integrity of the containment is of concern for long-term accidents such as Anticipated Transient Without Scram (ATWS) and Station Blackout. The code has incorporated a mechanistic containment model[1,9] which accounts for the dynamics of the wetwell (with suppression pool), drywell, vent systems, and ECC systems.

SBWR Specific Component Models

The RAMONA-4B code has been extended for applications to the SBWR by incorporating dynamic models[1] for SBWR specific components such as isolation condensers and new Standby Liquid Control System (SLCS) for automatic boron injection into the core bypass region.

Heat Slab Models

In addition to the thermal conduction in fuel elements, heat slab models[1] have been implemented in the code to account for the stored energy in the structures of RPV. This makes it possible to simulate startup transients where the stored energy is important.

RESULTS

The RAMONA-4B code has been used for safety analyses of both the BWR and SBWR. Here we shall present some recent results to highlight its features and capabilities. One of the BWR transients of recent interest is a dual recirculation pump trip from a full power but reduced flow (75%) condition with postulated scram failure. Figure 1 presents the transient response of relative fission power during such an event and Figure 2 shows that of both the feedwater flow and steam flow. We see the sustained high-amplitude power oscillation due to density-wave instability. The density-wave oscillation leads to the steam flow oscillation via vapor generation and the feedwater flow oscillation via turbine-driven feedwater pump. This clearly illustrates the extreme difficulty (if not impossibility) of prescribing the oscillatory steam and feedwater flow as boundary conditions.

SUMMARY

Many new and significant models have been incorporated into RAMONA-4B, making it a truly integrated and coupled system code for all BWRs. Limited assessments of the code have been made; however, more validations against plant data and test data are highly desirable.

REFERENCES

1. U. S. Rohatgi, H. S. Cheng, H. J. Khan, and L. Y. Neymotin, "RAMONA-4B: A Computer Code With Three-Dimensional Neutron Kinetics for BWR and SBWR System Transients," To Be Published, Brookhaven National Laboratory (1996).

2. W. Wulff, H. S. Cheng, D. J. Diamond, and M. Khatib-Rahbar, "A Description and Assessment of RAMONA-3B MOD.0 CYCLE-4: A Computer Code With Three-

Dimensional Neutron Kinetics For BWR System Transients," NUREG/CR-3664, BNL-NUREG-51746, Brookhaven National Laboratory (1984).

3. U.S. Rohatgi, et al., "Assessment of RAMONA-3B Methodology with Oscillatory Flow Tests," Nuclear Engineering & Design, 143 (1993), pgs. 69-82.

4. L. A. Carmichael and R. O. Neimi, "Transient and Stability Tests at Peach Bottom Atomic Power Station Unit 2 at End of Fuel Cycle 2," EPRI NP-564, Electric Power Research Institute (1978).

5. R. J. Dallman, et al., "Severe Accident Sequence Analysis Program - Anticipated Transient Without Scram Simulations for Browns Ferry Nuclear Plant Unit 1," NUREG/CR-4165, EGG-2379, Idaho National Engineering Laboratory (1987).

6. M. Ishii, "One-Dimensional Drift-Flux Model and Constitutive Equations for Relative Motion Between Phases in Various Two-Phase Flow Regimes," ANL-77-47, Argonne National Laboratory (1977).

7. RELAP5 Code Development Team, "RELAP5/MOD3.2 Code Manual, Volume I: Code Structure, System Models, and Solution Methods," NUREG/CR-5535, Idaho National Engineering Laboratory (1995).

8. W. Wulff, H. S. Cheng, S. V. Lekach, and A. N. Mallen, "The BNL Plant Analyzer," NUREG/CR-3943, BNL-NUREG-51812, Brookhaven National Laboratory (1984).

9. H. S. Cheng and W. Wulff, "A New Containment Model for RAMONA-4B," To Be Published, Brookhaven National Laboratory (1996).

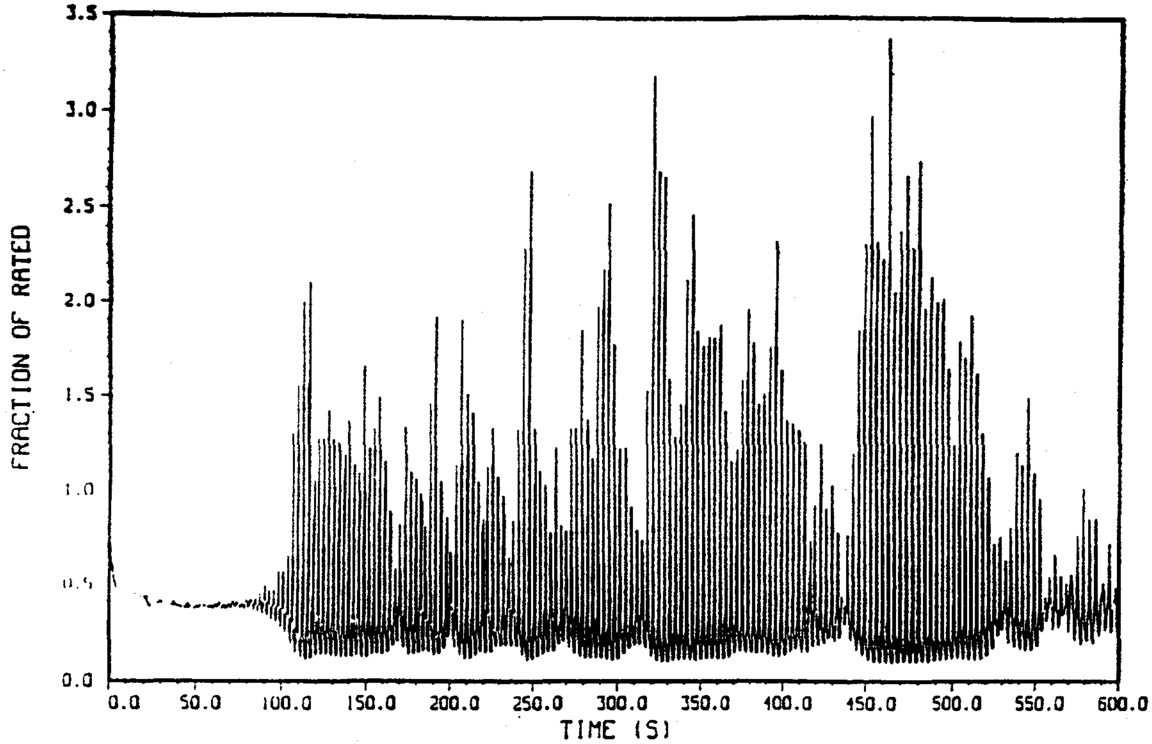

Figure 1. Reactor Power Response During the Recirculation Pump Trip Without Scram.

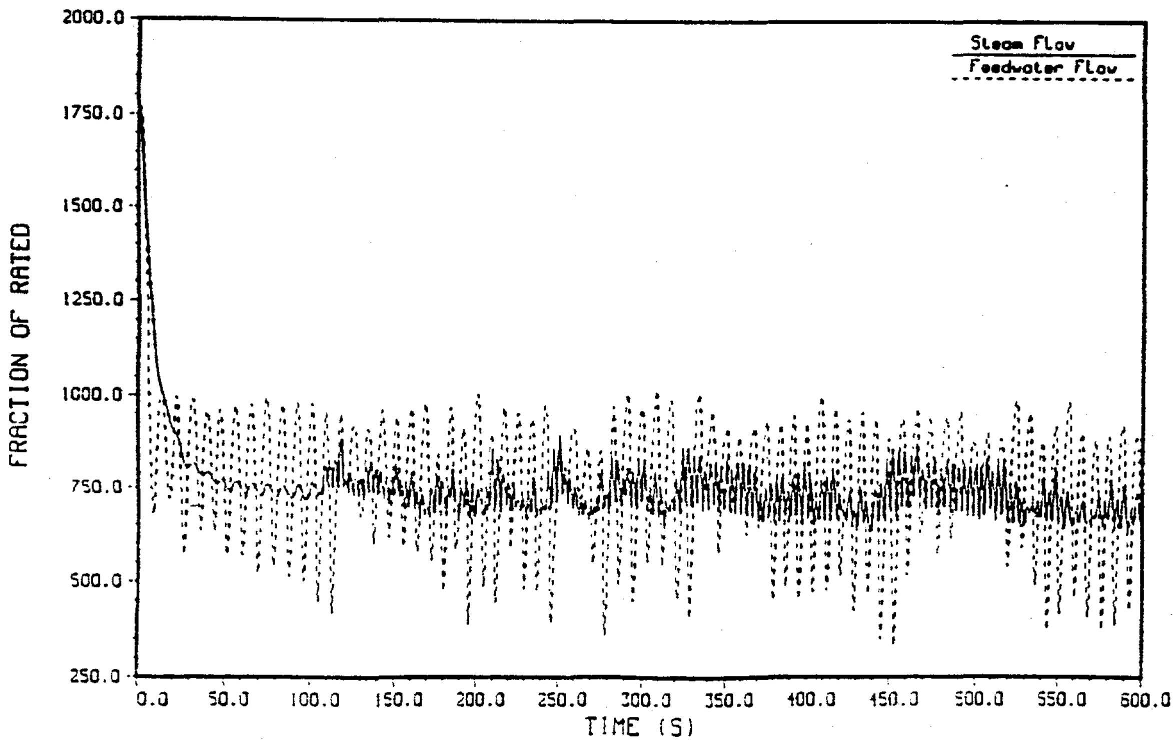

Figure 2. Steam and Feedwater Flow Responses During the Recirculation Pump Trip Without Scram.