RELAP5 MODELING OF A SAVANNAH RIVER SITE REACTOR (U)

by

R. A. Dimenna¹ and D. L. Caraher²

¹Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina 29808

²EG&G Idaho, Inc.
Idaho Falls, ID

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

A paper proposed for presentation at the
1990 Joint RELAP5 and TRAC-BWR International User Seminar
Chicago, IL
September 17-21, 1990

and for publication in the proceedings

MASTER

This paper was prepared in connection with work done under Contract No. DE-AC09-89SR18035 with the U.S. Department of Energy. By acceptance of this paper, the publisher and/or recipient acknowledges the U.S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering this paper, along with the right to reproduce and to authorize others to reproduce all or part of the copyrighted paper.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
RELAP5 Modeling of a Savannah River Site Reactor

R. A. Dimenna, Westinghouse Savannah River Company
C. B. Davis, EG&G Idaho, Inc.

ABSTRACT

Thermal-hydraulic system analysis in support of Savannah River Site reactor restart is being performed with a modified version of RELAP5/MOD2.5. This paper gives an overview of the Savannah River Site reactor system, the RELAP5 input models developed for the analysis, and the specific phenomena with which the code is having difficulty. The need for code development to address plenum phenomena, air/water behavior, fuel assembly behavior, and degraded pump performance is motivated in terms of the system response to a large break loss-of-coolant accident. Results of benchmark calculations show both the adequacy of the basic models and the need for a better representation of phenomena that are beyond the typical range of RELAP5 application.

INTRODUCTION

The RELAP5 computer code is being used to perform thermal-hydraulic analyses for the emergency cooling system (ECS) phase of a large break loss-of-coolant accident (LBLOCA) in the Savannah River Site (SRS) production reactors. Its specific function is to replace older SRS analytical methods with a calculated system response based on mechanistic models. The system calculation provides boundary conditions for a detailed fuel assembly analysis performed by another computer code. RELAP5 was selected for the system analysis both for its ability to represent the key features of the SRS reactors and its ability to run a LBLOCA.

The purpose of this report is to describe the changes to RELAP5 needed to represent the SRS reactors, as well as the models developed to perform the analysis. This will be accomplished by first describing the reactors, which have unique features that distinguish them from commercial reactors. After describing the reactor systems, a short description of the transients to be calculated by RELAP5 will be given. RELAP5 itself will not be described, but the changes made to develop an SRS version will be identified.

Three RELAP5 system models will be discussed: the "two-loop" model useful for scoping analyses, the "r-θ" model that captures certain multidimensional effects, and the "hex" model developed to test the calculational sensitivity to node density in the plenum and tank. The performance of the models will be described briefly, and the quality assurance (QA) used to verify their accuracy will be addressed.
Figure 1. Sketch of the SRS reactor loop.
plenum. Within the plenum is a dense array of vertical tubes within which are located fuel or target assemblies, control rods, or measurement instruments. The tubes containing the fuel assemblies are the permanent sleeve housings (PSH). They are approximately 5 inches in diameter, with three vertical slots, each 8-1/2 x 5/16-inch, equally spaced around the tube to allow water to flow from the plenum to the fuel assembly. The fuel assembly is contained within another tube, a universal sleeve housing (USH), which fits inside the PSH and extends from the top of the plenum to the bottom of the moderator tank. Water passes through the slots in the PSH, then through an array of 1/4-inch holes in the top of the USH and into the internals of the fuel assembly. Typically, there are over 400 fuel assemblies in a given charge (fuel loading). Coolant inside the assembly exits at the bottom through another array of holes and into the moderator tank. There is no direct hydraulic communication among the fuel assemblies; they are coupled only through the common water plenum and moderator tank.

The moderator tank has a free surface at the top, approximately 19 feet above the bottom, which is normally maintained at 5 psig overpressure by a blanket gas system. Under accident conditions that drain water from the system, vacuum breakers vent the top of the tank, so no vacuum is drawn. The hot legs are connected to the tank bottom in six symmetrical positions. Each exit location contains a series of baffles called the "muff". The hot leg drops approximately 13 feet to the pump suction. A single centrifugal pump in each hot leg, powered by both an AC and DC motor on a common shaft, pumps the water vertically upward to the heat exchangers as shown in Figure 1. Each loop contains two heat exchangers in parallel. Coolant flow is divided upstream of the heat exchangers, and is recombined after exiting the heat exchangers. The water then returns through the cold leg to the water plenum, completing the flow path.

The process coolant is heavy water. Light water is used for both the heat exchanger secondary side coolant and the ECS. Typical operating conditions for 50 per cent of historical full power (about 2400 MW) are shown on Figure 1. Under normal operating conditions, the pressure is only about 87 psia in the water plenum, and the discharge temperature of water from the fuel assemblies is below boiling.

THE RELAP5 CODE AND MODELS

Code Changes

Several code changes were implemented to allow RELAP5/MOD2.5 to better represent conditions specific to SRS reactors. The changes are implemented through unpublished input parameters; they are not normally utilized for typical applications. The options used for the SRS calculations are listed below

Option 8: Low pressure updates.
Option 10: Pressure controller on time step.
Option 11: Smooths the wall mass transfer correlation between heat transfer regimes at low pressures.
Option 12: Water packer modifications.

Dimenna and Davis-3
Two-loop model

The two-loop model was developed at the Idaho National Engineering Laboratory (INEL) as a scoping model to evaluate reactor design changes. A single loop is used to represent an average loop, and a combined loop is used to represent the remaining five loops. Both modeled loops contain a Bingham pump, heat exchangers, isolation valves, rotovalves (heat exchanger outlet valves), and connecting piping. The two parallel flow paths at the heat exchangers are lumped together into a single flow path.

The water plenum is modeled with a single vertically-oriented control volume. The gas plenum, the blanket gas space above the top shield, is modeled with three control volumes to resolve its draining characteristics. The moderator space below the top shield is also modeled with three control volumes. Two fuel assembly models are used. Each has an 8.75-inch top cell to allow the assembly to be connected to the plenum with a crossflow junction, a cell approximately 6 feet long to represent the top structure of the fuel assembly, five cells in the heated section, each 2.5 feet long, and an exit section about 2 feet long. The difference between the two fuel assembly models is the number of exit holes, or shell holes, in the USH. One model represents a 36-shell hole configuration, and the other a 28-shell hole configuration. The septifoils, which connect the heat exchangers and the reactor tank, and the flow paths through the top shield are modeled based on detailed system descriptions. The reactor vent paths included in the model are the gas ports, vacuum breakers, and the U-tube (also called the supplementary pressure relief system or downcomer). The blanket gas supply system, which controls gas plenum pressure during normal operation, is also modeled.

An ECS model was developed from a detailed representation of the actual ECS piping. The model represents the ECS piping and valves between the process system and a common header. Measured ECS flow vs. header pressure is supplied to the model as a boundary condition. The model represents the ECS control logic, including the actuation logic and several interlocks associated with the system.

Heat exchanger secondary side flow is represented by a constant flow boundary condition. The flow area on the secondary side is adjusted so the thermal efficiency of the model approximates the actual efficiency.

A detailed description of the two-loop model is found in Reference 2.

The r-θ Model

A six-loop, multidimensional RELAP5 model was developed at the INEL to represent behavior in the moderator tank and plenum that cannot be captured by the two-loop model. As shown in Figure 3, the model explicitly represents all six loops using a nodalization based on the two-loop model described above. The most significant differences between the r-θ and the two-loop models are in the plenum and tank, so only these components will be discussed.

Both the moderator tank and water plenum are modeled with six azimuthal sectors and three radial rings. The control volumes are oriented vertically, with a crossflow junction at the cell midplane for each radial and azimuthal junction. The

Dimenna and Davis-4
Figure 2. RELAP5 two-loop model of the SRS reactors.

Dimenna and Davis-5
Figure 3. RELAP5 r-9 model of the SRS reactors.

Dimenna and Davis-6
crossflow junctions provide a limited multidimensional flow analysis. The crossflow model uses a simplified form of the momentum equation to represent flow perpendicular to the main flow path. It neglects the momentum flux, or spatial acceleration, but accounts for temporal acceleration, interfacial friction, and form losses. Each plenum control volume in the inner two rings is connected to a model representing the number of fuel assemblies in that section of the reactor. In addition, a single fuel assembly model is connected to one plenum volume to represent a hot channel. Crossflow junctions connect the top cell of the fuel assemblies to the midplane of the plenum.

The water plenum model has a single axial level; the moderator tank axial divisions are based on the two-loop model. The height of the lowest level in the tank (60 in.) is set to give air aspiration under AC pump motor operation at the correct moderator level based on L-area benchmark comparisons. The lowest node height is changed to 20 inches for DC pump motor operation. Radial and azimuthal form losses were calculated from Idel'chik based on flow across a tube bundle and adjusted to match data from selected 1985 AC Process Flow Tests (see Reference 6).

**The hex model**

A third reactor model was developed to test the sensitivity of the results to the noding scheme. A hexagonal mesh imposed on the plenum and tank is used to develop corresponding control volumes. The result is a node size approximately one-half that of the r-θ representation. Crossflow junctions are used to connect each cell. Figure 4 shows the hexagonal mesh used in the plenum. The tank mesh is similar. With the exception of the number of cells in the plenum and tank, and the number of fuel assemblies associated with each cell, the hex model is the same as the r-θ model. Because of its large size, the model is used only for selected sensitivity runs.

**Quality Assurance**

A quality assurance review of all the models was performed to ensure their correctness and accuracy. The models were developed in accordance with procedures specified in EG&G Idaho Inc., Energy and Systems Technology (E&ST) Group, Standard Practice 2.0.

The initial step in developing each model was compiling a facility database consisting of items such as engineering drawings, technical reports and specifications, operating manuals, the Safety Analysis Report, and appropriate correspondence. With the information in the plant database, a system nodalization was defined to capture the important phenomena for the transients to be simulated. To ensure the accuracy of the model, an independent check of the component data was performed by an engineer who was not directly involved in the model development, but who had experience in facility modeling with RELAP5. The independent check included verifying all referenced information, calculations, assumptions and special methods, tabulating a comparison of the facility and the model, and transmitting the results to the lead engineer. Corrections were confirmed by the independent checker, and the corrected input deck was placed under configuration control.
Figure 4. Hexagonal mesh overlayed on a plenum facemap.
Code and Model Limitations

The models described above have certain known limitations. Some are related to the one-dimensional nature of the two-loop model and are addressed to a certain extent by the multidimensional models. Others are related to limitations of RELAP5 that affect all the models. The known limitations are summarized below.

Since the one-dimensional model contains only two loops, it cannot represent transients in which the behavior of more than one loop differs from the average. For most accident transients, this is not a significant limitation. In addition, the water plenum and moderator tank are one-dimensional components, and cannot be used to calculate phenomena associated with pressure or level distributions.

Phenomena related to mixing light and heavy water cannot be represented by RELAP5. Therefore, the code cannot mix light ECS water with heavy process water during a LOCA. Similarly, the code cannot mix primary and secondary fluids during a heat exchanger tube rupture. This limitation is not expected to be serious for most transients.

RELAP5 cannot model cavitation directly. A cavitation model that utilizes a control system to represent the macroscopic thermal-hydraulic effects of cavitation is incorporated into the model for use during the flow instability phase of a LOCA, but it is not employed for the ECS phase of the transient. It is not applicable for transients with reverse flow and is disabled for those cases.

No leakage between the water plenum and the gas plenum is modeled. The model assumes that the piston ring that seals the space between the PSH and the USH forms a perfect seal, so it may predict a greater vacuum in the water plenum than would actually occur. Scoping calculations have shown that this is not a serious problem for transients in which the AC pump motors continue to run, but it may be a problem when AC motors are tripped and the plenum pressure falls below atmospheric pressure.

In spite of the code and model limitations discussed above, RELAP5 can provide useful results for analysis of the SRS reactors. It requires careful application and thorough analysis of the results, but that requirement is universal.

MODEL APPLICATIONS AND CODE PERFORMANCE

This section of the paper provides an overview of the model applications to the SRS reactors to give a broad understanding of the code analysis and development task at SRS. The discussion will be grouped under phenomenological headings addressing the current areas of investigation.

Plenum behavior

Plenum behavior is important because plenum conditions determine the liquid flow into each of the fuel assemblies. Minimum assembly liquid flow, a key parameter provided to the assembly code, depends on the liquid distribution in the plenum, which in turn is influenced by the interaction of air and water, and possibly by the node size.

Dimenna and Davis-9
Calculations have indicated that the plenum liquid distribution depends on the qualitative flow regime description. 1989 L-area data show some evidence that the plenum is stratified up to nearly liquid full conditions. Under stratified conditions, the flow into the fuel assemblies is described by weir flow, which is represented in the SRS version of RELAP5 by forcing a small interfacial drag coefficient in the plenum characteristic of a stratified flow. The liquid level at which the plenum is described by a mixed flow regime is not well defined, and further work is needed to determine the plenum conditions and control logic to select the appropriate flow regime.

Noding sensitivity is addressed by the three models described above. The simple two-loop model is a limiting condition in that a single-node plenum is used. No distribution information can be obtained from this model. The r-0 model is designed to lend insight to flow, level, and pressure distributions in the water plenum. Benchmark calculations described in Reference 3 show that with some adjustments to the loss factors at the junctions in the plenum model, good comparisons with pressure data are obtained. Level comparisons are described in Reference 4. Calculations performed with the hex model show essentially similar results with finer noding. These comparisons imply that the plenum noding is adequate for the large break analysis, and that the r-0 model can be used as an effective analytical tool to explore system behavior.

**Fuel Assembly Behavior**

Fuel assembly behavior is closely tied to plenum behavior, since the flow source is from the water plenum. Liquid flow to the assembly is adequately described by the weir flow model mentioned above. The model requires that the interfacial drag at the topmost internal junction in the fuel assembly be set low to allow appropriate draining of the top fuel assembly control volume. In addition, the differencing scheme in RELAP5 requires that the hydraulic diameter in the plenum control volume and the associated fuel assembly control volume be set equal. This model is described in detail in Reference 8.

Air flow through the fuel assembly is more difficult to calculate accurately. The air flow at the plenum-to-assembly junction does not have a significant effect on the water flow, but the converse is not true. Wall and interfacial drag, especially in the channel region of the fuel assembly, have a significant influence on the air flow rate. Current calculations show an air flow rate much higher than the best estimates determined from various SRS data sources. Further experimental work is being defined to complement theoretical development of better wall friction, flow regime, and interfacial drag models.

**Tank, Muff, and Pump Behavior**

Air entrainment from the tank into the muff and hot leg has a significant impact on the system thermal-hydraulic response. Data have shown that air is entrained at a tank level of about 60 inches when the AC pump motors are running. RELAP5 is currently incapable of representing this air ingestion with a mechanistic model. The code can be forced to begin entraining air at this level if the height of the lowermost node is 60 inches. This, then, is the determining factor for setting the node size in the tank. Similar data show that under DC pump motor conditions
(AC motors tripped), air entrainment begins at about 20 to 24 inches, very close to the upper boundary of the muff. For accidents in which the AC motors are tripped early, a tank nodalization with a lowermost node boundary of about 20 inches is used. This introduces a significant question of how to deal with an AC motor trip at some intermediate time, and this question is under current investigation.

Reactor coolant pump performance is impacted by air ingested from the tank and transported to the pump and pump suction. Pump head degradation has been measured in the SRS reactors as a function of tank level. This level dependence is implemented into the RELAP5 model by using the pump control volume void fraction as a surrogate variable for tank level. For a given tank level, the pump volume void fraction can be calculated and the two-phase pump head degradation multiplier adjusted to give the measured pump differential pressure for the given tank level. The result is not a mechanistic model, but it allows the pump performance to be matched to one set of data. Unfortunately, the results are tied to a specific tank nodalization, so the method is not satisfying. Comparisons with 1989 L-Area data have shown good comparisons between calculated and measured loop liquid flow rates and plenum liquid level distributions. Calculated loop air flow rates are about four times too high, and liquid inventory in the loops is too low for a given tank level when compared to data.

Current thoughts concerning the tank and muff behavior are that the code cannot be easily fixed to address this problem in a mechanistic way. A means of imposing a correlation based on measured air and liquid flow rates, probably as a function of tank level, is being explored. Models similar to the vapor pull-through model already employed in the code are being considered, but no results are available at this time. Pump behavior is being investigated in an attempt to better represent the air/water behavior and avoid having to tune to a specific nodalization.

**Benchmarking**

The models described above have been benchmarked against both steady state and transient data. Single-phase comparisons were performed during the development and assessment stages to ensure the validity of the model. Plenum and tank liquid and flow distributions, loop flow rates and pressure drops, and assembly flow characteristics were checked, adjusted, and checked again against independent data bases before the model was applied to transients.

Benchmarking to two-phase, two-component, air-water data has been an ongoing effort, the principal data base being the 1989 L-Area tests. Plenum level distributions under low tank level conditions have shown reasonable comparisons between code and data. The code modifications described above are, in part, a result of questions raised during the benchmarking process. A later paper describes the benchmarking process in considerably more detail.

**SUMMARY**

Three RELAP5 models of the SRS reactors have been described. Each has particular attributes that make it useful. The two-loop model is a simplified model that runs quickly and can be used for scoping calculations. The r-0 model incorporates three-dimensional type modeling in an attempt to capture certain multidimen-
sional phenomena in the water plenum and the moderator tank. The hex model is a
detailed model that provides a nodalization sensitivity when compared to the r-q
model. The limitations of the models and of the code itself were addressed. The
conclusion was that the calculations made with this analytical tool were useful for
analysis of SRS reactor systems.

Application of the models to SRS transients was discussed in terms of par-
ticular areas of interest. These included the plenum, fuel assembly, tank, muff, and
primary coolant pumps. The discussion focused on the areas of the code that need
improvement. A brief description of current thoughts about each of the areas of
code development was provided to stimulate discussion on these topics.

REFERENCES


2. Cozzuol, J. M. and Davis, C. B., "Description of the Two-Loop RELAP5
   Model of the L-Reactor at the Savannah River Site", EGG-EAST-8449,
   December 1989.

3. Boitlander, M. A., and Davis, C. B., "Benchmarking the Six-Loop, Three-
   Dimensional RELAP5 L-Reactor Model with Savannah River Reactor Test

   r-q Model of an SRS Reactor to the 1989 L-Reactor Tests", 1990 Joint
   RELAP5 and TRAC-BWR International User Seminar, Chicago, Ill.,
   September 17-21, 1990.

5. Idel’chik, I. E., Handbook of Hydraulic Resistance Coefficients of Local

6. Koffman, L. D., et al., TRAC Calculation of the Initial Flow Decay in L-

7. Shaw, R. A., "Preliminary Benchmarking of the Hexagonal RELAP5 L-
   Reactor Model with Savannah River Reactor Test Data", EGG-EAST-8784,
   December 1989.

   Mark-22 Fuel Assembly with RELAP5", 1990 Joint RELAP5 and TRAC-

   RELAP5 L-Reactor Model with Savannah River Reactor Test Data", EGG-
   EAST-8336, April 1989.