EGG-M--89450

DE91 001934

RELAP5 BASED ENGINEERING SIMULATOR

T. R. Charlton, E. T. Laats and J. D. Burtt
Idaho National Engineering Laboratory
EG&G Idaho Inc.
P. O. Box 1625
Idaho Falls, Idaho, 83415

ABSTRACT

The INEL Engineering Simulation Center was established in 1988 to provide a modern, flexible, state-of-the-art simulation facility. This facility and two of the major projects which are part of the simulation center, the Advance Test Reactor (ATR) engineering simulator project and the Experimental Breeder Reactor II (EBR-II) advanced reactor control system, have been the subject of several papers in the past few years. Two components of the ATR engineering simulator project, RELAP5 and the Nuclear Plant Analyzer (NPA), have recently been improved significantly. This paper will present an overview of the INEL Engineering Simulation Center, and discuss the RELAP5/MOD3 and NPA/MOD1 codes, specifically how they are being used at the INEL Engineering Simulation Center.

It will provide an update on the modifications to these two codes and their application to the ATR engineering simulator project, as well as, a discussion on the reactor system representation, control system modeling, two phase flow and heat transfer modeling. It will also discuss how these two codes are providing desktop, stand-alone reactor simulation.

INTRODUCTION

The INEL Engineering Simulation Center was established in early 1988. The goal is to provide a modern, flexible, state-of-the-art simulation facility by unifying the computational simulation hardware and software, the experimental hardware, and the many years of related staff expertise at the Idaho National Engineering Laboratory (INEL). These capabilities have been developed over the past 35 years while designing, building and testing some 52 nuclear

*Work supported by the U. S. Department of Energy, Under Department of Energy contract No. DE-AC07-76ID01570.

reactors at the INEL for the U.S. Government. This facility and two of the major project which are part of the simulation center, the Advance Test Reactor (ATR) engineering simulator project and the Experimental Breeder Reactor II (EBR-II) advanced reactor control system, have been described in some detail in several conferences and papers in the past few years (References 1-5).

One of the initial applications of these capabilities has been focused on an engineering simulation capability for the Advanced Test Reactor (ATR). Recent events in the nuclear industry are demanding that the technical community pursue a higher degree of realism from nuclear power plant training simulators within their current limits of applicability, and also that their limits of applicability be extended to simulate severe accident scenarios. This improved simulation capability will greatly augment the training of plant operators in the recognition and mitigation of accidents.

RELAP5, in conjunction with the Nuclear Plant Analyzer (NPA) (Snider, 1989), is the primary simulation code used within the INEL Engineering Simulation Center. The RELAP5 Computer Code (Ransom, 1985) has been used for the past ten years by the international nuclear reactor community to analyze many type of transients in nuclear reactors. This code provides the light water reactor and recently the heavy water reactor simulation capability that is part of the INEL Engineering Simulation Center. The NPA provides the interactive and graphical output interface between the user and the RELAP5 code.

Both the RELAP5 code and the NPA have recently been changed significantly to provide improved simulation capabilities and also to provide and a stand-alone simulation capability. The NPA/RELAP5 codes can now reside on an engineers desk, to be used as a training tool in the classroom or to develop training scenarios for conducting emergency action drills for the NRC operation center and the NRC Regional Operations Centers. While the NPA/RELAP5 has existed for seven years, the desktop stand-alone capability has only been available since the release of RELAP5/MOD3 and NPA/MOD1 in 1989.

This paper will present an overview of the INEL Engineering Simulation Center and discuss the RELAP5/MOD3 and NPA/MOD1 codes, specifically how they are being used at the INEL Engineering Simulation Center.

ENGINEERING SIMULATION CENTER COMPONENTS AND STATUS

The INEL Engineering Simulation Center consists of numerous components, illustrated in Figure 1. The Center consolidates these components that are located at the INEL and other facilities nationwide.

The basic hardware components located at the INEL include:

- the CRAY X-MP/24 supercomputer with its associated software and hardware systems,
- the Reactor Control Room Simulator at the Advanced Test Reactor (ATR),
- the Experimental Breeder Reactor-II (EBR-II) with its associated control and monitoring systems, and
- the INEL site-wide data communications network that ties the INEL components together and provides the high speed links to the offsite components.

The offsite components identified as workstations and plant-specific simulators are located at NRC facilities throughout the U.S.

The basic software components of the INEL Engineering Simulation Center include:

- the RELAP5 reactor analysis code which is used to provide real time simulation of both light water and heavy water reactor transients,
- the Nuclear Plant Analyzer code which provides the graphics and interactive interface with the simulation codes,

- the ATHENA code (Chow,1985) is used to model thermal-hydraulic systems other than water systems,
- the TRAC codes (and Liles, et al., 1984) are used to provide 3-D simulations of water reactors,
- the DSNP code (Saphier, 1983) is used to provide simulation of liquid metal reactors.

The Center's supporting staff expertise includes the following areas:

- thermal hydraulic systems,
- control and instrumentation systems,
- operator training and examinations,
- human factors,
- probabilistic risk assessment,
- data communications,
- simulation hardware,
- artificial intelligence, and
- nuclear plant operations.

Taken collectively, these components provide a true engineering simulation testbed.

The hardware components within the INEL components is now operational. The data communications networks between the CRAY X-MP/24 and the ATR Reactor Control Room Simulator, and the CRAY X-MP/24 and the EBR-II data acquisition and display system are also operational. All of the simulation and development software systems have progressed at least to the beta testing phase and many are production systems that have been operational for about six years.

TWO KEY SOFTWARE COMPONENTS OF THE INEL ENGINEERING SIMULATION CENTER

The RELAP5 and NPA codes are two of the key software components of the INEL Engineering Simulation Center. These codes have both recently undergone significant changes to improve their capabilities. These changes are identified in the following discussion.

The RELAP5 is a large thermal hydraulic systems analysis computer code developed at the INEL. It has been used by the international nuclear reactor community for about ten years to simulate transients in all types of commercial reactors and some production reactors. These transients include operational transients, anticipated transients and design basis accidents with the exception of large break Loss-of-Coolant-Accident (LOCA). The current version of the code, RELAP5/MOD3 was released in January, 1990. It is the result of the efforts of several members of the International Code Assessment Program as well as the INEL and the NRC. The improvements to the code for this version provides large break LOCA capability as well as improving some of the deficiencies in the previous code, RELAP5/MOD2.

The major improvements to the code are listed in Table 1.

Table I RELAP5/MOD3 MODEL DEVELOPMENT TASKS

Counter-Current Flow Limiting
Interfacial Shear Modeling (UK)
Critical Heat Flux
Reflood Heat Transfer (PSI)
Critical Flow Modeling
Inception of Vertical Stratification
Inception of Horizontal Stratification (JAERI)
Pipe Offtake Model (UK)
Metal-Water Reaction (Sweden)
Fuel Mechanical Model (Sweden)
Radiation Heat Transfer Model (Sweden)
Improvements to Non-condensible Gas Model
Condensation in Horizontal Pipes
Downcomer Penetration and ECCS Bypass
Upper Plenum Deentrainment

These models are discussed in detail in (Weaver, et al., 1990). The interface shear modeling, critical heat flux, reflood heat transfer, vertical stratification, downcomer penetration and ECCS bypass, and upper plenum deentrainment are intended to improve the large break LOCA transient capability of the code. The other changes are to improve existing transient simulation capabilities or improve boiling water reactor simulation.

In addition to the model improvements, the code has been modified to improve its performance. The major effort in this area has been in the area of code portability. RELAP5/MOD3 will compile on a CRAY, CYBER, IBM, VAXes, Concurrent minicomputers and several workstations. The code computational speed has also been improved through vectorization and parallel processing.

The NPA has also been improved this past year with the release of the NPA/MOD1 code in October of 1989. The code was completely rewritten and many of the existing functions implemented through X-windows and the UNIX operating system rather than through separate software as was the case previously. This has simplified the code considerably, making it more reliable and less expensive to maintain. All of the functionality of the previous version has been maintained. Machine specific coding (for the Tektronix 4125) has been eliminated, allowing the code to be installed on many different computer systems with a minimal amount of machine specific software modifications.

There are several ways to use the NPA/RELAP5 code combination depending on the types of computers and workstations available at a particular installation. The first and newest capability is to use a stand-alone workstation such as a DECstation 3100. With both RELAP5 and the NPA installed on this machine, a typical Westinghouse Pressurized Water Reactor (PWR) transient simulation would run at one-tenth the speed of a transient simulation on a CRAY X-MP/24. However, this represents the most economical installation since it resides on the engineer's desk and, as the work station technology improves, the engineer can trade up in computer power.

A second way of using the NPA/RELAP5 code combination is to run the transient simulation on a mainframe computer (e.g. CRAY X-MP/24) and displaying the output on a workstation such as the DECstation 3100. This provides the speed of the CRAY to run RELAP5 and the interactive and graphics capability of the NPA on the workstation to control the simulation on the CRAY. It also facilitates having a stand-alone playback capability on the desktop since the workstation can playback the transients at real time.

Finally, the NPA/RELAP5 code combination can be run on a mainframe and the transient simulation displayed on a graphics terminal. All computations, displays and interactive commands would be carried out on the mainframe. The obvious flexibility of the NPA/RELAP5 code combination makes it ideal for the INEL Engineering Simulation Center.

With the portability improvements to both codes and the improvement of engineering workstations such as the DECstation VAX or DEC 3100, the desktop NPA is now available to the engineer. This system was demonstrated at the International Code Assessment and Applications Program meeting in Bethesda, Maryland, in October 1989, and at the November 1989 American Nuclear Society Winter Meeting in San Francisco as part of the Nuclear Power and Technology Exhibits.

TWO KEY APPLICATIONS OF THE INEL ENGINEERING SIMULATION CENTER

Two key applications of the INEL Engineering Simulation Center are being developed for the Advanced Test Reactor (ATR). The first is the ATR Reactor Control Room Simulator Upgrade. The second is the use of NPA/RELAP5 for classroom instruction for ATR operations. The following provides a discussion of these two applications.

ATR Reactor Control Room Simulator Upgrade

The ATR, located at the Idaho National Engineering Laboratory (INEL), has been in operation for over 20 years. Since construction in the mid 1960s, this test reactor has been used continually for materials irradiation research with major shutdowns only for scheduled maintenance. Its unique design makes it possible for up to nine experiments at one time to be subjected to very intense radiation for days to months at a time. The ATR is a low temperature (<240^{o}F), low pressure (<390 psig) light water cooled nuclear reactor with a maximum thermal power of 250 MW. This unique facility has three control rooms to handle the reactivity changes, the flow in the primary and secondary coolant loops, and the nine experiment loops, respectively.

The important role that the ATR fulfills for the U.S. Department of Energy is projected to be required for at least another 20 years. Modernization of various components of the plant is required to provide higher reliability systems for the additional years of operation. The reactor operator's control console and annunciator system are the first components to be redesigned and replaced supporting the updated requirements. A sequence-of-events recorder is also being added to monitor the status of the plant protection system.

The control room upgrade project created the requirement for a new control room simulator. Since 1966, the ATR reactor operators have had a training simulator available for practicing normal operations such as start-up, shutdown and routine power maneuvers. This simulator, using an analog computer system, was operational until early 1988. A totally new simulator facility was recently completed that is a "face front" duplicate of the updated reactor control room. The new simulator facility was designed to provide the same functionality as the actual control room.

The mathematical models being used for the ATR control room simulator are basically the same simplified models used in the previous simulator, i.e., the basic hydraulic requirement is that the coolant remain liquid (no two phase flow phenomena), and the core inlet conditions are input functions (no feedback from core outlet to core inlet through the plant heat exchangers). Single point reactor kinetics with six delay groups are used to calculate the reactor power. An average temperature is computed for each of five lobes (lumped coolant channels) in the core, and combined appropriately for the total reactor outlet temperature. Core pressure drops and quadrant water powers are computed for display purposes only. Rod withdrawal permissive logic and plant protective system logic are simulated on the interface computer. The automatic power control system and sequence of events recorder uses actual hardware for their functions. These models are adequate for normal operational transient training (start-up, shutdown, and power maneuvers).

Events in the nuclear industry (e.g., Three Mile Island, Chernobyl) indicate the importance of training operators with a high degree of realism for severe accident scenarios. To provide the range of fidelity required for this training, the ATR simulator software for the core thermal hydraulics and nuclear power calculation was replaced by the RELAP5 simulation code. The RELAP5 code resides on the CRAY X-MP/24 super-computer located some 50 miles from the simulator. The data link is via a fiber optic cable which was installed in the summer of 1989.

The RELAP5 model of the Advanced Test Reactor (ATR) used for the simulator, shown in Figure 2, illustrates the complexity of the model. The model has 192 volumes, 210 junctions and 46 heat slabs mostly in the vessel portion of the model. The vessel model was simplified from the original ATR model and has four single volumes representing the four quadrants of the ATR core. The Primary Coolant loop is modeled in detail with each size pipe from the four 18 inch outlet lines to the two 24 inch inlet pipes. All four primary coolant pumps are modeled, while the five heat exchangers are lumped into a single heat exchanger. Associated systems modeled include the pressurizing loop, with flow taken from the primary hot leg to the degassing tank, and a separate fill system to model the actual pressurizing pumps. The two emergency pumps are modeled, along with their associated recirculation piping. Safety systems like the utility cooling water and the firewater injection systems are modeled. In addition the PCR simulation model includes interaction controls for the secondary pumps, cooling tower fan speed, control values, and 19 separate break locations, which could be opened on user command.

The ATR control monitoring system in the simulation model utilizes 94 parameter trips, 79 logical trips, and 174 control variables. These controls provide the automatic plant functions and trips (i.e., reactor trip on low reactor inlet pressure) as well as drive the Reactor Simulator displays.

The real genius in this hardware strategy comes from using the ATR reactor control room simulator to handle all of the operator input, output and display (graphics) tasks, and using the RELAP5 code on the CRAY supercomputer only for the thermal-hydraulic model solutions. This technique presently requires the amount of data exchanged between the CRAY supercomputer and the simulator to be only a few variables, i.e., the RELAP5 code gets the net reactivity due to control rod motion from the simulator and outputs the power and core thermal-hydraulic conditions to the simulator. These data are exchanged ten times per second. This configuration was demonstrated in September 1988. The goal for the final operational system is to provide full operator controls and greatly enhanced ATR Simulator/RELAP5 data exchanges. Only then will the system have reached its full potential.

The fidelity of the ATR model and RELAP5 has been evaluated, on a limited bases, by comparing normal operational transients on the older simulator to the RELAP5 simulation. With no "fine tuning" of the RELAP5 model, the timing and magnitude of the older simulator's predictions have been overlaid by RELAP5. This result adds considerable confidence to the RELAP5 predictions since the older simulator has been continuously benchmarked over the past 20 years for these operational transients.

NPA/RELAP5 in the Classroom

The ATR RELAP5 model will also be utilized in a class room environment to agument the training of ATR Process Control Room (PCR) operators. Using the NPA displays on a workstation, the plant response and control room panels can be graphically simulated. The

RELAP5 model will still be running on the CRAY but the panel and plant response will be displayed on a DECstation 3100 in the class room. The six planned NPA display masks for the Simulator will include a plant overview, four control panels with dials, strip charts and colored lights, and an annunicator panel to display specific alarms. The control panels will provide the same information to the simulator user as is available to the ATR Process Control operator in the PCR. The students and instructor will be able to simulate any transient that the simulator can run and the panels in all three control rooms can be displayed on the workstation. When the students or instructors want to review a previously simulated transient they will be able to do it on the workstation without using the CRAY. This capability will greatly enhance the training capability at ATR.

SUMMARY

The need to increase the realism of nuclear power plant simulators and to reduce reactor operator burden has led to the establishment of the INEL Engineering Simulation Center in April 1988. Two major activities reported in this article are well underway that include the ATR simulator upgrade project and a project which will utilize the NPA/RELAP5 in the classroom. Both projects demonstra e prototype "first-of-its-kind" simulation tools being utilized to train reactor operators for accident conditions as well as normal operation of the plant. These capabilities are being made possible because of the fidelity of the RELAP5 code and the versitility of the NPA.

ACKNOWLEDGMENTS

This paper represents the diligent work of many people from many organizations, in particular, the

U.S. Nuclear Regulatory Commission, the U.S. Department of Energy, and EG&G Idaho, Inc. The authors wish to gratefully acknowledged these people for their contributions to the establishment of the INEL Engineering Simulation Center.

REFERENCES

1. E. T. Laats et al., "Engineering Simulations Facilities for Advanced Concepts Testing," Proceedings of the 1988 Eastern Simulation conference, April 18-21, 1988, Orlando, FL.

2. J. R. Venhuizen and E. T. Laats, "Development of a Full Scope Reactor Engineering Simulator," Proceedings of the 1988 Summer Computer Simulations Conference, July 25-28, 1988, Seattle, WA.

3. E. T. Laats, et al., "INEL Engineering Simulation Center" Proceedings of the Fourth International Symposium on Cray Supercomputers, October 1988, Minneapolis, MN.

4. J. D. Burtt, et al., "The Development of a Reactor Training Simulator at the ATR," Transactions of the Annual American Nuclear Society, June 4-8, 1989, Atlanta GA.

5. T. R. Charlton, et al., "User of Networking for simulation and Training by the Nuclear Regulatory Commission," Proceedings Interactive Networked Simulation for Training, April 26,27, 1989 Orlando, FL. pp. 4-7.

6. V. H. Ransom, et al., "RELAP5.MOD2 Code Manual," NUREG/CR-4312, August 1985.

7. D. Snider et al., "Draft Nuclear Plant Analyzer (NPA) Reference Manual", September 1989

8. H. Chow et al., (Principal Investigators), ATHENA Code Manual Volume 1: Code Structure, Systems Models, Solution Methods, and Input Data Requirements, DRAFT, EGG-RST-7034, September 1985.

9. TRAC-BD1 Code Development Group, TRAC-BD1/MOD1: An Advanced Best Estimate Computer Code For Boiling Water Reactor Transient Analysis, NUREG/CR-3733, EGG-2294, April 1984.

10. D. R. Liles, J. H. Mahaffy (Principal Investigators), TRAC-PF1/MOD1: An Advanced Best Estimate Computer Program For Pressurized Water

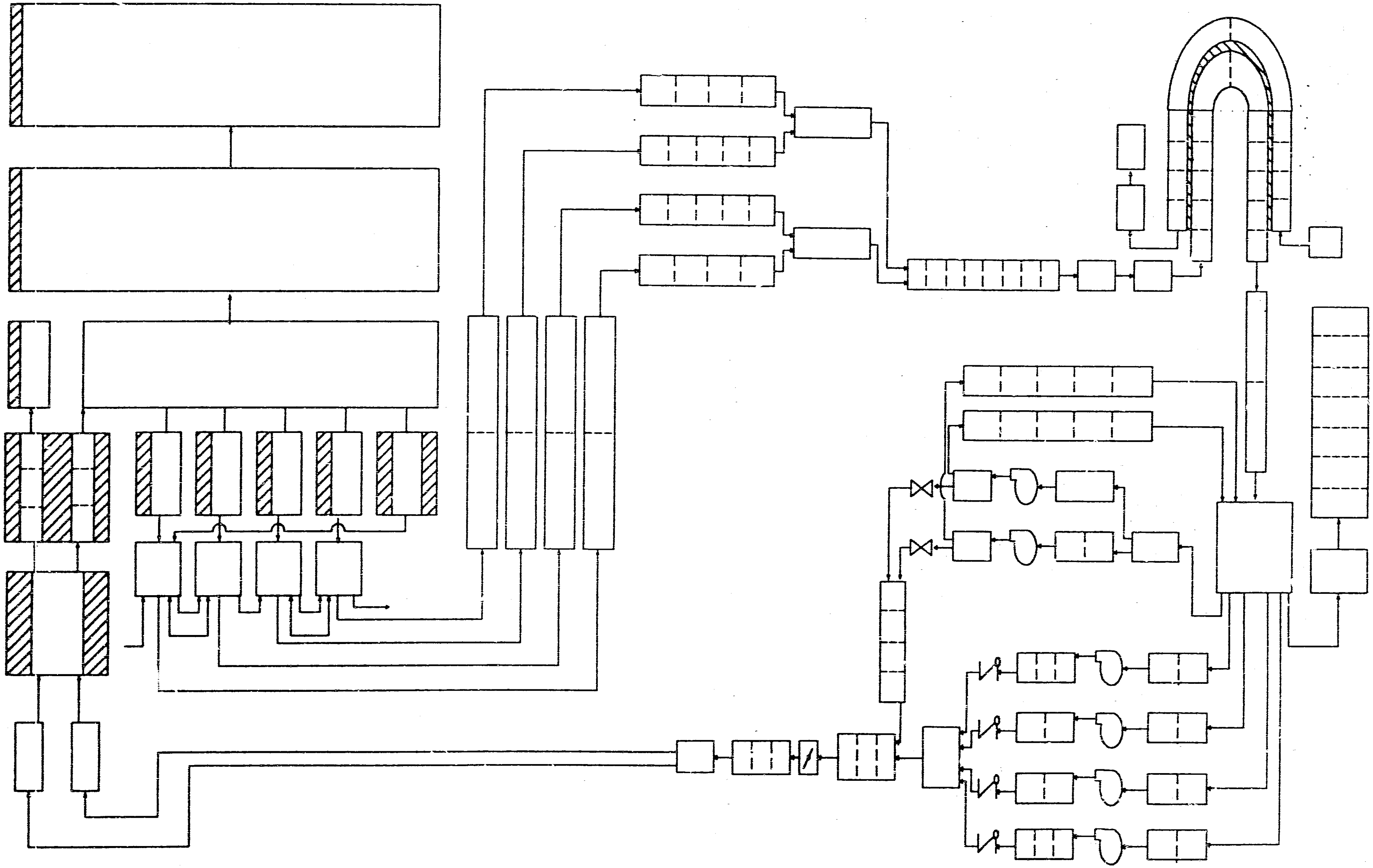
Reactor Thermal-Hydraulic Analysis, Los Alamos National Laboratory Draft Report, February 1984.

11. D. Saphier, "The Simulation Language of DSNP: Dynamic Simulation for Nuclear Power-plants (User Manual), "ANL-CT-20, Rev. 3.4, December 1983.

12. W. Weaver et al., "RELAP5/MOD3 Models and Correlations" To be published in March 1990

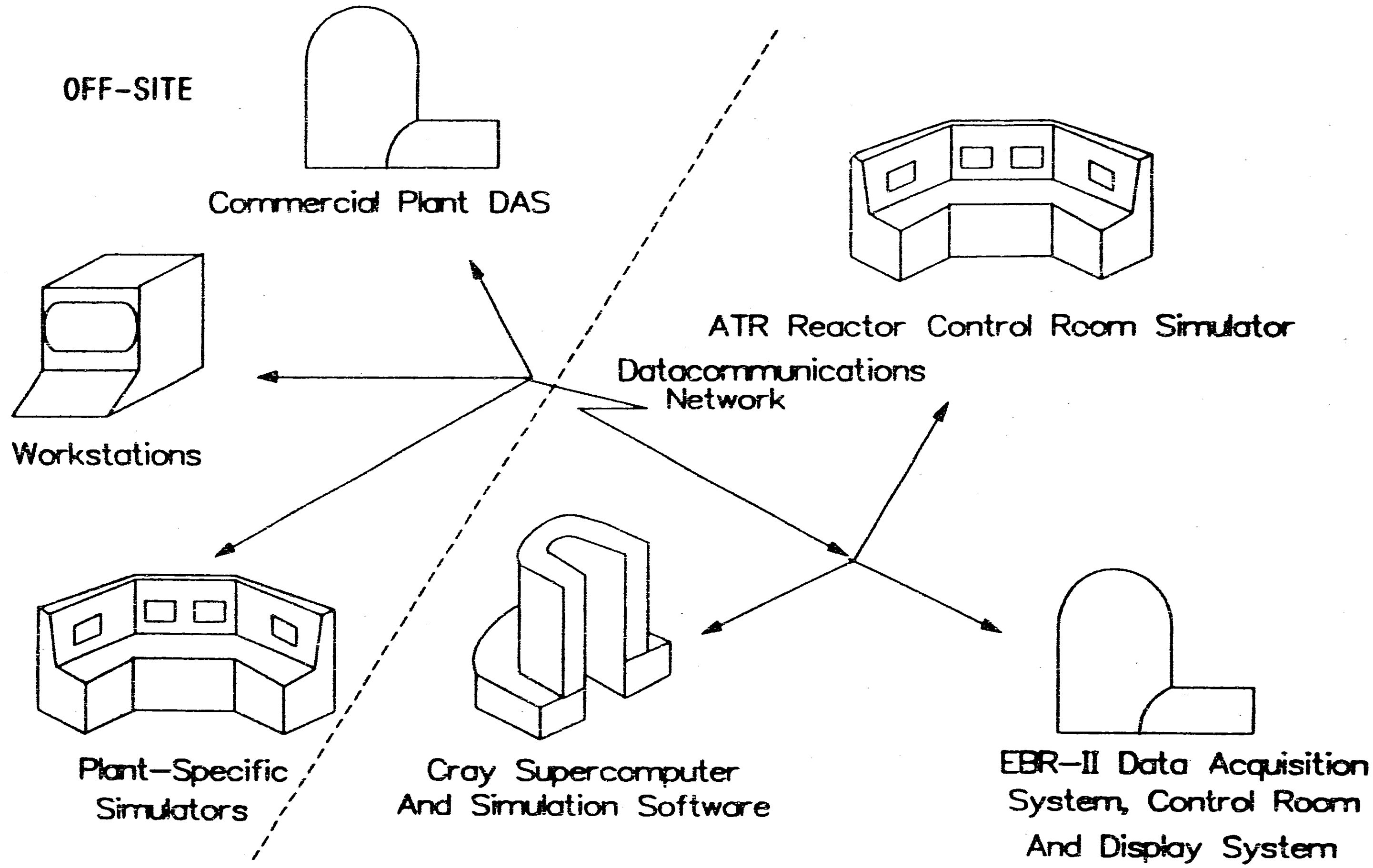
Figure 1. Components of INEL Engineering Simulation Center.

Figure 2. RELAP5 Model of the ATR for the Control Room Simulator.



ECO01866

INEL ENGINEERING SIMULATION CENTER CONFIGURATION



IDAHO NATIONAL ENGINEERING LABORATORY

END

DATE FILMED

11 / 28 / 90