OVERVIEW OF 1990-1991 RETRAN ACTIVITIES

OVERVIEW

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The major activities related to the RETRAN code during 1990-1991 are reviewed. These activities fall into two broad areas: the use of RETRAN-02 by the nuclear industry and the development, verification, and validation of RETRAN-03. Workstation versions of both codes are described along with support software. Several new applications of the code are reviewed.

INTRODUCTION

This paper presents an overview of the important events related to the RETRAN code that have occurred since the Sixth International RETRAN Conference in 1989. This paper covers the following topics:

1. recent RETRAN-02 activities including the current status of the RETRAN-02 safety evaluation report (SER) on MOD5 and the conversion of RETRAN-02 to various workstations
2. the release of RETRAN-03, the use of RETRAN-03 for boiling water reactor (BWR) stability analysis, and future activities that are currently planned
3. new applications of RETRAN-02 and RETRAN-03.

Each of these subjects is elaborated on in the following sections.

RETRAN-02 ACTIVITIES

U.S. Nuclear Regulatory Commission Review of RETRAN-02/MOD5.0

The U.S. Nuclear Regulatory Commission (NRC) contractor International Technical Services (ITS) has completed the technical review of RETRAN-02/MOD5.0. Their technical evaluation report (TER) indicates that RETRAN-02/MOD5.0 has restrictions similar to those placed on RETRAN-02/MOD4. The new models in MOD5.0 are the general transport model, the 1979 American Nuclear Society decay heat curve, and the reactivity edit. The user must justify to the NRC the use of either the transport or the decay heat model with respect to the application; i.e., the basic models are acceptable as coded, but the user must show that the uses are conservative for the specific application. This restriction is consistent with other uses of general models in RETRAN-02. The reactivity edits have been flagged as a "user beware" item by ITS as they may not always reflect the proper value of the component reactivity values.

The NRC issued the SER on RETRAN-02/MOD5.0 on November 1, 1991. It reflects the TER conditions. The SER has been published as an Appendix to Revision 5 of the RETRAN-02 computer code manual.[1]

Electric Power Research Institute Marketing Survey

Electric Power Research Institute (EPRI) management is evaluating the use of various EPRI-developed products. To accomplish this, they obtained the help of an independent marketing survey company. They used RETRAN as the lead product in developing methodology to determine market penetration and, secondarily, how frequently a product is used.

The survey obtained information from 19 of the 46 EPRI sponsors using RETRAN. This is 41% of all EPRI nuclear sponsors. The frequency of use of the code by various utilities was nine daily, seven weekly, two monthly, and one yearly. It was rated 8.1 out of a maximum 10 for "how well did it do what you thought it would do"; 8.6 out of a maximum 10 on "how valuable is RETRAN to your job or group"; and 8.1 out of a maximum of 10 on "how satisfied were you with RETRAN."

From project records, it was determined that of the 49 utilities currently operating nuclear plants, all but

4 have obtained a license for RETRAN and have used it. (This is 92% of the nuclear utilities.) The same analysis was performed from the list of U.S. plants. All but 3 of the 111 nuclear plants in the United States have had a RETRAN analysis. This is 97% of all nuclear plants in the United States.

There are three additional ways of identifying use of a code: (a) the utility has used it in a licensing submittal; (b) the utility has published a paper using the code; or (c) the utility is a member of the RETRAN Maintenance Group. Currently, EPRI is aware of 21 utilities having made one or more licensing applications using RETRAN. One or more papers have been published by at least 36 of the different utilities. Dues-paying Maintenance Group members total 30 utilities. Using any one of these criteria indicates that 41 utilities are using the code in some way. This is an 84% usage rate.

Workstation Versions of RETRAN-02

During 1989, the RETRAN-02 Maintenance Group authorized the development of a workstation version of RETRAN. The first nonmainframe version of RETRAN-02 was for the IBM-PC (386) and compatibles. Since then, RETRAN has been transported to the IBM-6000 by EPRI/Computer Simulation and Analysis, Inc. and to the HP-9000 by Yankee Atomic Electric Company. Work is ongoing by Power Computing Company to convert RETRAN to DEC, VAC, and Sun workstations.

The performance of RETRAN on the workstations is truly amazing. The IBM-PC version running at 33 MHz with a Weitek coprocessor is able to perform faster than a CDC 6600. The IBM RISC 6000 version has ~60% the performance of the Cray XMP. The cost per calculation is now such that only the engineering time controls how much analysis is performed. Figure 1 shows the performance of the various workstations running the RETRAN sample problem set. This was a very carefully controlled benchmark of the various computers.

There are difficulties in implementing workstation versions of RETRAN. One problem is the ability to transport the code to a new platform. This is really a test of the compiler and our ability to identify the correct set of compiler options needed to obtain the same results as the reference version of RETRAN used as the starting point. Any code changes needed to make RETRAN work on a different platform are generally limited to the extensions of FORTRAN that are not standard between various vendors.

Once the code is working, the immediate consideration is what to do with all the output. In general, a high-speed printer is needed for most mainframe versions of RETRAN. This type of printer is generally not associated with workstations. Another challenge is to obtain plots from the codes. Most of the mainframe codes use Calcomp plotters while most workstations have extensive built-in graphic capability. The problem is to use the plot files with the new capability contained in the workstation.

Another area that needs to be addressed is the transferal of support files from the mainframe to the workstation. Careful consideration must be given to what to transfer and what to re-create on the new platform. Finally, one must consider the quality assurance[2] (QA) process. There is far more flexibility in a workstation in the next office than in a mainframe under the control of an information systems division. While the new flexibility is welcome to the user, it generally is not consistent with a rigid QA program and may require additional QA procedures.

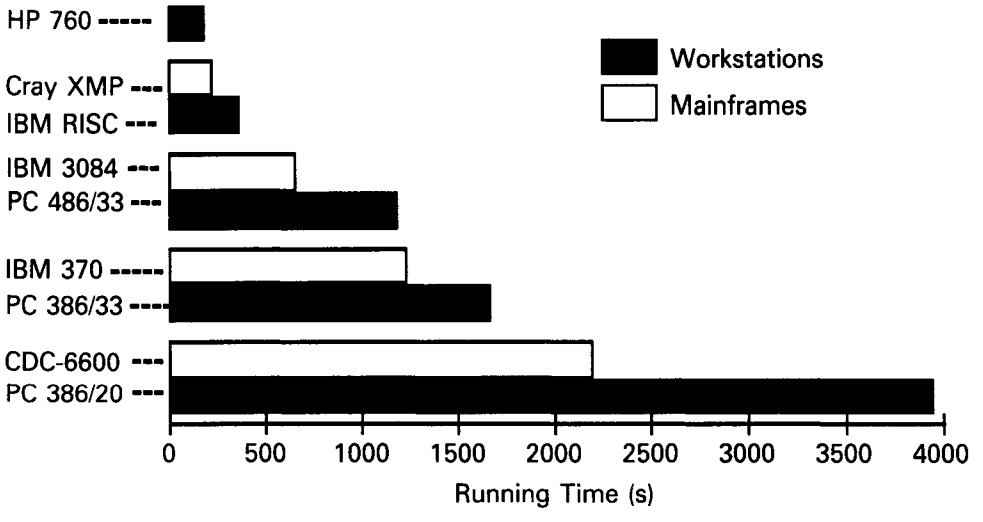

Fig. 1. Performance of various workstations running the RETRAN sample problem set.

Software for Use with Engineering Codes

Computing technology is undergoing significant changes with respect to engineering applications in the electric utility industry. These changes result mainly from the introduction of several UNIX workstations that provide mainframe calculational capability at much lower costs. Coupled with microcomputers through local area networks, these workstations provide the engineering group with a powerful and versatile analysis capability.

The RETRAN-02 Maintenance Group is taking further advantage of this computing capability by obtaining the Professional Engineering Graphics Analysis System (PEGASYS™) for use with RETRAN-02. PEGASYS is a software package for use with engineering analysis codes executed in a workstation environment. PEGASYS, through the user-friendly menus interface, provides pre-execution (preprocessor) and postexecution (postprocessor) support and an on-line monitoring (plot) capability. The development of PEGASYS is part of an overall program to provide engineers the opportunity to improve their productivity and to better understand the problems being analyzed.

The current PEGASYS RETRAN-02 application is limited to IBM-PC and compatible computers using an Intel®386/486 processor with MS-DOS®. This version is being converted to function under X-windows for use on UNIX operating systems. When work is completed later this year, PEGASYS will function on both UNIX and DOS computers. EPRI plans to develop generalized applications of PEGASYS for other engineering codes.

RETRAN-03 ACTIVITIES

Six international participants are active in the RETRAN-03 development and testing project. The original four participants (AEA Technology in the United Kingdom; Korea Electric Power Company in Korea; Paul Scherrer Institute in Switzerland; and Unión Iberoamericana de Tecnología Electrica S.A. in Spain) have been joined by Consejo de Seguridad Nuclear of Spain and Ente Nazionale per l'Energia Elettrica of Italy.

The RETRAN-03 code is available from the Electric Power Software Center in Dallas, Texas. It is currently being shipped with Vols. 1, 2, and 3 of the four-volume computer code manual.[3-5] (Volume 4 is scheduled for 1992.) One of the primary development goals for RETRAN-03 was to develop a code that is transportable to a variety of computer platforms, including the traditional IBM and CDC mainframe computers and the new generation of microcomputers that offer mainframe performance.

Both RETRAN-01 and RETRAN-02 were relatively difficult to transport to new operating platforms because of the environmental libraries that were written using assembly language. To realize the goal of making RETRAN-03 as transportable as possible, a common environmental library was written using FORTRAN-77. In several instances, vendor extensions to FORTRAN-77 were needed to eliminate assembly language code. In general, at least 95% of the environmental library source code is common to all platforms, while the remaining code is written using platform-specific extensions to FORTRAN-77. Several platforms require the use of one or two small (10- to 30-line) routines that use alternative languages such as C, assembly language, or CYBIL.

As a result of the RETRAN-03 development effort, the code is easily transported to new computing platforms. Installation and maintenance instructions are given in Ref. 4 for a variety of different computing platforms. Currently, there are specific versions for the IBM (MVS) and CDC (NOS) mainframe and operating system. A general 64-bit version is available for CRAY, CDC (NOS/VE), and CONVEX machines. The current workstation versions are for IBM RISC 6000 and IBM-PC (386 and 486) compatibles. Work is under way to make Sun, DEC, VAC, and HP versions.

The RETRAN-02 code was developed and maintained on the CDC systems using the UPDATE program. Because of this, the IBM source code modification history information was not directly available; it was only indirectly available via the CDC master program library.

This limitation has been eliminated for RETRAN-03 by using a source code maintenance program called SLIB77 (Ref. 6) that is transportable and runs on the same platforms as RETRAN-03. The RETRAN-03 source code and the companion environmental library are both maintained using the SLIB77 program. SLIB77 was specifically designed to maintain source or data records in compressed but readily available form. It was developed by the System Modeling Branch of the System Engineering Division of the Western Area Power Administration to accurately transmit computer program changes from one installation to another. SLIB77 is written in American National Standards Institute FORTRAN-77 to ensure compatibility with as many computers as possible. Details on the use of the program are given in Vol. 2 of the RETRAN computer code manual.[4]

The two most significant improvements in RETRAN-03 were the improved numerics that allow one to select time steps larger than the Courant limit and the thermal nonequilibrium capability. RETRAN-03 has both thermal equilibrium and thermal nonequilibrium options. The five-equation option is for special situations where subcooled liquid is in contact with saturated steam. Figure 2 shows how emergency core cooling system (ECCS) injection is computed in RETRAN-03 with the five-equation models compared with the four-equation RETRAN-02 results. The

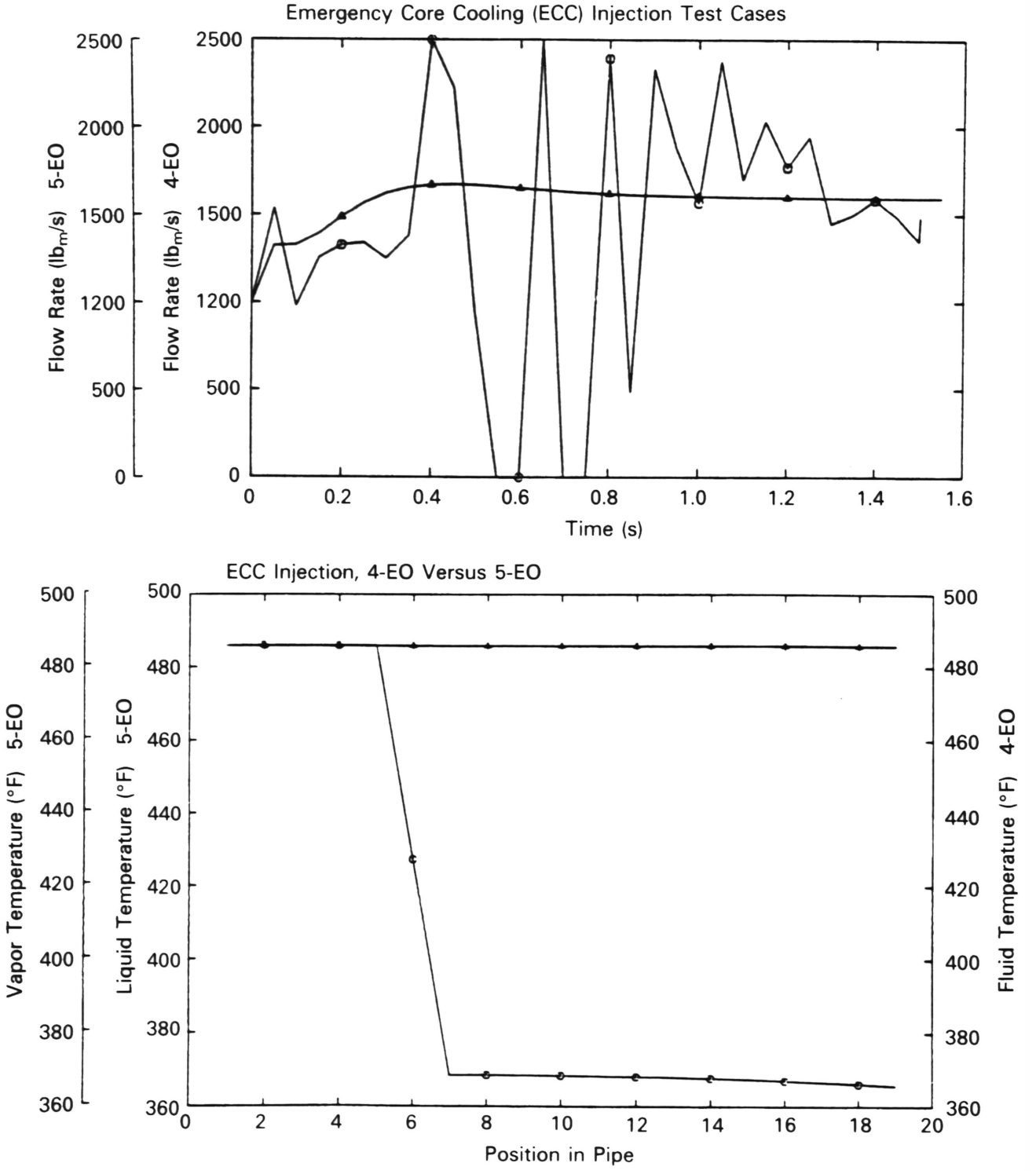

Fig. 2. Emergency core cooling systems injection computed by RETRAN-02 and RETRAN-03.

RETRAN-02 results are totally meaningless because of numerical oscillations.

The RETRAN-03 code has been validated for ECCS, BWR turbine trip, and BWR stability [including anticipated transient without scram (ATWS)] conditions. Figure 3 shows the results for the Peach Bottom turbine trip test. In general, the results from the thermal nonequilibrium case have lower power as the system is "softer" because of the subcooled void in the lower part of the core.

Additional verification and validation activities were undertaken with RETRAN-03 to address the

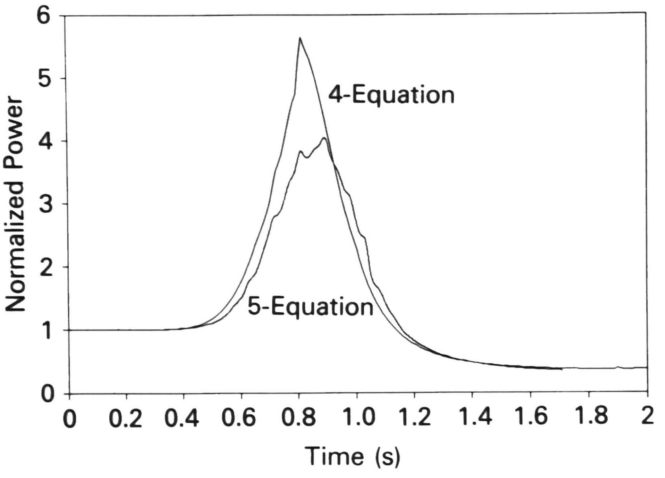

Fig. 3. Results of Peach Bottom turbine trip test.

deficiencies noted by the RETRAN-02 TER report. It is anticipated that this work should allow RETRAN-03 to build on the licensing analysis that qualified RETRAN-02 for its SER.

APPLICATIONS OF RETRAN

Liquid-Metal Space Reactor Safety Analysis

The RETRAN-02 code provided a unique framework for this analysis as a result of its modular design, flexible system modeling capabilities, large body of verification and validation data, acceptance as a licensing tool for light water reactor systems, and QA pedigree. RETRAN-02/MOD4 was thus selected by Los Alamos National Laboratory to perform the system analysis for the SP-100 space reactor safety analysis.

The SP-100 is a small, high-temperature, liquid-metal fast reactor system designed to produce electric power in a space environment. The highly enriched reactor core consists of fuel pins enclosed in hexagonal assemblies cooled by liquid lithium. The lithium coolant loop is driven by electromagnetic pumps. In the "generic" design, 100 kW of electric power is produced from 2.5 MW(thermal) by thermoelectric cells, and heat rejection is accomplished by a secondary sodium loop that transfers heat to a heat-pipe space radiator.

The RETRAN-02/MOD4 transient thermal-hydraulic analysis computer code was modified to include liquid lithium, liquid sodium, and water as operating fluids in separate hydraulic loops.

Advanced Test Facility

One of the new applications of RETRAN-02 involves an analysis of the Advanced Test Reactor (ATR) at the Idaho National Engineering Laboratory. This facility is operated by EG&G Idaho for the U.S. Department of Energy. The ATR has been in operation since 1967, and its main purpose is to investigate the effects of high radiation on reactor materials, primarily reactor fuels.

The ATR operates at a power of 250 MW(thermal) and has a maximum neutron flux of 10^{15} n/cm^2·s. The high power density in the core, coupled with the arrangement provided for test materials, allows radiation exposure experiments to be conducted in relatively short time periods (e.g., months instead of years). The ATR has nine test loops available for placing materials to be irradiated.

The RETRAN-02 application involved an analysis of the high-pressure loop with pressures exceeding the critical pressure. The purpose of the analysis was to establish fluid conditions in this loop at various values of core power and loop flow rate and pressure. These conditions were used as boundary conditions for an auxiliary multidimensional heat conduction code.

BWR Stability Analysis

Boiling water reactors are susceptible to thermal-hydraulic instabilities that must be considered in their design and operation. Early BWRs were designed to be very stable while operating under natural-circulation conditions. As reactor designs have been modified, stability margins have been reduced, and the potential for stability events, such as those that occurred at the LaSalle and Vermont Yankee plants, has increased. These events and other considerations point to the need for a reliable analysis tool for predicting the dynamic behavior of these events.

Frequency domain methods have been historically used to set stability limits and have been demonstrated to predict the onset of instability. The frequency domain method is based on a small perturbation made to a linearized first-order system where second-order (and higher) terms are neglected. Neglecting the second-order terms limits the applicability of frequency domain methods to the prediction of stability limits. Frequency domain methods cannot be used to predict the behavior of a system once it becomes unstable since the higher order terms influence the limit cycle behavior. Various time domain methods do not neglect the higher order effects and may provide a means of simulating the nonlinear behavior of unstable systems.

Time domain thermal-hydraulic codes have been used to analyze BWR stability events. They are not subject to the requisite linear assumptions that are applied to the frequency domain methods typically used to determine stability margins. However, the solution methods used by the time domain codes are known to be subject to numerical diffusion (see Fig. 4), which results in the answer being a function of time steps and can detrimentally affect stability analyses.

A solution to the mass and energy equation using the method of characteristics has extended RETRAN-03's

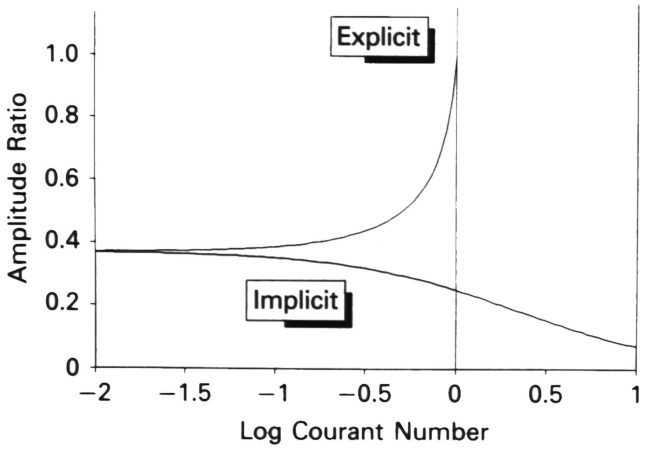

Fig. 4. RETRAN numerical results.

range of application to BWR stability events by eliminating numerical diffusion[7] (see Fig. 5). A comparison of the four- and five-equation models available in RETRAN-03 demonstrates that the thermal equilibrium model introduces an aphysical behavior for the computed measure of stability (decay ratio) as a boiling boundary is moved through a node boundary. The nonequilibrium model using the method of characteristics eliminates both the numerical diffusion and the aphysical boiling boundary effect. RETRAN-03 is a viable analysis tool for BWR stability events.

Independent Analysis Capability Needed for Advanced Light Water Reactor Applications

The Analysis and Testing Review Group strongly recommends that a utility independent analysis capability be developed now for the Advanced Light Water Reactor (ALWR) programs. The purpose is not to repeat the vendor or NRC work, but rather to ascertain that the issues significant to plant operations, design margins, and investment protection have been dealt with appropriately and adequately.

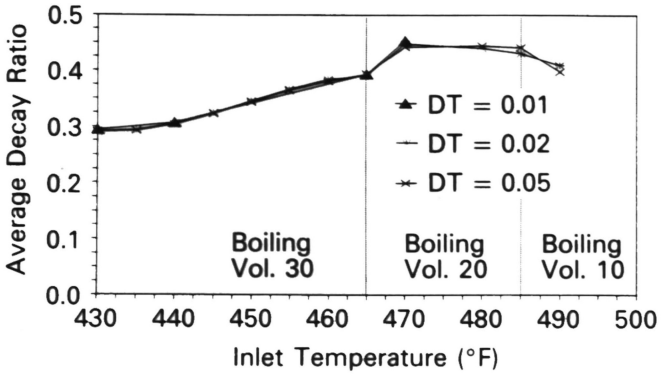

Fig. 5. RETRAN-03 results using nonequilibrium and method of characteristics.

The development of such an independent analysis capability should not involve significant code development if RETRAN-03 is used. It will be necessary to validate RETRAN-03 in some areas where ALWR phenomena are different from the phenomena in today's light water reactors (LWRs), and it will be necessary to build models of the AP600 and simplified BWR systems and containment designs. These models will then have to be checked to verify their adequacy.

The benefits of performing independent analysis were learned under the current LWR program in important areas such as safety system setpoints, ATWS response, emergency operating procedure development, and BWR stability. These were areas in which the vendor approach was modified as a result of independent utility/EPRI analyses. In the absence of an independent capability, utilities would now be following a less than optimum approach in these areas. A similar situation exists today in the ALWR program.

The vendor analysis programs tend to focus on design-basis and licensing considerations needed to achieve certification. This was also true of the current LWR program where the industry is still experiencing problems that involve long-term, non-worst-case events sometimes occurring under off-normal conditions. The same will probably be true for the ALWR designs, but just as before, vendor resources are geared toward the main goal of certification. An independent analysis capability will allow EPRI and the utilities to apply some resources early to investigate such noncertification but operationally significant issues. This would include events that might occur during startup or shutdown, low decay heat conditions, possible active system interactions with passive systems, and other investment protection issues.

FUTURE ACTIVITY

The RETRAN-03 development phase is in its closing stages. The only definite activity planned for RETRAN-03 in 1992 is to complete Vol. 4 of the manual. The application volume will be similar to RETRAN-02's Vol. 4. It will document the RETRAN-03 verification and validation plan and show how each step in the process was accomplished. The main addition to the RETRAN-02 report will be a section comparing a set of reference pressurized water reactor and BWR applications that were run by both RETRAN-02 and RETRAN-03. These comparisons show that for any engineering considerations, the results of both codes are identical if the same options are selected in both codes. Volume 4 will also include the results from the RETRAN-03 working group. Additional analysis will be added as it becomes available.

The design review planned for RETRAN-03 is very

similar to the one performed on RETRAN-02. A design review committee will be selected early in 1992. They will develop and document the design review plan, which is expected to be very similar to the RETRAN-02 plan. The main difference is that we expect to make use of the fact that RETRAN-02 and RETRAN-03 give the same results for Chap. 15 transients. This fact will allow the design review to cover the applications in a expeditious manner. The actual design review is anticipated to be completed in the third quarter of 1992 and the final report issued before the end of the year. This schedule may be shortened depending on the lead licensing utility needs.

The Electric Power Research Institute has identified the need to extend RETRAN-03 to allow air-water-steam as the fluid being described. This is required by the use of RETRAN-02 for midloop operations. A plan has been developed to upgrade RETRAN-03 to this level but requires additional funding, possibly from an additional international sponsor.

CONCLUSION

Most of the U.S. utilities are currently using RETRAN-02 for licensing submittals and operation support. RETRAN applications appear to be limited only by the creativity of the user. Now with the release of RETRAN-03, an extended list of analyses is possible. Many RETRAN-02 users are already in the process of converting to RETRAN-03. With the availability of PEGASYS and the workstation version of RETRAN, the required engineering and computer resources should be greatly reduced. With additional international participation and through the EPRI Advanced Reactor Group, RETRAN-03 is expected to be extended for midloop (air-water-steam) analysis and ALWR applications.

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