OVERVIEW OF 1988-1989 RETRAN ACTIVITY

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The major RETRAN-related activities during 1988-1989 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.

INTRODUCTION

This paper presents an overview of the important RETRAN-related events since the Fifth International RETRAN Conference in 1987. The paper covers the following topics:

1. development of in-house analysis capability by utilities that own or operate light water reactors (LWRs)
2. recent RETRAN-02 activities including the current status of the RETRAN-02 safety evaluation report (SER)
3. current status of RETRAN-03 and the plans for its completion
4. RETRAN applications to the analysis of boiling water reactor (BWR) instability.

STEPS IN DEVELOPING IN-HOUSE ANALYSIS CAPABILITY

Most domestic utilities that own or operate LWRs have demonstrated a need for in-house system analysis capability. A five-step progression of the development of this analysis capability is defined as follows:

1. The first step is the development of basic capability. At this point, the utility staff is learning about the analysis methodology. The vendor continues to perform the analyses required to support and license the plant. To start this activity, the utility needs basic analysis tools and the training required to apply them properly.

2. In the second step of the development, the utility has the capability to review the vendor's analyses and to perform some of the analyses required to support plant operation. The utility staff can now function as a technical monitor to the vendor. The vendor still has a lead role in the analyses and has responsibility for the plant licensing. To reach this point, the utility must demonstrate that it can reproduce the vendor analyses and must demonstrate competence with the basic analysis tools.

3. In the third step of the development, the utility has the capability to design the reload core and to perform most of the analyses required to support plant operation. The utility staff is now in a technical lead position. The vendor continues to act as the plant licensing agent. To reach this point, the utility must have developed a complete methodology for its plant-specific analyses, including guidelines and procedures.

4. In the fourth step, the utility has the capability to perform a complete reload safety evaluation and can analyze all of the anticipated events that are required for reload fuel licensing. The utility staff is now responsible for core licensing. The vendor performs technical reviews of the utility analyses as required. To reach this point, the utility must have licensing-grade methodology [i.e., codes and models have been described in licensing topical reports and approved by the U.S. Nuclear Regulatory Commission (NRC)] and analysis procedures that meet the quality assurance (QA) standards of the nuclear regulations.

5. At the fifth step, the utility has the complete capability to analyze design-basis accidents (DBAs) and

to perform analyses required to support plant modifications. The utility staff is now responsible for all aspects of plant licensing, and the vendor has a very limited role in the plant system analyses. To reach this point, the utility must have methodology for DBA application and for application to modifications of plant-specific technical specification and setpoints.

It is important to note that the utility staff cannot assume any aspect of licensing responsibility until they have developed licensing-grade methodology and analysis procedures that meet the QA standards of the nuclear regulations. In general, licensing-grade methodology requires that licensing topical reports be prepared and approved by the NRC in the form of SERs. The Electric Power Research Institute (EPRI) has supported this process for RETRAN analysis of LWR systems by completing an intensive design review of RETRAN-02. The objectives of the RETRAN design review were as follows:

1. Ensure that the EPRI criteria for code release were satisfied.
    a. Ensure that there is complete detailed documentation that adequately describes all models in RETRAN.
    b. Ensure that the code verification and validation are adequate.
    c. Define the range of RETRAN application in terms of specific operational transients and abnormal events.
2. Verify that the code was applicable to Final Safety Analysis Report Chapter 15 transients, excluding Appendix K-type analysis.

RETRAN-02 ACTIVITIES

The RETRAN-02 code is now under configuration control, and all modifications are made under QA procedures that conform to 10CFR50 Appendix B (Ref. 1). The NRC issued a generic SER for the application of RETRAN-02/MOD2 to LWR transient analysis. The NRC recently completed its review of MOD3 and MOD4 and has issued an SER relating to these versions of RETRAN-02.

The revised SER makes no fundamental change from the original SER. The current SER clarifies the status of MOD3 and approves the use of MOD4. The multiple control state control rod model option in MOD4 has been approved. A copy of the SER is contained in Revision 4 of the RETRAN-02 theory manual.[2]

The EPRI has published guidelines for system analysis[3-5] and RETRAN modeling.[6] The SER and these guidelines provide a foundation for the topical reports that a utility must prepare for their plant-specific analyses.

The responsibility for both the maintenance and NRC review of RETRAN-02 has been assumed by the RETRAN-02 Maintenance Group, which currently has ~30 members. It has authorized the development of RETRAN-02/MOD5 and will decide when to submit the code for NRC review.

The new features included in MOD5 are as follows:

1. under the QA program
    a. source code in FORTRAN 77, assembly language environmental
    b. generalized transport model (e.g., boron)
    c. American Nuclear Society standard decay heat
    d. reactivity edit for the new one-dimensional kinetics rod model
2. not under the QA program
    a. FORTRAN 77 environmental library
    b. a single-precision 60-bit all-FORTRAN 77 version
    c. a double-precision 32-bit all-FORTRAN 77 version.

The single-precision 60-bit version has been tested on Cyber machines, but it is intended to be the base code for all 60-bit machines (i.e., those that do not require double precision). The 32-bit version has been tested on IBM machines, but it is intended to be the base code for all 32-bit machines (i.e., those that do require double precision). The availability of these versions will greatly enhance the transportability of RETRAN-02. For example, the 32-bit version does not require auto double and thus can be used with non-IBM machines. Finally, compiler options have been identified that will ensure identical results among various computers, operating systems, and compilers.[7]

Some of the utilities in the maintenance group have expressed concerns regarding the differences among SIMULATE-E, SIGTRAN, and RETRAN-02. The first concern is the anomolous shape of the void coefficient versus void fraction curve generated by the point kinetics model of SIMTRAN. It was concluded that both SIGTRAN and SIMTRAN must be changed.[8] The second concern was an apparent discrepancy between the SIMULATE-E and RETRAN-02 core fluid density profiles. It was concluded that the density distribution is the same if care is taken to select the same models in each code. The final concern relates to the difference in the reactivity effect associated with a pressure change between RETRAN-02 and SIMULATE-E. This concern is currently unresolved and is being investigated.

RETRAN-03 ACCOMPLISHMENTS AND SCHEDULE

Four international participants are active in the RETRAN-03 development and testing project: AEA Technology in Great Britain; Korea Electric Power Company in Korea; Paul Scherrer Institute in Switzerland; and Union Iberoamericana de Tecnología Eléctrica S.A. (UITESA) in Spain. The objectives of the RETRAN-03 development are as follows:

1. Extend the range and types of analyses to include nonequilibrium conditions.
2. Improve performance by making the code more dependable, easier to use, and faster running.
3. Have a more transportable code.

The development of RETRAN-03 is in its final stages. Most of the objectives have been met and the remaining ones should be complete by the end of 1990. The theory and numerics manual, the programmer's manual, and the user's manual are planned to be finished in the first half of 1991. A draft version of the applications manual is planned for the same time. The plan calls for a prerelease version of the code with all features working in late 1990 and transmittal of RETRAN-03/MOD0 to the Electric Power Software Center in early 1991. A comparison of the major options and capabilities in RETRAN-02 and RETRAN-03 is shown in Table I.

The verification and validation of RETRAN-03 are well under way and are following the EPRI plan.[9] The objective of the RETRAN-03 verification and validation plan is to obtain a high degree of confidence that the RETRAN-03 results are valid. The strategy to obtain this objective has three elements:

1. The verification and validation of those models unchanged from RETRAN-02 (e.g., thermal equilibrium models) will be based on existing RETRAN-02 verification and validation results. All common models will be identified and the key basic RETRAN-02 verification and validation analyses (i.e., analytical solutions, simple experiments, and sample problems) will be repeated with RETRAN-03. The applicability of each verification and validation analysis to the common models will be shown in a matrix. The key RETRAN-03 application analyses [e.g., BWR operational transients and pressurized water reactor (PWR) operational transients] will be repeated with RETRAN-03. The relative importance of each specific model will be identified for each of the application analyses.

2. The RETRAN-02 models that have been modified for use in RETRAN-03 will be verified and validated separately.

3. New models (e.g., thermal nonequilibrium) will be verified and validated primarily by comparison of RETRAN-03 calculations to separate effects tests.

The BWR and PWR operational transients to be analyzed have been carefully chosen to exercise the RETRAN-03 models over a wide range of conditions. The operational transients and the plants to be simulated are as follows:

1. BWR
   a. loss of feedwater heating (Susquehanna)
   b. feedwater controller failure (Oyster Creek)
   c. turbine trip (Peach Bottom Unit 2 test at end of cycle 2)
   d. main steam isolation valve closure (UITESA start-up test)
   e. trip of both recirculation pumps (River Bend)

TABLE I

Comparison of the RETRAN Code Versions

Version	Major Options	Capabilities
RETRAN-02	Dynamic and algebraic slip Interactive numerics Point and one-dimensional neutron kinetics Auxiliary calculation of subcooled voiding Control system Nonequilibrium pressurizer Vector momentum	Applicable to both PWR and BWR operation transients Small-break loss-of-coolant accident (LOCA) blowdown (limited) PWR ATWS
RETRAN-03	Implicit numerics Nonequilibrium field equations Improved steady-state initialization Generalized transport Improved constitutive models	Enhanced operational transients Small-break LOCA BWR ATWS Enhanced PWR ATWS Natural circulation and long-term cooling

2. PWR
   - a. steam generator tube rupture (Prairie Island)
   - b. loss of normal feedwater flow (Three Mile Island Unit 1)
   - c. turbine trip (Arkansas Nuclear One Unit 2)
   - d. reactor coolant pump trip (typical Westinghouse plant)
   - e. anticipated transient without scram (ATWS) (Trojan)
   - f. steam line break (Calvert Cliffs).

These BWR and PWR transients have been run and careful comparisons have been made between RETRAN-02 and RETRAN-03 (Ref. 10). In general, the results are identical but RETRAN-03 requires much less time. A factor of 5 reduction in CPU time is typical, and factors of 20 or more have been obtained for some cases.

BWR INSTABILITY

One of the more demanding problems that has challenged RETRAN and its users in the last few years is that of BWR stability. A BWR can cycle due to the feedback between the thermal hydraulics (void fraction) and the power. Given a random small decrease in flow, the void fraction increases, which causes the power to decrease because the void feedback in the neutron cross sections causes a decrease in reactivity. This in turn causes the power, and the void fraction, to decrease. The void decrease feedback in the cross sections results in an increase in reactivity, which causes a power increase and the cycle is repeated.

The issue became an industry concern after the LaSalle event of March 9, 1988. This was the first time a BWR in the United States was known to have experienced an event where the decay ratio exceeded unity. The decay ratio is the ratio of two succeeding peaks of an oscillation, as shown in Fig. 1. Boiling water reactors are licensed to operate in regions where the decay ratio is <1. The LaSalle plant drifted outside of this region due to the failure of one of the feedwater heaters.

In attempting to analyze this event with RETRAN-03, it was discovered that the decay ratio was very sensitive to the time step and, quite unexpectedly, to the version of RETRAN used. Figure 2 shows the RETRAN-03 and RETRAN-02 analyses of a thermal-hydraulic loop. The RETRAN-03 code uses implicit numerics and the RETRAN-02 code uses explicit numerics. The most important observation is that both of the answers are wrong! The cause of the results can be traced to the upwind differencing of the energy equation used in both codes. This assumes that the fluid flowing into a control volume has the energy content of the upstream volume. This is a physically correct assumption that is used in most thermal-hydraulic codes; however, it introduces a large amount of numerical damping. This damping removes the "high-frequency noise," which is, for most transient analysis, quite acceptable and improves the performance of the code. However, for stability analysis, it is precisely the way this noise amplifies or decays that is of interest.

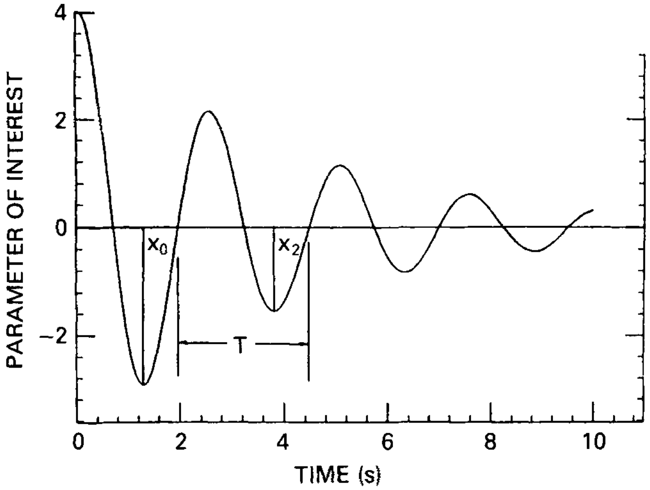


Fig. 1. Stability figure of merit.

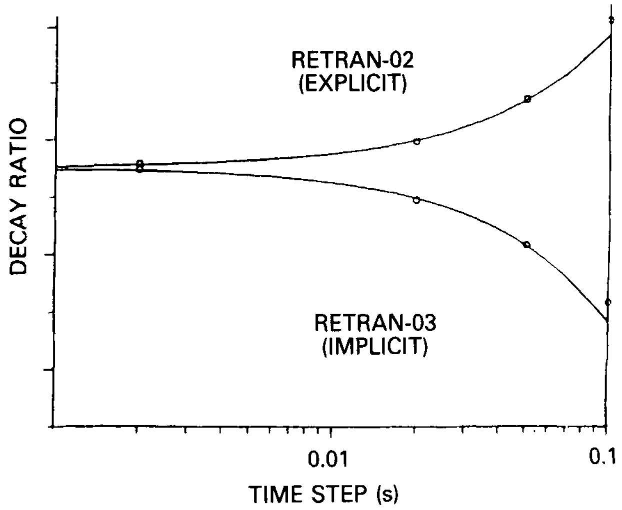
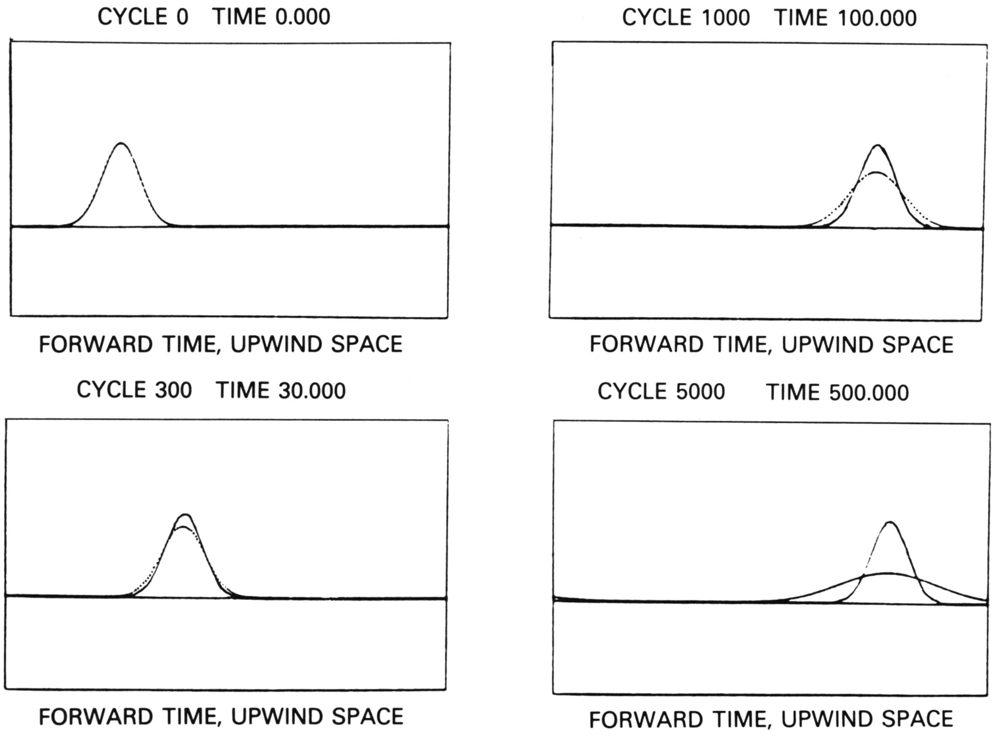


Fig. 2. RETRAN numerical results.

To understand the basic problem, let us review some results obtained by JAYCOR under an EPRI contract.[11] A simple traveling wave was followed using various differencing schemes. Physically, the wave should travel forever and not decay as there was no friction or other physical dissipation in the analysis. The future time upwind space difference scheme displays an extensive damping property as shown in Fig. 3. This effect is confirmed by analytically substituting the functional form of a sine wave into the differencing


CYCLE 0 TIME 0.000

FORWARD TIME, UPWIND SPACE

CYCLE 1000 TIME 100.000

FORWARD TIME, UPWIND SPACE

CYCLE 300 TIME 30.000

FORWARD TIME, UPWIND SPACE

CYCLE 5000 TIME 500.000

FORWARD TIME, UPWIND SPACE

Fig. 3. Numerical characteristics of the forward time upwind space finite difference method.

schemes. Figure 4 shows how the wave decays due to time step for both an implicit and explicit representation of spatial upwind differencing. The correct result is a constant line at 1.0. Note the similarity between this bugle-shaped curve and those of Fig. 2, which were obtained from the RETRAN-03 and RETRAN-02 analysis of the FRIGG loop. The work by JAYCOR shows that other schemes, generally those employing central difference schemes, preserve the shape of the wave. The fundamental problem is that the derivative is being evaluated outside of the range of interest and thus does not converge to the correct slope as the mesh is made smaller for the upwind difference scheme. The central difference schemes, however, do converge and appear to give the correct answer.

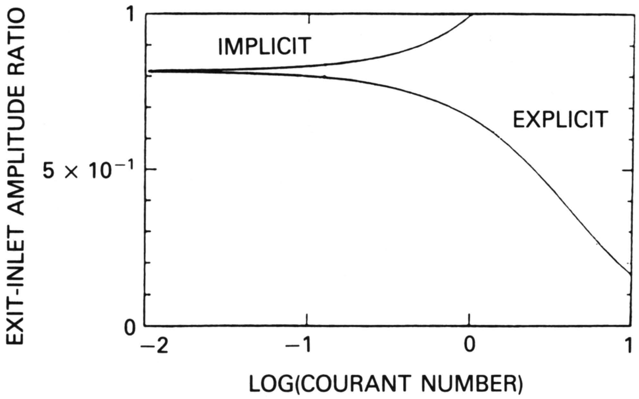


Fig. 4. Standing wave analysis of upwind differencing for the first-order explicit and implicit schemes.

Most current thermal-hydraulic codes are deficient with respect to time domain analysis of BWR stability. The primary reason for this is the common upwind difference assumptions and the resulting numerical damping. Because of this problem, the classical convergence method of reducing both time steps and spatial noding simply results in an incorrect answer. There are various alternative differencing schemes that appear to be suitable for stability analysis as they neither change or amplify the wave. However, implementation of these methods into a code like RETRAN will require extensive effort.

Based on our current knowledge, EPRI is initiating a project to correct the numerical scheme in RETRAN-03 to properly compute stability events. The effort includes selecting and implementing an improved scheme, verification of the scheme, and finally validating the results against both plant and test data.

CONCLUSION

The use of RETRAN has continued to grow over the last 2 years. The presentation of >25 analyses at the 6th International RETRAN Conference is indicative of its heavy use. The financial contributions from >30 different organizations to support RETRAN-02 maintenance are another example of its wide acceptance.

The ability of RETRAN to perform both realistic best-estimate analysis and conservative licensing calculations allows it to be used to examine both operational and licensing considerations. Clearly, no decision about operations can be made without addressing its effect on licensing. Likewise, the effect of licensing issues on operations needs to be well understood. Thus, RETRAN gives the plant support staff the tool they need to balance both sides of the equation. This is necessary to achieve operational goals in a safe and economical manner.

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