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Development & Testing of a RETRAN/MINET Composite Code and Application to the J.A. FitzPatrick Plant*

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ABSTRACT

The development and testing of the RETRAN/MINET Composite Code, based on RETRAN 02 Mod 3 and MINET Version 1.10, are described. The MINET Code was originally developed for the analysis of complex balance of plant (BOP) thermal-hydraulic systems and already serves that purpose in support of RAMONA-3B for BWR analyses and SSC for LMR analyses. The object in developing RETRAN/MINET was to extend the degree to which complex thermal-hydraulic systems can be analyzed, while providing the capability to use detailed RETRAN modeling of the reactor and other components, where needed. The project was sponsored by the Empire State Electric Research Corporation (ESEERCO), with co-sponsorship and engineering support provided by the New York Power Authority (NYPA).

Preliminary testing established proper code performance and data transmission, as well as stability under transient conditions. Two test transients postulated for the H. B. Robinson Plant were simulated using a two loop RETRAN/MINET representation extending to the condenser, and the results were compared against those generated using RELAP5. In addition, the RETRAN model was extended directly to the condenser and the transients were re-run. This provided for a three-way comparison between RETRAN/MINET, RELAP5, and RETRAN (alone). The results generated using RETRAN/MINET and RETRAN were very similar, which again indicates that the interface is performing correctly. The RETRAN/MINET representation through the feedwater train executed about 20% faster than in the RETRAN (alone) case, although more substantial improvements are expected for more complex systems. Both of there results were similar to the RELAP5 results, although there were enough differences in modeling and control system representations to make that comparison inconclusive. However, the principal objective of establishing correct performance of the composite code has been achieved.

INTRODUCTION

Prior to this effort to interface the RETRAN (1) and MINET (2) Codes, there has not been any good way to represent large portions of the power plant thermal hydraulic systems without spending very significant computer funds or manipulating everything through "judicious" boundary conditions. This project was directed toward developing such a capability, by interfacing RETRAN with the MINET code. In a composite RETRAN/MINET representation, RETRAN is generally used to represent the reactor and adjacent system, and MINET is used to represent the balance of plant.

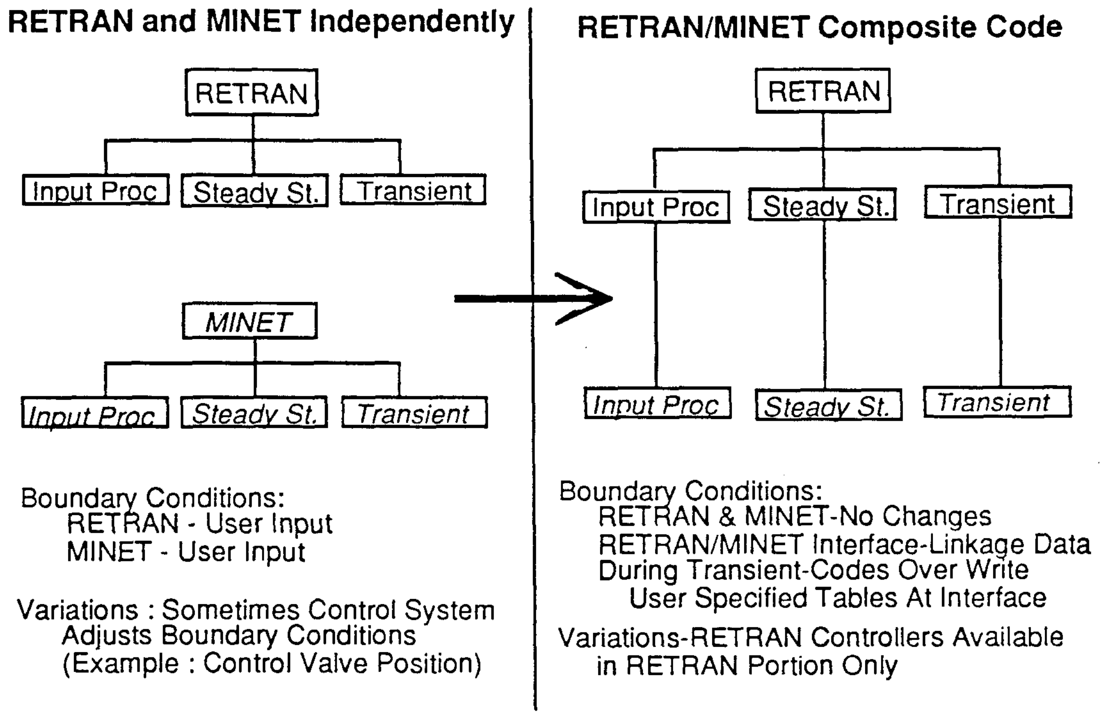
The MINET code is based on a momentum integral network formulation (3) and was designed for simulating large and complex systems such as the balance of plant. It is written in FORTRAN and was designed to be easily interfaced with other computer codes. MINET is also interfaced with SSC (4), for LMR systems, and RAMONA-3B (5) for BWR systems.

The goal of the work described herein was to develop a RETRAN/MINET interface so that a composite representation of the plant system could be implemented. The interfacing is generalized so that the user can utilize the two available models in various combinations, depending on the modeling needs. The process of testing and validating the RETRAN/MINET Composite Code was made easier by the fact that both RETRAN and MINET had been previously validated (for many applications) which allowed us to focus on the interface itself.

One of the guiding principles in developing an interface to combine these codes has been to preserve both codes. The connection is made through boundary conditions in both codes. This required addressing two basic problems; matching the thermal hydraulic conditions at the interface based on individual code requirements and establishing a sequence of computation between two codes.

It was decided that RETRAN would serve as the "host" code and that MINET sub-drivers -- for input processing, steady-state calculations and for transient calculations -- would be spliced into the RETRAN programming, as shown in Figure 1. This was primarily due to the modular structure of MINET, as the code was designed with such interfacing envisioned. As a result, the MINET processing became embedded into the RETRAN input processing, steady-state calculations and transient calculations.

Figure 1. Modular Interfacing of RETRAN and MINET



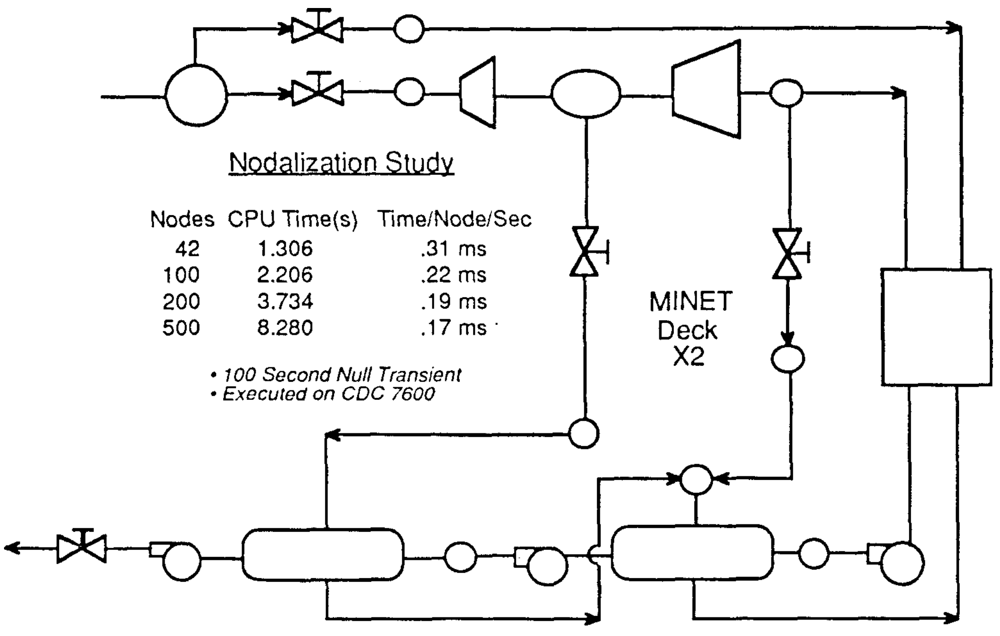
Boundary Conditions:
RETRAN - User Input
MINET - User Input

Variations : Sometimes Control System Adjusts Boundary Conditions (Example : Control Valve Position)

Boundary Conditions:
RETRAN & MINET-No Changes
RETRAN/MINET Interface-Linkage Data
During Transient-Codes Over Write User Specified Tables At Interface

Variations-RETRAN Controllers Available in RETRAN Portion Only

Figure 2. MINET Deck X2 Nodalization Study



Nodalization Study

Nodes	CPU Time(s)	Time/Node/Sec
42	1.306	.31 ms
100	2.206	.22 ms
200	3.734	.19 ms
500	8.280	.17 ms

- *100 Second Null Transient*
- *Executed on CDC 7600*

MINET CODE NUMERICS

The method employed in the MINET code is a major extension of a momentum integral method developed by Meyer (6). Meyer integrated the momentum equation over several linked nodes, called a segment, and used a segment average pressure, evaluated from the pressures at both ends. Nodal mass and energy conservation determined nodal flows and enthalpies, accounting for fluid compression and thermal expansion.

In MINET, a network structure was built around Meyer's momentum integral model for the flow segment. In this extended method, a system is represented using one or more flow networks, connected to one another only through heat exchangers. Each network is composed of segments, volumes, and boundaries. Segments contain one or more pipes, pumps, heat exchangers (either side of tubes), turbines and valves, each of which is represented using one or more nodes. Volumes represent voluminous components and significant flow junctions. Boundaries are essentially the border of the system representation, i.e., where various boundary conditions are specified. Volumes and boundaries are connected by segments.

One typically large and complex flow network is illustrated schematically in Figure 2, a system we designate "Deck X2". This is a simplified balance of plant configuration, composed of turbines, pumps, pipes, valves, heat exchangers, and various headers and tanks. In the initial run, a coarse nodalization was used in the pipes and heat exchangers, bringing the total number of nodes to 42 (including 11 volume nodes). A "null transient" (no changes from initial boundary conditions) was run to 100 seconds, using a time step limit of 5 seconds. The calculations were completed in 1.306 central processor unit (CPU) seconds on a CDC-7600 computer, which works out to .31 millisecond per node per simulated second. We then repeated the run with much finer nodalization in the piping, with the results as shown in the small table in Figure 2.

This trend is in sharp contrast to that experienced with codes based on a local pressure formulation, such as RETRAN. With a local pressure formulation, nodal mass and momentum equations must be coupled and advanced simultaneously, as discussed in Reference 3. For a large and complex system, such as a balance of plant representation, the matrix calculations can become unwieldy.

INTERFACE MODELING

One of the guiding principles in developing an interface to combine these codes has been to preserve both codes and to include this interface in RETRAN. The connection is made through boundary conditions in both codes. This required addressing two basic problems; matching the thermal hydraulic conditions at the interface based on individual code requirements and establishing a sequence of computation between two codes. The connection requires the boundary conditions for one of the codes to lag the other code.

Matching Thermal Hydraulic Conditions

If the non-homogeneous equilibrium RETRAN formulation is used, one has to be careful regarding interface conditions. For an interface in subcooled or superheated flow regimes the flow is essentially single phase and the non-homogeneous equilibrium representation is no longer relevant. However, if the interface is in a two-phase flow region there is the potential for inaccuracies at the interface. This could result from the RETRAN assumption of unequal phase velocities and the MINET assumption of equal phase velocities. Such a discrepancy would likely lead to different liquid and vapor flow rates on the two sides of the interface, and one would have to determine that such a discrepancy would not significantly impact on the analysis.

The obvious way to minimize any such problems is to locate the interfaces only in subcooled or superheated regions. Given the planned applications for RETRAN/MINET, e.g., for nuclear plant coolant systems, it is very likely that most interfaces would be in areas of single phase flow. In fact, it would seem unlikely that a modeler would intentionally place the interface in a two-phase region -- given the known differences in modeling. Thus, we have assumed that such an interface is not allowed, rather than confront an awkward problem.

Establishing Calculation Sequences

It was decided that RETRAN would serve as the "host" code, and that MINET sub-drivers -- for input processing, steady-state calculations, and for transient calculations -- would be spliced into the RETRAN programming. This was primarily due to the modular structure of MINET, as the codes was designed with such interfacing envisioned. As a result, the MINET processing became embedded into the RETRAN input processing, steady state calculations, and transient calculations.

Input Processing

The RETRAN and MINET input files were unchanged, so an insertion to the RETRAN input processor programming was the principal change. In addition, a small input file indicating linkages was utilized, and proper adjustments were made to the coding. Essentially, the extra data is used to establish a one-to-one correspondence between a RETRAN boundary and the adjoining MINET boundary. This is discussed in greater detail under the heading entitled Programming the Interface.

Steady State

The steady state begins with a data initialization, including the loading of linkage information. If a RETRAN steady state initialization has been requested, RETRAN does an internal iteration until the convergence criterion has been satisfied, or the maximum number of iterations has been exceeded. Boundary condition data from the converged RETRAN state are then loaded into the data interface for MINET. If a RETRAN steady state initialization has not been requested, the user specified RETRAN data are loaded into the data interface for MINET.

The MINET steady state is then executed. The data from the converged MINET steady state are loaded into the data interface for RETRAN and the steady state calculation is considered completed.

This procedure has given good results in the cases examined thus far. If problems are found to arise in the future that are due to inadequate steady state convergence, the procedure can easily be modified to include outer iterations over the RETRAN-MINET pair.

Of course the user should resolve the steady state conditions for each code separately before trying to solve for the combined steady state.

Transient

With the MINET transient package inserted in the RETRAN transient time stepping loop, both codes advance conditions to the end of the time step. RETRAN actually determines the time step size, but MINET can take multiple internal time steps to reach the objective end-of-step time.

One of the codes has to step first, which means it uses beginning of step (k) conditions at the interface boundaries. Once this code has advanced conditions to the end of the time step, the other code can access advanced step (k+1) conditions at the interface boundaries. This is a decided advantage with thermal-hydraulic analysis, as the numerics consistently perform better with implicit differencing, primarily due to the stiffness of the momentum equation. Further, for the next step, the first code receives updated (abruptly) information (beginning of the new step) at the interface boundary, and this could prove troublesome to the calculations.

Given that the code that steps first does have more challenging boundary conditions (i.e., abruptedly changing), and that MINET is generally the more stable code due to (1) the integral momentum equation, and (2) the larger plant systems (BOP) simulated, we chose to step MINET before RETRAN. Thus, the current stepping process is as follows:

a. MINET steps to k+1 using interface boundary values at step k and MINET boundary values at k+1. Conditions at the interface boundaries (from MINET) are advanced to step k+1.

b. RETRAN steps to k+1 using interface boundary values at step k+1 and RETRAN boundary values at k+1. Conditions at the boundaries (from RETRAN) are advanced to step k+1.

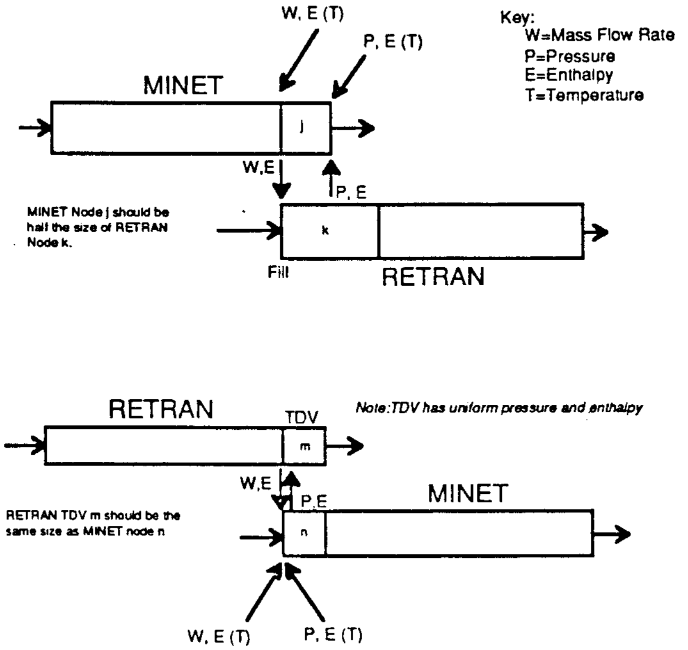
c. As an option, conditions at the interface boundaries can be examined, and an iterative step or a reduced in time step size could be implemented. To date, this has not been necessary. (All tests have indicated excellent stability.)

d. MINET would then step to k+2, with the process cycling back to Step a.

There are two possible interface boundary types, MINET Outlet to RETRAN fill (M-R) and RETRAN TDV to MINET inlet (R-M), as shown in Figure 3. In the R-M interface, RETRAN sends flows and temperatures to MINET and MINET returns pressures and temperatures. In the M-R interface, MINET sends flow and temperature to RETRAN and RETRAN returns pressure and temperature. As MINET always steps first, it sends advanced time boundary values to RETRAN, while RETRAN sends trailing values to MINET.

For the M-R interface, the linkage is very clear, as the MINET nodal interface lines up exactly with the RETRAN fill junction. If the last MINET node is one-half the length of the first RETRAN node, the pressure and temperature from RETRAN align

Figure 3. Local Nodalization Near Two Types of Interface Boundaries

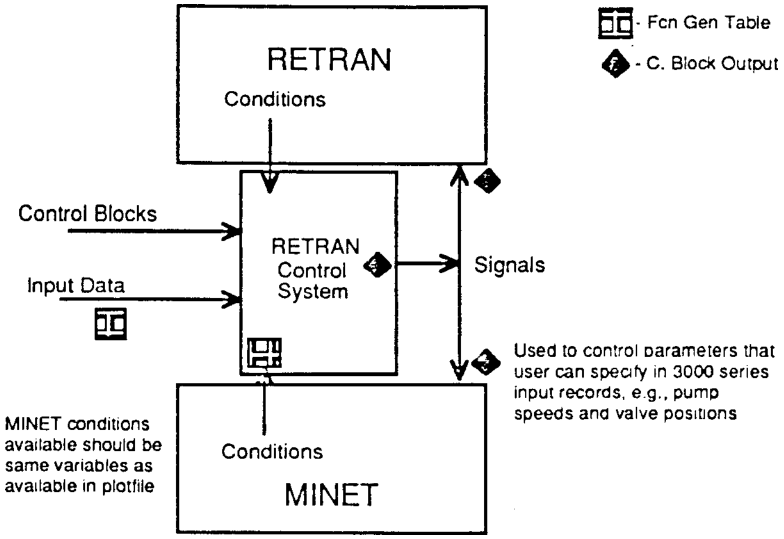


MINET Node j should be half the size of RETRAN Node k.

Note:TDV has uniform pressure and enthalpy

RETRAN TDV m should be the same size as MINET node n

Figure 4. RETRAN/MINET Control System Interface -Conceptual Design



Used to control parameters that user can specify in 3000 series input records, e.g., pump speeds and valve positions

MINET conditions available should be same variables as available in plotfile

Assumptions:

1) Can use Function Generator tables of the form: y(t) vs. t, with length at least 2 (vs. t is crucial)
2) Can specify Control Blocks with output that is not used by RETRAN (i.e., avoid error flags)

properly with MINET (see Figure 3). For the R-M interface, the RETRAN time-dependent volume boundary makes the situation more complex. It was necessary to exactly overlap the first MINET node with the RETRAN TDV. Thus RETRAN sends the TDV inlet junction flow and enthalpy to MINET, and MINET sends the corresponding junction pressure and enthalpy to RETRAN. Since the RETRAN TDV is assumed (within RETRAN) to have uniform pressure and enthalpy, utilization of MINET inlet values is appropriate.

The Control System Interface

Although not part of the original work scope for the project, a control system interface has recently become a priority item for development. The objective is to provide information regarding conditions within the MINET portion of the system to the RETRAN control system and to allow the user to control key MINET boundary conditions, e.g., pump speeds and valve positions, using the RETRAN control system. The challenge is to do this without giving RETRAN full access to MINET variables and without making major changes to either code library.

A tentative plan has been developed to forge the control system interface, and steps are being taken to confirm the viability of this approach -- which hinges on two assumptions, as shown in Figure 4. The first assumption is that the user can specify a y(t) versus time table via the function generator option for the RETRAN control system. If so, it should be practical to bring MINET transient data across to the RETRAN control system via the function generator tables, i.e., the interface would overwrite the dummy tables provided by the user. The second assumption is that it is not necessary for the output from a RETRAN control block to actually be utilized in constraining a variable within the RETRAN system. If this is true, we can construct RETRAN control blocks with the intention of taking the control block output across the interface to MINET.

PROGRAMMING THE INTERFACE

The general objectives of programming the interface were two fold:

1. Create a working interface between RETRAN and MINET.
2. Enable user specified separation of the RETRAN code portion from the MINET code portion.

The first objective was mandated by ESEERCO's desire to couple the computationally intensive RETRAN code with the flexibility of the MINET code to handle the balance of plant for reactor systems.

The second objective was for flexibility of programming and testing the interface of the combined codes. It also has the added effect of forcing the separation of the two codes (except at the interface) and enables easy integration of new versions of either RETRAN or MINET into the RETRAN-MINET combined code.

Modularity of the Interface

It was not desirable to make any major structural changes to either RETRAN or MINET in constructing the interface to the codes. Such an approach would be a very risky undertaking, and would likely lead to a loss of confidence by the users of the RETRAN/MINET Composite Code. In addition, any major structural changes would make it difficult to update either the RETRAN portion or the MINET portion if the stand-alone versions of either code was improved at some future date. Consequently, a modular approach was taken in combining the codes.

In the modular approach, RETRAN was chosen as the driver module for the RETRAN-MINET code. RETRAN determines whether the Steady State calculation will be performed and sets the time step for MINET to follow during the transient calculation. MINET is called to advance to the next time (determined by RETRAN), and then RETRAN advances to that time.

The structure of the RETRAN/MINET is indicated in Figure 5. Note that only three RETRAN subroutines are directly impacted, i.e., RMAIN, STSTAT, and TRAN. None of the MINET subroutines were altered, although the main program ("MINET") was effectively displaced in the calculational procedure. Of the nine new subprograms (either subroutines or functions) only three, STLINK, FILLM, and TDV are of significant length and complexity.

Interface Coupling Boundaries and Associated Data

Two types of RETRAN boundary nodes were chosen to make the interfacial links to the MINET code.

a. FILL - RETRAN Time Dependent Fill B.C. (flow into RETRAN)

b. TDV - RETRAN Time Dependent Volume B.C. (flow out of RETRAN)

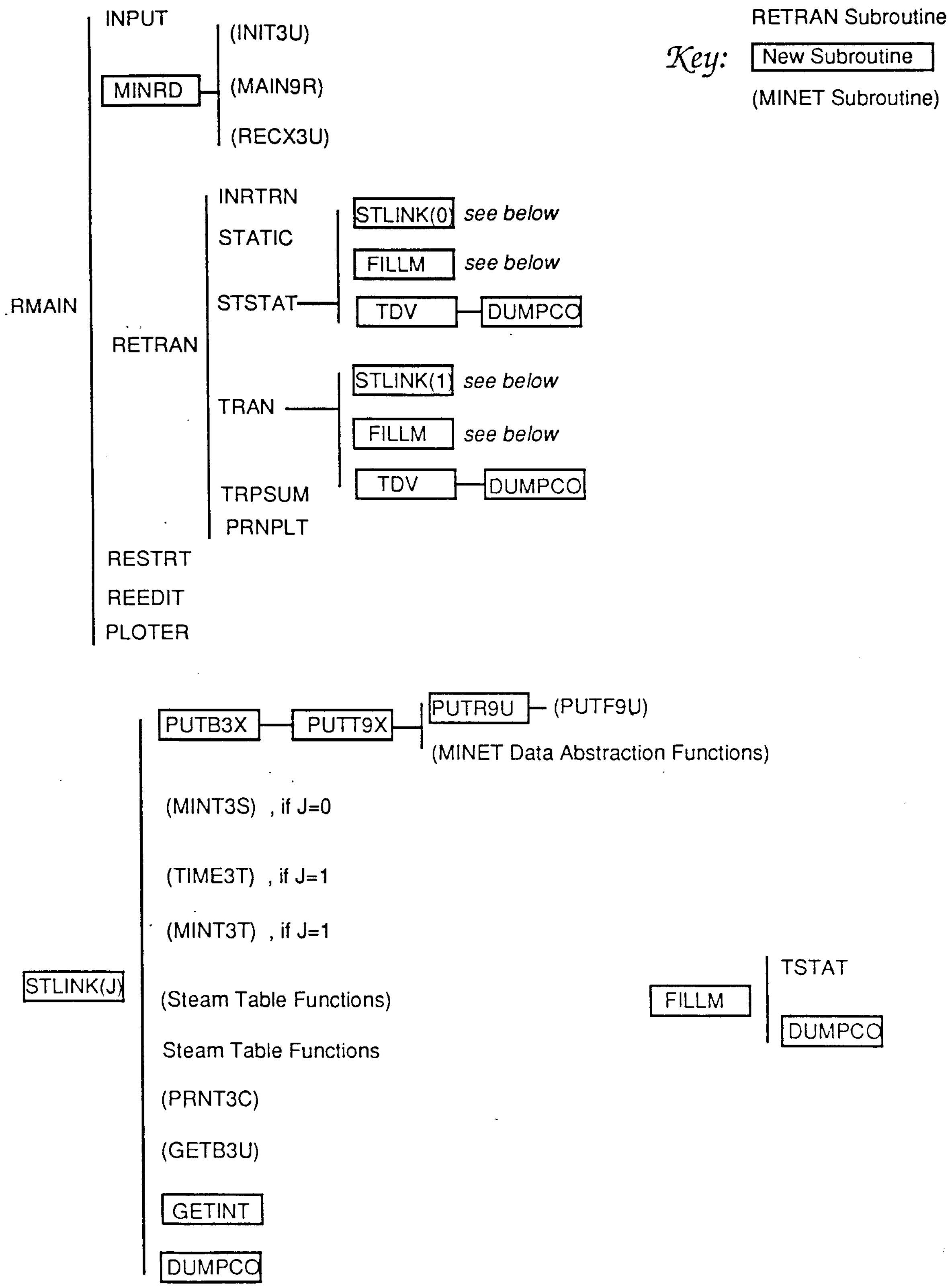


Figure 5. Structure of RETRAN/MINET Composite Code

At each of the boundary types, either FILL or TDV, flow reversal is permitted.

Normally, the RETRAN User inputs some time dependent tables at these nodes to specify the boundaries of the RETRAN problem. Similarly, the MINET User would input some time dependent tables to specify the boundaries of the MINET problem. In the coupled RETRAN-MINET code, these former boundaries to the stand-alone RETRAN code and the stand-alone MINET code become the transfer nodes for RETRAN and MINET to exchange information (e.g., thermodynamic state variables that the separate RETRAN and MINET codes need to perform their respective parts of the combined calculation), as indicated in Figure 3.

The additional data required to define the interface(s), as well as thermal-hydraulic conditions at the interface(s), are stored in common block /MINRAN/. This common block is used primarily as a data buffer, with the RETRAN data structure and the MINET data structure unchanged. Thus, information is passed between the codes through this buffer during RETRAN/MINET Composite Code execution.

Immediately prior to the calls to MINET all common boundary data needed by MINET is sent from RETRAN. Immediately after the return from MINET, the RETRAN boundary values are updated by new values from MINET.

Preparation of Input Data

The input processors of RETRAN and MINET have not been changed. The user prepares a separate input deck for RETRAN and a separate input deck for MINET that covers their respective parts of the calculation as if both codes were operating as stand-alone modules. This means that time dependent boundary input tables must be provided for both codes, even though this data will not be used at the interface between RETRAN and MINET. Each of these tables must have two or more time entries. The data in these tables can be any dummy data that will get through the error checking routines in the respective input processors of RETRAN and MINET.

A third input deck must be prepared to indicate the coupling between the RETRAN and the MINET code. This deck is extremely small and has only six variables to identify where the links between RETRAN and MINET are to occur. Usage of the three input decks, as well as reassignment of MINET input/output device numbers, are indicated in Figure 6.

Figure 6. RETRAN/MINET Composite Code Configuration and I/O Device Utilization

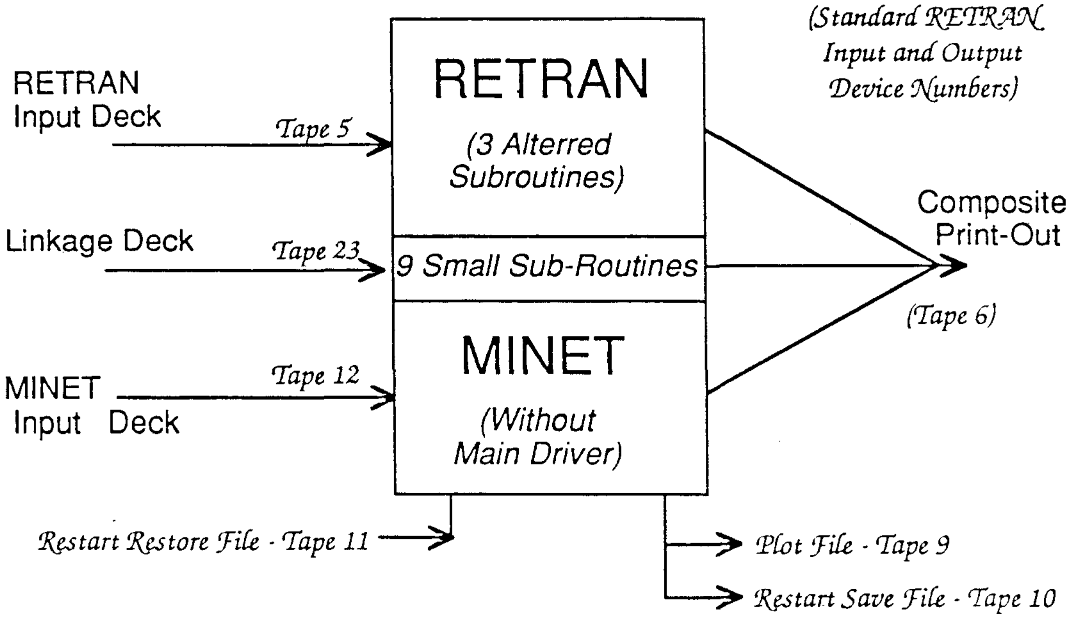
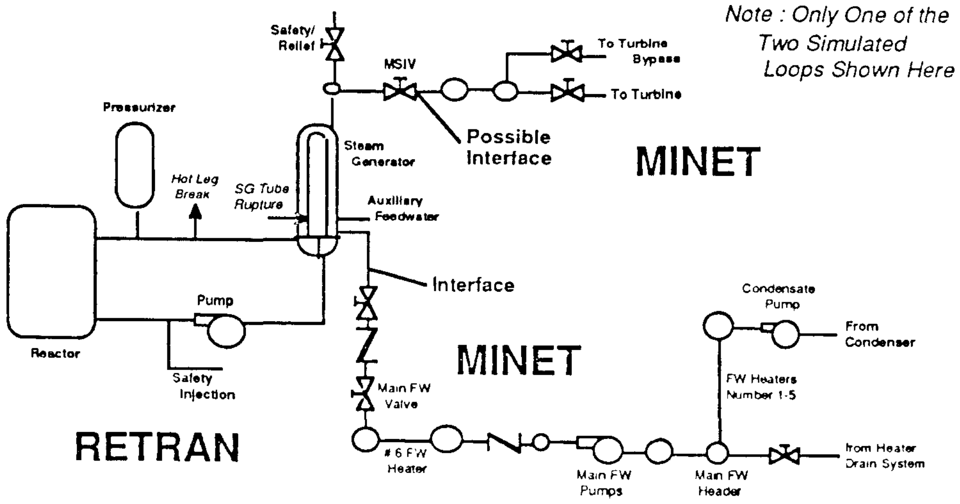


Fig. 7. RETRAN/MINET Representation of H.B. Robinson


Note : Only One of the Two Simulated Loops Shown Here

TESTING THE RETRAN/MINET COMPOSITE

Once it was determined that the RETRAN/MINET composite executed correctly in tandem, and that data transmission was correct, we proceeded to stability testing. Several runs were made. We observed both pressure pulses and flow rates being transmitted from node to node and from code to code exactly as intended. One interesting development was the observation of an enthalpy wave overshoot caused by the combination of a pressure wave pulse and the donor-cell differencing used in both the RETRAN and MINET energy equations. This overshoot was initially a surprise, but we soon recognized the nature of the problem, and developed a test of our theory. We ran each code separately with pressure pulses and obtained nearly identical enthalpy overshoots from both. Thus, the composite code is exactly replicating this behavior, which is little more than a numerical annoyance and causes no significant error in the analysis (small fractions of a degree, for example).

The composite code was tested with two-pipe problems. Different options in the interface were exercised. The boundary conditions were varied to investigate the stability of the composite code. Even for the step change in the boundary conditions, the interface did not contribute any instability to the predicted flow parameters. The next stage of validation was to compare the composite code prediction for a plant transient with another code (RELAP5) calculation.

The validation study consisted of three computer code calculations for two different transients in the H. B. Robinson plant. One set of calculations for the two transients, using RELAP5, was published (7), and we are simply using "data" from plots in that report. A second set of calculations is performed using the RETRAN/MINET Composite Code, with the RETRAN deck adapted from a previous study (8). The third set of calculations extends the RETRAN modeling to the condenser, thereby covering the same portion of the plant as is represented in the RETRAN/MINET simulation. This third set of calculations, sometimes referred to as the RETRAN/RETRAN model, was necessitated by the coarseness of the available RELAP5 output and provides us with a clean comparison between two calculations and a good comparison of computing speeds.

Hot Leg Break

The hot leg break transient involves a small break in the hot leg that connects with the pressurizer, as indicated in Figure 7. A scram follows shortly thereafter (along with turbine valves closing), with reactor coolant pumps continuing and feedwater flow ceasing later.

Results of the calculations are shown in Figures 8 through 11. In the case of pressurizer level, shown in Figure 9, the RELAP5 results were provided on a 200 second plot, so the curve labeled RELAP5 in Figure 9 should be a fair representation of the original calculations. For Figures 8, 10 and 11, the RELAP5 results were inferred from the first 1% of the 3000 second plots and, therefore, only approximate what was likely to have occurred in the analysis.

As a result of the pipe break, the pressurizer pressure (Figure 8) begins to fall quickly. At just over seven seconds, the reactor trips in both the RETRAN and RETRAN/MINET calculations, causing the fall in pressure to accelerate. Reportedly, the RELAP5 control system model did not scram the reactor until 16 seconds. Given the agreement in the calculations, particularly the two involving RETRAN, the composite code results look good.

The trends in Figure 9 for the liquid level in the pressurizer are nearly identical to those noted for the pressurizer pressure. There are some differences between the RETRAN/MINET and RETRAN levels evident in Figure 9. However, these differences begin too early (2 seconds) to be attributable to the interface portion of the calculations. Instead, we believe the differences between the RETRAN/MINET and RETRAN result are due to the failure of the RETRAN steady-state processor to fully resolve inconsistencies in user-specified initial conditions when the representation extends to the condenser. (There is an automatic fine tuning "bias" algorithm, designed for the more common RETRAN applications, but that fails to perform correctly when the model is extended through the feedwater system.)

The calculated steam generator pressures are shown in Figure 10. The fine scale makes the 1 psi difference between RETRAN and RETRAN/MINET appear to be significant, but the more important fact is that 1 psi difference is maintained consistently through the transient. This may be the most significant plot for this case, as it directly reflects the feedwater flow and temperature history. If the RETRAN/MINET interface was performing incorrectly, the result would likely show up (quickly) in the steam generator pressure.

The steam generator level, shown in Figure 11, does not change significantly in the first 16 seconds of this transient. In fact, all three calculations show identical

Fig. 8. Pressurizer Pressure for H.B. Robinson Hot Leg Break Event

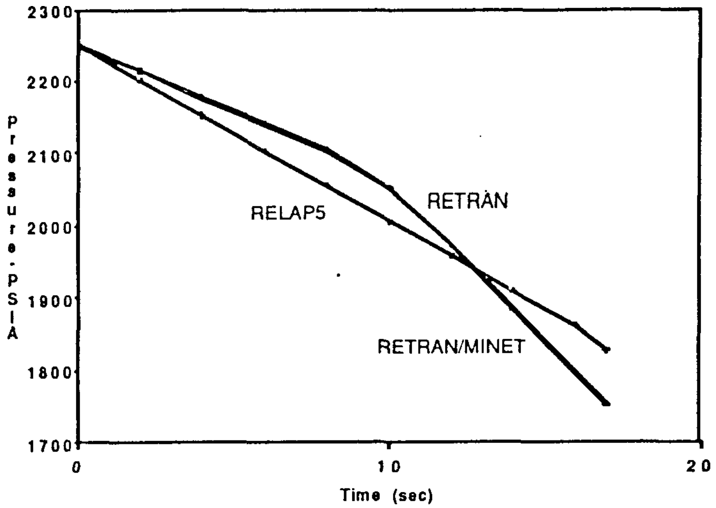


Fig. 9. Pressurizer Level for H.B. Robinson Hot Leg Break Event

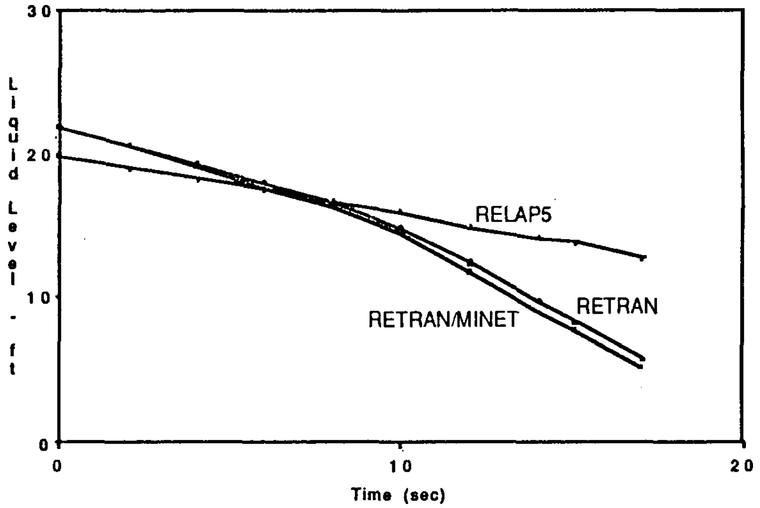


Fig. 10. Steam Generator Pressure for H.B. Robinson Hot Leg Break Event

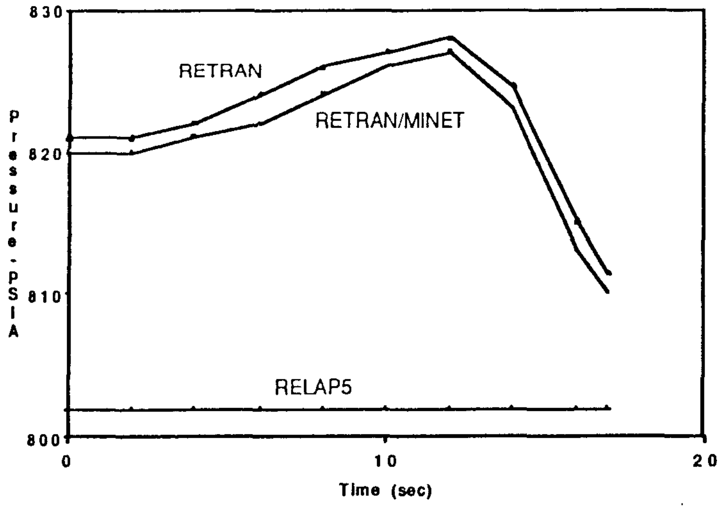
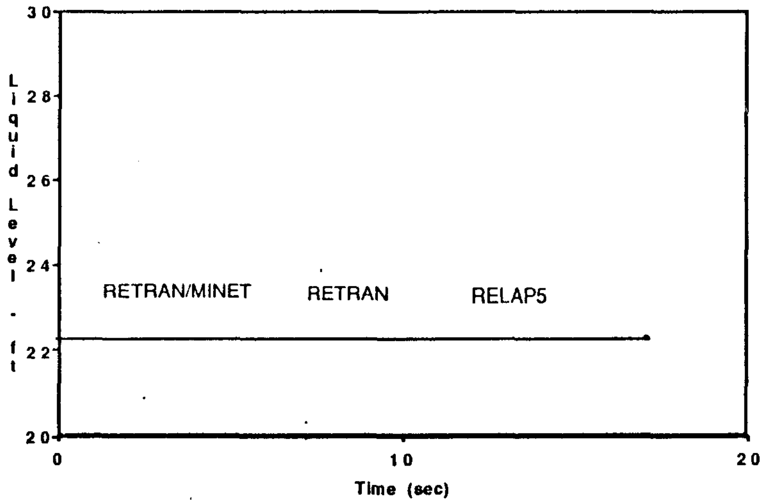


Fig. 11. Steam Generator Level for H.B. Robinson Hot Leg Break Event



levels through the transient. If there were errors in the RETRAN/MINET interface, they would likely impact on the steam generator liquid level.

Steam Generator Tube Rupture

The second transient, a steam generator tube rupture at full power (see Figure 7), was simulated to 80 seconds. Results from this analysis are shown in Figures 12 through 15.

The pressurizer pressure, shown in Figure 12, decreases as primary system water leaks into the secondary system, through the broken steam generator tube. The decrease in primary system inventory is also reflected in the pressurizer liquid level, as shown in Figure 13. Until 76 seconds, all three calculations give very similar results. At 76.2 seconds, a reactor trip is generated in the RETRAN/MINET calculation, coming one second earlier than the trip in the RETRAN calculation (it comes even later in the RELAP5 calculation). As a result, the rate of change in key parameters is somewhat different just before 80 seconds.

The calculated steam generator pressures and levels are shown in Figures 14 and 15. The RETRAN and RETRAN/MINET result are again in close agreement. Disagreement with the RELAP5 results likely traces to slightly different boundary conditions and difficulty in interpreting the coarse RELAP5 plots.

Conclusions from Robinson Study

Taken together, these calculations provide strong support for our contention that the RETRAN/MINET is performing correctly. Differences between the RETRAN and RELAP5 calculations are not very significant because (1) it is known that modeling differences in RETRAN vs. RELAP5 consistently lead to disagreements between the predictions from these two codes, and (2) differences in control system models and boundary conditions contribute to the discrepancies.

We also examined the performance of the RETRAN/MINET Composite Code with respect to CPU time on the Power Computing CYBER-860 machine. When we ran RETRAN for just the RETRAN portion of the system indicated in Figure 7 (no BOP), 0.63 CPU seconds were used per time step. In the RETRAN/MINET composite calculation of the entire system, 0.97 CPU seconds were used per time step, indicating that MINET added about 0.34 CPU seconds per step. When we extended the RETRAN representation to the condenser, 1.06 CPU seconds were needed per step, implying the RETRAN model of the BOP required an

Fig. 12. Pressurizer Pressure for Robinson Steam Generator Tube Rupture Event

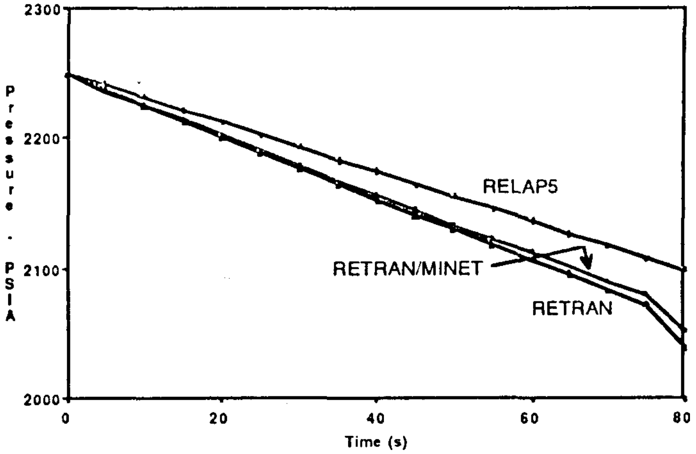


Fig. 13. Pressurizer Level for Robinson Steam Generator Tube Rupture Event

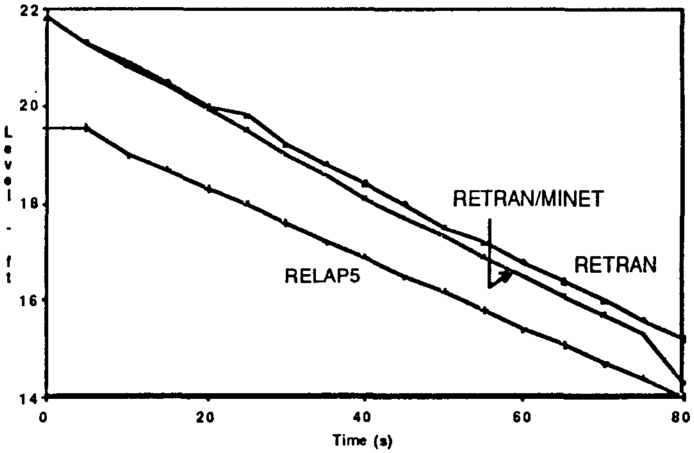


Fig. 14. Steam Generator Pressure for Robinson Steam Generator Tube Rupture

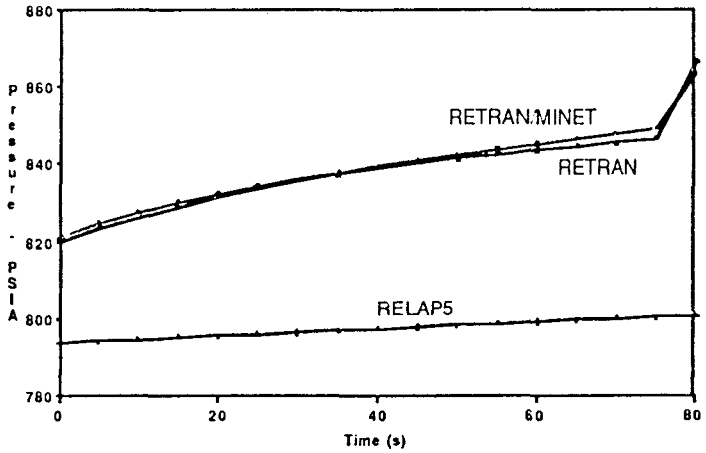
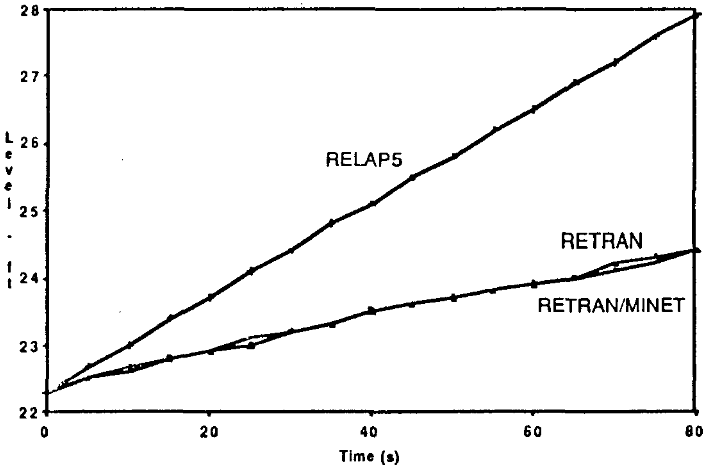


Fig. 15. Steam Generator Level for Robinson Steam Generator Tube Rupture



additional 0.43 CPU seconds per step. Thus, for this fairly simple application, MINET simulated the BOP about 20% faster than RETRAN (also, RETRAN was difficult to initialize when the model was extended). It should be noted that much greater improvements (than 20%) are expected when larger portions of the complex BOP system are simulated.

APPLICATIONS

As the current version of the RETRAN/MINET Composite Code has only recently been completed and documented, code applications are only beginning. In this section, we discuss a list of potential applications of the RETRAN/MINET Composite Code, as envisioned at the outset of the project and as considered today. We also briefly describe the ongoing effort at NYPA, with BNL assistance, to simulate the FitzPatrick Plant.

Composite Code Applications

The RETRAN/MINET Composite Code is a very powerful and versatile tool for the analysis of plant systems behavior. Several possible applications are suggested below, although this list is far from being complete.

Safety Analysis. With the local detail provided in the RETRAN representation and the extensive system representation that is possible when MINET is applied, a wide variety of postulated events can be analyzed. One event requiring such analysis would be a small break loss-of-coolant accident, such as the event at Three-Mile-Island (TMI). The proper analysis of the March 1979 TMI event requires: 1) a detailed two-fluid representation of the primary loop (PWR), 2) an extensive representation of the system -- including the BOP, where the event began, and 3) representation of the emergency core cooling system (ECCS), which was used intermittently during the transient.

Audit Calculations. Through the plant lifetime, various changes are made either in the reactor core (e.g., refueling) or plant system (e.g., steam generator tube plugging), that require re-evaluation of the plant system response to postulated events. Often the vendor will perform some of this analysis, but the utility must at least audit these calculations. The RETRAN/MINET composite code can provide the utilities with analytical capabilities in excess of those currently possessed by the vendors.

Parametric Studies and Stability Analysis. During the course of the plant lifetime, the utility must make several decisions regarding modifications to the plant systems. Parametric studies and stability analyses are necessary to determine the impact of removing a feedwater heater from service, for example.

Simulator Assessment. It is widely accepted that training simulators accurately represent the true operating characteristics of the power plant systems only during anticipated and slightly off-normal conditions. Because of modeling simplifications, these simulators will misrepresent the system behavior during accident conditions. The degree to which these accident simulations are in error should be assessed, and the RETRAN/MINET composite code is currently the only viable candidate for some of this analysis.

Plant Start-up Analysis. During plant start-up testing, various anomalies can be anticipated. A reliable computing tool, such as RETRAN/MINET, is needed in order to determine whether variations from anticipated behavior are significant, and whether further investigation and/or system modifications are necessary.

Emergency Response Guidelines. Prescribed operator actions must be carefully evaluated using analysis of the plant response during various "emergencies". In cases where significant portions of the plant are involved, a code such as RETRAN/MINET would have to be used.

Pressurized Thermal Shock Evaluation (9). The hypothesis is that the thermal transient resulting from various system shutdown events could result in an overly rapid cooldown of the reactor pressure vessel, leading to a weakening of the vessel itself (particularly for the older vessels). The analysis requires a more detailed representation of the balance of plant than had been the previous practice. Computer running times and costs incurred using LOCA codes were quite high, even with simplified BOP representations. The RETRAN/MINET composite code should be able to perform the same analysis with far greater speed and efficiency and with a more complete representation of the system.

Control System Studies. The power plant control systems are designed to smoothly and efficiently operate the facility under steady state and operational transient conditions. Any alterations in the balance of plant components and/or configuration are likely to alter the plant response to transients, and, under some conditions, modifications to the control system setpoints, etc., should be considered.

Support of Risk Assessment. An inherent part of probabilistic risk analysis is the anticipation of the system response to postulated failures. A flexible system simulation package is an essential part of such work.

Identification of Accident Signatures. As was so well demonstrated at TMI-2 in 1979, the inability of the reactor operators to recognize an event is progress can lead to unacceptable results. By using a powerful analytical tool, such as the RETRAN/MINET composite code to simulate postulated events ahead of time, one can hope to provide the reactor operators with an "accident signature" that can be recognized, and thereby facilitate mitigation of the event. These accident signatures would likely become part of the data base for future "expert systems".

Assessment of New Operating Procedures. During the course of a power plant lifetime, there will be various changes in prescribed operational procedures, in response to equipment modifications or changes in the perception of the best way to respond to various conditions. Any such changes could impact on the system response to postulated events, and should be investigated using a code such as RETRAN/MINET.

BWR ATWS Analysis. We believe that the 1D neutron kinetics in RETRAN is sufficient to represent a "symmetric" ATWS, such as one anticipates in response to a simple failure to scram after any given initiator. The MINET code can be used to represent the remainder of the plant in whatever detail necessary to determine 1) the flow rates and temperatures for the water entering the reactor vessel, 2) the pressures in the system, and 3) the conditions in key sectors of the plant, such as the pressure suppression pool.

"Inverse" Applications, such as Water Hammer. Because RETRAN is typically used to analyze the reactor and adjacent systems, and MINET is often applied for balance of plant simulation, one generally considers composite code applications that are consistent with this approach. However, an "inverse" application is entirely possible and could be quite desirable for analyzing a transient like "water hammer". In such an "inverse" application, MINET could be used to simulate a large portion of the plant (including the reactor), and RETRAN could be used to focus on local behavior in part of the feedwater train, for example.

Application to FitzPatrick

NYPA, with assistance from BNL, has developed an initial MINET representation of the FitzPatrick's BOP model, as illustrated in Figures 16 and 17. Performance of the composite code has been tested by running a null transient and a loss of feedwater heater transient, as summarized below.

In this study, a point kinetics core model was used. There were slight modifications to the plant's existing RETRAN nodalization, as indicated with Volume #100, and an additional junction was added between Volume #100 and Volume #22. The MINET model represents Fitzpatrick's BOP, and consists of a network of 9 volumes, 3 pumps, 9 valves, 6 heaters, 20 pipes, and 1 inlet and 3 outlet boundaries. Since the steam lines and turbine were included in the RETRAN deck, the inlet boundary for MINET mode was specified as the outlet of the condenser. Three pumps, the condensate, condensate booster, and feed pumps, were represented using component specific characteristic curves and MINET's built-in pump models. Six feedwater heaters were modeled as simple heated pipes with appropriate heating rate for each of them, in order to represent extraction steam energy.

The interface was from MINET outlet to RETRAN fill, i.e., (M-R) type, in which the last MINET volume was interfaced with feedwater inlet junction (fill junction 47 in Figure 17 for the RETRAN model). At this M-R interface, MINET calculated flow and temperature are passed these to RETRAN, and RETRAN returns pressure and temperature to MINET.

The results of a 10 second null transient were very stable. Having assured that no steady-state-transient mismatches occurred, we proceeded to analyze the loss of feedwater heater transient. The sixth heater was tripped in the first second of the 60 second transient, in order to evaluate the time lag in colder water injection incidents. The transient resulted in cooler feedwater entering the core and a power increase of approximately 10%, as shown in Figures 18 and 19. A very slight increase in reactor temperature was also predicted.

More detailed representations of the FitzPatrick feedwater train are in testing and will be implemented shortly. These models include detailed feedwater heater models with subcooled regions (drain coolers) and cascades from the extraction lines to the condenser.

Figure 16. Initial RETRAN/MINET Composite Code Representation of Fitzpatrick Plant

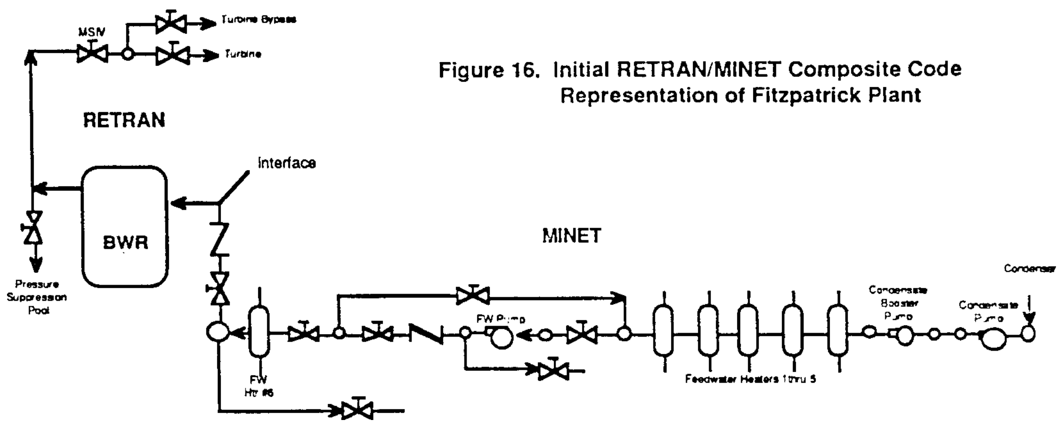


Figure 17. RETRAN Nodalization for J.A. FitzPatrick Representation

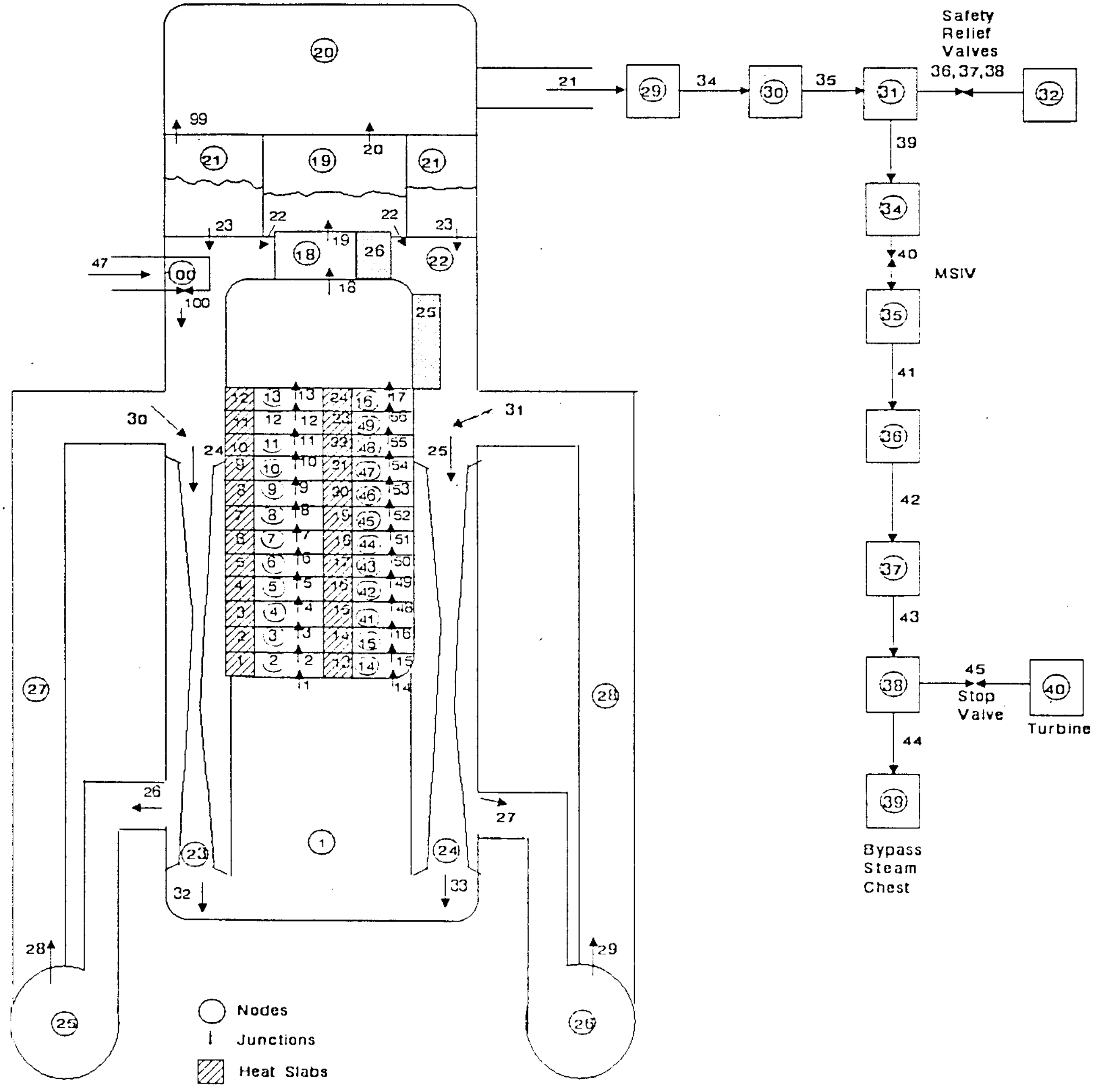


Figure 18. Relative Power for Unscrammed Loss of FW Heater #6, As Calculated by RETRAN/MINET

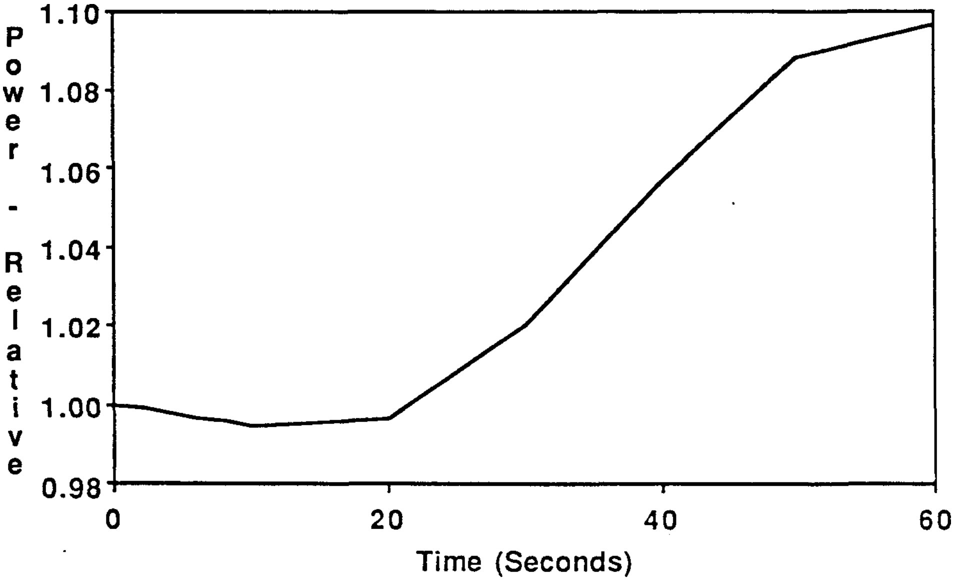
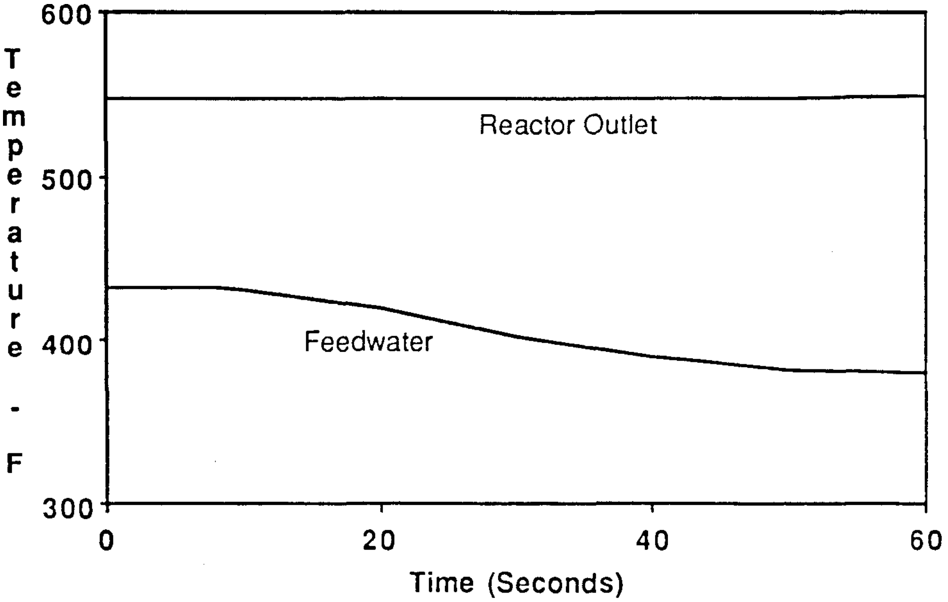


Figure 19. Calculated Reactor Outlet and Feedwater Temperatures for Unscrammed Loss of FW Heater #6



SUMMARY AND CONCLUSIONS

The project to interface the RETRAN and MINET computer codes was undertaken in order to combine the detailed modeling capabilities available in RETRAN with the MINET capabilities in representing large and complex systems. The result is a composite computer code that can model the reactor in detail and yet represent large portions of the balance of plant, as well as safety systems.

As both RETRAN and MINET have extensive validation bases, the principal task in validating RETRAN/MINET was in confirming proper performance at the interface(s). Much of this work was routine and involved simple hand calculations to confirm proper data transmission, as well as making several runs specifying various input combinations. The ultimate validation study for two postulated transients postulated for the H.B. Robinson Plant provided a direct inter-code comparison against RETRAN (alone) and RELAP5. While differences in the RELAP5 analyses made absolute comparison impractical, comparison to the RETRAN (alone) results provided strong indications that the RETRAN/MINET composite code is performing properly.

An initial RETRAN/MINET application to a postulated unscrammed loss of feedwater heater event illustrates the potential impact of the BOP on the reactor, i.e., a 10% power increase in response to colder feedwater temperatures. More detailed representations of the BOP are being developed, although these efforts have been slowed by the relative scarcity of detailed design data. In some cases, MINET steady state calculations have revealed design details about the feedwater heaters (integral drain coolers) and the cascade patterns that were not apparent in available drawings. This work is continuing at this time.

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