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MINET VALIDATION STUDY USING STEAM GENERATOR TRANSIENT DATA

Gregory J. Van Tuyle

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Abstract

Three steam generator transient test cases, that were simulated using the MINET computer code, are described, with computed results compared against experimental data. The MINET calculations closely agreed with the experiment for both the once-through and the U-tube steam generator test cases. The effort is part of an ongoing effort to validate the MINET computer code for thermal-hydraulic plant systems transient analysis, and strongly supports the validity of the MINET models.

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Acknowledgement

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1. INTRODUCTION

MINET (Momentum Integral NETwork) is a computer code developed for the transient analysis of intricate fluid flow and heat transfer networks, such as those found in the balance of plant in power generating facilities [1]. It can be utilized as a stand-alone code, or interfaced to another computer code for concurrent analysis. Through such coupling, a computer code currently limited by either the lack of required component models or large computational needs can be extended to more fully represent the thermal hydraulic system, thereby reducing the need for estimating essential transient boundary conditions.

Validation of the MINET computer code is an ongoing process, with several formal and informal studies now completed. Two of the more significant of these studies were the simulation of a 44 minute EBR-II plant transient [2,3], and the simulation of an 8 minute helical coil heat exchanger test transient [4].

In the validation study detailed in this report, transient test data from a once-through and a U-tube steam generator are used to test the MINET models, particularly those for simulating heat exchangers. All of the test information used in this effort and presented in this report is generally available [5,6,7].

Transient data for an Integral Economizer Once-Through Steam Generator (IEOTSG) [8,9] was obtained by Babcock & Wilcox at their test facility in Alliance, Ohio. Two of these transients were simulated using MINET, one a step reduction in feedwater flow rate and the other a step reduction in steam flow rate.

Test data for a U-Tube Steam Generator was obtained during startup testing of Unit 1 of the Donald C. Cook Nuclear Station [10]. The transient that was simulated using MINET was a turbine trip while the plant was operating at full power.

2. MINET

The method employed in the MINET code [1] is a major extension of a momentum integral method developed by Meyer [11]. 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 ex-hangers. Each network is composed of segments, volumes and boundaries. Segments contain one or more pipes, pumps, turbines, heat exchangers and valves, each of which is represented using one or more nodes. Volumes represent voluminous components and significant flow junctions. Volumes and boundaries are connected by segments.

While the momentum integral network method forms the basis for the MINET code, several component models, called "modules", are used to determine key parameters in the basic conservation equations. These parameters include the heating term in the energy equation and the pressure loss term in the momentum equation.

Segment modules include pipes, pumps, turbines, valves and heat exchangers. The pump and turbine models are based on known performance at some reference condition, and utilize minimal geometric detail. The valve model is based on a user input loss coefficient and the flow area through the valve opening. If choking is indicated by the extended Henry-Fauske, Moody, or isentropic models, the flow rate across the valve opening is limited accordingly. Heat exchangers are treated as two pipes linked via heat transfer through the tube wall. The heat transfer from the tube to the fluid is calculated at each time step and used in the nodal energy equations. A fixed mesh nodalization is used, with any change in heat transfer regime within nodes factored into the nodal heat flux calculation, i.e., heat flux is piecewise averaged.

Volume modules are used to represent voluminous system components, as well as locations in a network where pressure must be accurately monitored, e.g., significant flow junctions. For example, one would use one or more volumes (connected by short, wide pipes) to represent a pressurizer or steam drum, or for a header between flow paths of unequal resistance. Currently, one can specify the geometry as a box shape, a vertical or horizontal drum, or a partial box or drum, as well as the operating conditions, i.e., whether the contents are distributed homogeneously or, if saturated, divided into liquid and vapor regions.

External interfaces to the MINET system representation are provided through the boundary modules. At each boundary, two conditions are required: 1) pressure or flow, and 2) temperature, enthalpy, or quality (if saturated). These are supplied by the user or by another computer code. Generally, the temperature parameter will be used in the MINET calculations only when flow is entering the system. MINET will always calculate the unspecified flow/pressure parameter and the temperature of the flow exiting the system.

In addition to the basic MINET method and the supporting component models, various constitutive relations are needed for fluid properties and heat transfer. Currently MINET contains properties and correlations for water/steam, air, sodium, and eutectic NaK.

Because of the complexity introduced by phase changes, the package of functions for water and steam is the most extensive. The property functions are based on polynomial fits of the 1967 ASME steam tables, and are accurate between .7 KPa and the critical pressure. The heat transfer correlations include those for subcooled convection, subcooled nucleate boiling, forced convection vaporization, film boiling, superheated convection, and filmwise condensation.

The MINET code is relatively small and fast running, due to modular programming, careful data structuring, and an underlying numerical method that allows a large problem to be broken down into several small ones. In addition, steps have been taken to maximize the range of problems that can be analyzed, as well as the potential for concurrent analysis, i.e., with another computer code.

The MINET input processor reads in a deck of free-format input records, and temporarily stores the data using data abstractions. It then processes the data, linking the various components into segments and networks. The data is then organized according to computational module number, segment number, and network number, and loaded into the principal data container.

The steady state calculation is a four step iterative process. First, energy transfer rates throughout the system are checked against boundary conditions, and any required changes will be made through energy adjustment factors. Second, the adjusted energy transfer rates will be used to determine segment, volume, and boundary enthalpies in each network. Third, pressure losses will be evaluated for every segment in each network, for current flows and enthalpies. During this step, the heat exchangers must be initialized, with an area correction factor used to resolve any discrepancies between the required energy transfer rate and that indicated by the heat transfer correlations. Fourth, the segment flow rates and volumes and inlet boundary pressures are adjusted. At this point, if all the system enthalpies are not converged (from Step 2), the process is repeated, starting again at the first step.

The transient calculations are based on the momentum integral network method described earlier. Adjustment factors determined during the steady state calculations are applied consistently in the transient computations. Transients are driven by changes at the boundaries, via the pump and turbine speeds or valve positions, and through the heat sink term in non-heat exchanger modules. All of these parameters can be controlled through user-input value vs. time tables. Alternately, pumps and turbines can be tripped and coasted down and valves can be tripped open and closed in response to pressure (safety/relief) or flow (check). A compatible generic control system is planned, although not currently available.

3. THE STEAM GENERATOR

The steam generators used in current pressurized water reactor (PWR) designs are of central importance to overall system transient behavior, as they provide thermal linkage between the primary and secondary systems. Present PWR designs use either once-through or U-tube steam generators (OTSGs or UTSGs). These basic types differ significantly in both steady-state and transient operating characteristics. The most pronounced differences involve the generation of superheated steam in OTSG designs, and the recirculation flow in UTSG designs. Analysis of either type of steam generator in general requires modeling of complex two-phase flow and heat transfer phenomena within the framework of basic conservation equations for fluid flow and heat conduction. The transient behavior of the secondary liquid in the heat exchanger region may depend significantly on the compressibility and thermal expansion of water and steam.

3.1 ONCE-THROUGH STEAM GENERATOR [12]

The Babcock and Wilcox OTSG units produce superheated steam from subcooled feedwater for use in PWR plants. The steam generator design, as shown in Figure 1, is based upon a tube-and-shell, counter-flow heat exchanger with straight, vertical tubes used for primary flows. Reactor coolant flows downward through approximately 16,000 tubes and transfers heat to the shell side for generation of steam. The primary (reactor coolant) side of the steam generator includes the hemispherical inlet and outlet heads, tubesheets, and inner tube surfaces. The secondary coolant is contained in the shell side of the steam generator, which is bounded by the shell, tubesheets, and outer tube surfaces.

The original OTSG design for Babcock and Wilcox PWR plants uses a bypass steam flow for contact preheating of feedwater. This original design has since been modified by eliminating the bypass-flow-feedwater heating and using the lower tube bundle as an integral economizer (IE) region. The IEOTSG design increases steam production compared to the original OTSG design by increasing the overall heat transfer rate in the steam generator unit. IEOTSG units are used in the current Babcock and Wilcox NSSS [13].

The heat transfer mechanism for the primary side of OTSG designs is subcooled forced convection along the entire heat exchanger length. During normal operations the secondary side of the IEOTSG may be divided into the following heat transfer regions: subcooled convection, subcooled nucleate boiling, forced convection vaporization, film boiling and superheated convection.

Babcock and Wilcox have conducted experiments on a 19-tube IEOTSG test facility, in order to simulate performance of the full scale units. Results of these tests are described in an internal B&W report [14], which was utilized in a previous code (TRANSG) validation effort that has since been reported in detail [5,6,7]. The B&W report provides data for 35 transient tests of step changes in steam flow rate, feedwater flow rate, or primary flow rate at various power levels. The data include initial and final steady-state conditions, including the secondary temperature distributions, and transient plots of: steam outlet temperature, pressure, and flow rate; feedwater temperature and flow rate; primary inlet temperature, pressure and flow rate and: primary outlet temperature.

3.2 U-TUBE STEAM GENERATORS

U-tube steam generator designs are used in Westinghouse and Combustion Engineering PWR plants. A schematic diagram of a Westinghouse Series 51 U-tube steam generator is shown in Figure 2.

The Series 51 UTSG is a natural circulation flow steam generator, basically composed of a steam dome region, a downcomer, and a vertical tube-and-shell heat exchanger with 3388 nested U-tubes. The primary side of the UTSG includes inlet and outlet plena and the inner tube surfaces. A partition plate divides the lower hemispherical head into the inlet and outlet plena. Reactor coolant enters the steam generator inlet plenum through the primary coolant inlet nozzle. In the tube bundle region, reactor coolant flows inside the U-tube first upward and then downward. The coolant exits from the outlet plenum through the outlet nozzle.

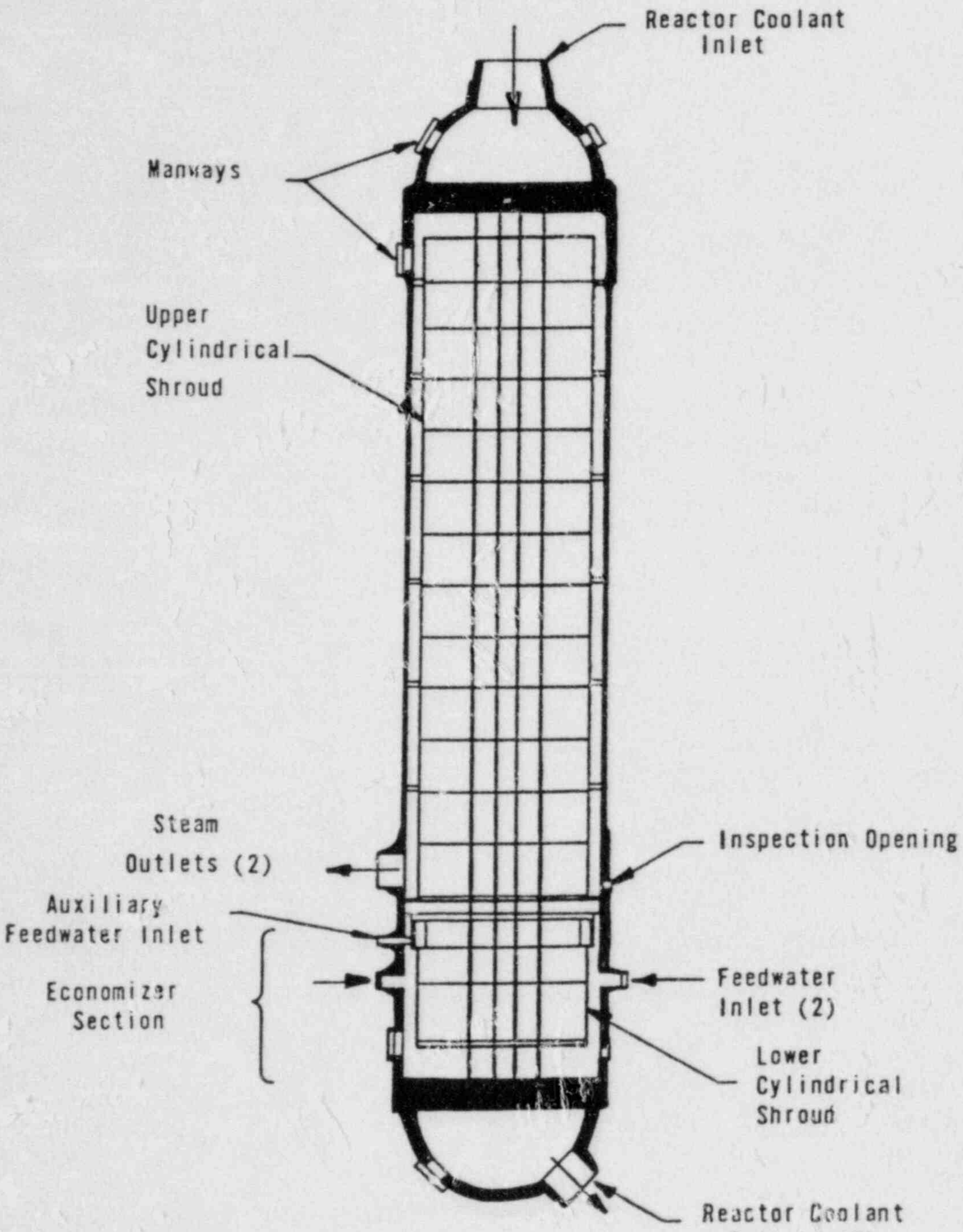

Figure 1.' Integral Economizer Once-Through Steam Generator.

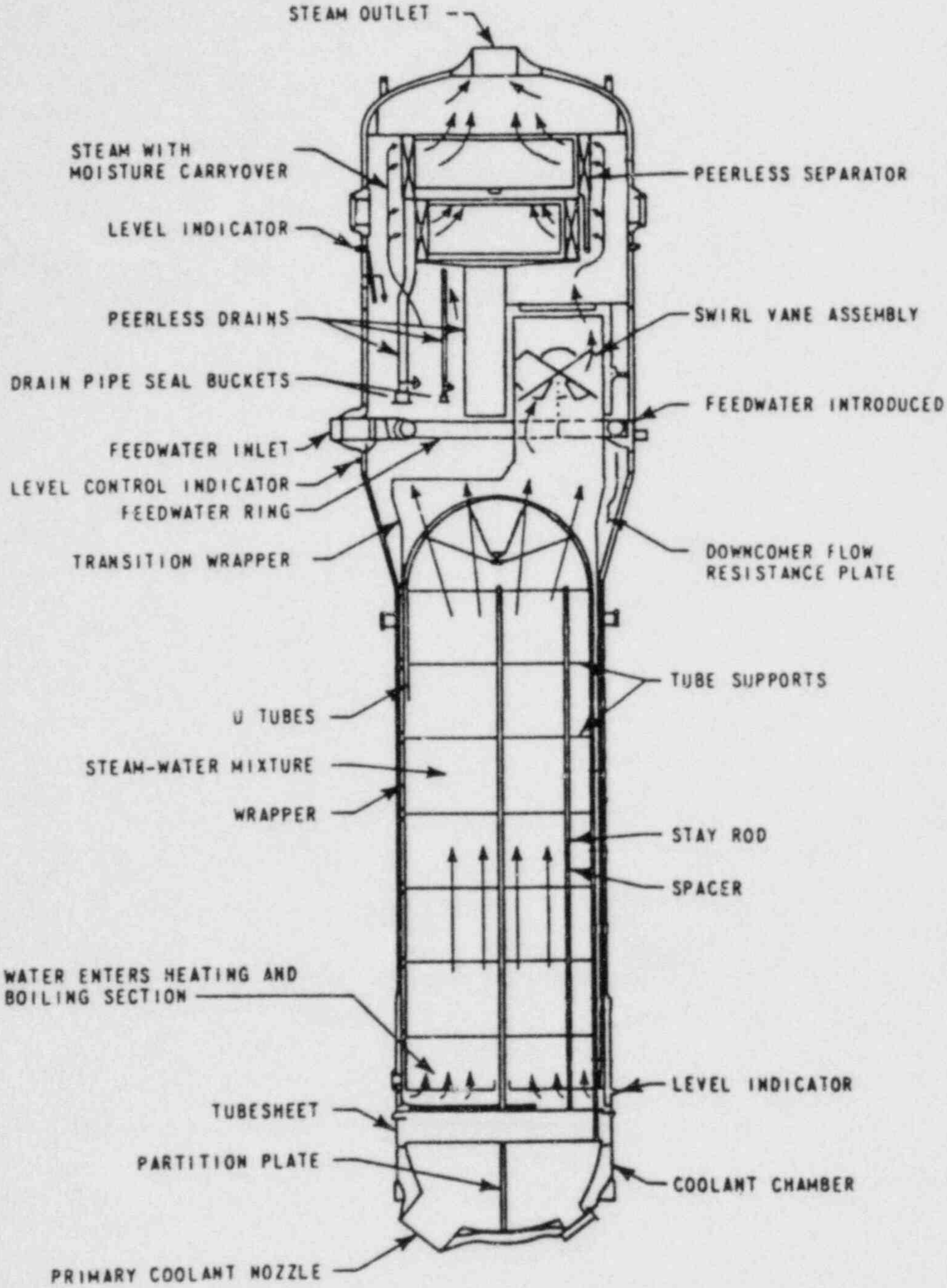

Figure 2. Westinghouse Series 51 Steam Generator.

On the secondary side, a wrapper divides the shell region into the tube bundle region and downcomer. Feedwater is introduced into the feed chamber through an annular ring and mixes with the drainage water from the steam-water separation devices. The water mixture flows downward in the downcomer region formed by the wrapper and shell. At the bottom of the downcomer, the feedwater enters the tube bundle region and flows upward. In the lower part of the tube bundle, the subcooled water is heated to saturation. Heat is added to the saturated water in the upper tube bundle region to produce a saturated mixture of steam and water, which flows upward to the steam-water separation devices within the steam dome region. Steam-water separation is accomplished by a combinatin of swirl vanes and Peerless chevron separators. The separated liquid phase is drained to the feedwater chamber for recirculation, while the vapor phase rises to the steam outlet in the upper steam dome. The moisture of the steam leaving the Peerless chevron separators is less than 0.25% in normal operating conditions.

4. MINET STEAM GENERATOR REPRESENTATIONS

The MINET representations of the steam generator units described in Section 3 are composed of standard MINET modules. Thus, the systems are composed entirely through input and require no modification to the MINET program library.

4.1 IOETSG TEST FACILITY

Because all tubes in an IEOTSG are essentially the same, i.e., radial heat transfer and flow redistribution are not important, these units can be simulated using a single representative tube. Thus, the MINET representation is simply a heat exchanger module and four connecting boundary modules. The representation is designated MINET Input Deck I1, as shown in Figure 3. Module identification numbers, assigned by the user to communicate with the computer code, are shown in Figure 4. For heat exchanger 301, counter-current flow is specified, and the MacBeth correlation is used to determine dryout on the secondary side (outside) of the tubes. The standard package of MINET heat transfer and friction correlations was utilized in the analysis [1].

4.2 D. C. COOK UTSG

The U-tube steam generator is inherently more complex to model, principally for two reasons. First, the spacing and radius of the U-tube bend varies from tube to tube, due to the nesting arrangement. Second, portions of the unit other than the tubing are important in determining pressure and recirculation rate, e.g., the steam dome and downcomer. In addition, one must account for the parallel flow and counter flow heat transfer processes occurring at the different ends of the U-tubes.

The MINET representation that was used, designated MINET Standard Input Deck U1, is shown schematically in Figure 5. Module identification numbers that were utilized are shown in Figure 6. Essentially the U-tube has been broken in half, and represented by parallel flow and counter flow heat exchanger modules arranged in parallel. The steam outlet path to the steam dome

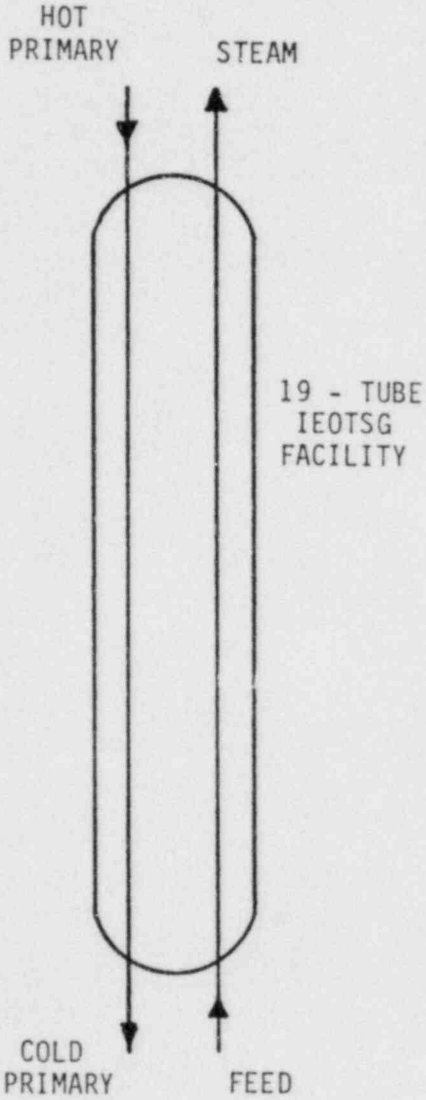

Figure 3. MINET Deck I1, for B&W 19-Tube Integral Economizer Once-Through Steam Generator

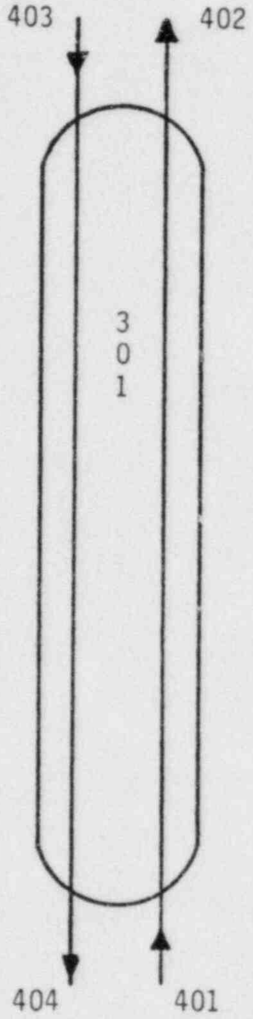

Figure 4. Module ID's for MINET Deck I1

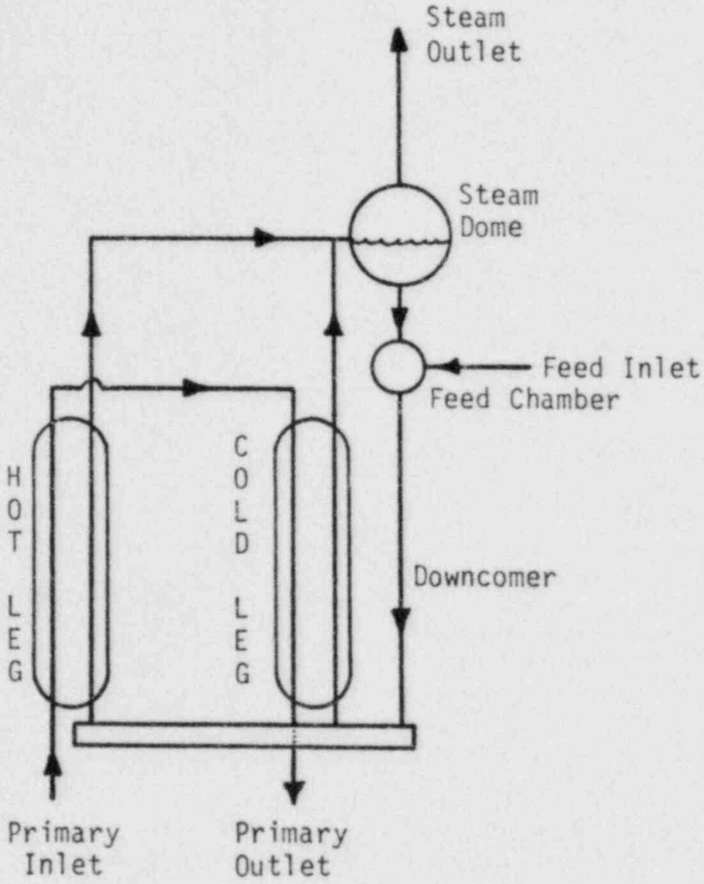

Figure 5. MINET Deck U1, U-Tube Steam Generator

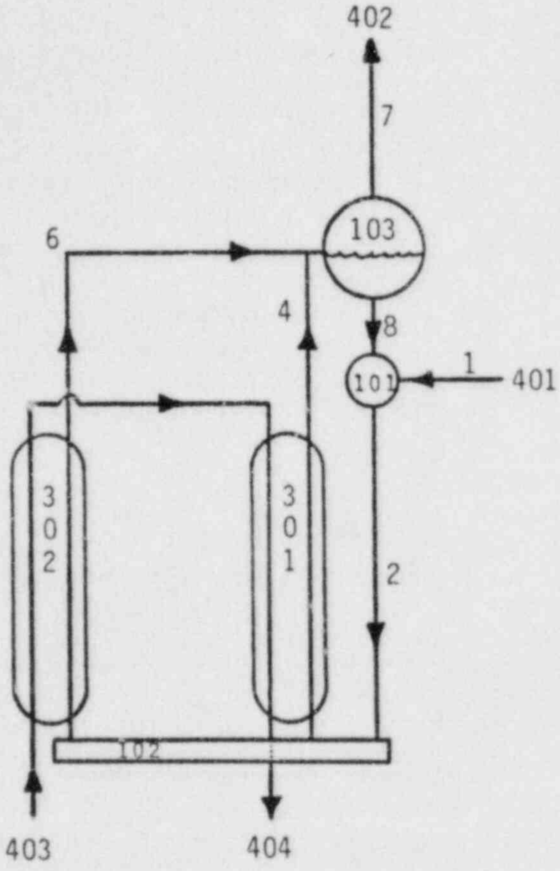

Figure 6. MINET Deck U1 Module IDs

is divided equally, so two parallel paths carry the secondary water/steam between the inlet plenum (module 102) and the steam dome (103). Primary water simply passes up through the parallel flow heat exchanger and back down through the counter flow unit. Form loss factors are adjusted to assure that the exit enthalpy of the water/steam mixture is equal for both pathways with equal area correction factors. This compensates for any flow redistribution that could occur, whereby fluid would migrate toward the hotter tubes in the natural circulation flow.

The separative work of the swirl vanes and Peerless Separators is modeled implicitly in the Steam Dome Volume (103), where the water/steam mixture is divided into saturated vapor and liquid. Dry saturated vapor rises out through the top of the dome and passed on toward the turbine header. Saturated water drops downward to mix with subcooled feedwater, and the slightly subcooled mixture passes through the downcomer to the inlet plenum. MINET modules 2 and 102 form what may be described as an extended downcomer and modules 103, 8, and 101 represent an extended feedwater chamber, and share the same flow area in the vertical direction. Because the cross-sectional area in the top portion of the steam dome is wider than the bottom (feedwater chamber) portion, and the fact that a uniform area in this volume was desirable for the level calculation, part of the physical dome volume was transferred into pipe 7.

The physical sizing of a U-tube steam generator is quite complicated, and a substantial effort is required to determine realistic input values for even the simple configuration shown in Figures 5 and 6. Fortunately, an appropriate set of values had already been determined for a somewhat similar representation [6,7], and a straightforward conversion was made to obtain geometric parameters for the MINET input deck. It should be mentioned that the average tube was determined by dividing the total primary tube flow volume by the number of tubes in the steam generator, and factoring in the known flow area through each tube [6,7].

5. INITIAL CONDITIONS

Prior to transient analysis, the initial conditions in the system must be determined. Based on geometric details, boundary conditions, physical laws, and constitutive relations, MINET performs a steady-state calculation, whereby all parameters needed for the transient calculations are properly initialized. While the user can influence the conditions somewhat through the form loss factors, much of the calculational process is tightly constrained and is an early indicator as to how well the system is being represented.

5.1 IEOTSG TEST CONDITIONS

Two test cases were simulated with slightly different initial conditions. In each case, known initial conditions at both ends of the unit were input and MINET calculated the remaining end conditions and internal distributions.

5.1.1. IEOTSG FEED REDUCTION

The temperatures, flows, and pressures that were input to MINET as initial values at the boundaries are shown in Table 1. The parameters labelled "guess" were adjusted by MINET, consistent with the physical modeling.

Table 1 Initial Parameters Case 1.1, Feed Reduction

Boundary	Module	Temperature (K)	Flow (kg/sec)	Pressure (MPa)
Feed In	401	484.1	.7812	Guess
Steam Out	402	Guess	Guess	7.216
Primary In	403	600.7	11.435	Guess
Primary Out	404	577.78	Guess	15.38

The MINET calculated end parameters, i.e., those labelled "guess" in Table 1, were consistent with mass and energy conservation, and pressure drop calculations. In particular: the outlet flows were .7812 and 11.435 for the secondary and primary, respectively; the steam outlet temperature was 598K; and the inlet pressures were 7.278 and 15.421 MPa for the secondary and primary sides, respectively.

The steady-state temperature profile along the secondary flow path, as calculated by MINET, is shown in Figure 7. Thermocouple readings are also included in the figure for comparison. As can be seen, the MINET calculated temperatures are in good agreement with the data, except near the onset of superheat. This discrepancy is due to an underestimate of the heat transfer in the superheated region, which is the result of ignoring the tube support plates, which improve the (physical) heat transfer by increasing the steam velocity and the heat transfer area. In order to represent these tube support plates, code modifications would have been necessary. Such component-specific code alterations are undesirable, given the MINET utilization as a generalized system code.

5.1.2 IEOTSG STEAM REDUCTION

The temperatures, flows, and pressures that were input to MINET as initial values at the boundaries are shown in Table 2. Again, those parameters labelled "guess" were adjusted by MINET, consistent with the physical modeling.

Table 2 Initial Parameters Case 1.2, Steam Reduction

Boundary	Module	Temperature (K)	Flow (kg/sec)	Pressure (MPa)
Feed In	401	484.1	0.7938	Guess
Steam Out	402	Guess	Guess	7.2513
Primary In	403	600.95	11.417	Guess
Primary Out	404	577.78	Guess	15.38

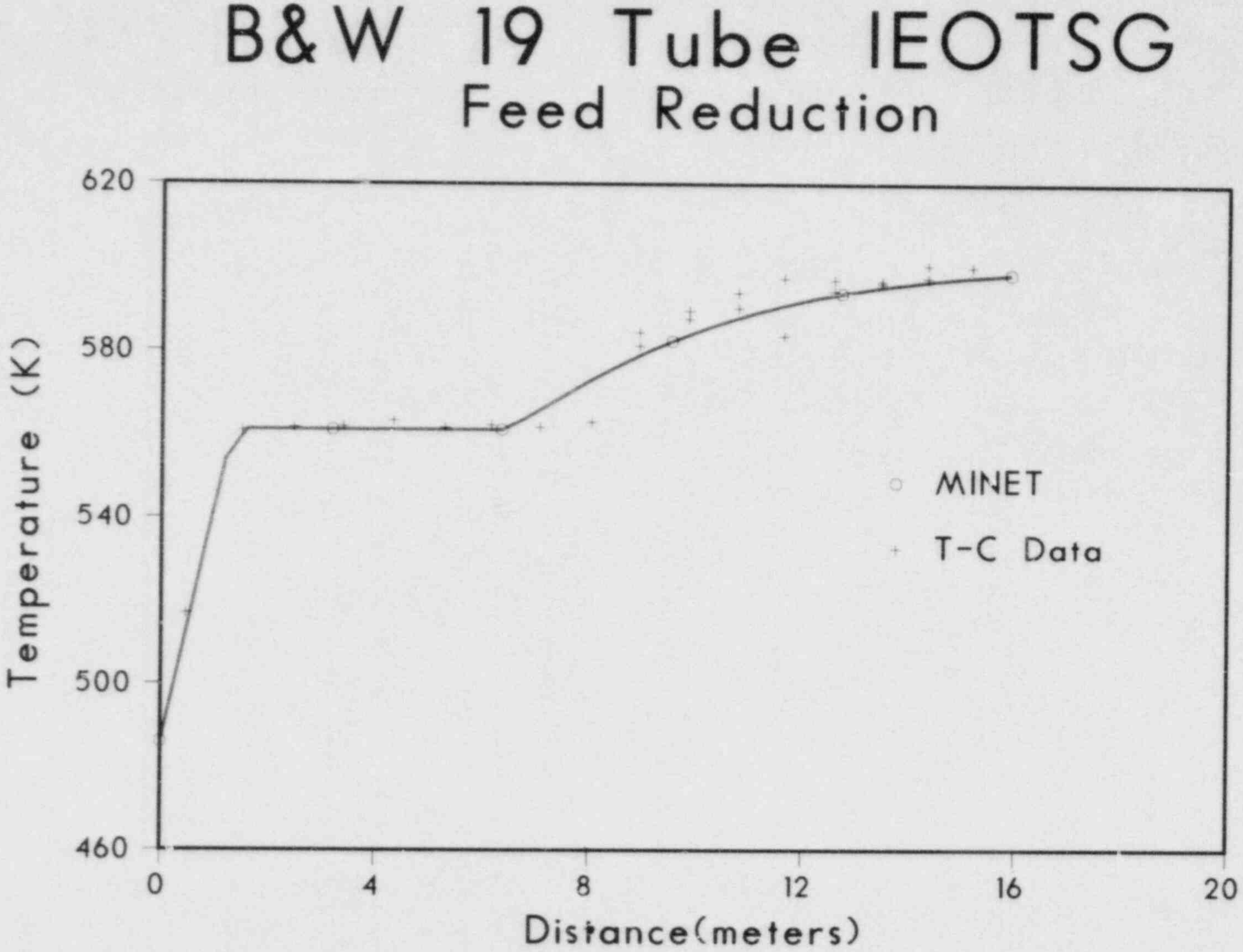

Figure 7 Steady-State Steam Temperature Distribution, IEOTSG Case 1

For the steam reduction case, the MINET calculated end parameters included a steam outlet temperature of 595 K, secondary outlet flow of .7938 kg/s and primary outlet flow of 11.417 kg/s. The inlet pressures were 7.33 MPa and 15.66 MPa for the secondary and primary sides, respectively.

The secondary temperature distribution for the steam reduction case, as calculated by MINET, is shown in Figure 8. Thermocouple readings are again included for comparison. Note that MINET again does well, except in the superheated steam region, where a higher heat transfer rate is indicated by the data. Again, this is believed to be due to the enhancement of the heat transfer process by the tube support plates, through both increased heat transfer area and increased local steam velocities.

5.2 U-TUBE INITIAL CONDITIONS

The temperatures, flows, and pressures that were input to MINET for the U-tube case are given in Table 3. Parameters actually calculated by the code are indicated as "guess".

Table 3 Initial U-Tube Parameters

Boundary	Module	Temperature (K)	Flow (kg/sec)	Pressure (MPa)
Feed In	401	496.89	415.8	Guess
Steam Out	402	Guess	Guess	5.087
Primary In	403	585.22	4624.12	Guess
Primary Out	404	Guess	Guess	15.285

A comparison of Tables 1, 2, and 3 reveals that an additional parameter is guessed for the U-tube, i.e., the primary outlet temperature. For the once-through units, specification of the primary flow rate and inlet and outlet temperature constrained the total heat to be transferred to the secondary side. For the U-tube, a similar constraint already exists, through the subtle fact that the steam rising from the steam dome is at saturation. This, taken with the user-specified feedwater flow rate and temperature (and outlet pressure) determines the total heat to be transferred across the unit.

In addition to the steam outlet temperature (saturation), MINET calculates the primary outlet temperature, by energy balance, as 555.3 K. The outlet flow rates are 415.8 and 4624.12 kg/sec for the secondary and primary sides, respectively. Inlet pressures were calculated to be 5.103 MPa and 15.44 MPa for the secondary and primary sides, respectively.

Because of the geometric complexity of the UTSG, additional information regarding initial conditions had to be considered. The feed chamber water level was set to 2.59 m, consistent with the data, as measured from the bottom of the feed chamber (101) to the top of the liquid region in the steam dome (103). A design value recirculation ratio of 3.25 was obtained by adjusting the form loss factors. The form loss factors between the two heat exchangers

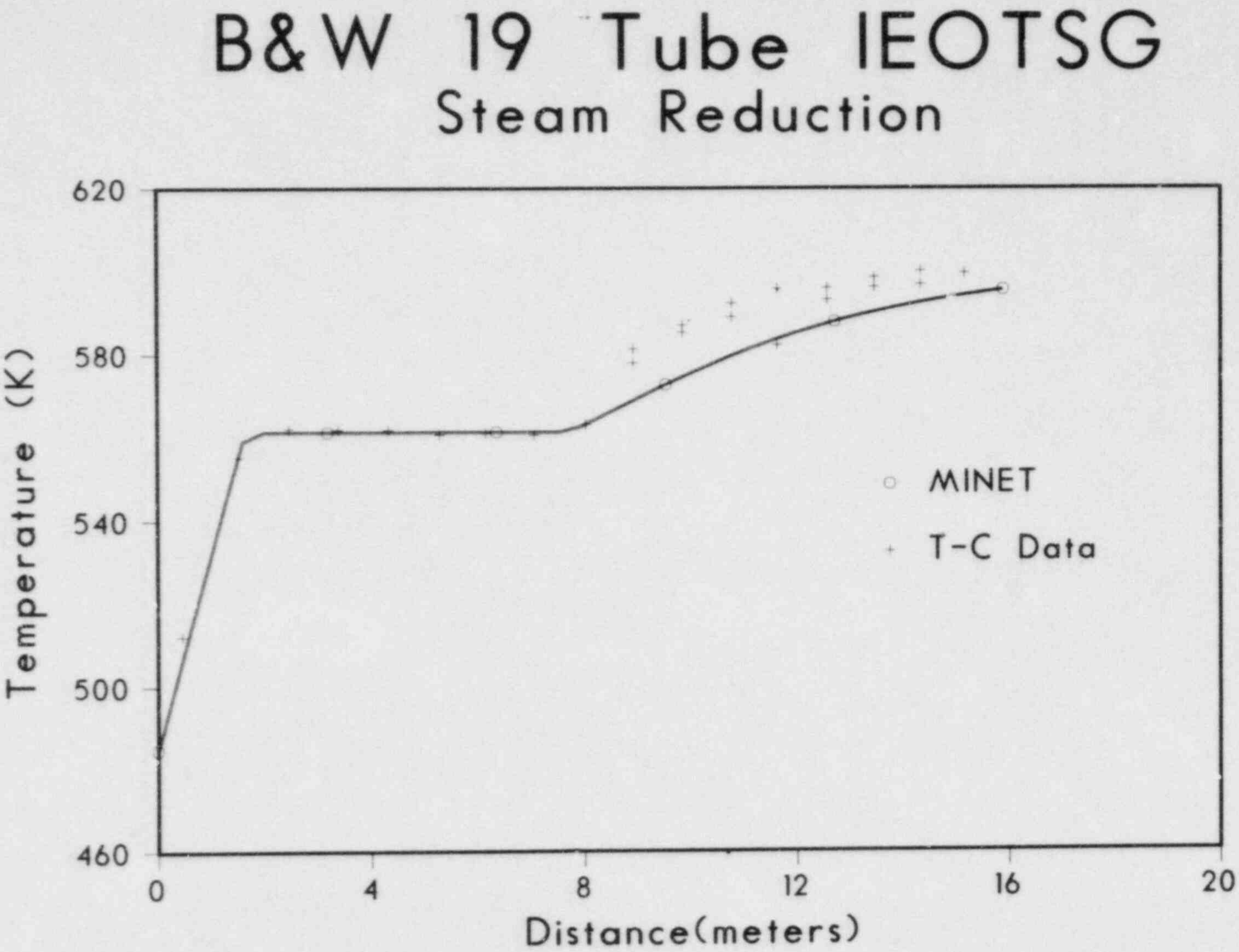

Figure 8 Steady-State Steam Temperature Distribution, IEOTSG Case 2

were adjusted to give equal water/steam mixture outlet enthalpies with equal heat transfer area correction factors. All such conditions and form loss factors were reasonable and consistent.

The U-Tube steam generators in the D. C. Cook Plant contain relatively little instrumentation, so it is difficult to judge the correctness of the MINET calculated initial conditions. While key parameters are placed at their correct initial values, there is a whole range of potential operating conditions that could lead to such a correct set of key indicators. The best indications are that the initial conditions calculated by MINET are reasonable and consistent, and are likely to be close to the physical conditions in the UTSG at the start of the transient.

6. TRANSIENT ANALYSIS

The transients for both steam generator types were driven using boundary conditions determined directly from experimental transient data. MINET calculated results were compared against other experimental data obtained during the same transient.

6.1 IEOTSG CASES

Two test cases were simulated using MINET. Models and initial conditions were as described in earlier sections of this report.

6.1.1 IEOTSG FEED REDUCTION CASE

The first IEOTSG case was a step reduction in feedwater mass flow rate from 65 to 55 per cent of rated capacity. The resulting experimental feedwater and steam mass flow rates for this 35 second transient were as shown in Figure 9. These curves were digitized and input to MINET. In addition, the feedwater temperature was held constant at 484.1 K, and the primary side inlet flow rate and temperature and outlet pressure were held at their initial values.

With flow in and flow out specified as secondary side boundary conditions, MINET calculated the pressures on both ends. The results of the steam pressure calculations are shown in Figure 10, together with the experimentally observed steam pressure. As can be seen, the MINET calculated pressure is in excellent agreement with the measured one, throughout the 35 second transient. No other experimental data was available for comparison, in this case.

6.1.2 IEOTSG STEAM REDUCTION CASE

The second IEOTSG case was a step reduction in plant load corresponding to a reduction in steam flow rate from 65 to 55 per cent rated capacity. The resulting experimental feedwater and steam mass flow rates for this 20 second transient were as shown in Figure 11. Again, these curves were digitized and input to MINET. In addition, the feedwater temperature was again held constant at 484.1 K, and the primary side inlet flow rate and temperature and outlet pressure were held constant at their initial values.

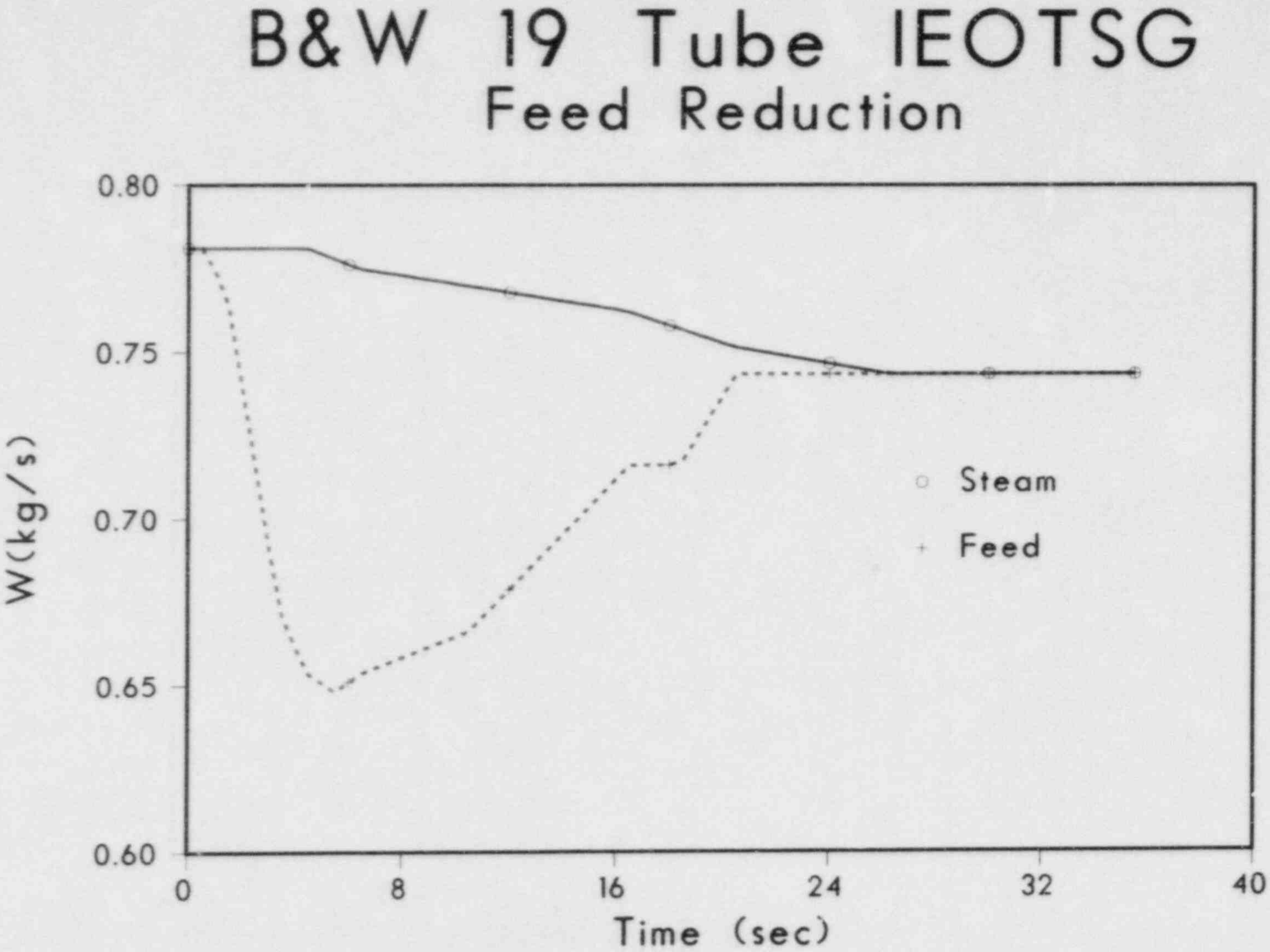

Figure 9 Feedwater and Steam Mass Flow Rates for IEOTSG Case 1

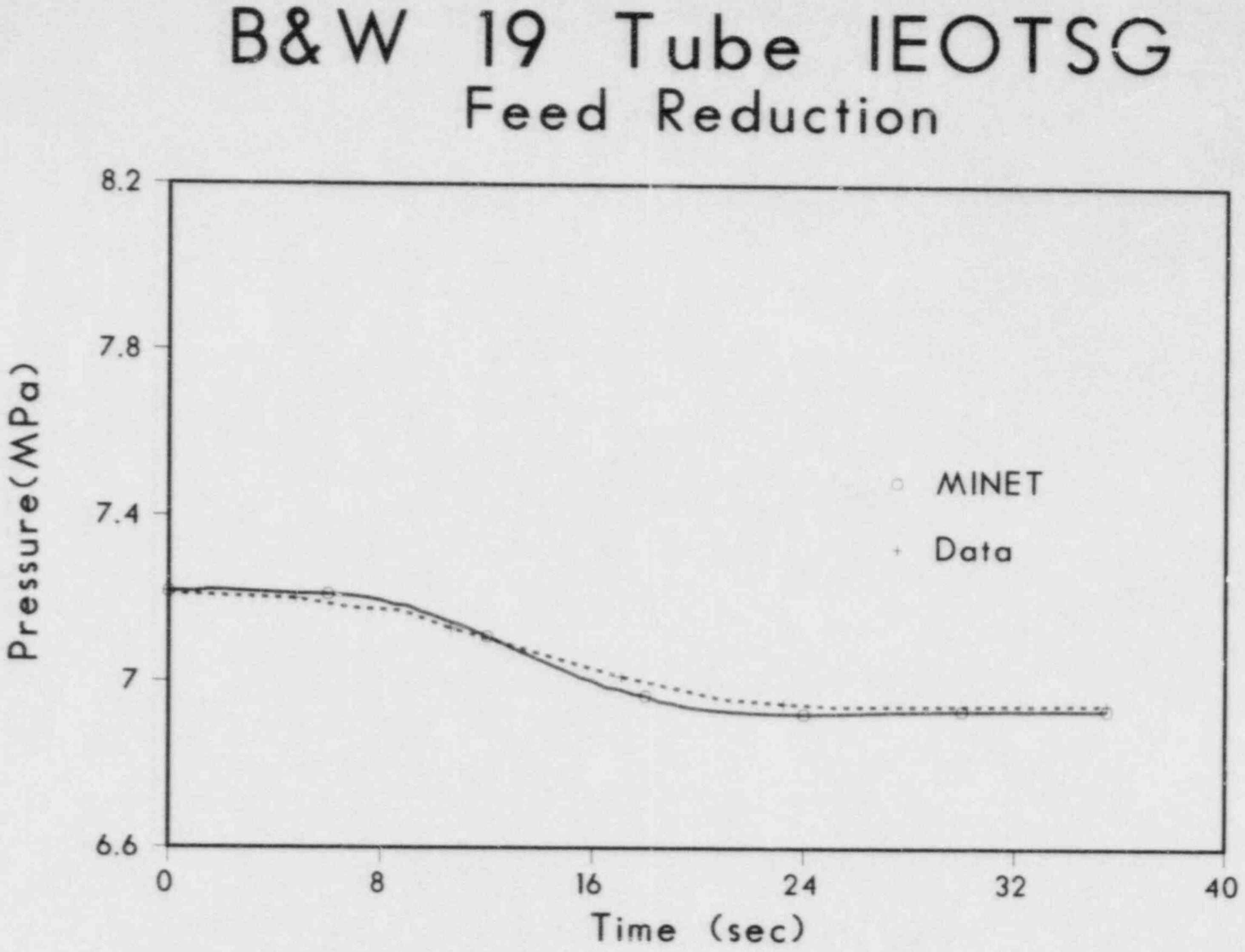

Figure 10 Steam Pressures for IEOTSG Case 1

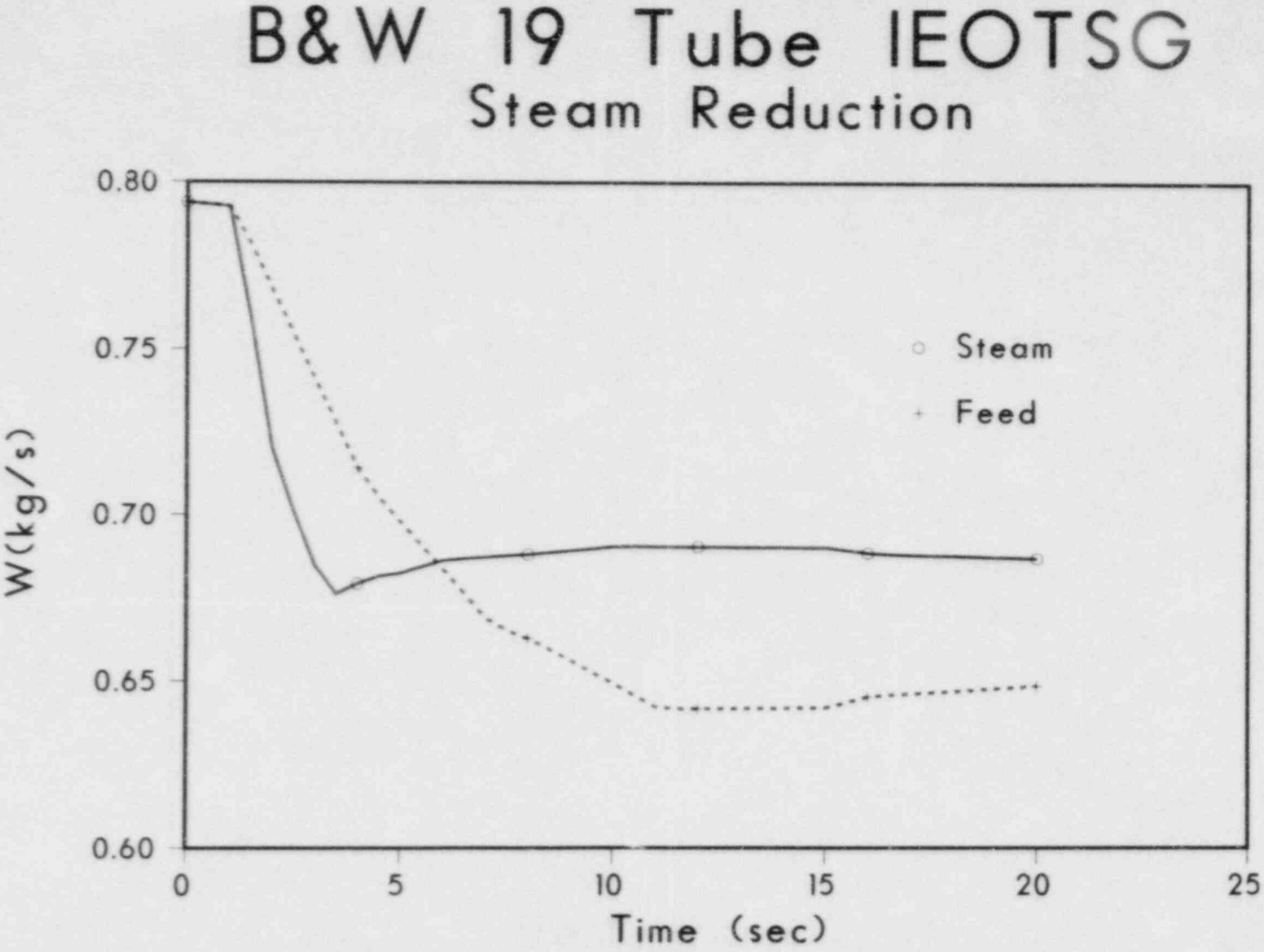

Figure 11 Feedwater and Steam Mass Flow Rates for IEOTSG Case 2

The results of the steam pressure calculation are shown in Figure 12, together with the experimentally observed steam pressure. Again, the MINET calculated pressures are in very close agreement with the measured values, throughout the 20 second transient.

MINET calculated primary outlet temperatures are shown in Figure 13, together with thermocouple readings taken during the transient. The agreement here is, once again, very strong. No other transient data was available for comparison.

6.2 UTSG CASE

The turbine trip transient, as reported in Ref. 10, was initiated by manually tripping the main turbine while the plant was operating at full power. As a result of the turbine trip, the main steam turbine stop valve was automatically closed, and in turn initiated immediate trips of the reactor and the turbine driven main feed pumps. Figure 14 shows the UTSG feed and steam outlet mass flow rates as a function of time during the transient. The steam flow rate decreased in step fashion after the closing of the turbine stop valve. About three seconds after initiation of the turbine trip, main steam relief valves opened due to high pressure and maintained a reduced steam flow rate for about 15 more seconds. The feed flow rate decreased almost linearly to zero about six seconds after initiation, as the feed pumps coasted down. The primary inlet temperature and reactor coolant system pressure decreased significantly over the 20 seconds following the reactor trip, as shown in Figures 15 and 16, respectively.

The following set of boundary conditions were used in the MINET simulation of the D. C. Cook UTSG transient:

Primary

Inlet Pressure as Figure 16
Outlet Mass Flow Rate Held Constant
Inlet Temperature as Figure 15

Secondary

Feedwater Flow Rate as Figure 14
Feedwater Temperature Held Constant
Steam Flow Rate as Figure 14

Of these boundary conditions, the assumption of constant primary mass flow rate carries the greatest uncertainty, since, while the reactor coolant pumps will provide a constant head, the scram of the reactor will effect the gravitational head, thereby impacting on the mass flow rate. Because we do not really know exactly what the effect on the flow would be, the assumption of constant primary flow is used, as it was in the previous study [5,6,7].

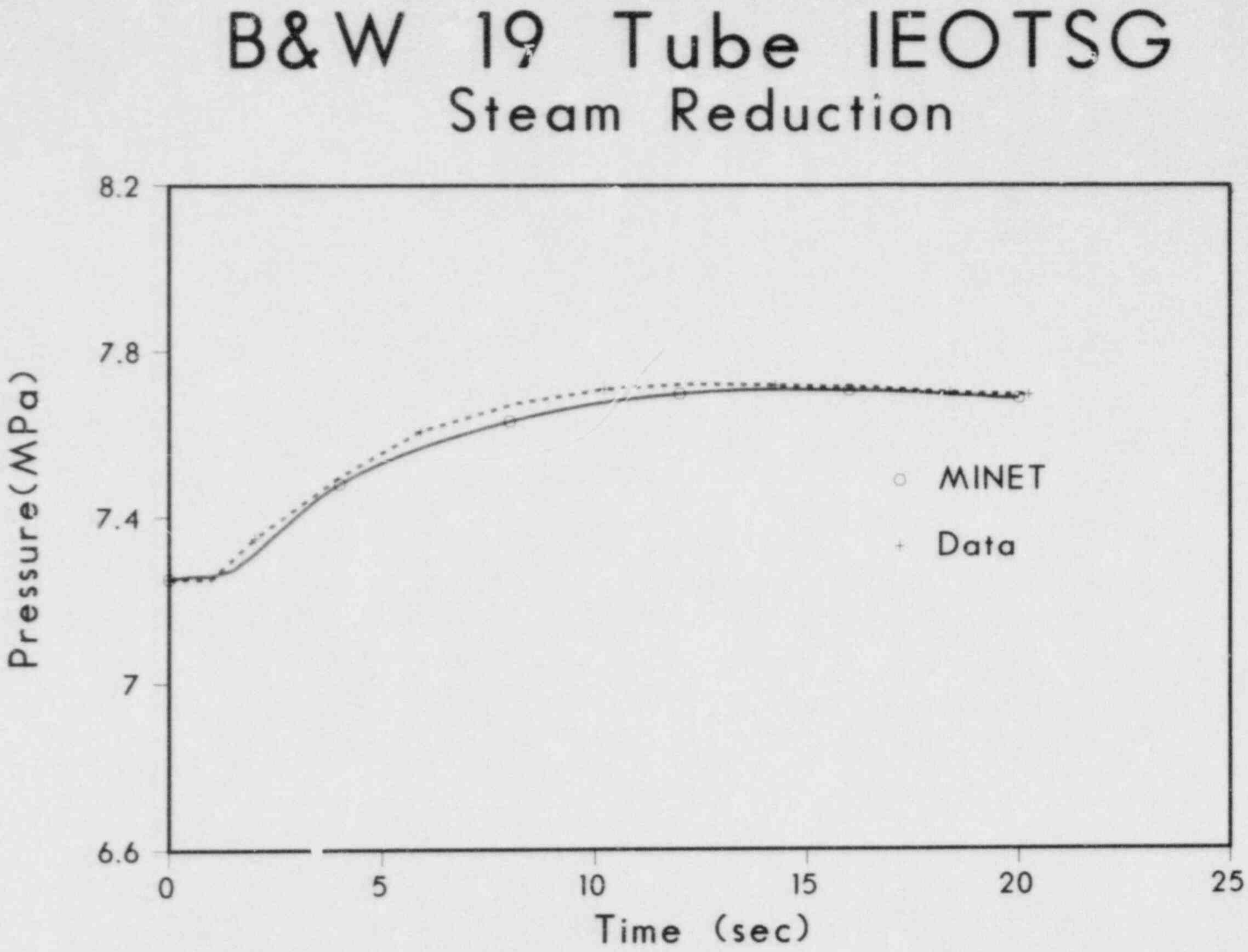

Figure 12 Steam Outlet Pressures for IEOTSG Case 2

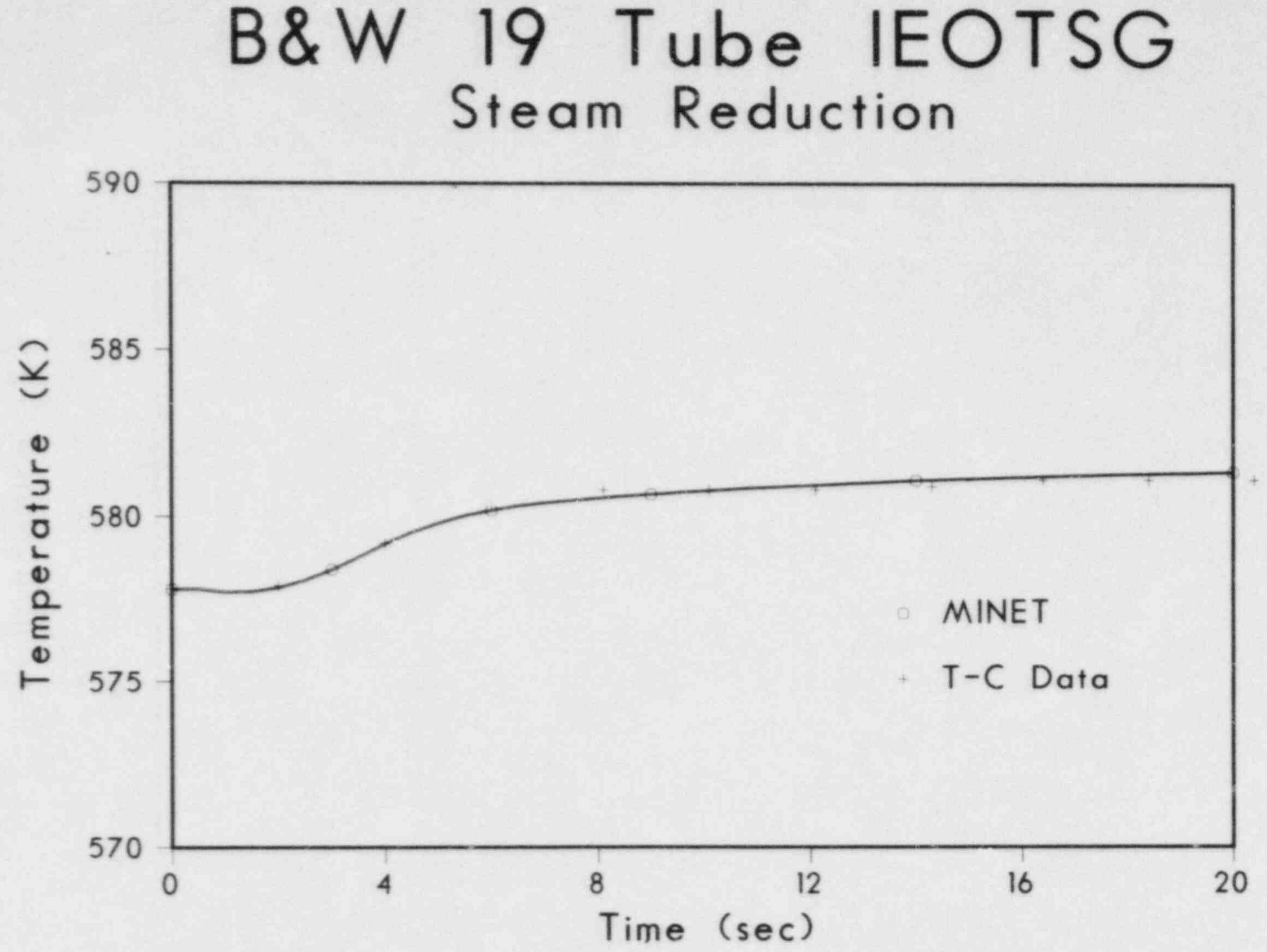

Figure 13 Primary Outlet Temperature for IEOTSG Case 2

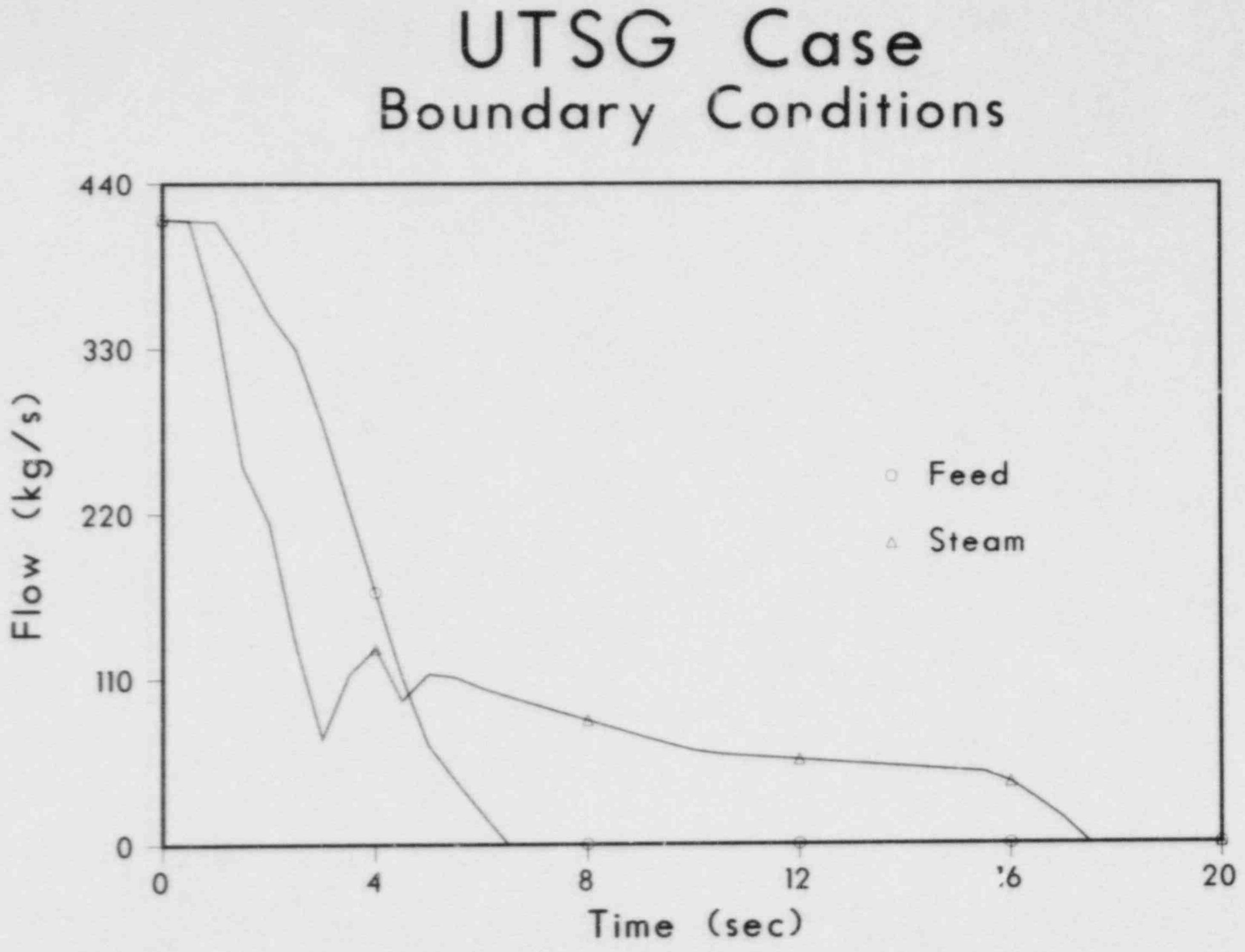

Figure 14 Secondary Flow Rates for UTSG Case

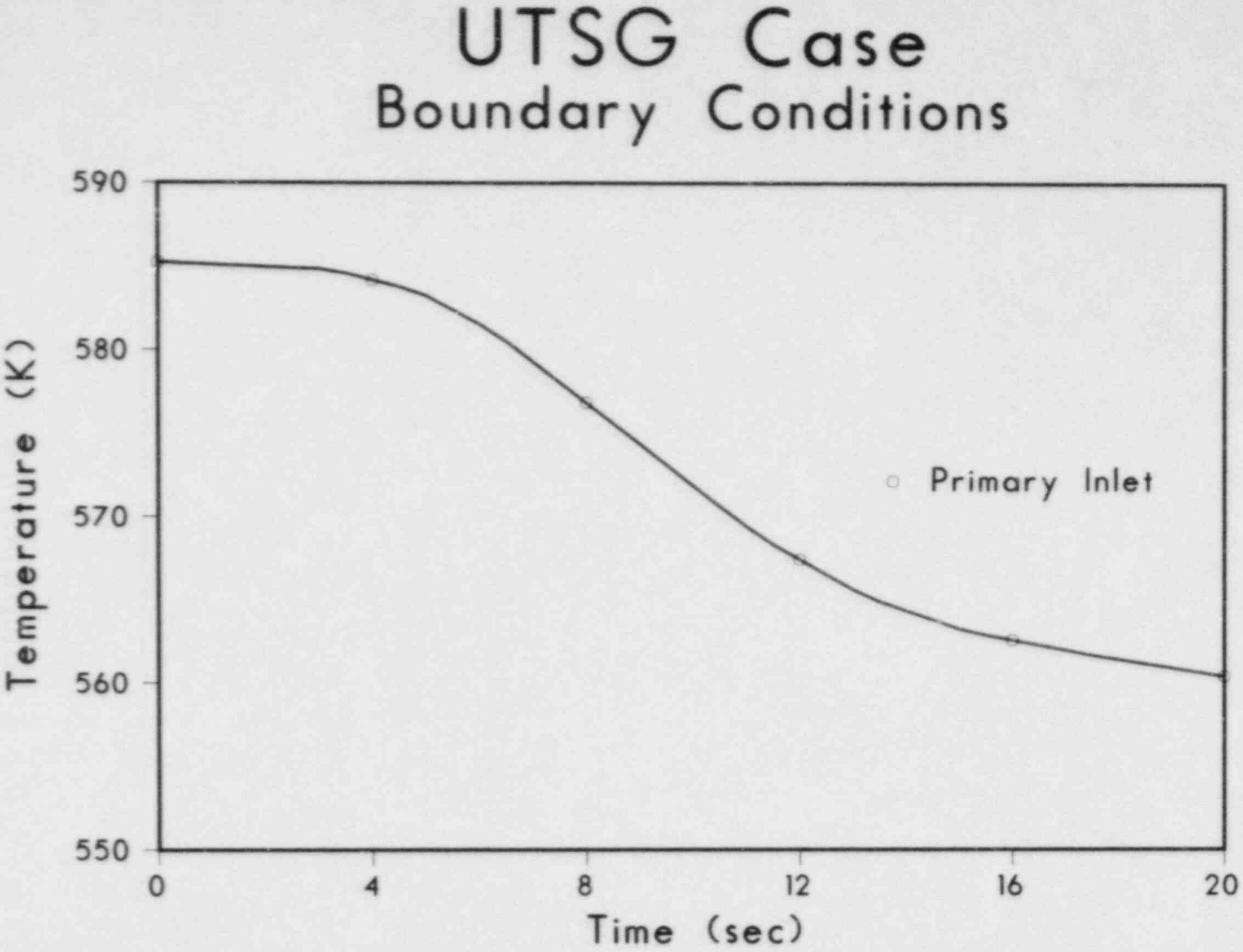

Figure 15 Primary Inlet Temperature for UTSG Case

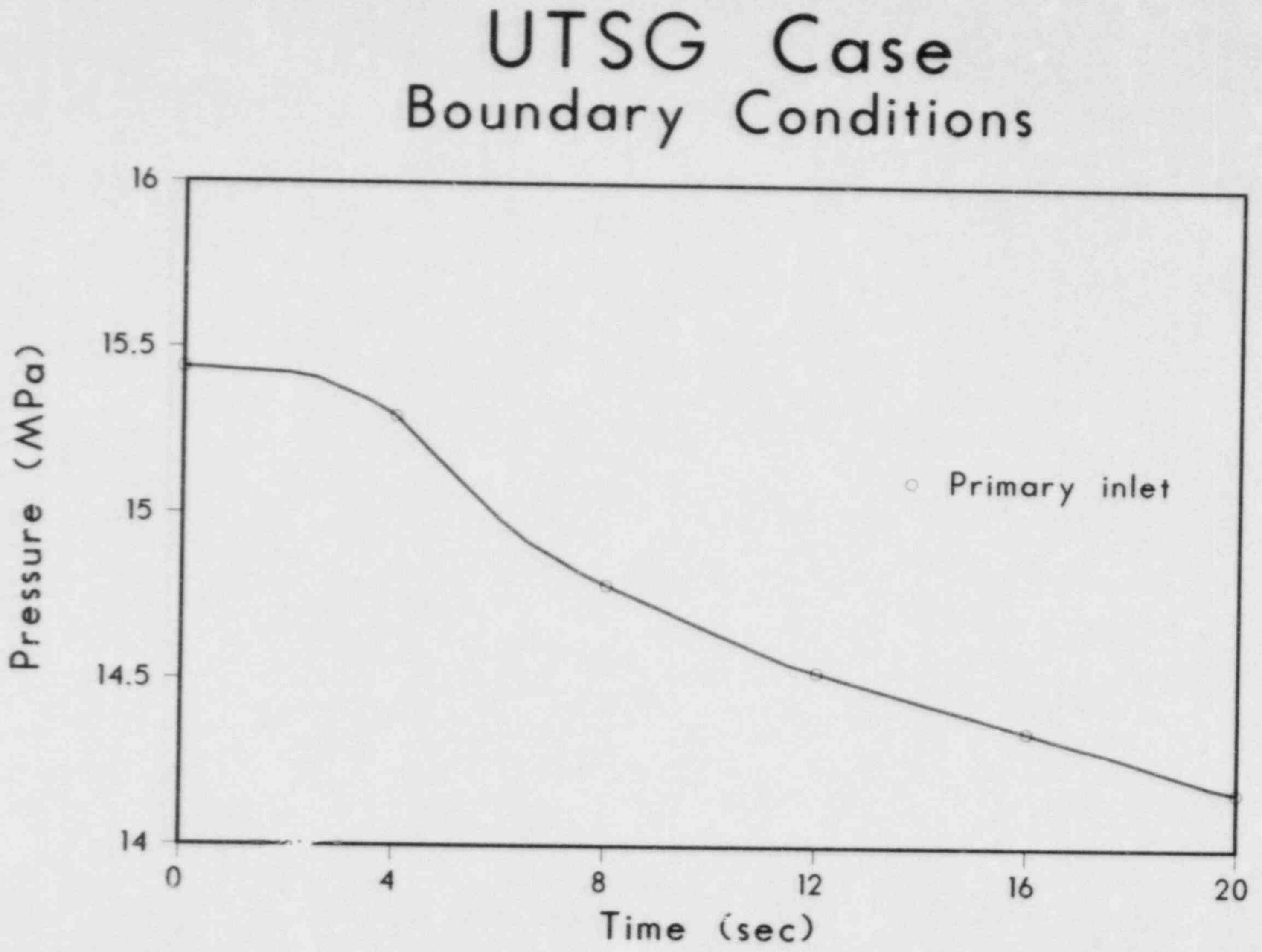

Figure 16 Primary Inlet Pressure for UTSG Case

The calculated values for steam dome pressure and feed chamber water level are shown in Figures 17 and 18. In addition to MINET calculational results, measured plant data and TRANSG code calculational results [5,6,7] are included for comparison. The pressure increase shown in Figure 17 results from the sharply reduced steam outlet flow rate and the continued heating of the secondary fluid. As the pressure increases, the voids in the secondary riser tend to collapse. This accelerates the downcomer flow into the riser and thus causes a drop in feed chamber water level shown in Figure 18. The favorable comparison between the calculated and measured value of the feed chamber water level shown in Figure 18 indicates that the internal mass redistribution in the secondary flow circuit is correctly predicted. The overprediction of the pressure increase shown in Figure 17 may result, in part, from effects in the external steam piping system not fully accounted for in the calculations made using both the MINET and TRANSG codes.

It should, perhaps, be noted that the reason the MINET calculated level flattens out at 0.3 m around 15 seconds is that the water level has dropped to the bottom of the steam dome volume, i.e., module 103 in Figure 6. From that time onward, steam is penetrating into pipe 8 and volume 101, i.e., the lower portion of the feed chamber. The tendency of the MINET calculated level to drift upward slightly after 17 seconds is due to the code finite differencing, which tends to entrain a small amount of saturated liquid in volume 103 on its way to pipe 8. This is all rather unimportant though, because available data and TRANSG results cease at 10 seconds, with regard to the feed chamber water level.

7. CONCLUSIONS

The IEOTSG test facility provides an excellent test of the MINET heat exchanger module, both because of its physical simplicity and the accuracy of the data that is provided. Thus, it is gratifying that MINET performed very well in simulating the two test transients. In previous studies, we have noted that MINET can predict heat exchanger temperatures quite accurately [2-4], so the agreement shown in Figure 13 was not at all surprising. However, this was the first clean test of the ability to accurately calculate the system pressure in response to flow rate driven transients, and MINET performed extremely well.

The UTSG test contained far greater uncertainty, with regard to behavior. The agreement between MINET calculations and the measured steam pressure and feed chamber water level is good, and looks even better when the TRANSG calculated results [5-7] are considered. This is because the MINET geometric assumptions are very similar to those used in the TRANSG analysis, and the codes calculate very similar steam pressures, i.e., the error is being replicated. While the UTSG study is not as conclusive as the IEOTSG study, it is clear that MINET representation of the UTSG is reasonably good.

Taken together, these studies support the validity of the MINET models, particularly the heat exchanger module. They support the use of MINET in simulating balance of plant transients, and particularly those involving pressurizer water reactor (PWR) system steam generators.

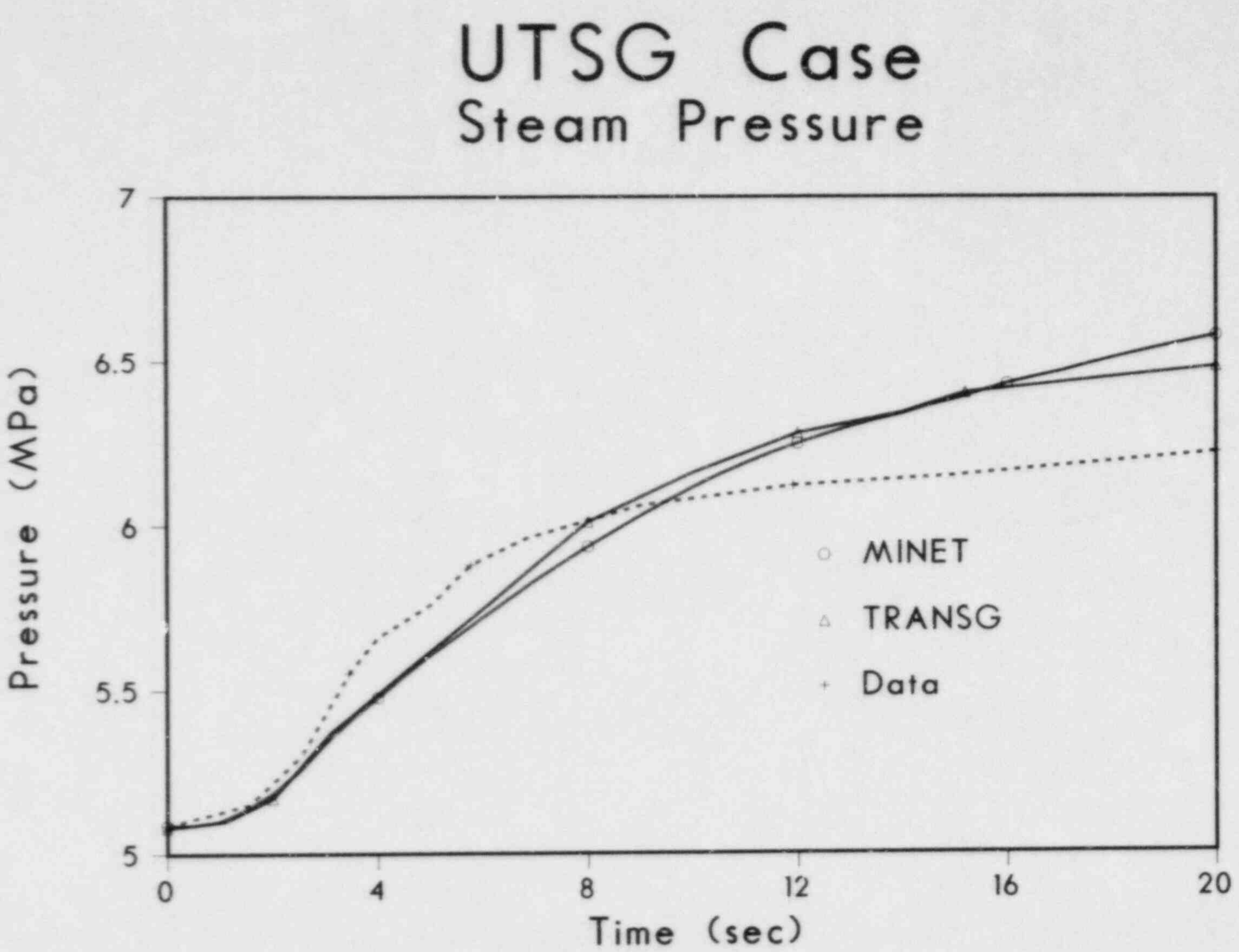

Figure 17 Steam Pressure(s) for UTSG Case

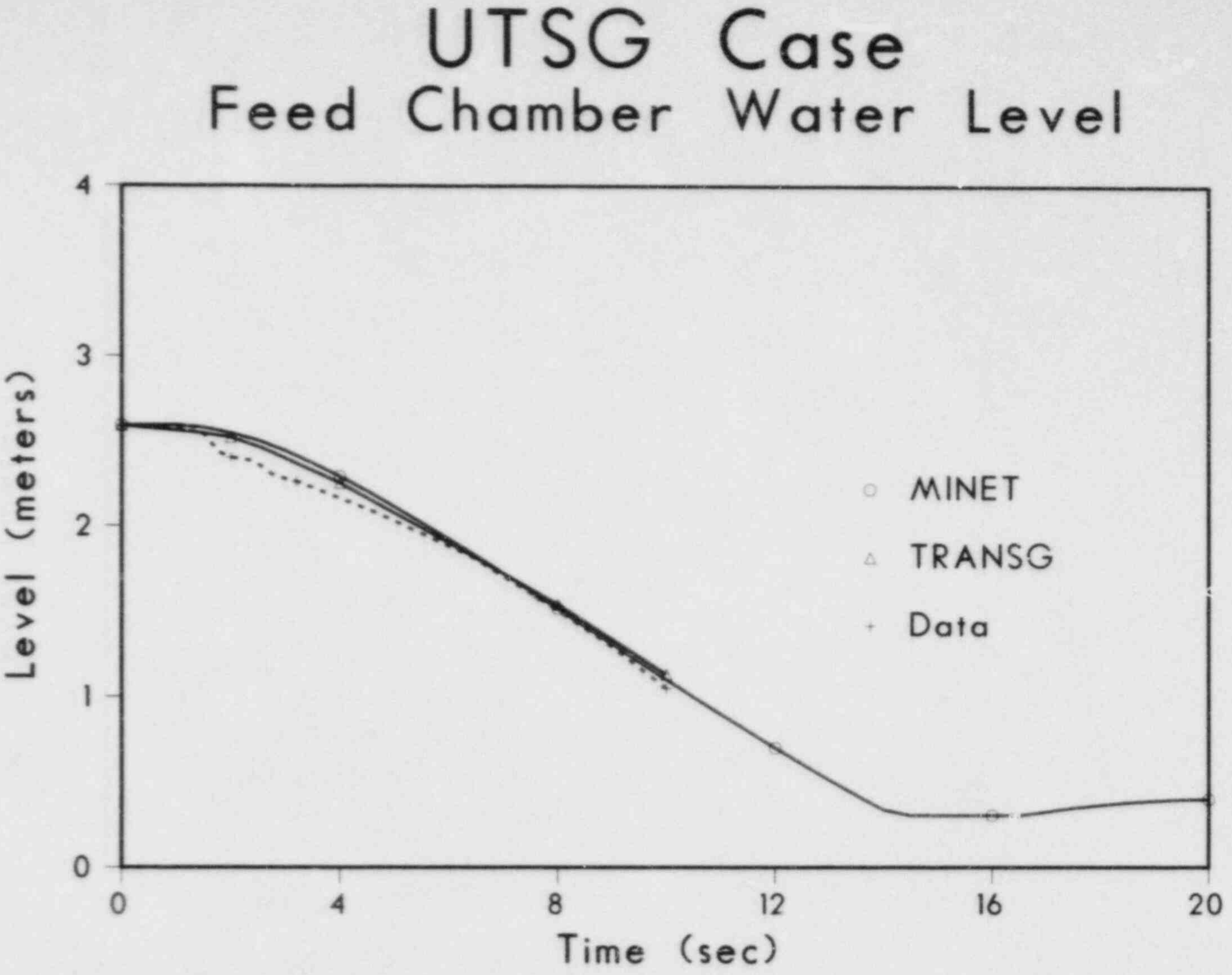

Figure 18 Feed Chamber Water Level, UTSG Case

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Three steam generator transient test cases, that were simulated using the MINET computer code, are described, with computed results compared against experimental data. The MINET calculations closely agreed with the experiment for both the once-through and the U-tube steam generator test cases. The effort is part of an ongoing effort to validate the MINET computer code for thermal-hydraulic plant systems transient analysis, and strongly supports the validity of the MINET models.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Transient Analysis	
Code Validation	
Once-Through Steam Generator	
U-Tube Steam Generator	

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