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2D/3D Analysis Program Report-1981

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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2D/3D Analysis Program Report-1981

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2D/3D ANALYSIS PROGRAM REPORT - 1981

by

W. L. Kirchner and K. A. Williams

ABSTRACT

The United States Nuclear Regulatory Commission (USNRC) is currently engaged in a multinational experimental and analytical research program (known as 2D/3D) on multidimensional thermal-hydraulic behavior during loss-of-coolant accidents (LOCAs) in large pressurized water reactors (PWRs). As a prime contractor to the NRC, the Los Alamos National Laboratory is providing analytical support for this program. This report documents the key results and findings from efforts during FY 1981. The Transient Reactor Analysis Code (TRAC), the main analytical tool in this program, was demonstrated to be a powerful tool for reactor safety analysis. By correctly predicting key results from the experimental test facilities over a wide range of test conditions, a significant level of confidence in the code was obtained. Complementary TRAC analyses of postulated PWR accidents show substantial safety margins below current licensing requirements. Future model development and assessment activities for TRAC are outlined and future 2D/3D activities of importance to NRC licensing activities are also described.

I. INTRODUCTION

The 2D/3D Program is a multinational (Germany, Japan, and the United States), experimental, and analytical nuclear reactor safety research program; which has as its main purpose the investigation of multidimensional thermal-hydraulic behavior during the refill and reflood phases of loss-of-coolant accidents (LOCAs) in pressurized water reactors (PWRs). The German contribution to the program is the planned Upper Plenum Test Facility (UPTF), a full-scale facility with vessel, four loops, and a steam-water core simulator. Also, though not directly involved in the program, our participation provides access to the German PKL (primary loop test facility) data, which currently is concentrated on small-break behavior. The Japanese are operating two large-scale test facilities as part of this program: the Cylindrical Core Test Facility (CCTF) and the Slab Core Test Facility (SCTF). CCTF is a 2000-electrically-heated-rod, four-loop facility, primarily for investigating integral reflood behavior. SCTF is a 2000-electrically-heated-rod, slab core (one fuel assembly wide, eight across, and full height), separate-effects reflood facility. Both facilities are scaled on a power-to-volume basis, preserving full-scale elevations, and are much larger than any existing facilities in the United States (including LOFT). All of these facilities are instrumented better than any existing facilities; conventional instrumentation data channels alone are in excess of one thousand in each facility. The United States contribution to the program is the provision of advanced two-phase flow instrumentation and analytical support.

The Los Alamos National Laboratory is the prime contractor to the NRC in the latter activity. The main analytical tool in this program is the Transient Reactor Analysis Code (TRAC), a best-estimate, multidimensional, nonequilibrium, thermal-hydraulics computer code developed for the NRC at Los Alamos.[1,2] Through code predictions of experimental results and calculations of PWR transients, TRAC provides the analytic coupling between the facilities and actual reactors. To achieve this coupling objective, the Los Alamos activities in support of the program are listed below:

1. Analysis support in facility design, construction, and operation.
2. Assistance in locating, ranging, and assessing the accuracy of facility instrumentaton.

3. Provide boundary and initial conditions for facility operation with reference to PWRs.
4. Perform pretest and posttest predictions and analyses.
5. Perform detailed calculations to provide insight into physical phenomena for TRAC modeling improvements.
6. Perform small-scale experiments in support of TRAC modeling requirements.
7. Use experimental results to validate and assess the multidimensional, nonequilibrium features in the TRAC code.

Results from this program already have addressed, and will continue to address, key licensing issues including: scaling, multidimensional effects, downcomer bypass and refill, reflood, steam binding, core blockages, alternate emergency core cooling systems (ECCS), small-break phenomena, and code assessment.

To communicate the results of this analysis effort in a more effective and timely manner, a system of issuing technical notes to document individual TRAC calculations and analysis activities has been adopted. These are internal reports, distributed to all participants in the 2D/3D Program, and are not formally recognized by the Laboratory. Where appropriate, this information is being published in Los Alamos reports or in technical journals. The Appendix contains an annotated bibliography of the technical notes issued in 1981. These are referred to in the text of this report as LA-2D/3D-TN-81-XX.

II. CYLINDRICAL CORE TEST FACILITY (CCTF)

The analytical efforts for CCTF involved demonstrating the capability of the TRAC code to predict correctly the parametric effects of both pressure and emergency core coolant (ECC) flow on the reflood phase of a LOCA. A "double-blind" pretest prediction of an Evaluation Model (EM) test was performed, which showed the code to err on the conservative side (higher temperatures and longer quench times) in predicting reflood behavior (LA-2D/3D-TN-81-12). Knowledge of actual boundary conditions and refinement of the TRAC input models will improve these results. This work is currently in progress. In addition, the multidimensional capability of the TRAC code was assessed against an asymmetric core temperature profile test in a "blind" prediction and the comparisons with data were extremely good. Based on these results and a careful review of the experimental data, conclusions regarding reactor licensing issues are drawn that could quantify, and hopefully reduce, many of the conservative margins currently in effect (see Section VIII).

A. CCTF Parametric Effects Calculations (R. Fujita and T. Okubo*)

To demonstrate the capability of the TRAC code to predict correctly the parametric effects of pressure and ECC injection rates, a series of CCTF calculations was performed. This included the base-case test (Run 14), the low-pressure test (Run 19), the high-pressure test (Run 21), and the high low-pressure injection (LPCI) flow-rate test (Run 15).[3,4,5,6] The TRAC-PD2/MOD1 code version and system noding model were the same for each calculation; only the initial and boundary conditions for each test were changed. Figure 1 is a CCTF system schematic and Figs. 2 and 3 show the associated TRAC models for the loops and vessel, respectively. In the interest of predicting trends rather than detail, the three intact loops were combined into one and a coarsely noded vessel model was employed.

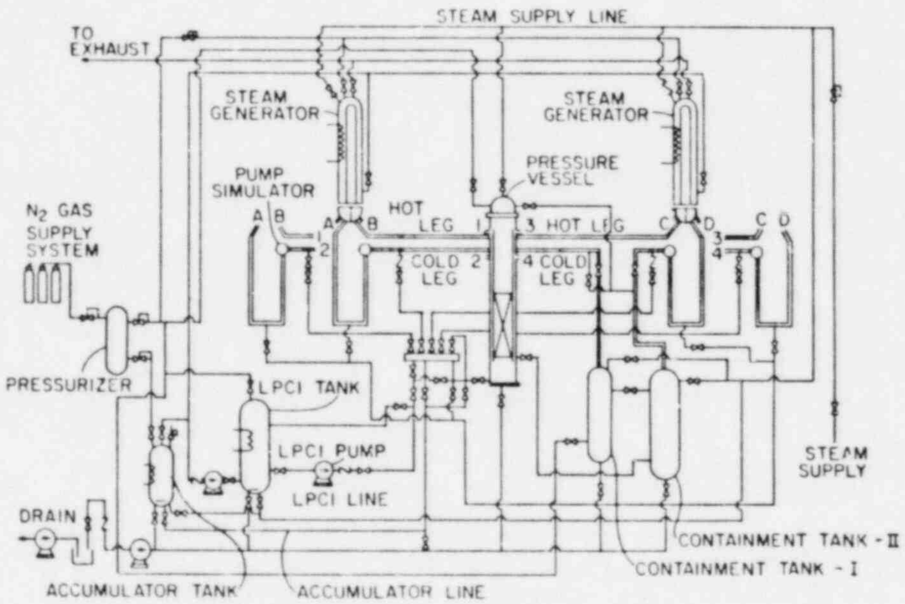


Fig. 1. Schematic diagram of the CCTF.

*Japan Atomic Energy Research Institute (JAERI) resident engineer at Los Alamos, 1981-1982.

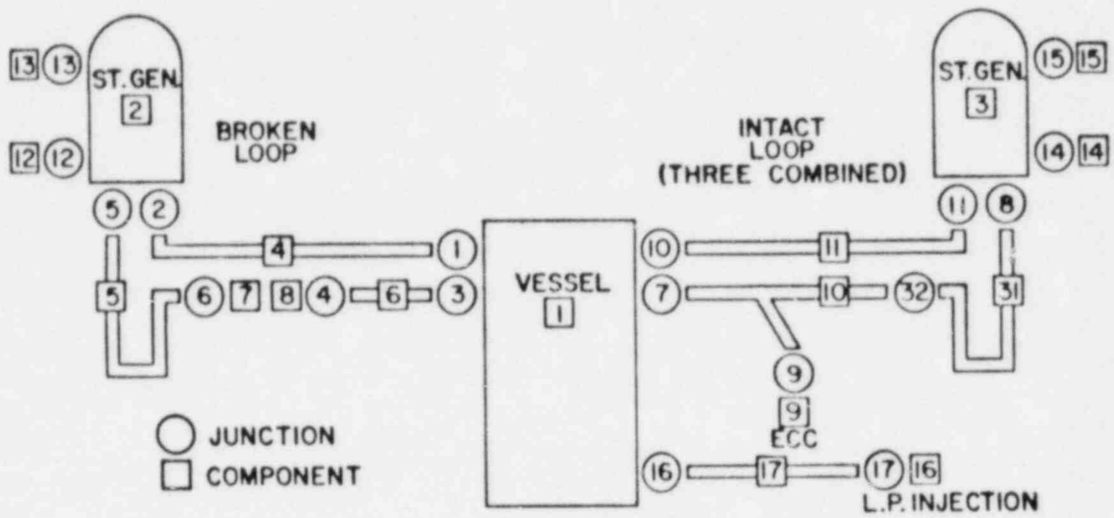


Fig. 2. TRAC noding schematic for CCTF.

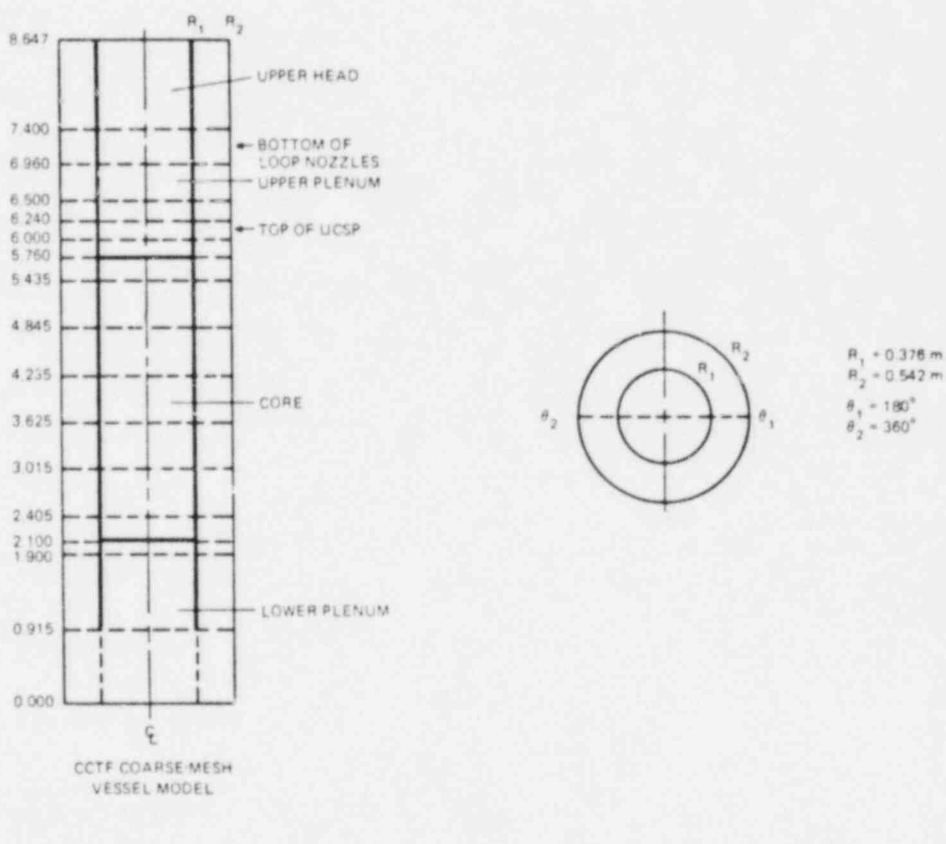


Fig. 3. TRAC coarse-node vessel model for the CCTF parametric-effects tests.

Figure 4 shows a plot of the measured quench envelopes for the four test runs and Fig. 5 shows the comparison TRAC results (LA-2D/3D-TN-81-26, 27, 30, 31, and 34). The following important points are noted: 1) the pressure effect on reflood is correctly predicted, e.g., reflood progresses at a faster rate at higher pressures, and 2) the increased (factor of two) LPCI flow-rate test does not depart noticeably from the base-case result. A slightly lower peak clad temperature and earlier turnaround time were measured, but these were within experimental error bands. The coarse-node TRAC predictions tended to overpredict the quench times (significantly in the low-pressure run in the upper half of the core), and this was the major discrepancy between experiment and prediction for the test series. The following section, which documents fine-node multidimensional calculations, indicates that this problem can be partially solved by increased noding.

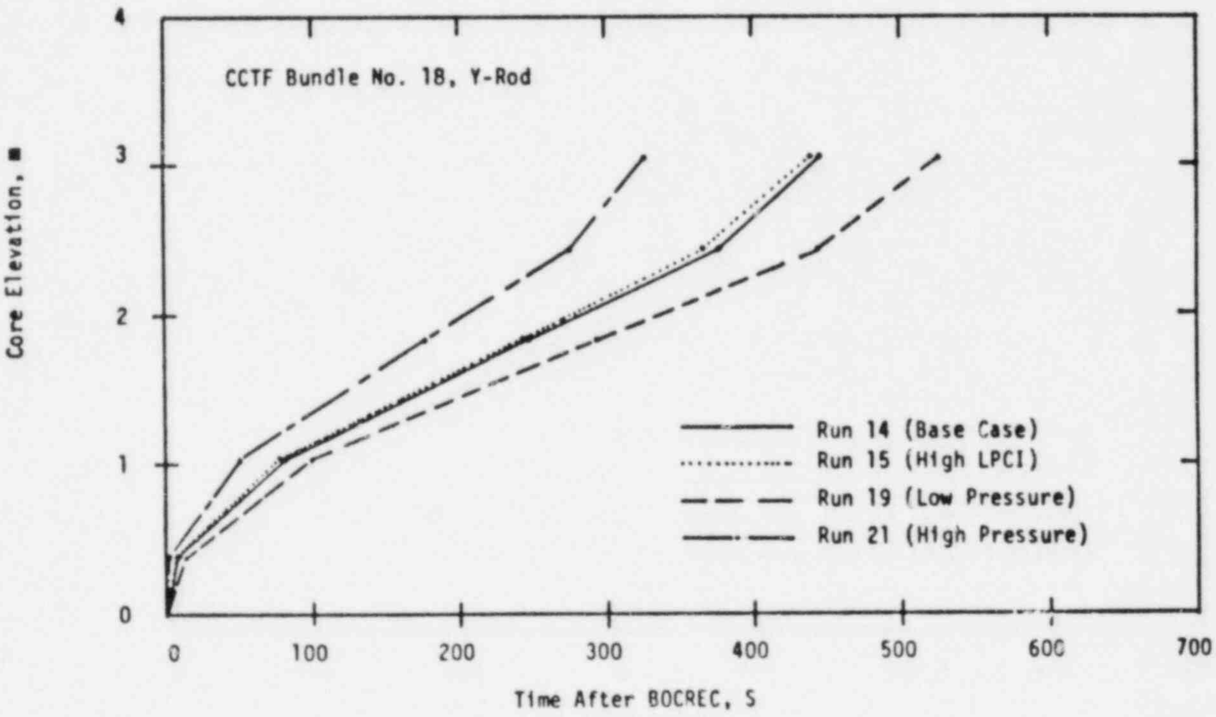


Fig. 4. Comparison of experimental quench envelopes for CCTF parametric-effects tests.

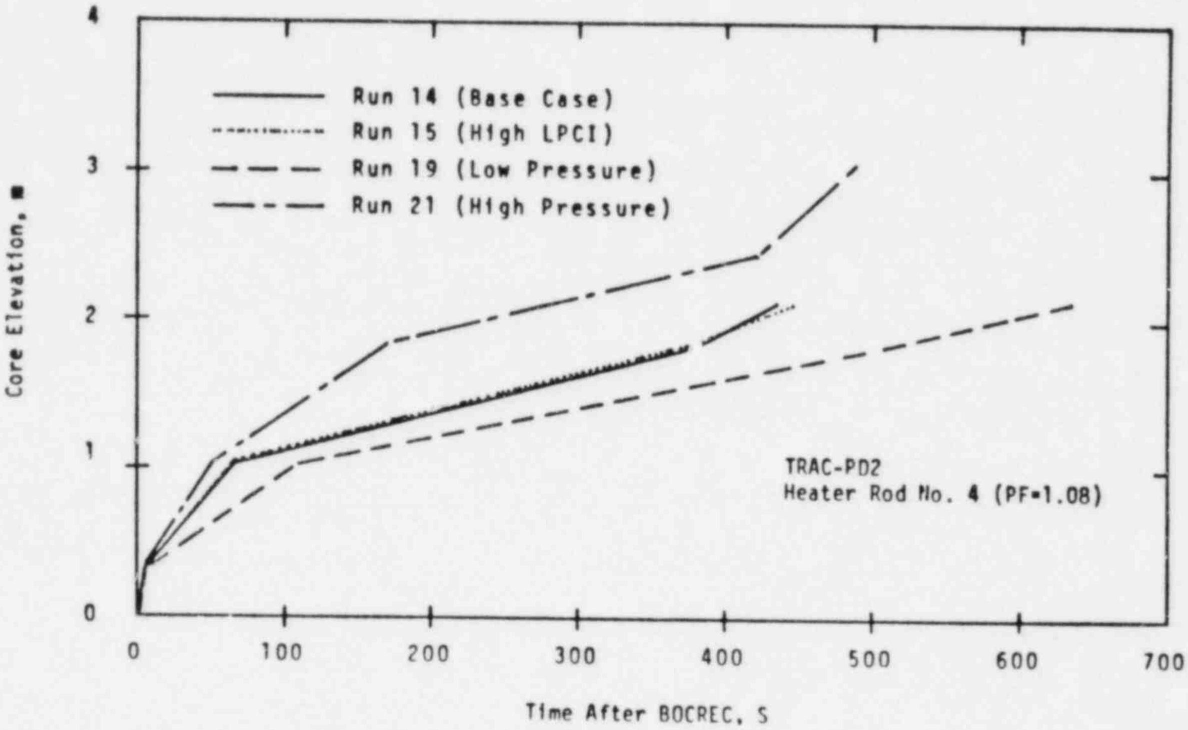


Fig. 5. Comparison of TRAC-predicted quench envelopes for CCTF parametric-effects tests.

B. CCTF Multidimensional-Effects Calculations (F. Motley)

To assess the multidimensional capabilities of the TRAC code against CCTF data, a fine-node vessel model (see Fig. 6) with the four loops modeled independently was used to analyze the CCTF base-case test (Run 14) and for a "blind" prediction of the CCTF multidimensional test (Run 39).[7] The fine-node base-case calculation showed improvement over the coarse-node calculation in estimating quench times and yielded the one-dimensional core behavior observed in the data (LA-2D/3D-TN-81-29).

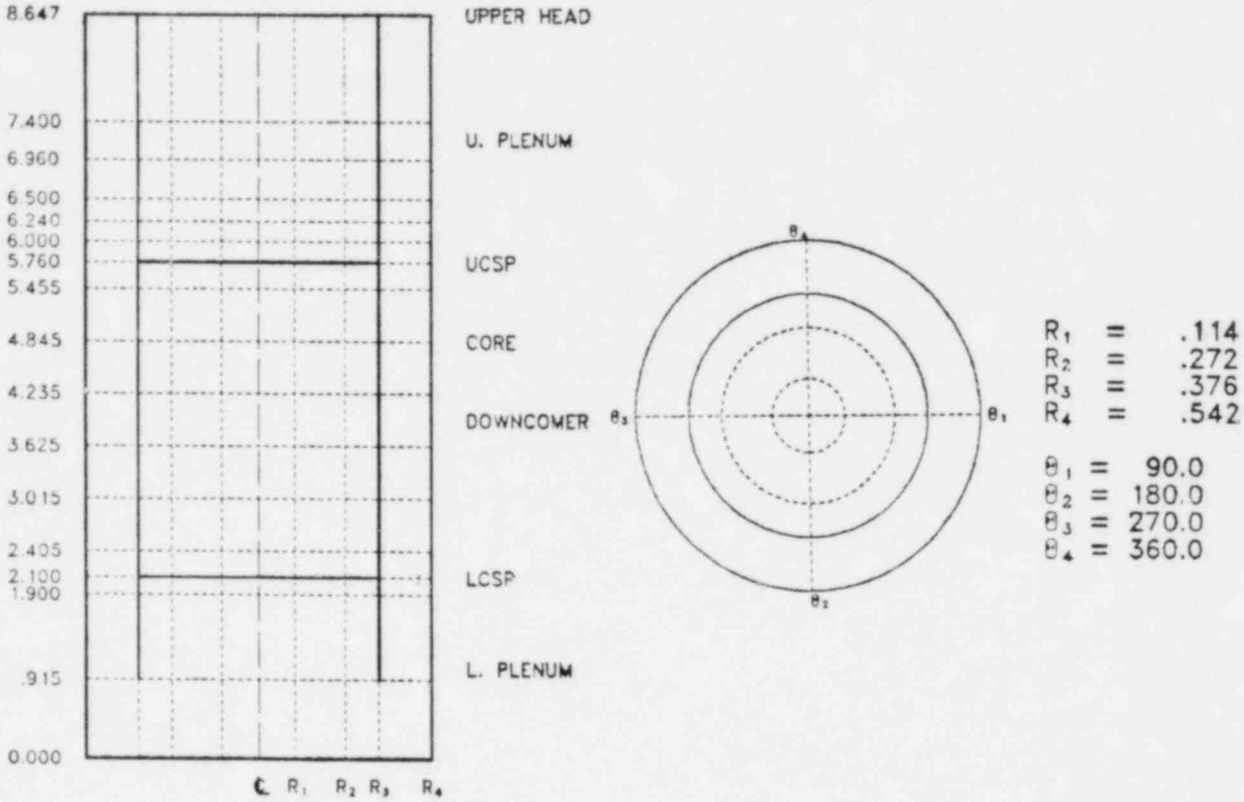


Fig 6. TRAC fine-node vessel model for the CCTF multidimensional tests.

By preferentially heating the rods across the CCTF core, an initial temperature distribution with a skew of up to 350°C was established for the multidimensional test. The "blind" test prediction showed excellent agreement with the data, particularly in the core temperature history comparisons both axially and across the core (LA-2D/3D-TN-81-28).[8] Figures 7 and 8 show actual data and code comparisons at the core midplane from the JAERI quick-look report for Run 39. Note that, although the thermal skew remains at the peak clad temperature turnaround time, the peak temperatures differ by only 150°C, whereas the initial skew was about 350°C. The midplane quench times for both sides of the core are comparable (see Fig. 9); this implies essentially one-dimensional hydraulic behavior, but with multidimensional thermal effects.

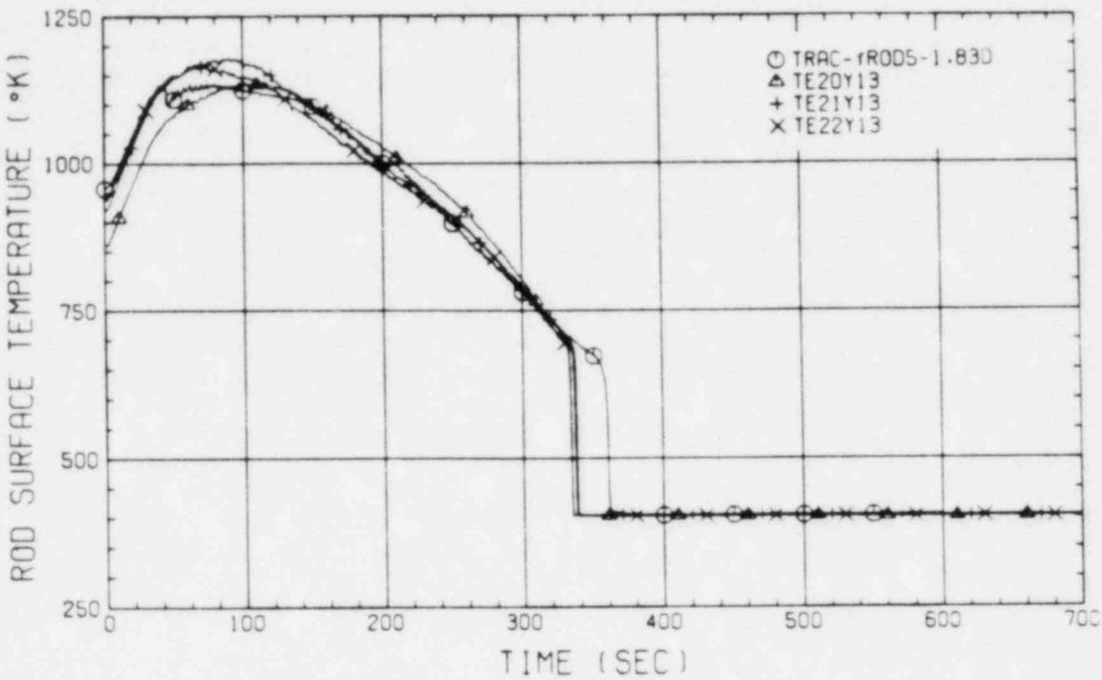


Fig. 7. TRAC and CCTF Run 39 midplane temperature histories - hot side of core.

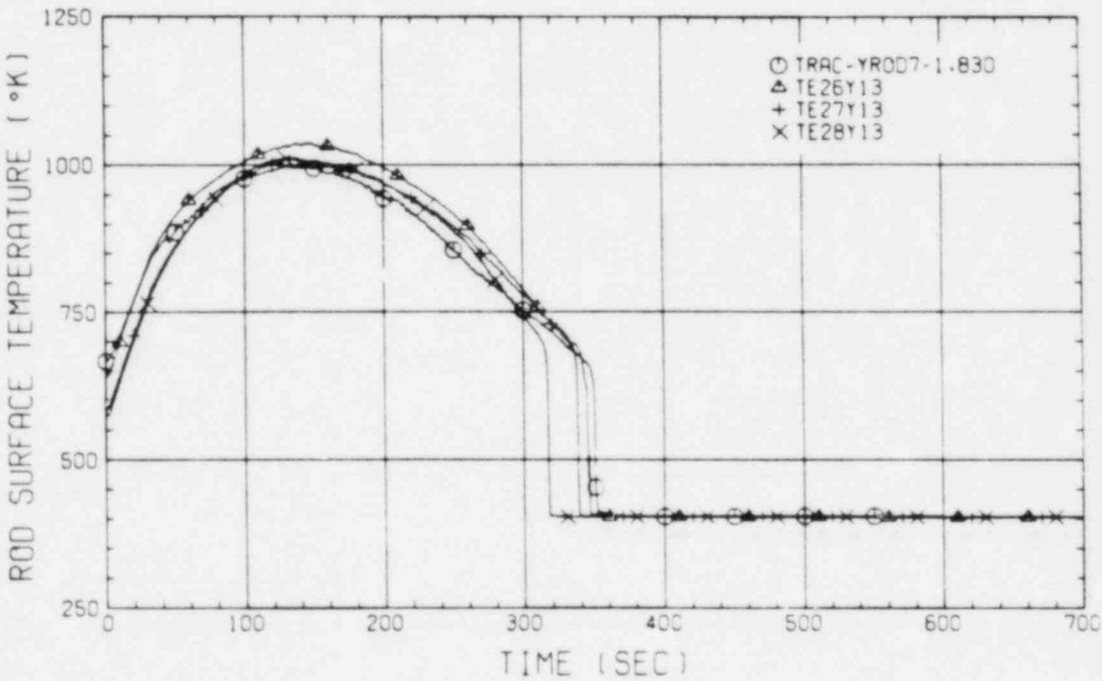


Fig. 8. TRAC and CCTF Run 39 midplane temperature histories - cold side of core.

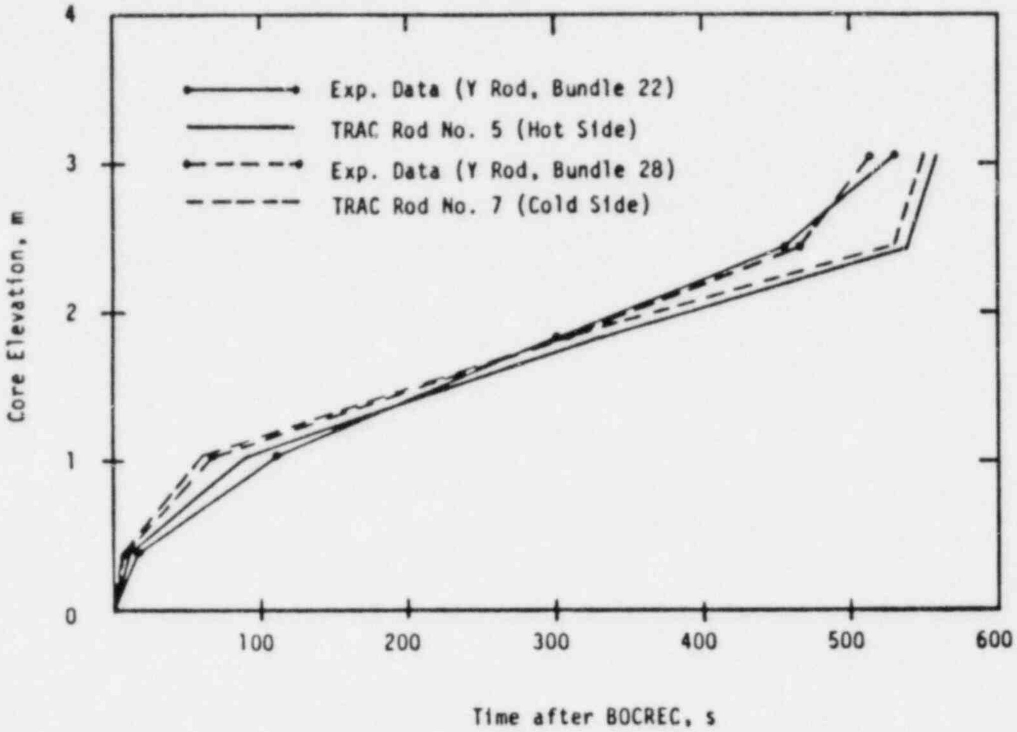


Fig. 9. Comparison of TRAC and measured quench envelopes for CCTF Run 39.

C. CCTF/TRAC Analysis Support (T. Brown, R. Fujita F. Motley, T. Okubo, J. Sugimoto*, and K. Williams)

In addition to the calculational work with TRAC described previously, a substantial effort was expended to understand the CCTF facility and experimental data better to aid in assessing our calculational results and to draw conclusions from our work that would affect reactor safety issues. Several detailed technical notes were issued that discussed specific topics in depth; these included: 1) an analysis of the uncertainty in reported ECC flow rates and its impact on obtaining a system mass balance (LA-2D/3D-TN-81-2), 2) a review of past refill experiments as an aid in running CCTF refill tests (LA-2D/3D-TN-81-6), 3) a simplified TRAC core model assessment calculation of the CCTF-FLECHT coupling test (LA-2D/3D TN-81-9), 4) comparison of the effect

*JAERI resident engineer at Los Alamos, 1980-1981.

of vessel azimuthal noding selection on TRAC-calculated CCTF results (LA-2D/3D-TN-81-11), 5) a detailed analysis of CCTF Run 20 experimental data (LA-2D/3D-TN-81-13), and 6) a detailed comparison and evaluation of the base-case and parametric-effects tests data (LA-2D/3D-TN-81-16).

III. SLAB CORE TEST FACILITY (SCTF)

To complement the CCTF analytical activities and further assess the TRAC reflood predictive capabilities, SCTF analytical work concentrated on establishing an accurate facility input model for TRAC, "blind" predictions of the parametric-effects tests, and detailed analyses of experimental and calculated results.

A. SCTF Shakedown Tests and TRAC Modeling (S. Smith and R. Fujita)

Because the most rigorous test for any analytical model is a prediction for a facility before it has ever operated, a "double-blind" TRAC pretest prediction of the very first SCTF shakedown test, Run 501, was performed (LA-2D/3D-TN-81-4). This high-ECC-injection-rate forced-flooding test was predicted to quench the entire core within 100 s of the start of accumulator injection, with a peak clad temperature of about 760 K. The very fast quenching and resulting system pressurization led to discovery of a programming error in a TRAC heat transfer subroutine: the pressure dependence in the minimum film boiling temperature correlation had been suppressed. Upon correcting the error and recalculating this shakedown test, more reasonable quenching times were predicted (LA-2D/3D-TN-81-5). An independent, detailed data analysis by R. Fujita (LA-2D/3D-TN-81-14), who was on assignment to JAERI at the time, indicated that good agreement between prediction and data was obtained.

Based upon information obtained by Fujita while on assignment and technical meetings with our JAERI colleagues, a detailed revision of the TRAC input model for SCTF was undertaken in preparation for the parametric effects tests calculations (LA-2D/3D-TN-81-17). The documentation of this effort is of particular importance: review of our calculational model by 2D/3D Program participants provides us with an additional quality assurance check.

Comparison of our input model with a recent SCTF design report[9] indicates that an accurate system model is in use.

One discrepancy in the TRAC calculations of the SCTF shakedown tests was the predicted heater-rod adiabatic heatup rate. Initially, this problem was thought to arise from multidimensional and radiation effects in the core, but subsequent analyses showed that the manufacturer's values for the heater-rod material properties were in error. It was demonstrated that the CCTF heater-rod properties, which have the same composition as those of SCTF, when used for TRAC calculations of SCTF yield excellent agreement with measured heatup rates (LA-2D/3D-TN-81-21).

B. <u>SCTF Parametric Effects Test and Analysis</u> (S. Smith and Y. Sudo*)

To complement the CCTF parametric effects tests, the same TRAC-PD2/MOD1 code version was used to perform "blind" predictions of the SCTF forced-flooding companion tests: the base-case test (Run 507), the high-pressure test (Run 506), and the low-pressure test (Run 508).[10,11,12] Figure 10 shows a

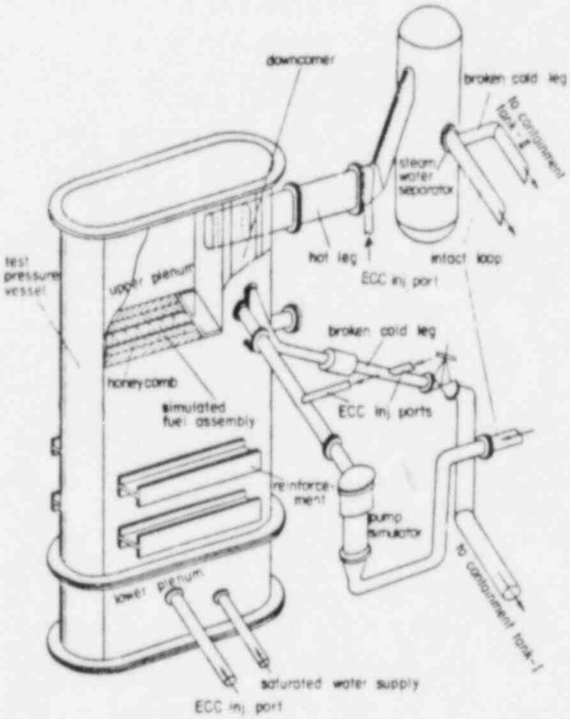


Fig. 10. Sketch SCTF.

*JAERI Visiting Scientist at Los Alamos (September 1981) .

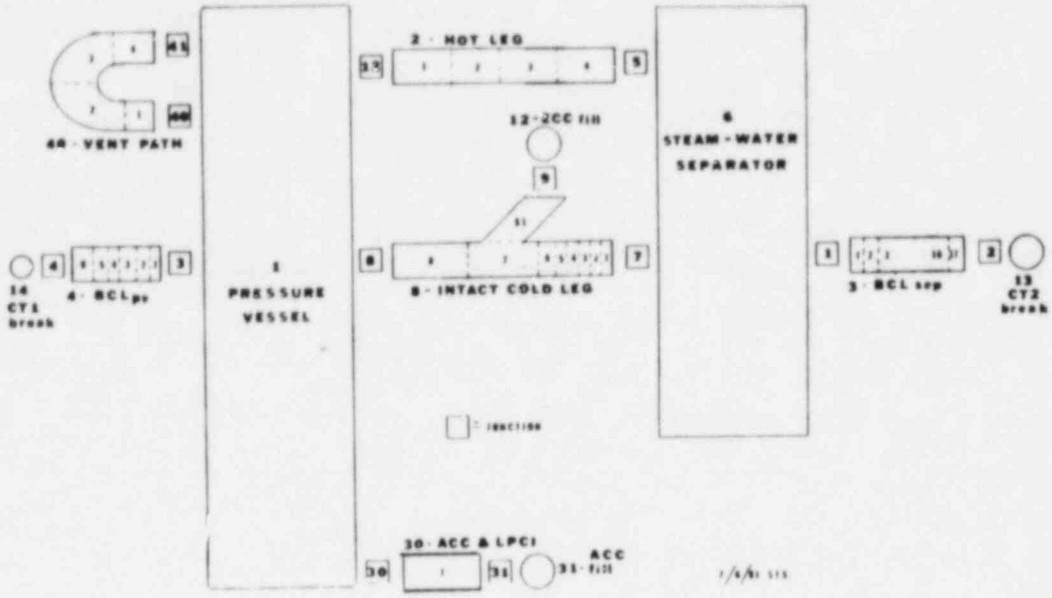


Fig. 11. TRAC system component noding diagram for SCTF.

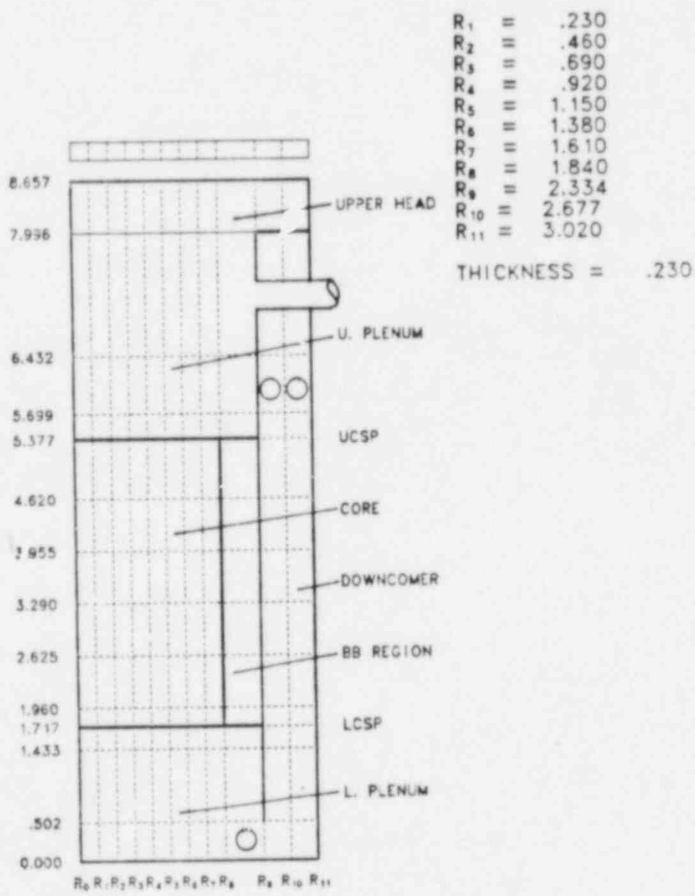


Fig. 12. TRAC vessel noding diagram for SCTF.

schematic diagram of the SCTF. Figures 11 and 12 show the associated TRAC system and vessel models, respectively.

Figure 13 shows plots of the calculated quench-front envelopes compared to experimental data as a function of radial core position for the three pressure-effects tests (LA-2D/3D-TN-81-22, 23, 24, and 33). Bundle 2 is one bundle from the core centerline and Bundle 8 is at the core periphery adjacent to the downcomer. The following important points are noted: 1) TRAC predicts the overall rod temperature transients reasonably well with regard to turnaround temperatures and quench times; 2) the predicted core differential pressures are in excellent agreement with the data; and 3) the general characteristics of liquid carryover are predicted well, but the large amount of steam generation calculated by TRAC's heat transfer package enhances the calculated entrainment rate, thus causing premature quenching on the upper half of the rods.[13]

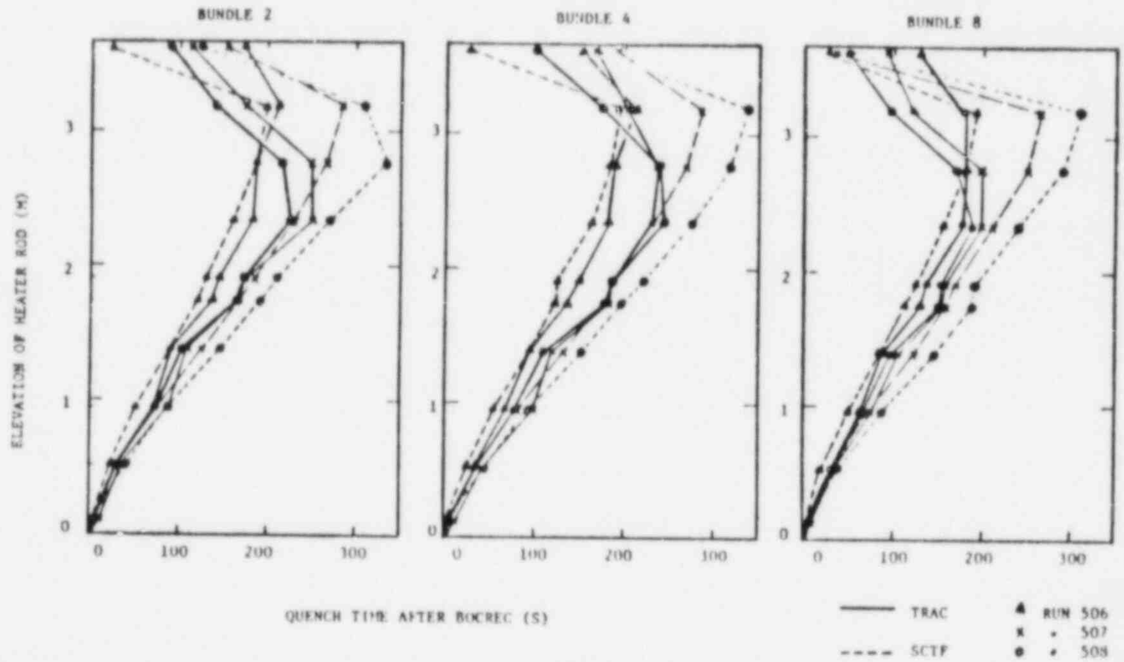


Fig. 13. Comparison of TRAC predicted and measured quench envelopes as a function of core radial position for the SCTF pressure-effects tests.

IV. UPPER PLENUM TEST FACILITY (UPTF)

With shakedown tests currently scheduled to begin in FY 1985, analysis efforts for UPTF have concentrated mainly on design assistance calculations (see Fig. 14 - UPTF schematic). Large system operational transient studies have been postponed in favor of separate-effects studies, which can have a positive impact on facility design. Two areas of critical importance that are under investigation are loop behavior with ECC injection and core simulator performance.

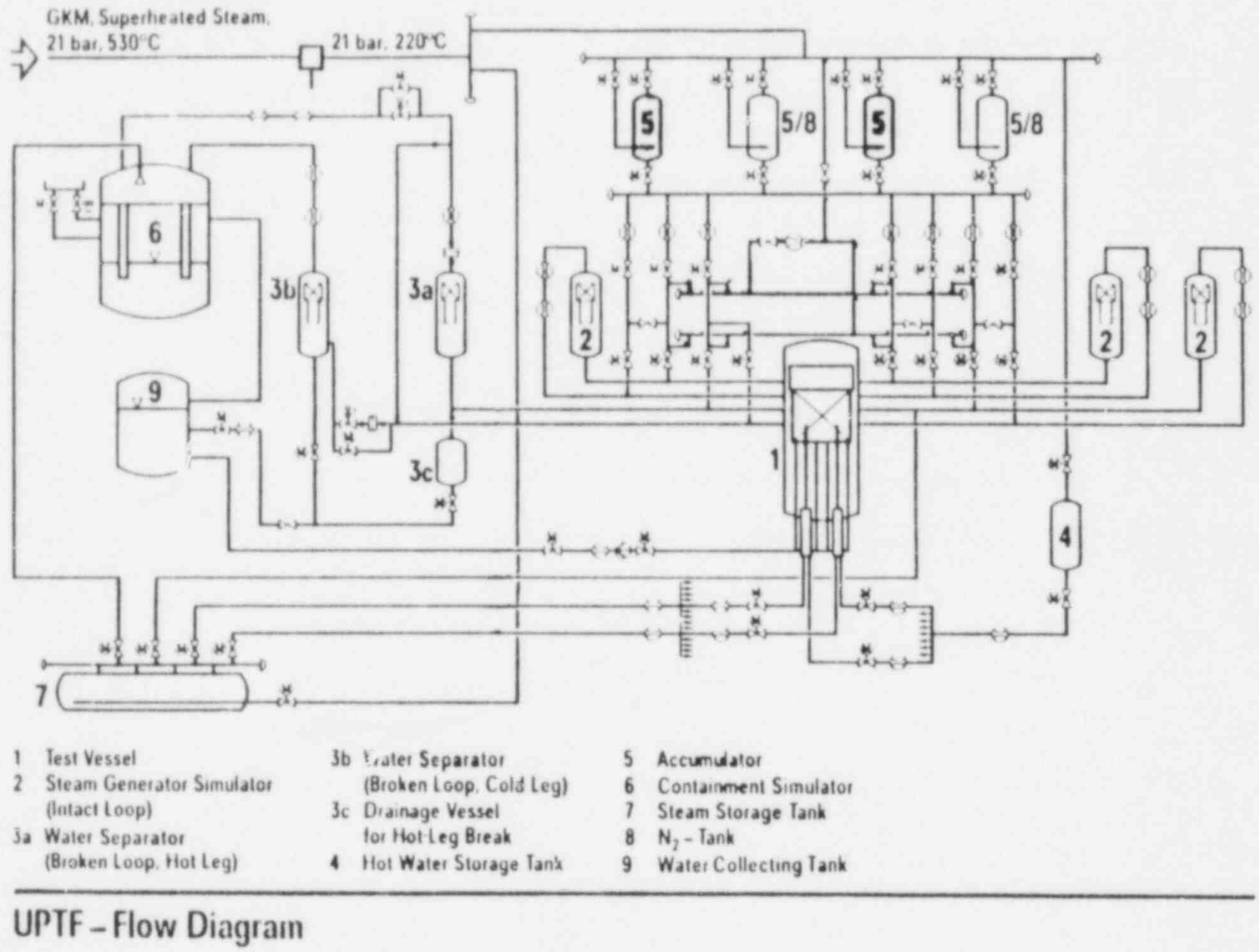


Fig. 14. UPTF system schematic.

A. Loop Oscillation Studies (M. Cappiello and F. Motley)

Past applications of the TRAC code to study combined-injection PWR LOCAs have always predicted ECC condensation-induced oscillations in the intact loops. This was perplexing because this behavior was entirely unexpected, at least in the hot legs, although it had been encountered in cold-leg injection ECC separate-effects tests. In retrospect, the occurrence of loop oscillations during combined-ECC injection should not have come as a complete surprise. Consider the following situation: initially, a strong positive steam flow (hot to cold leg) is established during blowdown for a cold-leg break; then, ECC-accumulator injection into the hot and cold legs is initiated as the primary system pressure drops below the accumulator set-point pressure; this creates a lower local pressure at the ECC-injection ports, and for the hot leg, serves to increase the steam flow rate; a simple momentum balance, neglecting condensation effects, shows that a small differential pressure across the injection port (about 20 mbar) is sufficient to reverse the hot-leg injected ECC flow, which is jetting toward the upper plenum; once the ECC flow reverses, it condenses steam in the piping and accelerates toward the steam generator; upon penetrating the steam-generator tube bundle, the higher secondary-side temperature causes flashing of the ECC liquid in the primary side; once enough steam is generated in the steam generator, the pressure differential reverses in the hot leg and the ECC liquid is driven toward the vessel (see sequence from TRAC calculations in Fig. 15); finally, the loop pressure imbalances driven by condensation can set up further oscillations. However, there was still good reason to suspect that such oscillations might be numerical anomalies; hence, a detailed program to study the problem was conducted during FY 1981.

1. TRAC Numerics

By extracting calculated loop boundary conditions from the German PWR (GPWR) calculation or assuming no differential pressure across the loop, separate-effects loop calculations were run to determine whether the TRAC numerics could model the combined-injection problem adequately. Results showed that, with certain boundary conditions, numerical plugging of the hot leg could induce flow oscillations with the use of the drift-flux model in TRAC-PD2 (LA-2D/3D-TN-81-1). In the second phase of this study, the same

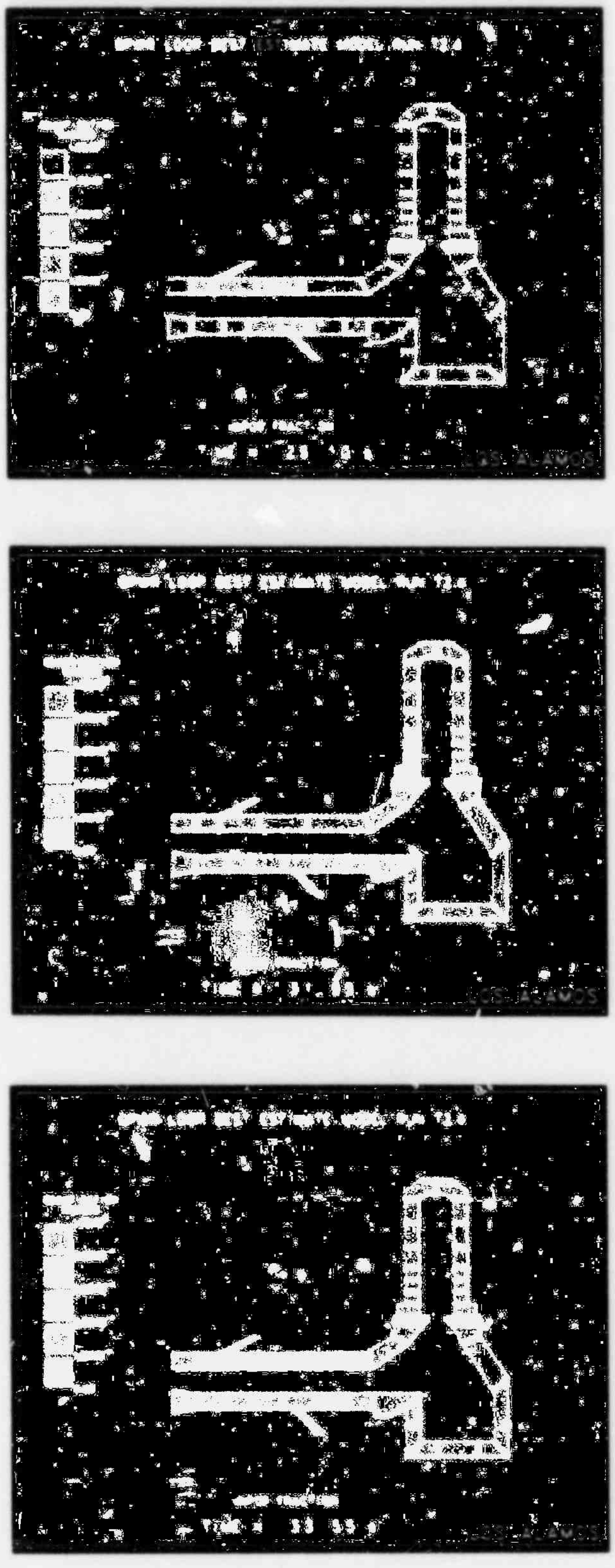


Fig. 15. Sequence of a TRAC-calculated combined-injection loop oscillation.

problem was investigated using the new two-fluid model in TRAC-PF1. The capability to model the counter-current flow problem in the hot leg was demonstrated; however, under certain flow conditions, oscillations were still predicted (LA-2D/3D-TN-81-3). This phenomenon was traced to sensitivity to the condensation model, indicating that further assessment against data was warranted.

2. TRAC ECC Modeling Assessment

To investigate the condensation model in TRAC-PF1 further, the code was used to model the Westinghouse cold-leg injection mixing tests.[14] Good agreement between code predictions and data was obtained for the tests analyzed, which spanned the range of flow conditions from co-current to oscillatory plug flow. The Stanton-number condensation heat-transfer coefficient that gave best agreement with data corresponded to the assessed TRAC-PD2 value (LA-2D/3D-TN-81-7). This ECC mixing study subsequently was adopted for use in assessing new code versions. Comparable agreement with data has been required before adopting new code versions for use in this program (LA-2D/3D-TN-81-15).[15]

3. GPWR/UPTF Loop Behavior

With the aforementioned studies completed, reasonable confidence that the TRAC code was not predicting loop oscillations artificially was achieved. This was supported by experimental results obtained by CREARE (our subcontractor, see Chapter VI.A.). A full GPWR system calculation of the refill phase of the LOCA then was calculated with TRAC-PF1, which has a stratified-flow, two-fluid model for loop components. As previously, condensation-induced oscillations were predicted in the hot and cold legs (LA-2D/3D-TN-81-8). The importance of system effects in driving these oscillations was also demonstrated (e.g., active steam generators and primary coolant pumps).

Separate-effects loop studies then were performed to compare the GPWR loop behavior against that of UPTF. The GPWR loop noding was updated to include more detailed information provided by our German colleagues. Loop calculations with boundary conditions from the previously discussed GPWR results yielded excellent agreement with the system calculation. This allowed us to perform relatively simple and economical parametric studies, confident that the results reasonably matched full system calculations (LA-2D/3D-TN-81-18). Comparison calculations with a UPTF loop simulation then were performed. Comparable agreement with the GPWR hot-leg results was achieved, but the cold leg differed significantly because of reverse ECC flow through the pump simulator into the loop seal (LA-2D/3D-TN-81-20). Further review of operational methods to obtain more prototypical response from the passive UPTF components is warranted.

B. Core Simulator Studies (M. Cappiello and F. Motley)

The UPTF facility will use a feedback-controlled, steam-water core simulator in place of a heated core to drive the facility. This will mean that a detailed understanding of transient flooding phenomena at the core/upper plenum interface will be required for simulator control, instrumentation interpretation, and TRAC modeling. To assess TRAC we have begun to model small-scale flooding experiments with TRAC. To date, predictions of the Kraftwerk Union (KWU) core-simulator tests[16] and the Bankoff perforated plate flooding experiments[17] have shown reasonable agreement with data using the released TRAC-PF1 code version. Further assessment and experiments are warranted, particularly for transient flooding phenomena where hysteresis (inertial) and subcooling effects may be important. A review of the GPWR calculational results was also conducted to aid in these activities (LA-2D/3D-TN-81-19).

V. LARGE PRESSURIZED WATER REACTOR SYSTEM ANALYSES

Two large PWR systems calculations were completed and analyzed in depth during FY 1981. The postulated accident for both efforts was a 200 per cent, double-ended, cold-leg break, with no assumption of multiple failures other than a loss of cold-leg ECC injection in the broken leg. The plants analyzed were a reference* 1100-MWe Westinghouse design (similar to Zion/Trojan) and a reference 1300-MWe Kraftwerk Union combined-injection design (similar to Grafenrheinfeld). Both calculations exhibited strong multidimensional effects, as will be described in the remainder of this section.

*Reference design refers to a generic plant type and not a specific plant.

A. Reference USPWR (Westinghouse) LOCA Analysis (J. Ireland)

Using input and plant configuration conditions from several sources,[18,19,20] a detailed input model of a reference cold-leg injection Westinghouse plant was constructed. Figures 16 and 17 show the TRAC noding for the system and the vessel, respectively. A total of nearly 750 nodes was used in this TRAC-PD2/MOD1 calculation, with 440 cells in the three-dimensional vessel and the remainder modeling the four loops. Note that the vessel noding explicitly models the downcomer, lower plenum, core, barrel-baffle region, upper plenum, and upper head. This enabled direct calculation of multidimensional effects, such as refill bypass. A steady-state calculation was then run to set consistent initial conditions comparable to typical plant values for the transient. The transient then was calculated in a single pass from blowdown through refill until the end of reflood with the same code and input model.

TYPICAL USPWR TRAC SCHEMATIC

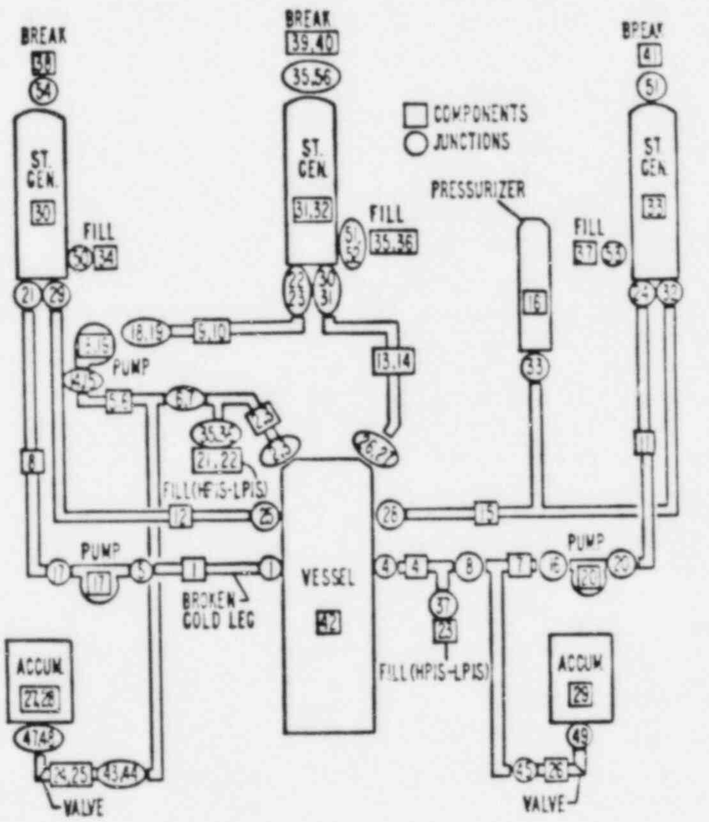


Fig. 16. TRAC system noding schematic for reference USPWR calculations.

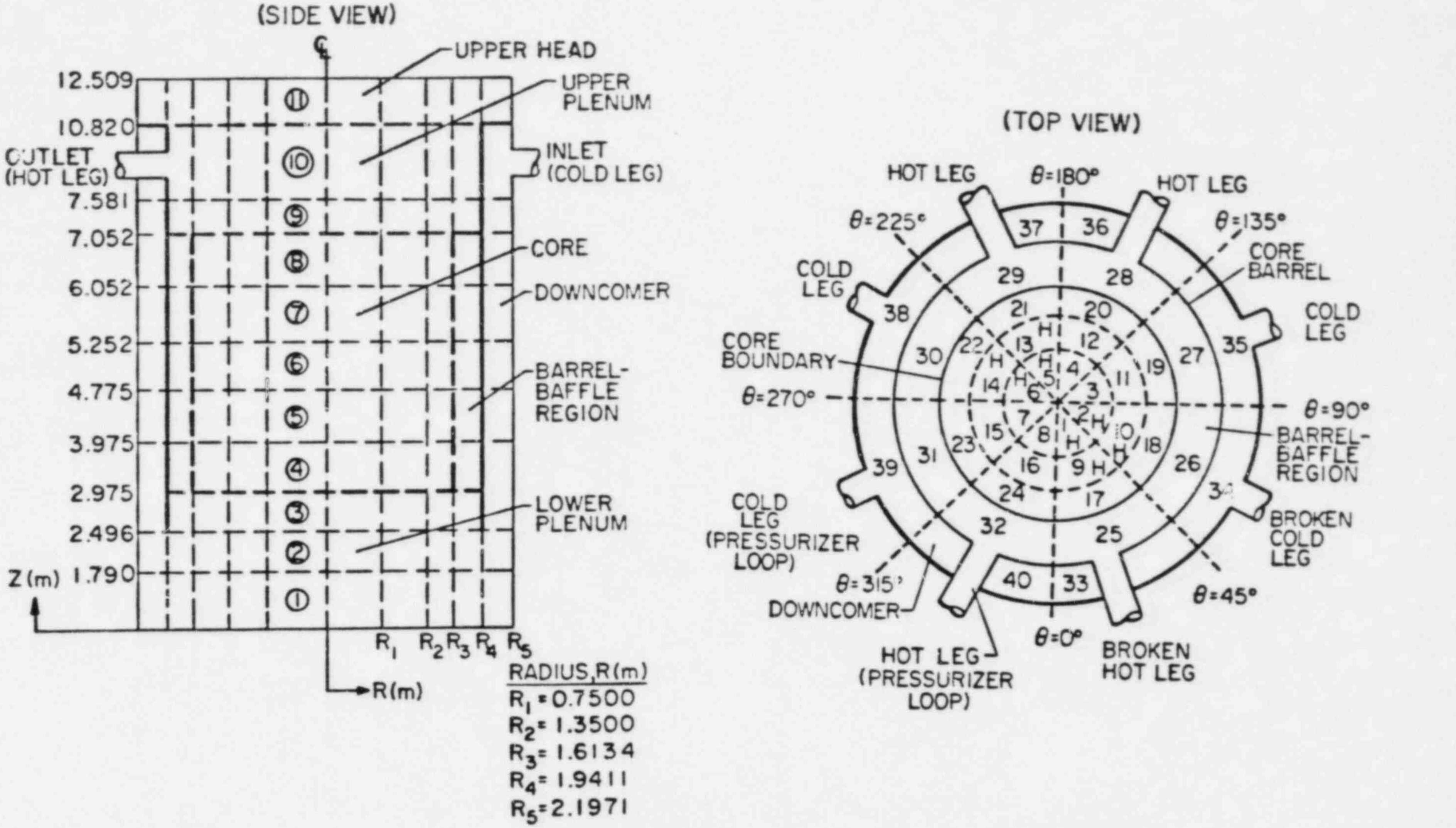
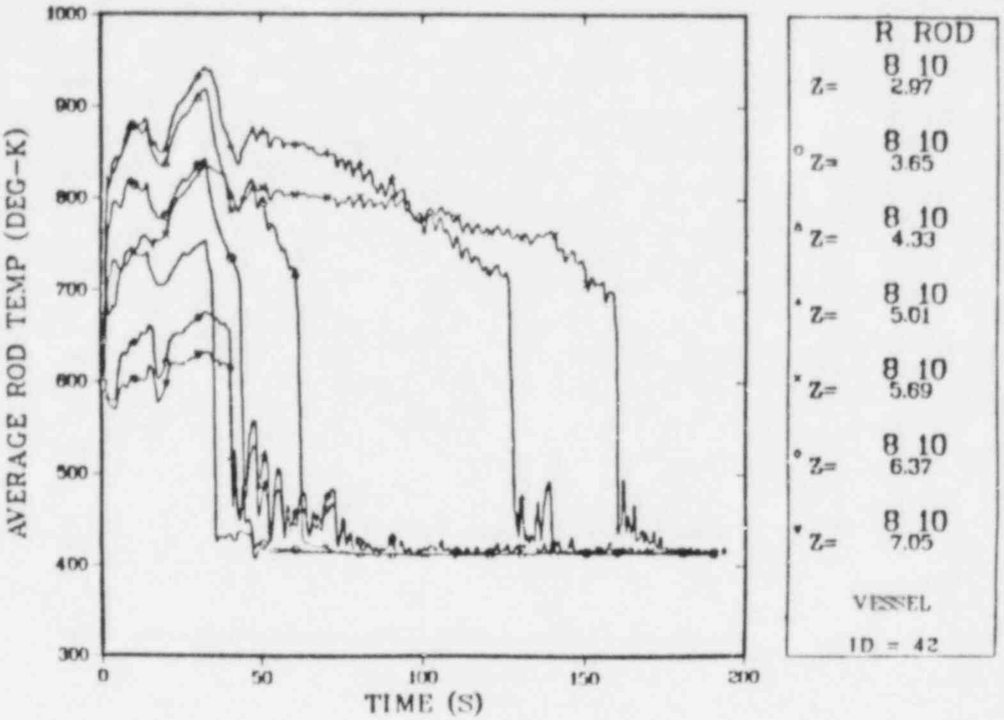


Fig. 17. TRAC vessel model for reference USPWR calculations.

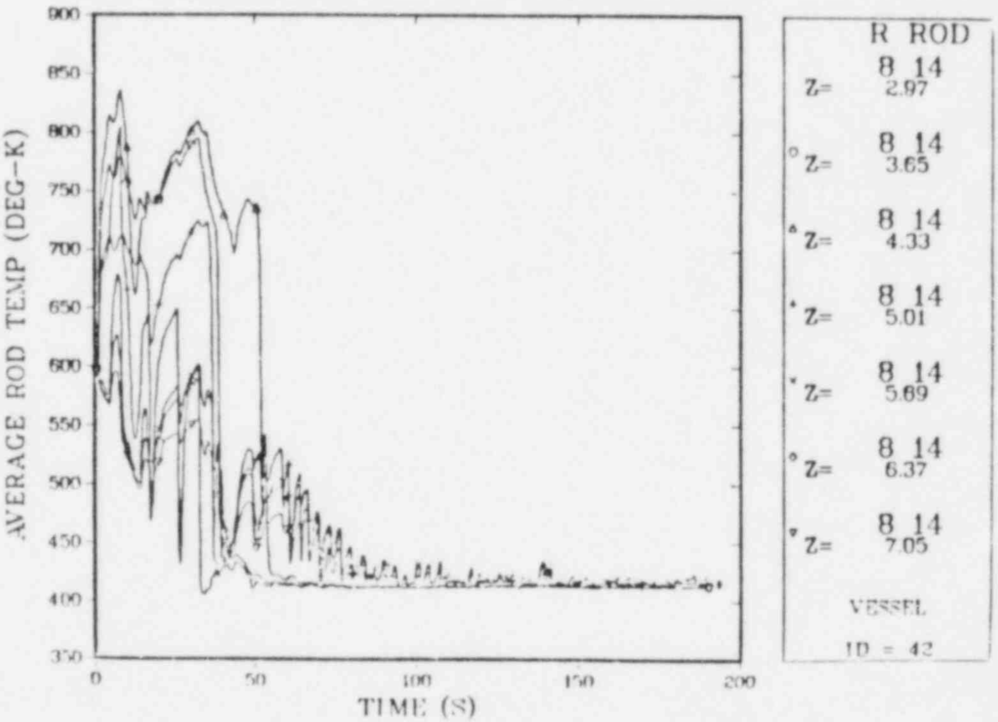
The important conclusions of this best-estimate analysis were (LA-2D/3D-TN-81-10):

1) The peak clad temperature of 950 K (1220^{o}F) occurred during <u>blowdown</u>.
2) An ECCS bypass period was calculated from approximately 12 to 26 s during blowdown.
3) The lower plenum refilled at 36 s (reflood initiated).
4) Both bottom and falling-film quench fronts were calculated during reflood.
5) A small pool (0.3 m deep) was formed above the upper core support plate (UCSP) by liquid carryover from lower core regions during reflood.
6) The midplanes of all fuel rod were quenched by 130 s.
7) Complete core quenching occurred by 190 s.
8) The core liquid fraction during reflood varied between 25-35 per cent because of manometer type oscillations between the downcomer and core.
9) Strong multidimensional effects were calculated, particularly with regard to rod quenching. Some rods located in core regions closest to the intact cold legs quenched 125 s sooner than rods located next to the broken loop because of cooling during blowdown and refill and asymmetric vessel filling during reflood. Figure 18 shows an average rod temperature history from the cooler side of the core (Cell 14 - see Fig. 17) and a corresponding rod temperature history from the hotter side (Cell 10).

Several interesting aspects of this calculational result that are corroborated by other 2D/3D Program results, both experimental and analytical, are worth noting. The thermal-hydraulic response matches many aspects of the CCTF results to date. For example, in the high-ECC-flow-rate CCTF test there was substantial <u>reflood</u> bypass of liquid out the break; this same result was calculated with TRAC for that test and in this PWR analysis (roughly 50 per cent bypass). Formation of a liquid pool in the upper plenum during reflood was calculated and also was observed in data. This liquid was available to feed falling-film quench fronts. The calculated bottom reflooding of the core showed liquid accumulation in the cold side of the core helping to flood the



Hot side of core.



Cold side of core.

Fig. 18. Multidimensional aspects of core cooling in reference USPWR calculations.

hot side; hence, there was a tendency toward one-dimensional hydraulic behavior, which helped minimize thermal skews resulting from asymmetric cooling during blowdown and refill. This same behavior was observed experimentally and calculated with TRAC in the CCTF multidimensional test (see Sec. II.B).

B. Reference GPWR (Kraftwerk Union) LOCA Analysis (F. Motley)

A companion analysis to the Westinghouse PWR calculation was performed for a Kraftwerk Union (KWU), 1300-MWe, combined-injection plant. Figures 19 and 20 show the system and vessel noding, respectively. (Figure 20 is a frame from a color movie showing the transient void fraction superimposed on the vessel noding schematic.) Note that more levels were used in this vessel model to model upper-plenum pool dynamics better. Because this calculation was completed at the beginning of the fiscal year, an older TRAC-PD2 code version was used to obtain the steady-state conditions and calculate a once-through transient.

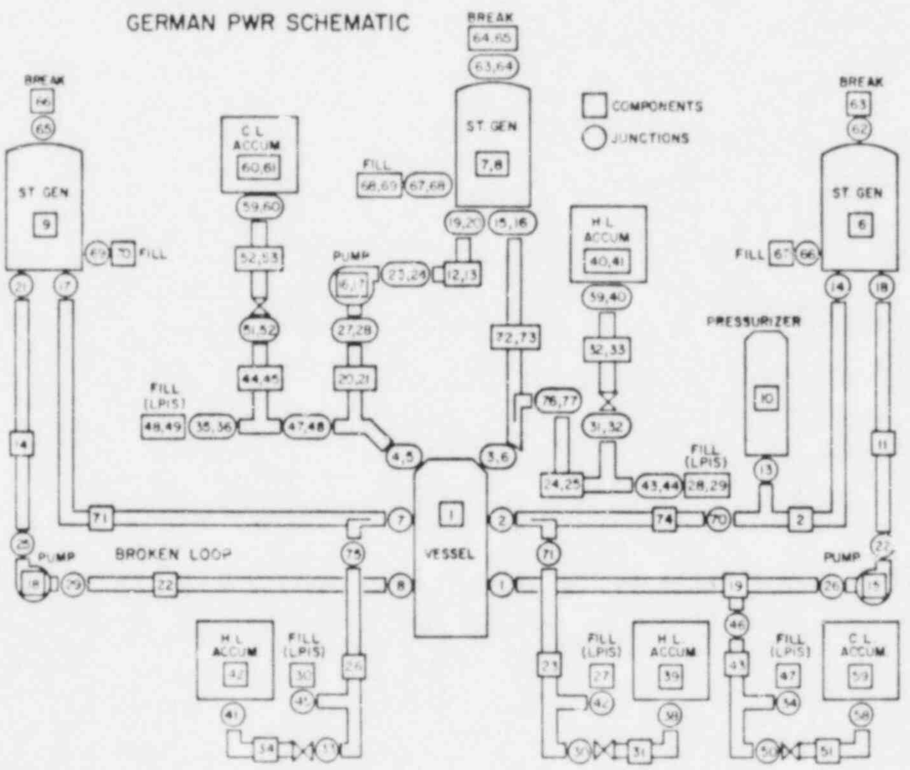


Fig. 19. TRAC system noding schematic for reference GPWR calculation.

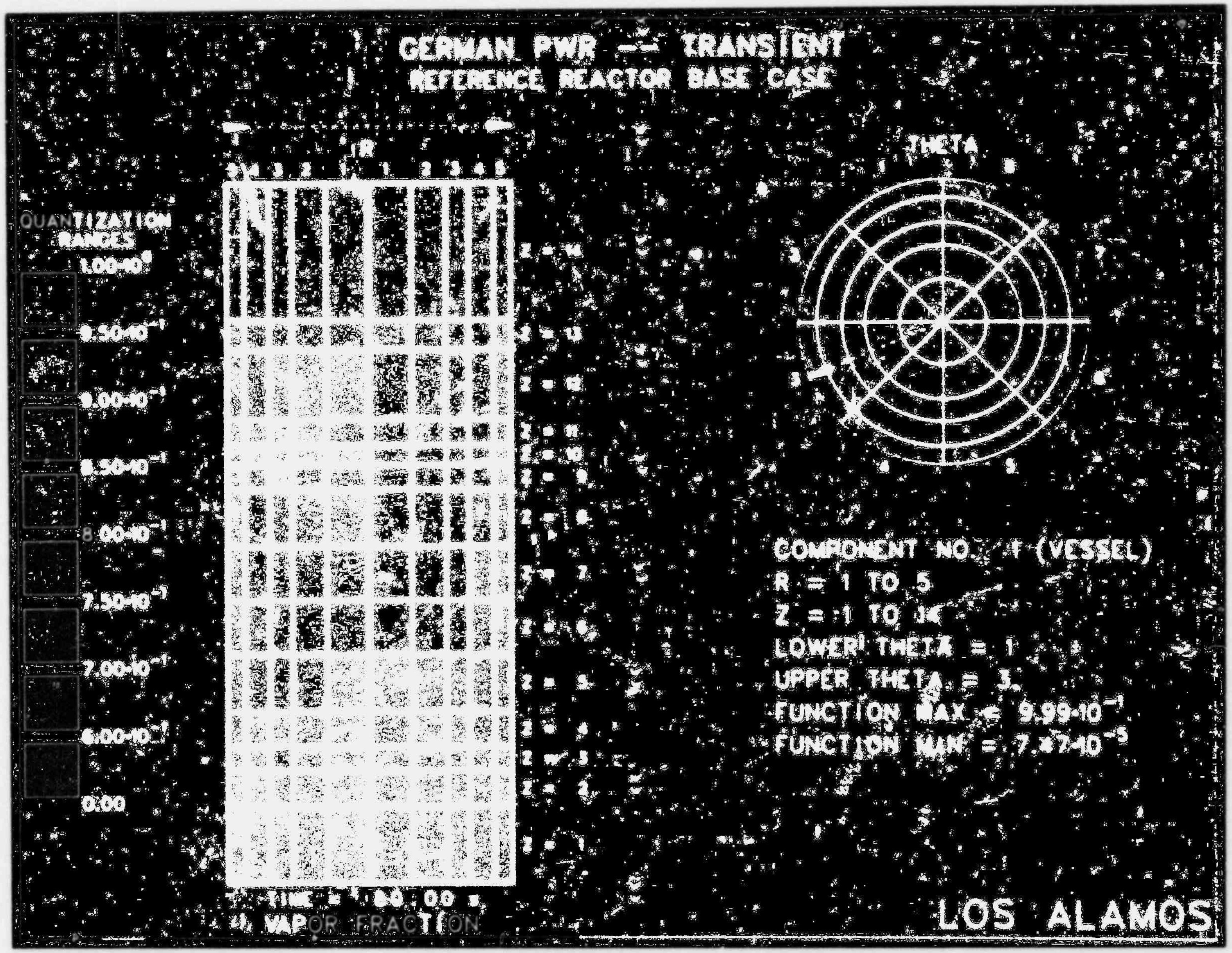


Fig. 20. TRAC vessel model for reference GPWR analysis with superimposed void fractions at 80s.

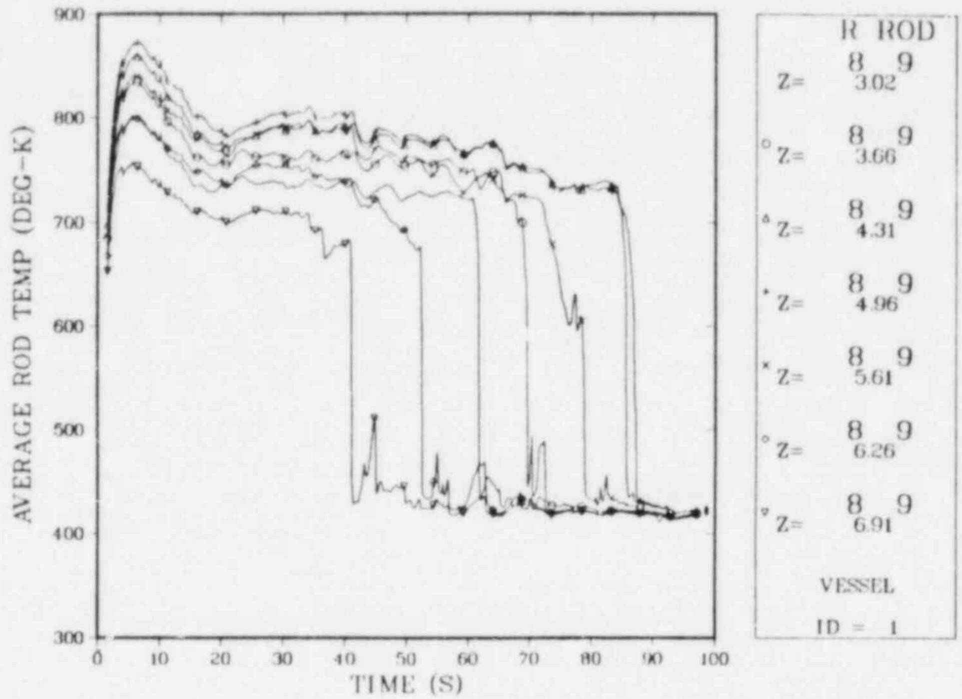
The important conclusions of this best-estimate analysis for a reference GPWR were (LA-2D/3D-TN-81-32):

1. A peak core temperature of 875 K (1115^{o}F) occurred during blowdown.
2. The ECC system was able to quench the entire core within 100 s.
3. Significant amounts of ECC fluid formed a large pool in the upper plenum, resulting in multidimensional liquid penetration into the core. Figure 20 shows the large quantity of liquid stored in the upper plenum and the preferential draining of this pool in cooler regions of the core. Figure 21 shows the resultant thermal skew across the core from this multidimensional behavior. Note that quenching occurs by combined falling-film and bottom quench fronts.
4. There was oscillatory behavior in the intact loops caused by the mixing of subcooled ECC water and steam, which is in reasonable agreement with separate-effects tests[14,21] and analytical studies. Also, once a substantial pool of water is established in the upper plenum, additional ECC injection causes loop oscillations.

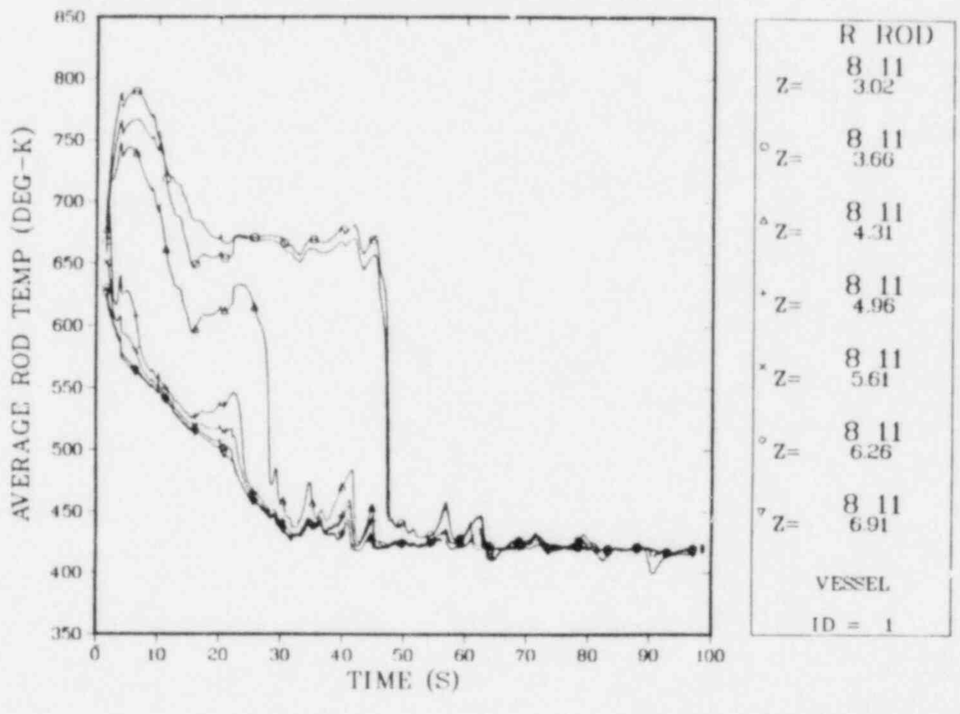
C. LPWR Comparative Analysis

The main conclusion from these PWR analyses is that best-estimate TRAC calculations show substantial margins below current licensing assumptions for peak clad temperature: less than 1000 K (1300^{o}F). To preclude one-to-one comparisons between these calculations, the following important differences should be noted:

1. The GPWR calculation was done with essentially the released version of the TRAC-PD2 code, whereas the Westinghouse calculation was done with TRAC-PD2/MOD1 plus updates.
2. The Westinghouse plant was an older 15 x 15 rod bundle design, the KWU plant was a newer 16 x 16 rod bundle design; hence, the differences in peak clad temperature during blowdown are attributable mainly to stored energy in the fuel rods.
3. The combined-injection design has accumulator injection in all hot and cold loops (except the broken cold leg), a lower set-point for injection (26 bars vs 40 bars in the Westinghouse plant), and larger



Hot side of core (broken cold leg).



Cooler side of core (pressurizer loop).

Fig. 21. Multidimensional aspects of core cooling in reference GPWR calculation.

volume accumulators. Hence, a much larger quantity of water injection accounts for a shorter transient duration. Subsequent analysis also uncovered an input error for the assumed hot-leg injection flow rates, which were too low. Correction of this error is not expected to change the results significantly.

4. The volumes of the two systems are different (Westinghouse is smaller); this combined with differences in ECC injection systems and set points accounted for a much faster blowdown in the Westinghouse-plant calculation.

VI. ANALYSIS SUPPORT

In addition to the main areas of activity described in the preceding chapters, a substantial supplementary effort is invested in analysis support for the Program. This has included input on instrumentation requirements (choice, location, ranging, accuracy, and frequency response), a Los Alamos resident engineer at JAERI (R. Fujita, June 1980 - May 1981), small-scale experiments (upper-plenum de-entrainment and CREARE hot-leg injection simulations), subcontracts to review ECC bypass and condensation-induced loop oscillation phenomena (CREARE), basic numerical-modeling research (Fluid Dynamics Group, T-3), and development of a mechanism for data transmittal between the facilities and Los Alamos.

A. Upper-Plenum De-entrainment Experiments (J. Dallman)

This work was funded initially from the Light Water Reactor (LWR) Safety Experiments Program (A7044) and was completed recently under this Program. The objective was to develop a phenomenological model for estimating de-entrainment rates in the upper plenum of a PWR. During a LOCA, the steam-droplet flow generated from the core region during reflood may either de-entrain on the upper-plenum internals or be carried out a hot leg, where it may vaporize in the steam generator and cause steam binding. To quantify this effect, air-droplet experiments in simulated upper-plenum geometries (staggered arrays typical of Westinghouse, Babcock and Wilcox, and KWU designs, and in-line arrays typical of the Combustion Engineering design) were conducted in a wind tunnel (see Fig. 22). Figure 23 shows the measured de-entrainment efficiency of a staggered array for typical reflood flow conditions. A physically based correlation was developed that predicts well these results (solid lines in Fig. 23) for both array configurations.[22,23,24] This model has been applied directly by code developers (COBRA[25]) and reactor safety analysts.

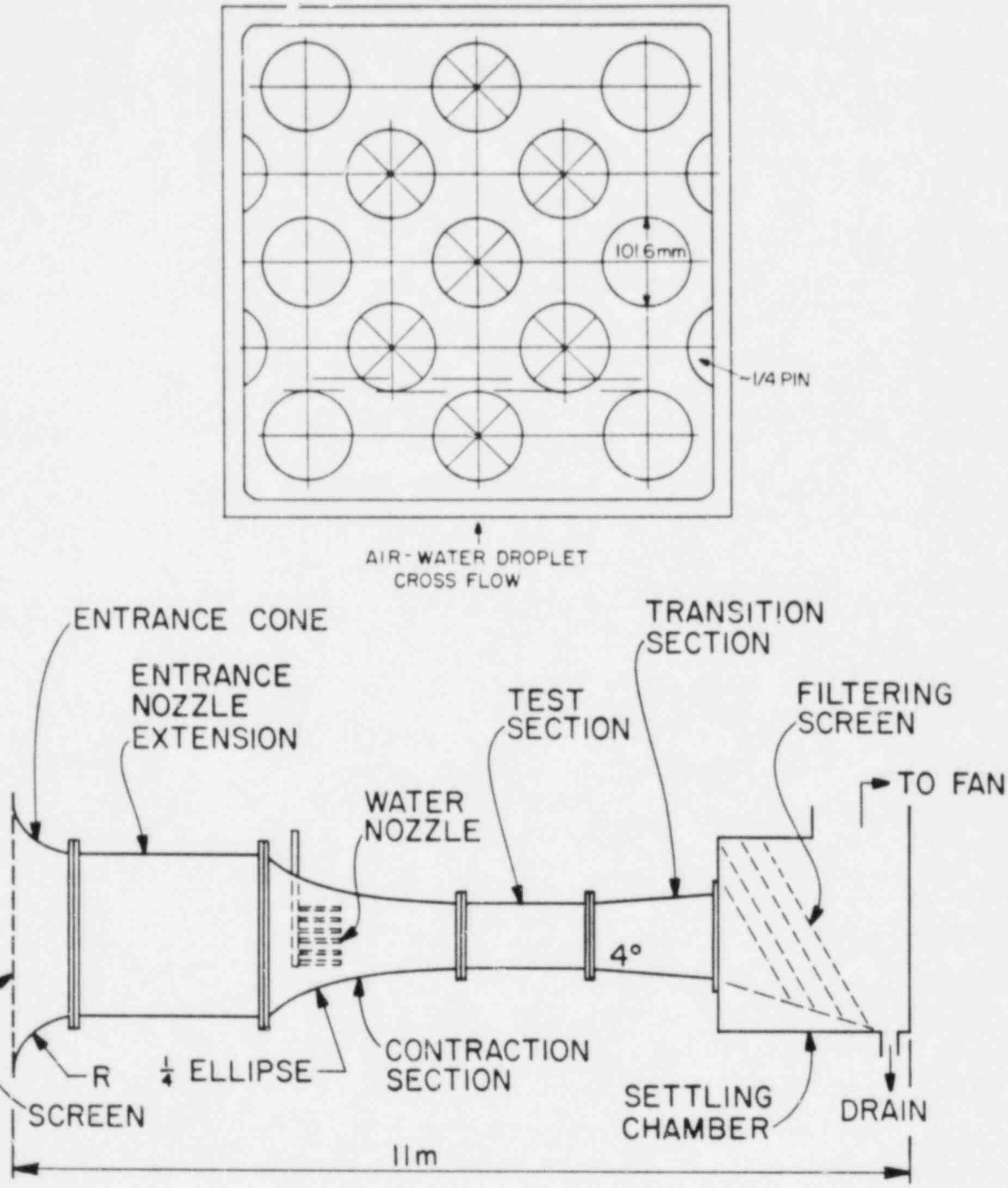


Fig. 22. Upper-plenum de-entrainment experiment wind tunnel and staggered-array test section.

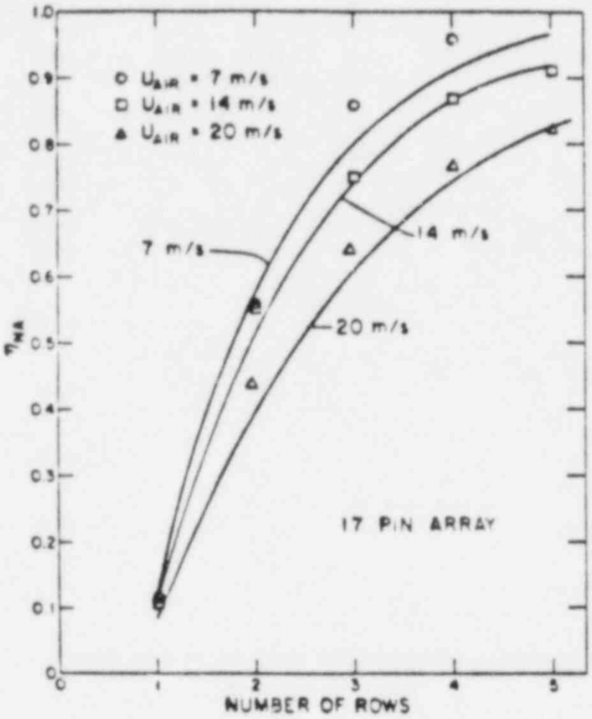


Fig. 23. Comparison of de-entrainment correlation vs data for an upper-plenum stagg..ed array.

B. Flow Reversal Studies (CREARE - P. Rothe)

The occurrence of loop flow oscillations in TRAC calculations of combined-injection PWR LOCAs has met with considerable skepticism in the past. For independent evaluation of the physical basis for such results and to review the code calculations, a subcontract was written to CREARE, Inc. (P. Rothe, Principal Investigator) to perform the following tasks: 1) review and critique the TRAC-PD2 calculation of the reference GPWR loop behavior, 2) perform scaled hot-leg injection separate-effects experiments and analyses, and 3) assess the above relative to operation of UPTF.

Based on the review of the TRAC calculation,[26,27] in which it was concluded that the calculated oscillations were physically reasonable in the cold-leg, and possible in the hot-leg, small-scale experimental simulations (1/5 and 1/10) of the hot-leg injection concept were run through a range of prototypical flow conditions to determine whether reversal of the injected ECC flow would occur in the hot leg (once substantial reversal of flow occurs, oscillations would be expected to follow in a loop configuration). For steam flows in excess of a thermodynamic ratio of unity, completely stable ECC flow reversal was achieved at the injector location, in spite of the liquid jet momentum toward the vessel. (The thermodynamic ratio is a measure of steam "energy" flow to the condensation "energy" potential of the subcooled liquid. A ratio less than one implies the capability to completely condense the steam flow, under equilibrium conditions.) For thermodynamic ratios less than unity, a region of flow reversal and plug oscillations in the pipe was observed.[28] This flow regime corresponded to GPWR estimated flow conditions.

Recommendations for UPTF operation were made based on these studies. They included: 1) planning for condensation-induced oscillations in the loops, 2) examining ways to operate UPTF to suppress these oscillations for separate-effects studies (blanking-off loops for vessel-only tests, steam injection in the loops, etc.), and 3) further modeling experiments at small-scale to study these phenomena.

C. Fluid Dynamics Analysis (B. Daly, Fluid Dynamics Group, T-3)

Detailed numerical analyses of the ECC-injection hot-leg flow-reversal problem and spatial distribution of ECC liquid that reaches the upper plenum have been completed in support of the TRAC GPWR calculations. Using the K-TIF code (a multidimensional, incompressible, two-fluid code), sensitivity studies were conducted to model counter-current steam-water flows in large horizontal pipes. Results indicated that relatively small pressure drops, about 20 mbar, were sufficient to cause reversal of liquid flow.[29] This result is compatible with TRAC-calculated GPWR flow conditions during the refill phase of a LOCA.

The detailed study of ECC injection into the upper plenum was performed to demonstrate the capability to model this complicated phenomenon and to provide guidance in developing macroscopic models for TRAC for use in systems calculations. K-FIX (a generalized, multidimensional, two-fluid code) was used initially to model air-water upper-plenum ECC-injection experiments that were performed in Germany (see Fig. 24). Reasonable agreement with data was achieved, although the stair-step representation of the circular control rod guide tubes was found to overestimate momentum exchange effects, resulting in less than measured liquid penetration to inner regions of the upper plenum.[30] K-FIX calculations[31] of ECC flow past individual columns of stair-step, square, and circular cross section indicated that approximately 40 per cent less flow was de-entrained by the circular column than by the stair-step or square configurations, and the de-entrainment occurred in the wake of the circular column but in front of the other shape columns. These results indicate that calculations of ECC flow past an array of circular control rod guide tubes would be in better agreement with experiment. This prompted a recalculation of the upper-plenum study with the SALE-3D code,[31,32] which allows a more nearly circular representation (octagon) of the guide tubes.

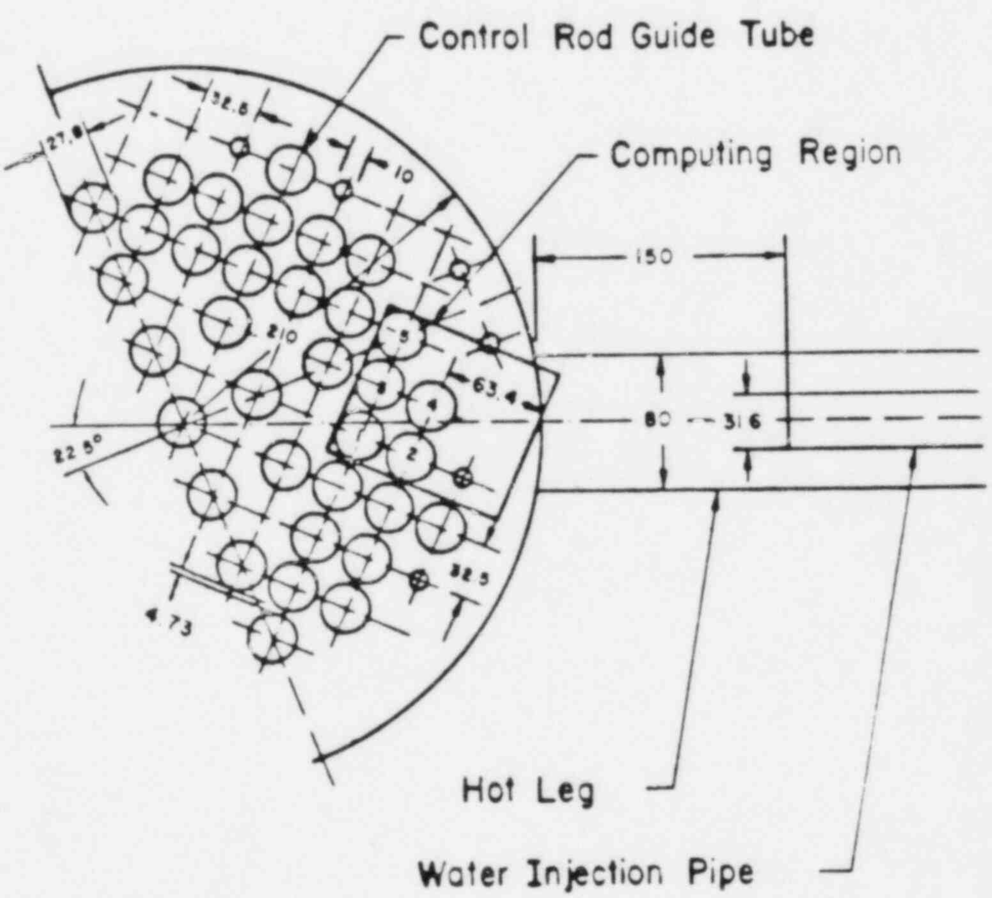


Fig. 24. Horizontal section of the air-water test facility and the computing region boundaries. Dimensions are in cm.

D. Data Transmittal (L. Bryan)

A significant problem in a program of this magnitude is the comprehensive and timely exchange of data. To facilitate this a mechanism for data transmittal was adopted based upon an agreed format for recording data/code results on magnetic tape (LA-2D/3D-TN-81-35). In addition, it was necessary to create a computer program (LUCCTF) to interpolate TRAC results when one-to-one comparisons with facility instrument locations and TRAC nodes could not be made. Presently data/code results are being exchanged at regular intervals between JAERI and Los Alamos for comparison and analysis. Figures 7 and 8 show "blind" TRAC predictions for CCTF Run 39, which were sent to JAERI for inclusion in the Run 39 quick-look report. Similarly, JAERI sends a comparable data tape to Los Alamos for use in detailed analysis work. Although much of this process is being automated and expanded, this activity remains a full-time effort for one person (approximately twelve tapes will be sent to JAERI in FY 1982).

VII. FUTURE 2D/3D ANALYSIS ACTIVITIES

In this section the balance of the 2D/3D analysis activities scheduled for FY 1982 and through the termination of the project are outlined. Table I lists past and projected calculational and analysis efforts and the associated facility testing schedules. For every calculation or series of calculations, appropriate documentation will be prepared and distributed to all participants in the Program. As mentioned previously, a system of internal reports has been adopted to expedite this documentation. As a result of FY 1981 activities, 36 of these technical notes were prepared (see Appendix), a number well in excess of the projected 26 documented calculations. Where appropriate, more formal documentation will be prepared (see References).

A. Cylindrical Core Test Facility (CCTF)

As a result of problems identified in the double-blind EM test prediction, this calculation will be rerun with a fine-node model in early FY 1982 to

TABLE I

TRAC CALCULATIONS FOR 2D/3D MINIMUM SET OF DOCUMENTED STUDIES

	FISCAL YEAR	78	79	80	81	82	83	84	85	86	87	88	TOTALS	
FULL-SCALE PWR	GERMAN	0	1	3	1	2*	2*	2*	0	0	0	1	15	
	W/J	4	2	0	1	1	1	1	0	1	1	1	13	
	B&W	0	0	0	0	0	1	0	1	1	1	0	4	
	TESTS	0	0	0	0	0	0	0	6	18	6	0		30
UPTF	CALCULATIONS:													
	DESIGN/COUPLING	2	2	1	7	6	6	6	0	0	0		30	
	PREDICTION/ANALYSIS	0	0	0	0	0	0	0	6	10	14	0	30	
	TESTS	0	4	16	4	2	8	4	4	2	0	0		44
CCTF	CALCULATIONS:													
	DESIGN/COUPLING	1	0	0	0	2	0	0	0	0	0	0	3	
	PREDICTION/ANALYSIS	0	2	4	9	3	8	4	4	2	0	0	36	
	TESTS	0	0	0	6	12	2	8	12	10	10	0		60
SCTF	CALCULATIONS:													
	DESIGN/OPERATION	3	4	4	0	0	2	0	0	0	0	0	13	
	PREDICTION/ANALYSIS	0	0	0	8	10	4	8	12	10	5	5	62	
TOTALS	TESTS	0	4	16	10	14	10	12	22	30	16	0		134
	CALCULATIONS	10	11	12	26	25	25	22	23	24	21	7	206	

1. Several test calculations may be combined into one write-up as one documented study, such as tests which vary only by one parameter; but each valid test will have one calculation as part of the documented study.
2. No more pre-test predictions, as agreed to by the TCC in March 1981.
3. In Design/Operation calculations, a documented study may consist of several calculations.
4. The calculation numbers listed in the table of Appendix III of the Agreement are individual calculations, but not documented studies.

* With FRG resident engineer assistance at Los Alamos.

complete the set of TRAC-PD2/MOD1 Core I analyses. Projected tests for FY 82 include refill bypass studies along the lines of past CREARE and Battelle downcomer studies. The larger size of the CCTF downcomer will allow further extrapolation of scale effects for ECC bypass phenomena. In addition to TRAC calculations, a subcontract has been arranged with CREARE to provide analytical support and guidance in operation and posttest analyses of these tests. Future Core-II tests are scheduled to include multidimensional core thermal effects, combined refill/reflood transients, and alternate ECC injection effects (upper-plenum injection, downcomer injection, hot-leg injection, and vent valves).

B. Slab Core Test Facility (SCTF)

Initial FY 1982 efforts will concentrate on the power effects tests (flat and steep radial core power distribution) and the ECC flow-rate effects tests. With the removal of the downcomer blockage plate, the facility will operate in the gravity reflood mode. Attention then will be focused on multidimensional thermal-hydraulic and blockage effects, phenomena that did not predominate during forced-flow reflood. Currently, two additional cores are planned for SCTF: an unblocked core (Core II) and a UPTF coupling core (Core III). Complementary tests to those run in CCTF are projected. T-3 will continue its numerical support by performing detailed studies of SCTF upper-plenum flow dynamics. This latter activity is expected to provide more physical insight on upper-plenum behavior and lead to macroscopic models for incorporation in TRAC.

C. Upper Plenum Test Facility (UPTF)

With shakedown tests currently scheduled in FY 1985, near-term activities will continue to concentrate on design and operational issues. These include a continuation of the loop studies and further investigation of the core simulator. Completion of the passive-loop component design study is expected in mid-FY 1982. Numerical studies of transient flooding with TRAC will continue to be useful for core-simulator studies, while at the same time assessing the code for application to PWR, CCTF, and SCTF transients. In particular, flooding at the core/upper-plenum interface has been identified as a key factor in controlling multidimensional vessel behavior. Longer term activities will include complete system calculations in preparation for operational transients.

D. Pressurized Water Reactors (PWRs)

The PWR analysis effort will be expanded to include a wider spectrum of break sizes, the Babcock and Wilcox vent-valve design, alternate ECCS, and multiple system failure transients (failure in ECC systems, steam generator tube rupture, etc.). Table II lists past and projected FY 1982 efforts in this area. In the final analysis, this activity represents the ultimate goal and result of the entire program: detailed PWR system calculations with an assessed TRAC to aid in the licensing process.

TABLE II

LPWR FULL SYSTEM CALCULATIONS

FY	REACTOR	CALCULATIONS (NO.)	CODE	REF.
78	W - US/J	Double-Ended Cold-Leg Break (1)	TRAC-P1	LA-7195-PR LA-7278-PR
	W - US/J	Refill ECC Bypass TRAC-P1 Sensitivity Study (3)	TRAC-P1	LA-7481-PR LA-7567-PR
79	GPWR	Double-Ended Cold-Leg Break (1)	TRAC-P1A	LA-7481-PR LA-7769-PR LA-7867-PR
	W - US/J	Coarse Noding Sensitivity Study (2)	TRAC-P1	LA-7769-PR
	B&W	TMI-2 Accident Simulation (2)	TRAC-P1A	LA-7968-PR LA-8171-PR
80	B&W	TMI-2 Accident Sensitivity Calculations (4)	TRAC-P1A	LA-8299-PR LA-8273-MS
	GPWR	Revised Noding Double-Ended Cold-Leg Break (1)	TRAC-P1A	LA-8690-PR
	GPWR	Intermediate Noding Hot-Leg Break (1)	TRAC-P1A	2D/3D Mtg. 11/79
	GPWR	Intermediate Noding Cold-Leg Break - Hot-Leg Injection in Upper Plenum (1)	TRAC-P1A	2D/3D Mtg. 11/79
81	GPWR	Double-Ended Cold-Leg Break (1) Rerun of Refill Phase (1)	TRAC-PD2 TRAC-PF1	LA-2D/3D-TN-81-32 LA-2D/3D-TN-81-8
	W - US/J	Double-Ended Cold-Leg Break (1)	TRAC-PD2	LA-2D/3D-TN-81-10
82	W - US/J	Double-Ended Cold-Leg Break (1)	TRAC-PF1	
	GPWR	Double-Ended Cold-Leg Break (1)	TRAC-PF1	
	GPWR	Double-Ended Hot-Leg Break (1)	TRAC-PF1	

E. Analysis Support

A significant result of this fiscal year's efforts was a comprehensive and systematic application of TRAC against a wide range of experimental configurations and tests. Based on this, several areas of necessary code improvements have been identified; most important are entrainment rates from the core, de-entrainment in the upper plenum, pressure oscillations, condensation heat transfer, and coupling of the heat transfer and hydrodynamics solutions when fluid crosses cell boundaries. The new TRAC-PF1 version should mitigate many of these problems and will be implemented during FY 1982. To a certain extent, this will require covering the same ground again, a necessary assessment activity. Also, in cooperation with the TRAC Development Group (Q-9), the 2D/3D Program is playing an important part in developing multifield methods and models for advanced TRAC code versions. Ultimately we expect to add a droplet field to the TRAC-PF1 code. This capability will address some of the problems listed here; assessed against the 2D/3D facility data, this code version should meet all requirements for LOCA analysis and the 2D/3D Program.

VIII. IMPACT ON REACTOR DESIGN AND LICENSING

The following examples illustrate how this program provides a technical basis for resolving many key licensing questions. Particular emphasis is given to UPTF and SCTF, which have full-scale features (implicit in these arguments are the multidimensional thermal-hydraulic effects).

A. Scaling/Multidimensional Effects

Previous reactor safety experiments have been at such a relatively small scale that the extrapolation to actual reactors has always been a modeling concern. UPTF and SCTF can provide prototypical data to address these issues: full-scale primary piping and ECCS simulation (UPTF), a full-scale downcomer (UPTF), and a full-scale radius and height heated core (SCTF). Some examples include: separate-effects tests in full-scale piping to study counter-current flow limitations (reflux conditions for a small break), thermal mixing in the primary piping and downcomer (pressurized thermal shock), and core/upper plenum flooding for multidimensional core cooling effects.

B. Downcomer Bypass and Refill

The TRAC code has been successful in predicting bypass phenomena in LOFT, CREARE, and Battelle experiments; however, the question of scaling effects can be addressed best with a facility such as UPTF. For evaluation of cold-leg ECC injection and alternate ECCS concepts, UPTF is a useful facility.

C. Reflood, Blockages, and Steam Binding

A firm understanding of reflood phenomena is crucial for predicting the course of a LOCA. This is true for the entire spectrum of possible break sizes. Despite the arbitrary dichotomy that is evolving between large breaks and small breaks, the primary objective in either postulated accident is the reflooding and cooling of the core. The rates and pressures may differ, but the phenomena are essentially the same. CCTF has demonstrated that current licensing assumptions about steam binding are very conservative and that the reflood rate is not unacceptably reduced when there is significant liquid carryover, but instead core cooling is substantially improved. Both the multidimensional-effects test in CCTF and the TRAC predictions showed that large core thermal gradients are minimized during reflood, which casts some doubt as to the validity of the current "hot rod" analysis requirements. TRAC was demonstrated to be capable of predicting pressure effects correctly in both SCTF and CCTF. Future SCTF gravity-reflood tests with blockages will provide information about multidimensional core effects, yielding insight into the question of blockage propagation.

D. Alternate ECCS

UPTF, SCTF, and CCTF, by means of experimental and analytic coupling, can yield significant results in this area. Besides investigating the prevalent cold-leg injection ECCS design and the German combined-injection concept, experiments are planned that will address upper-head and upper-plenum injection (Westinghouse) and downcomer injection and vent valves (Babcock and Wilcox). This is an area where the combined analytical/experimental effort can have a definite impact in improving reactor safety, with the TRAC code being used as a design tool.

IX. CONCLUSIONS

The 2D/3D Analysis Program is a valuable asset in the NRC's reactor safety research program and significant data and analytical results are expected in the coming years. Summarizing, the following points are noted:

1. The 2D/3D facilities generally are instrumented better and are of much larger scale than other existing water reactor safety facilities (such as FLECHT, Semiscale, or LOFT).
2. Results from the experiments have already addressed, and will continue to address, key licensing issues, including scaling, multidimensional effects, downcomer bypass and refill, reflood, steam binding, blockages, alternate ECCS, and small-break phenomena.
3. These facilities provide a unique testing capability that is unlikely to be reproduced in any future water reactor safety program.
4. Results from this program have been and will be used to develop models for and assess the multidimensional best-estimate TRAC code (and could be used in other NRC-sponsored code development programs).

   TRAC applications to the 2D/3D Program have demonstrated that the code is a powerful tool for reactor safety analysis. TRAC analyses of PWRs documented in this report show substantial safety margins below current licensing requirements. Confidence in these results is supported by the generally excellent agreement between predictions and experiments for a wide range of reactor conditions and experimental configurations.

In conclusion, the 2D/3D Program, particularly the UPTF/SCTF-III phase, will yield very useful results applicable to reactor licensing. The data from these facilities will bridge the scaling gap between existing small-scale experiments and the actual reactors, which is a critical need for accurately and reliably predicting nuclear reactor accidents. TRAC, completely assessed against this data, can provide the NRC with that capability.

ACKNOWLEDGMENTS

A special thanks is due to Frances Ortiz, who typed this report and many of those referenced herein.

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APPENDIX

2D/3D PROGRAM TECHNICAL NOTES

LA-2D/3D-TN-81-1 February 1981

TRAC-PD2 HOT-LEG SENSITIVITY STUDY, F. Motley and M. Cappiello.

As a result of the November 1980 2D/3D Coordination Meeting, a detailed analytical investigation of hot-leg ECC oscillations was planned. This report documents the first phase of that study. The capability of the drift-flux formulation in TRAC-PD2 to model ECC injection in the hot legs was studied with loop components and boundary conditions from the GPWR calculation. Results showed that under certain boundary conditions numerical plugging of the hot leg could cause the onset of flow oscillations. Conversion of loop component modeling to a two-fluid formulation was recommended.

LA-2D/3D-TN-81-2 January 1981

DISCREPANCY BETWEEN INJECTED ECC WATER MASS AND WATER MASS ADDITION TO THE VESSEL FOR CCTF TESTS C1-3 (RUN 12) and C1-11 (RUN 20), T. Brown.

Analysis of test data for CCTF Runs 12 and 20 revealed an uncertainty in the actual amount of ECC water entering the vessel as compared to the reported injection rates. Both the flow meter measured injection rates and the JAERI reported values do not concur with an ECC mass balance and appear to be too high. This can cause significant errors in TRAC calculations for the CCTF facility. Further investigation of this problem is warranted.

LA-2D/3D-TN-81-3 February 1981

TRAC-PF1 HOT LEG SENSITIVITY STUDY, M. Cappiello and F. Motley.

In the second phase of the hot-leg oscillation study, the new two-fluid code, TRAC-PF1, was used to investigate further ECC injection phenomena in the hot legs. Results showed that the two-fluid formulation with a stratified flow-regime constitutive package can model this counter-current flow problem successfully. However, sensitivity to the condensation modeling indicated that further assessment against experimental data was required.

LA-2D/3D-TN-81-4 January 1981

DOUBLE-BLIND PRETEST TRAC CALCULATION OF FIRST IN-HOUSE SCTF SHAKEDOWN TEST, S. Smith.

This report documents the TRAC-PD2 double-blind pretest prediction of SCTF shakedown test 501. Results showed a peak clad temperature of about 757 K, which occurred about 5 s after accumulator injection was initiated. The core quenched entirely within 100 s after accumulator injection. A significant pressurization of the system (4 bars) was calculated and a substantial amount of water was carried over to the upper plenum.

LA-2D/3D-TN-81-5 January 1981

DOUBLE-BLIND PRETEST TRAC CALCULATION OF FIRST IN-HOUSE SCTF SHAKEDOWN TEST USING PRESSURE-DEPENDENT HOMOGENEOUS NUCLEATION TEMPERATURE, S. Smith.

A repeat calculation of the TRAC-PD2 double-blind pretest prediction of SCTF shakedown test 501 was run with a correction to an error in the homogeneous nucleation temperature model. The pressurization of the system was reduced by 2 bars and more reasonable calculations for heater-rod quenching were obtained. As compared to the previous calculation (LA-2D/3D-TN-81-4), longer quenching times were predicted. Verbal information from JAERI indicated that this calculation agreed reasonably well with the test data, except at the blockage locations.

LA-2D/3D-TN-81-6 February 1981

ANALYSIS OF REFILL PHENOMENA IN REACTOR EXPERIMENTS, R. Fujita.

This report provides a critical discussion of past refill experiments as a background for possible use of CCTF for larger scale refill tests. A discussion of LOBI, LOFT, and CREARE refill experiments and key test phenomena is included.

LA-2D/3D-TN-81-7 February 1981

ASSESSMENT OF TRAC-PF1 AGAINST WESTINGHOUSE COLD-LEG EMERGENCY CORE COOLING WATER MIXING TESTS, M. Cappiello.

In the third phase of the hot-leg oscillation study, the TRAC-PF1 code was assessed against Westinghouse 1/14 scale and 1/3 scale cold-leg ECC mixing test data. Good agreement between code predictions and data was obtained for the four tests analyzed. A multiplicative constant of 3.0 times the constant Stanton-number condensation heat-transfer coefficient gave the best agreement with the data, which is consistent with the assessed TRAC-PD2 value.

LA-2D/3D-TN-81-8 February 1981

TRAC-PF1 CALCULATION OF A REFERENCE GPWR AT THE INITIATION OF ECC INJECTION, F. Motley.

In the fourth phase of the hot-leg oscillation study, TRAC-PF1 was used to recalculate the refill portion of a double-ended cold-leg break LOCA. Although the code included a stratified-flow two-fluid model for loop components, condensation-induced oscillations were still predicted in the hot and cold legs, as in the previous TRAC calculations. The importance of system effects in driving these oscillations was also demonstrated.

LA-2D/3D-TN-81-9 February 1981

TRAC-PD2 REFLOOD CODE ASSESSMENT FOR CCTF TEST C1-16, J. Sugimoto (JAERI Resident Engineer at Los Alamos).

A simplified TRAC core and vessel model for CCTF was constructed to test the code's reflood heat-transfer models against experimental data. Test C1-16 (Run 25), the FLECHT coupling test, was selected for this analysis. Reasonable agreement with rod temperature and differential pressure data for the core midplane and below was achieved, but upper elevations are less well calculated. Also, the de-entrainment phenomenon in the upper plenum was underpredicted.

LA-2D/3D-TN-81-10 March 1981

A TRAC-PD2 ANALYSIS OF A LARGE-BREAK LOCA IN A REFERENCE USPWR, J. Ireland and D. Liles.

A double-ended cold-leg break in a reference USPWR was calculated with TRAC-PD2. Results indicate peak cladding temperatures of 950 K during the blowdown phase and complete core quenching by 175 s. Strong multidimensional effects were observed, including top and bottom quenching, pool formation in the upper plenum, and significant spatial variation in the fuel rod quench histories.

LA-2D/3D-TN-81-11 January 1981

TRAC-PD2 POSTTEST ANALYSIS OF CCTF TEST C1-11 (RUN 20), T. Brown and K. Williams.

CCTF Test C1-11 (Run 20) was chosen as a base case for TRAC analyses of the Core-I test series. This report includes calculations using two vessel nodings: $270^0/90^0$ and $180^0/180^0$, where in each case the three intact loops were combined into one to reduce calculational times. Problems in calculating both rod temperatures and differential pressures correctly in the core were noted. These calculations predate several important code changes described in previous technical notes (LA-2D/3D-TN-81-2, 5, 9, and 10).

LA-2D/3D-TN-81-12 March 1981

DOUBLE-BLIND PRETEST PREDICTION OF THE CCTF CORE-I EVALUATION MODEL TEST USING TRAC-PD2, K. Williams.

This report documents the TRAC-PD2 double-blind pretest prediction of the CCTF Core-I EM test. Results showed a calculated peak clad temperature of 1080 K and quenching of the core midplane by 415 s. This calculation used the TRAC-PD2 MOD1 version, which included corrections to the homogeneous nucleation temperature model, the vessel gravity head term, and the heat slab model (see LA-2D/3D-TN-81-5 and 10).

LA-2D/3D-TN-81-13 April 1981

ANALYSIS OF CCTF CORE-I TEST C1-11 (RUN 20) DATA, R. Fujita.

A detailed posttest analysis of the data from CCTF Test C1-11 (Run 20) was performed and documented in this report. Key phenomena described include: ECC bypass, upper-plenum internals and their effect on top-down quenching, core thermal response, and primary loop behavior and oscillations. Results of this analysis indicate that the CCTF can produce repeatable and consistent data.

LA-2D/3D-TN-81-14 April 1981

ANALYSIS OF SCTF CORE-I SHAKEDOWN TEST (RUN 501) DATA, R. Fujita.

A detailed posttest analysis of the data from SCTF Shakedown Test 501 was performed and documented in this report. A description of the test facility and method of operation is included. Key vessel phenomena described include: vessel pressurization, two-dimensional effects in upper plenum, and detailed core thermal response and blockage effects.

LA-2D/3D-TN-81-15 May 1981

ASSESSMENT OF TRAC-PF1 VERSION 4.0 AGAINST WESTINGHOUSE COLD-LEG ECC WATER MIXING TESTS, M. Cappiello.

In this report the assessment of TRAC-PF1 against the Westinghouse cold-leg ECC water mixing tests is continued and updated with a new code version and improved geometric modeling of the test facility (see LA-2D/3D-TN-81-7). Comparable agreement with the data was achieved, although some specific aspects differ from the previous study. This study provides confidence in the ability of TRAC to model the nonequilibrium ECC injection phenomena.

LA-2D/3D-TN-81-16 May 1981

DATA ANALYSIS OF CCTF CORE-I BASE-CASE AND SELECTED PARAMETRIC EFFECTS TESTS, R. K. Fujita.

A detailed posttest data analysis of selected CCTF Core-I parametric tests vs the base-case test was performed and is documented in this report. Specifically, the high LPCI flow test (Run 15) and the pressure-effects tests (low - Run 19 and high - Run 21) are compared to the base-case test (Run 14). The high LPCI flow test surprisingly varied only slightly from the base case (e.g., somewhat earlier turnaround time and lower temperatures, but comparable quench times). The pressure-effects tests validated the widely known result that reflood occurs faster at higher system pressures.

LA-2D/3D-TN-81-17 October 1981

REVISION OF THE TRAC CALCULATIONAL MODEL FOR THE SCTF, S. Smith.

A revision of the TRAC-PD2 model for the SCTF has been made in order to update the additive friction in the loop component models and to match more closely the facility instrumentation and geometry with the vessel model. The loop components were checked separately with known boundary conditions; the results of the computer runs were checked against hand calculations and agreed well. The revised model has been reviewed and checked at Los Alamos and is thought to be accurate. The purpose of this technical note is to provide other 2D/3D Program participants a basis for evaluating TRAC SCTF calculations.

LA-2D/3D-TN-81-18 May 1981

TRAC-PF1 SENSITIVITY STUDIES OF A GPWR INTACT LOOP DURING ECC INJECTION, M. Cappiello.

A GPWR intact loop ECC injection sensitivity study was conducted and is documented in this report. Comparable results to the full system calculation were achieved by extracting loop pressure boundary conditions from that calculation and using them to drive the loop model. A noding study indicated that the system calculation noding is adequate in modeling the loop response. A revised noding of the hot leg to steam generator piping, which accounts for the "riser" section, had a significant impact on the oscillation phenomena. Careful review of the TRAC modeling is warranted before proceeding with further system calculations.

LA-2D/3D-TN-81-19 May 1981

REVIEW OF THE TRAC-CALCULATED GPWR UPPER-PLENUM/CORE FLOW CONDITIONS TO AID IN THE DESIGN OF UPTF, F. Motley.

A detailed analysis of fluid flow at the upper-plenum/core interface from the TRAC-PD2 GPWR calculation is presented (see also LA-2D/3D-TN-81-8). Spatial, flow, and subcooling effects are reported. Recommendations for UPTF separate effects tests and steam supply capabilities are included. This document provides a basis for further discussion of the UPTF core-simulator design.

LA-2D/3D-TN-81-20 May 1981

TRAC-PF1 CALCULATIONS OF A UPTF INTACT LOOP DURING ECC INJECTION, M. Cappiello.

A UPTF intact loop ECC injection study (counterpart to the GPWR study) was conducted and is documented in this report. Results show that the pump simulator allows reverse ECC flow into the loop seal region; this did not occur in the GPWR loop, which had an operating pump. Hence, although comparable agreement for the hot-leg ECC performance between the GPWR and UPTF was achieved, the cold-leg performance differed significantly. Further review of the passive component modeling is warranted, particularly the steam-water separator.

LA-2D/3D-TN-81-21 June 1981

A PARAMETRIC STUDY OF THE EFFECT OF MATERIAL PROPERTIES ON THE CALCULATED ROD HEATUP RATE FOR THE SCTF, S. Smith.

Uncertainties in the reported values for SCTF heater-rod material properties were the cause of considerable discrepancy in TRAC predictions of the measured adiabatic heatup rates in the facility. TRAC system reflood calculations with FLECHT property values, CCTF values, and values supplied by the manufacturer showed large differences in heatup rates and quenching times. It was concluded that CCTF property values yield the best agreement between prediction and data. Pending more accurate information from the manufacturer, the CCTF values will be used in future TRAC calculations.

LA-2D/3D/TN-81-22 October 1981

TRAC ANALYSIS OF THE SCTF HIGH-PRESSURE SHAKEDOWN TEST (RUN 506), S. Smith.

A blind posttest calculation of SCTF Run 506, a high-pressure test, was completed with TRAC-PD2/MOD1 using initial conditions provided by JAERI, but without knowledge of the actual test results. There is good comparison between the calculation and the data for rod temperatures, turnaround times, quench envelopes, core differential pressures, mass inventories, and loop velocities. The comparison is not so good for absolute pressures, upper-plenum pool formation, and fluid temperatures and mass accumulation in the steam-water separator. Some evident discrepancies can be explained by code anomalies or deficiencies, such as the nonphysical wide-band pressure surges the calculation experienced, the omission of radiation between rods and walls, the irregular liquid entrainment from the core liquid to the upper plenum, and the lack of a de-entrainment model specifically for the upper plenum. In general, however, the recently revised calculational model and TRAC-PD2/MOD1 give good agreement with the test data.

LA-2D/3D-TN-81-23 October 1981

TRAC ANALYSIS OF THE SCTF BASE-CASE TEST (RUN 507), S. Smith.

A blind posttest calculation of SCTF Run 507, the base-case test, was completed with TRAC-PD2/MOD1 using initial conditions provided by JAERI, but without knowledge of the actual test results. For Run 507, this report shows there is good comparison between the calculation and the data for rod temperatures, turnaround times, quench envelopes, core differential pressures, mass inventories, and loop velocities. The comparison is fair for absolute pressures, upper-plenum pool formation, fluid temperatures, and mass accumulation in the steam-water separator. Some evident discrepancies can be explained by code anomalies or deficiencies. In general, however, the recently revised calculational model and TRAC-PD2/MOD1 give good agreement with the test data.

LA-2D/3D-TN-81-24 October 1981

TRAC ANALYSIS OF THE SCTF LOW-PRESSURE TEST (508), S. Smith.

A blind posttest calculation of SCTF Run 508, the low-pressure test, was completed with TRAC-PD2/MOD1 using initial conditions provided by JAERI, but without knowledge of the actual test results. For Run 508, this report shows there is good comparison between the calculation and the data for core differential pressures, pressure vessel mass inventories, pressure vessel absolute pressures, and turnaround times and temperatures in lower core elevations. The comparison is fair for upper-plenum pool formation; fluid temperatures; mass accumulation in the steam-water separator; and rod temperatures, turnaround times, and quench envelopes in higher core elevations. Some evident discrepancies can be explained by known code deficiencies, which are under improvement. In general, however, the recently revised calculational model and TRAC-PD2/MOD1 give good agreement with the test data.

LA-2D/3D-TN-81-25 December 1981

TRAC ANALYSIS OF THE SCTF HIGH-SUBCOOLING TEST (RUN 510), S. Smith.

A blind posttest calculation of SCTF Run 510, the high-subcooling test, was completed with TRAC-PD2/MOD1 using initial conditions provided by JAERI, but without knowledge of the actual test results. There is good comparison between the calculation and the data for rod temperatures, turnaround times, quench envelopes, core differential pressures, mass inventories, and loop velocities. The comparison is fair for absolute pressures, upper-plenum pool formation, and fluid temperatures and mass accumulation in the steam-water separator. Some evident discrepancies can be explained by code anomalies or deficiencies. In general, however, the recently revised calculational model and TRAC-PD2/MOD1 give good agreement with the test data.

LA-2D/3D-TN-81-26 October 1981

ANALYSIS OF A TRAC-PD2 POSTTEST CALCULATION OF CCTF TEST C1-5 (RUN 14), T. Okubo.

An analysis of a TRAC-PD2 posttest calculation of CCTF test C1-5 (Run 14) has been performed. Run 14 is the base-case test for the CCTF Core-I series; analysis of this calculation forms the basis for evaluating the other companion TRAC parametric effects calculations. In general, the calculational results show good agreement with experimental data in cooling the lower half of the core, but not as good in the upper half. A calculated core-inlet mass flow rate less than the measured value and problems in the core heat transfer and entrainment models seem to be main reasons for the discrepancy noted.

LA-2D/3D-TN-81-27 October 1981

TRAC-PD2 POSTTEST ANALYSIS OF CCTF TEST C1-5 (RUN 14), R. Fujita.

A posttest analysis of the CCTF Core-I Base-Case reflood test, C1-5 (Run 14), was performed with the TRAC-PD2 computer code using a coarse-node model of the test facility. TRAC adequately predicted the general trends of the data. The results of this calculation will be used as a reference for future parametric test analysis.

LA-2D/3D-TN-81-28 October 1981

TRAC-PD2 ANALYSIS OF CCTF MULTIDIMENSIONAL TEST II (C1-20, RUN 39), F. Motley.

The results of the single blind posttest prediction of the second CCTF multidimensional test using the TRAC code agree very well with the experiment. The effect of the initial temperature skew is evident in the bottom half of the core, with the cold side quenching earlier than the hot side. In the top half of the core there is some delay in the turnaround of the temperature on the cold side, which equalizes the temperatures across the core so that quenching occurs uniformly. The three-dimensional analysis capability of the TRAC code is verified by the good agreement between the data and the calculation. A comparison of the multidimensional test to the base case (Run 14) shows that the initial temperature skew did not have much effect on the quench times of the most limiting (hottest) core locations.

LA-2D/3D-TN-81-29 October 1981

TRAC ANALYSIS OF CCTF BASE-CASE C1-5 (RUN 14) WITH A MULTIDIMENSIONAL INPUT MODEL, F. Motley.

A multidimensional input model of the base-case CCTF run was prepared for analysis using the TRAC-PD2 code. The calculational results demonstrated the importance of proper modeling of the test facility and the boundary conditions. The multidimensional modeling showed no tendency to calculate behavior not observed in the data; thus, the TRAC code did not introduce artificial multidimensional effects. With proper modeling and boundary conditions, the TRAC multidimensional model can predict the results of the CCTF test facility relatively accurately. Entrainment and quench-front modeling improvements to TRAC would improve agreement with the data.

LA-2D/3D-TN-81-30 October 1981

TRAC-PD2 POSTTEST ANALYSIS OF CCTF TEST C1-10 (RUN 19), R. Fujita.

TRAC-PD2 was used to analyze a low-pressure CCTF reflood test, C1-10 (Run 19), as part of a pressure-effects parametric study. A coarsely noded model of the test facility utilized in previous posttest analyses was used to determine the ability of TRAC to predict the effects of system pressure on the reflooding behavior of the heated core. TRAC predicted correctly the trends of this low-pressure test, where quench times were later than those of high-pressure tests.

LA-2D/3D-TN-81-31 October 1981

TRAC-PD2 POSTTEST ANALYSIS OF CCTF TEST C1-12 (RUN 21), R. Fujita.

TRAC-PD2 was used to analyze a high-pressure CCTF Core-I reflood test, C1-12 (Run 21), as part of a pressure-effects parametric study. A coarsely noded model of the test facility utilized in previous posttest analyses was used to determine the ability of TRAC to predict the effects of system pressure on the reflooding behavior of the heated core. TRAC predicted the correct trends of this high-pressure test, where quench times were earlier than those of the lower pressure test.

LA-2D/3D-TN-81-32 October 1981

TRAC-PD2 CALCULATION OF A DOUBLE-ENDED COLD-LEG BREAK IN A REFERENCE GPWR, F. Motley and K. Williams.

The TRAC-PD2 code version was used to calculate a double-ended (200 per cent) cold-leg break in a representative GPWR. The results indicate that the peak clad temperature of 875 K occurs during the blowdown phase and that complete core quenching occurs at 87 s. The quenching is from both bottom and top due to the combined ECC water injection into the hot and cold legs.

LA-2D/3D-TN-81-33 October 1981

ANALYSIS OF TRAC AND SCTF RESULTS FOR SYSTEM PRESSURE-EFFECTS TESTS UNDER FORCED FLOODING (RUNS 506, 507, AND 508), Y. Sudo.

The TRAC and the SCTF results are compared for the three system pressure-effects tests (Runs 506, 507, and 508) with forced injection into the lower plenum. The result shows that the TRAC can predict well the overall transients of core rod temperature, core differential pressure, and liquid carryover into the hot leg as well as in the upper plenum, effects that are strongly dependent on the system pressure. Comparisons also are presented that show major differences between the SCTF test and the TRAC results that should be improved in the future.

LA-2D/3D-TN-81-34 October 1981

AN ANALYSIS OF A TRAC-PD2 POSTTEST CALCULATION OF CCTF TEST C1-6 (RUN 15), T. Okubo.

An analysis of a TRAC-PD2 posttest calculation of CCTF test C1-6 (Run 15) has been performed. Run 15 is one of the flow-rate parametric-effect tests of the CCTF Core-I series; the LPCI flow rate of this test is twice that of the base-case test (Run 14). The calculational results show almost the same tendencies as those of the Run 14 calculation, as does the data; however, the predicted system behavior during the early period is more stable in the Run 15 calculation. This is because of more accumulator injection in the lower plenum and a higher LPCI flow rate. Both data and calculations indicate that a threshold exists for ECC injection; once the downcomer is filled, additional LPCI flow has little effect on core cooling.

LA-2D/3D-TN-81-35 December 1981

THE GENERATION OF MAGNETIC DATA TAPES FOR THE MULTINATIONAL REFILL/REFLOOD EXPERIMENTAL PROGRAM, L. Bryan.

The method for generating magnetic data tapes for the multinational (Germany, Japan, and USA) refill/reflood program is described in this document. The tapes contain TRAC calculations or experimental results in an agreed upon format as delineated by members attending the 2D/3D Review Meeting held in Munich, Germany, June 1979. A description of the tape format is included.

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