NUREG/CR-2606
SAND81-1932

Analyses of 1/15 Scale Creare Bypass Transient Experiments

Prepared by L. N. Kmetyk, L. D. Buxton, R. K. Cole, Jr.

Sandia National Laboratories

Prepared for
U.S. Nuclear Regulatory Commission

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, or any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use, or the results of such use, of any information, apparatus, product or process disclosed in this report, or represents that its use by such third party would not infringe privately owned rights.

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W.
   Washington, DC 20555
2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission,
   Washington, DC 20555
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations,* and *Nuclear Regulatory Commission Issuances.*

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

GPO Printed copy price: $5.00

NUREG/CR-2606
SAND81-1932

Analyses of 1/15 Scale Creare Bypass Transient Experiments

Manuscript Completed: February 1982
Date Published: September 1982

Prepared by
L. N. Kmetyk, L. D. Buxton, R. K. Cole, Jr.

Sandia National Laboratories
Albuquerque, NM 87185

Prepared for
Division of Systems Integration
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN A1115

ACKNOWLEDGMENTS

The authors wish to express their gratitude to John Orman and Katherine McFadden for their programming assistance in making five different thermal-hydraulic codes operational on the Sandia computer system. Without the manifold contributions of Pat Rosario, this report would only appear in crayon on the back of used computer output. Norm Lauben of NRC provided assistance in obtaining the required data from Westinghouse Electric Corporation.

ANALYSES OF 1/15 SCALE CREARE BYPASS TRANSIENT EXPERIMENTS

Abstract

RELAP4 analyses of several 1/15 scale Creare H-series bypass transient experiments have been done to investigate the effect of using different downcomer nodalizations, physical scales, slip models, and vapor fraction donoring methods. Most of the analyses were thermal equilibrium calculations performed with RELAP4/MOD5, but a few such calculations were done with RELAP4/MOD6 and RELAP4/MOD7, which contain improved slip models. In order to estimate the importance of nonequilibrium effects, additional analyses were performed with TRAC-PD2, RELAP5 and the nonequilibrium option of RELAP4/MOD7. The purpose of these studies was to determine whether results from Westinghouse's calculation of the Creare experiments, which were done with a UHI-modified version of SATAN, were sufficient to guarantee SATAN would be "conservative" with respect to ECC bypass in full-scale plant analyses.

The two major results of this study are that (1) a nonequilibrium code may be needed to correctly model the dominant flow phenomena of these particular Creare tests, and (2) results from a full-scale nodalization developed via K* scaling criteria cannot be validly compared to the 1/15 scale Creare data. Therefore, the calculations reported here indicate that Westinghouse's Creare analysis results have not proven their UHI-modified version of SATAN will always generate conservative values for ECC bypass.

Table of Contents

List of Figures

1. INTRODUCTION

The term Upper Head Injection (UHI) is used to describe a relatively new ECC design feature developed by Westinghouse for use in PWRs having ice condenser containment systems. The UHI system supplements the standard ECC system by delivering coolant, at room temperature, directly to the upper head of the reactor vessel from an additional accumulator. The nature of the UHI system increases the need for adequate thermal-hydraulic code modelling of such phenomena as top-down quenching in the core, separated two-phase flow, and transfer of fluid from the upper head to the remainder of the system. Therefore, Westinghouse proposed[1] several changes to their proprietary SATAN code[2] which they would use for licensing analyses of LOCAs in UHI-equipped plants.

The NRC originally asked Sandia to help evaluate the Westinghouse UHI modifications to SATAN by assessing their effects on large break LOCA analyses for full scale plants. This was done by modifying the standard audit tool, RELAP4/MOD5,[3] to simulate the new Westinghouse models. A topical report[4] has been written which discusses both those detailed evaluation calculations and a PWR large-break LOCA audit calculation using all of the UHI models developed.

Among the new models whose effects were to be evaluated is the Westinghouse-Zuber UHI-modified slip model. A standard treatment for modelling separated two-phase flow with relative velocity (slip) between the phases is to have the slip velocity be a simple function of void fraction, as is normally done in RELAP4/MOD5. For UHI calculations, Westinghouse proposed a drift flux model for separated flow in which the component volumetric fluxes are functions of total mass flux, void fraction, flow distribution parameter and drift velocity. The latter two in turn depend on flow regime, void fraction, fluid material properties and Reynolds' number. The use of a split downcomer to simulate azimuthal noding was another part of the UHI model modifications that Westinghouse developed for SATAN analyses of LOCAs in UHI-equipped plants.

As a follow-on in evaluating these particular SATAN UHI modifications, the NRC asked Sandia to analyze several 1/15 scale Creare bypass transient experiments (both with and without the UHI models in RELAP), and to compare the results to those from Westinghouse calculations. If the results proved unsatisfactory, we were to investigate what additional model changes might be required to adequately analyze the Creare data. The purpose of this study was to determine whether SATAN contained suitable features which would cause a LOCA analysis using that code to always be "conservative", since Creare experiment analyses with the UHI-modified SATAN had predicted conservative results.[1] (The term "conservative" here means that the code would predict more cold leg ECC bypass than would actually be expected during a LOCA.)

The Creare bypass transient tests to be studied (the "H-series" experiments) are part of a continuing effort to develop analytical tools and predictive techniques to permit calculation of lower plenum filling rates, as a function of time, during a postulated LOCA in PWRs. The effects of countercurrent flow, lower plenum voiding, steam in the cold leg, and superheated downcomer walls have all been investigated separately and in combination under test conditions which included elevated vessel pressure, transient steam flows, transient vessel pressure, and coupling of reverse core and cold leg steam flows.[5] A range of geometric and hydraulic parameters were tested at Creare, including two annulus gap sizes, a scaled and a deep lower plenum, and various ECC water temperatures and flow rates. The particular Creare tests for which Westinghouse performed analyses that are of interest here will be described in more detail in Section 2.

The Westinghouse SATAN analyses, summarized in Section 3, consisted of imposing steam flow transients on an isolated PWR-size lower plenum and downcomer. The results were compared to the experimentally determined bypass threshold (the time when water delivery to the lower plenum began) and the rate of water downflow for the 1/15 scale tests. The SATAN results showed that the bypass threshold predictions were conservative relative to the measured data, that the predicted lower plenum filling rates were slower than the experimental rates, and that the observed relationship between bypass threshold and steam ramp rate was preserved.

In the Sandia study, equivalent calculations were done for both an actual 1/15 scale Creare model and a full PWR scale model. Two basecase nodalizations were developed, with a single and a split downcomer respectively, which are described in Section 4. Besides studying the effects of these different downcomer models, calculations were also done which compared the results of using the generic RELAP4 slip correlation and the Westinghouse-Zuber UHI-modified slip model. Most of these calculations were made using RELAP4/MOD5 and are discussed in Section 5, but calculations were also performed with other thermal-hydraulic codes. Section 6 gives the results of analyses using RELAP4/MOD6[6] and RELAP4/MOD7[7] (both equilibrium and nonequilibrium calculations were done with MOD7). Results found using the new nonequilibrium code RELAP5[8] are presented in Section 7.

All of the RELAP codes and SATAN are one-dimensional codes. Since multi-dimensional effects might be important in these analyses, a final set of calculations was performed with TRAC-PD2[9], which allows three-dimensional noding of the vessel in addition to nonequilibrium thermodynamics. These results are given in Section 8.

2. DESCRIPTION OF CREARE EXPERIMENTS AND FACILITY

The H-series experiments to be modelled were performed at the Creare 1/15-scale cylindrical elevated pressure facility, with the vessel geometry shown in Figure 1. The vessel is a 0.609 m (24 in) cylinder with an inside diameter of 0.292 m (11.5 in) and walls 4.44 cm (1.75 in) thick. The core barrel walls are approximately 3.18 cm (1.25 in) thick, and provide a downcomer gap size of 1.27 cm (0.5 in). The lower plenum is a hemisphere with a 0.146 m (5.75 in) radius. Four cold legs are simulated by 7.62 cm (3.0 in) OD and 4.76 cm (1.875 in) ID pipes. Four hot leg locations are each represented by a sealed-off region in the downcomer. The broken cold leg discharges into a containment-simulating separator vessel 0.914 m (3 ft) in diameter and 2.134 m (7.0 ft) tall, with a volume of 0.946 m^3 (250 gal) below the cold leg. This separator vessel was vented to the atmosphere during the tests considered, allowing an uncontrolled depressurization.

The 1.58 cm (0.626 in) ID ECC injection pipes in the intact cold legs are located 0.277 m (10.9 in) from the vessel inner wall, at a 60° angle to the cold leg pipe. For the H-series experiments modelled, each ECC pipe carried 1.255 kg/sec (2.77 lb/sec or 20 gpm) of 327 K (130°F) subcooled water. Steam entered the core region through many holes in a manifold pipe extending into the core barrel. During the bypass transients considered here, the steam mass flow started at 0.34 kg/sec (0.75 lb/sec), large enough to ensure perfect bypass of the injected ECC water, and was then ramped from this initial value to zero in a given time, τ, by closing a valve in the steam line. In the first 12, basecase, H-series experiments, the time period between the start of the transient and complete valve closure was varied from 10 to 150 seconds.

Typical results from three such experiments are shown in Figure 2. Comparison of these plots illustrates the effect of decreasing the rate of the steam mass flow transient, from a fairly fast transient (τ = 16 seconds) to a fairly slow transient (τ = 104 seconds). The start of lower plenum filling occurred at greater and greater values of the dimensionless steam flow j_{gc}^* (see Appendix I) as the duration of the transient was increased. The results of all the basecase series of tests are summarized in Figure 3, in which the dimensionless steam flow rate at the time water begins to be delivered to the lower plenum has been plotted against the inverse of τ, which represents the rate of the j_{gc}^* transient. Also indicated on the figure are the no-penetration (i.e., no water delivered to the lower plenum) and complete-penetration (i.e., all the ECC water delivered to the lower plenum) limits of j_{gc}^* determined from steady state experiments using the same water flow conditions.

Since these transient experiments were started at j^*_{gc} (0) = 0.325 ± 0.025, they were all well above the perfect bypass limit initially. The fact that the transient data do not fall within the steady state limits merely indicates that the controlling flow phenomena are time-dependent. (Further discussion of the controlling phenomona is beyond the scope of this document, and Ref. 10 should be consulted for additional details.)

3. WESTINGHOUSE RESULTS

As demonstration that the SATAN UHI downcomer model conformed to NRC licensing criteria, Westinghouse performed an analysis that consisted of imposing steam and water flows on an isolated PWR-size lower plenum and downcomer. The results indicated conservative predictions of the bypass threshold and the rate of water downflow relative to the Creare 1/15 scale steady state results (the no-penetration and complete-penetration limits in Figure 3). In addition to this steady state data comparison, SATAN analyses using the UHI downcomer model were also required by NRC for the Creare transient steam flow tests.

Two approaches were considered for simulation of these transient tests. A SATAN-UHI model of the Creare 1/15 scale facility was developed; the input description for this model included the actual dimensions of the Creare vessel and the experimental steam and water flow rates. The second approach applied a full-size PWR downcomer model to the Creare tests, and the results were then compared via K* scaling (see Appendix I) to the Creare 1/15 scale transient test data. Both approaches included the UHI drift-flux calculation and the downcomer azimuthal noding representation shown in Figure 4. All calculations were initialized by fixing the steam flow at its initial value from 0 to 4 seconds, ramping the water flow from zero to full flow from 2 to 4 seconds (the water flow was kept at zero from 0 to 2 seconds), and then initiating the steam flow ramp as soon as the water flow reached its full value at 4 seconds. No steady state analyses were performed.

The Creare basecase transient test series was selected for comparison purposes by Westinghouse because these tests most closely approached the anticipated plant coolant injection rates and injection water subcooling. The basecase test series consisted of tests run with minimum vessel wall superheat. From the entire 12-test series, tests H1, H5, and H8 were initially chosen by Westinghouse as reasonable bounds to the expected PWR transient times.

The most direct approach, transient calculations with the actual Creare vessel representation, was tried first. The control volume sizes that were required for this model were extremely small, due to the small physical size of the Creare test facility, and computer code stability problems (possibly due to the small control volumes) were encountered during the water flow ramp, which terminated the calculation. Meaningful results could not therefore be obtained through SATAN calculations with this model. The PWR downcomer model was then used for the transient calculation. (It should be noted that this model is a representation of an actual PWR and not a carefully scaled-up Creare vessel.)

When observed bypass thresholds were compared to the first PWR-scale SATAN-UHI predictions of tests H1, H5, and H8, a conservative result was obtained only for the H1 calculated transient. Although the calculated results for H5 and H8 yielded a nonconservative prediction of bypass threshold, the filling rate of the lower plenum was still much slower than indicated in the recorded data. Thus, a "conservative" filling rate was predicted for all three transient calculations. (This is not surprising when one realizes that the absolute ECC flow rate obtained using K^* scaling is $\sim \sqrt{15}$ lower than the absolute ECC flowrate based on the Creare j^* scaling, and that while the lower plenum volume scales as $(15)^3$ the ECC flow rate using K^* scaling increases only as $(15)^2$.)

The premature SATAN prediction of water downflow for tests H5 and H8 was found to result from differences in the calculated fluid conditions between the two control volumes modelling the upper annulus. A wide variation in void fraction with a preferential filling of the intact loop side of the upper annulus and the resulting lower void fraction within the intact loop side control volume contributed a significant hydrostatic head compared to the head associated with the break side control volume. This hydrostatic head difference was a major factor in determining the steam flow distribution below the upper annulus. The head difference acted to redistribute the steam toward the break side of the annulus and contributed to an earlier prediction of water downflow on the intact loop side of the annulus.

The void fraction distribution for the upper annulus control volumes is determined in part in SATAN by the horizontal flow calculated between these volumes. The relatively low crossflow between upper annulus nodes was found to be associated with the flow path modelling assumption--horizontal flow with no elevation terms considered. A modification was made in SATAN to the annulus crossflow calculation to include the density difference between these nodes in the pressure gradient that drives flow. While this modification is included for all cross flow paths modelled in the downcomer, it has the most impact for the crossflow at the upper annulus.

The simulations of Creare tests H1, H5, and H8 were rerun with the crossflow modification included, and in addition, tests H2 and H3 were modelled. The new bypass threshold predictions were all "conservative" relative to the measured data, as seen in Figure 5. (In fact, the H1 calculation indicated perfect ECC bypass, even when the steam flow was identically zero.) The lower plenum filling rate predicted in the new calculations for the water accumulation was always less than the measured collection rate. (As already mentioned, this is only to be expected.) None of the new calculations show the lower plenum more than 20% full at the end of the calculation.

The lower plenum pressure[11] and void fraction calculated for the 32-second H5 transient are shown in Figures 6 and 7. Although the pressure was set to the correct experimental initial pressure at t = 0 of the calculation, it had dropped substantially by the time the steam ramp was initiated at t = 4s of the calculation (which is t = 0 for the experiment). Experimental pressures (offset by 4 seconds) are provided for comparison in Figure 6 and show little agreement with the calculated value for pressure, which is low at early times and high at late times. The experimental values for the lower plenum void fraction, also offset by 4 seconds, are provided for comparison in Figure 7. (Westinghouse apparently only offset their calculated end-of-bypass times by 2 seconds, which seems to be an error large enough to reduce their conservative margin significantly, but not large enough to make a supposedly conservative calculation nonconservative.)

4. RELAP4 NODALIZATIONS AND INITIALIZATION

Two basic RELAP nodalizations were used to model the Creare transient experiments at Sandia. The first, a single downcomer nodalization, is shown in Figure 8; the core region, lower plenum and separator vessel are represented by large single volumes, while the three intact cold legs are lumped together into a single equivalent volume. The downcomer and break pipe are each composed of several small volumes. Heat slabs modelling the core barrel and vessel wall are included, and the containment volume is held at a constant 1 atm pressure.

The single downcomer calculations were started with an established steam flow equal to the experimental initial value of 0.75 lb/sec through the vessel and out the break pipe, with the lower plenum initial pressure at the specified experimental value. The ECC water flow was then ramped up to its full 60 gpm value in 1 second, similar to the Westinghouse initialization procedure. With only the steam flowing, the system depressurized rapidly. As ECC flow was introduced, the system pressure first increased and then dropped again as the intact cold legs, upper downcomer and break pipe gradually filled with water. As the steam originally present in these volumes condensed, the water packing associated with crossing the saturation line in RELAP4 drove pressure waves around the system and caused a discontinuity in the calculated solution. Depending on parameters such as the time step size and ECC water pressure and temperature, the run either terminated abnormally due to water-pack instabilities (as shown in Figure 9), or achieved a smooth solution after the upper downcomer was filled with subcooled water (Figure 10), whereupon the system again began to depressurize.

As seen in Figure 10, the lower plenum pressure usually returned to the experimental initial value (27 ± 4 psia) twice during these initialization calculations. At the first point (~ 2s), the upper downcomer was full of saturated water and the pressure continued to drop, while at the second (~ 4s) it was filled with subcooled water and the pressure remained constant for a short time. This second solution was then used as the initial conditions for the transient calculation, after an additional form loss coefficient of ~ 1.5 was added at the break pipe exit. With this added form loss, the system remained at a steady state until the steam ramp was initiated. Without this added form loss coefficient, the pressure began dropping again past ~ 5s as shown in Figure 10. The single downcomer transient calculations were thus started with the core region, lower plenum and lower downcomer filled with saturated steam and the upper downcomer, intact cold legs and break pipe filled with subcooled ECC water (i.e., perfect bypass), and the steam flow ramp was initialized with time reset to zero to facilitate comparison with the data.

A second nodalization in which the downcomer is split into two separate, equal-area vertical flow paths was studied in an attempt to model the multi-dimensional nature of the downcomer flow more realistically. Open crossflow paths were provided at the various downcomer axial volume stacks, with the only flow restriction being the hot legs extending through the upper downcomer. This nodalization is shown in Figure 11. The three lumped cold legs were replaced by a single intact cold leg entering the upper downcomer half where the break pipe is located, and by two lumped cold legs connecting to the other half of the upper downcomer. The heat slabs representing the vessel and core barrel were eliminated to increase calculational speed, since studies performed with the single-downcomer nodalization showed them to have a negligible effect on results. The rest of the nodalization was unchanged.

At first we attempted to initialize the double-downcomer calculations as we did the single downcomer--with the steam flow fully established at 0.75 lb/sec and the ECC flow ramped up from zero to its full value over several seconds. In this case, however, the water packing did not cause a discontinuous jump in the solution; the water simply oscillated between saturated and subcooled conditions around the downcomer. Therefore, an alternate method of finding the initial steady state was found. The new initialization calculations were started with the core region, lower plenum and lower downcomer volumes filled with saturated steam and the upper downcomer, intact cold legs and break pipe volumes filled with subcooled ECC water, as calculated by the single-downcomer nodalization. All the crossflow was assumed to be in the upper downcomer; it was set to zero in the lower downcomer. The vessel pressure was specified to be at ~ 27 psia initially, to match the measured lower plenum initial pressure of 27±4 psia. The steam and water fills were run at constant values for 5 to 15 seconds to allow establishment of crossflow patterns in the lower downcomer. A good steady state was reached when using this procedure, as seen in Figure 12, and the transient calculations were then started.

It should be noted again that, for all these initialization calculations (both single and double downcomer nodalizations), a large artificial form loss of ~ 1.5 was needed at the break pipe in order to maintain the vessel pressure at the correct experimental value during the steady state. Without the additional form loss the system depressurized, and a good starting condition for the transient could not be produced.

5. RELAP4/MOD5 TRANSIENT PREDICTIONS

Calculations for the Creare transient experiments described in section 2 were first done with RELAP4/MOD5. Both a single and a double downcomer nodalization, described in the previous section, were used. Predictions were made using both the generic RELAP4/MOD5 slip correlation and the Westinghouse-Zuber UHI-modified slip model, for both 1/15 scale and PWR-scale vessels. Various other code changes were also implemented; these included using a continuous analytic equation of state rather than the discrete water property table lookups normally used by RELAP, and correcting the void fraction calculation at junctions to self-consistently include the flooding curve derived from the slip models in the drift-flux formalism (see Appendix II).

The transient calculations were begun from a perfect bypass steady state, and an appropriate steam flow ramp for the experiment in question was initiated at t = 0, as discussed in the previous section. For all but one experimental steam flow transient modelled with the single downcomer nodalization, complete ECC bypass was predicted until several seconds after the steam flow was totally shut off. This bears out old PWR results[4] indicating that ECC bypass will not end for a single downcomer nodalization until the system pressure falls below containment pressure. The system pressure in these calculations remains almost constant for the entire transient, dropping abruptly some seconds after the steam flow is shut off, when penetration of ECC water begins. The maintenance of a too-high system pressure can be traced to the form loss coefficient required for the break pipe during the initialization calculations. A typical lower plenum pressure is shown in Figure 13, where it is compared to the experimental data and results calculated using the double downcomer nodalization.

This double downcomer nodalization was then used to study several steam flow transients; calculations were made using both the generic RELAP4/MOD5 slip correlation and the Westinghouse-Zuber UHI-modified slip model. The early time behavior is quite similar to that predicted using the single downcomer nodalization. The system pressure remains almost constant for an extended period of time before rapidly decreasing, but the onset of ECC penetration in the split downcomer calculations occurs before the steam flow reaches zero. Shortly after the pressure dropped and penetration began, the calculations usually terminated abnormally due to either steam table or choked flow table failures (generally associated with water packing and violent flow reversals). The lower plenum at this time was only 5-10% full; the lower plenum water mass for the calculations shown in Figure 13 is given in Figure 14.

The behavior was qualitatively the same for most of the transients studied, with only a change in the time of the sudden pressure collapse and the corresponding start of penetration. Only one split downcomer calculation (for the 10-second H1 transient) did not terminate abnormally. The lower plenum pressure and water mass for that calculation are shown in Figure 15 together with the results for H1 calculations in which the time step was reduced. When we cut the maximum allowed time step in an effort to remove the pressure oscillations, we found that the original solution was not converged. Unfortunately, the converged solution terminated abnormally, as all the other runs had, making it clear that these numerical problems are not the result of convergence problems.

If the sudden pressure drop does indeed always mark the start of ECC penetration even though the calculations terminate, then the results of calculations done for various transients with the two slip models usually bracket the "correct" experimental penetration time (except for very short transients), as shown in Figures 16 and 17 for test H8 and as indicated in the following table:

Transient	Generic Slip	Experiment	UHI Slip
10 sec H1	4 sec	7 sec	4 sec
16 sec H2	6	8	9
16 sec H3	6	8	11
50 sec H8	8	19	31
120 sec H11	18	32	76
160 sec H12	22	44	107

Various code changes were implemented in an effort to eliminate the anomalous behavior after the start of penetration. Using an analytic equation of state rather than the water property tabular lookups normally used by RELAP made no appreciable difference in the results calculated. Correcting the junction void fraction calculation for consistency with the flooding curve described in Appendix II had no effect on results obtained using the double downcomer nodalization. However, it did have a drastic effect on the single downcomer calculations - rather than perfect ECC bypass continuing until many seconds after the transient steam flow reached zero, penetration began during the transient, as shown in Figures 18 and 19 for test H8. The predicted penetration times agreed reasonably well with the experimental penetration times, as seen in the following table:

Transient	Experiment	Single Downcomer With Flooding Changes	Double Downcomer
15 sec H2	8 sec	6 sec	6 sec
50 sec H8	19	17	31
100 sec H10	24	30	51
160 sec H12	44	51	107

While the double downcomer nodalization with the Westinghouse-Zuber UHI-modified slip model gives conservative predictions for all but the short transients, the single downcomer with self-consistent flooding gives the "best" agreement with experiment although penetration may be early or late. The calculations still terminated abnormally after penetration was initiated.

To facilitate comparison with the Westinghouse results, the split downcomer nodalization was next scaled up (using K* scaling) to a full-size PWR model. Perhaps because the refill rate is lower than in the 1/15 scale calculations, these full-scale calculations could occasionally complete the transient without code failure. Unlike the behavior seen in the 1/15 scale calculations, in the full-scale calculations the system pressure decayed reasonably, as seen in Figure 20 for test H1. (The additional form loss coefficient of 1.5 was left in the nodalization, but no calculations were made to see if the initial condition was a steady state.) Since the lower plenum scaled as the volume (15^3) and the ECC flow scaled as the area (15^2), the lower plenum refilled more slowly than in the experiments and it was only 10-20% full at the end of the transient, as seen in Figure 21 for test H1. The penetration onset trends found in the 1/15 scale and PWR scale calculations were quite different, as seen by comparing the results in the following tables:

Creare Scale

Transient	Generic Slip	Experiment	UHI Slip
10 sec H1	4 sec	7 sec	4 sec
16 sec H2	6 sec	8 sec	9 sec
16 sec H3	6 sec	8 sec	11 sec
120 sec H11	18 sec	32 sec	76 sec

PWR Scale

Transient	Generic Slip	Experiment	UHI Slip
10 sec H1	8 sec	7 sec	4 sec
16 sec H2	9 sec	8 sec	5 sec
16 sec H3	9 sec	8 sec	5 sec
120 sec H11	10 sec	32 sec	6 sec

For the PWR-scale calculations, the UHI-modified slip model predicts the earlier penetration and the generic MOD5 slip model seems conservative for short transients only. This is opposite to the effect of these slip models in the 1/15 scale analysis.

Besides studying the conservatism of the various slip models and downcomer nodalizations, we wanted to examine oscillations which had been observed in the UHI plant audit calculations and their possible effect on ECC delivery. Generally our calculations (particularly at 1/15 scale) terminated just as these oscillations were beginning, but the full-scale calculations did occasionally complete the transient without code failure. Figure 22 shows the mass flow rate in the junction between the lower plenum and the downcomer, for two PWR-scale H1 transient calculations. Both slip models show mass flow oscillations starting at the onset of penetration, but the UHI-modified slip model does produce large oscillations throughout refill while the generic MOD5 slip models produce oscillations almost an order of magnitude smaller. This confirms the old plant calculation results[4].

6. RELAP4/MOD6 AND MOD7 RESULTS

The Creare transients were also analyzed using RELAP4/MOD6 and the thermal equilibrium option of MOD7. The split downcomer nodalization was utilized in the analyses. As seen in Figures 23 and 24 for test H8, none of these calculations showed any change in the overall systems behavior. The time at which the pressure drop and subsequent code termination occurred agreed with that calculated using the Westinghouse-Zuber UHI-modified slip package in MOD5 rather than with the time calculated using the generic MOD5 slip model. Since the generic slip models in MOD6 and MOD7 consist of different correlations in different flow regimes (some of which are identical to those in the UHI slip model), this result is not unexpected.

Calculations were then attempted with the nonequilibrium option in RELAP4/MOD7. Starting from perfect bypass, it was found to run very slowly and to yield widely oscillating pressures and junction mass flows even during the first second of the initialization calculation (when the steam and water fills were held constant to allow crossflows to be established). When the calculation was started by ramping the steam and water flow, it still ran very slowly but did come to a "steady state" perfect bypass which was very oscillatory (due to water packing) and usually resulted in an abnormal code termination before the transient was well underway. However, no additional form loss was needed in the break pipe to maintain the vessel pressure during the initialization because the flow out the break pipe was choked. The calculation, in fact, maintained too high a pressure (~ 60 psia).

7. RELAP5 RESULTS

Calculations run with the nonequilibrium option of RELAP4/MOD7 seem to indicate that the problem of correctly initializing the Creare transient tests at a perfect bypass steady state without adding artificial form loss coefficients may involve nonequilibrium effects. Additional analyses were tried with RELAP5, a fully nonequilibrium code, in an effort to verify this.

RELAP5/MOD0 and early versions of RELAP5/MOD1 generally terminated during the initialization due to code errors. These errors have been fixed in later versions of RELAP5/MOD1, since INEL has adopted our Creare transient model as a test problem. Results obtained using the current release version of MOD1 are shown in Figures 25 (lower plenum pressure) and 26 (lower downcomer-to-lower plenum mass flow). These are not transient calculations - they are still initialization calculations. The results show the break flow to be nonequilibrium and choked, and wildly oscillatory. No transient calculations were tried.

8. TRAC-PD2 RESULTS

In addition to RELAP, we also tried using the TRAC-PD2 code to predict the Creare transient experiments, since TRAC is a non-equilibrium code with a multi-dimensional vessel module. The nodalization used is shown in Figure 27. The vessel is modelled using five axial levels with each level subdivided into two radial and four azimuthal zones, for a total of 40 mesh cells. The four cold legs are each divided into three mesh cells; one cold leg is connected to a 1 atm break while the other three are connected to fills representing the ECC injection. Four pipes are used to ensure symmetric injection of the steam into the four cells of the core region in the top vessel level.

The calculation was started with the steam flow and water flow both zero, and the vessel filled with saturated steam. The steam flow was ramped up to its full value in one second; the ECC water was ramped up to its full value over the next two seconds and the calculation was run for an additional few seconds to verify that a valid steady state (perfect bypass) was reached before the transient was started. TRAC is the only code which has proved capable of calculating the initial steady-state conditions without using any artificial form loss coefficient or other assumptions.

The lower plenum pressure seen in a TRAC calculation of the Creare H1 transient is seen in Figure 28. The initial system pressure calculated is too high (31 rather than 28 psia), but within the uncertainty of 27 ± 4 psia, and the overall behavior matches the experiment very well. The lower plenum began to refill 6 seconds into the 10 second transient as seen in Figure 29, earlier than the experiment which began refill at 7 seconds, and was completely full by the end of the transient. The calculation was very slow running, with the 5-second steady state and 10-second transient requiring about 3 hours of 7600 computer time.

The TRAC calculation did correctly predict that at the start of the transient the flow out the break pipe was choked. This was due to the presence of a small amount of saturated vapor carried along with the subcooled liquid. The penetration time of 6 seconds found in the TRAC calculation agrees very well with the 6 second penetration time seen for the same 10 second transient in the only RELAP4 calculation that did not terminate abnormally. (As previously mentioned, it was one of the split downcomer calculations.) The RELAP4 calculated system pressure, however, is very different from that seen in the experiment and in the TRAC calculation. It not only remains high for long periods of time, but also lacks the lower plenum pressure oscillations seen in Figure 22 for the TRAC calculation (which are also present in the experiments). Similar lower plenum oscillations have also been seen in full-scale PWR plant calculations when done with the UHI-modified slip model in RELAP4/MOD5.[4]

9. DISCUSSION AND CONCLUSIONS

Westinghouse compared SATAN-UHI results to experimental steam transient tests data from the Creare 1/15 scale test facility, to show that the UHI downcomer model conforms to NRC criteria (i.e., is conservative). They state that the bypass threshold predictions are all conservative relative to the measured data when the crossflow modification is included in the downcomer model, that the predicted lower plenum filling rates are lower than measured rates, and that the observed relationship between bypass threshold and steam ramp rate is preserved.

The Westinghouse report does not explain the computer code stability problems that prevented use of the extremely small control volume sizes required by the model of the actual Creare vessel. The report also does not explain how results from the full-size PWR downcomer model are compared via K* scaling to the 1/15 scale Creare transient tests. This is important since the j* scaling used in the Creare results differs from K* scaling by a factor of $\sqrt{\text{length scale}}$. The void fraction plots presented in Ref. 1 usually show the lower plenum less than 25% full at the end of the transient, and the calculated results for the H1 transient show perfect bypass continuing even when the ramped steam flowrate is zero. The lower "conservative" refill rate is most likely a demonstration of the differences between K* and j* scaling. The bypass threshold prediction was usually nonconservative until the crossflow modification was introduced, but a 2-second error in the initialization calculation time offset reduces the conservatism claimed by Westinghouse.

For comparison purposes, equivalent calculations were run at Sandia with RELAP4 and, later, RELAP5 and TRAC. Most of the calculations were for the 1/15 scale Creare vessel, and the calculations usually terminated with water-pack-induced oscillations at the beginning of end-of-bypass. A split downcomer model or a change in junction void fraction calculation was found necessary for ECC penetration to occur. Unlike the Westinghouse H1 calculation, once a split downcomer nodalization was used, end-of-bypass always occurred sometime during the transient. For a double downcomer nodalization, the results of two slip models (generic RELAP4/MOD5 and SATAN-UHI) usually bracket the experimental penetration time, with the SATAN-UHI slip model being conservative for all but the shortest transients. The "flooding curve" changes to the calculation of junction void fraction give the "best" agreement to experiment, with early penetration for shorter transients (< 50 sec) and late penetration for longer transients (> 50 sec).

The qualitative behavior in all the RELAP4 runs is identical -- relatively constant system pressure for significant periods of transient time, followed by a a very sudden pressure drop and the onset of large flow oscillations, followed usually by code failure, as the lower plenum refills. (In the calculation run to completion, the lower plenum refilled at almost exactly the measured fill rate.) The high system pressure is maintained by the large form loss coefficient added to the break pipe during initialization. Without it, the initial perfect bypass is not a steady state condition and the vessel begins to blow down instantly (as, indeed, the lower plenum pressure trace shown in Figure 6 indicates was also predicted by the Westinghouse SATAN-UHI calculations).

The results were quite different when the RELAP4/MOD5 model was scaled up to a full size PWR using K* scaling. The SATAN-UHI slip model predicts earlier ECC penetration than the generic MOD5 slip model and the generic slip model is conservative, although only for short transients. The vessel pressure decays relatively smoothly and the lower plenum refill rate is much slower than the measured experimental value.

No substantive differences were seen for calculations performed with RELAP4/MOD7, until the nonequilibrium option in MOD7 was used. In this case, no additive form loss coefficient was needed. The initial system pressure was maintained at a steady, albeit too high, value because the break flow was in a choked, nonequilibrium condition. The transient could not be run because of stability problems. RELAP5/MOD1 had similar stability problems -- the system pressure oscillated wildly during the initialization calculation, whether the water flow was ramped up from zero or the system was started at perfect bypass. The break flow was predicted to be choked and nonequilibrium, as it was in the TRAC-PD2 calculation. Only TRAC-PD2 showed a smooth and well-behaved initial nonequilibrium choked flow, followed by the proper system pressure drop during the transient. During the transient, TRAC correctly predicted that the lower plenum refilled at exactly the measured fill rate. All these nonequilibrium calculations ran very slowly.

None of the calculations reported here indicate that the Westinghouse analysis with the UHI downcomer model has been shown to be conservative. The two major results to emerge are that (1) a nonequilibrium code is needed to correctly model the Creare experiments and (2) results from a full-size PWR downcomer model cannot be validly compared via K* scaling to the 1/15 scale Creare transient tests, which are based on j* scaling.

APPENDIX I - Scaling Laws

The dimensionless variable used in presenting the 1/15 scale Creare countercurrent flow test data is the Wallis parameter, defined as

$$j^*_{g,\ell} = j_{g,\ell} \sqrt{\frac{\rho_{g,\ell}}{gw\,(\rho_\ell - \rho_g)}}$$

where w is the average downcomer annulus circumference, ρ_g and ρ_ℓ are the steam and water densities respectively, g is gravity and $j_{g,\ell}$ is the gas or liquid volumetric flux (referenced to the downcomer flow area).

The Kutateladze number is defined as

$$K^*_{g,\ell} = j_{g,\ell} \sqrt[4]{\frac{\rho^2_{g,\ell}}{g\sigma\,(\rho_\ell - \rho_g)}}$$

where σ is the gas-liquid surface tension. Unlike j* scaling, the Kutateladze number contains no overt length scale, but depends only on fluid properties.

APPENDIX II - Effect of Flooding on Vertical Junction Void Fraction

Although the vapor volume fraction (void fraction) is basically a cell center ("volume") quantity, any drift-flux code such as RELAP must include a prescription for defining its value at a cell boundary ("junction"). This value is used both to calculate a relative velocity and to resolve the net mass flux (from the momentum equation) into its liquid and vapor components. This is a generalization of the classic problem of treating advective terms in Eulerian hydrocodes, where considerations of numerical stability have led to the practice of "upwind differencing" or "donoring." Current versions of RELAP use combinations of component donoring and average values. We believe that this problem is implicated in observed stability problems with these codes.

Void fraction and mixture density are equivalent variables. In the absence of slip, stability requires use of the value for the upstream ("donor") volume. While slip should not change this conclusion for strongly cocurrent flow, there is an obvious problem for countercurrent or near-countercurrent flow. Some insight may be gained from a characteristics analysis, recognizing that the no-slip donor cell is upstream on the material characteristic. As shown in Ref. 12 the generalization of the material characteristic to a drift-flux model is the continuity-wave characteristic, so that "donor" should be replaced by "upstream for continuity waves."

This concept, although derived and stated rather differently, is the basis for the Westinghouse model incorporated in SATAN and in Sandia versions of RELAP modified for UHI analysis. The "donor" is to be chosen either as the void fraction in the lower volume, α_{BOT}, or as that in the higher volume, α_{TOP}. A continuity wave travels with the velocity $V_{cw} = (\partial j_g/\partial \alpha)_j$, where j_g is the gas volumetric flux (superficial velocity), j is the total volumetric flux, and α is the void fraction. If one assumes that a finite-amplitude continuity wave, or "continuity shock," travels with the velocity $V_{cs} = \Delta j_g/\Delta\alpha$, where $\Delta\alpha \equiv \alpha_{BOT} - \alpha_{TOP}$ and Δj_g is the difference in gas fluxes computed with the two void fractions, $\Delta j_g \equiv j_g(\alpha_{BOT}) - j_g(\alpha_{TOP})$, the sign of V_{cs} may be used to define a donor. The results may be expressed as:

1. If $\alpha_{BOT} < \alpha_{TOP}$, which is almost equivalent to $\rho_{BOT} > \rho_{TOP}$ and corresponds to a gravitationally stable density gradient, use that α which gives the lesser upward j_g and therefore minimizes phase separation.

2. If $\alpha_{BOT} > \alpha_{TOP}$, corresponding to a gravitationally unstable density gradient, use that α which gives the greater upward j_g and maximizes phase separation.

Examination of a few cases will show that this reduces to the conventional definition of "donor" for strongly co-current flow.

The scheme just described contains a serious flaw. Consider a situation involving pure liquid suspended above pure vapor with no initial vertical motion. This occurs during the complete bypass phase of emergency core coolant (ECC) injection or, more prosaically, when a glass full of water is suddenly inverted. Sooner or later, one would expect the liquid to fall. However, neither of the cellcenter void fractions, $\alpha = 0$ or $\alpha = 1$, permits countercurrent flow and the fall must be initiated on numerical "noise." This is the basic reason that a split downcomer model is essential for ECC penetration in most of the calculations described in this report: The fall of liquid can then develop from a circulatory flow rather than from accumulation of "noise."

This problem may be solved using a generalization of the argument which led to the previous model. One imagines a continuous variation in void fraction along the path connecting adjacent volumes, considers the development of this profile in time under the influence of continuity waves, and takes as the cell-boundary void fraction that which will ultimately exist after propagation and interactions of these waves. The result is remarkably simple: The Westinghouse result is changed only to the extent that the entire range of α from α_{BOT} to α_{TOP} must be considered in finding a cell boundary α which minimizes or maximizes the rate of phase separation.

It is clear that if this generalization allows a solution differing from the previous result, the solution must satisfy $(\partial j_g/\partial\alpha)_j = 0$. This relationship defines the flooding curve, a locus of states of two-phase flow through which no continuity-wave information may propagate.[13] While there are exceptions (see Fig. 4.4 in Ref. 13) the flooding curve is primarily the limit of countercurrent flow, and it is thus that it solves our problem of falling water. Between $\alpha = 0$ and $\alpha = 1$, there is a point on the flooding curve, say α_F, which corresponds to zero net mass flow. The generalized rule will find this value, α_F, as the initial cell-boundary void fraction, and the water will fall (when pressure differentials permit) in a state of flooding.

While the generalized rule has further implications, they are beyond the scope of this Appendix.

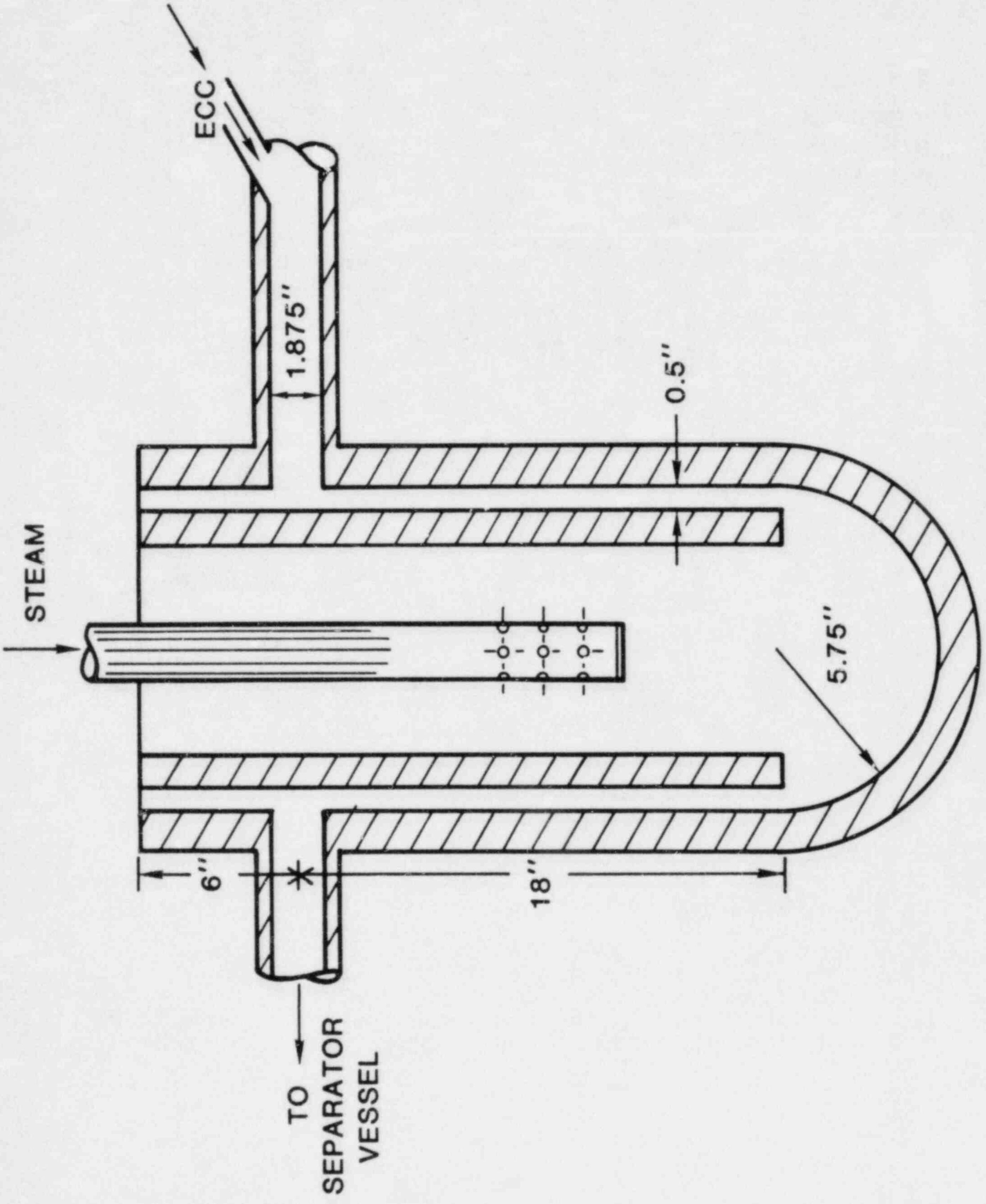

Figure 1: Schematic Diagram of Creare 1/15-Scale Vessel

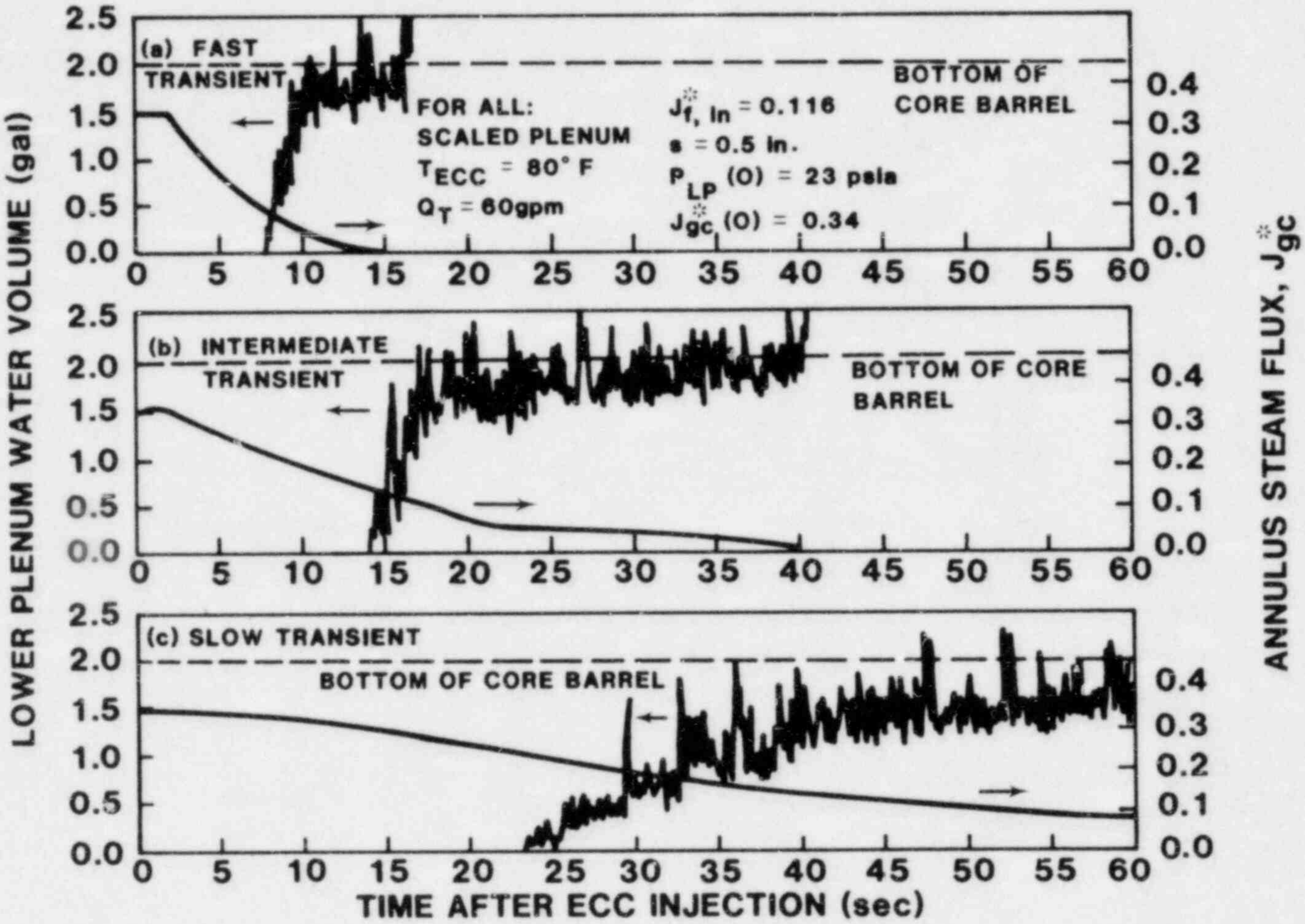

Figure 2: Comparison of Creare Bypass Transient Results for Different Steam Flow Ramp Rates (taken from Ref. 5)

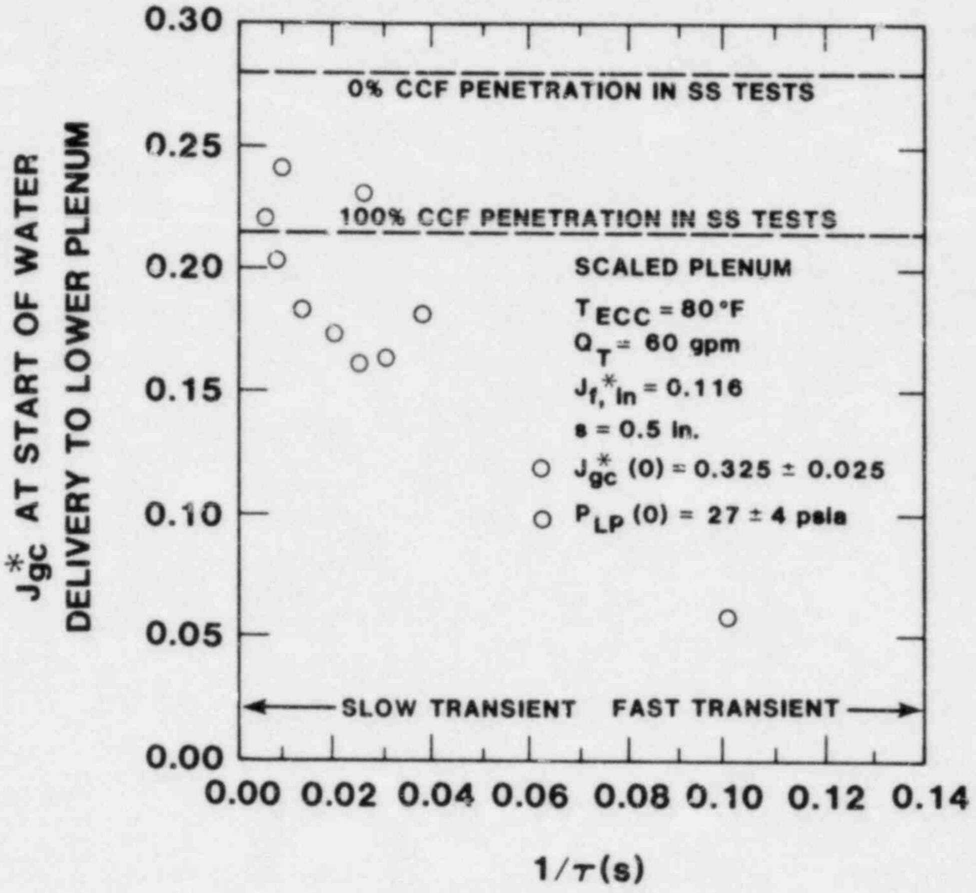

Figure 3: Effect of Transient Steam Flow Ramp Rate on j_{gc}^{*} at Start of Water Delivery to Lower Plenum (taken from Ref. 5)

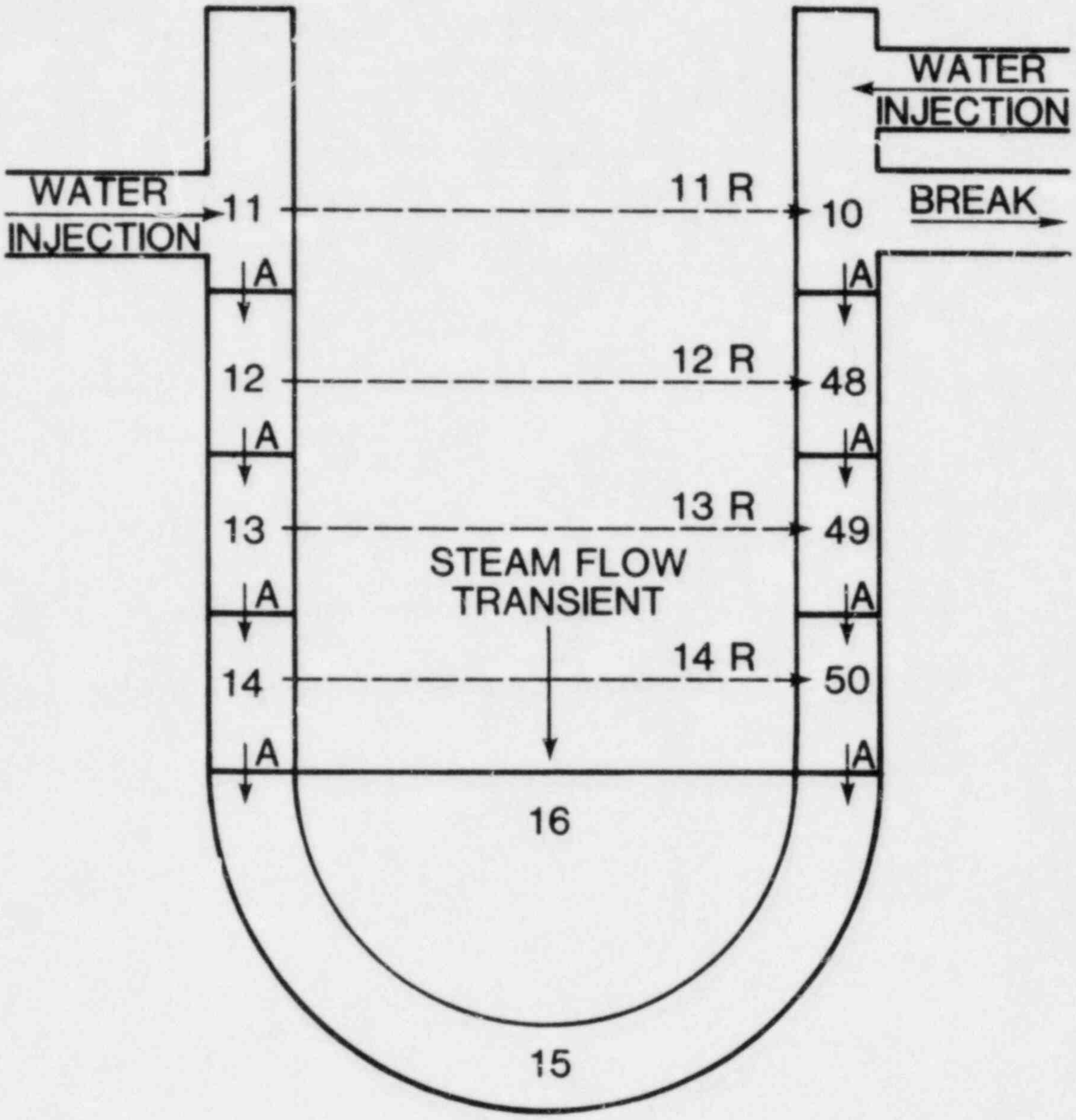

Figure 4: SATAN Nodalization Used for Creare Analyses (taken from Ref. 1)

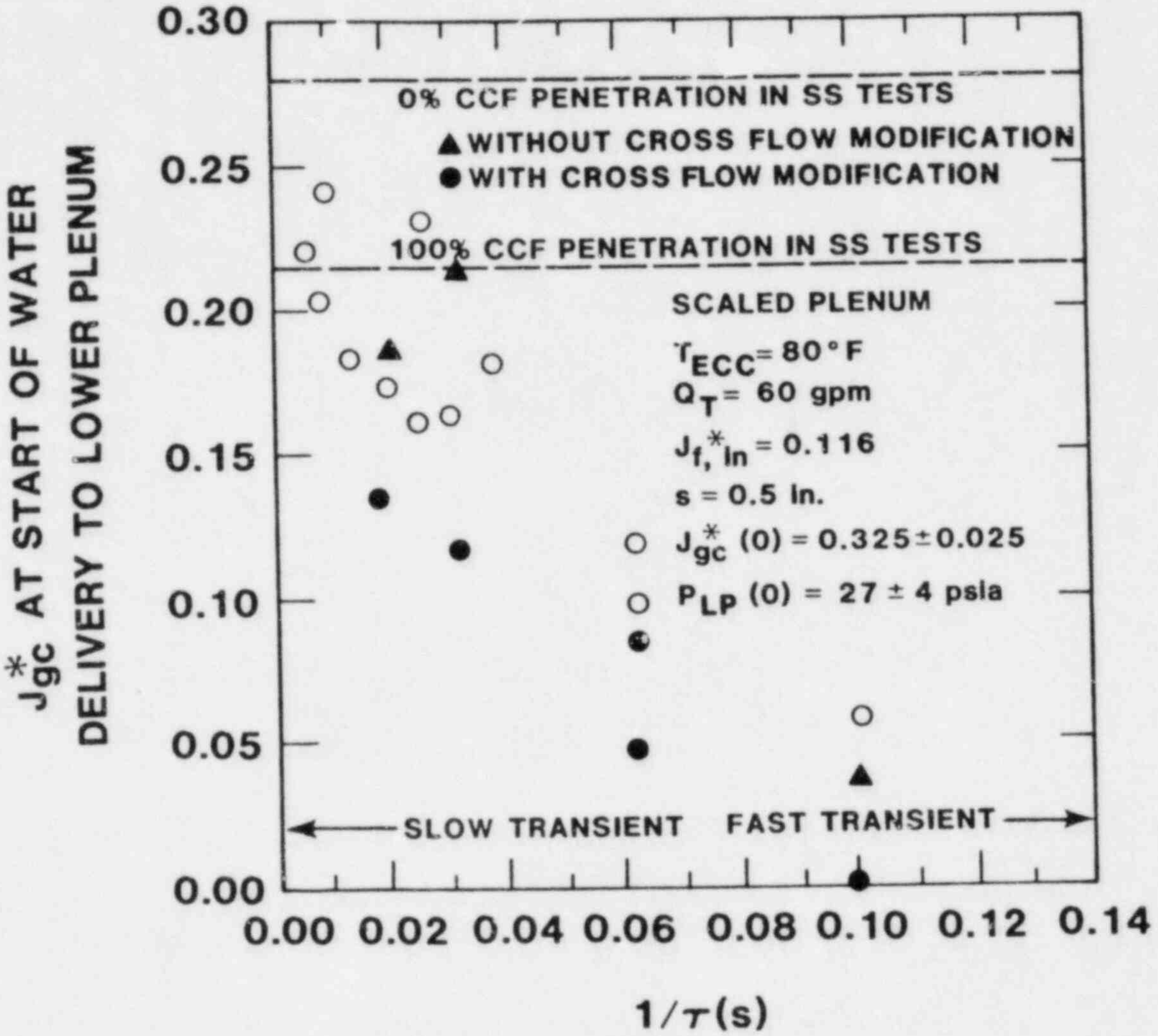

Figure 5: Comparison of SATAN and Creare Results for j^*_{gc} at Start of Water Delivery (taken from Ref. 1)

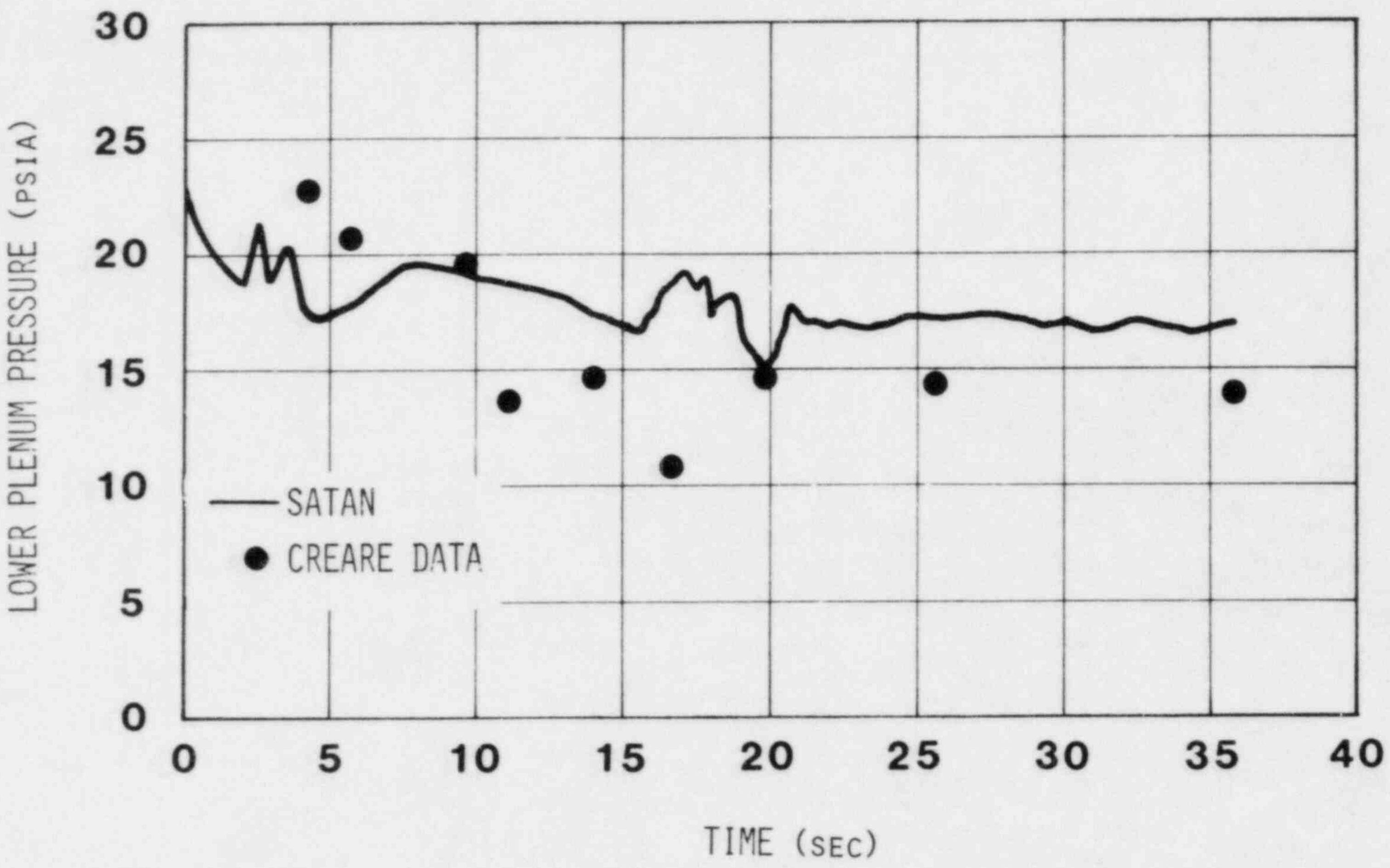

Figure 6: Comparison of SATAN and Creare Results for Lower Plenum Pressure - Test H5 (Data taken from References 5 and 11)

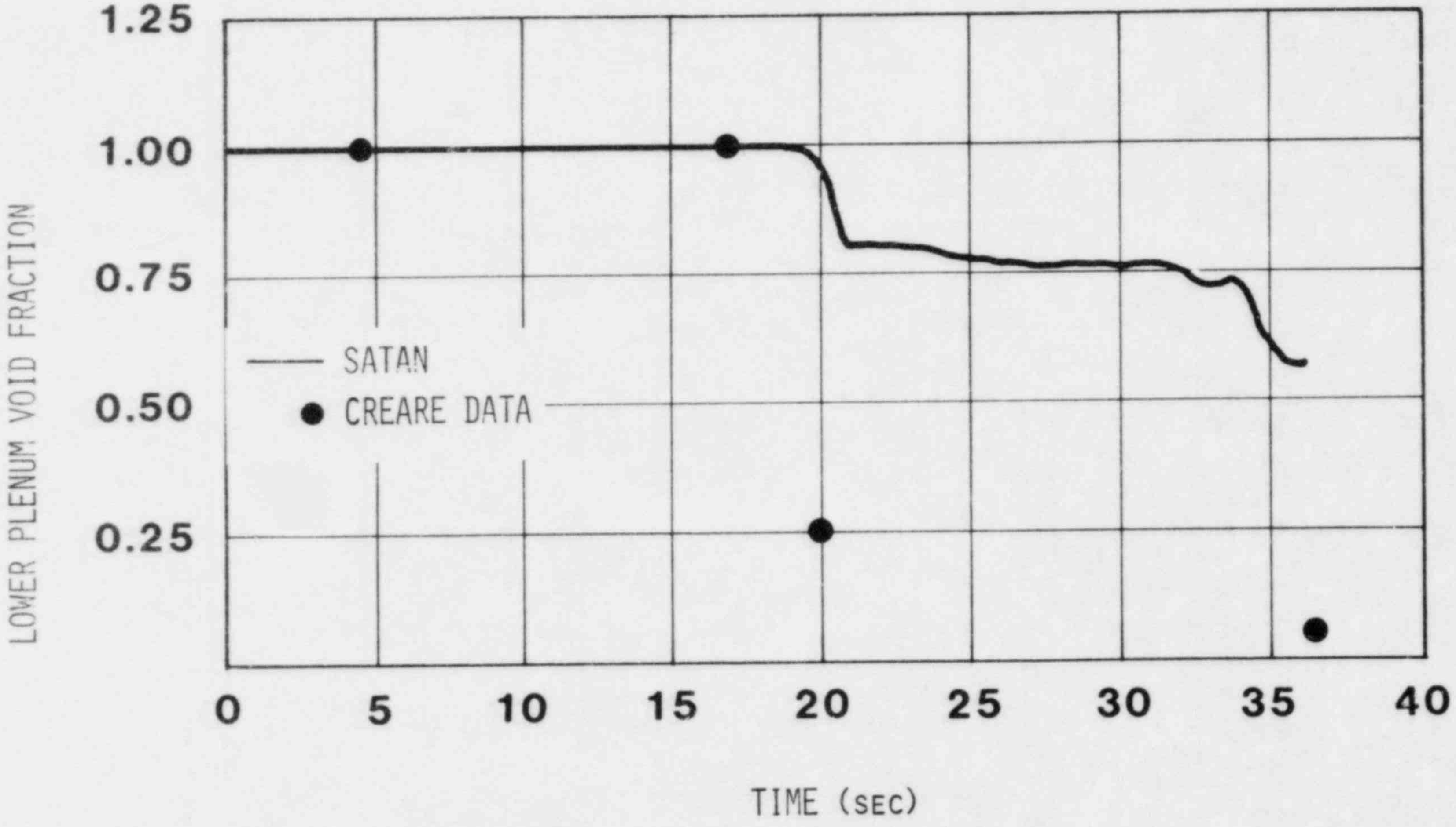

Figure 7: Comparison of SATAN and Creare Results for Lower Plenum Void Fraction - Test H5 (Data taken from References 1 and 5)

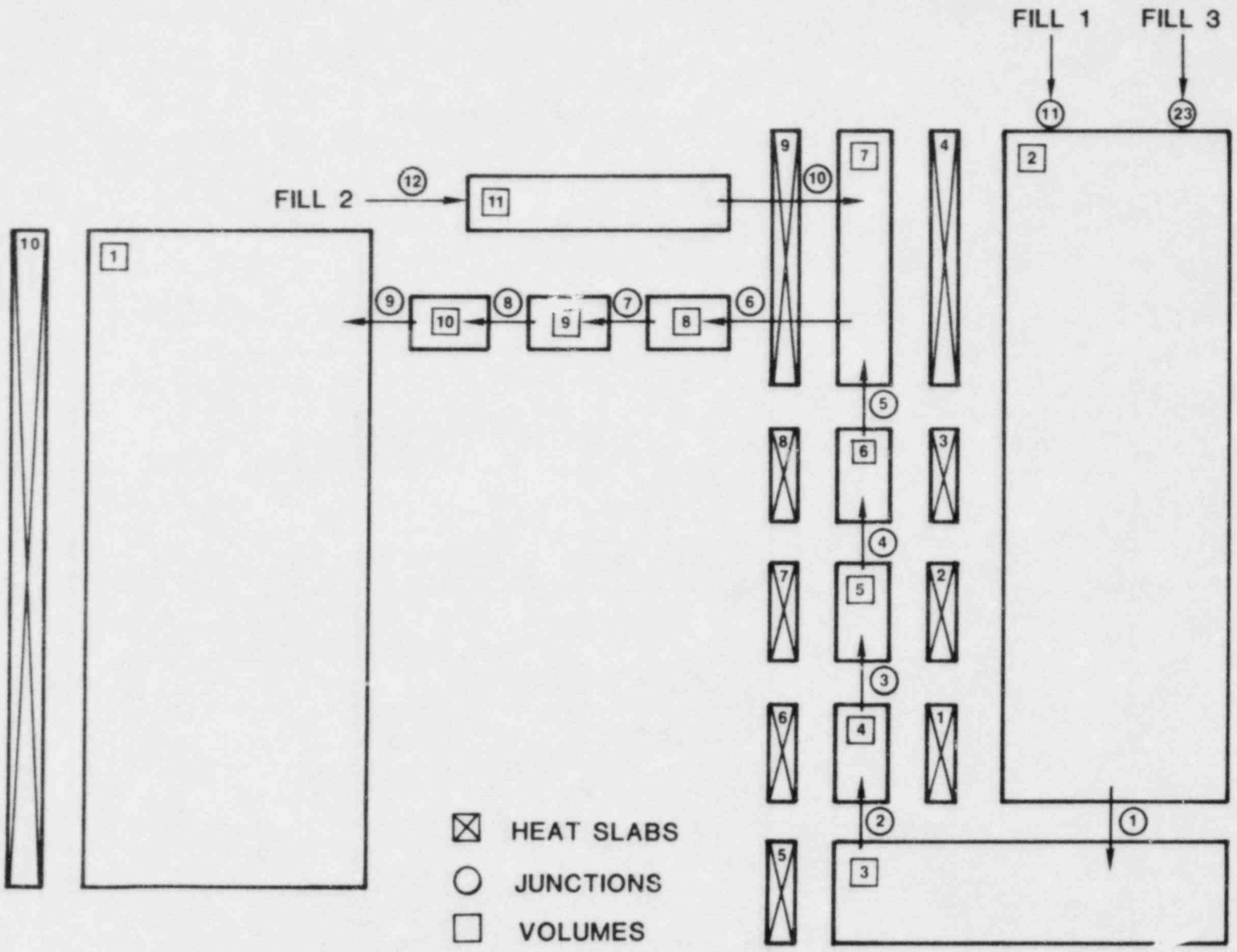

Figure 8: RELAP4 Single Downcomer Nodalization Used for Creare Analyses

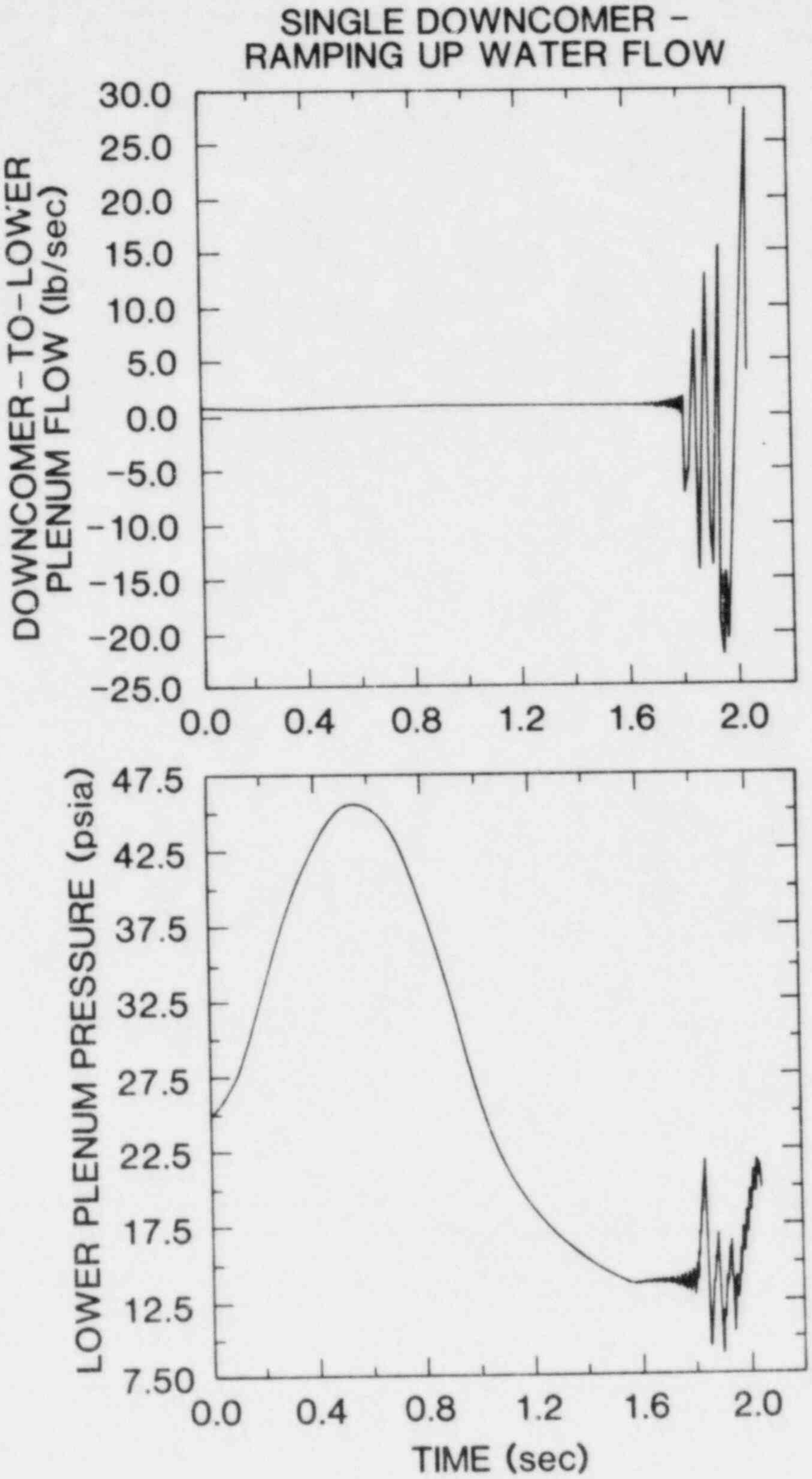

Figure 9: Steady State Initialization Results Using the Single Downcomer Nodalization - Abnormal Termination

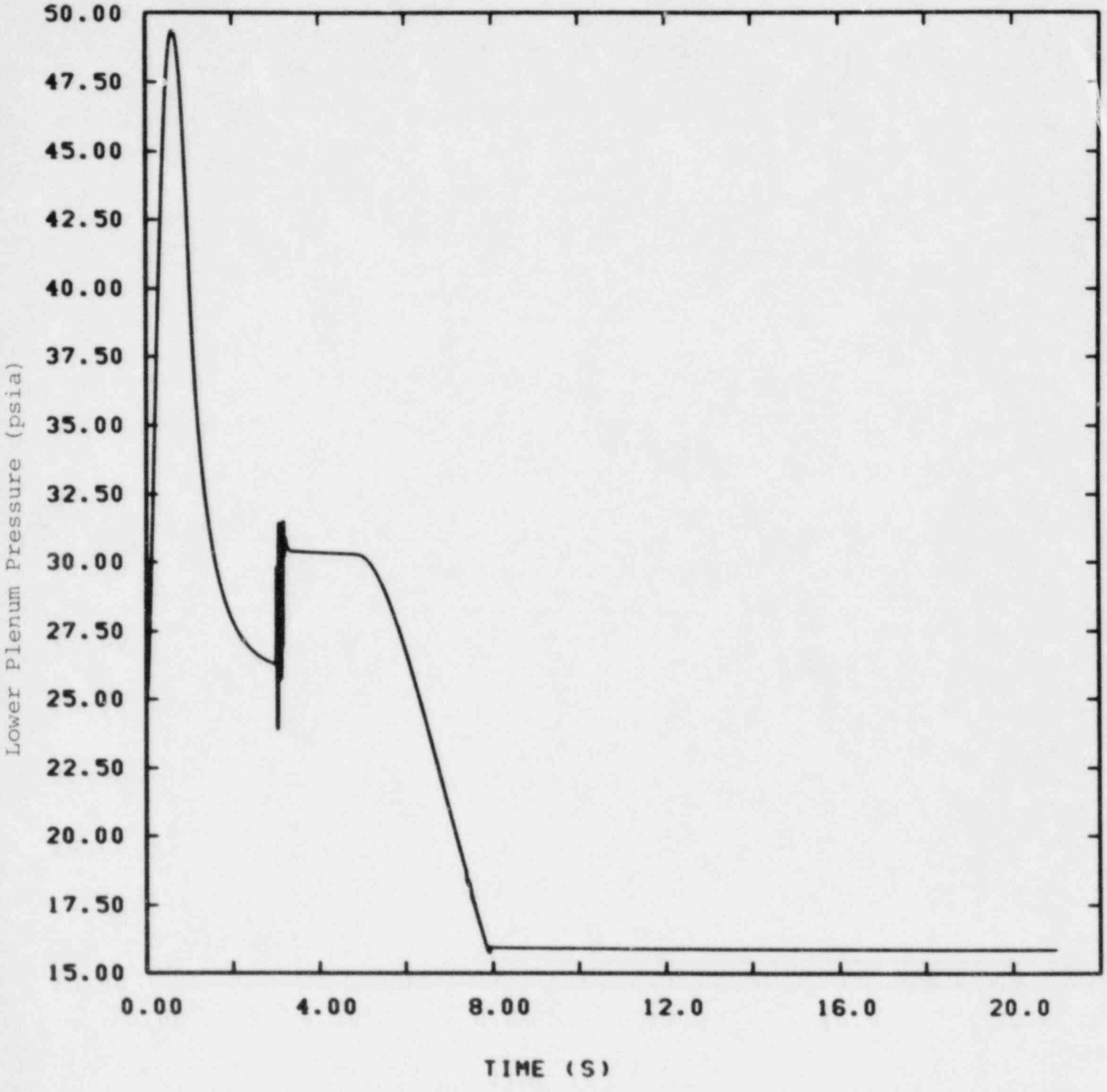

Figure 10: Steady State Initialization Results Using the Single Downcomer Nodalization - Smooth Solution

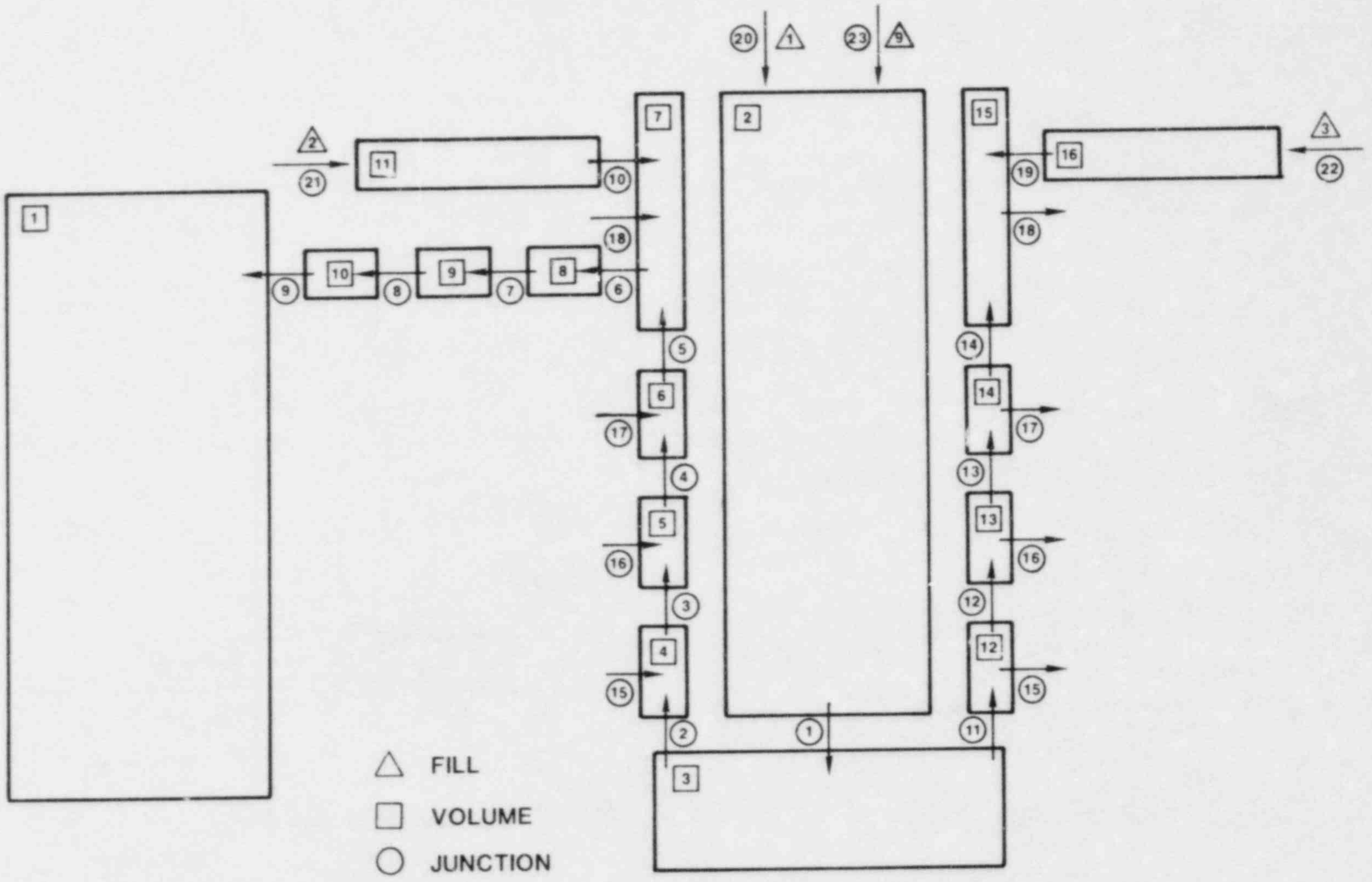

Figure 11: RELAP 4 Double Downcomer Nodalization Used for Creare Analyses

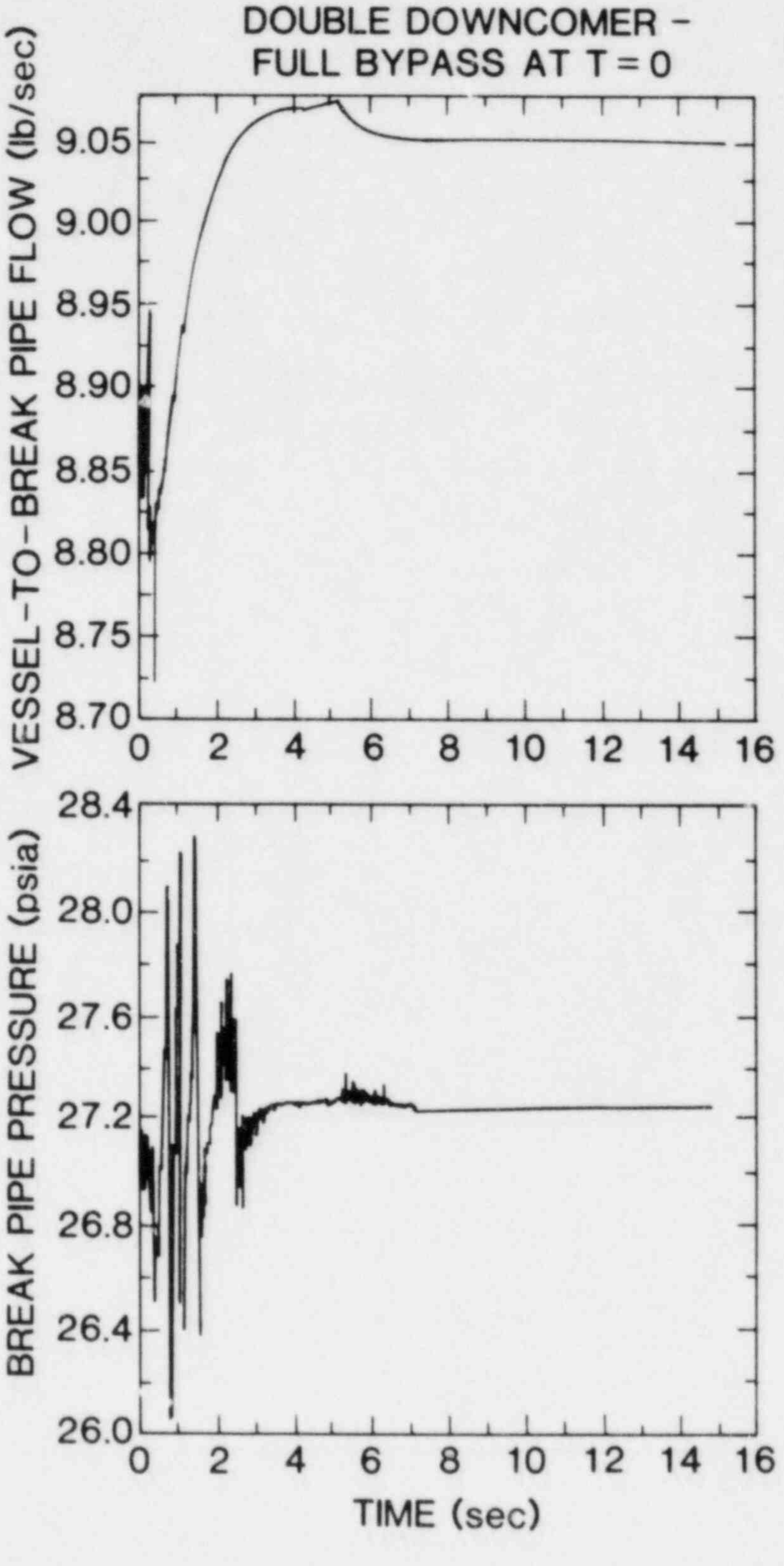

Figure 12: Steady State Initialization Results Using the Double Downcomer Nodalization

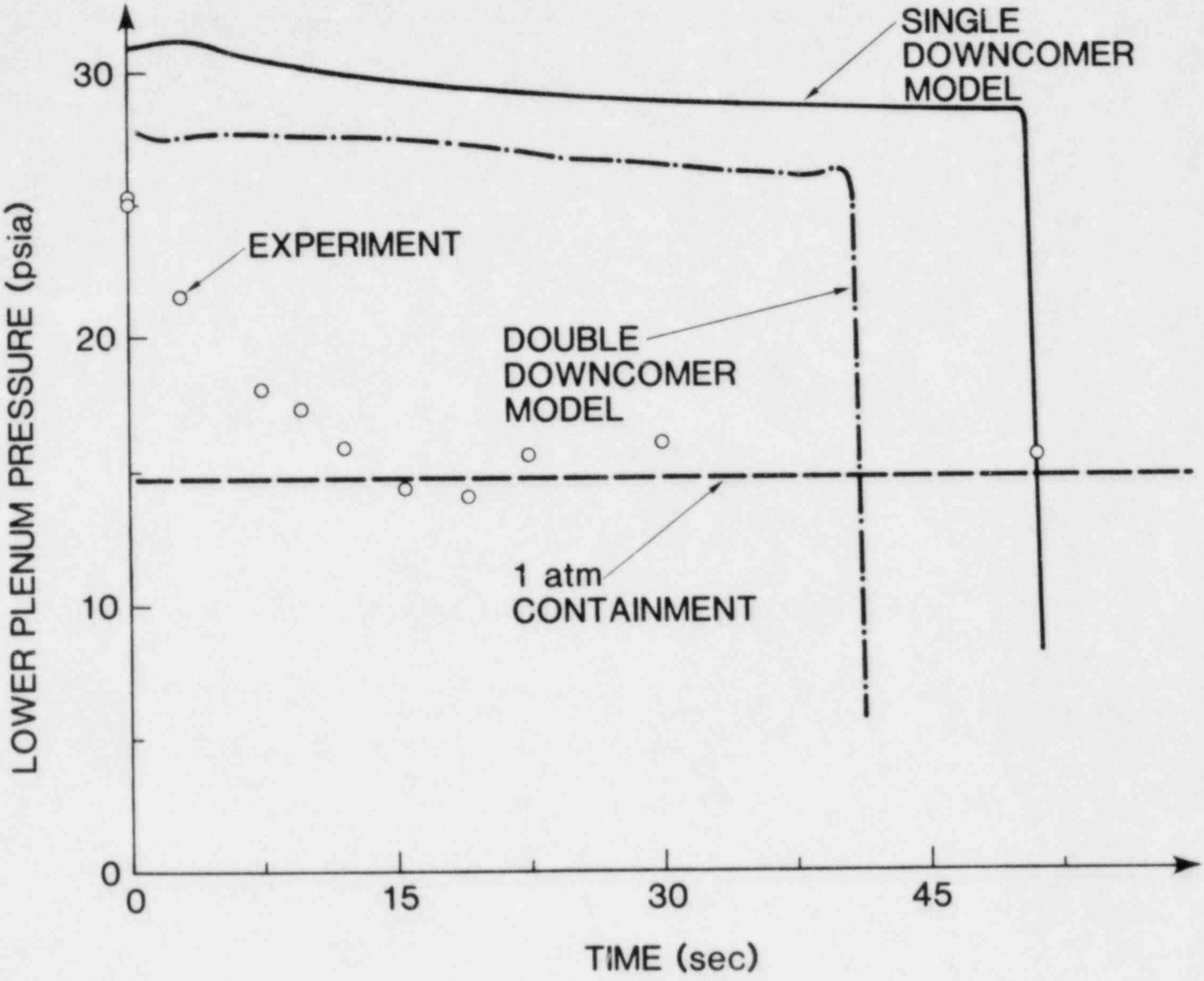

Figure 13: RELAP4/MOD5 Predictions of Lower Plenum Pressure - Creare Test H8 - Single vs. Double Downcomer

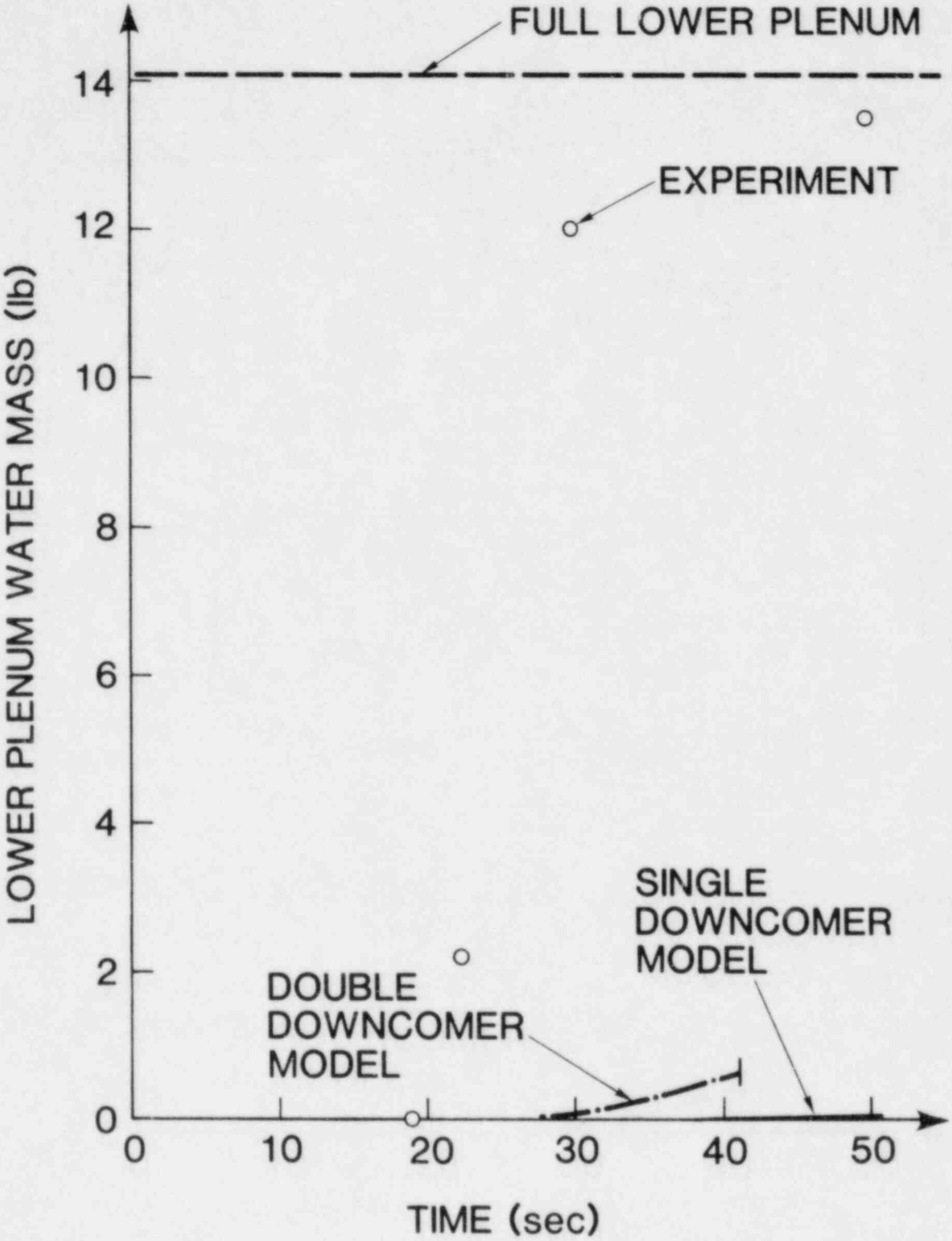

Figure 14: RELAP4/MOD5 Predictions of Lower Plenum Filling - Creare Test H8 - Single vs. Double Downcomer

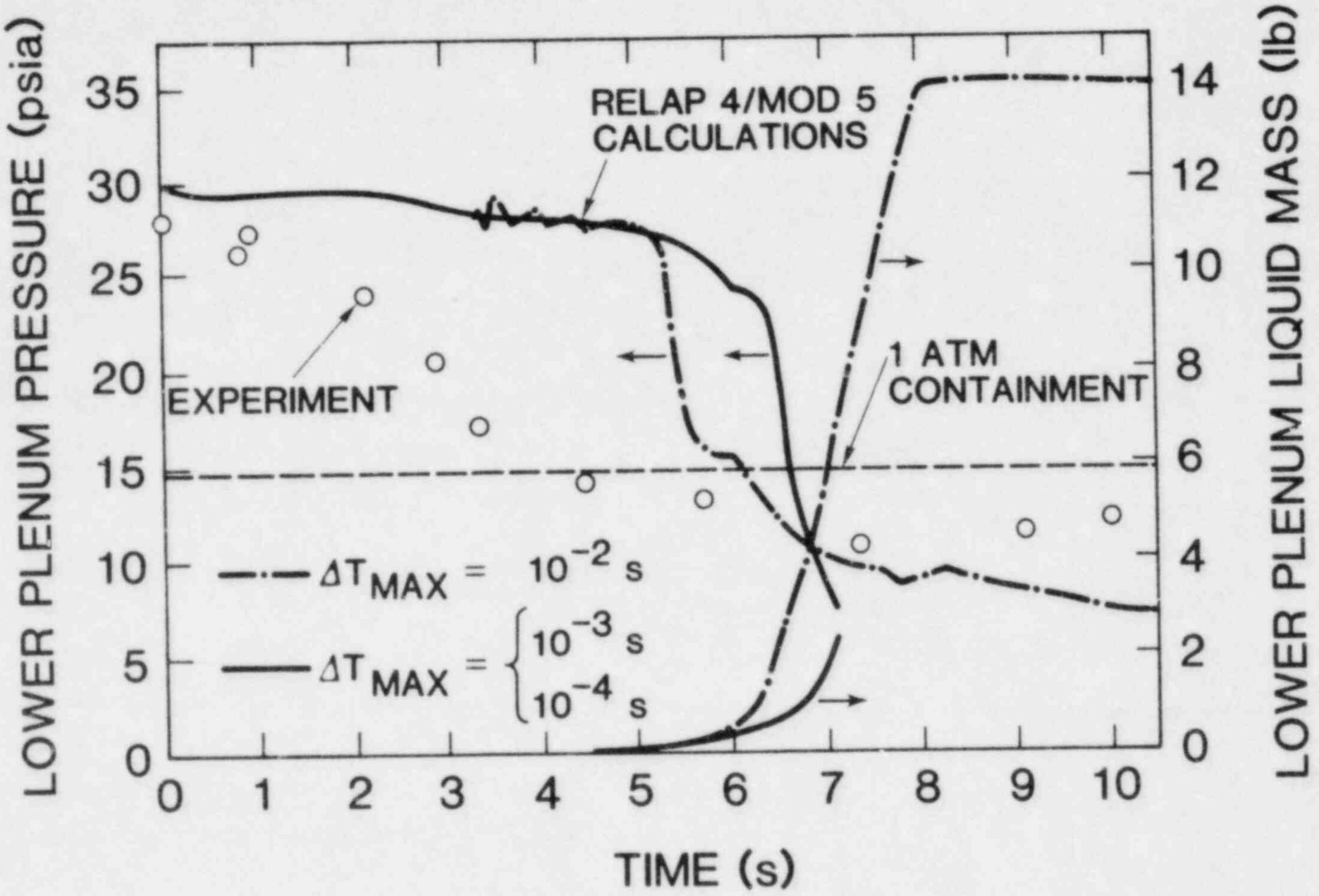

Figure 15: RELAP4/MOD5 Predictions of Lower Plenum Pressure and Lower Plenum Filling - Creare Test H1 - Double Downcomer

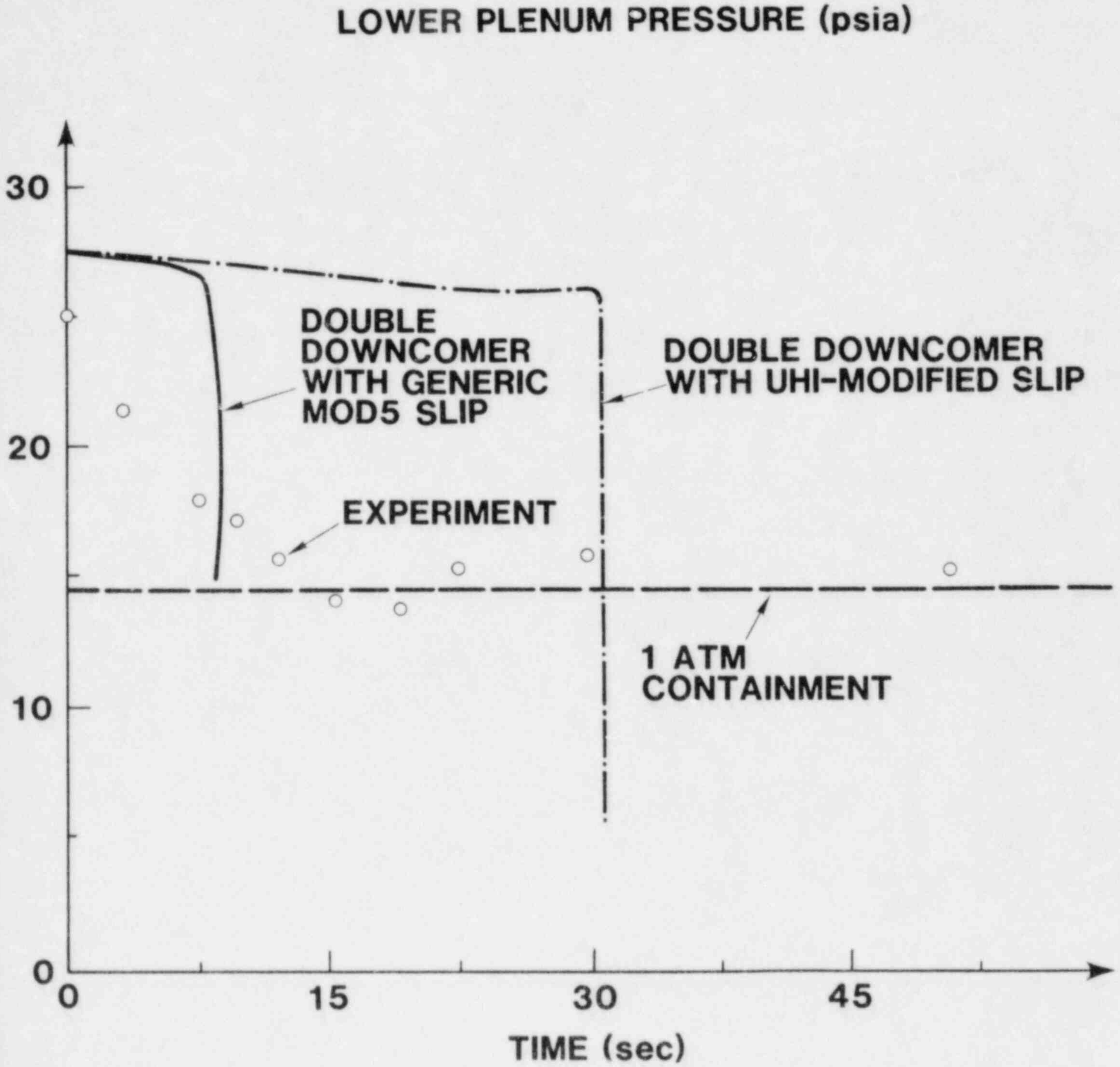

Figure 16: RELAP4/MOD5 Predictions of Lower Plenum Pressure - Creare Test H8 - Generic vs. UHI Slip

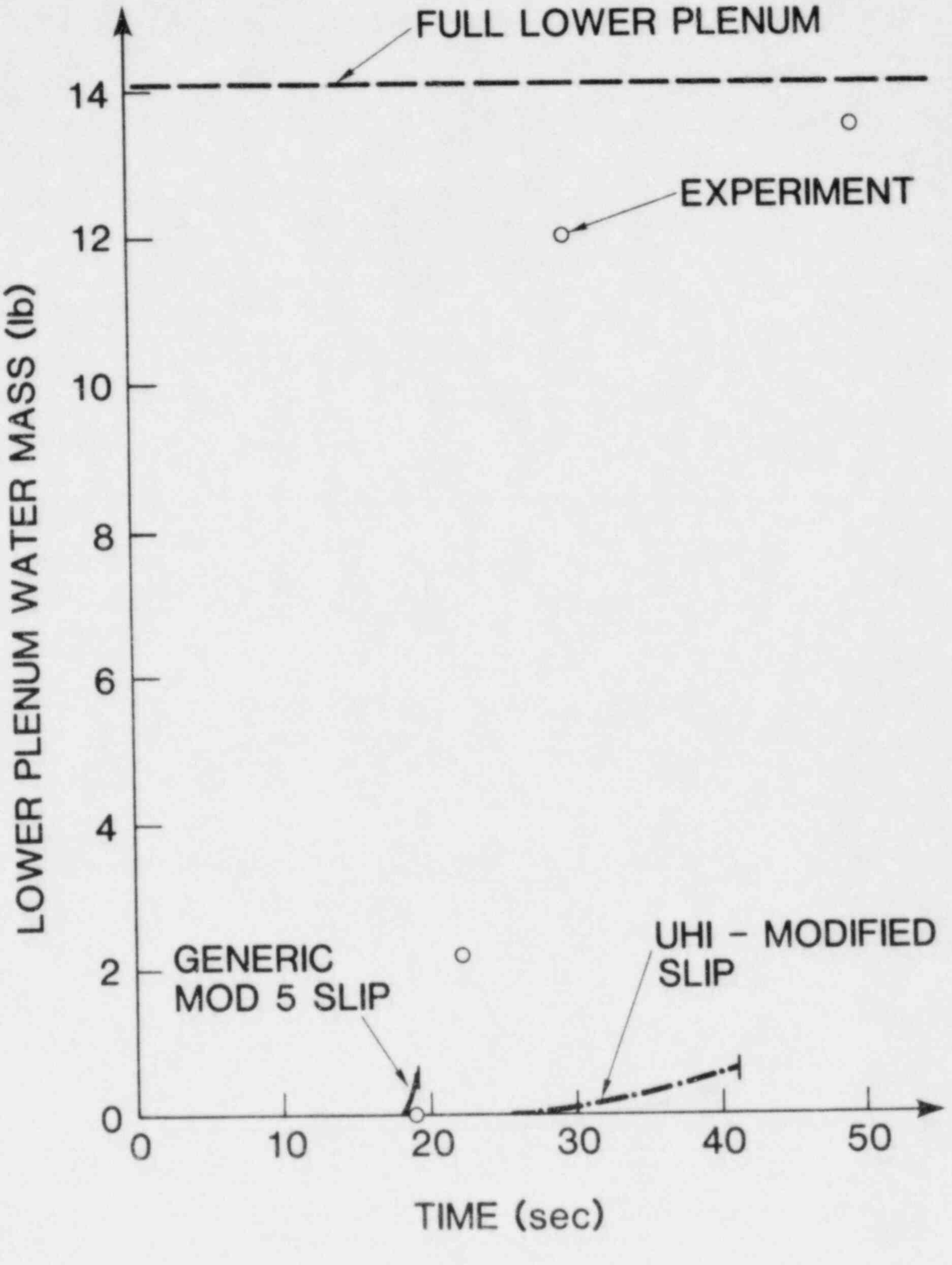

Figure 17: RELAP4/MOD5 Predictions of Lower Plenum Filling - Creare Test H8 - Generic vs. UHI Slip

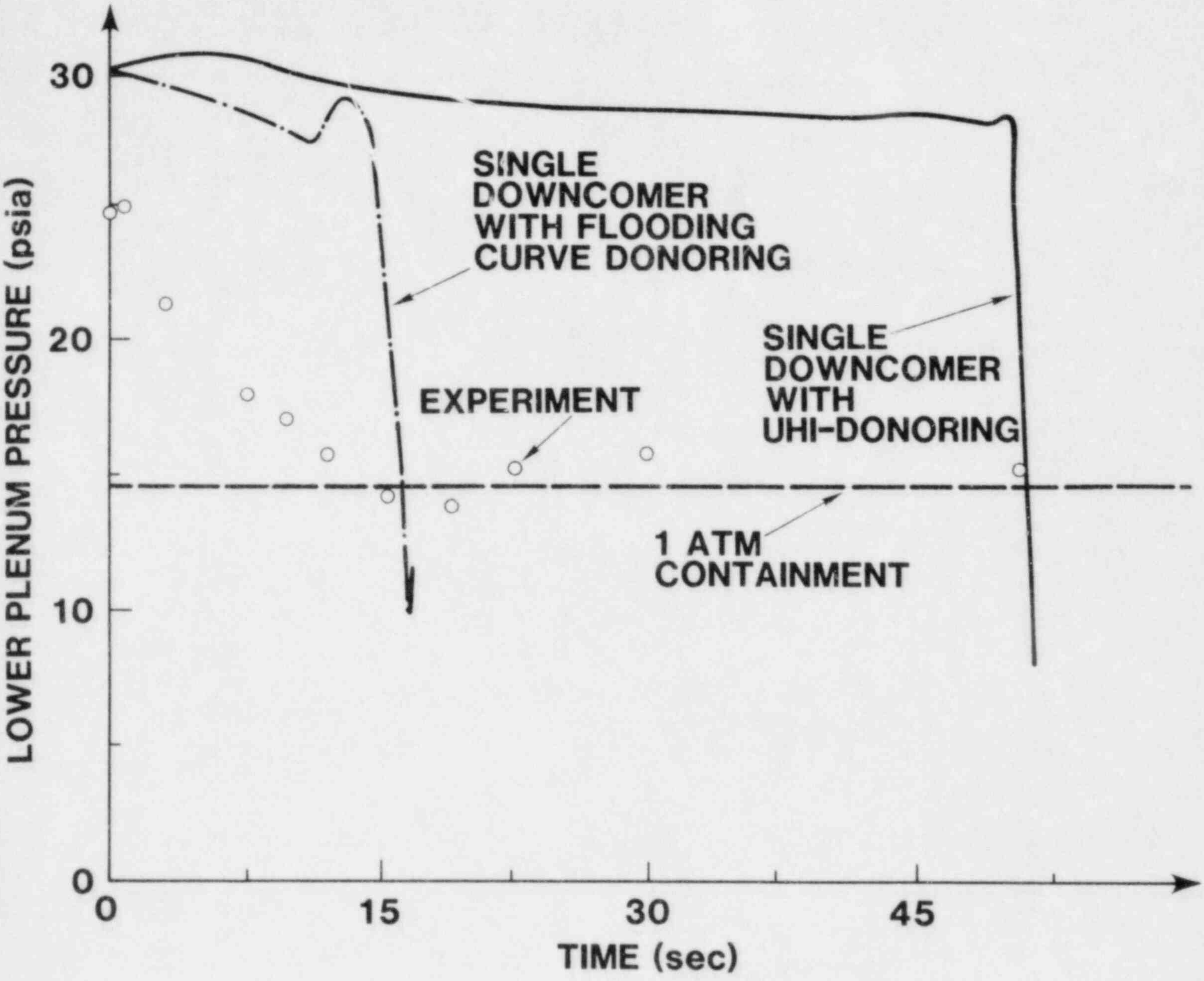

Figure 18: RELAP4/MOD5 Predictions of Lower Plenum Pressure - Creare Test H8 - Flooding Curve vs. UHI Donoring

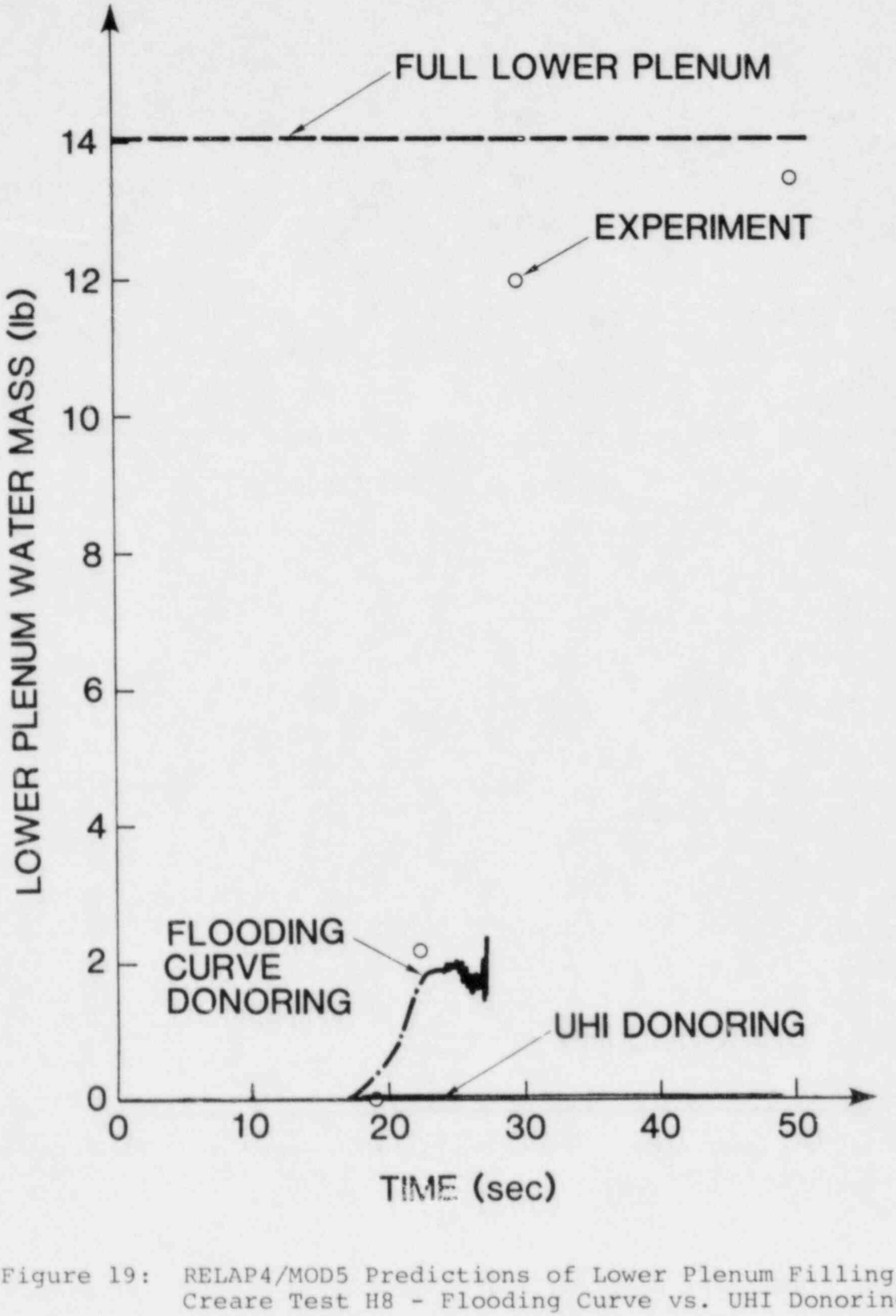

Figure 19: RELAP4/MOD5 Predictions of Lower Plenum Filling - Creare Test H8 - Flooding Curve vs. UHI Donoring

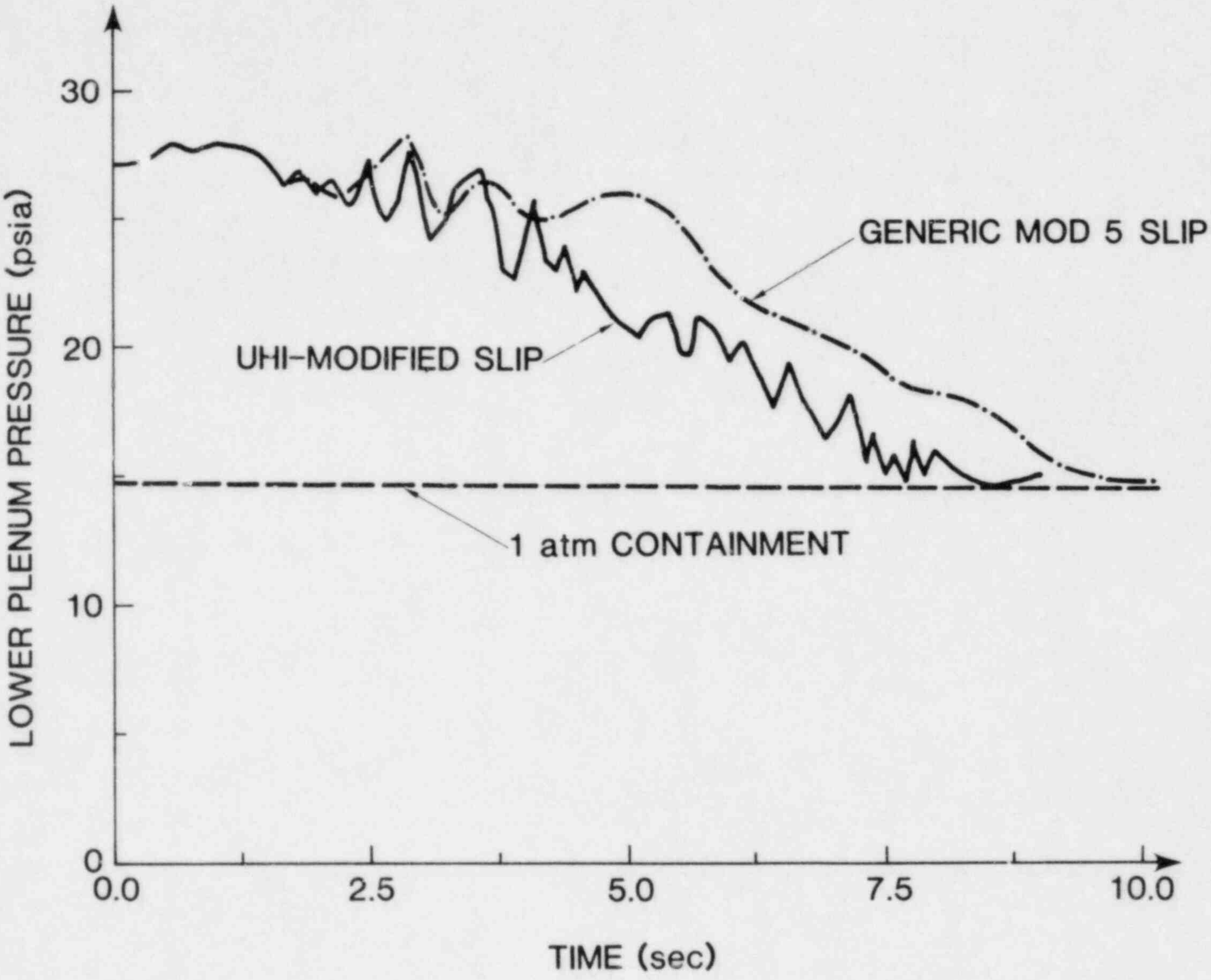

Figure 20: RELAP4/MOD5 Predictions of Lower Plenum Pressure - Scaled Up Creare Test H1 - Generic vs. UHI Slip

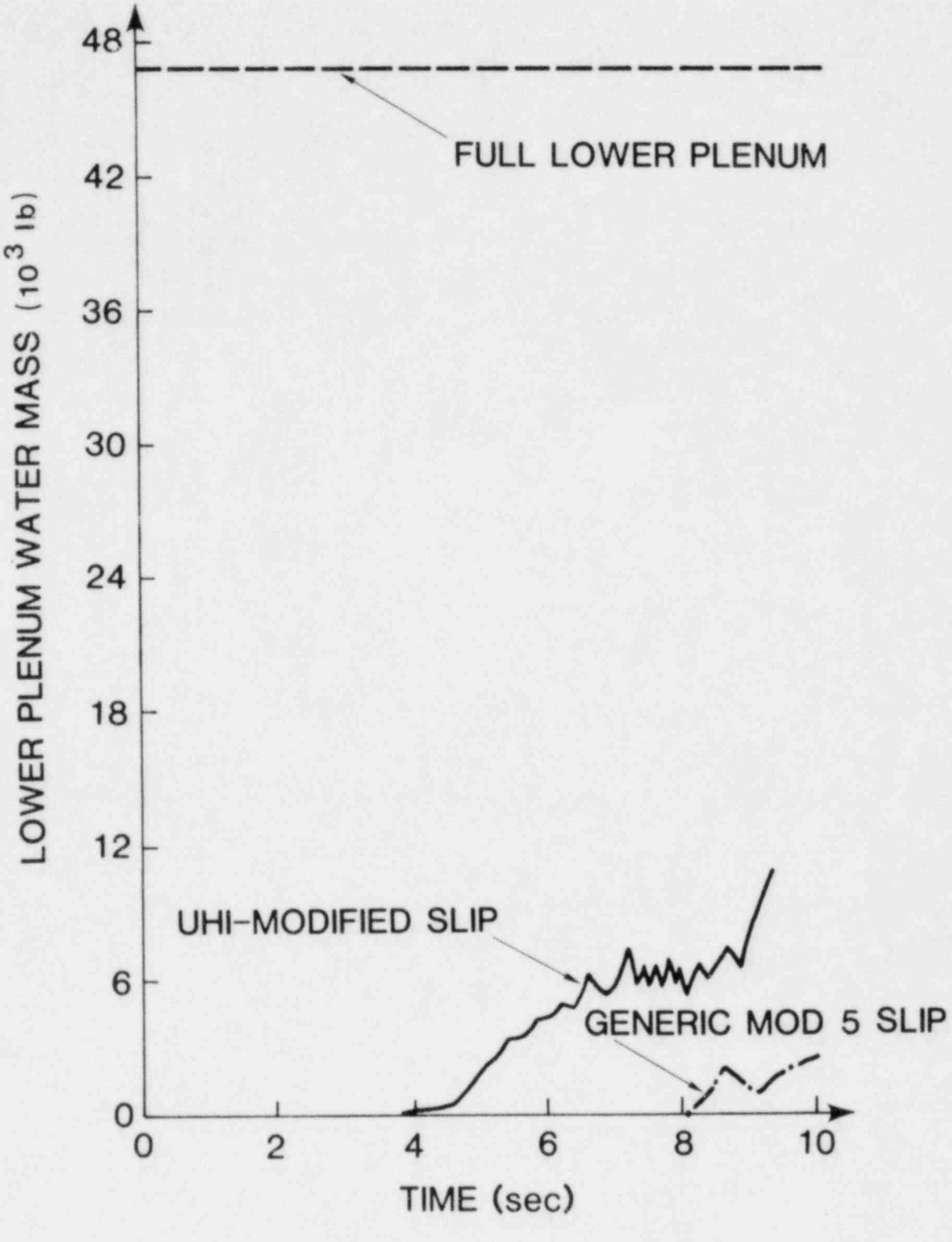

Figure 21: RELAP4/MOD5 Predictions of Lower Plenum Filling - Scaled Up Creare Test H1 - Generic vs. UHI Slip

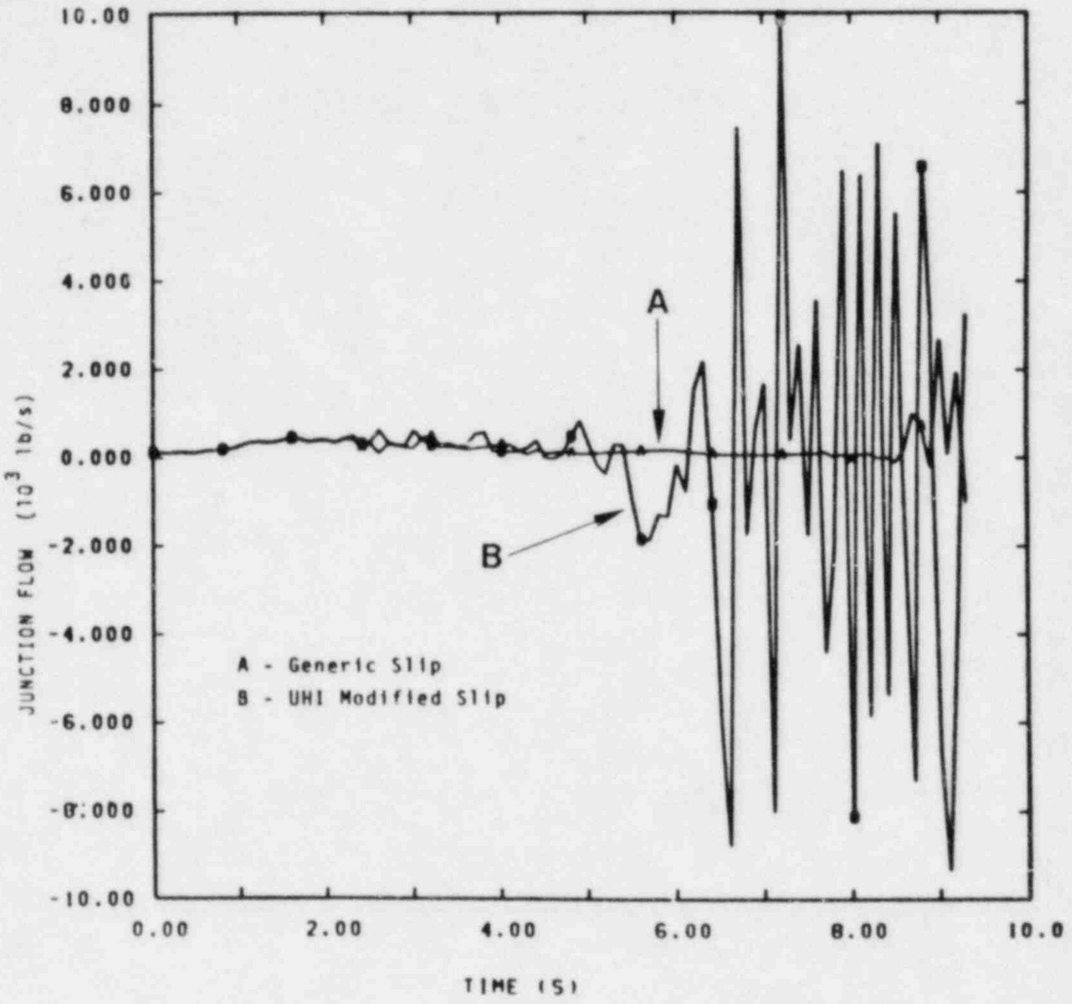

Figure 22: RELAP4/MOD5 Predictions of Lower Downcomer to Lower Plenum Mass Flow - Scaled Up Creare Test H1 - Generic vs. UHI Slip

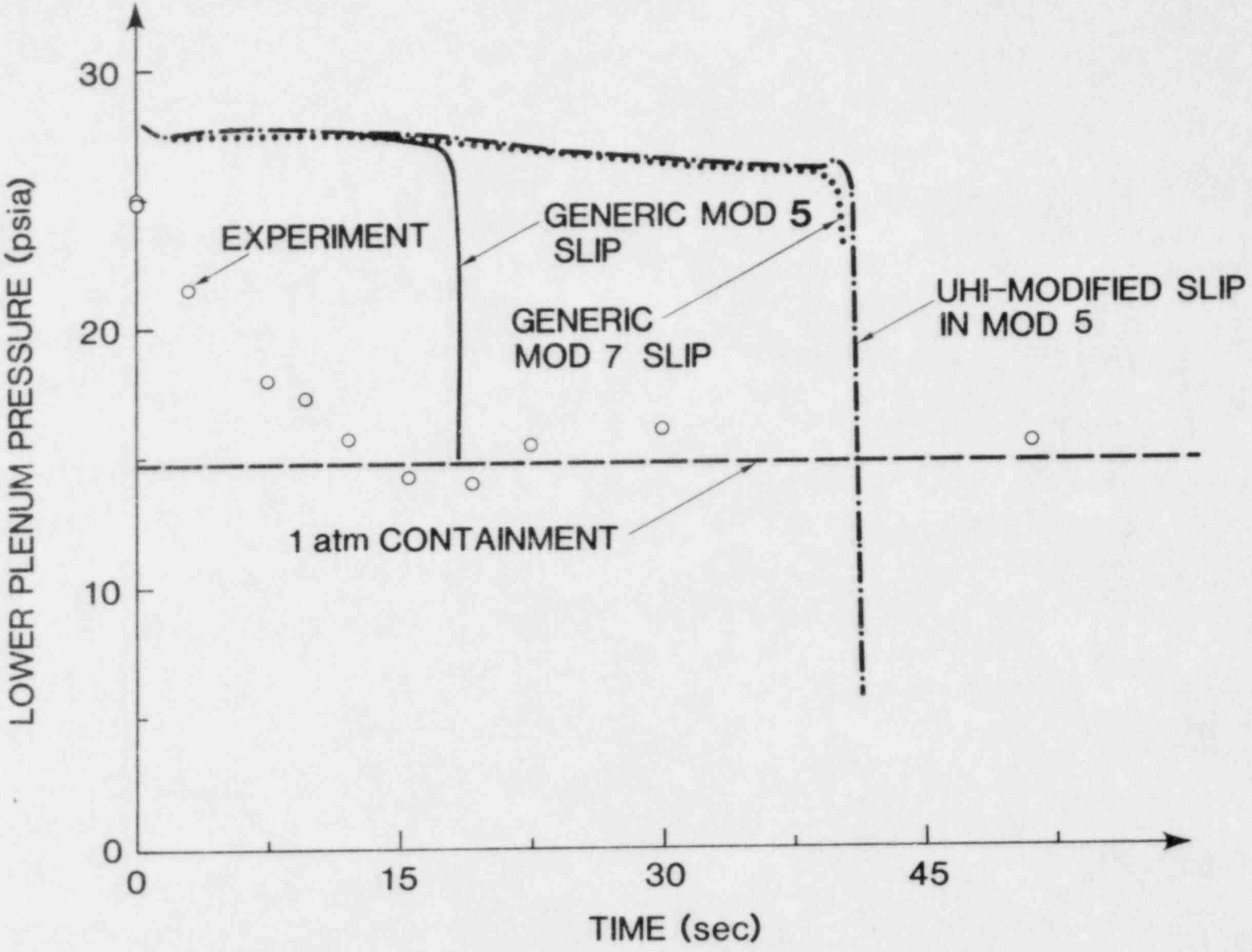

Figure 23: RELAP 4 Predictions of Lower Plenum Pressure - Creare Test H8 - Generic MOD5 vs. UHI MOD5 vs. Generic MOD7 Slip

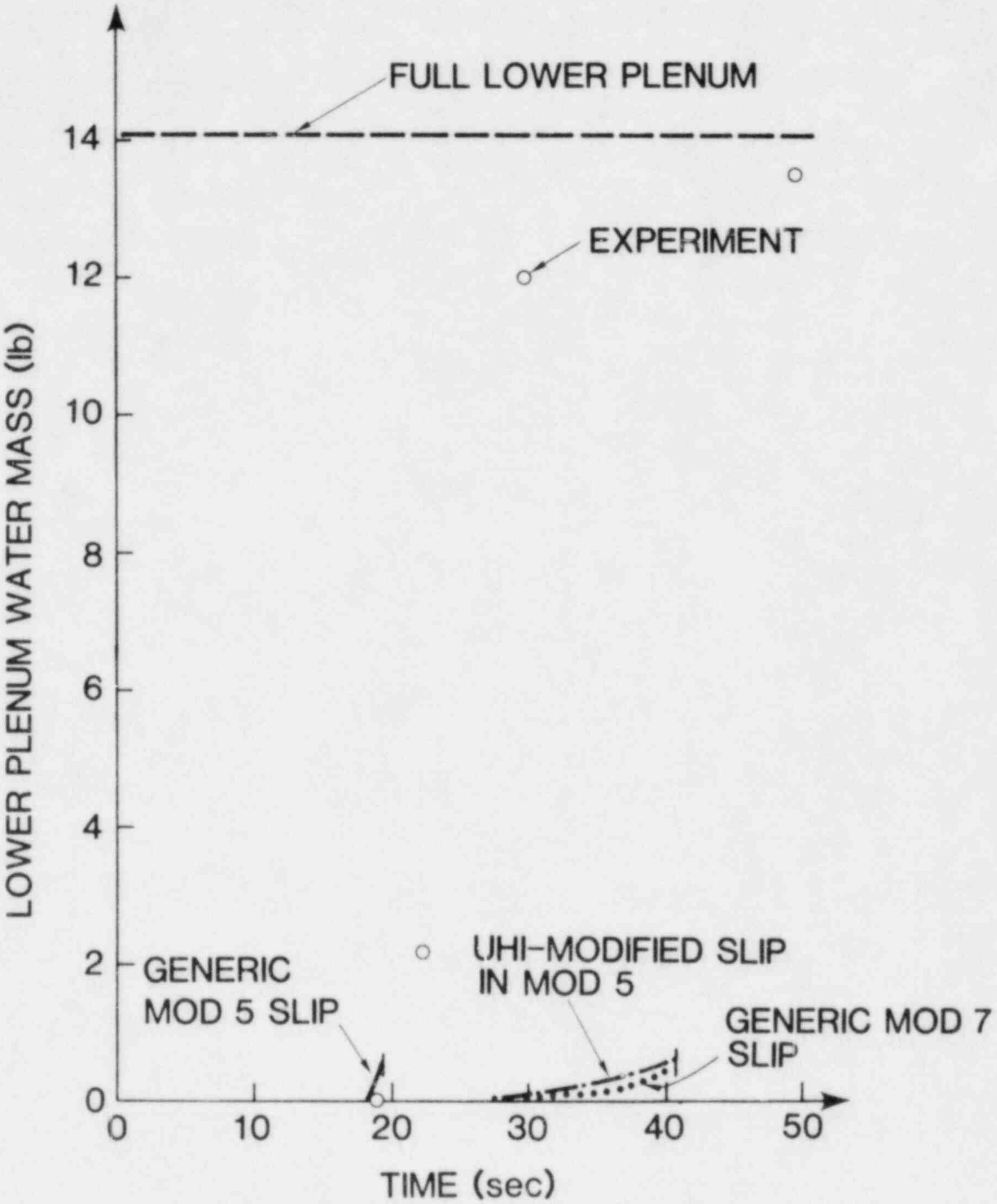

Figure 24: RELAP4 Predictions of Lower Plenum Filling - Creare Test H8 - Generic MOD5 vs. UHI MOD5 vs. Generic MOD7 Slip

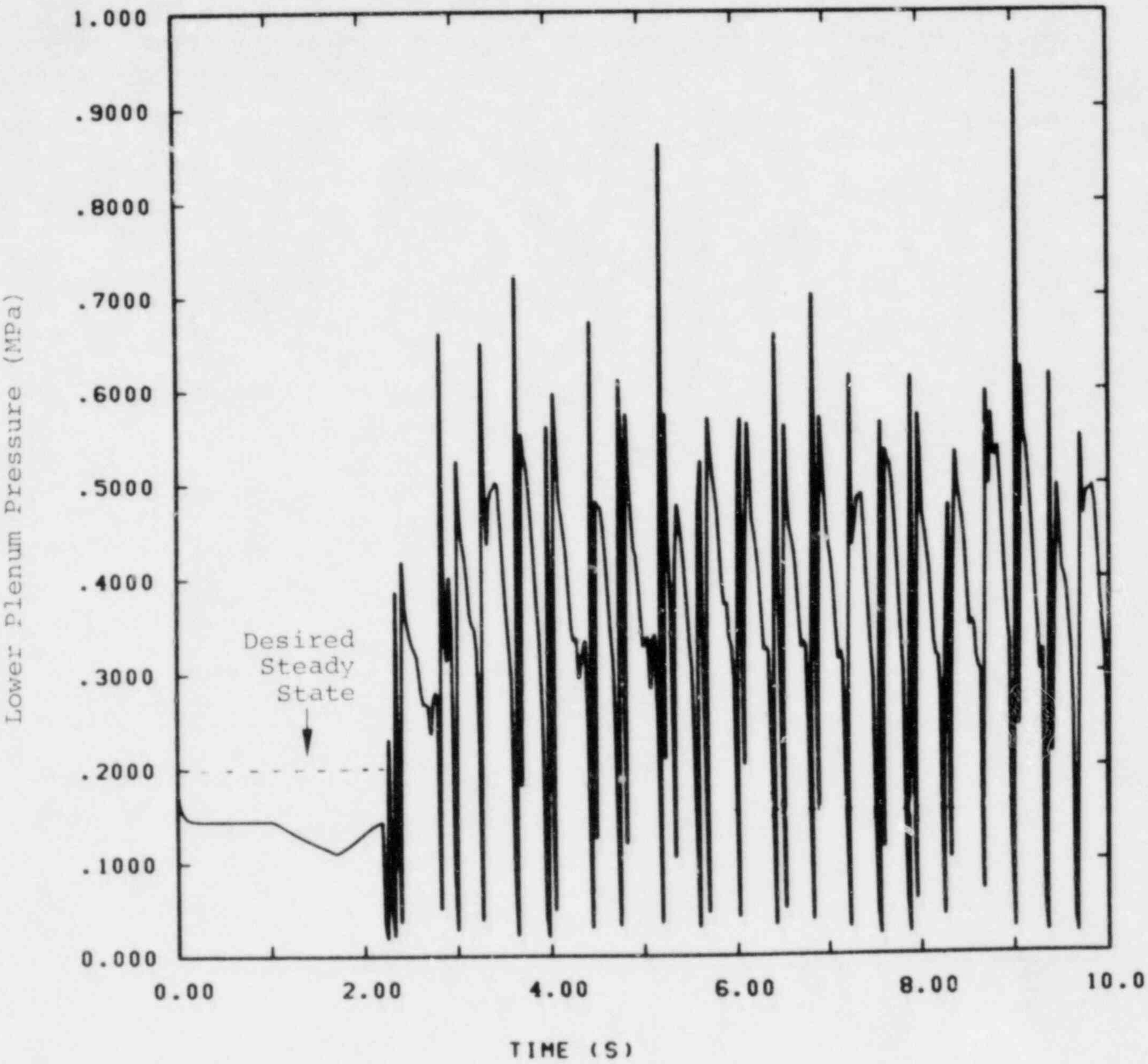

Figure 25: RELAP5/MOD1 Steady State Initialization Prediction of Lower Plenum Pressure - Creare Test H1

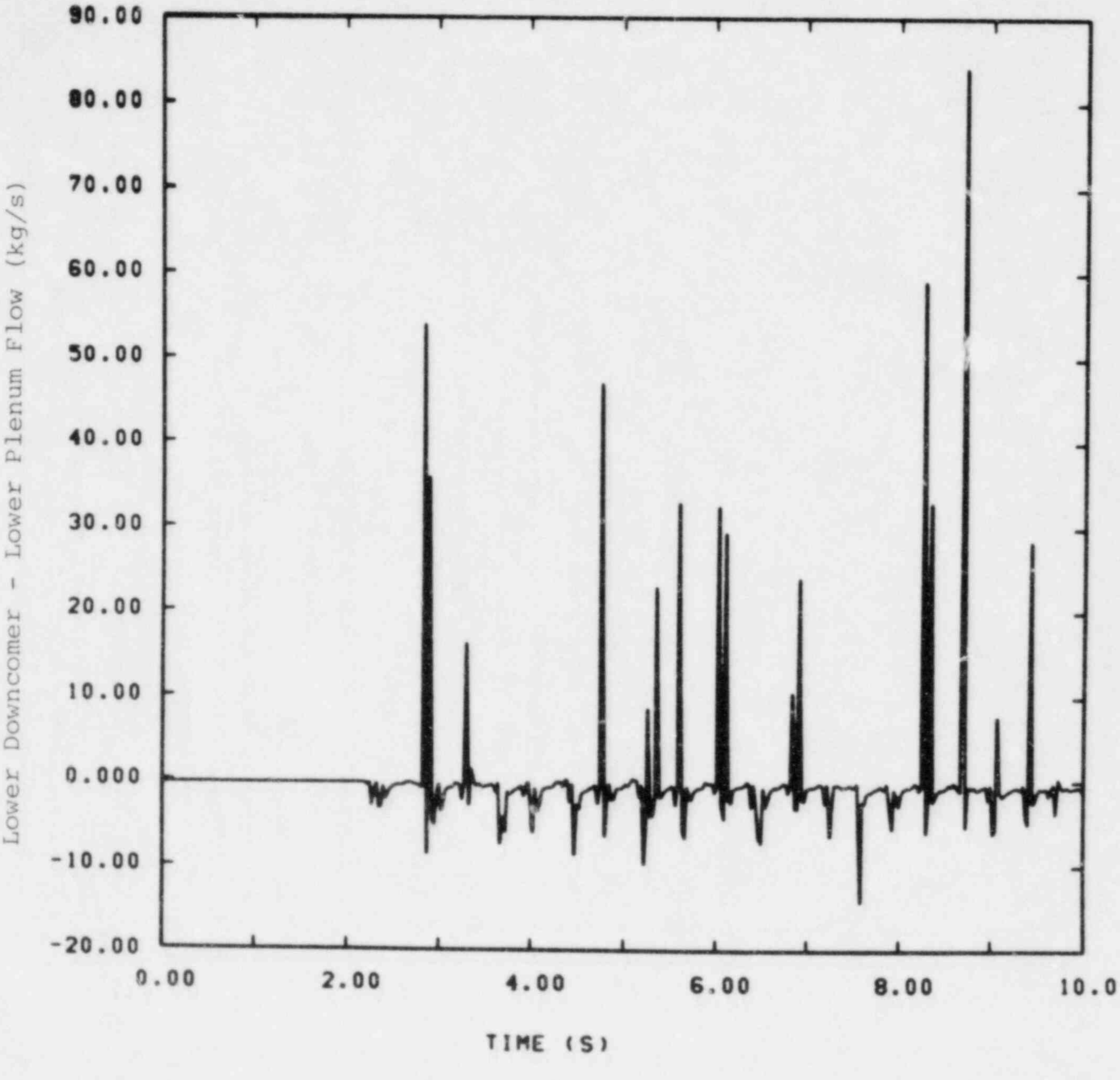

Figure 26: RELAP5/MOD1 Steady State Initialization Prediction of Lower Downcomer to Lower Plenum Mass Flows - Creare Test H1

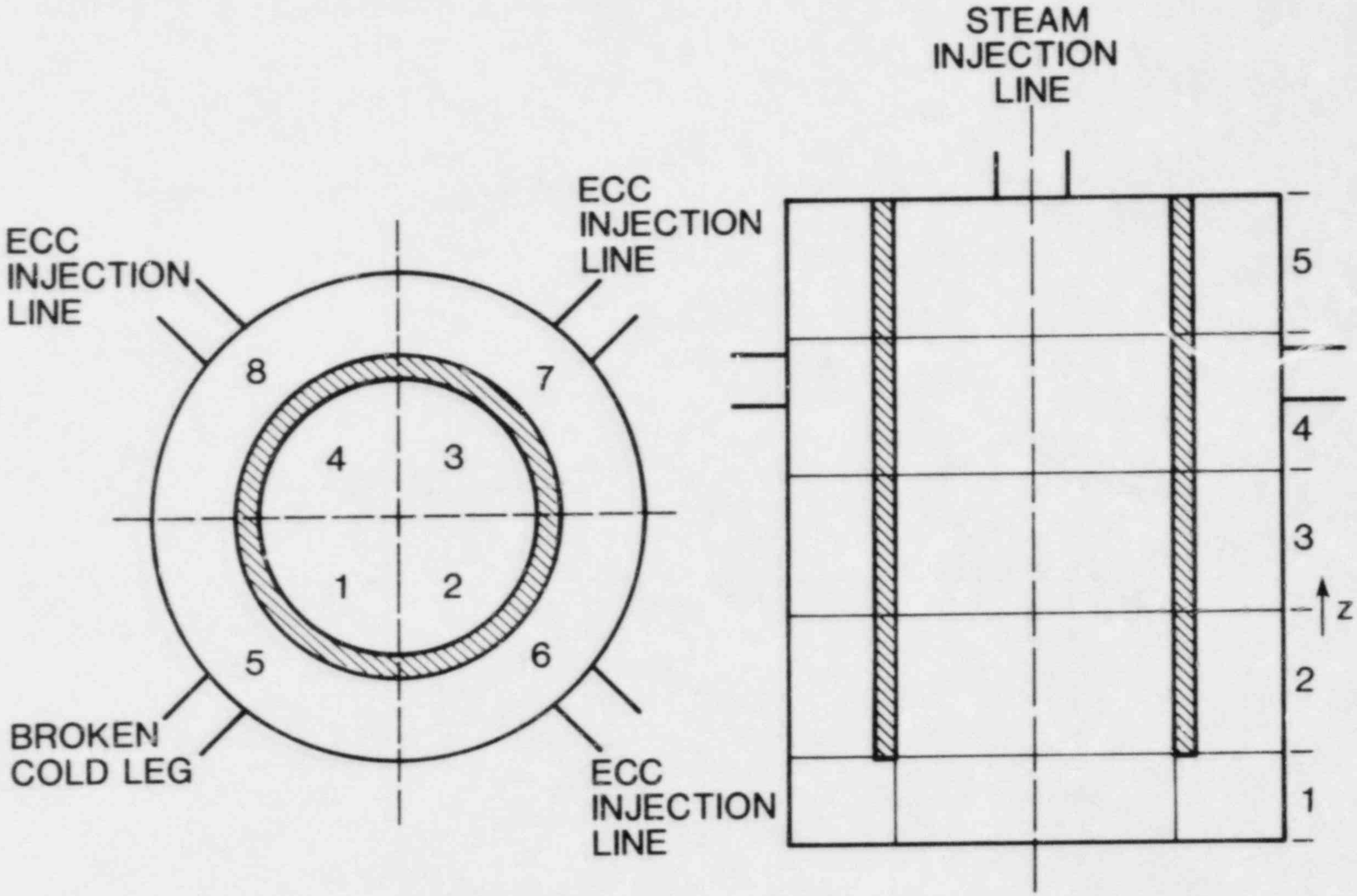

Figure 27: TRAC-PD2 Nodalization Used for Creare Analyses

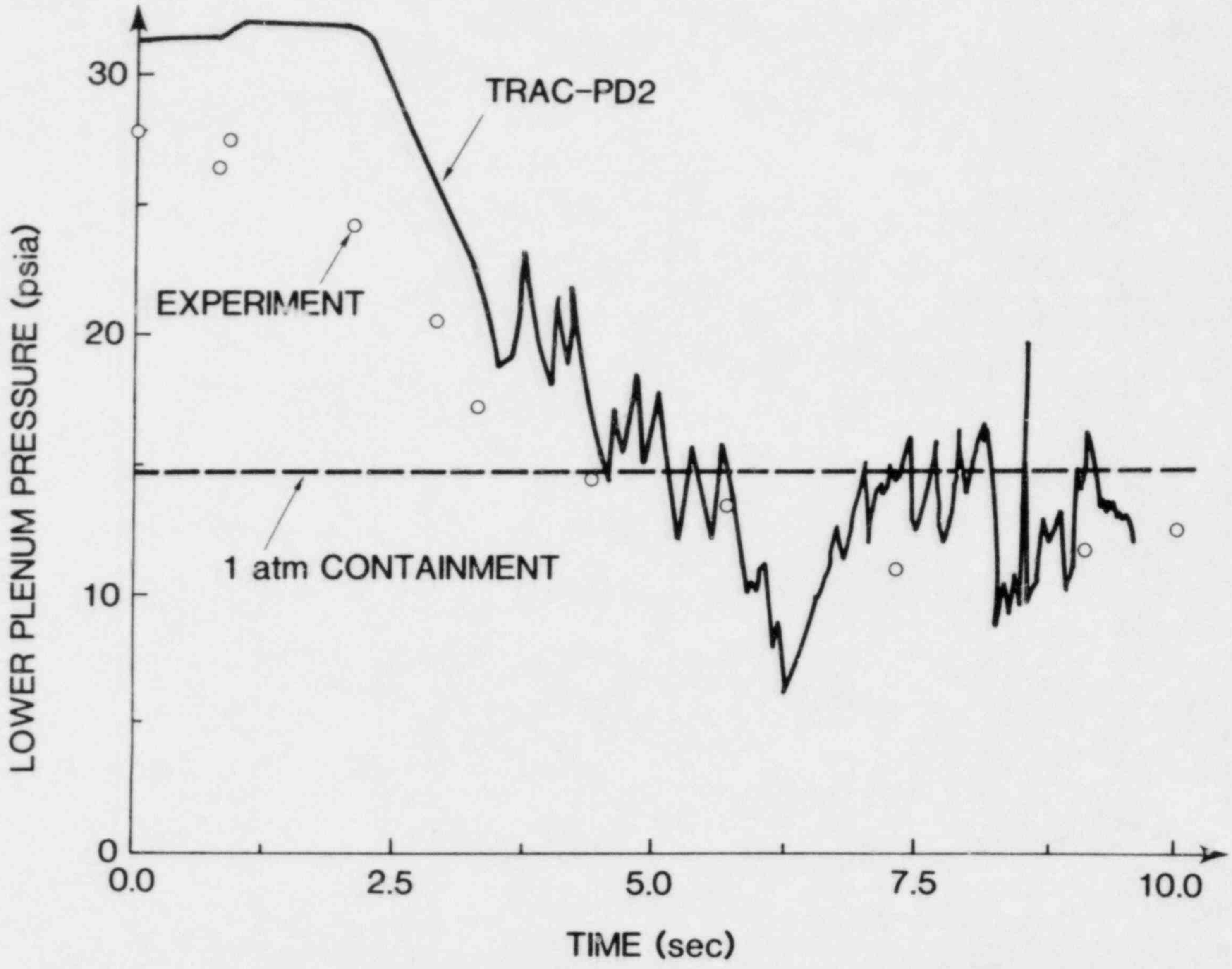

Figure 28: TRAC-PD2 Prediction of Lower Plenum Pressure - Creare Test H1

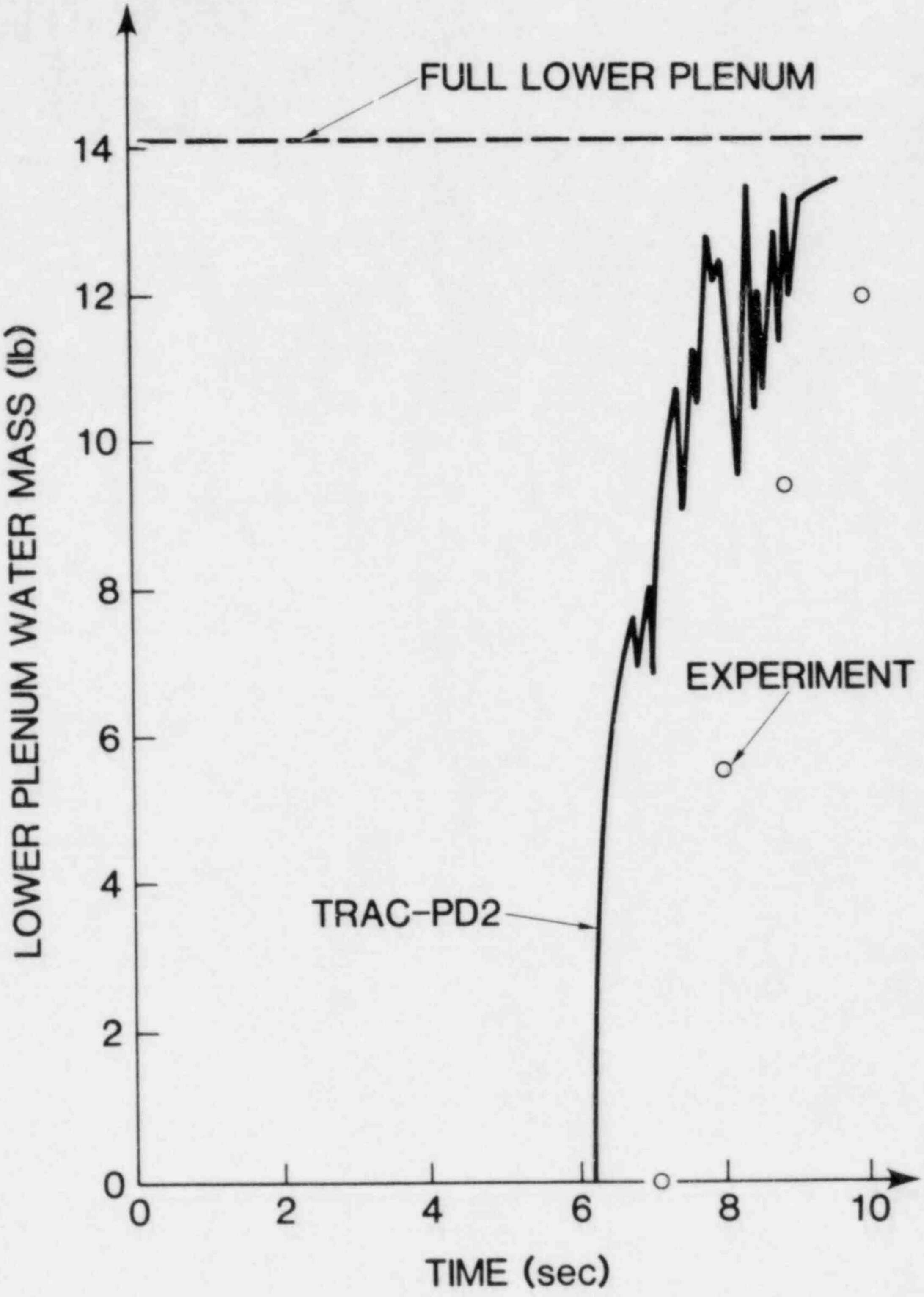

Figure 29: TRAC-PD2 Prediction of Lower Plenum Filling - Creare Test H1

REFERENCES

1. M. Young et al., Westinghouse ECCS Evaluation Model Application to Plants Equipped with Upper Head Injection, WCAP 8479-P, Revision 2, Westinghouse Electric Corporation, (Proprietary), Undated, but probably 1977.

2. F. M. Bordelon et al., SATAN VI Program: Comprehensive Space-Time Dependent Analysis of Loss-of-Coolant, WCAP-8302, Westinghouse Electric Corporation, June 1974.

3. RELAP4/MOD5 - A Computer Program for Transient Thermal-Hydraulic Analysis of Nuclear Reactors and Related Systems, ANCR-NUREG-1335, Aerojet Nuclear Company, Idaho National Engineering Laboratory, September 1976.

4. T. J. Bartel et al., Calculations Conducted in Developing an Audit Capability for ECCS Analysis, SAND-80-1149 (NUREG/CR-1470), Sandia National Laboratories, to be published.

5. C. J. Crowley et al., Downcomer Effects in a 1/15-Scale PWR Geometry - Experimental Data Report, NUREG-0281, Creare, Inc., May 1977.

6. RELAP4/MOD6 - A Computer Program for Transient Thermal-Hydraulic Analysis of Nuclear Reactors and Related Systems - User's Manual, CDAP-TR-003, EG&G Idaho, Inc., Idaho National Engineering Laboratory, January 1978.

7. G. W. Johnson et al, RELAP4/MOD7 (Version 2) - User's Manual, CDAP-TR-78-036, EG&G Idaho, Inc., Idaho National Engineering Laboratory, August 1978.

8. V. H. Ransom et al., RELAP5/MOD1 Code Manual, NUREG/CR-1826, EG&G Idaho, Inc., Idaho National Engineering Laboratory, (Draft) November 1980.

9. TRAC-PD2: An Advanced Best Estimate Computer Program for Pressurized Water Reactor Loss-of-Coolant Accident Analysis, LA-8709-MS, Los Alamos Scientific Laboratory, (Draft) April 1981.

10. A. Segev and R. P. Collier, Development of a Mechanistic Model For ECC Penetration in a PWR Downcomer, BMI-2051 (NUREG/CR-1426), Battelle Columbus Laboratories, June 1980.

11. Unpublished Westinghouse data obtained via a letter from T. M. Anderson to Paul S. Check (NRC) dated February 16, 1981.

12. Light Water Reactor Safety Research Program Quarterly Report July-September 1978, SAND79-0359 (NUREG/CR-0661), Sandia National Laboratories, April 1979.

13. G. B. Wallis, One-Dimensional Two-Phase Flow, McGraw Hill, 1969.

SUGGESTED DISTRIBUTION:

US NRC Distribution Contractor (CDSI) (380)
7300 Pearl Street
Bethesda, MD 20014
355 copies for R4
25 copies for NTIS

US Nuclear Regulatory Commission (4)
Office of Nuclear Regulatory Research
Washington, DC 20555
Attn: N. Zuber
L. H. Sullivan
L. Shotkin
J. N. Reyes, Jr.

US Nuclear Regulatory Commission (8)
Division of Systems Integration
Office of Nuclear Reactor Regulation
Washington, DC 20555
Attn: B. Sheron
N. Lauben
E. Throm
T. Speis
S. Boyd
J. Guttman
R. Audette
G. Mazetis

US Department of Energy
Operational Safety Division
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, NM 87185
Attn: J. R. Roeder, Director

Westinghouse Electric Corp. (2)
PWR System Division
Water Reactor Divisions
P.O. Box 355
Pittsburgh, PA 15230
Attn: S. Cadek
R. Kemper

EG&G - Idaho, Inc.
P.O. Box 1625
Idaho Falls, ID 83401
Attn: V. Ransom

Creare Inc. (2)
Box 71
Hanover, NH 03755
Attn: P. Rothe
C. J. Crowley

Los Alamos National Labs
P.O. Box 1663
Los Alamos, NM 87545
Attn: M. Stevenson

Sandia National Labs

4400	A. W. Snyder
4410	D. J. McCloskey
4412	J. W. Hickman
4420	J. V. Walker
4421	R. L. Coats
4422	D. A. Powers
4423	P. S. Pickard
4424	M. J. Clauser
4425	W. J. Camp
4440	G. R. Otey
4441	M. Berman
4441	R. K. Cole, Jr. (5)
4441	G. G. Weigand
4442	W. A. Von Riesemann
4443	D. A. Dahlgren
4444	B. W. Burnham
4444	L. D. Buxton (5)
4444	R. K. Byers
4444	L. Kmetyk (10)
4444	K. McFadden
4444	J. Orman
4444	S. L. Thompson (10)
4444	D. Tomasko
3141	T. L. Werner (5)
3151	W. L. Garner (3)
8214	M. A. Pound

NRC FORM 335
(11-81)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER *(Assigned by DDC)*
NUREG/CR-2606
SAND81-1932

2. *(Leave blank)*

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE *(Add Volume No., if appropriate)*
ANALYSES OF 1/15 SCALE CREARE BYPASS TRANSIENT EXPERIMENTS

5. DATE REPORT COMPLETED
MONTH February YEAR 1982

7. AUTHOR(S)
L. N. Kmetyk, L.D. Buxton and R. K. Cole, Jr.

DATE REPORT ISSUED
MONTH September YEAR 1982

9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Sandia National Laboratories
Albuquerque, NM 87185

6. *(Leave blank)*

8. *(Leave blank)*

12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*
Division of Systems Integration
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D.C. 20555

10. PROJECT/TASK/WORK UNIT NO.

11. FIN NO.
A 1115

13. TYPE OF REPORT
Technical

PERIOD COVERED *(Inclusive dates)*

15. SUPPLEMENTARY NOTES

14. *(Leave blank)*

16. ABSTRACT *(200 words or less)*

RELAP4 analyses of several 1/15 scale Creare H-series bypass transient experiments have been done to investigate the effect of using different downcomer nodalizations, physical scales, slip models, and vapor fraction donoring methods. Most of the analyses were thermal equilibrium calculations performed with RELAP4/MOD5, but a few such calculations were done with RELAP4/MOD6 and RELAP4/MOD7, which contain improved slip models. In order to estimate the importance of nonequilibrium effects, additional analyses were performed with TRAC-PD2, RELAP5 and the nonequilibrium option of RELAP4/MOD7. The purpose of these studies was to determine whether results from Westinghouse's calculations of the Creare experiments, which were done with a UHI-modified version of SATAN, were sufficient to guarantee SATAN would be "conservative" with respect to ECC bypass in full-scale plant analyses.

The two major results of this study are that (1) a nonequilibrium code may be needed to correctly model the dominant flow phenomena of these particular Creare tests, and (2) results from a full-scale nodalization developed via K* scaling criteria cannot be validly compared to the 1/15 scale Creare data. Therefore, the calculations reported here indicate that Westinghouse's Creare analysis results have not proven their UHI-modified version of SATAN will always generate conservative values for ECC bypass.

17. KEY WORDS AND DOCUMENT ANALYSIS

17a. DESCRIPTORS

17b. IDENTIFIERS/OPEN-ENDED TERMS

18. AVAILABILITY STATEMENT
Unlimited

19. SECURITY CLASS *(This report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES

22. PRICE
$

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

NUREG/CR-2606

ANALYSES OF 1/15 SCALE CREARE BYPASS TRANSIENT EXPERIMENTS

SEPTEMBER 1982