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TRAC L REACTOR MODEL: GEOMETRY REVIEW AND BENCHMARKING (U)

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TRAC L REACTOR MODEL: GEOMETRY REVIEW AND BENCHMARKING

Summary

The primary geometric parameters in the TRAC L reactor model were reviewed to confirm their fidelity to the reactor geometry. The review was accomplished by comparing the TRAC model with the model notebooks that were prepared during the development of the RELAP5 L reactor models. These RELAP5 models and notebooks were developed at the INEL independently of the SRL TRAC model and subjected to a detailed QA review.

The TRAC model review confirmed the basic fidelity of the model to the reactor geometry. In general, the model was found to be an accurate reflection of L reactor. However, a few discrepancies were discovered, the most important of which were in the plenum height, the plenum volume, the tank diameter and total volume, and the sparjet junctions. The plenum height and sparjet junctions were corrected. Discrepancies in the diameter and total volume of the moderator tank and a residual discrepancy in the plenum volume did not warrant correction prior to K reactor restart because they were judged to be acceptable for the current application of the model in full tank benchmarking and Flow Instability LOCA analysis. It is recommended, however, that these remaining discrepancies in the model be corrected in the future.

The correction of discrepancies found during the model geometry review produced an improved TRAC L Reactor model. The plenum and loop K-factors in the model were then carefully adjusted to achieve good agreement with Test I of the 1985 L Reactor AC Flow Tests. The resulting model gave excellent agreement with measured tank bottom pressure, process water temperature, loop flow rates, and plenum pressures in the inner three radial rings. Calculated plenum pressures were in good agreement with the data in ring 4 , but were higher than the data in ring 5. Calculated loop pressures were in good agreement with the data except at the heat exchanger outlet, where they were too high.

Though the overall agreement with Test I was not perfect, the agreement with the most important parameters, i.e., plenum pressures in rings 1-4 and loop flow rates, was quite good. Better agreement with the other parameters might have been obtained with significant reworking of the model, but this would have required

significantly more time with no guarantee of obtaining improved results. Furthermore, it is agreement with the other AC Flow tests, particularly the backflow tests, that validates the model for use. Accordingly, the model was then benchmarked against selected AC Flow tests.

The TRAC code and L Reactor model were benchmarked against data from eight of the remaining 1985 L Reactor AC Flow Tests. These tests included three symmetric tests similar to Test I, three backflow tests which simulate certain conditions expected during a LOCA, and two high flow tests. The agreement for the three symmetric tests was similar to that of Test I, though the results for the low temperature tests (B and C) were not quite as good as for the high temperature tests (H and I).

The backflow test benchmark results were, in general, very good. Calculated plenum pressures in the backflow sectors were in excellent agreement with the data. The agreement in the forward flow sectors was similar to that of the symmetric tests. The comparison of measured and calculated loop flows and pressures in the forward flow loops was basically the same as that of the symmetric tests. However, in the backflow loops the calculated flow rates were 7 to 10% low and the heat exchanger discharge pressures were low by 8 to 11 psi. Examination of the heat exchanger discharge pressure measurements for the backflow loops suggests either data anomalies or some hydraulic behavior not captured by the code. Additional insight on this issue may be available from new qualified data from the 1989 L reactor tests, which included full tank backflow tests. It is recommended that benchmarking against this data be done in the future.

The high flow test benchmark analyses produced mixed results. Good agreement with the data was achieved for loop flow rates and inner ring plenum pressures in the flow sectors. As in all the TRAC simulations, calculated plenum pressures in the outer ring of flow sectors were higher than the data. The TRAC results for the non-flow sector plenum pressures also did not agree well with the data. The data shows higher pressures in the non-flow sectors, apparently due to stagnation zones. This type of pressure distribution was not predicted well by the code. However, this type of pressure and flow field is not representative of a DEGB LOCA, so the lack of agreement was not considered important enough to perform additional model development at this time. The agreement between measured and calculated loop pressures was the same as seen in the other tests.

1. Introduction

1.1 Background

The analysis of the Design Basis Loss of Coolant Accident (LOCA) for Savannah River Site (SRS) reactors involves the best estimate reactor system thermal-hydraulics code TRAC-PF1/MOD1 (referred to hereafter as TRAC) [1]. Power levels for the L-3.1 and P-10.2 subcycles were determined based, in part, on TRAC analyses of the first few seconds of a plenum inlet break LOCA [2, 3]. The TRAC code is currently being used to analyze reactor system response for the Double Ended Guillotine Break (DEGB) LOCA, the Expansion Joint Bellows Break LOCA, the Loss of Pumping Accident (LOPA), and the Pump Shaft Break event. Currently, the DEGB LOCA analysis is performed with TRAC only for the flow instability (FI) phase of the accident. This analysis provides input to the determination of operating power limits for the K-14.1 subcycle [4].

TRAC model development for SRS reactors has been ongoing for several years both at Savannah River Laboratory (SRL) and Los Alamos National Laboratory (LANL). Informal review of the models has accompanied the model development. Data from the 1985 L Reactor AC Flow Tests have been used in the model development. Benchmarking of these models against reactor data was also done previously to demonstrate their capabilities for analyzing SRS reactors [2].

1.2 Objectives

The current work has five objectives:

1. to perform a formal and independent review of the basic TRAC reactor model for fidelity of the geometric representation to the reactor;

2. to improve the model by finding and correcting any errors in the geometric representation that may affect the analyses of interest;

3. to determine new loop and plenum loss coefficients for the improved model using appropriate integral reactor data;

4. to perform benchmark analyses with the improved model of selected tests from the 1985 L Reactor AC Flow Tests; and,

5. to analyze the results of the benchmark analyses and assess the performance of the model.

J. M. Cozzuol of the Idaho National Engineering Laboratory (INEL) performed the work comprising the first four objectives. D. P. Griggs and J. M. Cozzuol performed the work addressing the final objective. Chapter 2 presents the model geometry review and Chapter 3 presents the benchmarking. Chapter 4 presents conclusions and recommendations.

2. Model Geometry Review

2.1 Overview

A detailed SRS production reactor model for the TRAC code has been developed over several years. One basic model exists for the Process Water System (PWS) loops, moderator tank, and plenum. This model was created by LANL using K Reactor drawings. Individual reactor models are variations of the basic model, incorporating reactor-specific core and top shield features. Variations in loop geometry among reactors are not reflected in the models for L and P Reactors. These variations, which consist of differences in the lengths of certain horizontal pipes and in the location of certain vertical (or near-vertical) pipe runs, are not considered to have a significant impact for the DEGB LOCA.

The original LANL model has been reviewed informally and modified by L. D. Koffman and others [2, 5]. A number of people have worked with the basic model to produce specific models for L Reactor (1985 AC Flow Test Benchmark model, L-1.1 [2] and L-3.1 subcycle models), P Reactor (P-10.2 subcycle model [3]), and K Reactor (K-14.1 subcycle model [6]). In the process, the basic model has continued to receive informal review and, in the process, reached a certain level of maturity. However, prior to this project, no formal independent review of the model had been performed. The K Reactor Restart Plan [7] includes the performance of an independent review as one element of a program to support the use of TRAC in the LOCA power limits methodology, in lieu of formal certification.

2.2 Approach and Scope

A previous project at the Idaho National Engineering Laboratory (INEL) involved the development of RELAP5 [8] models of L Reactor. The first of these models was a two loop, one-dimensional representation [9]. Subsequently, a six loop, multidimensional model was developed [10]. These models were developed from plant drawings and documented in detailed model notebooks. The model notebooks contain both "raw" dimensions, elevations, etc. from drawings and other sources and calculated quantities needed to put together the models. The notebooks were subjected to detailed independent technical review by INEL personnel. These notebooks, then, represent a verified and substantially complete distillation of the reactor geometric information needed to perform a review of the

SRL TRAC model. Accordingly, the INEL notebooks were the main resource used in the review of the TRAC model. Additional drawings were consulted as necessary. Thus, the independent review compared the TRAC model to the RELAP5 model(s) and, implicitly, to plant drawings.

The scope and level of detail of the review were limited by the approach taken and the complexity of the TRAC model. The content of the RELAP5 model notebooks established the type of information that was readily available. The size of the complete TRAC model, with over 2000 computational cells and 10,000 lines of input, made it desirable to prioritize and limit the review. The resulting scope was as follows.

First, the review was limited to confirming the fidelity of the TRAC model geometric representation to that of the RELAP5 model notebooks and, by implication, to that of the reactor drawings. The review did not address non-geometric aspects of the model, such as control system logic, modeling options, power shape representations, material properties, or time step selection.

Second, the review did not cover all existing reactor models, but was limited to consideration of K and L Reactors. The RELAP5 model was specifically developed for simulating the 1985 L Reactor AC Flow Tests.

Third, the review did not cover all of the geometrical representations in the model. The review encompassed the external loops, plenum, moderator tank, and fuel assemblies. The top shield, blanket gas space, and vent path models were not reviewed because SRL put extensive effort into the development and documentation of these models [5].

Fourth, since the RELAP5 model is less detailed than the TRAC model, the level of geometric detail considered in the review was limited. In fact, the nodalizations used in the models are sufficiently different that it was necessary to compare most geometric quantities on a basis having less detail than that of either model. The basis for comparison is discussed in Section 2.3. The review did confirm the correct translation of the geometry into TRAC input format.

Finally, the review did not address the adequacy of the geometric representation for benchmarking or LOCA analysis. This was left to the assessment of the benchmark results and to other code assessment efforts, such as a direct TRAC/RELAP5 LOCA analysis comparison [11].

2.3 Model Review Results

The review of TRAC model geometry included the external loops, plenum and tank, and core. The results for each are presented in the following sections.

2.3.1 External Loop Models

The first comparison between the RELAP5 and TRAC models was, for each PWS loop, the total volume and length of the following loop sections:

1. moderator tank outlet to pump inlet;
2. pump inlet to heat exchanger inlet;
3. heat exchanger inlet to heat exchanger outlet;
4. heat exchanger outlet to plenum inlet; and,
5. entire loop.

The results of this comparison are given in Table 2.1. The two models were reasonably similar in the lengths and volumes used to represent the loops. For the four loop sections considered, the RELAP5 and TRAC models generally agreed within about 4%. The lengths and volumes for the entire loops in the TRAC model were between 2.6 and 3.4% higher than in the RELAP5 model. This is comparable to the limits of accuracy for obtaining geometry information from drawings and is therefore considered to be acceptable agreement.

Flow areas for piping sections and at well-defined system boundaries were also checked. TRAC model flow areas for regions such as the interiors of the plenum inlet nozzles were not recalculated based on the RELAP5 model information, but were reviewed for consistency.

Two cases in Table 2.1 were looked at in more detail. The volume of the piping from the moderator tank to the pump inlet was higher in the TRAC model by 8.5 to 10.5%. This difference is mainly attributable to the RELAP5 model being based on Schedule 40 pipe, which has a smaller inside diameter than the Schedule 20 pipe assumed in the TRAC model. Schedule 20 is the correct pipe size, so the TRAC model volumes are appropriate.

The other comparison that revealed an apparently significant difference (7.3 to 8.6%) was the total length from the pump inlet to the heat exchanger inlet. In both models of this section of the loop, there are cells that represent the branching section and parallel pipes of the "ram's horn" as a single lumped pipe. The appropriate lengths to be used in the models depends on how the parallel pipes are combined and how the pipes are nodalized. In the RELAP5 model, the length used is fictitious, corresponding to the length of a uniform pipe having the actual volume of the ram's horn and a selected flow area. In this approach, the length used depends on which flow area is selected to represent the component. The basis for the length used in the TRAC model is not known. The differences in length are insignificant in terms of frictional resistance to flow; furthermore, the adjustment of loop K-factors to match reactor data compensates for small differences in pipe lengths. Given that the total volumes for this section differ at most by 1.6%, the differences in length are considered acceptable.

2.3.2 Plenum and Moderator Tank

Table 2.2 presents the comparison of RELAP5 and TRAC plenum and moderator tank model geometries. The parameters compared were total height, total axial area, and total volume. This comparison revealed two problems with the TRAC model. First, the plenum height was wrong and, as a result, the plenum volumes, flow areas, and elevations were also wrong. The TRAC model used a height of 0.273 m (10.75"), the distance between the outer surfaces of the plenum, instead of 0.222 m (8.75"), the distance between the inner surfaces of the plenum. This was corrected in the model, along with the affected volumes, flow areas, and elevations.

The corrected total plenum fluid volume in the TRAC model is still about 20% larger than in the RELAP5 model. Several unsuccessful attempts were made to reproduce the TRAC plenum fluid volume. It appears that the remaining discrepancy reflects some unknown error made when the model was developed. However, as will be seen later, the modeling philosophy embodied in the TRAC model places a higher priority on achieving overall hydraulic fidelity (based on full-scale reactor data) than on the precise matching of reactor geometry. Because the model application of interest for this work (i.e., the FI phase of a DEBG LOCA) does not involve the draining of the plenum, the remaining discrepancy in plenum volume was considered acceptable. However, it is recommended that the plenum fluid volume be corrected in the future.

The second problem was found in the TRAC moderator tank model. The comparison showed that the two models had essentially identical total heights. However, differences were found in the diameters and total volumes. It was found that the TRAC tank model incorrectly used the identical diameter as the plenum model. The RELAP5 model (based on SRS Drawing W134124) notebook shows that the moderator tank inside diameter is smaller than that of the plenum by about 0.33 m (13"). This means that, given that the liquid volume fractions are correct, the liquid volumes of the outer ring of moderator tank cells in the TRAC model are too large and, of course, the total tank liquid volume is too large as well. The resulting TRAC tank liquid volume is about 13% larger than the RELAP5 tank liquid volume.

With the error in tank radius corrected, the TRAC total moderator tank liquid volume would agree fairly well with the RELAP5 model. However, because this error affects liquid volume fractions, flow areas, hydraulic diameters, and radial and azimuthal loss coefficients, it was judged to be more complicated to correct than the plenum height problem. Since the phenomena associated with tank draining are not significant for the benchmarking and LOCA-FI analyses to which the model would be applied [12], the somewhat higher tank liquid volume was considered relatively unimportant. Therefore, the correction of this error was left for future work.

2.3.3 Core Model

The TRAC and RELAP5 core models were also compared. Table 2.3 shows a comparison of the total lengths, volumes, and flow areas for the inlet, fuel, and endfitting regions of all the fuel assemblies in the core. The most significant differences are in the endfitting region, where the TRAC model total area and volume are twice as large as in the RELAP5 model. These discrepancies are attributable to differences in modeling philosophies rather than to errors. The RELAP5 fuel assembly models are designed to preserve the actual internal volumes and average flow areas of the assemblies, while the TRAC model is intended to provide the correct overall hydraulic resistance. As discussed previously, in the TRAC (SRL) modeling approach, the flow areas and volumes need not always be physically correct. In fact, the flow areas used for the inlet and endfitting regions are based on the nominal outside diameter of the assembly. K-factors appropriate for these flow areas are obtained from comparisons with data. Notice, however, that the actual flow area in the fuel region is used. In this region, the modeling of heat transfer between the fuel and coolant requires that fluid velocities be approximately correct on the average.

There are also discrepancies in the lengths of the assembly regions and in the total length. Because of the different lengths of the nested fuel tubes and the variation in the length of inactive tube, the boundary between fuel and non-fuel regions is subject to some interpretation by the modeler. The inlet length used in the RELAP5 model represents the distance from the top of the plenum to the top of the active fuel, assuming a nominal active fuel length. The TRAC assembly model does not include the full plenum height in the inlet length and considers the fuel region to be the top of the first fuel tube. Similarly, the fuel region lengths shown in Table 2.3 reflect the same differences in modeling conventions. In the endfitting region, the RELAP5 model assumes the fuel assembly extends to the bottom of the tank, while the TRAC assembly model does not extend all the way to the bottom.

The observed differences in the dimensions of the fuel assembly models represent legitimate modeling decisions rather than errors. Hydraulic losses depend on both the dimensions and the loss coefficients used in the model. In the case of TRAC, non-physical dimensions may actually give better agreement with pressure/flow measurements [13]. In view of these factors, the TRAC assembly model geometric parameters shown in Table 2.3 are considered acceptable.

2.3.4 Nodalization Review

The nodalization of the external loops, plenum, tank, and fuel assemblies were checked for reasonableness and consistency. Diagrams were prepared for each of the external loops showing the individual cells with their numbers and cell-centered elevations. The component numbers and connecting junction numbers are also shown. The cell-centered elevations were checked against the RELAP5 model for reasonableness, but were not compared strictly since RELAP5 uses the elevation difference between cell boundaries rather than cell-centered elevations. The junction numbers were checked for consistency in the input deck. The same type of diagram was produced and checked for the septifoil cooling system model. The nodalization of the plenum and tank were checked, along with the junctions to the loops and fuel assemblies. As a result of this check, an error was found in the junction numbers for the sparjet model. These junction numbers were reversed in the input deck, causing the bottom of the sparjet to be connected to the plenum and the top to be connected to the tank bottom. This was corrected in the model prior to the benchmarking.

3. Benchmarking the Improved L Reactor Model

3.1 Overview

Prior to the restart of L Reactor in 1985, a series of tests were performed to provide integral hydraulic data pertinent to various modes of PWS operation. Among these tests were a group of eleven referred to as the "AC" tests because of the use of 3, 5, or 6 AC pump motors to drive the pumps in the PWS external loops. This data has subsequently been used in the development and benchmarking of L Reactor models for the TRAC, RELAP5, and TRAC-PF1/MOD2 [14] system thermal-hydraulics codes. In particular, the original L Reactor model used at SRL to analyze the DEGB LOCA was developed with and benchmarked against the 1985 AC tests by L. D. Koffman, R. E. Pevey, and A. M. White [2]. In this work, the L-1.1 model was shown to give, in most instances, good agreement with the test data.

The current work revisits the work of Koffman, *et al.* for two reasons. First, the changes to the model resulting from the geometry review effort already discussed were significant enough to require a second round of analyses. The reduction in plenum height by approximately 20% affected the volumes of the 30 plenum cells as well as numerous plenum cell and fuel assembly inlet flow areas. With these changes, the original model no longer gave good agreement with the data. An additional motivation was provided by the earlier benchmark report, in which the authors stated that "... more analysis of the benchmarks needs to be done and some further fine tuning is also desirable as a future goal." Accordingly, our goals for the current work were: 1. to repeat and, if possible, improve upon the performance of the original model; and, 2. to do more analysis of the benchmark results.

3.2 1985 L Reactor AC Flow Tests

Table 3.1 presents the basic configuration of the eleven 1985 AC Flow tests. These isothermal tests were performed with 3, 5, or 6 pumps operating under AC power, with the septifoil upflow cooling system on or off, with rotovalves open or closed, and at process water temperatures of approximately 22 or 60 °C. The tests were performed with a fresh Mark 16/31 mixed lattice charge at zero power. The tank level was maintained at overflow with no helium cover gas and the blanket gas space vented to atmosphere.

One of the primary goals of the 1985 AC Tests was to measure the plenum pressure distribution in some detail. Special pressure tap plenum plugs were used to measure pressures inside the permanent sleeve and USH at approximately 90 plenum locations. The location of these pressure measurements on a reactor facemap is shown in Figure 3.1. As the figure shows, the measurements were concentrated in a 120° sector, with fairly limited coverage elsewhere. Crowley and Hamm [15] give the accuracy of these measurements as ±1 foot of D_2O, which for these tests is about ± 0.5 psi. Koffman converted the pressure measurements made inside the USH to average plenum pressures outside the permanent sleeve using data on pressure drop and flow rate measured in "A" tank. These converted plenum pressure measurements are used for benchmarking TRAC and are referred to herein as "plenum data." The measured data, plenum data, and data conversion is presented and discussed in Ref. 2.

Loop flow rates were measured with ultrasonic meters. According to Crowley and Hamm [15], the ultrasonic loop flow rate measurements had an uncertainty of ±4%. Hamm and Crowley [16] give ultrasonic loop flow rates for three tests. However, Koffman used the ultrasonic measurements only for reverse flow rates. For forward flow, Koffman determined loop flow rates from the measured pressure rise across the pumps using Hamm and McLain's pump curves [17]. We used Koffman's flow rates in this work and, for convenience, refer to them as "data" or "measurements."

The uncertainty in the derived loop flow rates includes contributions from both the pressure measurements and the pump curves. The pump curves have uncertainties due to the curve fitting and the uncertainties in the original data. A rigorous uncertainty analysis of the Koffman flow rates has not been performed. However, comparisons of the pump head curves with the measured Bingham pump data for the L Reactor pumps show agreement between measured and calculated flow rates to within 2% over the range of interest for these analyses. Crowley and Hamm report measurement standard deviations of 0.5% and 0.25% for the original Bingham Company head and flow data, respectively. Assuming that the pump head measurement uncertainty for the 1985 data is of similar magnitude, the uncertainties in the forward flow rates are estimated to be about ±3%.

Pressures in all 6 external loops were measured at taps located near the pump suction, pump discharge, heat exchanger inlet, and heat exchanger outlet. Pressures were also measured at taps near the Emergency Cooling System (ECS) injection points in 2 loops. Process water temperature at the pump suction and tank bottom pressures at two locations were measured. Process room barometric pressure was also measured. This data is presented in References 2 and 15. [Note: Because of an elevation error in the program ACDATA2 used by Koffman to convert raw pressure tap measurements to absolute pressures, the tank bottom pressures given in Ref. 2 are high by about 0.36 psi. Corrected values are used in this report.]

3.3 Approach

The approach taken was patterned after that outlined in Ref. 2. The improved L Reactor benchmark model was taken as a starting point. One AC Flow Test (Test I) was used as a basis for adjusting additive loss coefficients ("K-factors") in the plenum and external loops. In order to preserve the good agreement previously obtained, loss coefficients were changed proportionally where possible. Null K-factors were not changed. All other tests were analyzed without the benefit of further adjustments, providing true benchmarks of the model's capabilities.

One requirement of this effort was the development of a consistent and appropriate way of judging the results obtained with a given set of K-factors. First, the uncertainties in the measurements themselves had to be considered. Second, the impact of volume averaging by the code had to be accounted for, particularly for the plenum where the spatial detail provided by the data is much greater than that of the model. Third, the various hydraulic parameters available for comparison had to be prioritized. Since the current use of TRAC at SRS is to provide pressure boundary conditions for detailed fuel assembly models, first priority was given to matching plenum and tank bottom pressures. Second priority was given to matching loop flow rates and third priority to loop pressures.

As in the earlier work, 9 of the 11 AC Flow tests were analyzed. The remaining 2 tests, A and G, were not modeled because they involved closing off one of two parallel heat exchangers in each loop. Since the TRAC model uses a single lumped heat exchanger in each loop, it would require some modification to analyze these tests.

The 9 tests can be combined into three groups with similar pumping configurations. Tests I, H, C, and B were all conducted with 6 AC pump motors running, providing flow rates and pressures comparable to normal operation. This group of tests can be termed "symmetric," because of the nominally symmetric delivery of process water to the reactor plenum.

Tests D, E, and J were conducted with 5 AC pump motors running and the remaining pump inoperative. For these tests, the pressurization of the plenum by the 5 operating pumps produces reverse flow in the remaining external loop, thereby simulating some of the hydraulic conditions expected during a postulated DEGB LOCA. We refer to these as "backflow" tests.

Tests F and K were conducted with 3 AC pump motors operating and 3 pumps inoperative. Rotovalves in the three inoperative loops were closed, preventing any flow. This configuration produced high flow rates in the operating loops. In Test F, the pumping configuration was symmetric, while Test K had an asymmetric configuration. In addition to high loop flow rates, these tests are characterized by lower plenum pressures and atypical plenum pressure profiles. We refer to these as the "high flow" tests.

3.4 Symmetric Tests

Tests I, H, C, and B provide integral data for assessing the capability of the TRAC model to calculate loop flows and pressures and plenum pressures for the pumping configuration used in normal operation. The individual tests provide data reflecting the impact of system temperature and septifoil cooling system operation on these parameters. Among these tests, Test I most nearly reflects normal operation in that the septifoil cooling system was on and the system temperature was high. Of course, during normal operation at power, there is a significant variation in coolant temperatures within the reactor. Furthermore, during normal operation the blanket gas system increases the PWS pressure by about 5 psig. Nevertheless, Test I provides a good basis for evaluating the ability of TRAC to represent the basic hydraulic behavior of the reactor. Accordingly, Test I was selected as the test against which the model would be adjusted until the best agreement was obtained. The other tests provide benchmarks of the code's ability to account for the impact of system temperature and septifoil closure while confirming that the model provides a reliable hydraulic characterization of the reactor.

3.4.1 Test I

The Test I model was identical to that used in Ref. 2 except for the corrections discussed previously and the loop and plenum K-factors. The final K-factors from the previous benchmarking were taken as a starting point and an iterative process was followed to optimize agreement with the data. As mentioned previously, loop K-factors were adjusted uniformly by multiplying them by a constant. The initial adjustment to the plenum loss coefficients was also a simple multiplier, reflecting the flow area reductions resulting from the correction in plenum height. It proved necessary, however, to exercise more flexibility in adjusting plenum K-factors, because the reduction in plenum height had a strong impact on the radial plenum pressure gradient. Because the thinner plenum was more resistive, K-factors in the plenum and loops had to be reduced, while the septifoil cooling system K-factors had to be increased to maintain the correct flow-split.

It proved difficult to maintain good agreement in loop flowrates and match the plenum radial pressure gradient. A trial and error process showed that very high plenum edge pressures or very low plenum center pressures were unavoidable unless the plenum K-factors in the outer rings were reduced more relative to the original values than those in the inner rings. In particular, the radial loss coefficient for ring 4 was reduced to 0.0 in an effort to bring the ring 5 pressures down while still matching the data in the other rings. The resulting trial and error process eventually produced results that were judged to be acceptable for this code and model, given the approach selected. Table 3.2 shows the final K-factors that produced the best agreement with the Test I data. Compared to Koffman's model, these represent a reduction in plenum loss coefficients of 20% in rings 1 and 2 and 30% in rings 3 and 4 (except for the radial K-factor in ring 4, which was reduced to zero). The loop loss coefficients were decreased uniformly by 20% and the septifoil cooling system loss coefficients were increased by 50%.

3.4.1.1 Plenum Pressures

Figure 3.2 shows the TRAC plenum grid overlaid on a standard reactor facemap. The identical nodalization is used for each of 6 axial levels of the moderator tank model. TRAC calculates an average pressure for each of the 30 cells in the plenum. To assess the performance of the model, this relatively coarse pressure distribution must be compared with 90 separate plenum pressure measurements taken at the locations shown in Figure 3.1. To that end, Figure 3.3 shows the measured plenum pressures and the TRAC calculated pressures as a function of radial distance from the core centerline. Superimposed on this is the average of the data over the 5 TRAC radial rings. This figure shows that there is a relatively flat pressure distribution in the region corresponding to ring 1 of the TRAC model. The calculated pressures match the data very well here. Indeed, the ring-average of the data and the TRAC cell pressures differ by less than 0.4 psi. This is less than the measurement uncertainty of about 0.5 psi (1 ft. of D_2O).

The pressure profile changes dramatically at radial distances farther from the plenum center. On average, the data show the expected trend toward higher pressures; however, individual pressures are also seen to be lower than those in the center. Indeed, the spatial variation in the data in the regions corresponding to TRAC rings 2 through 5 is the most striking feature of the data. Figure 3.4 shows the TRAC plenum grid overlaid on a facemap of the pressure data This figure gives some insight into the nature of and reason for the pressure variations. The significant transverse pressure gradient immediately in front of the nozzles of loops 1 and 6 show that the flow distribution in the plenum is very complicated. This is underscored by the fact that the flow coming from loop 6 produces a stronger transverse gradient than does the flow from loop 1.

For operation with 6 AC pump motors, it is known that nozzle stalls exist and flow from the nozzles enters the plenum at an angle rather than along a radius, creating a swirl flow pattern in the plenum [15]. The swirl flow can be either clockwise or counter-clockwise, depending on the startup sequence of the pumps. The resulting nozzle stalls are alternately strong and weak, moving circumferentially from nozzle to nozzle. This produces flow patterns having a nominal 120° symmetry that result in areas of high and low pressure as shown.

As Figure 3.3 shows, the variation in the data ranges from about 9 psi (ring 2) to more than 20 psi (ring 4). Even with this variation, TRAC does an excellent job of calculating the average pressures in rings 2 and 3 and a good job in ring 4. As in ring 1, the averaged data and TRAC results for rings 2 and 3 differ by less than 0.4 psi. The ring 4 TRAC pressure is about 2.1 psi (2.2%) below the ring 4 data average.

Ring 5 shows the largest difference between TRAC results and the data. In addition to exceeding the data average by about 10 psi, the calculated pressures exceed all of the individual measurements. There are several potential reasons for this apparent discrepancy. First, the pressures in the loops feeding the plenum are too high. As will be discussed later, the calculated heat exchanger outlet pressures exceed the data by between 5 and 7 psi. This contributes to the excess pressure at the plenum edge. Second, because of the locations of the pressure taps, the measured pressures may not be indicative of the overall pressure in the TRAC outer ring. Since the measurements were all at locations near the interior boundary of the TRAC ring, it is fair to say that the "correct" ring average pressure is higher than the average of the ring 5 pressure measurements. Finally, the modeling of the inlet nozzles and plenum edge cells, while faithful to the reactor geometry, may induce TRAC to produce some erroneous results at their interface. This concern is discussed in the Appendix.

The fact that the calculated ring 5 pressures are higher than the data is not necessarily a serious problem because the calculated pressures in the inner rings agree well with the data. Ring 5 contains no fuel assemblies, so there is no direct impact on assembly flow. In addition, the performance of the model in benchmark tests with backflow is more indicative of its suitability for LOCA analyses.

3.4.1.2 Loop and Tank Parameters

Table 3.3 shows a comparison of measured and calculated parameters in the loops and tank. The agreement is generally good, and is comparable to that reported previously [2]. The calculated flow rates (converted to volumetric flow) are in very good agreement, though slightly below the data. The maximum disagreement of -406 gpm in loop 3 is only about 1.5% of the measured flow rate. In terms of total pump flow rate, the combined error for all the loops is about -1.1%. This magnitude of error is well within the uncertainty of the data and is considered insignificant.

Calculated pump suction pressures are approximately 1 to 2.5% below the data, while calculated pump discharge pressures (and pump Δp's) and heat exchanger inlet pressures are approximately 1 to 2% above the data. The agreement between the calculated results and data for the heat exchanger outlet pressures is not as good. For loop 6, TRAC calculates a pressure approximately 7 psi (6.5%) higher than the measured value. The calculated pressures in the other loops are between 5.5 and 6.0 psi too high. The same trend was seen in the earlier benchmark results, although the error was between about 3 and 5 psi.

Table 3.3 shows that the process water temperature in the TRAC analysis was about 3 °C below the measured value. This difference has little impact on the results. Calculated and measured tank bottom pressures differ by less than 0.4 psia, which is comparable to the measurement uncertainty.

3.4.2 Test H

Test H differed from Test I only in that the septifoil cooling system was closed off and the process water temperature was slightly higher. Closing off the septifoil cooling system increases the overall resistance of the system, resulting in lower total pump flow and higher pump head. However, since all the pump flow was delivered to the plenum, total core flow was greater than in Test I. The only changes to the model were increased process water temperature and closed septifoil cooling system.

3.4.2.1 Plenum Pressures

Figure 3.5 shows the Test H plenum pressures on an L reactor facemap overlaid with a TRAC plenum grid. The pressure distribution is essentially identical to Test I, though the magnitudes are somewhat higher. Figure 3.6 shows the radial distribution of the data, the TRAC cell pressures, and the ring averages of the data. The comparison of data and TRAC results is very similar to that seen for Test I. The averages of measured and calculated pressures in ring 1 are in excellent agreement (within 0.2 psi), and in rings 2 and 3 the agreement is very good (within 1.0 psi). In ring 4, TRAC again calculates pressures that are well within the variation of the data, but somewhat (2.9 psi) below the ring average of 103 psi. For ring 5, TRAC again calculates pressures that exceed all the individual measurements as well as exceeding the ring average of the data by a significant amount (9.6 psi).

3.4.2.2 Loop and Tank Parameters

Table 3.4 shows a comparison of data and TRAC results for some of the key system parameters. The results are generally in good agreement with the data; the differences are quite similar to those for Test I. The calculated loop flow rates are all slightly less than the data. The maximum difference of -385 gpm is again in loop 3. Overall, the calculated loop flows are within 1.5% of the data and, hence, within the uncertainty of the measurements.

As Table 3.4 shows, calculated pump suction pressures are approximately 1 to 2% lower than the data, while calculated pump discharge pressures and heat exchanger inlet pressures are approximately 1 to 2% higher than the data. These differences are comparable to the data uncertainty. However, as in Test I, the agreement in heat exchanger discharge pressures is not as good. TRAC calculates pressures that exceed the measured values by 4 to 6%. As in Test I, the maximum difference of about 7 psi is for loop 6.

Finally, the measured and calculated process water temperatures are effectively equal. As in Test I, the difference in measured and calculated tank bottom pressure (0.3 psi) is comparable to the measurement uncertainty.

In summary, the Test H benchmark calculations show essentially the same agreement with the data that was seen for Test I. The agreement was obtained without any additional adjustments to the model. This shows that the model correctly accounts for the impact of closing the septifoil cooling system and that the accuracy of the basic hydraulic representation was repeatable.

3.4.3 Tests B and C

Tests B and C were essentially identical to Tests H and I, respectively, except that the process water temperatures were lower (about 22° C and 25° C, respectively). Thus, these tests show TRAC's ability to account for temperature effects on system hydraulic behavior. Of course, during normal operation temperatures like these (and lower) could be found within the heat exchangers, in the heat exchanger discharge piping, in the water plenum, and within the fuel assemblies. The remainder of the system would have higher temperatures.

3.4.3.1 Plenum Pressures

Figures 3.7 and 3.8 show, for Tests B and C respectively, the ring averages and the radial distributions of the measured plenum pressures along with the calculated plenum cell pressures. For both tests, the calculated cell pressures in rings 1 through 4 are within the data but below the data average, while the calculated pressures in ring 5 exceed all the individual values as well as the average. The differences between the average calculated and measured pressures for rings 1 through 4 range from about 1 to 3.5 psi. For both tests, the calculated ring 5 pressure exceeds the data average by about 8.5 psi.

In general, the agreement between measured and calculated plenum pressures for these low temperature tests is not as good as for the corresponding high temperature tests. Table 3.5 shows a comparison of the measured and calculated ring average plenum pressures for all four tests. Notice that the difference between data and calculation for rings 1 through 3 is at least twice as great for the "cold" tests as it is for the "hot" tests. In ring 4, the disagreement in calculation and data for the cold tests is also greater than for the corresponding hot test, but not in the same proportion as the inner 3 rings. The calculated outer ring pressures are actually slightly better in the "cold" tests.

A comparison of data and TRAC results for corresponding "hot" and "cold" tests (I&C, H&B) shows the temperature effect on plenum pressure more clearly. The data shows that plenum pressures are higher for the cold tests than for the corresponding hot tests. However, the TRAC results show a negligible change in plenum pressure with temperature. This is reflected in the increased amount by which the TRAC results for the "cold" tests underpredict the data.

3.4.3.2 Loop and Tank Parameters

Tables 3.6 and 3.7 summarize the TRAC results and the corresponding data for Tests B and C, respectively. The calculated loop flows for Tests B and C agree well with the data (within about

2%), though not quite as well as Tests I and H. In view of the uncertainty in the loop flows, these differences are not significant. It is noteworthy that the temperature effect of reduced flow is shown by TRAC, even though the plenum pressure effect was not.

Tables 3.6 and 3.7 also show that the comparison between data and TRAC results for loop pressures is very similar to Tests I and H. The underprediction of pump suction pressures by TRAC is slightly greater for Tests B and C, while the overprediction of the heat exchanger discharge pressures is not quite as large. As in Tests I and H, the calculated pump discharge and heat exchanger inlet pressures are within 2% of the measured values.

Calculated process water temperatures for both tests do not differ significantly from the measured values. Similarly, calculated tank bottom pressures are within about 0.3 psi of the data, which, again, is less than the measurement uncertainty.

3.5 Backflow Tests

The three backflow tests, D, E, and J, provide important information on the ability of the TRAC model to predict plenum pressures during a DEGB LOCA. For these tests, the model must be able to calculate the magnitude of the backflow in one loop and the associated plenum pressure distribution. In the accident, a qualitatively similar backflow results from the pressure difference between the plenum and atmospheric pressure at the end of the nozzle; its magnitude depends on the flow resistance of the nozzle. In the tests, the backflow results from the pressure difference between the plenum and tank bottom and the flow resistance of the loop. Hence, the driving pressure in the test is lower and the resistance to flow higher than in the accident. As a result, the backflow rates in the tests are only about one-third of that expected during a LOCA. Nevertheless, the impact of the backflow on the plenum pressure distribution in the tests is both significant and, we believe, qualitatively similar to that expected during the FI phase of a plenum inlet DEGB LOCA.

It should also be noted that only the TRAC plenum pressures for the backflow sector are used in the determination of nominal FI flowzone effluent temperature limits. The pressures calculated for the other sectors contribute to the core-wide uncertainty. Hence, if the TRAC model can calculate the appropriate plenum backflow sector pressure distribution for the backflow rates of the tests, it should have similar success for the higher backflow rates of the LOCA. Of course, the model's ability to calculate plenum pressure distributions in either case is related to the accuracy of the calculation of backflow or break flow rates.

In the subsequent discussions of plenum pressure measurements and calculations, much use is made of the concept of a plenum sector, which is a 60° "slice" of the plenum defined by the TRAC nodalization (see Fig. 3.2). These sectors are numbered from 1 to 6 in a counter-clockwise direction so as to be consistent with the node numbering scheme used by TRAC. Unfortunately, the numbering scheme for the loops (or "systems") in the SRS reactors is based on a clockwise numbering scheme, so the sector numbers differ from the loop numbers. The TRAC model was set up so that loop 1 is attached to sector 1; the remaining loops and sectors are associated as follows:

loop 2:	sector 6
loop 3:	sector 5
loop 4:	sector 4
loop 5:	sector 3
loop 6:	sector 2

The sector numbers correspond to the TRAC plenum cell numbers for ring 1.

3.5.1 Plenum Pressures

Figures 3.9, 3.10, and 3.11 show the plenum pressure measurements for Tests D, E, and J, respectively. For Test D, loop 6 was in backflow, while for Tests E and J, loop 1 was in backflow. Notice that in all three tests the variation in the data near the backflow nozzle and in the interior of the plenum is significantly less than was observed for the symmetric tests. This region of relatively flat pressure profile also contains the lowest pressures measured. The presence of the backflow loop actually makes the pressure distribution less complicated and, as will be seen, more amenable to calculation with TRAC.

Figures 3.12, 3.13, and 3.14 show comparisons of the measured and calculated backflow sector plenum pressures for Tests D, E, and J, respectively. The agreement is excellent. The differences between the TRAC cell pressures and the cell-averaged data are generally less than 1 psi. The maximum difference is in Test J, where the calculated pressure for ring 1 exceeds the data by 1.4 psi (2.2%). Notice that the calculated pressures for ring 5 of the backflow sectors are within 1 psi of the data averages.

Figure 3.15 shows measured and calculated plenum pressures in Sectors 1 and 3 for Test D. The agreement for these forward flow plenum sectors is quite similar to that of the symmetric tests already discussed. The calculated pressure in ring 5 exceeds the data average by 10.5 psi (13.7%).

Figures 3.16, 3.17, 3.18, 3.19, and 3.20 show comparisons by radial ring of the measured and calculated plenum pressures for Test D. In these graphs, the x-axis origin corresponds to the radial boundary between TRAC sectors 1 and 6; each plenum sector occupies about 1.05 radians. Measured and calculated pressures for the backflow sector (2) are found between about 1.05 and 2.09 radians. Since the pressure taps were concentrated in sectors 1 and 2, most of the data occurs between about 0 and 2.1 radians.

For all rings the agreement in the backflow sector is excellent. This is most evident in Fig. 3.16, which shows data and TRAC results for ring 5. The pressures in the backflow sector exhibit relatively little variation and can be easily distinguished from the rest of the data. There, the TRAC cell-average pressure matches the data very well even though the calculated pressures in the rest of ring 5 are consistently and, in some cases, significantly higher than the data. This illustrates that the overprediction of pressures in the outer ring of flow sectors does not prevent TRAC from matching the pressure in the outer ring of a backflow sector.

Figure 3.17 shows the same kind of result for ring 4. The agreement between the data and the calculation in the backflow sector is very good. The TRAC result for forward flow sector 1 falls about in the middle of the data, which has significant variation. The TRAC pressures for the other 4 sectors appear to be low rather consistently. However, the data is more sparse there and reflects pressure tap locations primarily on the boundary between rings 4 and 5. Hence, it is not apparent that any reliable conclusion can be drawn from sectors 3 - 6.

Figure 3.18 also shows good agreement between TRAC and the ring 3 data for the backflow sector. In this ring, the backflow sector data is not distinguishable from the adjacent flow sector 1. However, the

TRAC result shows a clear azimuthal distribution symmetric about the backflow sector. The ring 3 data does not show this symmetry (though the data for rings 4 and 5 do).

Figures 3.19 and 3.20 show that the agreement between TRAC and the data is very good for the rings 1 and 2. This is especially true for ring 1, where the data is nearly uniform azimuthally and the TRAC pressures fall within the very minimal data variation.

3.5.2 Loop and Tank Parameters

Tables 3.8, 3.9, and 3.10 summarize the comparisons of measured and calculated loop flow rates and pressures, process water temperatures, and tank bottom pressures for Tests D, E, and J, respectively. As in the symmetric tests, the agreement between calculated and measured water temperatures and tank bottom pressures is excellent. The flow rates in the forward flow loops are also in excellent agreement, differing at most by about 1.2%. Uncertainties aside, this is better agreement than seen for the symmetric tests.

Tables 3.8 through 3.10 also show that the agreement between measured and calculated pressures in the forward flow loops is similar to that seen in the symmetric tests. Calculated pump suction pressures are within 1.2 psi (5.2%) of the measurements. The maximum errors in calculated pump discharge pressures and heat exchanger inlet pressures are 3.2 psi (1.6%) and 2.6 psi (1.4%), respectively. As in the symmetric tests, the largest disagreement between TRAC and the data for the forward flow loops is at the heat exchanger outlet. In general, the calculated pressures at this location are high by between 3.8 psi (4.3%) and 5.6 psi (5.8%). However, for each test there is one loop for which the calculated and measured heat exchanger discharge pressures differ by 0.6 psi or less.

The comparisons of measured and calculated flows and pressures in the backflow loops are not as favorable. In contrast to the forward flow loops, the calculated backflow rate is between 7.3% (Test J) and 10.3% (Test D) less than was measured. Since the calculated plenum and tank bottom pressures are in good agreement with the data, the flow rate discrepancy would seem to indicate too much resistance in the backflow loop. There are several possible sources of this difference. First, the same K-factors were used for the forward and reverse flow directions. No use was made of TRAC's directional K-factor capability. It is certainly possible that loop resistances are directional. The homologous curves for the pump head at zero angular velocity and negative flow may not be accurate. Another possible explanation is that additional resistance is artificially added at the area contraction going from the plenum to the nozzle because of the differencing technique used by TRAC [18].

Table 3.8 also shows that the agreement between measured and calculated pressures in the backflow loops is not as good as in the forward flow loops. Calculated pressures at the heat exchanger outlet and inlet and at the pump discharge are low by as much as 11.4 psi (heat exchanger discharge, Test J) and 16.8% (heat exchanger inlet, Test J). The differences between measured and calculated pressures in the remainder of the loop are primarily due to the propagation of this discrepancy and, secondarily, because of the lower calculated flow rate. Analyses with RELAP5 [10,19] produced a similar disagreement in heat exchanger outlet pressure.

These large discrepancies are surprising both in terms of their magnitude and their sign. For backflow, pressures in the loop reflect the net effect of the driving head provided by the plenum, the irreversible losses in the pipes, fittings, and components, and, at most points, an increasing static head because of the decrease in elevation. When fluid is flowing, friction and form losses counteract the elevation head, producing either a net increase or decrease in pressure. The elevation change from the plenum to the heat exchanger is -13.26 ft, which corresponds to a static pressure rise of about 6.23 psi. This is the maximum pressure rise that can occur. However, the data for Test J shows a significant pressure increase (≈12.8 psi) from the outer ring of 4" positions at the edge of the plenum to the heat exchanger outlet. TRAC calculates a much smaller pressure increase (≈0.7 psi). For Tests D and E, the measured pressure increases were ≈10.6 and 11.8 psi, while the calculated pressure increases were ≈1.8 and 0.9 psi, respectively.

These are puzzling results. The measured increase in pressure from plenum to heat exchanger discharge is significantly greater than can be attributed to the available elevation head. Davis [19] suggested two possible explanations for the discrepancy. First, the measurement may not be reliable. The proximity of the pressure tap to an upstream (for backflow) elbow may have caused a significant dynamic component to be included in the measurement. However, this explanation alone probably is not sufficient, since the available velocity head (based on superficial velocities) is around 3.5 psi.

The second explanation is that the plenum pressure measurements taken inside the permanent sleeves in the outermost row may not adequately represent the available driving head for the reverse flow. The essentially open area at the edge of the plenum raises the possibility of a significant dynamic pressure head at the entrance to the backflow nozzle. This would not be fully reflected in the measured plenum pressures. A higher effective plenum edge pressure implies a lower pressure rise from plenum to heat exchanger outlet, making the measured heat exchanger outlet pressure more reasonable physically. However, this effect is not predicted by the codes. As has been discussed, the calculated cell-average pressures at the edge of the plenum (ring 5) in the backflow sectors agree very well with the outer row measurements. The cell average pressures calculated by TRAC for the break sector are higher at the plenum edge than in the interior, though by less than 1 psi.

In summary, the assessment of TRAC performance in calculating pressures for a loop in backflow is clouded by difficulties in interpreting the data. The TRAC results seem reasonable qualitatively; a more definitive assessment may be possible when benchmark calculations of the 1989 L reactor tests are performed in the future.

Finally, Tables 3.8, 3.9 and 3.10 show that the TRAC analyses were in excellent agreement with the measured process water temperatures and tank bottom pressures.

3.6 High Flow Rate Tests

The two high flow rate tests were conducted with three pumps working and three loops shut down and valved off. The septifoil cooling systems were also valved off. This configuration reduced the effective core resistance to flow for each operating pump, resulting in pump flow rates that were near the operational limits of the pumps and drive trains.

3.6.1 Plenum Pressures

Figures 3.21 and 3.22 show the plenum pressure measurements for Tests F and K, respectively. The active and inactive loops for each test are noted on the figures. Overall, the plenum pressures in these tests are lower and the gradients less pronounced than in the other tests. However, the variation in pressure in front of the active loops is still significant. In the discussions that follow, plenum sectors receiving flow from active loops will be called "flow" sectors and those not receiving flow will be called "non-flow" sectors.

Figures 3.23 and 3.24 show the radial variation of measured and calculated plenum pressures for Test F in the flow and non-flow sectors, respectively. For the flow sectors, the agreement is good except in ring 5. The TRAC pressures are within 1 psi of the data average for rings 1 and 2 and within 2 psi for rings 3 and 4. The disagreement in ring 5 is consistent with all the results discussed previously. The agreement in the non-flow sectors is not as good. The calculated cell pressures are consistently less than the data averages, with the disagreement increasing toward the plenum edge.

When the measured and calculated pressures in the flow and non-flow sectors are compared, two observations stand out. First, the differences between flow and non-flow sector average pressures for rings 2 through 5 are greater in the calculated results than in the data. This suggests that the azimuthal loss coefficients in the model may be too large. The second observation is that the measured pressures are, on the average, higher in the non-flow sectors than in the flow sectors. As Davis [10] observed, this may be the result of stagnation points in the non-flow sectors caused by azimuthal flow from the flow sectors.

The asymmetric nature of Test K makes a comparison based on flow and non-flow sectors less valid than for the symmetric Test F. When the data is averaged over the TRAC cells, the results suggest a more detailed and appropriate basis for comparison, namely:

a. consider adjacent flow sectors 1 and 2 together;
b. consider adjacent non-flow sectors 3 and 4 together;
c. consider "isolated" sectors 5 (flow) and 6 (non-flow) separately.

Figures 3.25 and 3.26 show the radial variation of measured and calculated plenum pressures for Test K in the adjacent and isolated flow sectors, respectively. For the adjacent flow sectors, the agreement between cell-averaged data and TRAC cell pressures is good except in ring 5. The maximum error in the internal rings is 2.4

psi (5.8%). As usual, the calculated ring 5 pressures are high. The agreement for the isolated flow sector is somewhat better. The maximum error in the internal rings is 1.4 psi (3.4%); the calculated pressure in ring 5 is still high.

Figures 3.27 and 3.28 show the radial variation of measured and calculated plenum pressures for Test K in the adjacent and isolated non-flow sectors, respectively. For the adjacent non-flow sectors, the TRAC results are consistently below the data by between 4.5% and 10.5%. The worst overall agreement between calculation and data is in the isolated non-flow sector, where the TRAC pressures are high by 4 to 5% in rings 1 and 2 and low by 4 to 15% in rings 3 through 5. As in Test F, this difference appears to be due to the presence of stagnation zones in the non-flow sectors producing high pressures. The sparseness of the data in the non-flow zones may also render the cell-averaged data less meaningful. This type of plenum pressure distribution is not representative of a DEGB LOCA; it may be pertinent to the analysis of the LOPA.

3.6.2 Loop and Tank Parameters

Tables 3.11 and 3.12 present comparisons of measured and calculated loop and tank bottom parameters for Tests F and K, respectively. For both tests, the agreement between measured and calculated loop flows is excellent. The maximum difference of about 1.1% is well within the uncertainty of the data. The agreement between measured and calculated loop pressures for the active loops is similar to that of the other benchmark cases. Hence, the TRAC results are good except for the heat exchanger discharge pressures. The maximum errors in the calculated pump suction and discharge pressures are 1.0 psi (4.9%) and 3.8 psi (2.3%), respectively. The maximum errors in heat exchanger inlet and discharge pressures are 2.4 psi (1.5%) and 7.8 psi (10.5%), respectively. The high calculated heat exchanger discharge pressures probably account for some of the overprediction in ring 5 plenum pressures discussed previously.

The pressures in the isolated loops are best examined in two distinct groupings, reflecting the relative locations of the pressure taps and heat exchanger outlet rotovalves. The pressure taps upstream (with respect to normal flow direction) of these rotovalves were isolated from the plenum, so measurements taken there simply reflect a static elevation head higher or lower than the tank bottom pressure. For these locations, which include the pump suction and discharge and the heat exchanger inlet, the maximum error in the calculated pressures for both tests was 0.9 psi (3.1%).

The pressure taps for the heat exchanger outlet pressure measurements were located downstream of the closed rotovalves. Hence, the pressures at these locations reflect the plenum pressures near the corresponding inlet nozzles plus the static head associated with the higher elevation of the plenum. As Tables 3.11 and 3.12 show, there are significant differences between the measurements and the TRAC results. The calculated pressures are low by between 5.9 and 14.5 psi (10.6 and 24.8%). This is a direct reflection of TRAC's inability to match the plenum edge pressures in the non-flow sectors.

Finally, the TRAC calculation of tank bottom pressures and process water temperatures for Tests F and K was excellent.

4. Conclusions and Recommendations

The geometry review effort confirmed the basic fidelity of the TRAC model to the reactor geometry. A few errors were discovered, the most important of which were the plenum height, the plenum liquid volume, the tank diameter, and the reversal of sparjet junctions. The plenum height and sparjet junctions were corrected. The plenum liquid volume and tank diameter were judged to be acceptable for the current application of the model in full tank benchmarking and FI LOCA analysis. It is recommended, however, that the model be corrected in the future.

The correction of errors found during the model geometry review produced an improved TRAC L Reactor model. The plenum and loop K-factors in the model were then carefully adjusted to achieve good agreement with Test I of the 1985 L Reactor AC Flow Tests. The resulting model gave excellent agreement with measured tank bottom pressure, process water temperature, loop flow rates, and plenum pressures in the inner three radial rings. Calculated plenum pressures were in good agreement with the data in ring 4 , but were higher than the data in ring 5. Calculated loop pressures were in good agreement with the data except at the heat exchanger outlet, where they were too high. The agreement for the other three symmetric tests was similar to that of Test I, though the results for the low temperature tests were not quite as good as for the high temperature tests.

Though the overall agreement with the symmetric tests was not perfect, the agreement with the most important parameters, i.e., plenum pressures in rings 1-4 and loop flow rates, was quite good. Better agreement with the other parameters might have been obtained with significant reworking of the model, but this would have required significantly more time with no guarantee of obtaining improved results. Furthermore, it is not clear that model changes giving better agreement with the symmetric tests would also give equal or better agreement with the other benchmark tests, particularly the backflow tests. In light of the overall performance of the model, the agreement with the symmetric tests was acceptable.

The backflow test benchmark results were, in general, very good. Calculated plenum pressures in the backflow sectors were in excellent agreement with the data. The agreement in the forward flow sectors was similar to that of the symmetric tests. The comparison of measured and calculated loop flows and pressures in the forward flow loops was basically the same as that of the symmetric tests. However, in the backflow loops, the calculated flow rates were 7 to 10% low and the heat exchanger discharge pressures were low by 8 to 11 psi. Examination of the heat exchanger discharge pressure measurements for the backflow loops suggests that the data is either unreliable or indicative of some hydraulic behavior not captured by the code. It is recommended that this issue be addressed in the future by additional benchmarking against appropriate qualified data from the 1989 L reactor tests.

The high flow test benchmark analyses produced mixed results. Good agreement with the data was achieved for loop flow rates and inner ring plenum pressures in the flow sectors. As in all the TRAC simulations, plenum pressures in the outer ring of flow sectors were overpredicted. The TRAC results for the non-flow sector plenum pressures also did not agree well with the data. The data shows higher pressures in the non-flow sectors, apparently due to stagnation zones. This type of pressure distribution was not predicted well by the code. However, since it is also not representative of the pressure distribution expected during a DEGB LOCA, the lack of agreement was not considered important enough to require additional model development at this time. The agreement between measured and calculated loop pressures was the same as seen in the other tests.

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Figure 3.1 Plenum Pressure Measurement Locations

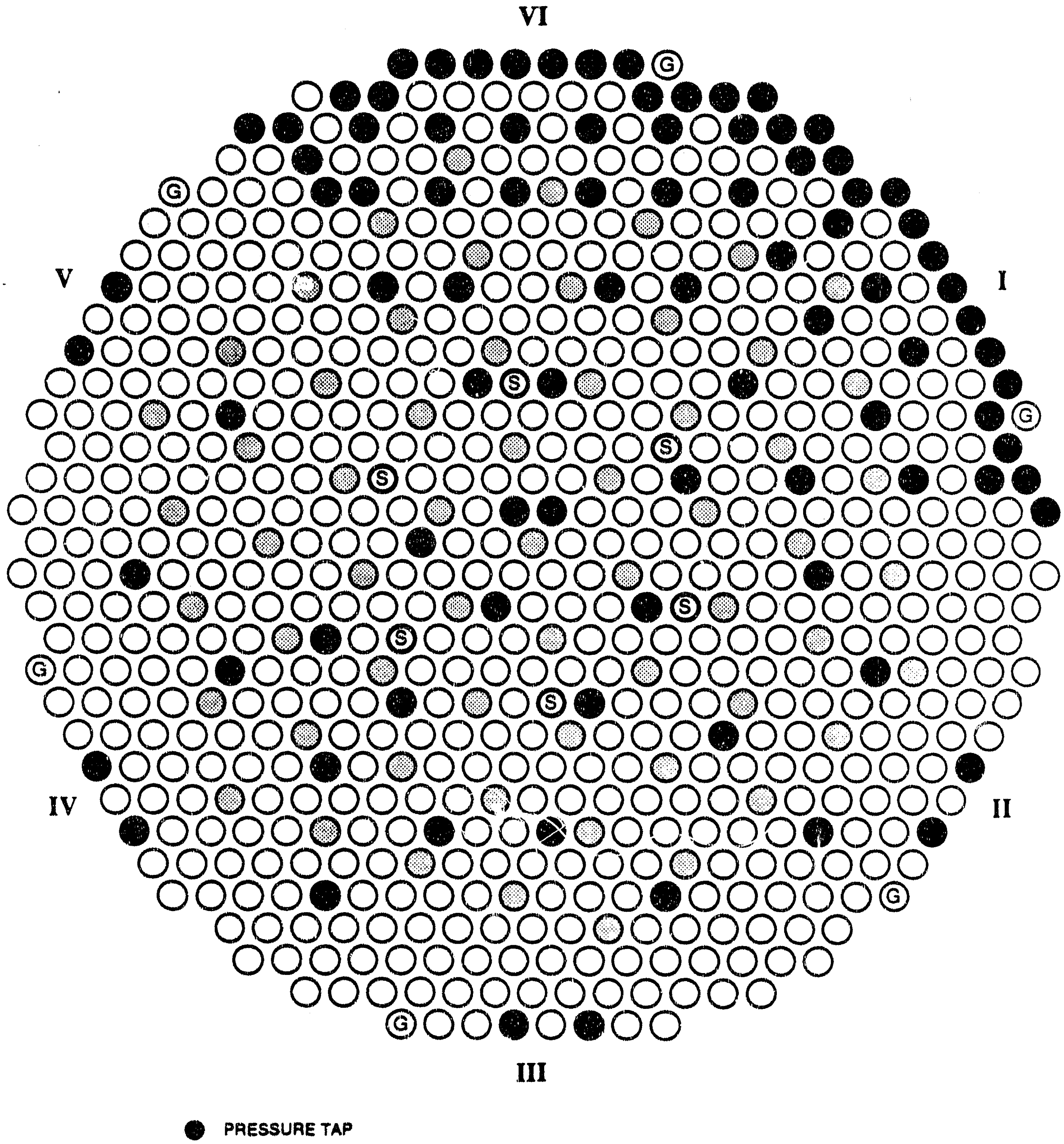


Figure 3.2 TRAC Grid Over L-1.1 Facemap

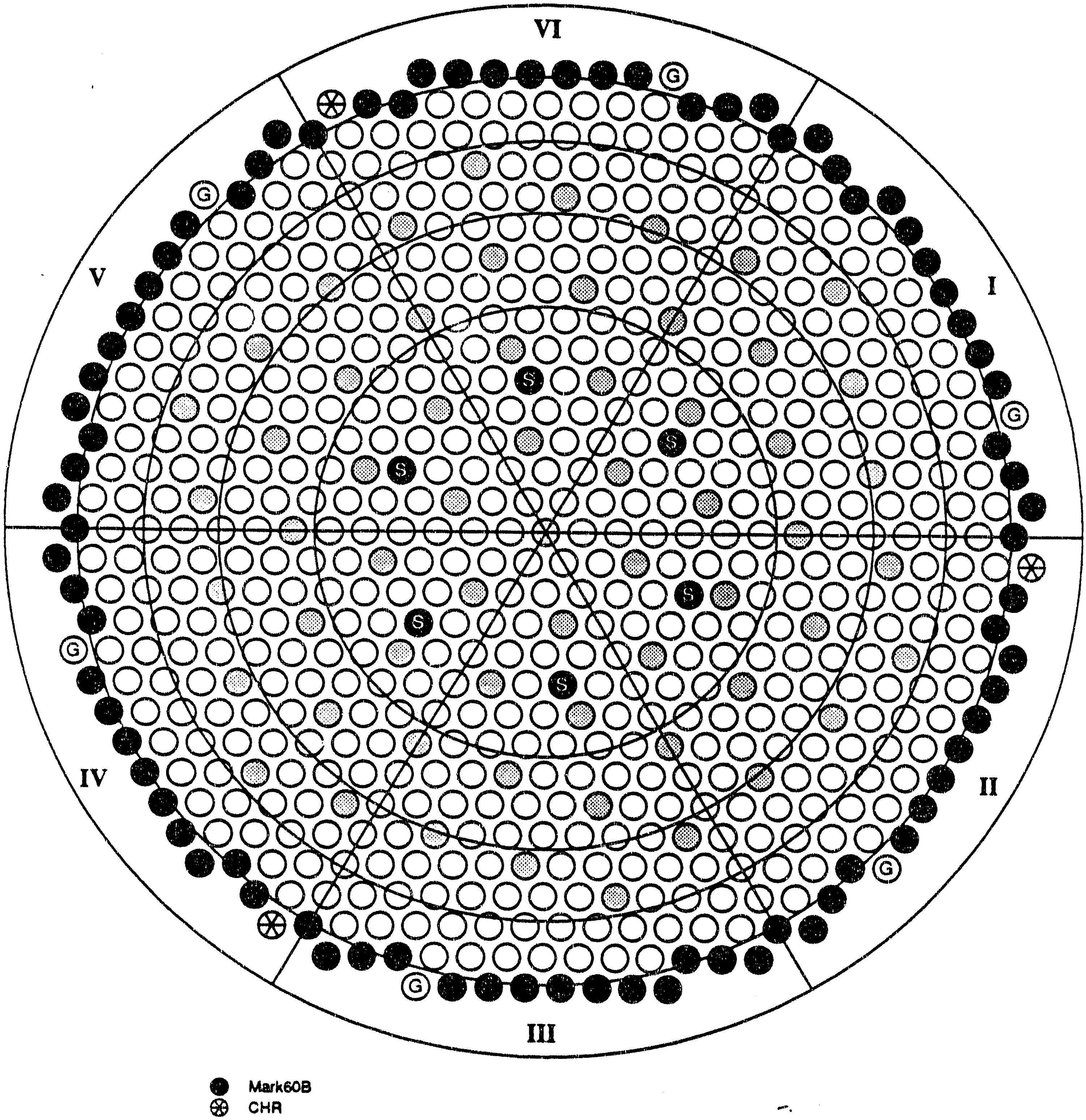


FIGURE 3.3 PLENUM PRESSURES:
L REACTOR AC FLOW TEST I vs. TRAC

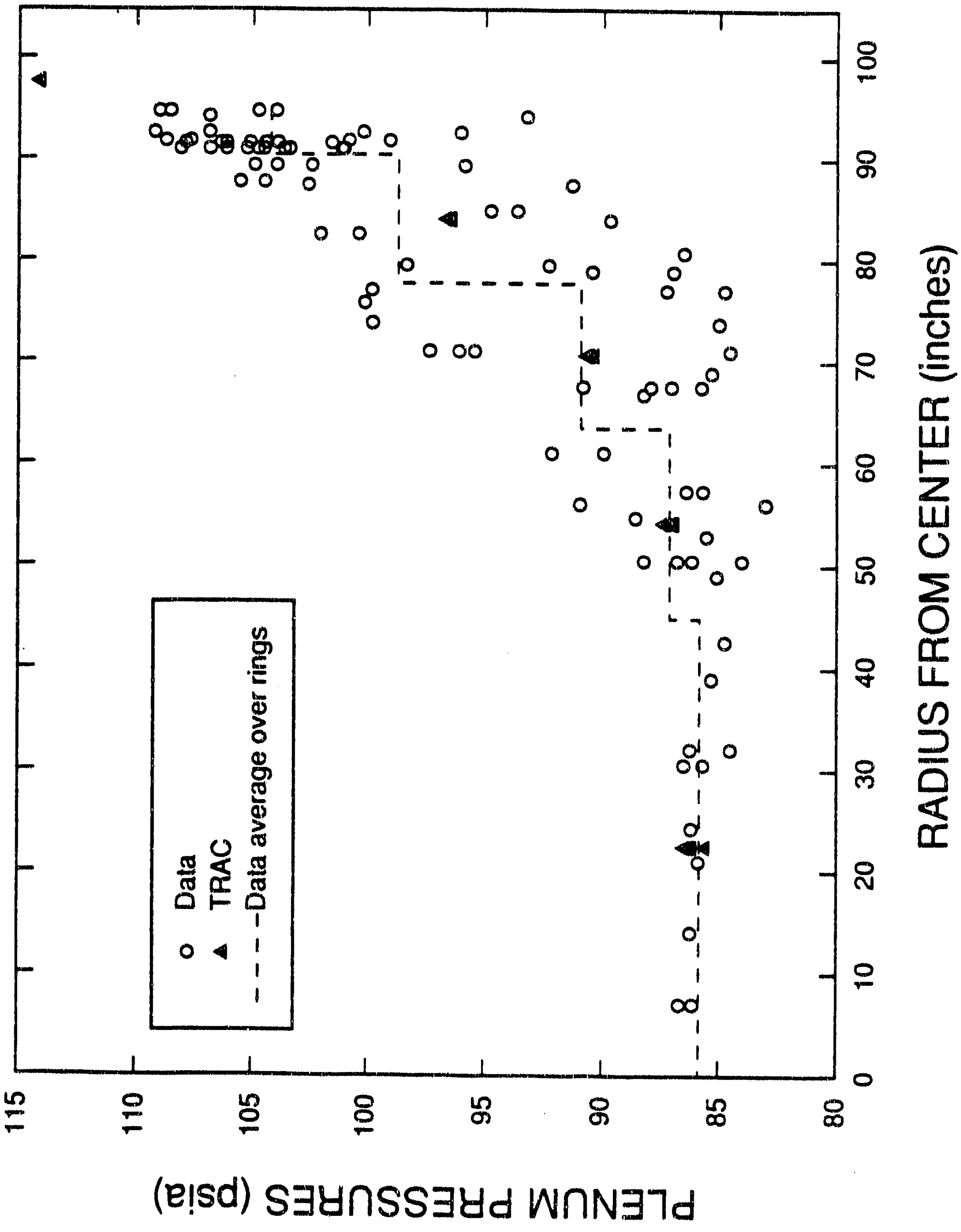
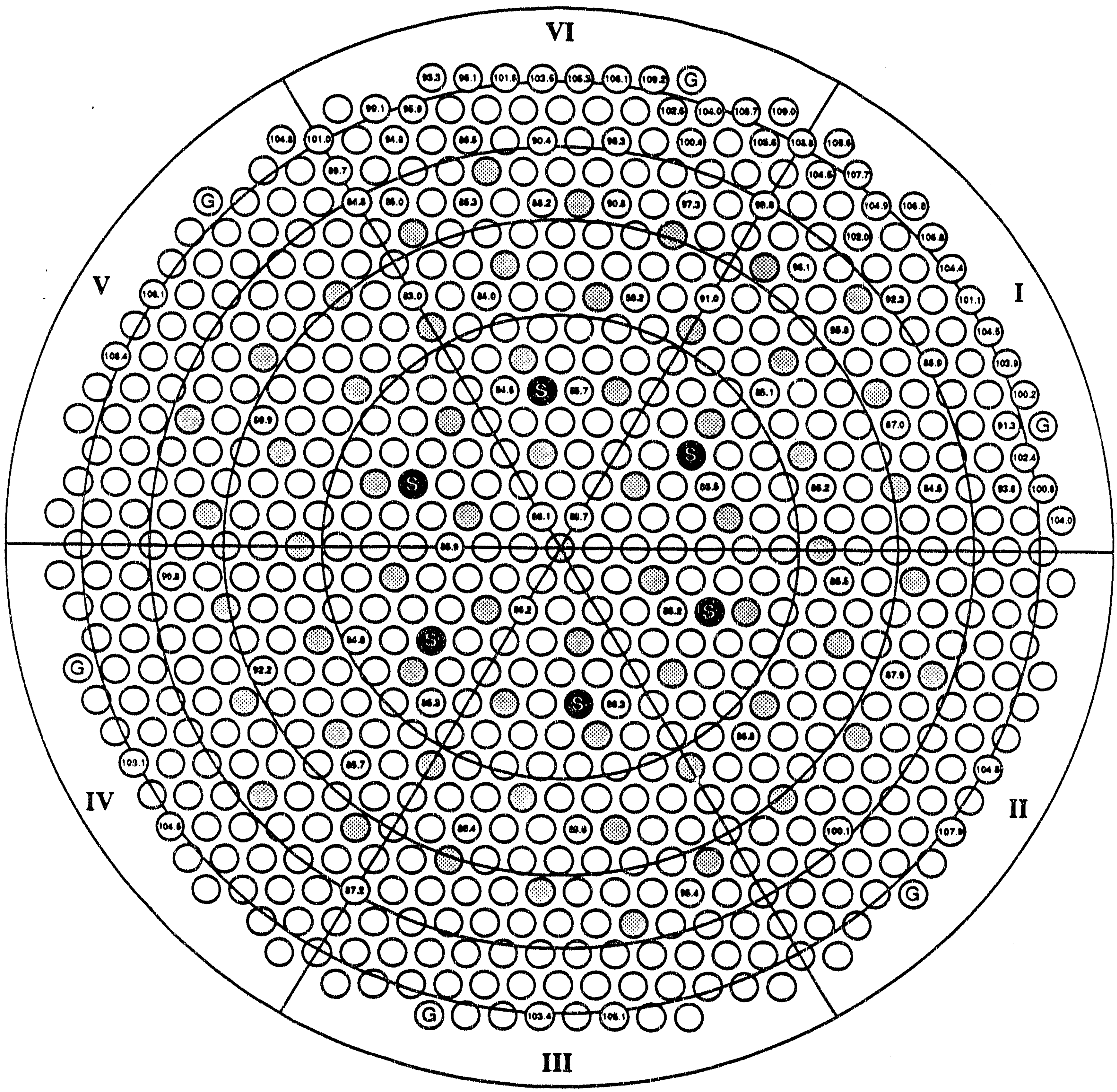
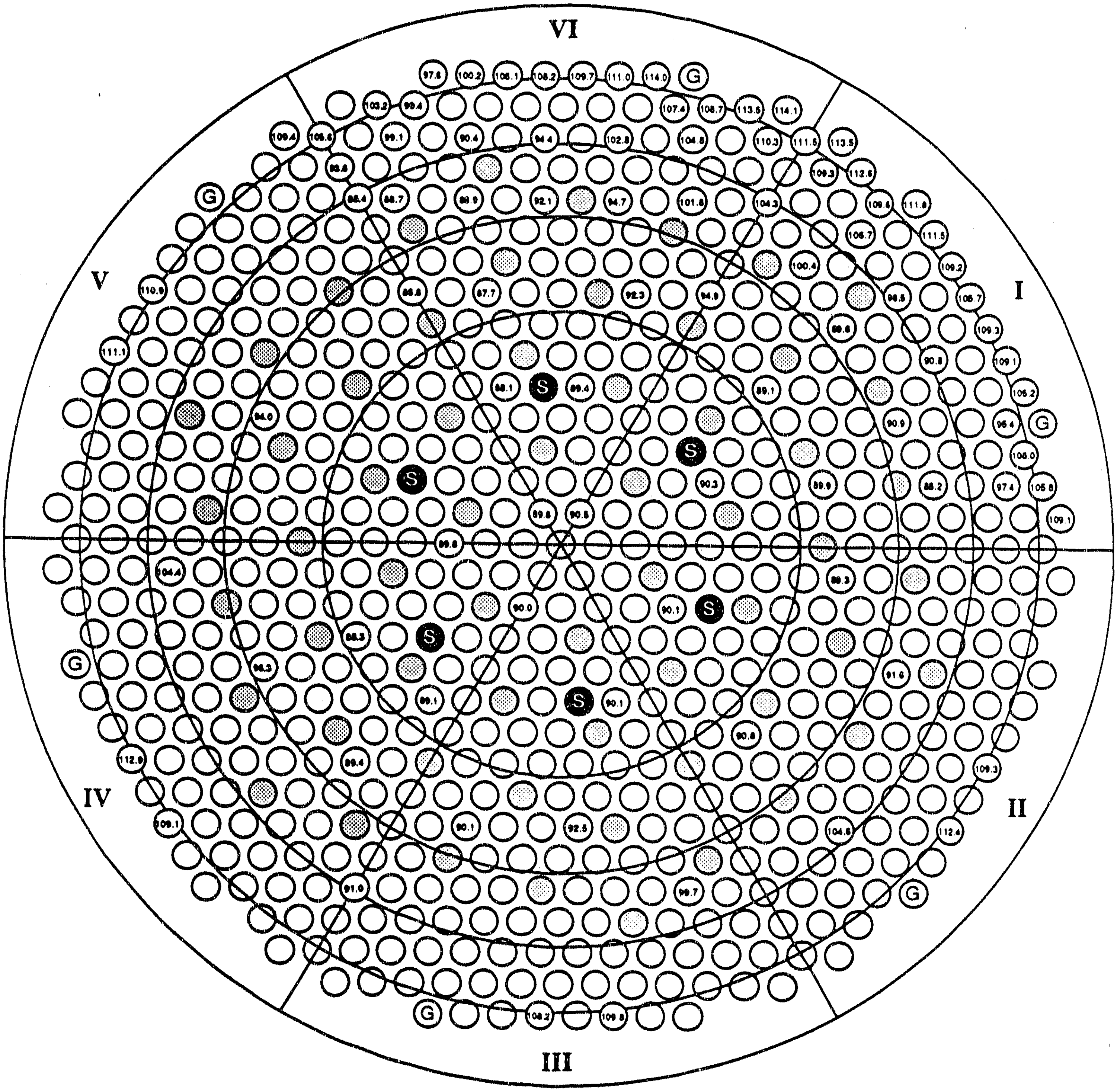


Figure 3.4 Test I Plenum Pressures



ABSOLUTE PRESSURE

Figure 3.5 Test H Plenum Pressures



ⓧ ABSOLUTE PRESSURE

FIGURE 3.6 PLENUM PRESSURES:
L REACTOR AC FLOW TEST H vs. TRAC

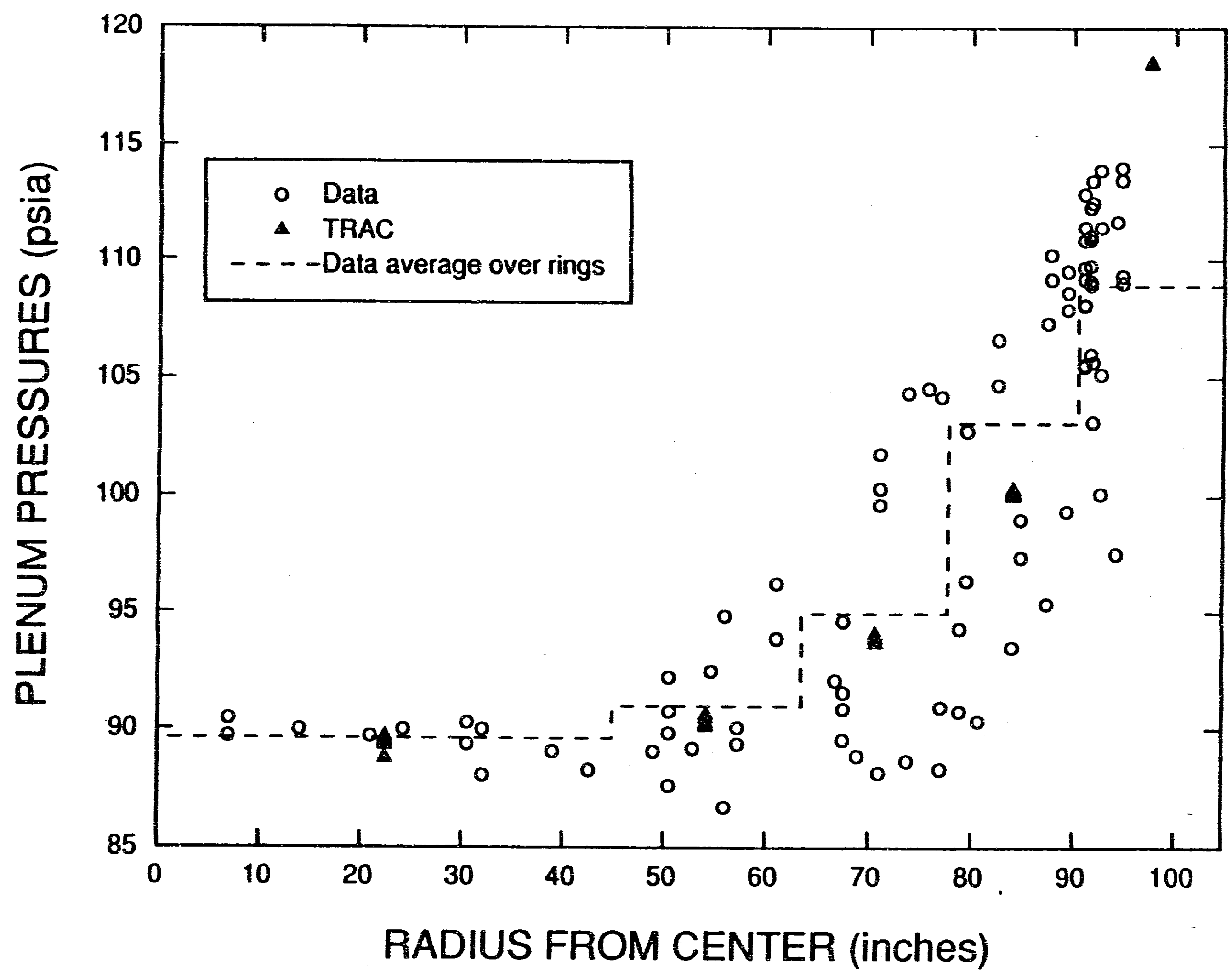


FIGURE 3.7 PLENUM PRESSURES:
L REACTOR AC FLOW TEST B vs. TRAC

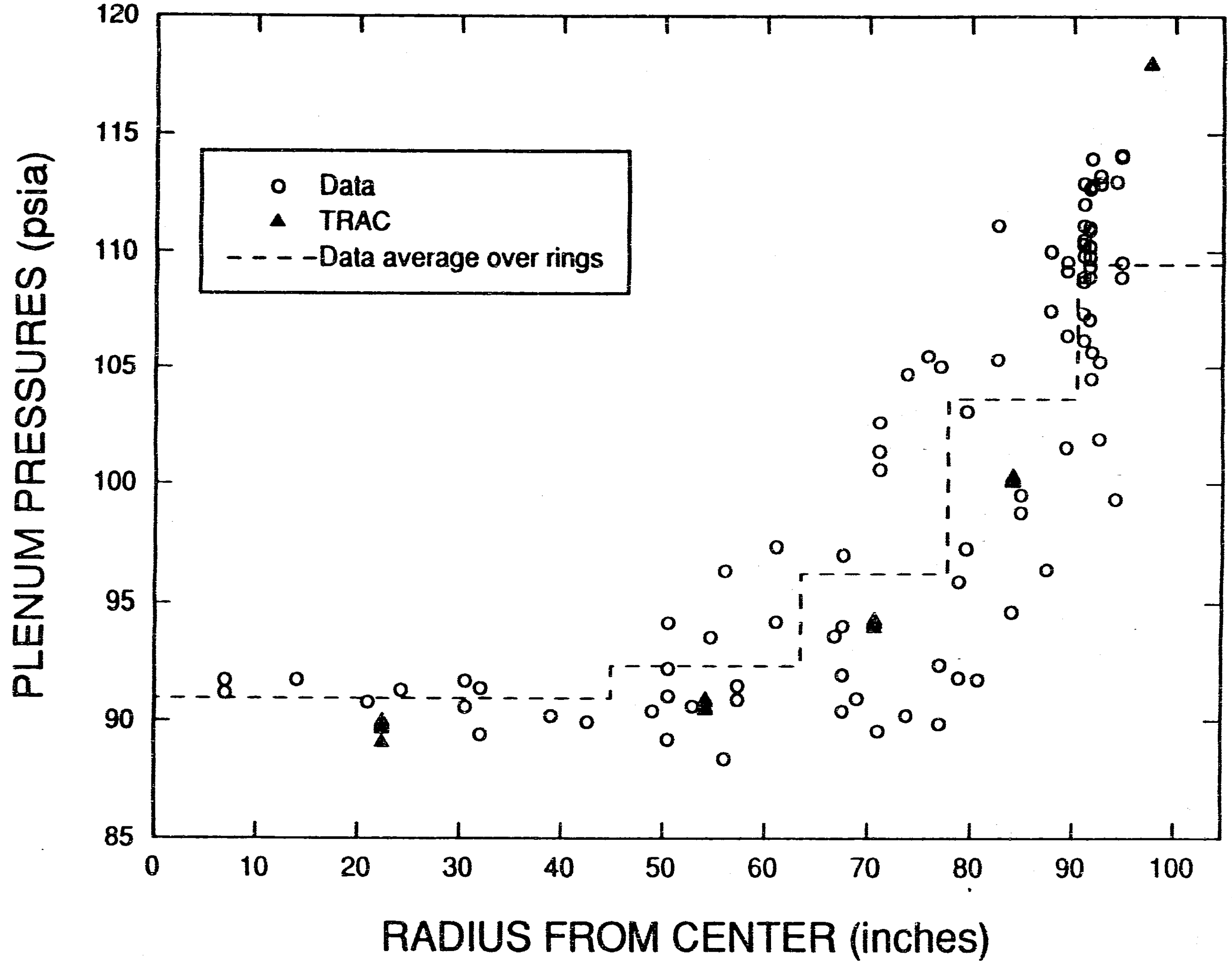


FIGURE 3.8 PLENUM PRESSURES: L-AREA AC FLOW TEST C vs. TRAC RESULTS

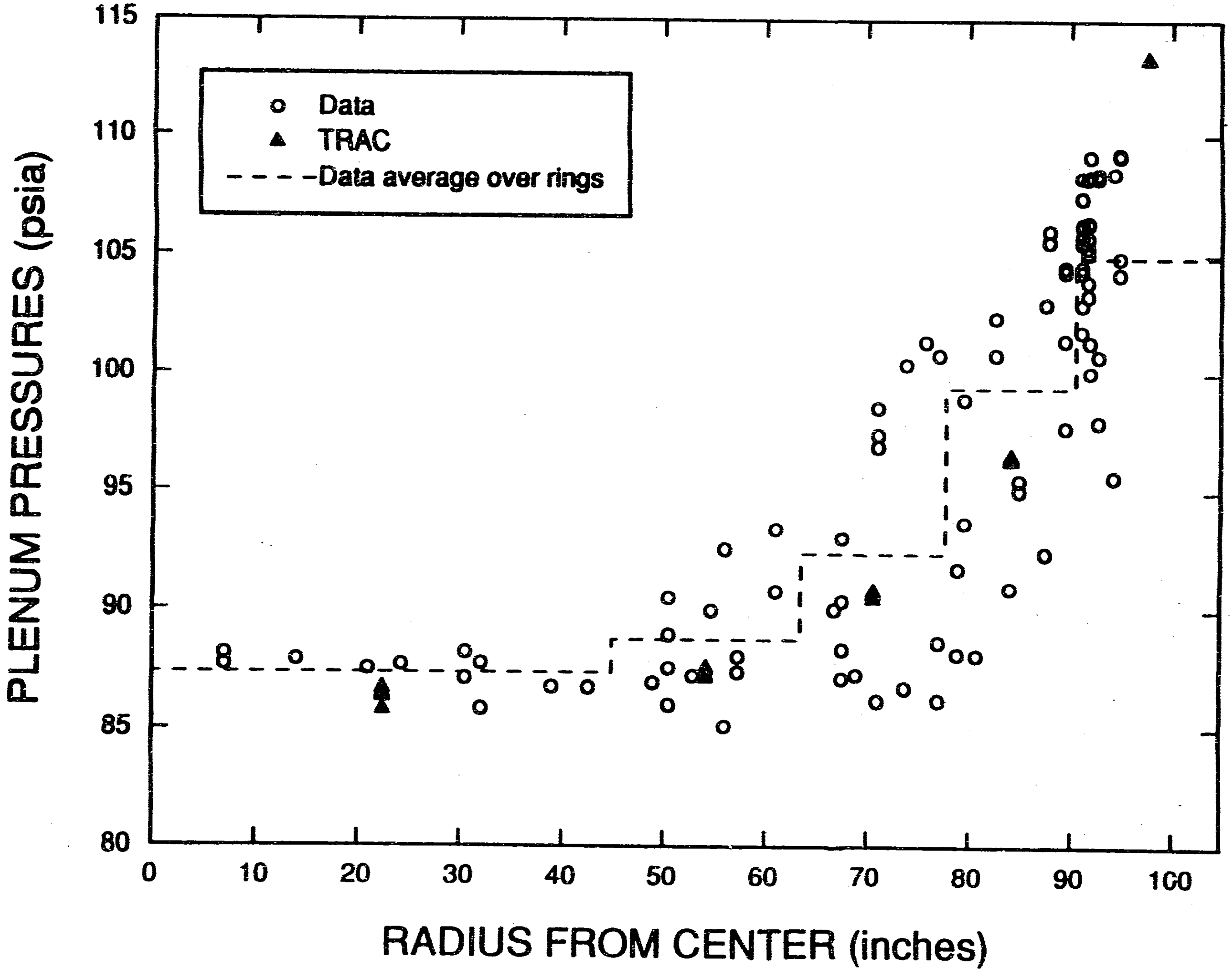
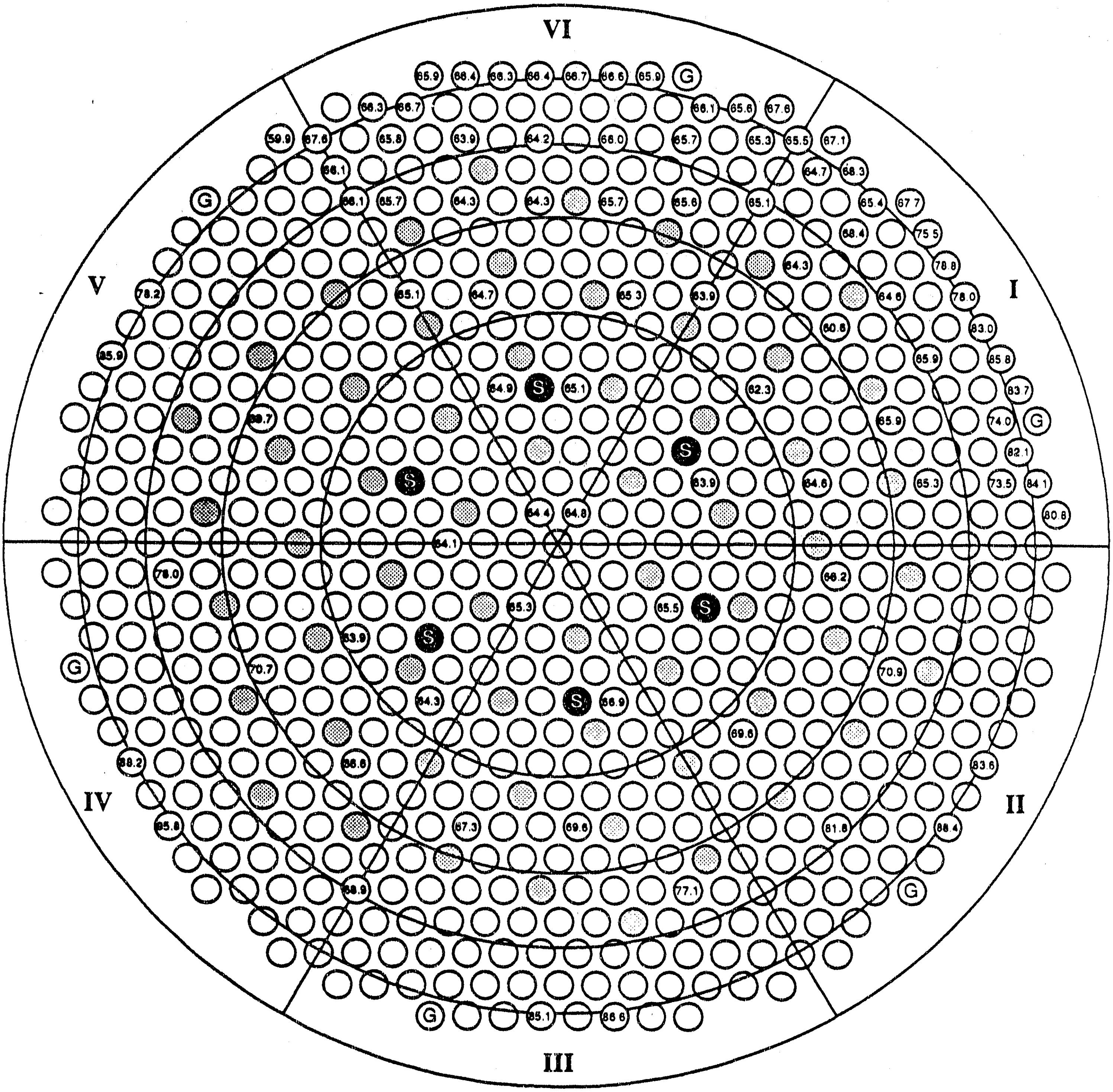


Figure 3.9 Test D Plenum Pressures



ⓧ ABSOLUTE PRESSURE

Figure 3.10 Test E Plenum Pressures

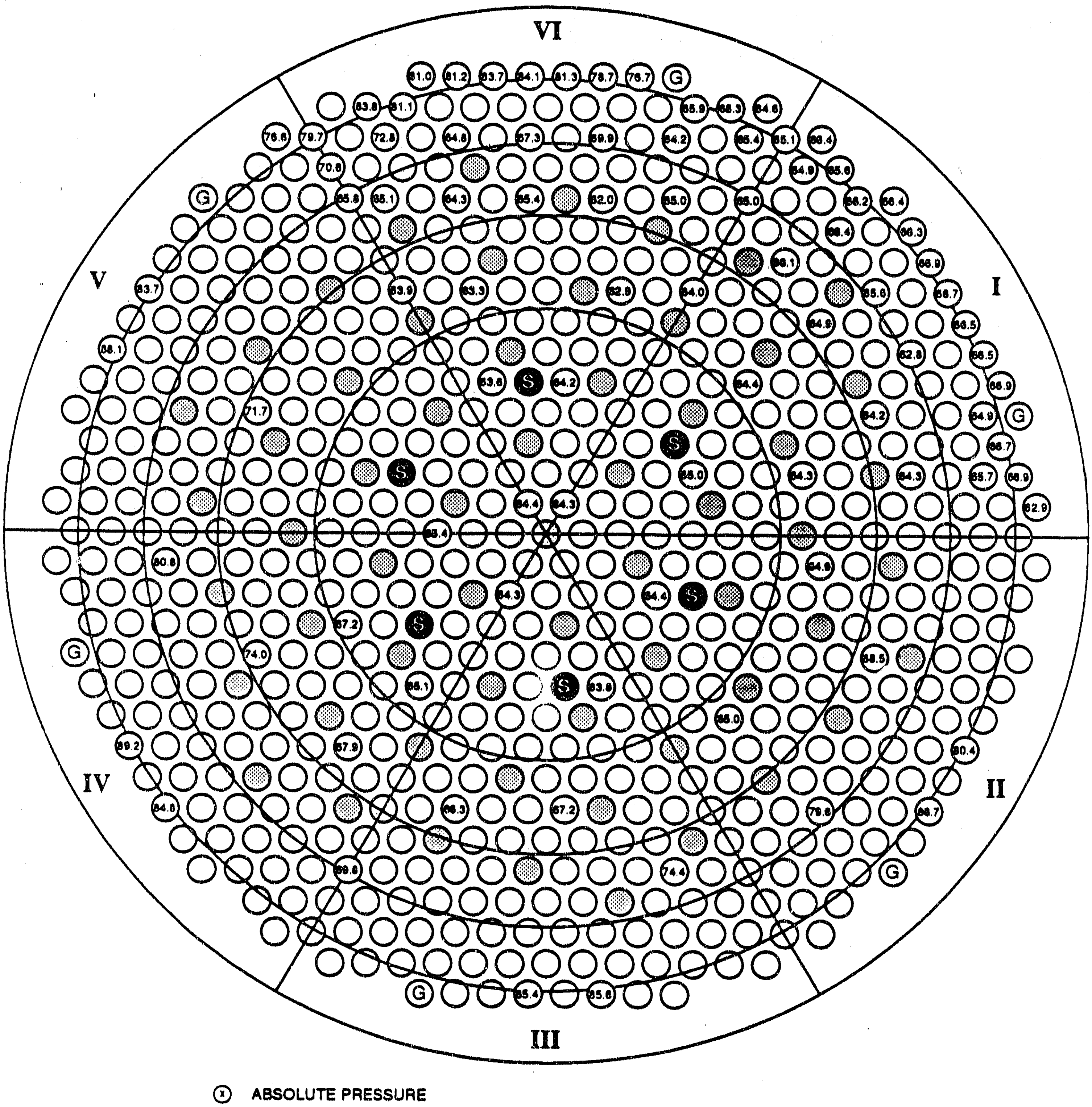
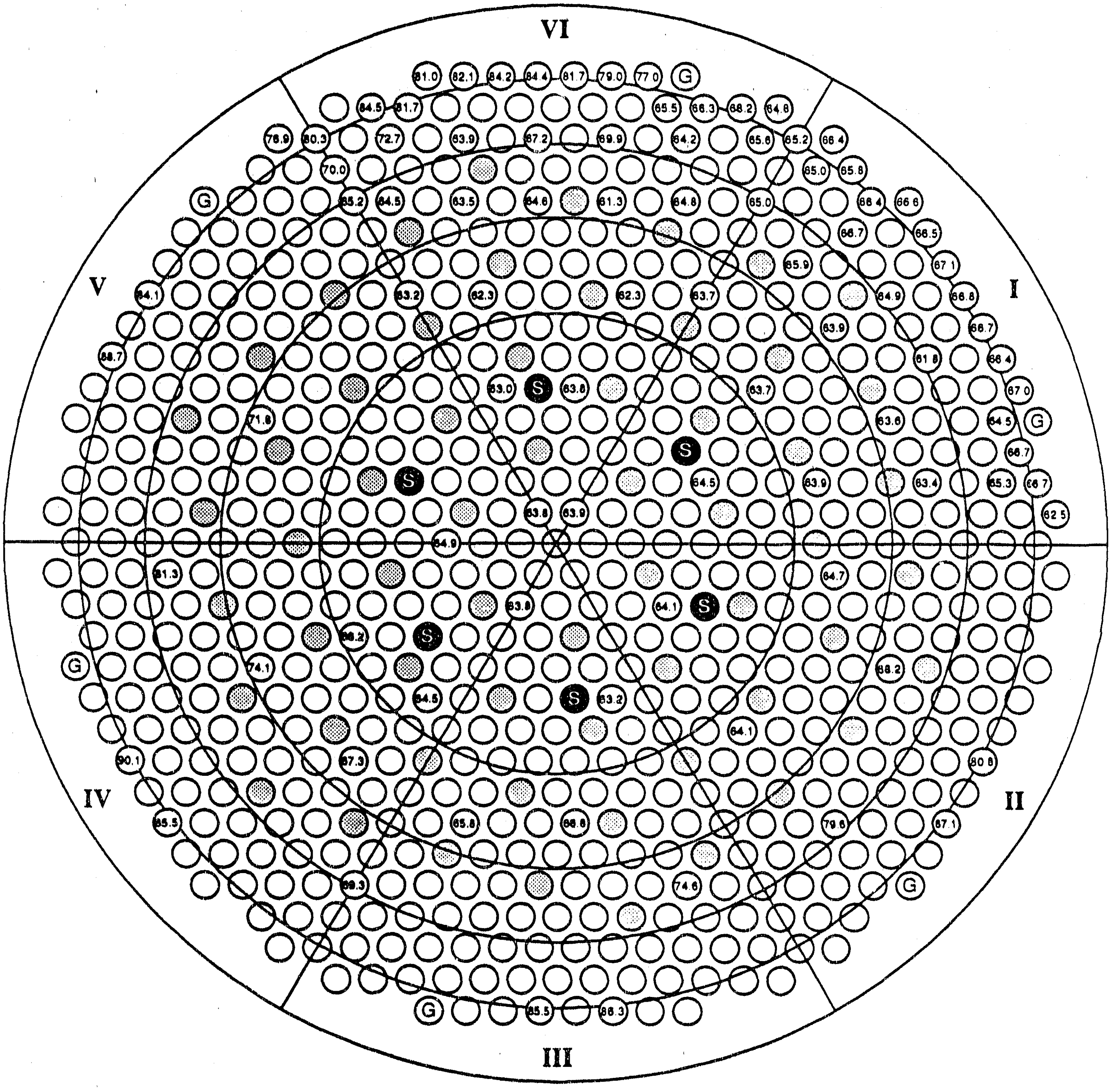


Figure 3.11 Test J Plenum Pressures



(x) ABSOLUTE PRESSURE

FIGURE 3.12 SECTOR 2 PLENUM PRESSURES: L-AREA AC FLOW TEST D vs. TRAC RESULTS

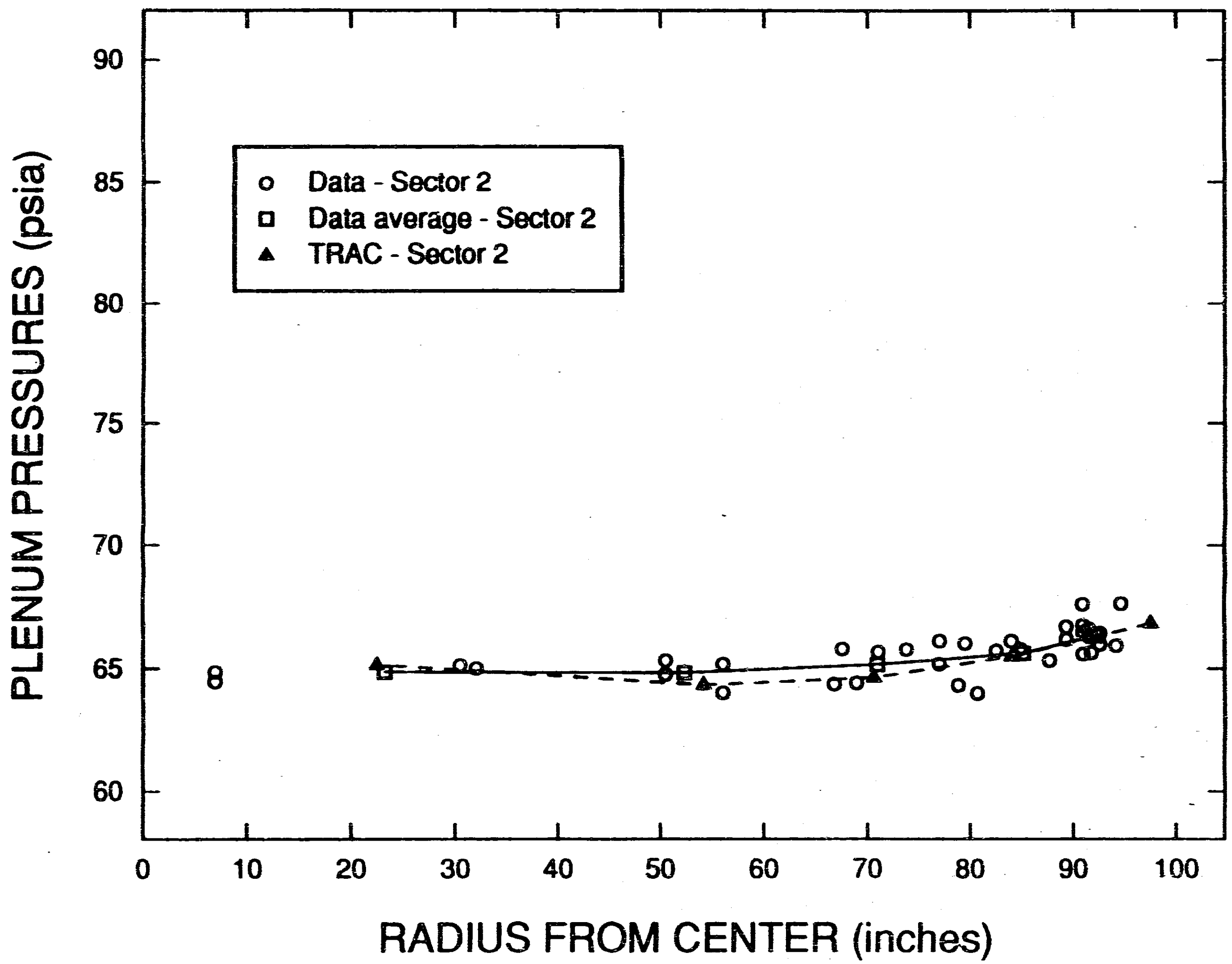


FIGURE 3.13 SECTOR 1 PLENUM PRESSURES:
L-AREA AC FLOW TEST E vs. TRAC RESULTS

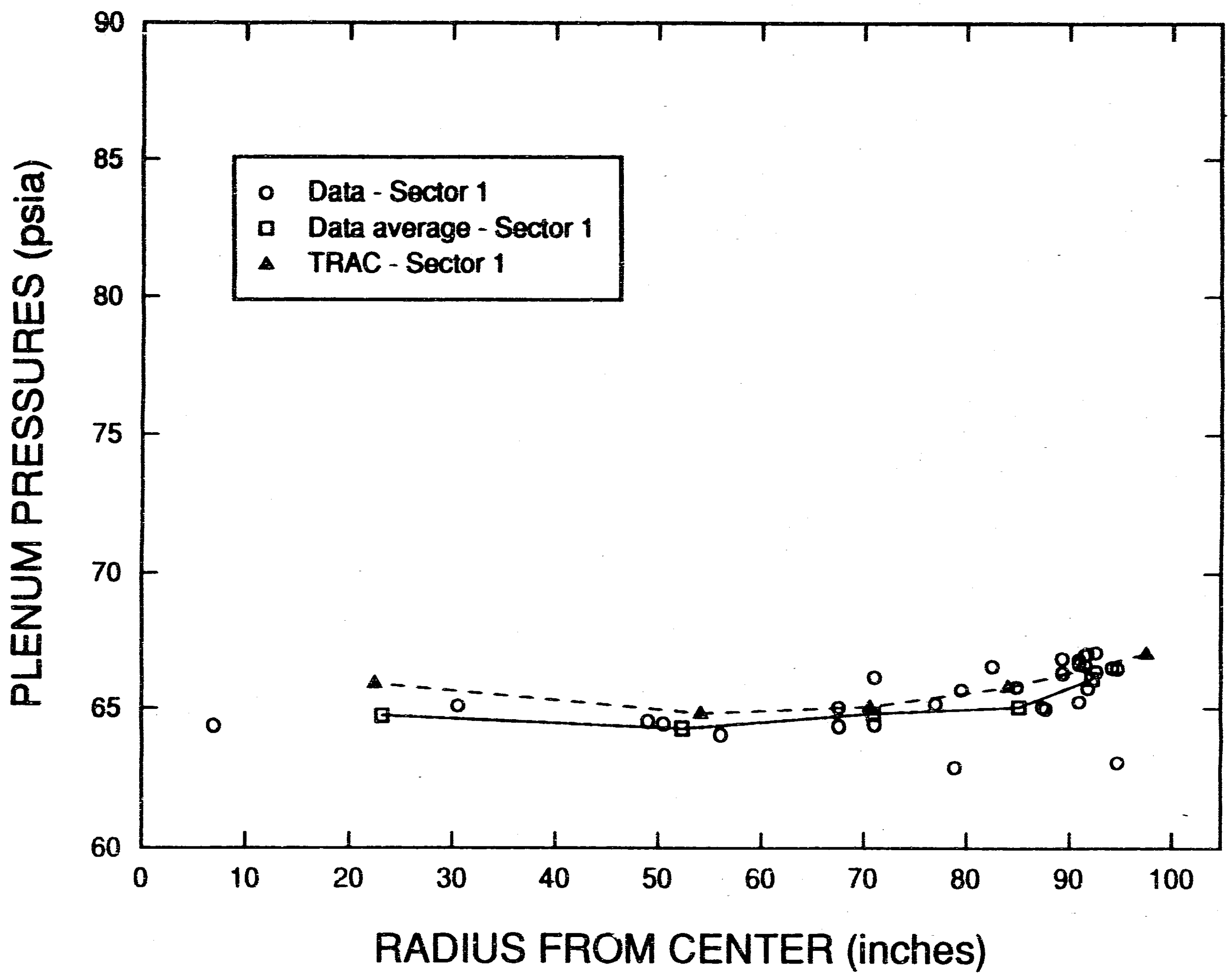


FIGURE 3.14 SECTOR 1 PLENUM PRESSURES: L-AREA AC FLOW TEST J vs. TRAC RESULTS

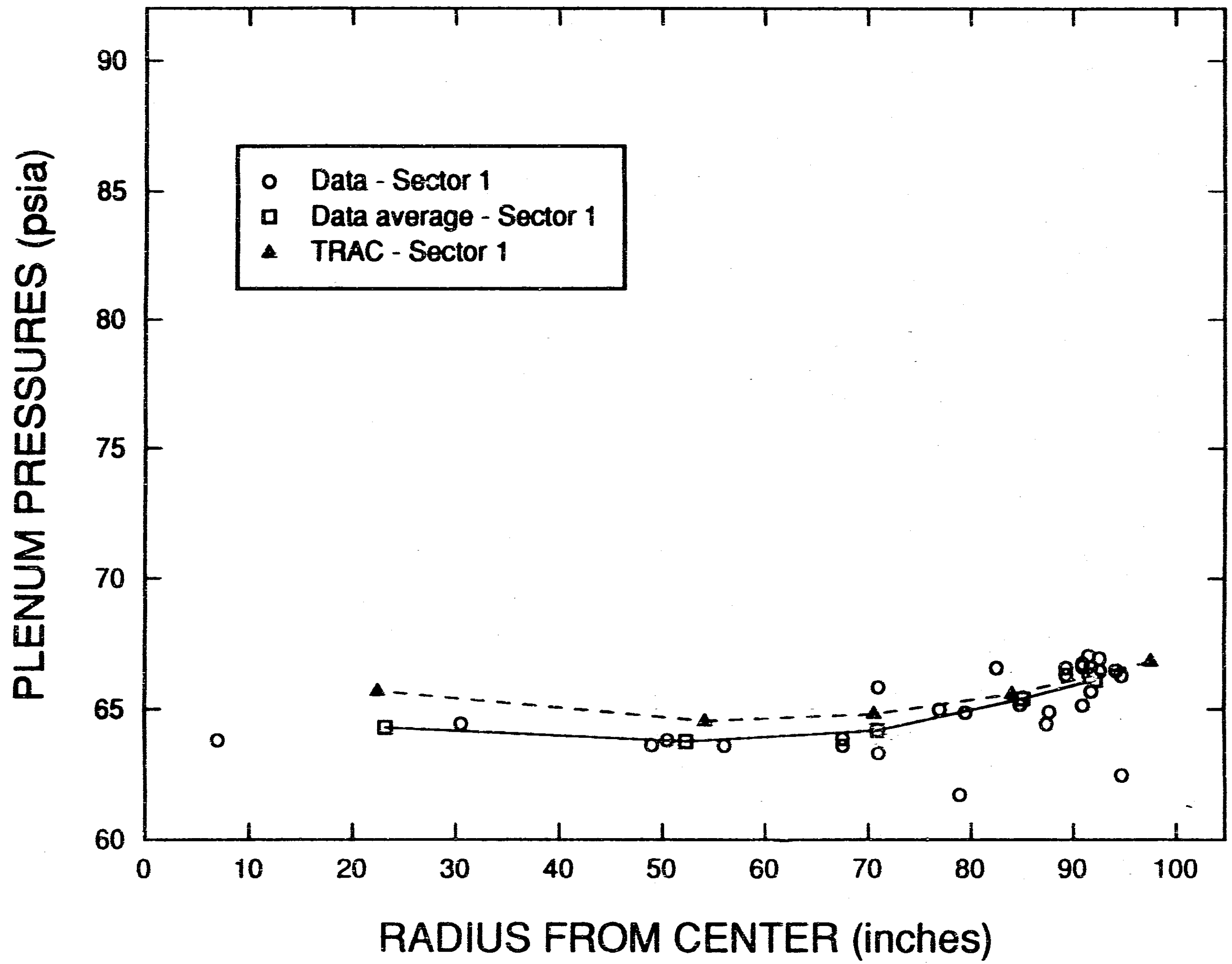


FIGURE 3.15 AC FLOW TEST D vs. TRAC PLENUM PRESSURES IN SECTORS 1 AND 3

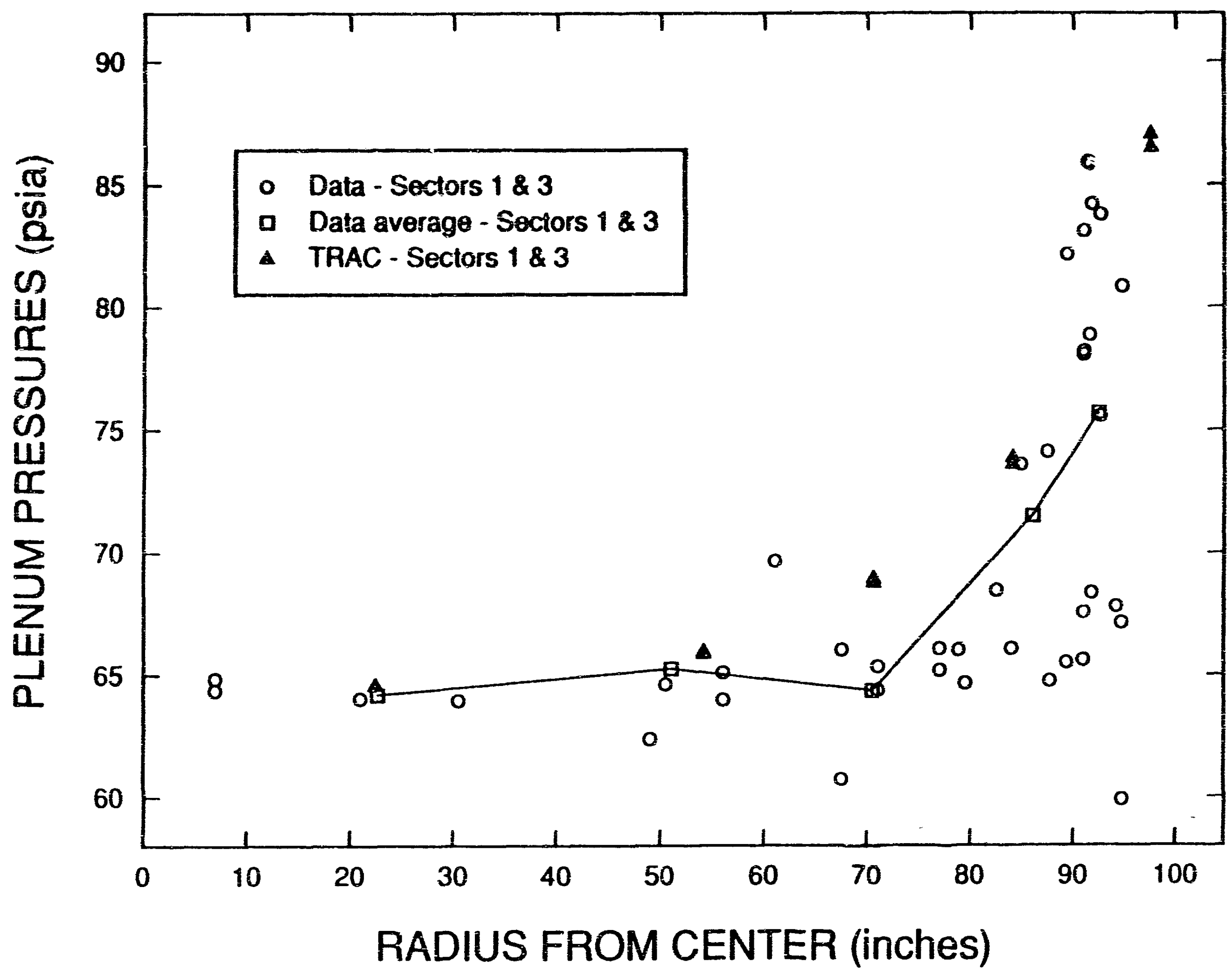


FIGURE 3.16 AC FLOW TEST D vs. TRAC PLENUM PRESSURES IN TRAC RING 5

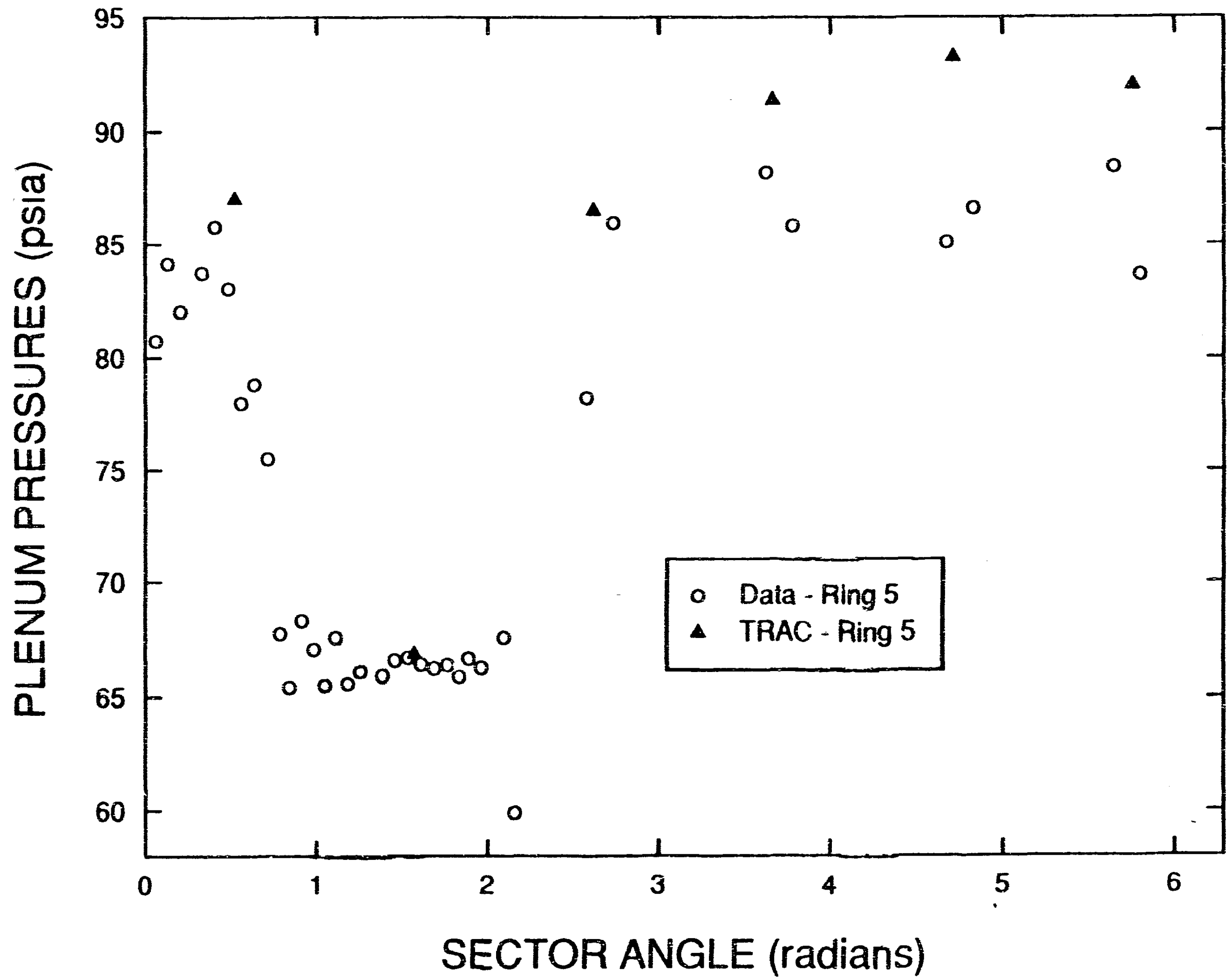


FIGURE 3.17 AC FLOW TEST D vs. TRAC PLENUM PRESSURES IN TRAC RING 4

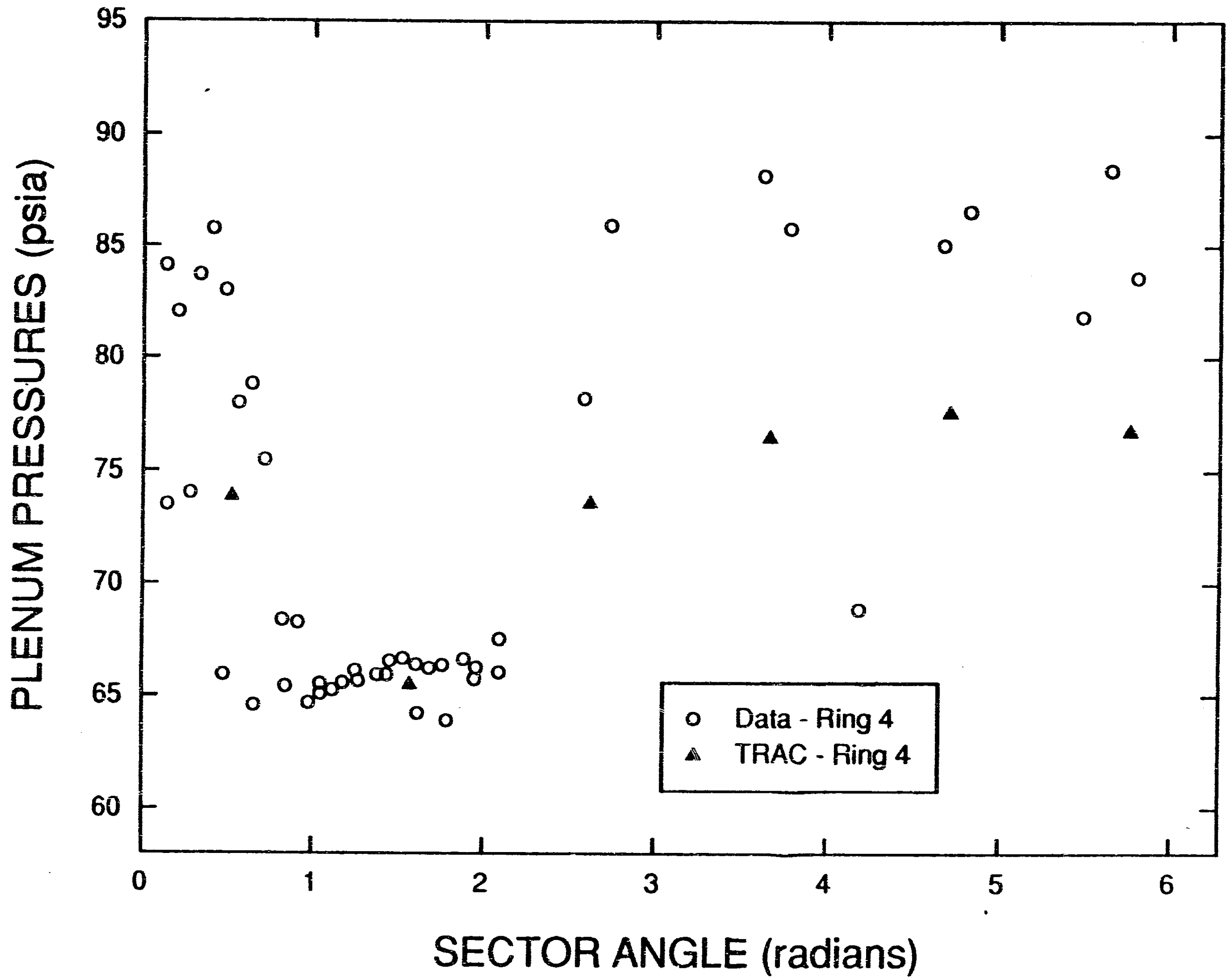


FIGURE 3.18 AC FLOW TEST D vs. TRAC PLENUM PRESSURES IN TRAC RING 3

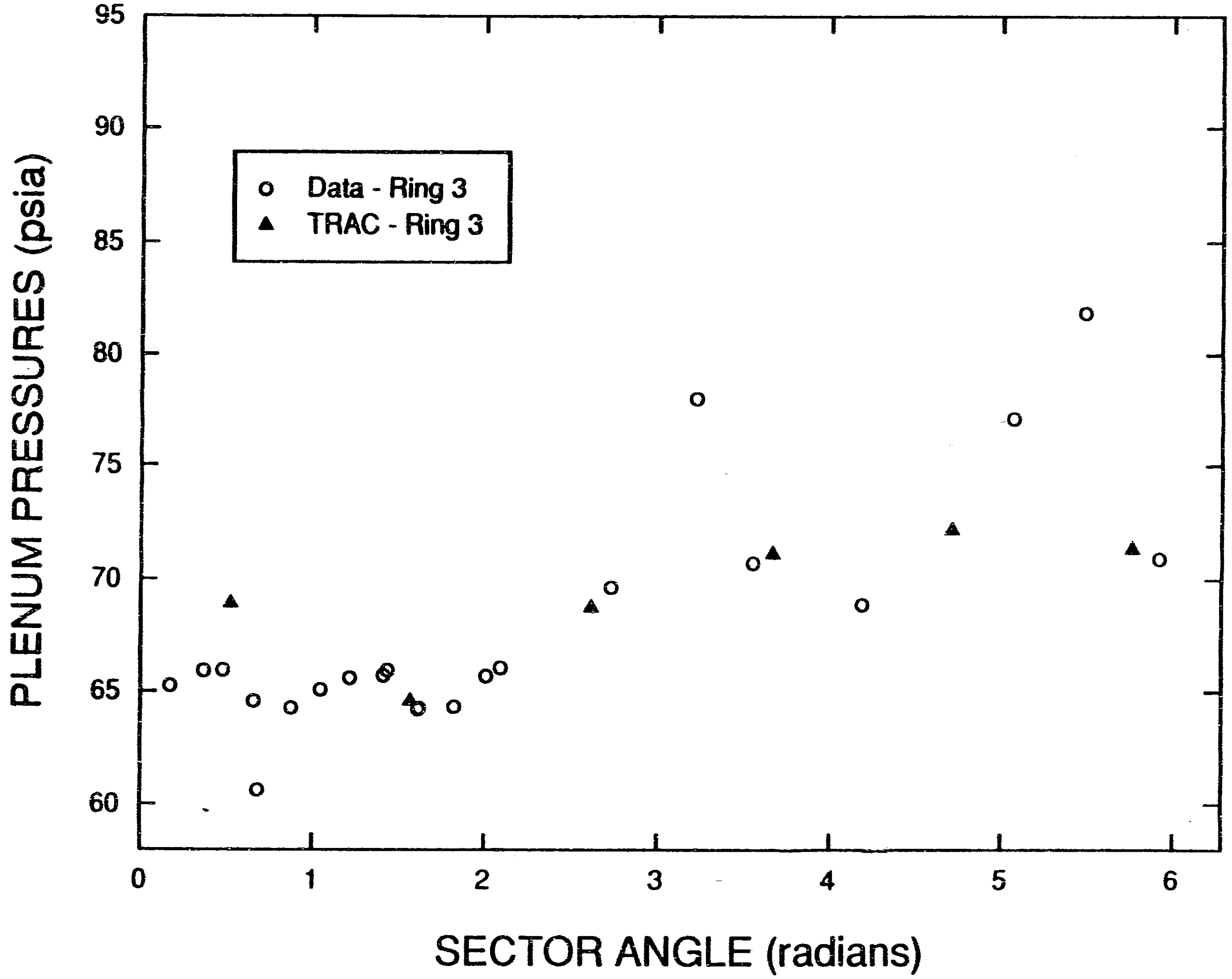


FIGURE 3.19 AC FLOW TEST D vs. TRAC PLENUM PRESSURES IN TRAC RING 2

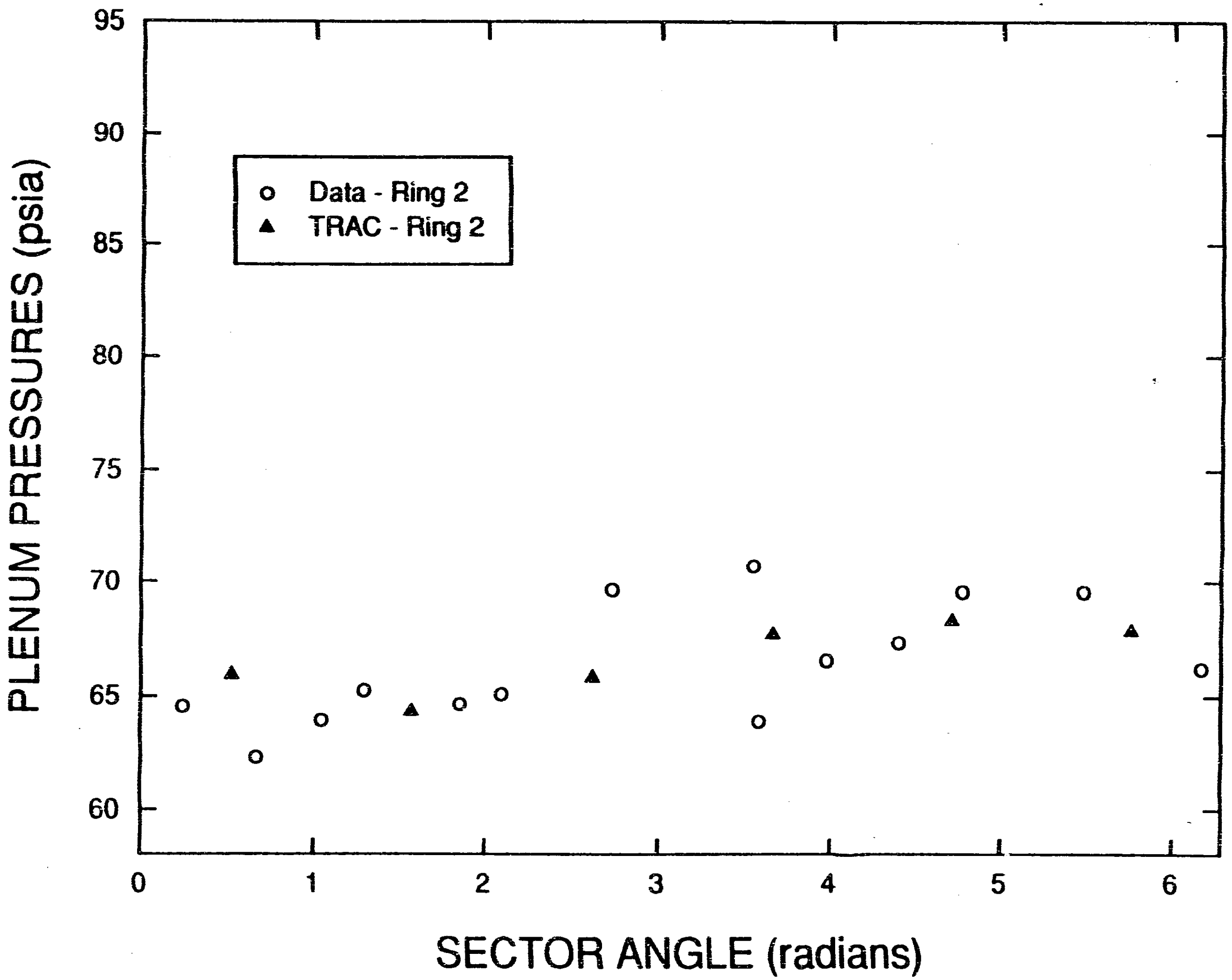


FIGURE 3.20 AC FLOW TEST D vs. TRAC PLENUM PRESSURES IN TRAC RING 1

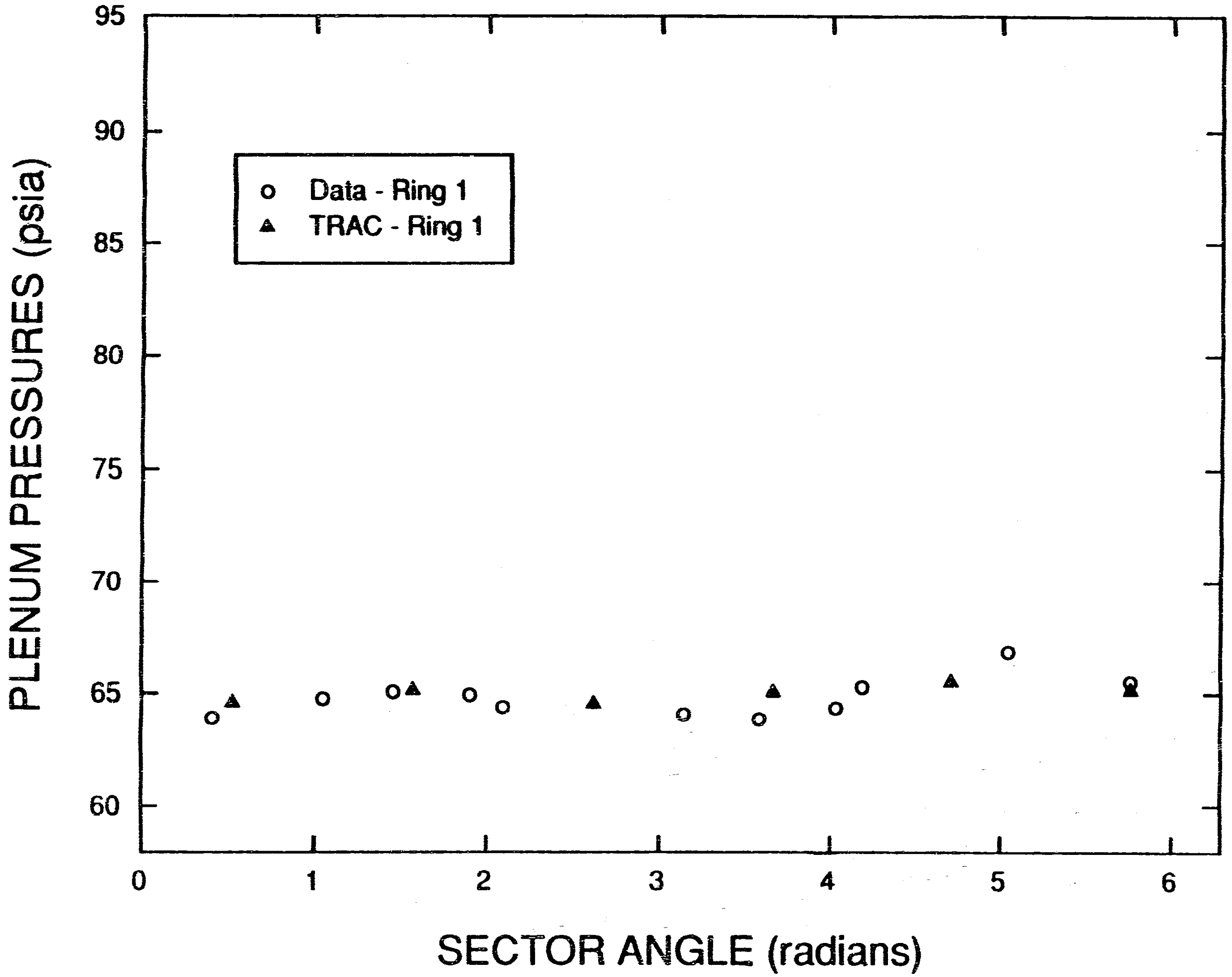


Figure 3.21 Test F Plenum Pressures

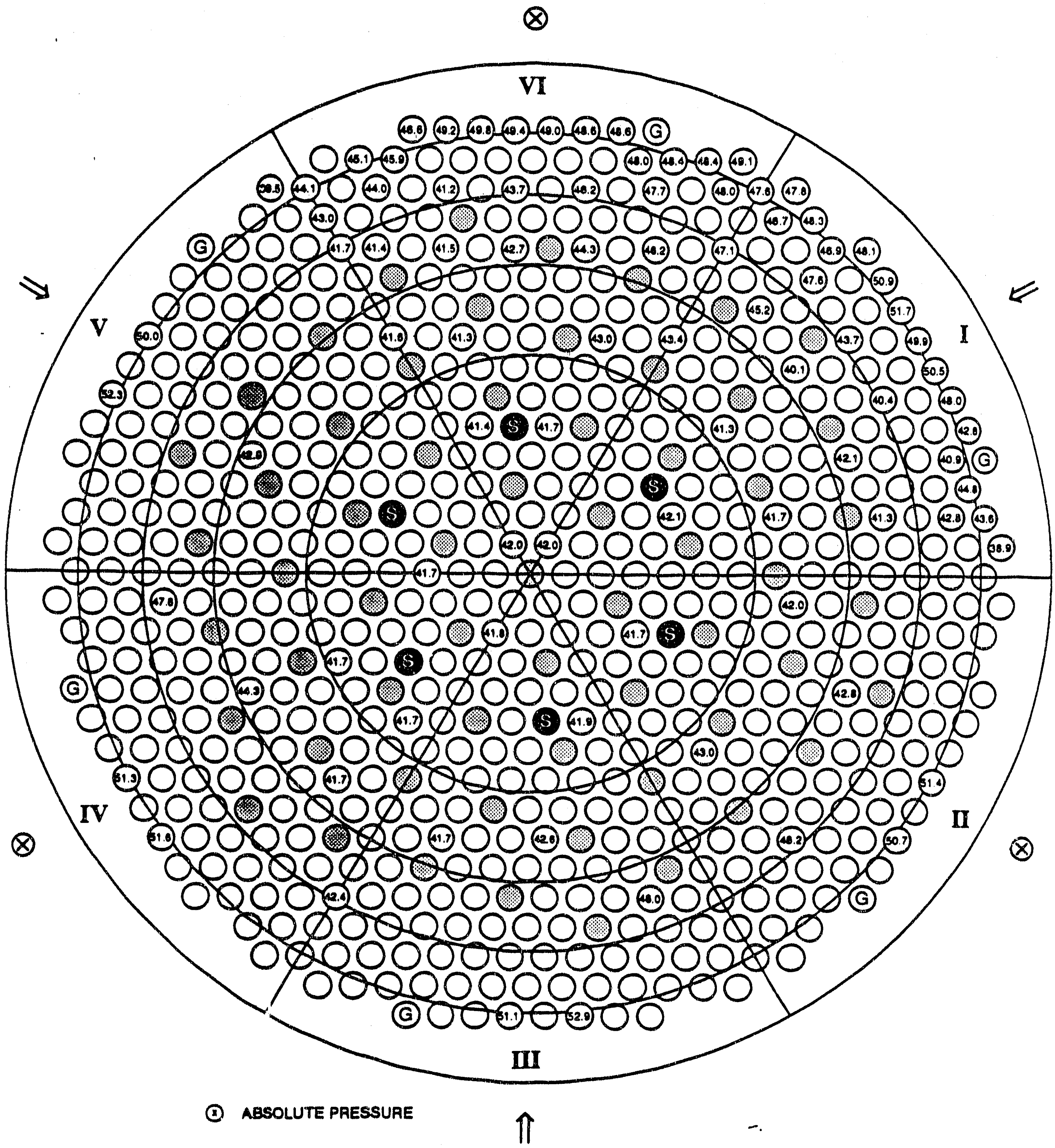


Figure 3.22 Test K Plenum Pressures

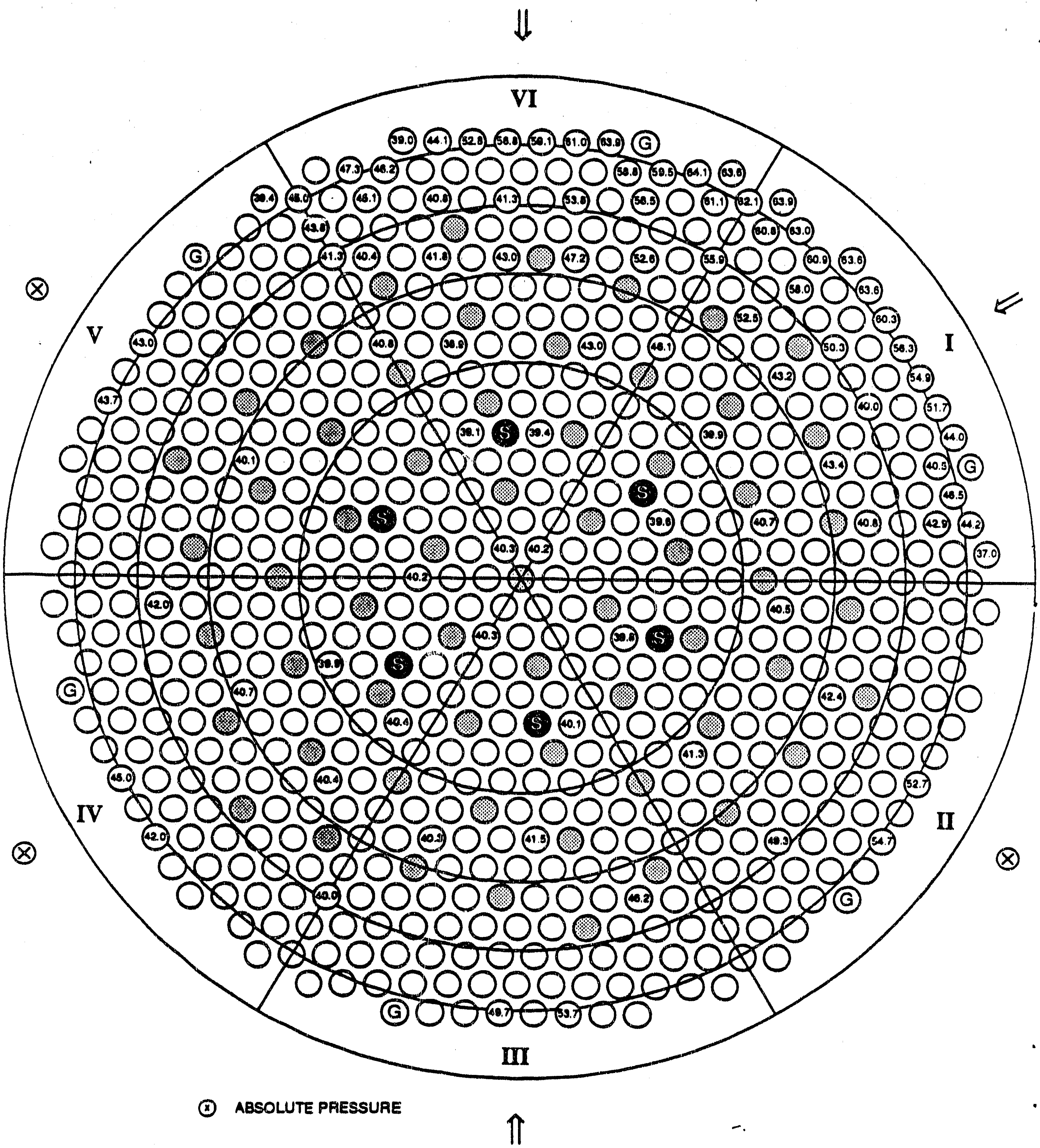


FIGURE 3.23 AC FLOW TEST F vs. TRAC PLENUM PRESSURES IN FLOW SECTORS

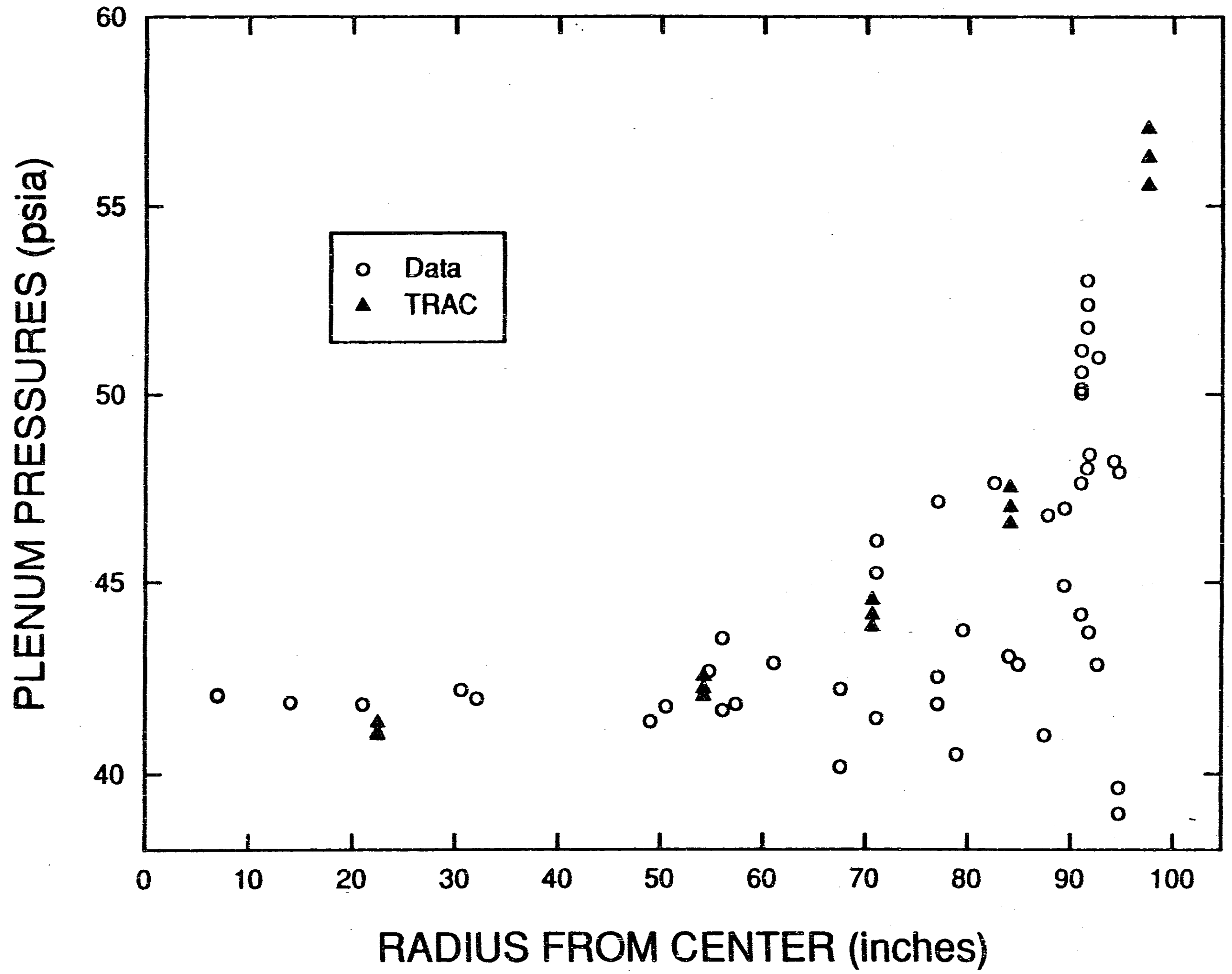


FIGURE 3.24 AC FLOW TEST F vs. TRAC
PLENUM PRESSURES IN NON-FLOW SECTORS

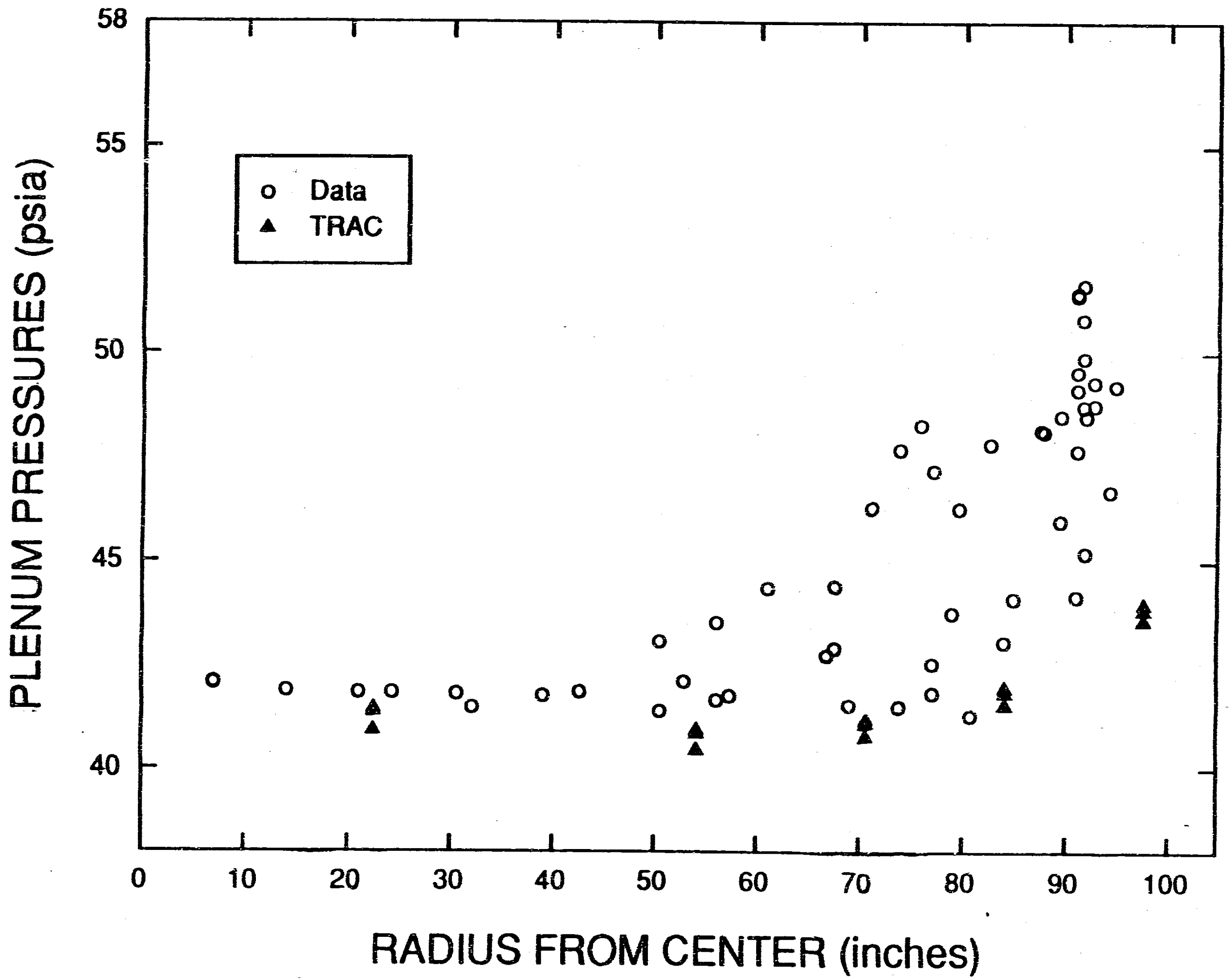


FIGURE 3.25 AC FLOW TEST K vs. TRAC
ADJACENT FLOW SECTOR PLENUM PRESSURE

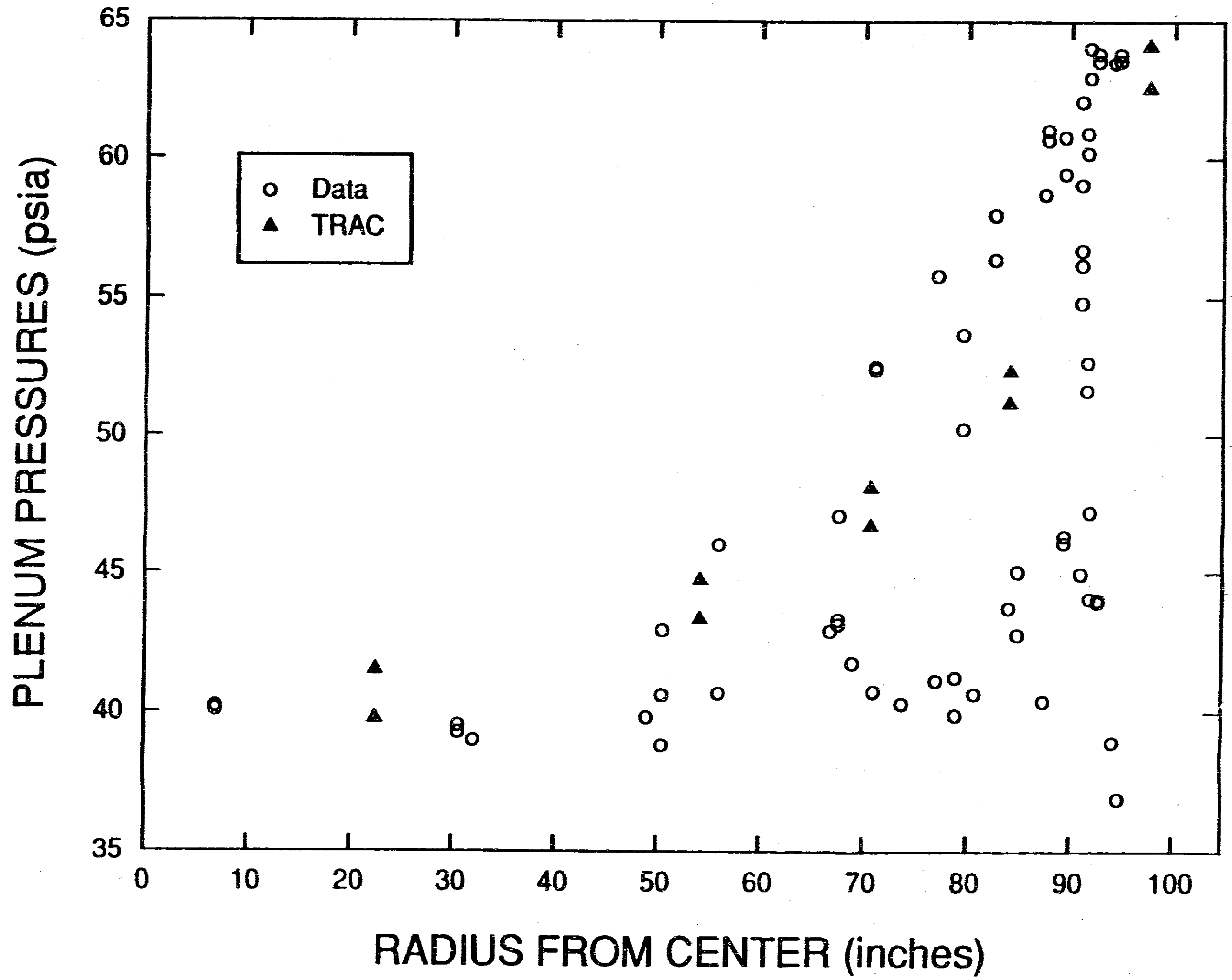


FIGURE 3.26 AC FLOW TEST K vs. TRAC
ISOLATED FLOW SECTOR PRESSURES

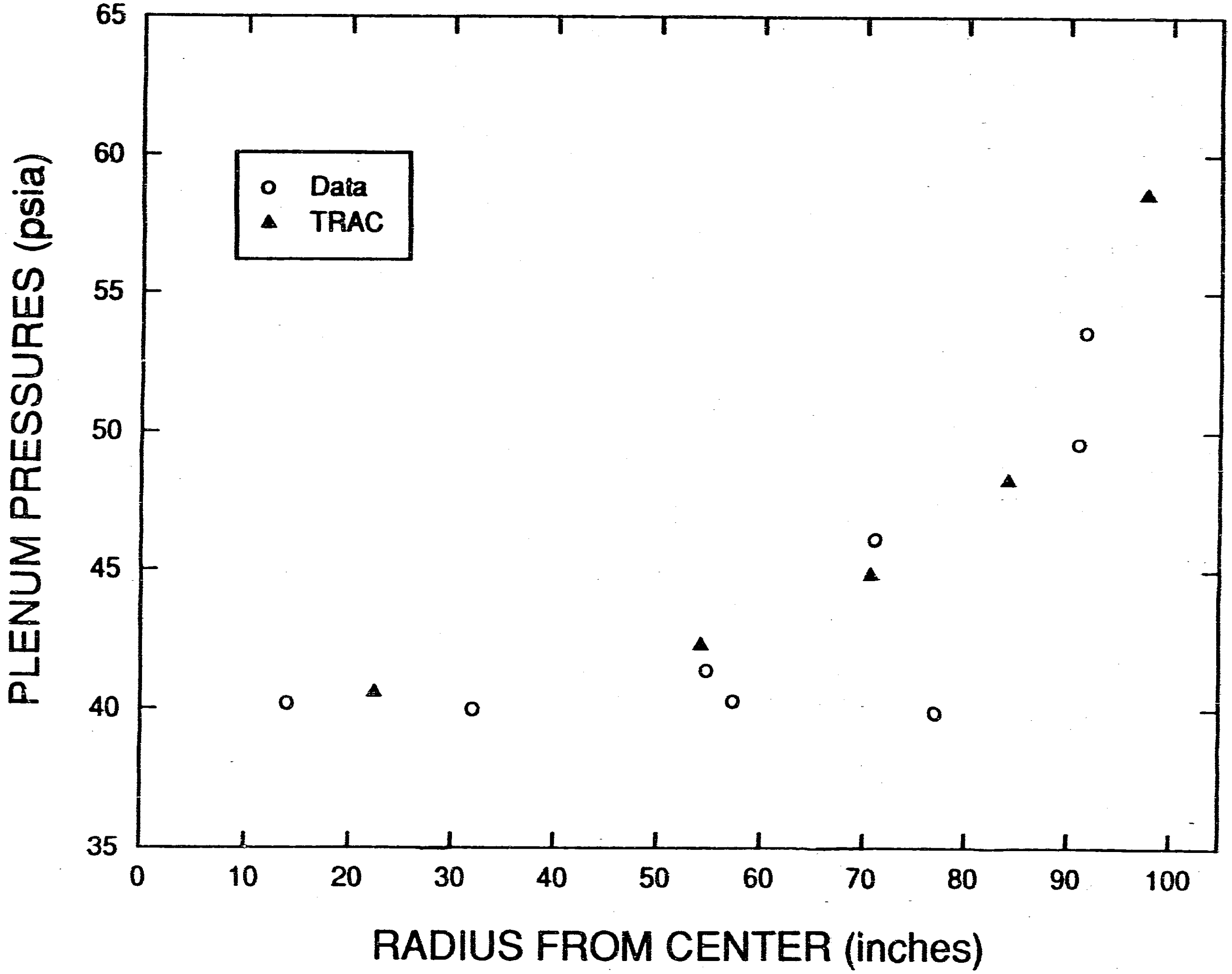


FIGURE 3.27 AC FLOW TEST K vs. TRAC
ADJACENT NON-FLOW SECTOR PRESSURES

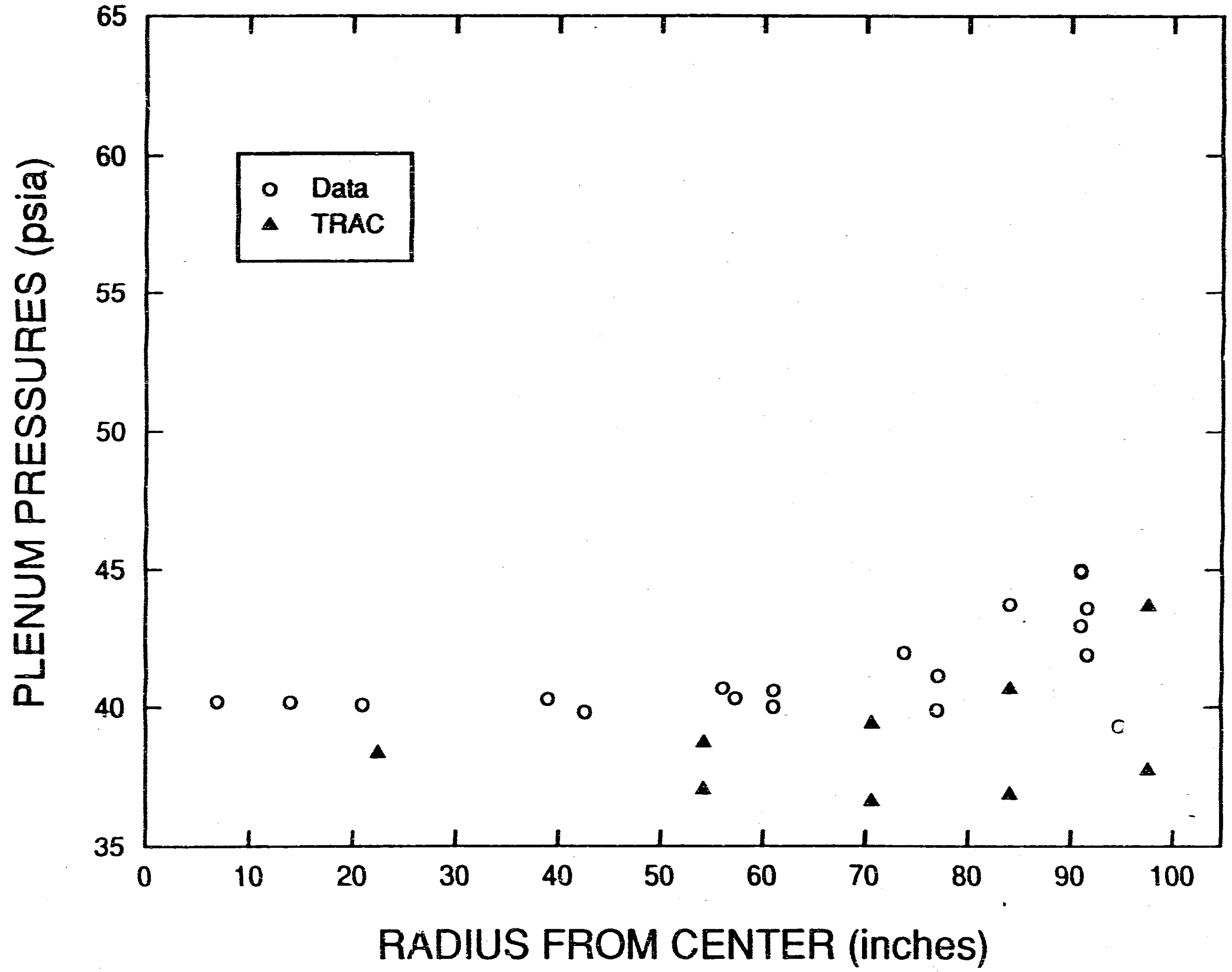


FIGURE 3.28 AC FLOW TEST K vs. TRAC
ISOLATED NON-FLOW SECTOR PRESSURES

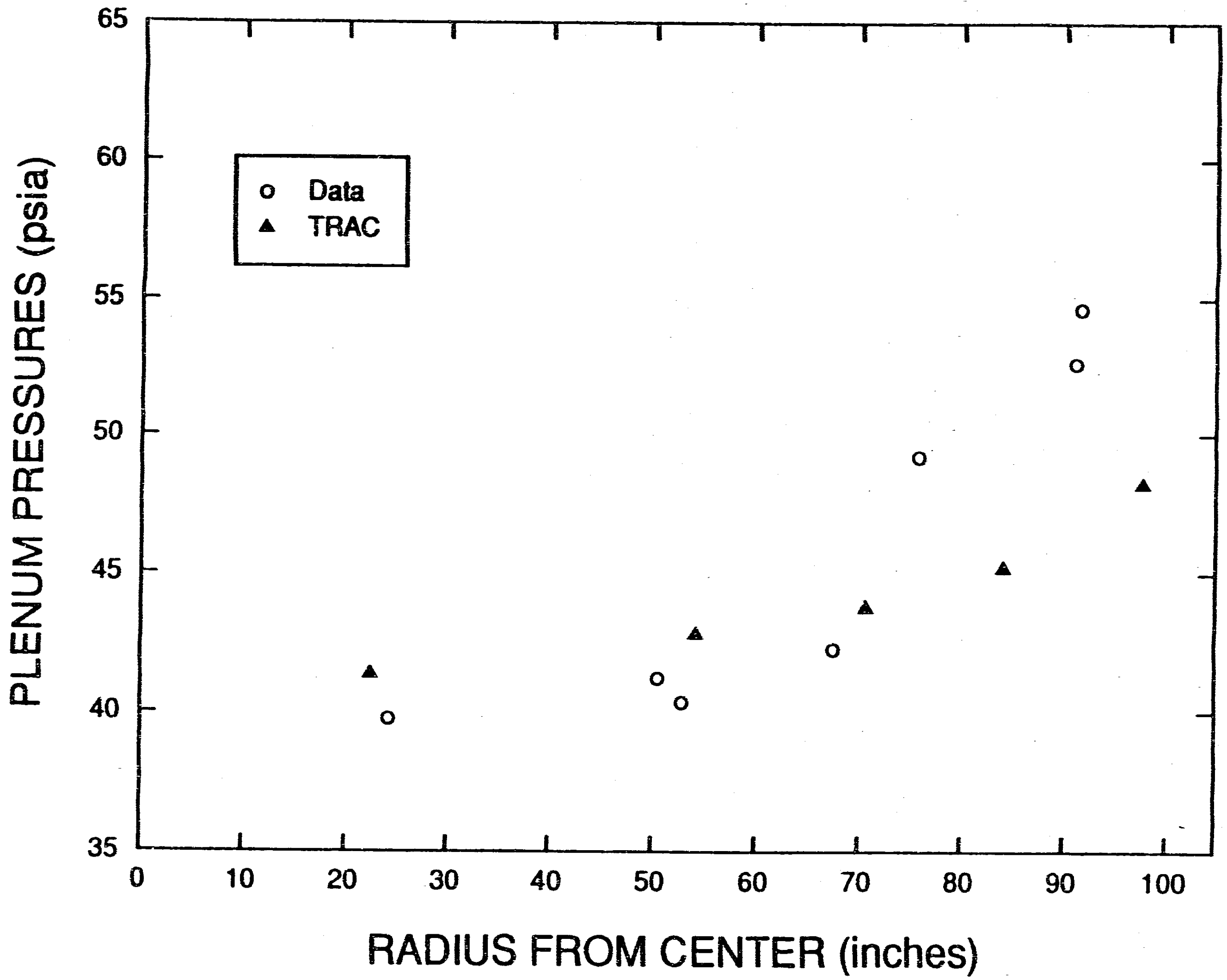


TABLE 2.1 COMPARISON OF RELAP5 AND TRAC LOOP PARAMETERS

LOCATION	LOOP	TOTAL LENGTH (M) RELAP5	TRAC	DIFFERENCE, %	TOTAL VOLUME (M^3) RELAP5	TRAC	DIFFERENCE, %
TANK OUTLET TO PUMP INLET	1	12.41	12.55	1.1	2.77	3.01	8.8
	2	12.92	13.05	1.0	2.90	3.15	8.8
	3	8.99	9.12	1.5	2.03	2.24	10.4
	4	12.41	12.55	1.1	2.77	3.01	9.0
	5	12.92	13.05	1.0	2.91	3.15	8.5
	6	8.99	9.12	1.5	2.03	2.24	10.4
PUMP INLET TO HEAT EXCHANGER INLET	1	21.89	23.76	8.6	3.87	3.83	-1.0
	2	22.78	24.45	7.3	3.97	3.91	-1.6
	3	21.76	23.94	8.2	3.85	3.80	-1.3
	4	21.89	23.76	8.6	3.87	3.83	-1.0
	5	22.78	24.45	7.3	3.97	3.91	-1.6
	6	21.76	23.54	8.2	3.85	3.80	-1.3
HEAT EXCHANGER INLET TO HEAT EXCHANGER OUTLET	1	10.23	10.21	-0.2	7.30	7.60	4.1
	2	10.23	10.21	-0.2	7.30	7.60	4.1
	3	10.23	10.21	-0.2	7.30	7.60	4.1
	4	10.23	10.21	-0.2	7.30	7.60	4.1
	5	10.23	10.21	-0.2	7.30	7.60	4.1
	6	10.23	10.21	-0.2	7.30	7.60	4.1
HEAT EXCHANGER OUTLET TO PLENUM	1	18.25	18.14	-0.6	2.28	2.24	-1.8
	2	18.25	18.14	-0.6	2.28	2.24	-1.8
	3	12.09	11.80	-2.4	1.58	1.52	-3.7
	4	18.25	18.41	0.8	2.28	2.27	-0.4
	5	18.25	18.41	0.8	2.28	2.27	-0.4
	6	12.09	11.80	-2.4	1.58	1.52	-3.7
ENTIRE LOOP	1	62.78	64.65	3.0	16.22	16.69	2.9
	2	64.18	65.85	2.6	16.45	16.90	2.8
	3	53.07	54.68	3.0	14.76	15.16	2.7
	4	62.78	64.92	3.4	16.22	16.72	3.1
	5	64.18	66.12	3.1	16.46	16.94	2.9
	6	53.07	54.68	3.0	14.76	15.16	2.7

TABLE 2.2 COMPARISON OF RELAP5 AND TRAC PLENUM AND MODERATOR TANK PARAMETERS

	TOTAL HEIGHT (m)		TOTAL VOLUME (m^3)		DIAMETER (m)	
	RELAP5	TRAC	RELAP5	TRAC	RELAP5	TRAC
PLENUM	0.222	0.273 (1)	2.60	3.81 (1)	5.28	5.32
TANK	4.67	4.67	64.08	72.50 (2)	4.95	5.32 (2)

NOTES:

(1) plenum height in original TRAC model was incorrect; corrected 0.222 m (8.75") for benchmarking; volume reduced to 3.10 m^3.

(2) moderator tank diameter incorrectly modeled as equal to plenum diameter; total volume reflects diameter error. With tank diameter corrected, total volume would be about 62.3 m^3.

TABLE 2.3 COMPARISON OF RELAP5 AND TRAC CORE PARAMETERS

	TOTAL LENGTH (m)		TOTAL VOLUME (m^3)		TOTAL AREA (m^2)	
	RELAP5	TRAC	RELAP5	TRAC	RELAP5	TRAC
INLET	1.86	1.45	6.85	6.01	3.69	4.13
FUEL	3.81	4.01	6.53	6.88	1.71	1.71
ENDFITTING	0.48	0.53	1.03	2.18	2.13	4.13
TOTAL	6.15	5.99	14.41	15.07	----	----

TABLE 3.1. 1985 AC PROCESS FLOW TEST CONFIGURATIONS

Test	Pumps on	Septifoil	Rotovalves open[1]	Temperature, °C
A	1 - 6	off	A only	22.01
B	1 - 6	off	A and B	25.10
C	1 - 6	on	A and B	22.46
D	1 - 5	off	A and B	22.35
E	2 - 6	off	A and B	22.28
F	1, 3, 5	off	A and B	22.89
G	1 - 6	off	A only	60.59
H	1 - 6	off	A and B	60.17
I	1 - 6	on	A and B	59.94
J	2 - 6	off	A and B	59.49
K	1, 3, 6	off	A and B	58.40

1. Each loop has two rotovalves, designated A and B. Tests with only one rotovalve open (A and G) were not analyzed.

TABLE 3.2 L REACTOR MODEL LOOP AND PLENUM K-FACTORS

a. LOOP K-FACTORS

LOOP NUMBER	1	2	3	4	5	6
BEND, PUMP DISCHARGE PIPE	0.1547	0.1266	0.0000	0.1617	0.1546	0.1330
HX INLET, INCLUDING RAM'S HORN	0.1691	0.1038	0.2318	0.4142	0.3534	0.1814
HX OUTLET, INCLUDING ROTOVALVES AND Y-CASTING	0.1691	0.1038	0.2318	0.4142	0.3534	0.1814
HX TO PLENUM NOZZLE PIPE: BEND 1 EXIT	0.1458	0.1767	0.0106	0.1874	0.2175	0.0496
BEND 2 ENTRANCE	0.1458	0.1767	0.0106	0.1874	0.2175	0.0496
BEND 2 EXIT	0.2000	0.2000	0.2000	0.2000	0.2000	0.2000
SEPTIFOIL SYSTEM (10 locations)	1.8000	1.8000	1.8000	1.8000	1.8000	1.8000

b. PLENUM K-FACTORS

RADIAL RING NUMBER	1	2	3	4	5
AZIMUTHAL (6 SECTORS)	0.9400	2.2693	2.5876	3.0808	0.0000
RADIAL (6 SECTORS)	1.7952	0.7436	0.4991	0.0000	0.0000

TABLE 3.3. A COMPARISON OF CALCULATED AND MEASURED PARAMETERS FOR AC PROCESS FLOW TEST I.

Parameter		Loop 1	Loop 2	Loop 3	Loop 4	Loop 5	Loop 6
Pressure (psia)							
Pump Suction							
	Data	21.95	21.91	21.67	22.28	22.44	21.90
	TRAC	21.56	21.49	21.51	21.94	21.89	21.58
	Δ%	-1.78	-1.92	-0.74	-1.53	-2.45	-1.46
Pump Discharge							
	Data	206.0	204.9	201.2	211.8	211.4	202.6
	TRAC	208.6	207.8	205.2	213.3	212.8	206.1
	Δ%	1.28	1.42	1.97	0.72	0.67	1.75
Heat Exchanger Inlet							
	Data	186.4	185.5	186.3	192.4	192.1	183.1
	TRAC	189.5	188.9	188.0	194.5	193.9	186.8
	Δ%	1.67	1.84	0.90	1.10	0.94	2.03
Heat Exchanger Discharge							
	Data	115.7	116.6	109.8	116.8	118.2	109.5
	TRAC	121.6	122.6	115.4	122.8	123.6	116.7
	Δ%	5.13	5.12	5.11	5.12	4.59	6.53
Loop Flow Rate (gpm)							
	Data	25919	26069	26547	25107	25203	26387
	TRAC	25612	25710	26141	24957	25018	26018
	Δ%	-1.18	-1.38	-1.53	-0.60	-0.73	-1.40

	Data	TRAC
Process Water Temperature (°C)	59.94	56.85
Gang 1 Tank Bottom Pressure (psia)	24.28	23.91

TABLE 3.4. A COMPARISON OF CALCULATED AND MEASURED PARAMETERS FOR AC PROCESS FLOW TEST H.

Parameter		Loop 1	Loop 2	Loop 3	Loop 4	Loop 5	Loop 6
Pressure (psia)							
Pump Suction							
	Data	22.26	22.23	22.07	22.59	22.78	22.24
	TRAC	21.95	21.88	21.87	22.33	22.28	21.95
	Δ%	-1.39	-1.57	-0.91	-1.15	-2.19	-1.30
Pump Discharge							
	Data	209.7	208.8	205.1	215.6	215.2	206.4
	TRAC	212.3	211.6	208.9	217.0	216.5	209.9
	Δ%	1.24	1.34	1.85	0.65	0.60	1.70
Heat Exchanger Inlet							
	Data	190.4	189.6	190.3	196.4	196.2	187.2
	TRAC	193.5	193.0	191.9	198.5	197.9	190.9
	Δ%	1.63	1.79	0.84	1.07	0.87	1.98
Heat Exchanger Discharge							
	Data	120.7	121.4	114.4	121.7	123.4	114.1
	TRAC	126.1	127.0	119.6	127.3	128.1	120.9
	Δ%	4.47	4.61	4.55	4.60	3.81	5.96
Loop Flow Rate (gpm)							
	Data	25426	25553	26061	24581	24670	25901
	TRAC	25111	25209	25676	24443	24499	25541
	Δ%	-1.24	-1.35	-1.48	-0.56	-0.69	-1.39

	Data	TRAC
Process Water Temperature (°C)	60.17	60.15
Gang 1 Tank Bottom Pressure (psia)	24.35	24.06

TABLE 3.5

COMPARISON OF MEASURED AND CALCULATED RING-AVERAGE PLENUM PRESSURES

PLENUM	TEST I				TEST H			
RING	DATA	TRAC	Δ,psi	Δ,%	DATA	TRAC	Δ,psi	Δ,%
1	85.84	86.22	.38	.44	89.60	89.39	-0.21	-0.23
2	87.12	87.10	-0.02	-0.02	90.99	90.31	-0.68	0.75
3	90.93	90.58	-0.35	-0.38	94.95	93.94	-1.01	-1.06
4	98.68	96.54	-2.14	-2.17	103.10	100.16	-2.94	-2.85
5	104.22	114.14	9.92	9.52	108.94	118.52	9.58	8.79

PLENUM	TEST C				TEST B			
RING	DATA	TRAC	Δ,psi	Δ,%	DATA	TRAC	Δ,psi	Δ,%
1	87.36	86.40	-0.96	-1.10	90.97	89.71	-1.26	-1.39
2	88.74	87.31	-1.43	-1.61	92.34	90.65	-1.69	-1.83
3	92.38	90.69	-2.14	-2.32	96.24	94.19	-2.05	-2.13
4	99.35	96.41	-2.94	-2.96	103.66	100.19	-3.47	-3.35
5	104.89	113.36	8.47	8.08	109.48	117.98	8.50	7.76

TABLE 3.6. A COMPARISON OF CALCULATED AND MEASURED PARAMETERS FOR AC PROCESS FLOW TEST B.

Parameter	Loop 1	Loop 2	Loop 3	Loop 4	Loop 5	Loop 6
Pressure (psia)						
Pump Suction						
Data	22.37	22.66	22.54	23.09	23.30	22.68
TRAC	22.11	22.04	22.05	22.46	22.41	22.12
Δ%	-1.16	-2.74	-2.17	-2.73	-3.82	-2.47
Pump Discharge						
Data	215.7	215.2	211.7	221.5	221.1	212.5
TRAC	218.6	217.9	215.5	222.9	222.5	216.4
Δ%	1.34	1.25	1.79	0.63	0.63	1.84
Heat Exchanger Inlet						
Data	196.4	196.1	196.6	202.4	202.2	193.6
TRAC	199.7	199.2	198.3	204.3	203.8	197.2
Δ%	1.68	1.58	0.86	0.94	0.79	1.86
Heat Exchanger Discharge						
Data	121.4	122.2	115.2	121.9	123.3	114.7
TRAC	125.8	126.7	119.4	126.9	127.8	120.7
Δ%	3.62	3.68	3.65	4.10	3.65	5.23
Loop Flow Rate (gpm)						
Data	24921	25040	25537	24116	24227	25411
TRAC	24498	24584	25039	23877	23929	24907
Δ%	-1.70	-1.82	-1.95	-0.99	-1.23	-1.98

	Data	TRAC
Process Water Temperature (°C)	25.10	25.15
Gang 1 Tank Bottom Pressure (psia)	24.39	24.13

TABLE 3.7. A COMPARISON OF CALCULATED AND MEASURED PARAMETERS FOR AC PROCESS FLOW TEST C.

Parameter		Loop 1	Loop 2	Loop 3	Loop 4	Loop 5	Loop 6
Pressure (psia)							
Pump Suction							
	Data	22.28	22.25	22.25	22.66	22.82	22.35
	TRAC	21.67	21.60	21.63	22.03	21.98	21.70
	Δ%	-2.74	-2.92	-2.79	-2.78	-3.68	-2.91
Pump Discharge							
	Data	212.9	212.3	209.6	218.9	218.5	209.8
	TRAC	215.6	214.9	212.6	219.9	219.4	213.4
	Δ%	1.27	1.22	1.43	0.46	0.41	1.72
Heat Exchanger Inlet							
	Data	193.3	192.8	194.4	199.5	199.2	190.6
	TRAC	196.4	195.8	195.2	200.9	200.4	194.0
	Δ%	1.60	1.56	0.41	0.70	0.60	1.78
Heat Exchanger Discharge							
	Data	116.6	117.7	110.4	117.3	118.3	110.3
	TRAC	121.2	122.0	115.1	122.2	123.1	116.3
	Δ%	3.95	3.65	4.26	4.18	4.06	5.44
Loop Flow Rate (gpm)							
	Data	25362	25445	25831	24518	24602	25817
	TRAC	24908	24917	25428	24305	24358	25311
	Δ%	-1.79	-2.08	-1.56	-0.87	-0.99	-1.96

	Data	TRAC
Process Water Temperature (°C)	22.46	22.45
Gang 1 Tank Bottom Pressure (psia)	24.23	23.92

TABLE 3.8. A COMPARISON OF CALCULATED AND MEASURED PARAMETERS FOR AC PROCESS FLOW TEST D.

Parameter	Loop 1	Loop 2	Loop 3	Loop 4	Loop 5	Loop 6*
Pressure (psia)						
Pump Suction						
Data	20.99	21.42	21.21	21.93	22.18	30.40
TRAC	20.69	20.83	20.91	21.28	21.02	30.78
Δ%	-1.43	-2.75	-1.41	-2.96	-5.23	0.04
Pump Discharge						
Data	202.2	202.4	199.2	209.6	208.8	62.2
TRAC	202.8	204.6	202.4	210.3	207.2	58.0
Δ%	0.30	1.09	1.61	0.33	-0.77	-6.75
Heat Exchanger Inlet						
Data	181.6	182.1	183.7	189.4	188.6	53.4
TRAC	182.4	184.7	184.3	190.5	187.1	48.3
Δ%	0.44	1.43	0.33	0.58	-0.80	-9.55
Heat Exchanger Discharge						
Data	93.5	96.7	89.2	96.1	96.4	77.0
TRAC	95.1	101.1	94.0	100.8	97.0	68.7
Δ%	1.71	4.55	5.38	4.89	0.61	-10,78
Loop Flow Rate (gpm)						
Data	26639	26670	27061	25740	25900	-12185
TRAC	26587	26341	26729	25649	26024	-10932
Δ%	-0.20	-1.23	-1.23	-0.35	0.48	-10.28

	Data	TRAC
Process Water Temperature (°C)	22.35	22.35
Gang 1 Tank Bottom Pressure (psia)	24.10	24.00

* backflow loop

TABLE 3.9. A COMPARISON OF CALCULATED AND MEASURED PARAMETERS FOR AC PROCESS FLOW TEST E.

Parameter		Loop 1*	Loop 2	Loop 3	Loop 4	Loop 5	Loop 6
Pressure (psia)							
Pump Suction							
	Data	30.38	21.36	21.21	21.91	22.16	21.39
	TRAC	30.75	20.55	20.66	21.29	21.17	20.68
	Δ%	1.22	-3.79	-2.59	-2.83	-4.47	-3.32
Pump Discharge							
	Data	62.0	202.3	199.2	210.0	209.3	197.9
	TRAC	57.2	202.0	201.8	211.1	209.8	200.3
	Δ%	-7.74	-0.15	1.31	0.52	0.24	1.21
Heat Exchanger Inlet							
	Data	54.0	181.9	183.6	189.8	189.1	177.5
	TRAC	47.9	181.9	183.8	191.4	189.9	179.7
	Δ%	-11.30	0.00	0.11	0.84	0.42	1.24
Heat Exchanger Discharge							
	Data	77.9	96.4	89.3	96.9	97.5	85.1
	TRAC	67.9	96.3	93.1	102.4	102.3	89.6
	Δ%	-12.84	-0.10	4.26	5.68	4.92	5.29
Loop Flow Rate (gpm)							
	Data	-11950	26668	27054	25687	25819	27244
	TRAC	-10833	26667	26784	25535	25692	26975
	Δ%	-9.35	~0.0	-1.00	-0.59	-0.49	-0.99

	Data	TRAC
Process Water Temperature (°C)	22.28	22.25
Gang 1 Tank Bottom Pressure (psia)	24.07	23.94

* backflow loop

TABLE 3.10. A COMPARISON OF CALCULATED AND MEASURED PARAMETERS FOR AC PROCESS FLOW TEST J.

Parameter		Loop 1*	Loop 2	Loop 3	Loop 4	Loop 5	Loop 6
Pressure (psia)							
Pump Suction							
	Data	30.21	21.18	20.74	21.58	21.72	20.84
	TRAC	30.76	20.51	20.76	21.28	21.18	20.63
	Δ%	1.82	-3.16	0.10	-1.39	-2.49	-1.01
Pump Discharge							
	Data	67.6	195.3	191.4	202.9	201.9	190.1
	TRAC	58.6	194.0	193.7	204.0	202.7	192.0
	Δ%	-13.31	-0.67	1.20	0.54	0.40	1.00
Heat Exchanger Inlet							
	Data	59.4	174.7	175.8	182.4	181.5	169.4
	TRAC	49.4	174.0	175.9	184.3	182.9	171.6
	Δ%	-16.84	-0.40	0.06	1.04	0.77	1.30
Heat Exchanger Discharge							
	Data	78.9	96.8	89.1	97.2	97.9	84.9
	TRAC	67.5	96.5	93.2	102.8	102.6	89.6
	Δ%	-14.45	-0.31	4.60	5.76	4.80	5.54
Loop Flow Rate (gpm)							
	Data	-12060	27260	27699	26302	26456	27872
	TRAC	-11178	27429	27546	26224	26365	27740
	Δ%	-7.31	0.62	-0.55	-0.30	-0.34	-0.47

	Data	TRAC
Process Water Temperature (°C)	59.49	59.45
Gang 1 Tank Bottom Pressure (psia)	24.17	24.02

* backflow loop

TABLE 3.11. A COMPARISON OF CALCULATED AND MEASURED PARAMETERS FOR AC PROCESS FLOW TEST F.

Parameter	Loop 1	Loop 2*	Loop 3	Loop 4*	Loop 5	Loop 6*
Pressure (psia)						
Pump Suction						
Data	19.71	29.49	19.57	29.52	20.84	29.49
TRAC	19.46	29.39	19.44	29.39	19.83	29.39
Δ%	-1.27	-0.34	-0.66	-0.44	-4.85	-0.34
Pump Discharge						
Data	183.9	29.0	178.6	29.1	189.9	28.9
TRAC	185.6	29.4	181.2	29.5	190.9	29.8
Δ%	0.92	1.38	1.46	1.37	0.53	3.11
Heat Exchanger Inlet						
Data	161.5	18.3	162.0	18.3	167.8	18.3
TRAC	163.9	18.5	162.1	18.5	169.3	18.5
Δ%	1.49	1.09	0.06	1.09	0.89	1.09
Heat Exchanger Discharge						
Data	59.4	60.4	51.4	60.7	58.8	58.5
TRAC	64.6	50.3	56.7	50.2	66.6	49.9
Δ%	8.75	-16.72	10.31	-17.30	13.27	-14.70
Loop Flow Rate (gpm)						
Data	28728	0	29308	0	28159	0
TRAC	28552	0	29084	0	27962	0
Δ%	-0.61	0	-0.76	0	-0.70	0

	Data	TRAC
Process Water Temperature (°C)	22.89	22.85
Gang 1 Tank Bottom Pressure (psia)	23.97	23.96

* non-flow loop

TABLE 3.12. A COMPARISON OF CALCULATED AND MEASURED PARAMETERS FOR AC PROCESS FLOW TEST K.

Parameter	Loop 1	Loop 2*	Loop 3	Loop 4*	Loop 5*	Loop 6
Pressure (psia)						
Pump Suction						
Data	19.85	29.38	19.56	29.39	29.34	19.79
TRAC	19.70	29.40	19.42	29.41	29.41	19.66
Δ%	-0.76	0.07	-0.72	0.07	0.24	-0.66
Pump Discharge						
Data	180.9	28.9	169.1	29.1	28.9	175.5
TRAC	181.4	29.4	172.9	29.5	29.4	176.8
Δ%	0.28	1.73	2.25	1.37	1.73	0.74
Heat Exchanger Inlet						
Data	158.9	18.5	152.6	18.4	18.5	153.9
TRAC	160.1	18.6	154.0	18.6	18.6	155.2
Δ%	0.76	0.54	0.92	1.09	0.54	0.84
Heat Exchanger Discharge						
Data	69.7	62.3	51.4	55.8	58.5	60.9
TRAC	72.0	54.5	57.7	49.9	44.0	63.6
Δ%	3.30	-12.52	12.26	-10.57	-24.79	4.43
Loop Flow Rate (gpm)						
Data	28850	0	30120	0	0	29453
TRAC	28854	0	29804	0	0	29398
Δ%	0.01	0	-1.05	0	0	-0.19

	Data	TRAC
Process Water Temperature (°C)	58.40	58.45
Gang 1 Tank Bottom Pressure (psia)	24.03	24.03

* non-flow loop

6. Appendix

Discussion of TRAC Overprediction of Plenum Edge Cell Pressures

The TRAC benchmark results presented in the body of this report consistently show an overprediction of the pressures in the outer ring of the plenum for forward flow sectors. Part of this discrepancy appears to be attributable to the high values of the calculated heat exchanger outlet pressures. This component of the problem may be correctable by adjustments to system loss coefficients. However, the magnitude of the plenum pressure errors cannot be explained solely by the heat exchanger discharge pressures.

Another potential source of error may be found in conflicts between certain limitations of TRAC-PF1/MOD1 and the nodalization of the model. As mentioned in Section 4.1, the modeling of the inlet nozzles and plenum edge cells, while faithful to the reactor geometry, may induce TRAC to produce some erroneous results. There are two potential problems in this regard. First, the flow areas of the PIPE components representing the plenum inlet nozzles are approximately twice those of the inner faces of the ring 5 VESSEL component cells representing the plenum edge. It is at these inner faces that the momentum from the nozzles enters the plenum. According to Ref. [19], these momentum sources are based on the simple velocity difference between the one-dimensional PIPE components and the three dimensional VESSEL cells. This introduces a limitation in TRAC that our model may violate. The TRAC User's Guide [17] states that, in applying this momentum source term "... no correction for relative mass flux is made, even in the liquid equation. As a result, artificially high momentum fluxes can occur from the 1D to the 3D ..." The TRAC User's Guide also states that user's "...are cautioned against connecting to the VESSEL any component (usually a PIPE or TEE) with a connecting flow area that is greater than the flow area of the mesh-cell face to which it is connected because erroneous pressure gradients may result. The area of the connecting component should never exceed the available mesh-cell face area."

The second potential modeling problem involves the nozzles and TRAC's handling of sudden expansions. The actual geometry of the nozzles provides a gradual increase in flow area as liquid flows toward the plenum. The L Reactor model nodalization provides 12 one-dimensional cells, most of which represent expansions in area for forward flow. Though most of the area changes are small, they occur for almost every cell. The TRAC User's Guide states that the numerical formulation gives the correct pressure drop for an abrupt expansion, but not until the second cell downstream of the area change. Accordingly, it recommends that "To avoid unexpected results, the code user should space abrupt area changes at least two cells apart."

It is not known whether either of these TRAC-PF1/MOD1 limitations contribute to the disagreement in calculated and measured plenum edge pressures. At some point, it may be worthwhile to do some sensitivity analysis to assess the impact. However, the problem with ring 5 pressures does not preclude very good agreement with the pressure distribution in a backflow sector. There is also some uncertainty about the interpretation of the data, given: 1. where the measurements were made, 2. the open geometry of the edge cells, 3. the complex flow pattern near the nozzles, and 4. the absence of pressure measurements in or near the nozzles. Hence, further investigations into the problem of high calculated pressures in the outer ring do not appear to be necessary at this time. Additional insight into these questions will be available from future benchmarks against the 1989 L Reactor data.

END

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