Pump Two-Phase Performance Program
Volume 2: Steady-State Tests

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EPRI PERSPECTIVE

PROJECT DESCRIPTION

This final report under RP301 documents the findings of an experimental research effort to develop a data base on reactor coolant pump single- and two-phase performance behavior. Tests were performed on a geometrically scaled model of an actual reactor coolant pump. Both steady-state and transient blowdown tests were performed over sufficiently large ranges of thermal-hydraulic operating conditions and typical pump performance parameters to cover calculated hypothetical loss-of-coolant accident (LOCA) conditions.

PROJECT OBJECTIVES

Current analytic pump models used in LOCA analyses are based on a limited amount of experimental data. The goals of this project were (1) to establish a sufficiently large data base of steady-state and transient pump performance data to substantiate, and ultimately improve, analytic pump models currently used for reactor coolant pump LOCA analysis; and (2) to obtain data on pump characteristics under two-phase transient blowdown conditions to aid the evaluation of reactor coolant pump overspeed.

PROJECT RESULTS

The pump data base collected in this project is considered sufficiently large and diverse to cover a significant range of pump performance of primary importance to LOCA analysis. Initial evaluation of the test results indicates that pump rated head and torque degrade significantly under two-phase flow conditions. Pump free-wheeling speed (pump motor power off) is closely coupled to the volumetric flow rate through the pump during a blowdown transient. The maximum free-wheeling speed observed was near twice the rated speed for a discharge break equal to the flow area of the pump. For smaller size discharge breaks, the peak speed observed was less than twice the rated speed. With electric power to the pump drive motor on throughout the blowdown, however, the pump speed was maintained at an almost constant value.

Additional reduction and analysis of this data base is required before it can be used to support the development of an improved analytic model for pump two-phase performance.

This final report consists of eight volumes, as presented in the table of contents in the first volume. Volumes 1, 2, 3, 4, and 7 present the results and conclusions, as well as substantial discussion and description, of the entire project and the test data. Volumes 5 and 6 present the tabulated test data in computer printout and graphic format, which will be useful for further analyses. Volume 8 contains a description of the data processing methods. Volumes 2 through 8 are available from the Research Reports Center* upon request.

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ABSTRACT

The primary objective of the C-E/EPRI Pump Two-Phase Performance Program was to obtain sufficient steady-state and transient two-phase empirical data to substantiate and ultimately improve the reactor coolant pump analytical model currently used for LOCA analysis. A one-fifth scale pump, which geometrically models a reactor coolant pump, was tested in steady-state runs with single- and two-phase mixtures of water and steam over ranges of operating conditions representative of postulated loss-of-coolant accidents. Transient tests were also run to evaluate the applicability of the steady-state-based calculational models to transient conditions.

This project has produced test data which can appropriately be utilized for reactor coolant pump modeling in LOCA analyses. The steady-state test data show general coherence of the test results and overall pump performance trends for a model pump that should be representative of a reactor coolant pump to the extent that scaling laws apply. Both head and torque data correlate well in the form of homologous curves. Two-phase head degradation curves are approximately comparable to head degradation curves obtained in other test programs. Two-phase torque degradation curves have also been developed. The collected data should be useful for analytical model development.

Volume II: Steady-State Tests

CONTENTS

CONTENTS (Cont'd.)

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd.)

TABLES

Section 1

INTRODUCTION

The model pump test facility was constructed at the Kreisinger Development Laboratories at Combustion Engineering, Inc., Windsor, Connecticut during 1974 and 1975. The scale model pump and the test system (Figure 1-1) are described in detail in Volume VII-Test Facility Description.

The scale model pump steady-state performance tests in single- and two-phase steam-water flow were carried out to gain knowledge on how a pump, designed for single-phase operation in water, would perform in a two-phase medium. The motivation for this investigation is the postulated occurrence of a hypothetical loss-of-coolant accident (LOCA) in a nuclear reactor, which would cause the normally subcooled water passing through the pump to become saturated and subsequently two-phase.

Approximately 1000 steady-state tests were performed. Each test provided about 200 measured and derived parameters. The different conditions for which the scale model pump was tested under steady-state conditions included variations in several parameters. Measurements were made after establishing steady-state operation at desired combinations of fluid pressure level, void fraction, volumetric flow rate, and impeller speed. These pump performance tests covered forward, zero, and reverse flows and speeds in various combinations. Fluid conditions upstream of the pump were set to provide a variety of single-phase steam or water and two-phase mixtures of steam and water, ranging from all water to all steam. Also, fluid pressure was set at several different values.

Special-purpose steady-state tests included instrument zero checks and preblowdown cross-comparison calibration runs of certain instruments, such as turbine meters vs steam and water orifices. Additional pump performance data was derivable from some of these calibration runs. Supplementary tests were performed to determine the internal friction and windage torque characteristics of the model pump.

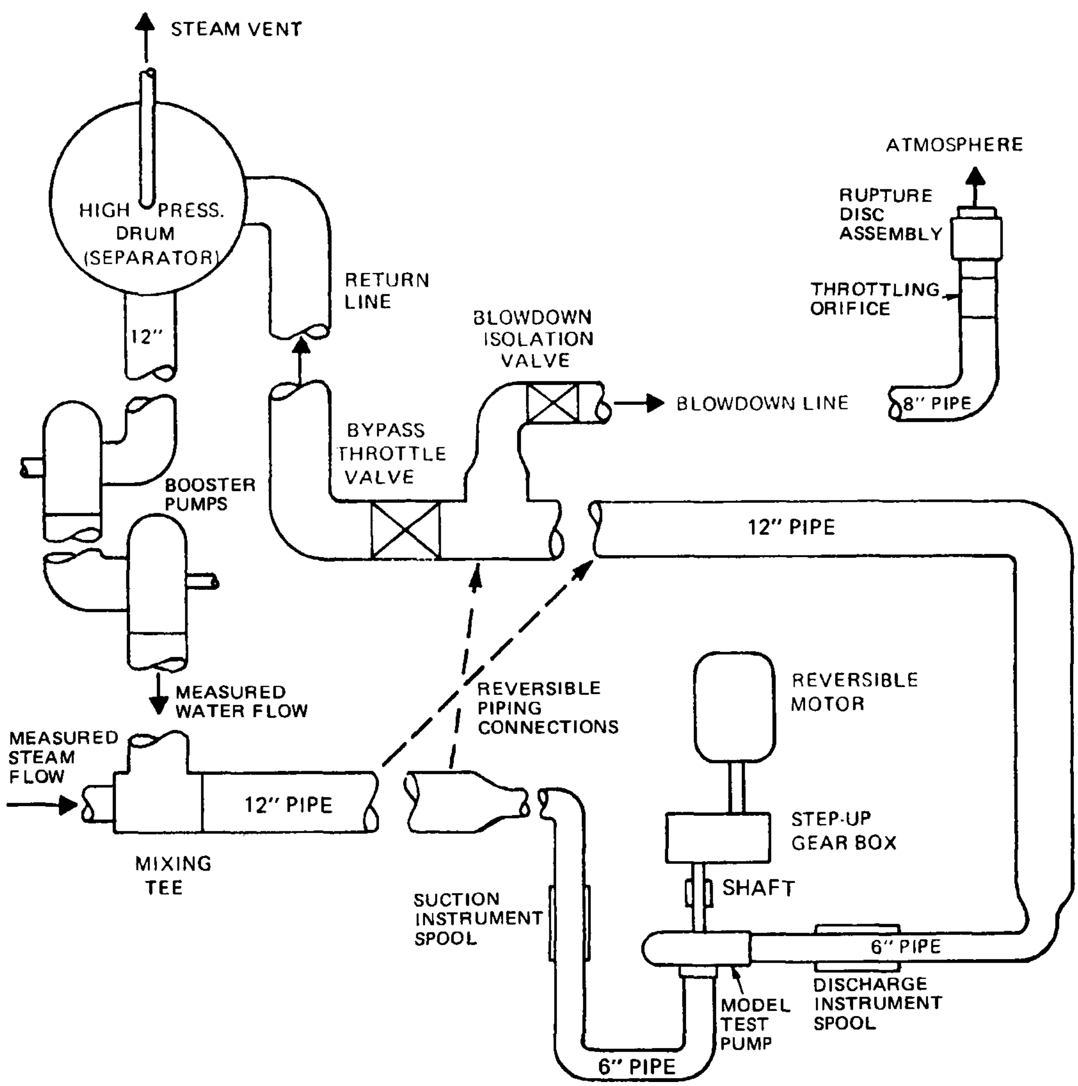


Figure 1-1. Basic elements of test system

The following sections in this volume describe the steady-state test parameters, tests performed, a summary of the results, and the associated data evaluation performed under this project. The complete set of steady-state data are presented separately in Volume V - Steady-State Data.

Section 2

TEST PROCEDURES

2.1 SYSTEMS CONFIGURATIONS AND OPERATING MODES

Single phase water and steam tests were performed to determine pump performance and to provide in situ calibration data for certain instruments. Two-phase flow tests were done to obtain pump flow characteristics under various conditions of void fraction, volumetric flow rate, pressure, pump speed, direction of pump rotation, and direction of flow.

Towards the end of preparing the test system for operation, the system was checked out and debugged in a series of shakedown tests. The system was operated first with a pipe section in place of the model pump and then with the pump installed. As the equipment and operating techniques were proven out, the pump performance tests were started.

In order to obtain the required characteristics called for during a specific test sequence, it was necessary to configure the system to provide those characteristics. Changing the direction of fluid flow through the test pump involved the most significant system modifications. Either forward or reverse flow through the test pump could be selected by suitable piping changes. For the forward flow configuration, the booster pump discharge was piped to the suction of the test pump. To achieve reverse flow, the booster pump discharge was piped to the test pump discharge. Once a fluid flow direction was selected, a range of other operating conditions could be achieved by changing system valve alignments and test pump motor controls. Startup of the system was always done in the single phase water mode after which single phase steam or two-phase testing could be established.

In the single-phase water configuration, water was circulated through the loop by the booster and/or the test pumps. Steam was admitted to the high pressure drum to produce the temperatures and pressures required for the test point.

Single-phase steam testing was achieved by directing the steam to the mixing tee. Water flow from the booster pumps was then diverted through a bypass back to the drum allowing only steam to flow from the mixing tee through the test pump.

Two-phase flow was obtained by directing the steam flow to the mixing tee and allowing water flow from the booster pumps to mix with the steam at the mixing tee. The resulting saturated water and steam mixture then passed through the test pump. Volume ratios of steam to water were adjusted by the operator. Steam flow was controlled by boiler firing rate and water flow was controlled by throttling the main or bypass water valves upstream of the mixing tee.

Test pump speed and direction of rotation for a specific test point were achieved by manipulation of the test pump motor controls by the operator. Figure 2-1 displays the different combinations of pump mode and flow direction which were tested.

A detailed description of the steady-state operating configurations and testing modes can be found in Volume VII - Test Facility Description. Details of nominal and actual operating conditions, tests procedures, and measurements are given in the following sections and also in Volume VII.

2.2 INSTRUMENTATION AND DATA RECORDING SYSTEMS

Two categories of instrumentation were utilized during the test phases. They are defined as loop instrumentation and test instrumentation. Loop instruments were those instruments required by the operator to run the test loop to attain the specified test point conditions safely and efficiently. Test instruments were those instruments necessary to measure and record the parameters required for analysis of the test pump performance at the specified test point conditions. In some instances both these functions were performed by the same device, however, in general, separate instruments were utilized. A pictorial display of the test instrumentation provided in the test loop is shown in Figure 2-2. A comprehensive list and detailed description of loop and test instrumentation can be found in Section 4 of Volume VII - Test Facility Description.

The data acquisition system used for steady-state testing consisted of transducers, signal conditioners and a recording device. During steady-state testing,

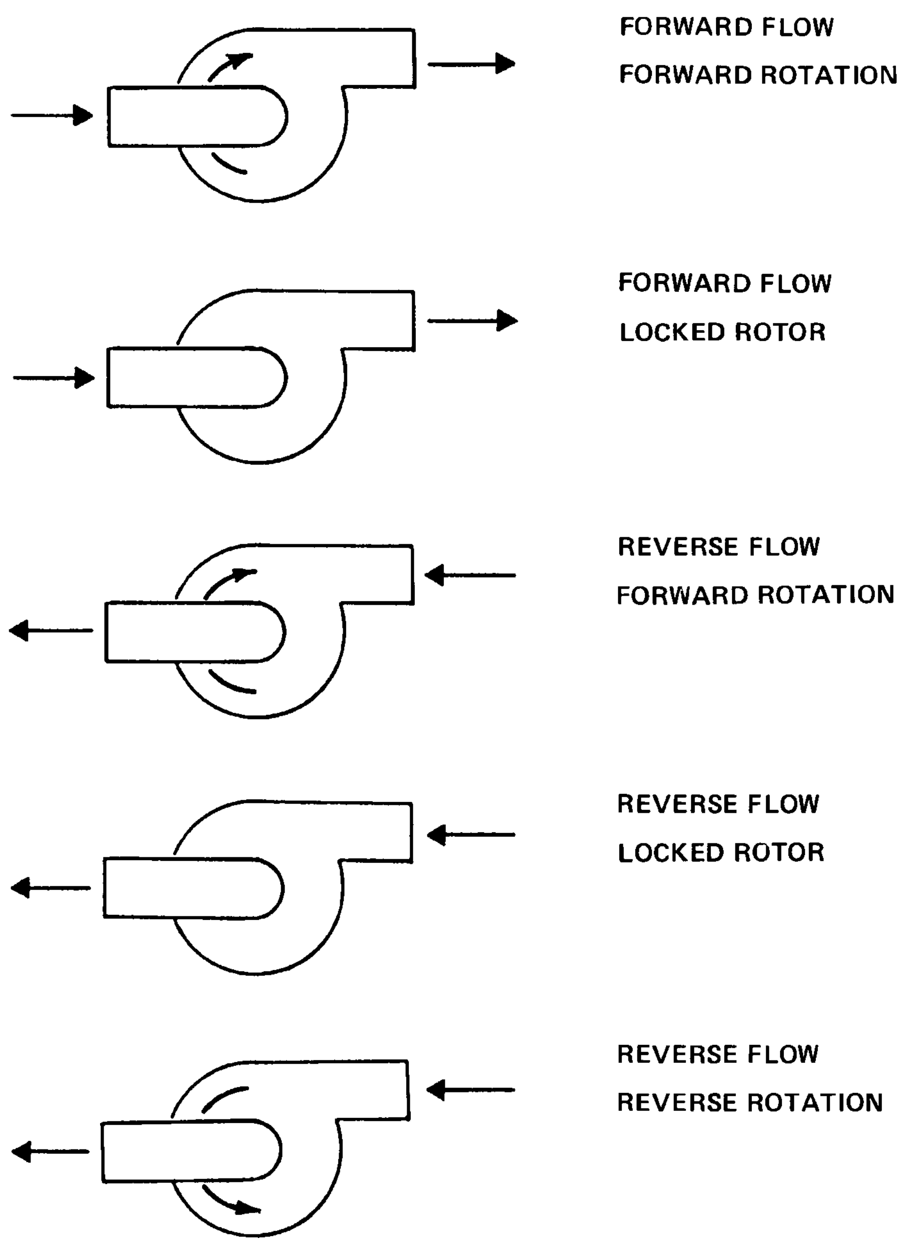


Figure 2-1. Steady-state pump test modes

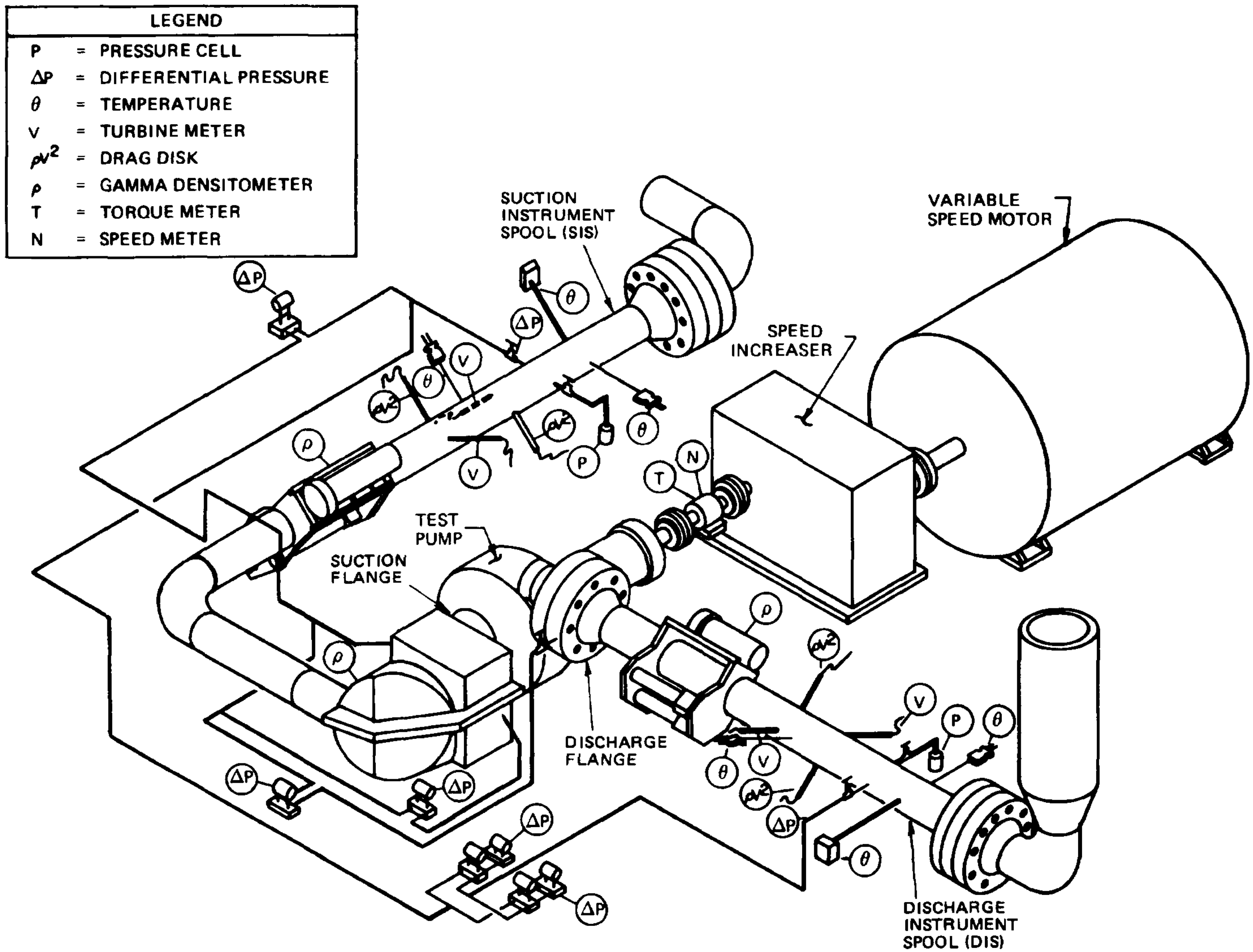


Figure 2-2. Isometric of test system and mainstream instrumentation for test pump

the specific parameters sought were held reasonably constant during the recording of the data and, therefore, a relatively slow data scanner was utilized. Signals from the test instrumentation transducers were received, after conditioning, by the scanner and recorded on magnetic tape. Five consecutive scans of all test instruments were taken at each test point condition. The data recorded was then transferred to a punched paper tape. The punched tape was read into the main computer on site where it was reduced and permanently stored. A detailed description of the steady-state data acquisition system is given in Section 4 of Volume VII - Test Facility Description.

2.3 TEST PROCEDURES DESCRIPTIONS

2.3.1 Pump Performance Point Procedures

Three basic types of steady-state tests were performed. These were single phase points (steam or water), two-phase points (steam and water) and special purpose points (e.g., friction and windage).

Loop operating procedures necessary to obtain these test points varied to some degree. The following brief description of the various operational procedures is provided here so that the reader may understand the basic concepts involved. Detailed descriptions of the test loop configurations and operating modes, as well as system schematics can be found in Volume VII - Test Facility Description.

2.3.1.1 Single-Phase Points - Water or Steam. A single phase test point is one in which the fluid passing through the test pump is either all water or all steam. The single phase water point was achieved by the following steps; (1) configuring the loop for forward or reverse flow, (2) filling the test loop with deaerated water, (3) raising the pressure and temperature of the loop water to the specified test point conditions, (4) obtaining specified flow and test pump speed and (5) recording data. The loop water was heated in the high pressure drum with steam supplied by the test boiler. Saturated water conditions from 0 to 1200 psig were maintained by throttling the high pressure drum vent valve. Water was circulated around the loop by the booster pumps. The booster pumps also supplied additional head required to achieve test matrix conditions. Loop flow rates were controlled by throttling a valve in the test pump discharge line to ensure that the fluid in the pump was maintained slightly subcooled. Pump speed and direction of rotation were determined by setting the motor controls. When the conditions specified had been reached and stability achieved, data was recorded on the data scanner and on FM tape.

To obtain single phase steam points, the same procedure with some additional steps was utilized. The pressure and temperature of the specified test point were obtained in a single phase water mode. At this time the steam flowing to the high pressure drum was diverted to the mixing tee upstream of the test pump. Boiler firing rate was then adjusted to produce sufficient steam to obtain the desired steam flow through the test pump. Meanwhile, the water flowing from the booster pumps was diverted from the test loop back to the high pressure drum through a bypass line. Therefore, loop water circulated from the drum to the booster pumps and back to the drum. Steam entered the mixing tee, passed through the test pump and flowed back to the drum where it was used to maintain loop water at saturated conditions. Once all the desired conditions for a test point was reached and stabilized, data were recorded.

When single phase steam testing was complete the system was returned to a single phase water mode by reversing the steps above.

2.3.1.2 <u>Two-Phase Points</u>. A two-phase test point is one in which a mixture of steam and water passes through the test pump. To obtain this condition, the loop water had to be saturated at the specified test point pressure. The loop water was first brought to saturated conditions with the loop in a single-phase water mode. Once there, steam was diverted from the high pressure drum to the mixing tee upstream of the test pump. The volume of steam supplied to the mixing tee was predominantly controlled by adjusting the boiler firing rate. The saturated loop water was also supplied to the mixing tee via the booster pumps. Water flow was controlled with the main or bypass water flow control valves. The operator regulated the steam/water volume ratio or void fraction until the specified test conditions were reached. Test pump speed, direction of rotation, and flow direction were all set prior to attaining the void fraction desired. The steam and water mixture, after passing through the test pump, returned to the drum where excess steam was vented and loop water was reheated to maintain saturated conditions.

With the test point conditions satisfied and all parameters stable, data were recorded. After the data were checked, the operator could proceed to adjust the system in order to attain the conditions specified for the following test point in the test point sequence.

Adjustment of steam and water flow to obtain specific void fractions was an iterative process which was difficult and time consuming. To aid the operator in this task, a computer program called SETACT was developed. This program allowed the operator to home in on the proper steam and water flows and achieve the void fractions desired in a timely manner. A more detailed description of the SETACT program and its use during two-phase flow testing is given in Section 5 of Volume VII - Test Facility Description.

2.3.2 Calibration Files

Calibration Files contain instrument zeros and calibration constants for each instrument used during the testing program. Calibration constants were generated for each instrument by the calibration procedures outlined in Volume VIII - Data Processing Methods. Most of these procedures were performed during scheduled loop outages provided specifically for this purpose. However some instruments did require in situ calibrations. These instruments were drag discs, turbine meters, and gamma densitometers. In addition, it was necessary to perform zero checks of the pressure and differential pressure cells on a regular basis. Each in situ calibration and each zero check required a special loop operation procedure and generated a unique test point. These special operating procedures are briefly discussed in the following paragraphs and in more detail in Volume VII - Test Facility Description.

2.3.2.1 Pressure and Differential Pressure Cell Zeros. Pressure and differential cell zeros were taken as often as practicable during steady-state test phases. They were taken during startup with the loop cold (170°F) and again with the loop at 850 psia, saturated condition. Pressure cells were zeroed by isolating them from the loop and venting the cells to atmosphere. Differential pressure cells were zeroed by isolating them from the loop and cross connecting both sides of the cell to eliminate any differential pressure across the membrane. Once the cells were in the zero condition, five data scans were recorded. The zero data was then reduced with the Instrument Calibration Constant Update Program (ICCUP).

2.3.2.2 Gamma-Densitometer Calibration. Air, steam, and water points were utilized to determine the calibration constants for the gamma densitometers. These points were obtained during the test phases whenever the particular system configuration permitted.

For transient tests air, cold water, hot water (850 psia, saturated), and steam points were generally obtained during the steady-state preparatory stages to a blowdown. Prior to each blowdown, a gamma densitometer air point was taken before filling the loop while the test piping was still dry. Once the loop was filled with cold water (170°F) a cold water point was taken. During the pre-blowdown sequence with the system at 850 psig, a hot water point was taken. Steam points were obtained at the very end of the transient after all water had been discharged through the blowdown nozzle and only steam was left in the piping. Each of these gamma densitometer points consisted of five data scans with the gamma densitometers in their normal operating mode, and five data scans with low calibration shims in. Data points obtained in this manner were then reduced with ICCUP to obtain the latest calibration constants (see Volume (VIII). Initial experience with the gamma-densitometers revealed a definite drift in output with time. To minimize the effects of this drift on the transient test results, these air, water, and steam calibrations were conducted as close in time to the actual blowdown as possible.

To minimize the effects of this drift on the steady-state data, hot water water (850 psia) calibration points were also taken on a daily basis to obtain updated gamma densitometer calibration constants.

2.3.2.3 Drag Disc Calibration For drag disc calibrations, the loop was set up for single phase water operation at 850 psia saturated condition. Flow was varied by manipulating the loop flow control valve located downstream of the drag discs. When a specified flow rate was obtained five data scans were recorded with the data scanner. This process was repeated for different flow rates until sufficient data were obtained to accurately determine the relation between momentum flux and drag disc output. Because the drag discs showed significant temperature sensitivity they were also calibrated for this parameter. This calibration was performed in water by conducting a loop heat-up in steps. At each specified temperature the flow was completely stopped and five data scans recorded. From the data obtained, a temperature sensitivity coefficient was deduced for each drag disc.

2.3.2.4 Turbine Meter Calibration. Turbine meters were calibrated with the loop in a single-phase steam mode. This mode allowed higher fluid velocities to be obtained than possible with single-phase water operation. Flow was varied in steps by means of the flow control valve downstream of the turbine meters with five data scans recorded at each step. Calibration constants for the velocity versus turbine meter output relation were then determined from the recorded data.

Section 3

STEADY-STATE TESTS CONDUCTED

3.1 TEST PHASES

The pump two-phase performance project was divided into two testing periods, Phases I and II, separated by an intermission which provided time for data evaluation, recalibration and servicing of test equipment, and review and modification of plans and procedures for the remaining tests. Phase I tests ran from January through May, 1977, and Phase II from September into December, 1977.

In general, Phase I provided initial exploration of test operations, data analysis, and pump behavior, and went on to cover most of the steady-state operating conditions of prime interest. Phase II then provided data to fill in gaps or extend pump performance curves where required, and also to check out questions regarding some deviations and special effects noted in the Phase I results.

Related roles of Phases I and II in the transient blowdown testing are discussed in Volume III - Transient Tests.

3.2 PURPOSES FOR GROUPS OF TESTS

In describing and listing the tests that were planned and/or run, it is helpful to group the tests according to purpose. Such purposes for the steady-state tests were to determine:

a. Single-phase water performance

b. Single-phase steam performance

c. Effects of two-phase void fraction for several combinations of constant pressure, volumetric flow rate and speed.

d. Full mapping of performance at an intermediate pressure and void fraction.

e. Extensive mapping at a low void fraction.

f. Extensive mapping at a high void fraction.

g. Steady-state performance at operating conditions selected to match some conditions observed during blowdown tests.

h. Characteristics of special effects (from seal leakage, onset of cavitation, etc.)

These purposes sometimes overlap, and a single test may relate to more than one purpose. The primary purpose of each group is indicated in the listings provided in the following sections, and some of the tests are entered more than once where dual purpose was a feature of the planning.

3.3 TEST MATRIX

The steady-state test matrix comprises an array of operating conditions at which pump performance measurements were performed. Selection of the operating conditions was aimed at (1) spanning the ranges of interest for calculating pump performance during postulated NSSS LOCA's, (2) spacing the test points to favor good interpolation and development of quantitative relationships which can be used in the analytical pump performance model, and (3) accommodating the practical limitations of test facility capabilities and an affordable number of tests. In the laboratory it was endeavored to achieve the desired settings of pump upstream pressure level, void fraction, and volumetric flow rate, plus pump speed. To produce these conditions, the controls were manipulated in ways described in the previous section on test procedures. In cases when the desired absolute levels of flow or speed could not be achieved, the settings were adjusted to preserve the desired values of the homologous flow-to-speed ratio ν/α_N that relates to scaling.

Set point tolerances were specified, within which it was desired that the actual operating conditions match the requested conditions in order to readily fulfill the purposes of the tests. These set point tolerances varied somewhat, depending on the purposes of the tests and particular ranges of the variables. If post-test reviews indicated the actual operating conditions to be within or close enough to the listed tolerances, then a test is considered to provide data appropriate for its original purpose. Even if beyond acceptance for the originally specified point, a test may constitute an acceptable alternate choice or contribute useful data for other purposes (interpolation between curves, sensitivity to variations, etc.). These aspects are discussed further as a part of data evaluation below.

As stated in Volume I, the ranges of interest for the operating parameters were derived from the calculated results for typical postulated NSSS LOCA's compiled in or similar to those in Section 4.2 of the Preliminary Test Plan (Ref. 1) and are summarized below. Limitations of the test facility capabilities are also indicated where pertinent.

Specifying the matrix combinations of upstream pressures and void fractions in Figure 3-1 is based on using these parameters as the indexes of fluid density and two-phase mixture. Both upstream and pump path average void fractions are possible correlating parameters for two-phase effects on performance. For practical operation of the test system, settings were specified in terms of upstream fluid conditions, and Figure 3-1 is constructed on this basis.

The variations of inlet pressure versus upstream void fraction calculated for the representative NSSS LOCA's are summarized by the envelope curves superimposed on the matrix in Figure 3-1. These envelope curves serve to indicate the range of interest and form a basis for entries in the matrix. The band within these envelope curves includes both discharge and suction leg breaks. As detailed in Reference 1, the shapes and ranges of bands covered by LOCA curves for the various locations of a pump relative to the break would be roughly the same. Values for large and small breaks are sometimes similar, especially for the broken leg pump, although the timing for reaching the points during the blowdowns varies considerably.

The limited experimental information previously available for two-phase effects on pump performance (e.g. for the Semiscale pump) indicated that two-phase effects varied most rapidly over a narrow range of void fractions at low values and again in the final approach to all steam. To check this, the initial matrix included extra points in the 0 to 20 and 80 to 100 percent void fraction ranges. Actually the test process included "feeling out" the presence and location of any performance gradients, and the void fraction selections were then adjusted accordingly before running the closest-spaced points. This procedure illustrates that the test matrix was part of a dynamic plan which mapped out an approach but adjusted the specific settings in response to test results obtained.

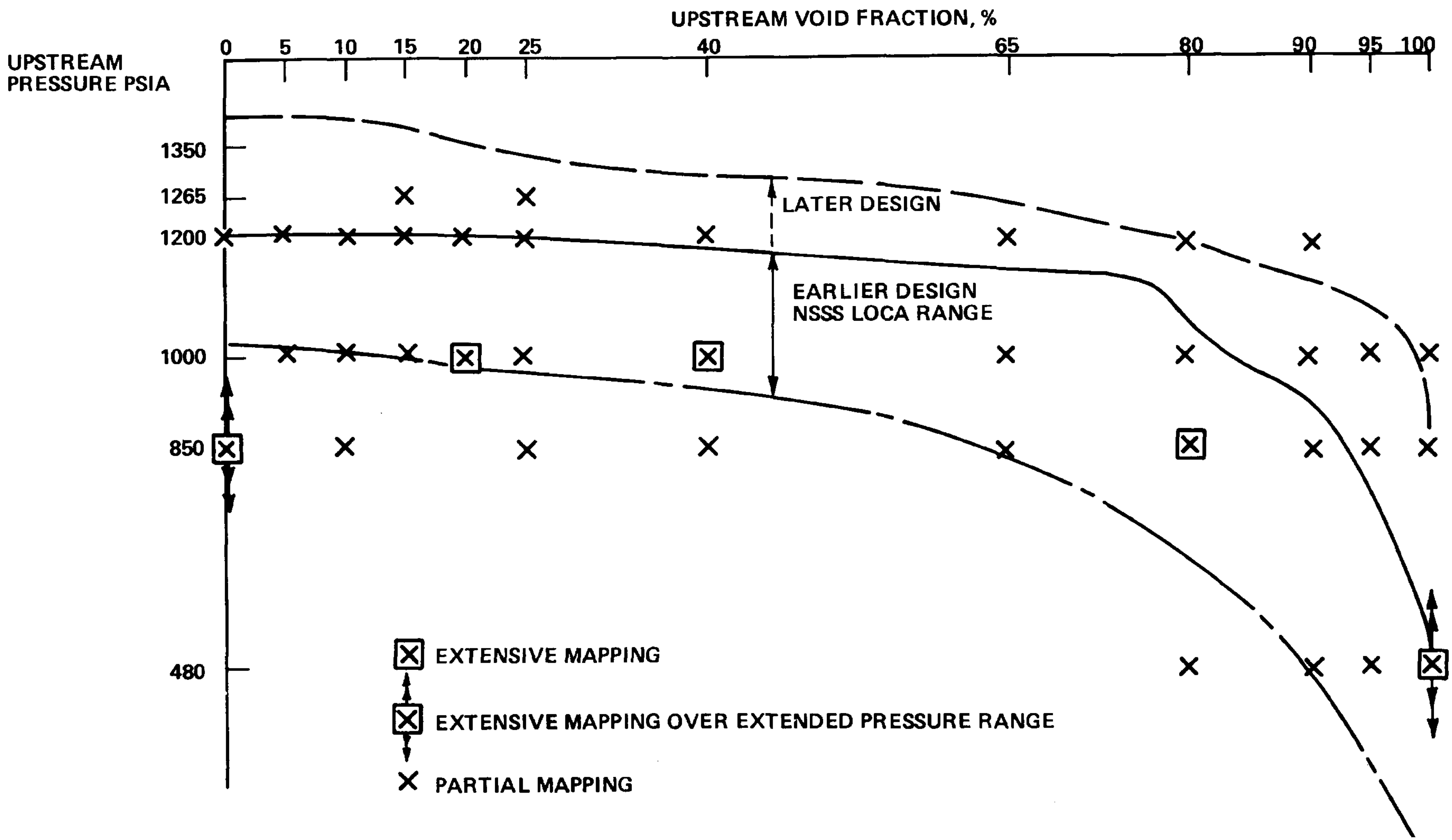


Figure 3-1. Planned steady-state test matrix vs LOCA conditions.

Operating conditions for the actual tests which were run primarily to determine effects of void fraction at constant pressure, volumetric flow rate, and speed are shown in Sections E and F of Table 3-1. Each "X" in the matrix in Figure 3-1 represents only one combination of upstream pressure and void fraction, but any number of combinations of pump speed and volumetric flow ranging from a single speed and flow to full performance mapping. Single-phase water performance was anticipated to be largely independent of pressure and temperature level as long as sufficient subcooling was maintained and fluid density taken into account. Therefore, tests at a variety of pressures were expected to contribute to a single performance map. This is indicated by the extended square on the zero void fraction line in Figure 3-1. Similarly, single-phase steam performance tests over a range of pressures were expected to contribute to the same map as long as sufficient superheat was maintained. How these items worked out in practice is discussed later in the analysis of results.

Full or extensive mapping for two-phase conditions was planned for the three pressure and void fraction combinations indicated in Figure 3-1 by [X]'s. The [X]'s were placed as shown on the basis of (1) spacing the maps across the pressure and void fraction ranges, (2) recognizing the trend to higher void fractions at lower pressures, (3) determining one map at an intermediate void fraction for which two-phase effects might be near maximum and not very sensitive to small deviations in void fraction, (4) obtaining a map at low void fraction to show two-phase performance with small amount of vapor with relatively small effects, and (5) obtaining a map for high void fraction but before the final approach to single-phase all steam.

The other partial mapping X 's were spaced to sample performance over the rest of the pressure and void fraction ranges of interest and generate data for cross-plots at constant pressure or constant void fraction in order to separate the effects of the variables. This provides information for interpolating between the full maps and for determining steady-state performance at more conditions similar to those in selected test system blowdowns.

Single-phase performance was first spot checked to see how the pump manufacturer's (Bryon-Jackson) cold water data compared with cold and hot water tests in the different configuration loop used at C-E. The water tests were subsequently extended to provide new performance curves. Many water tests were run specifically to provide pre-blowdown steady-flow calibrations of drag discs and turbine meters against water orifice readings. These calibration runs were also effective in providing much single-phase performance data. Operating conditions for the actual single-phase water tests performed are listed in Sections A and B of Table 3-1.

Single-phase steam performance was expected to be similar to water performance, after accounting for density differences, and interest was primarily in the lower pressure and higher flow-to-speed ratio ν/α_N regions. Actual steam test operating conditions are listed in Sections C and D of Table 3-1.

For full performance mapping at any given combination of upstream pressure and void fraction, the speed and volumetric flow combinations were laid out in a fashion illustrated in Figure 3-2. The coordinates of percent rated speed vs percent rated volumetric flow provide the framework for a four-quadrant performance map of constant percent head and torque lines (See Figure 3-3). Typical lines for zero head and torque are shown. The area in which tests were to be made is bounded, as shown in Figure 3-2, by (1) the highest positive and negative volumetric flows which could be achieved in the test loop at the model pump, when the combined heads of the two booster pumps and the model pump just balanced the pressure losses in the system with the throttle valve in the return line wide open, (2) the highest (twice the rated) positive or negative speed at which the speed controller would operate the test pump, and/or, (3) the highest torque or power output available from the test pump drive motor at each speed, and (4) the limit of interest to those combinations of speed and flow considered possible or likely in postulated LOCA's, which excludes positive flow with negative speed and negative torque with negative flow and speed.

Within the bounded test area of Figure 3-2, several lines of constant speed were selected, including 0.5, 1.0, and 1.5 times rated speed -- both positive and negative -- and zero (locked rotor) speed. Along these speed lines, various volume flows were selected based on the following factors:

1. Spacing several points along each full length positive or zero speed line,
2. Including maximum forward and reverse flow attainable,
3. Using some of the same flow settings on several speed lines to allow checking speed and flow effects separately,

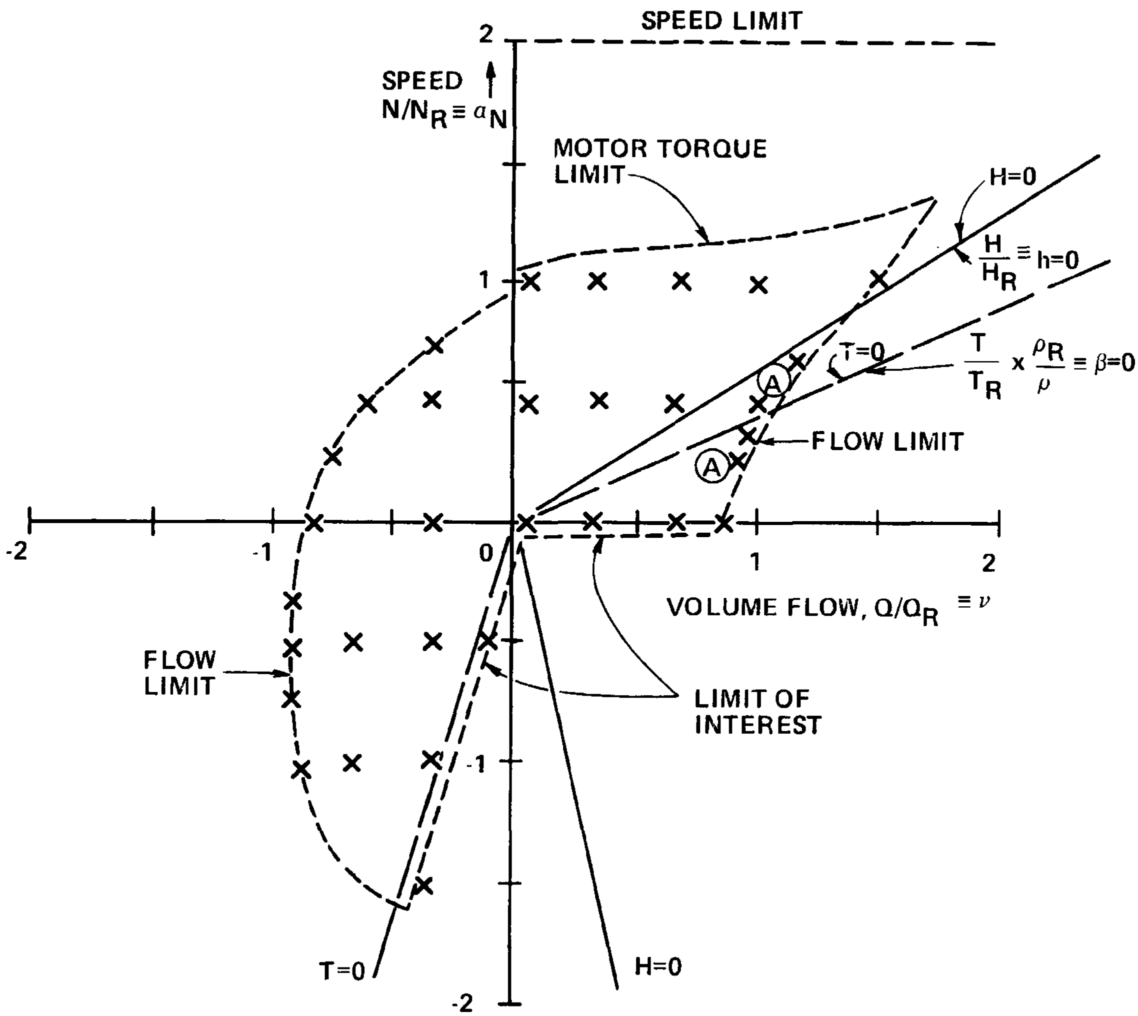


Figure 3-2. Sample steady-state performance map boundaries and point locations.

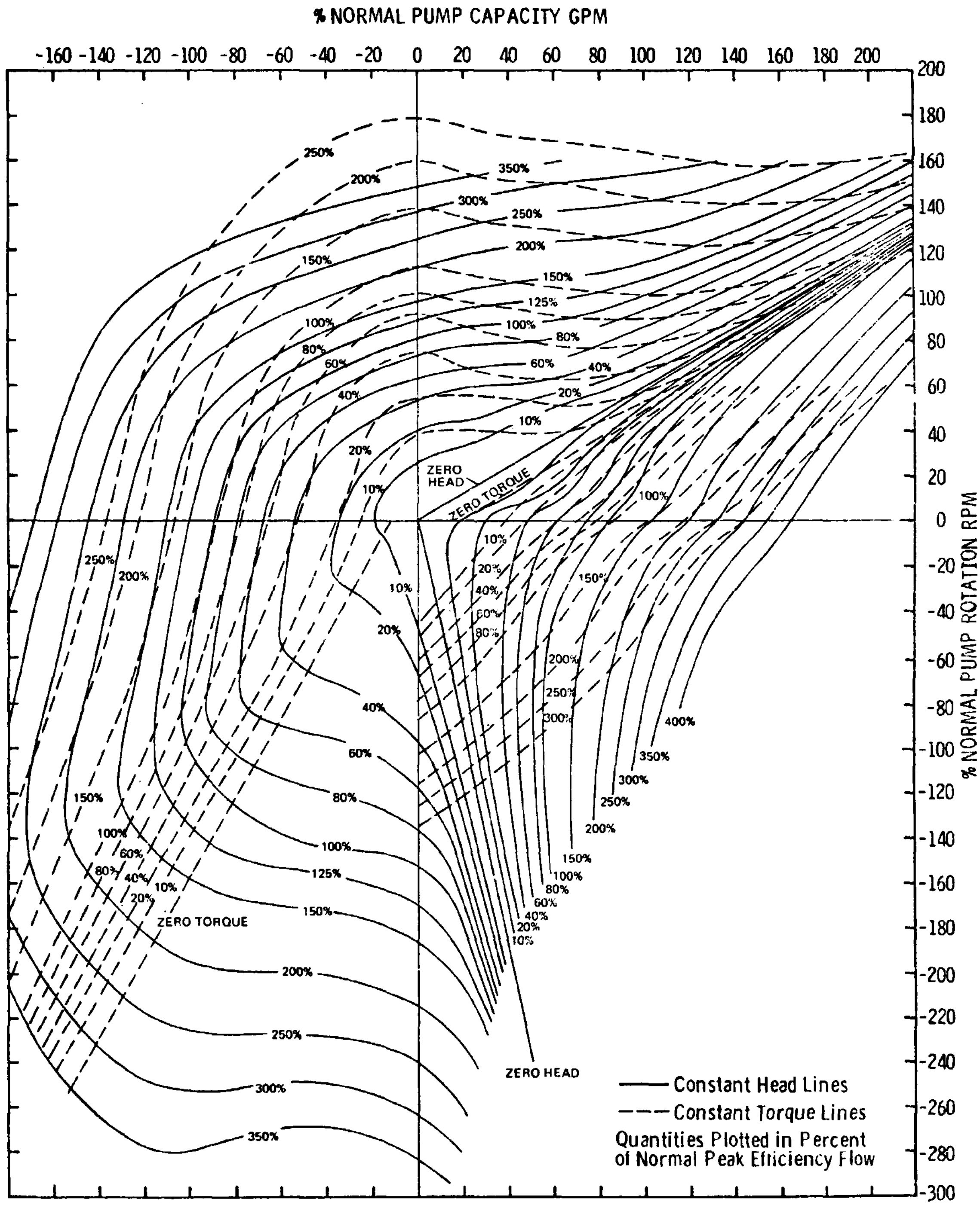


Figure 3-3. Typical single-phase four-quadrant performance map.

4. Spacing points along the homologous head and torque curves,

5. Setting the same flow/speed ratio ν/α_N on different speed lines to check the effectiveness of flow similarity parameters and scaling,

6. Reserving some points for filling in where needed as indicated by the early results. For example, the fill-in process of additional test points in Phase II included some points along the homologous head and torque curves developed from the measurements in Phase I. This involved some additional measurements at low speeds in order to achieve the higher ν/α_N values as indicated in Figure 3-2 at the locations indicated by the Ⓐs.

Maximum volumetric flow rates available in the test section were estimated in advance, for several void fractions and two values of model pump head, 0 ft. (neutral) and -252 ft (loss) across the pump. Due to the changing thermal-hydraulic conditions in the test system, the test pump head was different for each test condition and thereby affected the shape of the flow limit boundaries in the manner illustrated in Figure 3-2.

Based on the above approach for laying out test points, Figure 3-4 shows the estimated boundaries and initially planned point locations for the full performance map at 1000 psia and 40 percent void fraction. Since the amount of two-phase head degradation for the model pump was not known yet, estimated flow boundaries were drawn first for undegraded test pump performance. Degradation would then result in shifting of the flow limits in a manner indicated by the additional lines, with the amount of shift dependent on the amount of degradation. In the early stages of running the tests, the maximum flows achievable at each speed were determined. Then the test point selections near the boundaries of the map were adjusted to give an achievable and workable pattern.

Within the actual achievable boundaries, the test points run for the 40 percent void fraction map were distributed as shown in Figure 3-5 and Sections G and H of Table 3-1. Tests for mapping performance at 20 and 80 percent void fractions are listed in Sections I and J plus K and L of the Table.

Additional runs were made at steady-state conditions selected to match various transient pump operating conditions which were either predicted or actually measured to occur during forward and reverse test system blowdowns. This is illustrated in Figure 3-6, which is a reproduction of Figure 3-1 but with the addition of a predicted typical medium size break forward blowdown trace and heavy dots marking similar hydraulic conditions and some representative samples of additional steady state tests to more directly match the blowdown conditions.

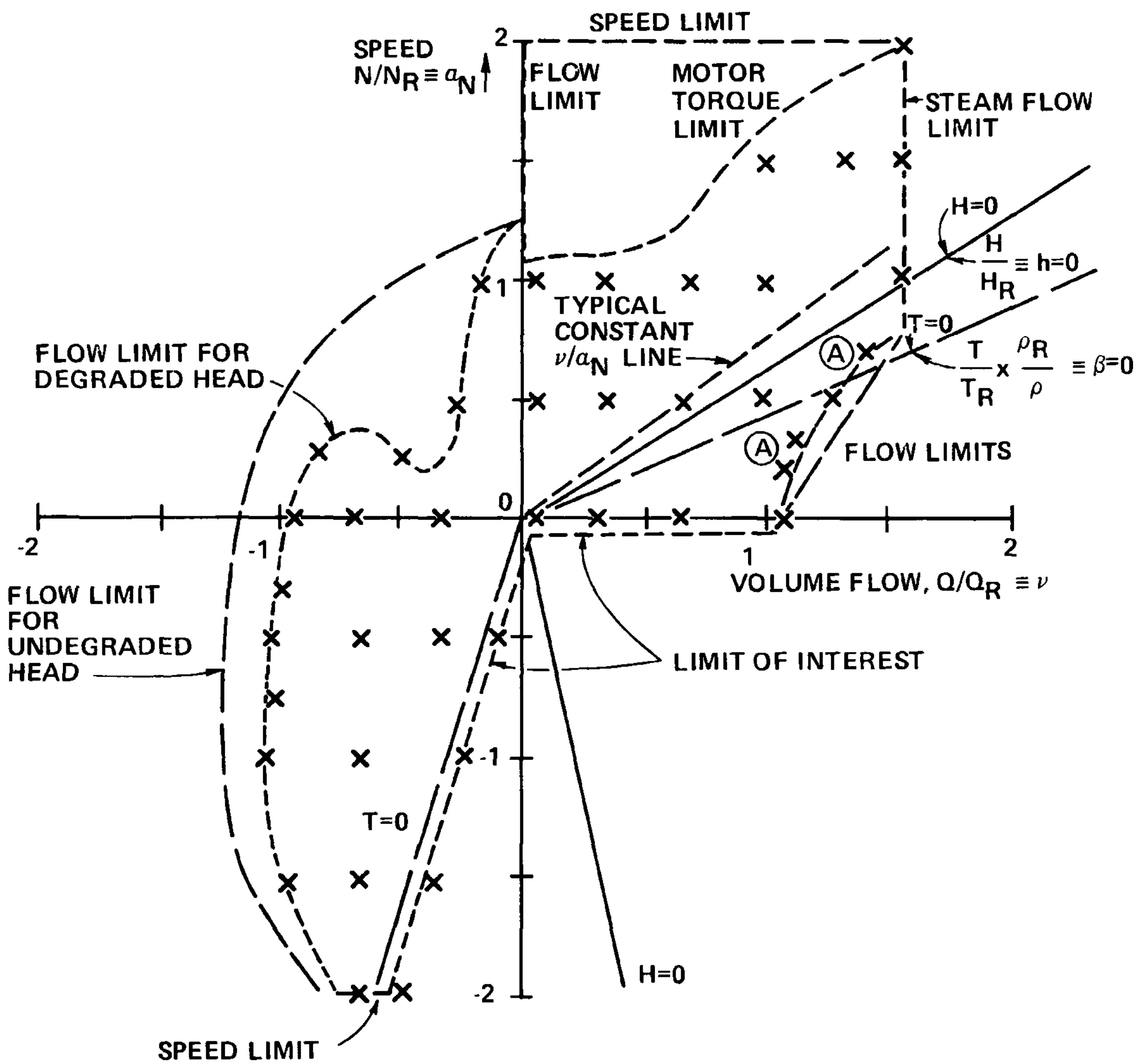


Figure 3-4. Estimated steady-state performance map boundaries and planned point locations for 1000 PSIA and 40% void fraction.

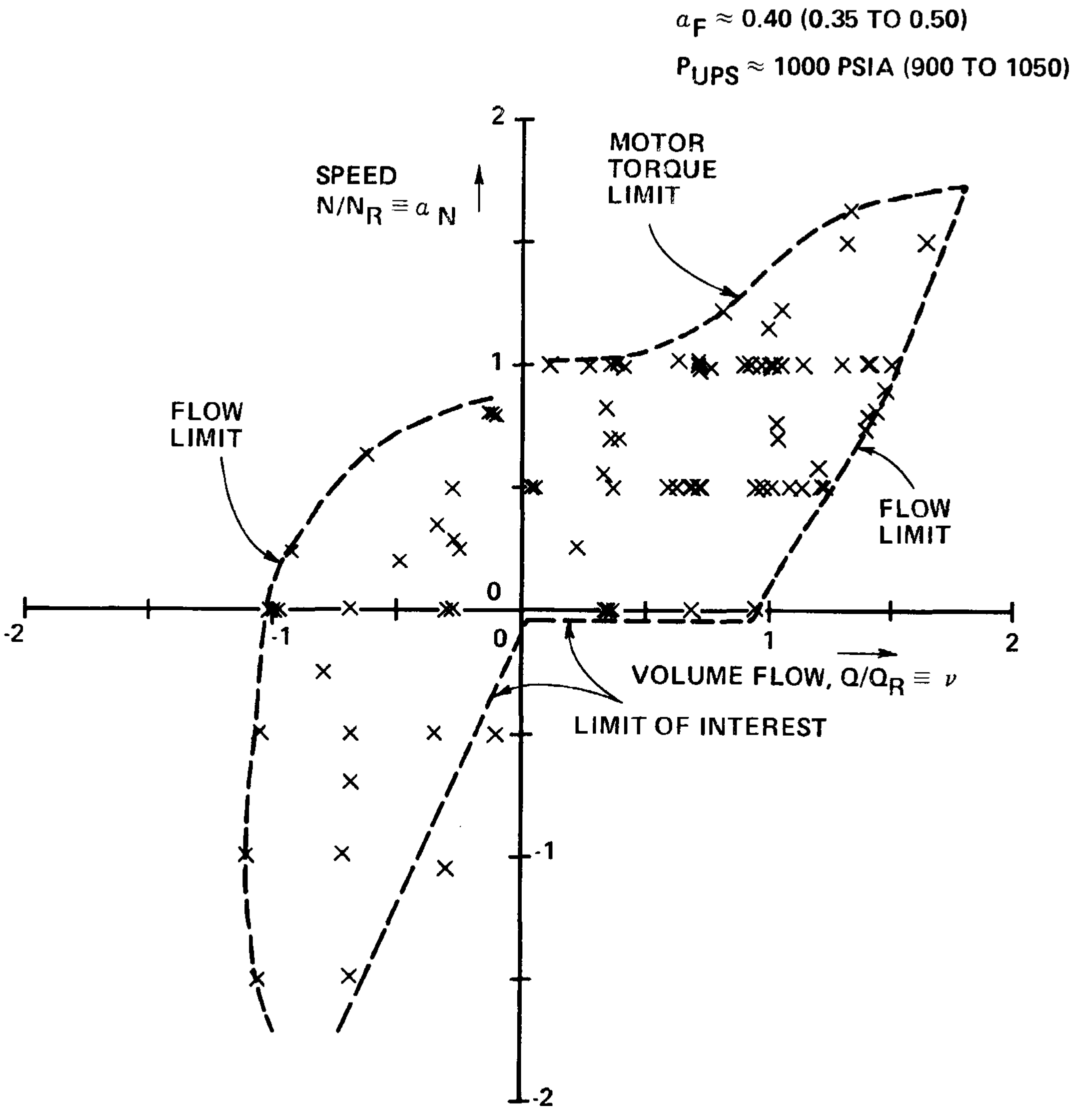


Figure 3-5. Locations of actual steady-state performance testpoints for 1000 PSIA and 40% void fraction.

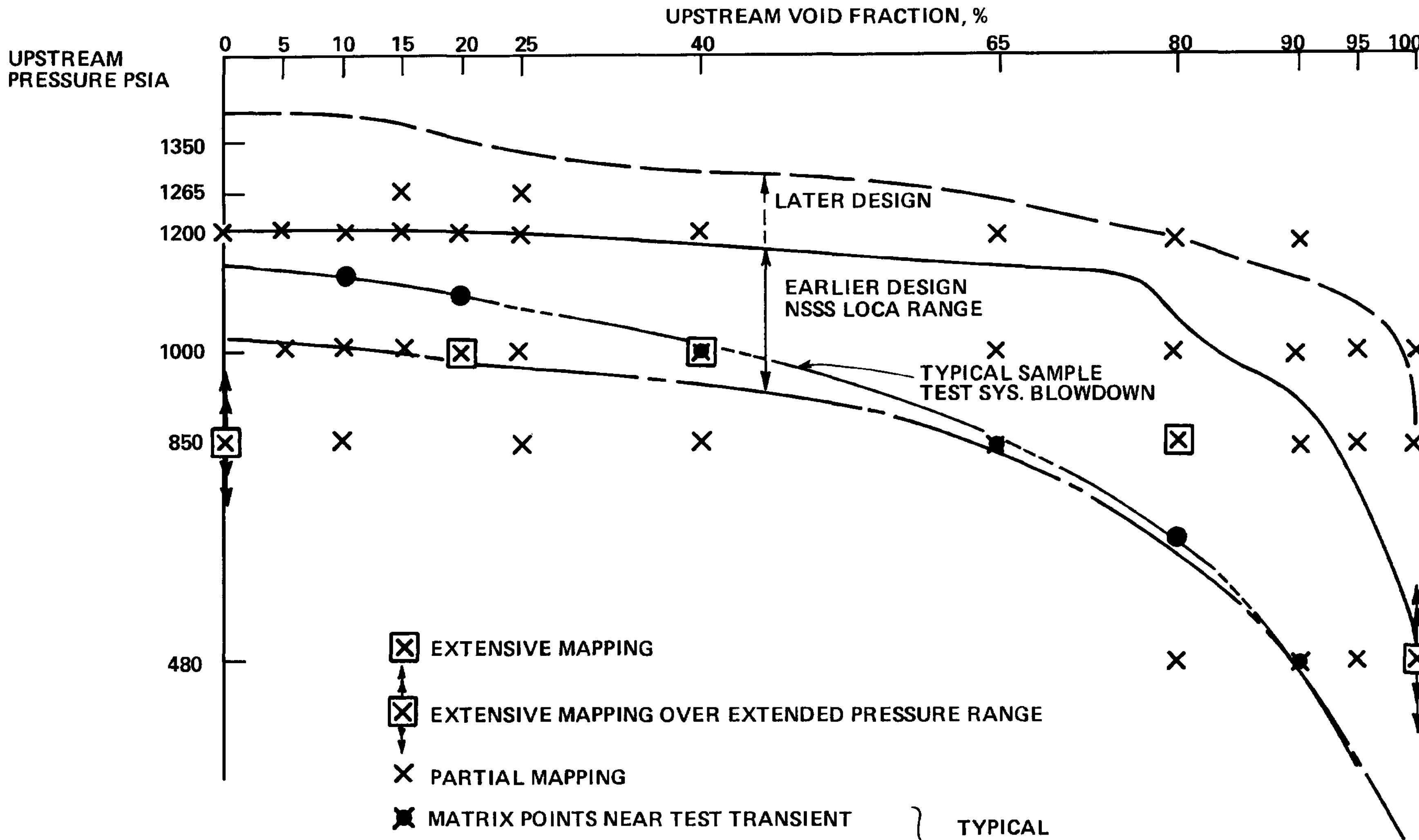


Figure 3-6. Planned steady-state test matrix vs LOCA and predicted test blowdown conditions.

The speeds and volumetric flows for these matching steady-state runs were set at values close to those for the blowdown, or if a blowdown speed or flow could not be duplicated directly in the steady-state test, then the normalized transient flow/speed ratio ν/α_N was matched as a basis for scaling to the blowdown condition. More details about how representative transient operating conditions were extracted from blowdown test data will be given in Volume III - Transient Tests. The maching steady-state test conditions actually run are listed in Sections M and N of Table 3-1.

Notes on Table 3-1:

1. Within the groups of Table 3-1, the test points are not necessarily ordered in any systematic way.

2. In groups containing two-phase test points, single-phase test points which would otherwise fit in the group are referenced by footnotes.

TABLE 3-1

STEADY-STATE TEST MATRIX

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Single-Phase Water Tests, Forward Flow						
Phase I	209	1017	0.000	.442	.999	.442
	210	991	0.000	.830	.997	.832
	211	993	0.000	.994	.997	.977
	212	1012	0.000	1.141	.998	1/.875
	213	1010	0.000	1.354	1.001	1/.739
	214	1007	0.000	.470	1.000	.470
	251	922	0.000	.669	1.002	.667
	255[a]	56	0.000	.792	.989	.801
	256[a]	102	0.000	.431	.990	.435
	257[a]	107	0.000	.913	.579	1/.634
	258[a]	106	0.000	.919	.409	1/.446
	259[a]	106	0.000	.919	.402	1/.437
	260[a]	105	0.000	.926	.446	1/.482
	310	1194	0.000	1.132	.500	1/.442
	311	1205	0.000	.968	.498	1/.515
	321	115	0.000	1.168	.996	1/.853
	322	100	0.000	1.238	.997	1/.805
	323	147	0.000	.852	.995	.857
	324	166	0.000	.627	.997	.629

[a]Mixing plate installed.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	325	170	0.000	.309	.998	.309
	326	187	0.000	.045	.998	.045
	335[a]	1197	0.000	1.429	1.193	1/.835
	336[a]	1202	0.000	.014	1.291	.011
	342[a]	1211	0.000	1.061	.503	1/.474
	343[a]	1188	0.000	1.325	1.000	1/.755
	365[a]	14	0.000	.043	.498	.086
	366[a]	31	0.000	.297	.498	.598
	367[a]	71	0.000	.588	.498	1/.846
	368[a]	107	0.000	.859	.499	1/.581
	369[a]	94	0.000	.998	.504	1/.505
	370[a]	91	0.000	.042	.000	1/.002
	371[a]	99	0.000	.303	.000	1/.000
	578	869	0.000	.315	.500	.630
	579	869	0.000	.573	.499	1/.870
	580	867	0.000	.290	.499	.582
	581	862	0.000	.763	.499	1/.654
	582	960	0.000	.960	.501	1/.522
	583	425	0.000	.930	.498	1/.535
	584	178	0.000	.891	.497	1/.558
	585	172	0.000	.941	.501	1/.532
	586	166	0.000	.986	.501	1/.508
	587	84	0.000	.948	.503	1/.531

[a]Mixing plate installed.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	588	96	0.000	.990	.500	1/.505
	602	1213	0.000	.153	-.000	-1/.001
	603	1211	0.000	.122	-.000	-1/.002
	604	1220	0.000	.103	-.000	-1/.002
	605	1214	0.000	.074	-.000	-1/.003
	606	1213	0.000	.053	-.000	-1/.004
	616	90	0.000	.970	.499	1/.514
	617	141	0.000	.965	.498	1/.516
	618	403	0.000	.915	.497	1/.543
	619	400	0.000	.929	.497	1/.535
	623	868	0.000	.771	.499	1/.647
	624	875	0.000	.578	.498	1/.861
	625	871	0.000	.289	.499	.580
	627	1137	0.000	.770	.499	1/.648
	628	1146	0.000	1.005	-.000	-1/.000
	636	25	0.000	.052	.497	.105
	637	25	0.000	.098	.955	.099
	638	20	0.000	.231	.994	.232
	639	166	0.000	.17	.060	1/.345
	642	821	0.000	.078	.002	1/.024
	643	718	0.000	.440	.177	1/.403
	648	865	0.000	.289	.503	.575
	649	866	0.000	.281	.501	.561
	650	865	0.000	.578	.501	1/.867
	661	98	0.000	.161	.057	1/.351
	663	387	0.000	.215	.075	1/.347

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	668[a]	869	0.000	.287	.498	.577
	669	863	0.000	.579	.498	1/.860
	670	853	0.000	.789	.498	1/.631
	671[a]	858	0.000	.587	.498	1/.849
	672[a]	851	0.000	.780	.500	1/.640
	673[a]	846	0.000	.980	.502	1/.512
	674[a]	852	0.000	.889	.501	1/.564
	675[a]	1109	0.000	1.001	.501	1/.501
	676	963	0.000	.667	1.018	.655
	688	145	0.000	.226	.089	1/.393
	689	371	0.000	.292	.498	.585
	695	867	0.000	.292	.498	.585
	696	857	0.000	.577	.498	1/.863
	697	868	0.000	.775	.498	1/.643
	698	860	0.000	.866	.499	1/.576
	699	871	0.000	.976	.501	1/.513
	700	1130	0.000	1.002	.500	1/.499
	701	982	0.000	.715	.996	.718
	717	1015	0.000	.098	.860	.114
	736	948	0.000	.483	.500	.967
	777	948	0.000	.635	.566	1/.891
	778	935	0.000	.751	.566	1/.754
	779	909	0.000	.984	.567	1/.577
	780	868	0.000	.291	.566	.514
	795	873	0.000	.296	.107	1/.362

[a]Mixing plate installed.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	796	871	0.000	.587	.249	1/.424
	797	871	0.000	.780	.343	1/.439
	798	873	0.000	.970	.437	1/.451
	799	869	0.000	.880	.388	1/.441
	830	160	0.000	.258	.098	1/.381
	832	440	0.000	.280	-.001	-1/.004
	838	873	0.000	.288	.105	1/.364
	839	867	0.000	.552	.233	1/.421
	840	863	0.000	.786	.346	1/.440
	841	877	0.000	.874	.389	1/.445
	842	868	0.000	1.004	.453	1/.452
	843	873	0.000	1.010	.499	1/.494
	844	858	0.000	.988	.500	1/.506
	845	1061	0.000	1.009	.998	1/.990
	846	969	0.000	.693	1.002	.692
Phase II	856	79	0.000	1.257	.983	1/.782
	857	90	0.000	1.207	.833	1/.691
	858	236	0.000	1.095	.594	1/.542
	859	126	0.000	.950	.494	1/.528
	860	137	0.000	.846	.492	1/.581
	861	73	0.000	.688	.491	1/.714
	862	92	0.000	.457	.491	.932

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	863	106	0.000	.188	.491	.384
	864	87	0.000	1.321	.998	1/.756
	865	93	0.000	1.228	.874	1/.712
	866	108	0.000	1.120	.643	1/.574
	867	121	0.000	.996	.348	1/.360
	868	55	0.000	.846	.541	1/.640
	869	68	0.000	.723	.276	1/.381
	870	93	0.000	.425	.183	1/.431
	871	104	0.000	.183	.069	1/.379
	872	111	0.000	.691	.003	.004
	907	861	0.000	.988	.249	.252
	928	78	0.000	.842	.472	1/.560
	929	79	0.000	.841	.472	1/.561
	930	78	0.000	.840	.472	1/.562
	931	94	0.000	.694	.471	1/.679
	932	95	0.000	.695	.471	1/.678
	933	94	0.000	.694	.471	1/.679
	934	114	0.000	.462	.470	.983
	935	114	0.000	.462	.470	.981
	936	114	0.000	.462	.470	.983
	937	93	0.000	1.315	1.000	1/.761
	938	92	0.000	1.320	1.000	1/.757
	939	92	0.000	1.311	1.000	1/.763

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	940	119	0.000	.932	.431	1/.462
	941	110	0.000	.896	.431	1/.480
	942	102	0.000	.875	.430	1/.492
	943	113	0.000	1.056	.516	1/.489
	944	161	0.000	1.038	.492	1/.474
	945	163	0.000	1.031	.491	1/.477
	946	148	0.000	1.156	.596	1/.516
	947	148	0.000	1.159	.596	1/.515
	948	148	0.000	1.160	.596	1/.514
	949	133	0.000	1.261	.786	1/.623
	950	133	0.000	1.249	.787	1/.630
	951	133	0.000	1.257	.786	1/.625
	952	119	0.000	1.341	.979	1/.730
	953	118	0.000	1.356	.978	1/.721
	954	119	0.000	1.355	.977	1/.721
	965	481	0.000	.819	.427	1/.522
	971	712	0.000	1.118	.498	1/.445
	972	841	0.000	1.116	.498	1/.446
	973	837	0.000	1.066	.497	1/.466
	974	845	0.000	1.014	.497	1/.491
	975	850	0.000	.959	.496	1/.518
	976	837	0.000	.888	.498	1/.561
	977	855	0.000	.811	.498	1/.613

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	978	843	0.000	.739	.499	1/.675
	979	836	0.000	.639	.498	1/.779
	980	847	0.000	.501	.500	1/.999
	981	833	0.000	.315	.500	.629
	982	841	0.000	.147	.501	.294
	983	848	0.000	.337	.501	.673
	984	849	0.000	1.400	.943	1/.674
	1003	55	0.000	1.387	1.288	1/.929
	1004	186	0.000	1.509	1.106	1/.733
	1005	199	0.000	1.421	1.097	1/.772
	1006	228	0.000	1.318	.939	1/.713
	1007	252	0.000	1.216	.939	1/.772
	1008	262	0.000	1.091	.937	1/.859
	1009	227	0.000	.939	.953	.986
	1010	232	0.000	.825	.953	.866
	1011	231	0.000	.690	.945	.730
	1012	282	0.000	.517	.507	1/.980
	1013	286	0.000	.233	.508	.459
	1015	276	0.000	.235	.508	.463
	1016	343	0.000	.512	.508	1/.992
	1017	312	0.000	.682	.948	.719
	1018	316	0.000	.824	.947	.871
	1019	313	0.000	.941	.947	.994

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	1020	359	0.000	1.089	.919	1/.844
	1021	354	0.000	1.217	.923	1/.758
	1022	358	0.000	1.338	.922	1/.690
	1023	347	0.000	1.457	1.042	1/.715
	1024	339	0.000	1.554	1.130	1/.727
	1026	334	0.000	.235	.185	1/.788
	1027	333	0.000	.500	.339	1/.678
	1028	311	0.000	.674	.804	.839
	1029	305	0.000	.809	.803	1/.993
	1030	275	0.000	.931	.803	1/.863
	1031	269	0.000	1.073	.824	1/.768
	1032	256	0.000	1.199	.922	1/.769
	1033	239	0.000	1.316	1.062	1/.807
	1034	292	0.000	1.418	.933	1/.658
	1035	277	0.000	1.515	1.081	1/.713
	1036	288	0.000	1.424	1.014	1/.712
	1037	291	0.000	1.323	1.047	1/.791
	1038	301	0.000	1.221	.997	1/.817
	1039	297	0.000	1.095	1.030	1/.941
	1040	259	0.000	.947	1.029	.920
	1041	267	0.000	.825	.975	.847
	1042	264	0.000	.690	1.009	.684
	1043	262	0.000	.513	1.032	.497

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	1044	245	0.000	.233	1.152	.202
	1046	269	0.000	.234	.366	.641
	1047	260	0.000	.518	.570	.908
	1048	245	0.000	.692	.765	.904
	1049	256	0.000	.826	.808	1/.978
	1050	305	0.000	.939	.837	1/.892
	1051	296	0.000	1.095	.872	1/.796
	1052	293	0.000	1.219	.928	1/.762
	1053	284	0.000	1.330	.972	1/.731
	1054	276	0.000	1.440	1.019	1/.708
	1055	242	0.000	1.525	1.124	1/.737
	1056	256	0.000	1.440	.998	1/.693
	1057	259	0.000	1.341	.997	1/.743
	1058	268	0.000	1.245	.997	1/.801
	1059	282	0.000	1.121	.996	1/.888
	1060	242	0.000	.964	.992	.972
	1061	246	0.000	.841	.993	.848
	1062	245	0.000	.705	.993	.709
	1063	252	0.000	.532	.992	.536
	1064	250	0.000	.253	.995	.254
	1066	286	0.000	.252	.772	.327
	1067	287	0.000	.528	.771	.685
	1068	269	0.000	.700	.994	.704

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.	1069	269	0.000	.841	.993	.847
	1070	254	0.000	.972	.992	.980
	1071	288	0.000	1.125	.993	1/.883
	1072	285	0.000	1.237	.995	1/.805
	1073	282	0.000	1.366	.996	1/.729
	1074	352	0.000	1.483	1.065	1/.718
	1075	364	0.000	1.564	1.156	1/.739
	1133	251	0.000	.428	.186	1/.435
	1134	308	0.000	.863	.192	1/.222
	1135	225	0.000	1.495	1.084	1/.725
	1137	171	0.000	.899	.409	1/.455
	1139	425	0.000	.949	.410	1/.432
	1140	914	0.000	.013	.406	.031
	1141	917	0.000	.984	.409	1/.416
	1145	889	0.000	.979	.409	1/.417
	1146	863	0.000	1.501	1.164	1/.775
	1147	866	0.000	1.272	.794	1/.624
	1148	878	0.000	.492	.221	1/.449
	1149	883	0.000	.430	.186	1/.434
	1151	914	0.000	.941	.471	1/.501
	1152	876	0.000	1.209	.903	1/.747
	1153	841	0.000	1.441	1.070	1/.743
	1155	1121	0.000	.996	.999	.996

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.	1156	948	0.000	.624	1.009	.619
	1159	125	0.000	.252	.094	1/.374
	1160	126	0.000	.252	.094	1/.373
	1164	162	0.000	.889	.405	1/.455
	1165	340	0.000	.431	.186	1/.433
	1166	318	0.000	.867	.453	1/.523
	1167	268	0.000	1.518	1.086	1/.715
	1169	450	0.000	.935	.199	1/.213
	1170	894	0.000	.506	.499	1/.986
	1171	925	0.000	.993	.502	1/.505
	1172	855	0.000	1.531	1.196	1/.781
	1178	1025	0.000	1.005	.998	1/.993
	1179	984	0.000	.677	1.009	.671
	1186	291	0.000	.431	.186	1/.432
	1187	272	0.000	.855	.416	1/.486
	1188	264	0.000	1.476	1.015	1/.688
	1189	283	0.000	.443	.186	1/.419
	1190	253	0.000	.976	.613	1/.628
	1191	305	0.000	1.105	.416	1/.376
	1192	285	0.000	1.269	.683	1/.539
	1193	264	0.000	1.436	.957	1/.666
	1194	268	0.000	.806	.332	1/.412
	1197	172	0.000	.897	.409	1/.456

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.	1199	417	0.000	.948	.432	1/.456
	1201	882	0.000	.313	.112	1/.357
	1203	885	0.000	.518	.209	1/.403
	1204	919	0.000	.864	.242	1/.281
	1205	886	0.000	1.113	.488	1/.439
	1206	862	0.000	1.306	.816	1/.624
	1207	836	0.000	1.479	1.099	1/.735
	1208	826	0.000	1.549	1.203	1/.777
	1210	1024	0.000	.984	.999	.985
	1211	1022	0.000	.684	.994	.688
	1213	240	0.000	1.459	.964	1/.661
	1214	249	0.000	1.387	.856	1/.617
	1215	259	0.000	1.308	.726	1/.556
	1216	270	0.000	1.213	.565	1/.466
	1217	280	0.000	1.121	.526	1/.469
	1218	284	0.000	1.042	.549	1/.527
	1219	234	0.000	.912	.576	1/.632
	1220	241	0.000	.792	.575	1/.726
	1221	250	0.000	.663	.503	1/.758
	1222	262	0.000	.455	.504	.904
	1231	278	0.000	.558	.287	1/.514
	1232	261	0.000	.811	.555	1/.684
	1233	250	0.000	.969	.621	1/.641

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.	1234	298	0.000	1.124	.599	1/.533
	1235	285	0.000	1.257	.653	1/.520
	1236	270	0.000	1.380	.858	1/.622
	1245	292	0.000	.559	.591	.945
	1246	278	0.000	.802	.592	1/.738
	1247	266	0.000	.972	.642	1/.660
	1248	313	0.000	1.124	.652	1/.580
	1249	302	0.000	1.258	.664	1/.528
	1250	287	0.000	1.373	.847	1/.617
	1252	189	0.000	.903	.349	1/.386
	1254	437	0.000	.916	.191	1/.209
	1258	926	0.000	1.099	.490	1/.446
	1259	941	0.000	.940	.411	1/.438
	1260	966	0.000	.619	.258	1/.417
	1263	869	0.000	1.284	.748	1/.583
	1264	892	0.000	1.430	.965	1/.675
	1265	857	0.000	1.566	1.194	1/.763
	1266	1140	0.000	.835	-.001	-1/.001
	1274	240	0.000	.553	.185	1/.335
	1275	227	0.000	.796	.324	1/.407
	1276	284	0.000	.974	.211	1/.217
	1277	265	0.000	1.129	.440	1/.390
	1278	245	0.000	1.273	.687	1/.540

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	1279	230	0.000	1.377	.863	1/.627
	1280	200	0.000	1.380	.881	1/.639
	1282	174	0.000	.905	.407	1/.450
	1284	441	0.000	.937	.414	1/.442
	1296	226	0.000	.559	.270	1/.482
	1297	218	0.000	.790	.328	1/.415
	1298	260	0.000	.975	.331	1/.340
	1299	255	0.000	1.118	.429	1/.383
	1300	234	0.000	1.256	.666	1/.530
	1301	215	0.000	1.379	.876	1/.635
	1302	297	0.000	.534	.185	1/.347
	1303	318	0.000	1.124	.469	1/.417
	1304	186	0.000	.873	.204	1/.234
	1307	414	0.000	.933	.206	1/.221
	1311	847	0.000	.629	.267	1/.425
	1313	857	0.000	.901	.189	1/.210
	1314	860	0.000	1.098	.541	1/.492
	1315	852	0.000	1.289	.781	1/.606
	1316	853	0.000	1.432	.988	1/.690
	1317	839	0.000	1.559	1.181	1/.758
	1318	985	0.000	1.180	1.000	1/.847
	1319	985	0.000	.723	.995	.726
	1326	322	0.000	.552	.185	1/.336

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	1327	308	0.000	.791	.325	1/.411
	1328	289	0.000	.970	.601	1/.619
	1329	295	0.000	1.130	.816	1/.722
	1330	268	0.000	1.259	.817	1/.649
	1331	287	0.000	1.382	.880	1/.637
	1333	177	0.000	.914	.415	1/.454
	1335	420	0.000	.942	.208	1/.221
	1340	983	0.000	.487	.530	.919
	1341	868	0.000	1.566	1.198	1/.765
	1342	898	0.000	1.444	.990	1/.686
	1343	906	0.000	1.297	.767	1/.592
	1344	920	0.000	1.117	.464	1/.416
	1345	941	0.000	.923	.190	1/.206
	1346	902	0.000	.661	.186	1/.282
	1349	1019	0.000	1.006	.998	1/.992
	1350	1027	0.000	.954	.750	1/.786
	1351	1014	0.000	.496	.756	.656
	1358	242	0.000	.325	.186	1/.575
	1359	228	0.000	.468	.186	1/.398
	1360	256	0.000	.561	.187	1/.333
	1361	252	0.000	.643	.188	1/.292
	1362	255	0.000	.723	.215	1/.297
	1363	251	0.000	.795	.320	1/.402

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
A. Cont'd.						
	1364	119	0.000	.829	.520	1/.606
	1366	352	0.000	.847	.511	1/.603
	1371	846	0.000	.905	.575	1/.636
	1372	868	0.000	.742	.479	1/.645
	1373	863	0.000	.634	.642	.989
	1375	884	0.000	.397	.242	1/.609
	1376	876	0.000	.524	.550	.953
	1377	845	0.000	.823	.631	1/.766
	1379	1094	0.000	.415	.996	.417
	1380	986	0.000	.287	1.003	.286
	1384	580	0.000	.325	.125	1/.384
	1401	856	0.000	.988	.499	1/.506
B. Single-Phase Water Tests, Reverse Flow						
Phase I	393	41	0.000	-.257	-.499	.516
	394	58	0.000	-.505	-.500	1/.991
	395	91	0.000	-.515	-1.000	.515
	396	110	0.000	-.770	-1.001	.770
	397	70	0.000	-.051	.499	-.103

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
B. Cont'd.						
	398	27	0.000	-.052	-.000	1/.001
	399	40	0.000	-.283	-.000	1/.000
	401	1210	0.000	-.921	-.799	1/.868
	402	1255	0.000	-.920	-.799	1/.868
	421	997	0.000	-.685	-.499	1/.727
	422	1000	0.000	-.685	-.700	.980
	430	80	0.000	-.256	.498	-.514
	431	120	0.000	-.521	.497	-1/.954
	432	193	0.000	-.073	.992	-.074
	433	67	0.000	-.520	-.000	1/.000
	434	119	0.000	-.769	-.000	1/.000
	436	989	0.000	-.249	.499	-.499
	446	1197	0.000	-.147	-.000	1/.002
	447	1199	0.000	-.117	-.000	1/.002
	448	1197	0.000	-.099	-.000	1/.002
	449	1200	0.000	-.070	-.000	1/.003
	450	1199	0.000	-.049	-.000	1/.004
	462	137	0.000	-.846	-.000	1/.000
	463	207	0.000	-.577	-.000	1/.000
	464	492	0.000	-.575	-.000	1/.000
	465	912	0.000	-.576	-.000	1/.000
	468	842	0.000	-.851	-.000	1/.000
	469	835	0.000	-.668	-.000	1/.000

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
B. Cont'd.						
	470	847	0.000	-.261	-.000	1/.001
	471	1161	0.000	-.598	-.000	1/.000
	474	1164	0.000	-.590	-.000	1/.000
	475	1171	0.000	-.043	-.000	1/.011
	486	15	0.000	-.560	.172	-1/.307
	487	143	0.000	-.558	.172	-1/.309
	488	414	0.000	-.564	.173	-1/.306
	489	948	0.000	-.569	.174	-1/.305
	492	846	0.000	-.817	.164	-1/.201
	493	841	0.000	-.650	.170	-1/.262
	494	843	0.000	-.487	.175	-1/.359
	495	842	0.000	-.251	.179	-1/.715
	496	1152	0.000	-.557	.175	-1/.313
	502	934	0.000	.098	.988	.099
	511	1202	0.000	-.158	-.095	1/.604
	512	1212	0.000	-.124	-.063	1/.506
	513	1210	0.000	-.157	-.090	1/.576
	514	1207	0.000	-.102	-.029	1/.283
	515	1207	0.000	-.070	-.000	1/.005
	516	1208	0.000	-.049	-.002	1/.034
Phase II	1441	142	0.000	-.846	-.001	1/.001
	1442	150	0.000	-.782	-.001	1/.001

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
B. Cont'd.	1443	178	0.000	-.694	-.001	1/.001
	1444	188	0.000	-.605	-.001	1/.002
	1445	196	0.000	-.494	-.001	1/.002
	1446	205	0.000	-.360	-.001	1/.003
	1449	145	0.000	-.293	-.001	1/.003
	1450	182	0.000	-.833	-.001	1/.001
	1452	391	0.000	-.308	-.001	1/.003
	1453	427	0.000	-.831	-.001	1/.001
	1454	395	0.000	-.021	-.001	1/.058
	1458	911	0.000	-.392	-.001	1/.003
	1459	919	0.000	-.025	-.001	1/.053
	1460	904	0.000	-.554	-.001	1/.002
	1461	960	0.000	-.687	-.001	1/.002
	1462	952	0.000	-.785	-.001	1/.001
	1463	947	0.000	-.846	-.001	1/.001
	1464	1099	0.000	-.848	-.001	1/.002
	1468	980	0.000	-.516	.397	-1/.770
	1469	1002	0.000	-.522	.401	-1/.768
	1486	250	0.000	-.912	-.908	1/.995
	1487	256	0.000	-.846	-.764	1/.904
	1488	242	0.000	-.771	-.839	.918
	1489	239	0.000	-.676	-.609	1/.901
	1490	218	0.000	-.559	-.516	1/.923

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
B. Cont'd.	1491	313	0.000	-.444	-.402	1/.905
	1494	207	0.000	-.590	-.529	1/.896
	1496	434	0.000	-.432	-.386	1/.894
	1498	502	0.000	-.906	-.977	.927
	1503	889	0.000	-.922	-.903	1/.978
	1504	896	0.000	-.836	-.900	.928
	1505	863	0.000	-.372	-.893	.417
	1506	855	0.000	-.521	-.895	.583
	1507	912	0.000	-.643	-.896	.717
	1508	902	0.000	-.749	-.898	.834
	1509	1001	0.000	-.810	.169	-1/.209
C. Single-Phase Steam Tests, Forward Flow						
Phase I	267[a]	477	1.000	1.012	.500	1/.494
	268[a]	477	1.000	1.017	.999	1/.982
	300	990	1.000	.897	.503	1/.561
	301	993	1.000	.990	.504	1/.509
	302	1185	1.000	.781	.504	1/.645
	308	996	1.000	1.436	.504	1/.351

[a]Mixing plate installed.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
C. Cont'd.						
	309	990	1.000	1.421	.998	1/.703
	315	447	1.000	2.173	1.005	1/.463
	316	440	1.000	2.249	.499	1/.222
	318	437	1.000	2.353	.998	1/.424
	319	448	1.000	2.558	.998	1/.390
	320	458	1.000	2.400	.497	1/.207
	357[a]	995	1.000	.960	.500	1/.521
	358[a]	996	1.000	.954	.998	.955
	591	45	1.000	8.201	1.479	1/.180
	592	48	1.000	5.587	.602	1/.108
	593	50	1.000	7.815	-.000	-.000
	594	48	1.000	7.925	-.000	-.000
	595	34	1.000	7.555	-.000	-.000
	596	26	1.000	6.543	-.000	-.000
	597	32	1.000	3.554	-.000	-.000
	598	30	1.000	4.970	-.000	-.000
	822	301	1.000	1.577	.500	1/.317
Phase II	873	36	1.000	4.658	.997	1/.214
	874	38	1.000	3.819	.997	1/.261
	875	34	1.000	3.661	.997	1/.272
	876	33	1.000	2.941	.997	1/.339
	877	33	1.000	2.368	.997	1/.421
	878	26	1.000	2.144	.997	1/.465

[a] Mixing plate installed.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
C. Cont'd.						
	879	28	1.000	1.013	.218	1/.215
	916	846	1.000	1.041	.499	1/.479
	1076	68	1.000	4.682	.497	1/.106
	1077	64	1.000	.985	-.001	-1/.001
	1078	54	1.000	1.499	-.000	-1/.000
	1079	54	1.000	2.137	-.087	1/.041
	1080	55	1.000	2.709	.227	1/.084
	1081	53	1.000	3.000	.228	1/.076
	1082	60	1.000	3.750	.228	1/.061
	1083	60	1.000	4.318	.267	1/.062
	1084	73	1.000	4.648	.608	1/.131
	1085	53	1.000	2.685	.431	1/.161
	1086	54	1.000	1.327	.031	1/.024
	1087	53	1.000	1.640	.030	1/.018
	1088	56	1.000	2.401	.114	1/.047
	1089	56	1.000	2.856	.221	1/.077
	1090	56	1.000	3.188	.220	1/.069
	1091	58	1.000	3.684	.220	1/.060
	1092	57	1.000	3.858	.221	1/.057
	1093	59	1.000	4.364	.552	1/.126
	1095	54	1.000	1.503	.552	1/.367
	1096	55	1.000	2.570	.551	1/.215
	1097	56	1.000	3.029	.552	1/.182

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
C. Cont'd.	1098	56	1.000	3.409	.551	1/.162
	1099	60	1.000	3.768	.552	1/.146
	1100	60	1.000	4.826	.886	1/.184
	1101	88	1.000	4.843	.998	1/.206
	1102	54	1.000	2.993	.998	1/.333
	1118	54	1.000	4.706	1.625	1/.345
	1119	50	1.000	4.825	1.625	1/.337
	1120	51	1.000	4.798	1.155	1/.241
	1121	49	1.000	2.343	1.154	1/.492
D. Single-Phase Steam Tests, Reverse Flow						
Phase I	428	997	1.000	-.703	-.498	1/.708
	518	999	1.000	-.699	-.700	.999
	524	997	1.000	-.273	.500	-.546

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
E. Effects of Void Fraction and Pressure, at Various Volumetric Flow Rate and Speed Combinations for Forward Flow						
Phase I	278[a]	982	.234	1.007	.992	1/.985
	279[a]	978	.230	.973	1.041	.935
	216	999	.224	1.035	1.003	1/.970
	234[a]	998	.416	.965	.997	.967
	235[a]	994	.458	.904	.998	.906
	313	984	.420	1.008	.997	1/.989
	344[a]	989	.447	1.054	1.001	1/.950
	346[a]	996	.633	.970	.999	.971
	347[a]	1006	.801	.975	1.002	.973
	215	991	.112	1.053	1.000	1/.950
b						
	223[a]	991	.137	.974	.994	.980
	350	989	.176	1.057	.995	1/.941
	232[a]	989	.317	1.057	.998	1/.945
	224[a]	986	.366	1.135	.998	1/.880
	233[a]	998	.387	1.017	1.003	1/.986

[a]Mixing plate installed.

[b]See also water test 211.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
E. Cont'd.						
	355[a]	996	.908	.958	.998	.960
	354[a]	994	.947	.956	.998	.958
	802	972	.194	1.096	.504	1/.460
	801	971	.223	1.005	.501	1/.498
	800	971	.230	1.006	.500	1/.497
b						
	219[a]	1005	.074	1.006	.501	1/.499
	220[a]	1008	.083	1.016	.500	1/.493
	349[a]	999	.092	.978	.499	1/.510
	222[a]	1006	.180	1.005	.501	1/.498
	221[a]	1004	.165	.989	.501	1/.506
	351[a]	994	.220	.974	.503	1/.507
	294[a]	992	.276	1.014	.502	1/.495
	230[a]	985	.428	.943	.498	1/.528
	231[a]	992	.415	.984	.499	1/.507
	293[a]	999	.407	.984	.502	1/.510
	312	998	.424	1.006	.499	1/.496
	345[a]	1001	.655	.989	.499	1/.504
	348[a]	1003	.799	.996	.500	1/.502
	356[a]	994	.906	.967	.500	1/.521
	353[a]	998	.947	.949	.499	1/.526
	279[a]	978	.230	.973	1.041	.935
	352[a]	993	.214	.973	.450	1/.462
	569	1210	.052	.934	.701	1/.750

[a] Mixing plate installed.

[b] See also water test 582 and steam tests 301, 357, and 358.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
E. Cont'd.						
	738	936	.340	.700	.499	1/.712
	739	940	.394	.692	.500	1/.722
	740	904	.449	1.034	.765	1/.740
	241	990	.408	.682	.498	1/.730
	280	991	.429	.719	.503	1/.700
	292	991	.422	.715	.500	1/.699
	314	994	.424	1.482	.999	1/.674
	330	963	.404	1.412	.998	1/.707
	331	986	.396	1.402	.996	1/.711
b						
	377[a]	1187	.102	.977	.997	.980
	379[a]	1198	.196	1.055	.996	1/.945
	381[a]	1190	.274	1.017	1.001	1/.984
	572	1117	.041	.943	.998	.944
	570	1218	.064	1.265	.702	1/.555
	364[a]	1211	.102	.985	.499	1/.506
	378	1193	.214	.982	.499	1/.509
	380	1195	.253	.993	.502	1/.506
	382	1190	.409	.989	.498	1/.504
	383	1196	.786	.980	.498	1/.508
c						
	269[a]	846	.795	.962	.995	.967
	387	841	.794	.975	.999	.976

[a]Mixing plate installed.

[b]See also water tests 213, 581, and steam tests 302, 343, and 309.

[c]See also water tests 311, 342, 675, 700 343, and 778.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
E. Cont'd.						
	296[a]	840	.059	.966	.489	1/.516
	390	843	.122	1.003	.500	1/.498
	297[a]	834	.155	.862	.501	1/.581
	389	843	.253	.997	.501	1/.502
	388	845	.430	1.007	.500	1/.496
	386	845	.792	.963	.499	1/.518
	747	839	.558	1.006	.446	1/.443
	748	841	.557	1.001	.445	1/.444
	749	836	.550	1.001	.450	1/.449
	750	838	.554	.985	.450	1/.457
	751	841	.510	.973	.450	1/.462
	752	808	.619	1.035	.455	1/.439
	753	807	.618	1.030	.455	1/.442
	754	818	.609	1.017	.455	1/.447
	761	756	.674	1.098	.500	1/.455
	762	754	.718	1.125	.500	1/.445
	763	753	.703	1.128	.500	1/.443
	772	844	.539	1.015	.449	1/.443
	842	868	0.000	1.004	.453	1/.452
	843	873	0.000	1.010	.499	1/.494
	844	858	0.000	.988	.500	1/.506
[b]						
	264[a]	478	.788	.935	1.000	.935

[a]Mixing plate installed.

[b]See also water tests 673, and 699.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
E. Cont'd.						
[b]						
	263[a]	482	.770	.889	.500	1/.562
	265[a]	521	.876	.790	.499	1/.631
	266[a]	481	.946	.962	.500	1/.519
[c]						
Phase II	960	1176	.496	1.140	.999	1/.877
	961	1106	.423	1.043	.998	1/.957
[d]						
	1116	951	.187	1.036	1.001	1/.966
	1115	955	.187	1.033	1.002	1/.970
	1114	958	.203	1.045	1.007	1/.964
	1113	936	.219	1.053	1.008	1/.957
	1112	951	.266	1.077	1.007	1/.935
	911	853	.640	.983	.998	.985
	918	848	.951	1.012	.998	1/.986
	987	482	.686	1.128	1.001	1/.887
	988	487	.613	.901	1.000	.901
	989	479	.650	.994	1.000	.994
	993	475	.817	1.049	1.001	1/.954
	995	479	.948	1.022	1.001	1/.980
	990	476	.197	1.035	.994	1/.960
	991	478	.208	1.042	.993	1/.953
	992	479	.216	1.050	.996	1/.949

[a]Mixing plate installed.

[b]See also steam test 268.

[c]See also steam tests 316, 320, 618, and 619.

[d]See also water tests 1121, 1159, 1178, 1210, and 1349.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
E. Cont'd.						
	881	465	.218	1.001	1.004	.997
	967	482	.371	.965	.999	.967
	994	481	.901	1.008	1.000	1/.993
	1122	482	1.000	1.017	.997	1/.981
a						
	912	843	.659	.983	.498	1/.507
	917	849	.900	1.029	.498	1/.485
	916	846	1.000	1.041	.499	1/.479
b						
	962	505	.018	.937	.498	1/.532
	965	481	0.000	.819	.427	1/.522
	986	487	.655	1.029	.498	1/.484
	996	485	.901	1.010	.501	1/.496
	1123	482	1.000	.993	.498	1/.502
	964	485	.043	.801	.427	1/.533
	963	484	.218	.921	.463	1/.503
	966	472	.348	.935	.500	1/.535
	1433	484	.217	.878	.501	1/.570
	1434	489	.439	1.090	.502	1/.461
	1435	482	.207	.893	.501	1/.562
	1391	497	.781	2.145	1.155	1/.538
c						
	900	1002	.167	1.063	.702	1/.661
	1416	964	.225	1.102	.745	1/.676

[a]See also water tests 1039, 1040, 1060, 1070 and steam test 1121.

[b]See also water tests 973-976, 1151, 1171, 1314, and 1401.

[c]See also steam test 1120.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
E. Cont'd.						
	901	996	.231	1.028	.702	1/.683
	1415	959	.260	1.106	.746	1/.674
	902	996	.359	1.041	.703	1/.676
	904	1005	.667	1.052	.704	1/.669
	958	998	.794	.985	.704	1/.715
a						
	907	861	0.000	.988	.249	1/.252
b						
	908	834	.517	1.199	.277	1/.231
	909	846	.660	1.145	.269	1/.235
	910	847	.664	1.151	.278	1/.241
	913	849	.798	1.397	.350	1/.250
	914	843	.904	1.454	.348	1/.239
	915	954	.951	1.440	.348	1/.242
	1124	483	.990	1.130	.349	1/.308
	1125	483	.991	1.229	.348	1/.284
	1126	484	.991	1.219	.330	1/.271
c						

[a] See also water tests 958, 978, 984, 1207, 1264, 1316, 1342, 1024, and steam tests 1152 and 1153.

[b] See also water tests 1204, 1345, 1313, 1346, and 914.

[c] See also water tests 1169, and 1254.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
F. Effects of Void Fraction and Pressure, at Various Volumetric Flow Rate and Speed Combinations for Reverse Flow						
Phase I	403	1012	.041	-.703	-.499	1/.710
	404	1002	.220	-.704	-.498	1/.708
	405	990	.398	-.689	-.497	1/.722
	406	996	.791	-.677	-.495	1/.731
	421	997	0.000	-.685	-.499	1/.727
	423	1000	.139	-.712	-.499	1/.701
	426	1000	.586	-.685	-.499	1/.728
	517	997	.950	-.693	-.496	1/.717
	428	997	1.000	-.703	-.498	1/.708
	413	1003	.101	-.686	-.698	.983
	414	1003	.395	-.682	-.698	.977
	415	998	.795	-.695	-.699	.994
	422	1000	0.000	-.685	-.700	.980
	518	999	1.000	-.699	-.700	.999
	436	989	0.000	-.249	.499	-.499

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
F. Cont'd.	437	995	.281	-.297	.498	-.595
	418	996	.792	-.270	.499	-.540
	522	1004	.035	-.261	.496	-.526
	523	1000	.372	-.276	.497	-.555
	524	997	1.000	-.273	.500	-.546
	443	998	.132	-.840	-.000	1/.000
	453	846	.738	-1.598	-.000	1/.000
	452	844	.608	-1.259	-.000	1/.000
	451	846	.413	-1.008	-.000	1/.000
Phase II	1466	999	.204	-.885	-.002	1/.002
	1467	1001	.203	-.864	-.001	1/.002
	1471	1011	.229	-.568	.401	-1/.706
	1472	1003	.225	-.765	.225	-1/.294
G. Forward Flow Portion of Full Performance Map for 40% Void Fraction at 1000 Psia						
Phase I	333[a]	990	.432	1.797	1.721	1/.957
	332[a]	989	.427	1.642	1.495	1/.911

[a]Mixing plate installed.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
G. Cont'd.	313	984	.420	1.008	.997	1/.989
	314	994	.424	1.482	.999	1/.674
	330[a]	963	.404	1.412	.998	1/.707
	331[a]	986	.396	1.402	.996	1/.711
	299	994	.414	1.217	.508	1/.417
	566	1015	.361	.947	.000	1/.000
	291[a]	1007	.430	.684	.000	1/.000
	290[a]	1002	.397	.350	.000	1/.000
	334[a]	986	.432	1.328	1.628	.815
	359[a]	991	.415	1.319	1.482	.890
	360[a]	985	.411	1.303	.999	1/.767
	224	986	.366	1.135	.998	1/.880
	338[a]	990	.436	1.049	1.219	.861
	344	989	.447	1.054	1.001	1/.950
	361[a]	999	.404	.997	1.148	.868
	230[a]	985	.428	.943	.498	1/.528
	231[a]	992	.415	.984	.499	1/.507
	293[a]	999	.407	.984	.502	1/.510
	312	998	.424	1.006	.499	1/.496
	281[a]	979	.501	.796	1.239	.643
	225[a]	992	.429	.722	.987	.732
	339[a]	987	.426	.716	1.007	.710
	280[a]	991	.429	.719	.503	1/.700

[a]Mixing plate installed.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
G. Cont'd.						
	292[a]	991	.422	.715	.500	1/.699
	362[a]	1003	.399	.342	.833	.410
	284[a]	993	.369	.358	.699	.512
	229[a]	986	.488	.409	.993	.412
	228[a]	992	.485	.396	.700	.566
	283[a]	992	.456	.373	.499	.747
	363	998	.389	.337	.550	.613
	289[a]	972	.565	.063	.996	.063
	287[a]	997	.421	.052	.499	.105
	233[a]	998	.387	1.017	1.003	1/.986
	234	998	.416	.965	.997	.967
	235	994	.458	.904	.998	.906
	237[a]	985	.514	.656	1.001	.655
	238[a]	992	.497	.594	.499	1/.840
	239[a]	981	.471	.711	.999	.712
	240[a]	985	.442	.631	.498	1/.789
	241[a]	990	.408	.682	.498	1/.730
	242[a]	985	.427	.766	.990	.774
	217	902	.380	.629	1.020	.617
	226[a]	976	.481	.811	1.221	.664

[a]Mixing plate installed.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
G. Cont'd.						
	286[a]	1000	.411	.384	1.103	.348
	243[a]	980	.366	.932	.999	.933
	285	1004	.385	.356	1.007	.354
	726	949	.361	.719	.503	1/.699
	737	942	.414	.792	.500	1/.632
	739	940	.394	.692	.500	1/.722
	740	904	.449	1.034	.765	1/.740
	746	940	.367	1.136	.500	1/.440
	806	914	.433	1.229	.499	1/.406
Phase II	898	1045	.421	.361	-.001	-1/.002
	899	1027	.422	.363	-.001	-1/.002
	902	996	.359	1.041	.703	1/.676
	959	1004	.434	.224	.250	.895
	921	1006	.472	.110	.995	.110
	922	1013	.425	.267	.996	.268
	1417	988	.478	.053	.497	.106
	1420	991	.386	.039	.498	.079
	1393	1012	.438	1.170	.282	1/.241
	1394	964	.435	1.441	.817	1/.567
	1395	946	.418	1.406	.792	1/.563
	1396	946	.414	1.392	.762	1/.547

[a] Mixing plate installed.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
H. Reverse Flow Portion For Full Performance Map for 40% Void Fraction at 1000 psia						
Phase I	405	990	.398	-.689	-.497	1/.722
	407	999	.358	-1.057	-.499	1/.472
	408	1005	.387	-1.101	-1.000	1/.908
	409	1001	.412	-1.055	-1.498	.704
	412	1005	.398	.096	.499	.192
	414	1003	.395	-.682	-.698	.977
	419	1005	.415	-.922	-.235	1/.255
	420	1010	.396	-.492	.197	-1/.400
	424	988	.428	-.713	-.996	.715
	425	1001	.399	-.690	-1.489	.463
	427	1009	.387	-.346	-.498	.695
	441	1000	.385	-1.009	-.000	1/.000
	442	996	.376	-.689	-.000	1/.000
	444	997	.391	-.299	-.000	1/.001
	445	996	.346	-.281	-.000	1/.001
	503	995	.401	-.777	-.252	1/.320

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
H. Cont'd.						
	504	998	.409	-.787	-.252	1/.320
	505	996	.411	-.246	.249	-.989
	506	1003	.362	-.277	.287	-.966
	507	1000	.383	-.339	.344	-.985
	508	998	.385	-.623	.629	.991
	521	1004	.390	-.297	-1.047	.284
	523	1000	.372	-.276	-.497	.555
	525	1042	.357	-.985	.002	-1/.002
Phase II	1473	1001	.503	-.123	.800	-.154
	1474	1000	.466	-.118	.799	-.147
	1475	998	.464	-.116	.802	-.145
	1476	1001	.384	-.102	.802	-.127
I. Forward Flow Portion of Full Performance Map for 20% Void Fraction at 1000 psia						
Phase I	216	999	.224	1.035	1.003	1/.970
	221	1004	.165	.981	.501	1/.506
	222	1006	.180	1.005	.501	1/.498

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
I. Cont'd.	278	982	.234	1.007	.992	1/.985
	279	987	.230	.973	1.041	.935
	350	989	.176	1.057	.995	1/.941
	351	994	.220	.974	.503	1/.517
	352	993	.214	.973	.450	1/.462
	571	1111	.235	1.165	1.301	.895
	719	966	.195	.485	.573	.847
	720	966	.175	.495	.572	.865
	800	971	.230	1.006	.500	1/.497
	801	971	.223	1.005	.501	1/.498
	802	972	.194	1.096	.504	1/.460
Phase II	888	994	.253	.646	.991	.652
	900	1002	.167	1.063	.702	1/.661
	901	996	.231	1.028	.702	1/.683
	903	1001	.248	1.068	.834	1/.781
	1113	936	.219	1.053	1.008	1/.957
	1114	958	.203	1.045	1.007	1/.964
	1115	955	.187	1.033	1.002	1/.970
	1116	951	.187	1.036	1.001	1/.966
	1416	964	.225	1.102	.745	1/.676

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
J. Reverse Flow Portion of Full Performance Map for 20% Void Fraction at 1000 psia						
Phase I	404	1002	.220	-.704	-.498	1/.708
	417	1010	.250	-.182	.498	-.365
	527	1123	.151	-.862	.001	-1/.002
	539	947	.188	-.767	.390	-1/.509
	540	948	.158	-.745	.384	-1/.516
Phase II	1466	999	.240	-.885	-.002	1/.002
	1467	1001	.203	-.864	-.001	1/.002
	1471	1011	.229	-.568	.401	-1/.706
	1472	1003	.225	-.765	.225	-1/.294
	1478	887	.200	-.025	.997	-.025

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
K. Forward Flow Portion of Full Performance Map for 80% Void Fraction at 850 psia						
Phase I	269	846	.795	.962	.995	.967
	270[a]	844	.798	.986	1.506	.655
	271[a]	847	.795	.996	1.909	.522
	273[a]	842	.811	.360	.500	.721
	274[a]	846	.811	.356	.249	1/.700
	275[a]	839	.813	.353	.999	.354
	276[a]	856	.816	.371	1.496	.248
	277[a]	844	.852	.440	1.495	.294
	384	850	.715	.775	.497	1/.641
	386	845	.792	.963	.499	1/.518
	387	841	.794	.975	.999	.976
	762	754	.718	1.125	.500	1/.445
	763	753	.703	1.128	.500	1/.443
	813	742	.732	1.158	.501	1/.433
	814	740	.762	1.174	.500	1/.426

[a]Mixing plate installed.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
K. Cont'd.						
Phase II	913	849	.798	1.397	.350	1/.250
	919	849	.801	1.022	.847	1/.828
	920	847	.817	.095	.999	.095
	887	868	.799	1.406	-.000	-1/.000
L. Reverse Flow Portion of Full Performance Map for 80% Void Fraction at 850 psia						
Phase I	406	996	.791	-.677	-.495	1/.731
	415	998	.795	-.695	-.699	.994
	418	996	.792	-.270	.499	-.540
	453	846	.738	-1.598	-.000	1/.000
	544	847	.737	-1.184	-1.215	.974
Phase II	1477	855	.811	-.259	.998	-.260
	1479	869	.814	-.120	.995	-.121
	1480	851	.829	-.119	.995	-.119

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
M. Steady-State Tests for Comparison with Snap-shots of Conditions in Forward Blowdowns						
Phase I	717	1015	0.000	.098	.860	.114
	721	968	.297	.568	.571	.993
	739	940	.394	.692	.500	1/.722
	740	904	.449	1.034	.765	1/.740
	742	868	.503	1.126	.864	1/.767
	744	870	.450	1.208	.582	1/.482
	745	888	.448	1.196	.541	1/.452
	746	940	.367	1.136	.500	1/.440
	754[a]	818	.609	1.017	.455	1/.447
	757[a]	802	.635	1.104	.480	1/.434
	763[a]	753	.703	1.128	.500	1/.443
	766[a]	707	.745	1.212	.509	1/.420
	770[a]	638	.802	1.337	.520	1/.389
	772	844	.539	1.015	.449	1/.443
	773	952	.263	.972	.568	1/.584
	786[a]	277	.987	1.270	.551	1/.434
	800	971	.230	1.006	.500	1/.497

[a]Mixing plate installed.

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
M. Cont'd.						
	801	971	.233	1.005	.501	1/.498
	803	951	.328	1.147	.466	1/.406
	804	946	.288	1.100	.437	1/.397
	805	845	.554	1.163	.499	1/.429
	806	914	.433	1.229	.499	1/.406
	807	893	.470	1.203	.498	1/.414
	808	856	.525	1.199	.497	1/.415
	809	846	.554	1.163	.499	1/.429
	810	848	.618	1.147	.499	1/.435
	811	797	.648	1.144	.499	1/.436
	812	745	.676	1.136	.500	1/.440
	813	742	.732	1.158	.501	1/.433
	814	740	.762	1.174	.500	1/.426
	815	645	.811	1.183	.500	1/.423
	816	645	.810	1.179	.500	1/.424
	817	302	.980	1.415	.500	1/.353
	819	301	.989	1.459	.500	1/.343
	820	305	.992	1.508	.500	1/.331
	821	303	.992	1.537	.500	1/.326
	822	301	1.000	1.577	.500	1/.317
Phase II	1113	936	.219	1.053	1.008	1/.957
	1114	958	.203	1.045	1.007	1/.964
	1115	955	.187	1.033	1.002	1/.970

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
M. Cont'd.						
	1116	951	.187	1.036	1.001	1/.966
	1414	782	.674	1.270	.657	1/.517
	1385	557	.891	2.179	.991	1/.455
	1386	461	.930	2.553	.992	1/.389
	1387	481	.912	2.394	.993	1/.415
	1388	480	.926	2.467	.991	1/.402
	1389	477	.919	2.415	.992	1/.411
	1408	409	.981	3.139	.685	1/.218
	1416	964	.225	1.102	.745	1/.676
	1394	964	.435	1.441	.817	1/.567
	1395	946	.418	1.406	.792	1/.563
	1396	946	.414	1.392	.762	1/.547
	1412	790	.622	1.218	.529	1/.434
	1413	798	.654	1.328	.529	1/.398
	1410	553	.806	1.339	.477	1/.356
	1409	533	.881	1.323	.295	1/.223
	1406	427	.982	3.076	.449	1/.146
	1407	417	.954	3.094	.455	1/.147
	1403	279	.979	3.367	.598	1/.178
	1404	312	.979	3.113	.407	1/.131
	1405	283	.980	3.248	.407	1/.125

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
N. Steady-State Tests for Comparison with Snapshots of Conditions in Reverse Blowdowns						
Phase I	438	997	.071	-.555	.477	-1/.859
	439	1193	.096	-.571	.478	-1/.836
	525	1042	.357	-.985	.002	-1/.002
	526	1093	.510	-1.124	.000	-1/.000
	527	1123	.151	-.862	.001	-1/.002
	528	1127	.133	-.814	.001	-1/.001
	529	1129	.119	-.819	.000	-1/.000
	530	1130	.110	-.820	.005	-1/.006
	531	1131	.085	-.812	.000	-1/.000
	532	660	.639	-1.251	.000	-1/.000
	533	657	.641	-1.234	.000	-1/.000
	534	456	.899	-1.686	.001	-1/.001
	535	445	.926	-1.697	.000	-1/.000
	538	952	.092	-.469	.654	-.718
	539	947	.188	-.767	.390	-1/.509
	540	948	.158	-.745	.384	-1/.516
	541	934	.226	-.984	-.482	1/.489

TABLE 3-1

STEADY-STATE TEST MATRIX (Cont'd.)

TYPE OF TEST	TEST NO. --	UPSTREAM PRESSURE PSIA --	UPSTREAM VOID FRACTION α_F	UPSTREAM HOMOLOGOUS FLOW PARAMETER ν	PUMP HOMOLOGOUS SPEED PARAMETER α_N	FLOW - SPEED RATIO $\frac{\nu}{\alpha_N}$
N. Cont'd.						
	542	921	.318	-.916	-.998	.918
	543	904	.624	-1.050	-1.089	.964
	544	846	.737	-1.184	-1.215	.974
	558	538	.784	-1.166	-.930	1/.798
O. Effects of Seal Injection Inflow						
Phase I	287	997	.421	.052	.499	.105
Phase II	1418	989	.552	.054	.497	.108
	1419	991	.556	.054	.498	.109
	1421	989	.576	.058	.497	.117
	1423	968	.655	.070	.495	.141
	1424	985	.648	.069	.496	.138
	1425	990	.652	.069	.496	.139
	1426	996	.646	.066	.496	.134
	1427	996	.639	.064	.496	.130
	1428	997	.619	.060	.496	.121
	1429	1000	.618	.060	.496	.122

Section 4

TEST DATA

4.1 MEASURED AND DERIVED PARAMETERS USED IN DATA PRESENTATION

Both measured and derived parameters are included in the steady state data presented in this report. This section will indicate what types of parameters are included in these two categories. Details of data processing, presentation formats, and actual numbers will be given in the sections below.

The raw, measured data was recorded as electrical voltages from the instrumentation circuits for five successive scans for each instrument channel. (See Volume VII for details). On the basis of instrument calibrations, the scan voltages were converted into engineering units. These resulting quantities are also considered measured data and comprise pressures, pressure differences, temperatures, gamma-densitometer beam densities (or specific volumes), pump rotational speed, shaft torque, turbine meter velocities, drag disc momentum fluxes, and seal injection outflow. These quantities are included in the data presentation as five-scan averaged values. It should be noted that some of the instrument calibration procedures, especially for gamma densitometers, turbine meters, and drag discs, involved cross-checks with other measurements, at least in certain ranges, and therefore some of the resulting test data may be considered to fall into the derived data category. These gamma densitometer, turbine meter, and drag disc measurements are most essential for transient (blowdown) tests but are included also in steady-state data to provide alternate measurement comparisons, information on density distributions and flow regimes, and aid in comparing steady-state and transient pump performance.

Derived parameters are considered to be those obtained by combining or manipulating the measured data. Manipulations may be mathematical (differences, products, etc.), empirical (ASME Steam Table properties), or analytical (e.g. ratio of local to stream-average values). Derived data presented in this report include non-dimensional and/or dimensional volumetric flow rates, stream-average specific volumes and void fractions, pump head, friction-and-windage torques, hydraulic torques, mass flow rates, stream velocities, and superficial phase velocities. Also displayed is information regarding deviations from desired set points, drifts during the five-scan time period, measurement uncertainties and standard deviations.

Details of how various parameter values are derived from the measured data are give in Section 4.2 below. Table 4-1 provides a visual schematic display of how the measured and derived data are related.

4.2 DATA REDUCTION AND PROCESSING METHODS

Key information is given here, and extensive details are provided in Volume VIII-Data Processing Methods, regarding how the steady-state test data were converted from raw measurement data (electrical voltages) to measured quantities in engineering units and then combined and manipulated to produce the variety of derived parameters listed in the previous section and shown schematically in Table 4-1. Conversion to engineering units and derivation of parameters to the extent indicated in Table 4-1 plus storage of the resulting reduced data was done by digital computer using the Steady-State Data Reduction Code described below. Another computer code, the Pump Steady-State Review Code, and its output Summary Table Code, which are also described below, were then used to further process the data for review of data consistency and examination of performance results.

The format of the printouts and tables produced by the data processing codes is detailed in Section 4.3, and graphical presentations are covered under Section 5, Data Analysis.

4.2.1 Data Reduction Code

The purpose of the Steady-State Data Reduction (SSDR) Code is to calculate parameters relevant to pump performance from the raw output signals of each transducer using the appropriate calibration constants. This is a two step process. First, the raw data file is read in and combined with the appropriate values from the calibration file to produce instrument outputs in engineering units. In the second step, the derived parameters are calculated from the instrument outputs. This process is discussed here and is described in detail in Volume VIII, Section 1.2.

Table 4-1

MEASURED AND DERIVED PARAMETERS

PARAMETERS (Suction, Discharge and/or Average)	REQUIRED QUANTITIES		MEASURED DATA PARAMETERS	MEASUREMENT LOCATIONS
Volumetric Flow Rate (Q, ν)	$\dot{M}$ mixture	$\dot{M}$ water	°F, P, ΔP	Water Line Orifices
		$\dot{M}$ steam	°F, P, ΔP	Steam Line Orifices
	ρ mixture	- See Below		Pump SIS
	Q rated	- Known		Pump DIS
Fluid Mixture Density (ρ) Void Fraction (α_F)	Quality(x) mixing tee	$\dot{M}$ water as above		
		$\dot{M}$ steam as above		Lines to mixing tee
	ρ sat liquid		°F or P	or Pump SIS
	ρ sat vapor		°F or P	or Pump DIS
	corrections for heat, in or out	From mixing tee to leg upstream of pump	°F or P	Pump SIS or DIS
		Pump work: $\dot{M}$ (above), H (below)		
		Seal Injection $\dot{M}$ and enthalpy	°F, ΔP °F, Q meter	Injection inlet orifice Injection outlet
	or			
	γ - ray attenuation Density distribution	γ - densitometer	3 beam strengths	Pump SIS Pump suction flange Pump DIS
	ρ sat liquid and vapor	As above		

Table 4-1 (Cont'd.)

MEASURED AND DERIVED PARAMETERS

PARAMETERS (Suction, Discharge and/or Average)	REQUIRED QUANTITIES		MEASURED DATA PARAMETERS	MEASUREMENT LOCATIONS
Pressure (P)	Measured		P	Pump SIS Pump DIS
Pump Head (H,h)	ΔP Pump		ΔP	Pump SIS-to-DIS Pump inlet flange-to-outlet flange
	ρ in, ρ out, or ρ any	as above	(See above)	
Pump Speed (N, α_N)	N	Measured	N	Pump Shaft
	N rated	Known		
Pump Torque (T_{hyd}, β_h)	T shaft	Measured	T	Pump Shaft
	T friction & windage	N as above P upstream leg	P	Pump SIS or DIS
	T rated	Known		
	ρ mixture	as above	(See above)	
	ρ rated	Known		
Stream Velocity (V)	Q	as above	(See above)	
	A pipe	known		
	or			
	V at a point (Turbine meter) Assumed velocity profile		V	Pump SIS Pump DIS

Table 4-1 (Cont'd.)

MEASURED AND DERIVED PARAMETERS

PARAMETERS (Suction, Discharge and/or Average)	REQUIRED QUANTITIES		MEASURED DATA PARAMETERS	MEASUREMENT LOCATIONS
Stream Momentum Flux (ρV^2)	ρ as above from mixing tee, etc.			
	V stream as above from Q and A pipe			
	or			
	ρ	as above from γ - densitometer		
	V stream	as above from Q and A pipe		
	or			
	ρV^2	Drag disc at a point	ρV^2	Pump SIS
		Assumed profile		Pump DIS
Flow Regime	Density (ρ) distribution:	γ-densitometer	3 beam densities	Pump SIS
	ρ sat liquid and vapor	as above		Pump suction flange
	or	Q as above	(See above)	Pump DIS
	V_{SL}, V_{SG}	α_F as above	(See above)	
	Flow Regime Map	A pipe - Known		
Drum Inventory	Liquid head		ΔP	Drum, bottom-to-top
	Liquid density		°F	Drum lower region
	Drum Volume vs height	Known		

Data from each test point is contained in a data file which consists of five complete scans of all steady-state instruments. Calibration constants and zeros for each instrument are contained in a separate file. The SSDR Code first reads both files and then proceeds to calculate the output of each instrument in engineering units on a scan-by-scan basis, for all five scans, consecutively. That is, raw data values from the first scan only are used during the first pass through the calculation section. The parameters calculated include water and steam flow at the respective orifice and injection inlet and outlet flows. From these values the fluid properties, mass and volumetric flows, fluid velocity and momentum, and void fraction upstream and downstream of the test pump are calculated. Average values across the test pump are also computed, as well as uncertainties in all the above quantities. Once all calculations for the first scan are complete, the program loops back and performs the same calculations on raw data from the second scan. This continues until all five scans have been separately reduced. At this time the average value, drift and standard deviation are calculated. Finally, the results are printed out and written to a computer file for later used by the Pump Steady State Review Code. A more detailed discussion of the data reduction code may be found in Volume VIII-Data Processing Methods.

4.2.2 Pump Steady-State Review and Summary Table Codes

The Pump Steady-State Review (PSSR) Code was developed and used to access the reduced steady-state data files and further process the data for review of data consistency and examination of performance results. The Summary Table Code was developed to summarize key output of the PSSR Code. Two versions of the PSSR Code were developed, one for processing forward flow steady-state test data, and the other for reverse flow tests. The description provided here is specifically for the PSSR forward flow version. Explanations are added, however, to clarify the reverse flow version. Also provided in this section is a description of the Summary Table Code. An extended detailed report on these codes is to be found in Volume VIII.

The PSSR code is structured to calculate:

a. homologous ratios for the pump-developed static and total heads,

b. homologous ratio for the pump hydraulic torque,

c. homologous ratios of pump flow and speed,

d. pressure drops based on handbook K-factors, and actual K-factors based on measured pressure drops for flow of fluid in the pump suction and discharge legs, and

e. mechanical, hydraulic and total efficiencies of the pump.

The input to the code is taken from computer data files and is fully automated except to retain the flexibility by the user to analyze any desired test.

The output is in the form of a detailed review of significant test parameters and calculated values for each test. The supplemental Summary Table Code is used to extract certain results obtained by the PSSR Code and to generate a comprehensive summary table which lists the key test parameters and calculated homologous ratios for all the tests.

4.2.2.1 Algebraic Relations Used in the Code

4.2.2.1.1 Dimensionless quantities. The pump test parameters, expressed in dimensionless quantities, are given by:

$$\nu = \frac{Q}{Q_R} = \frac{\text{Pump Volumetric Flow Rate}}{\text{Rated Pump Volumetric Flow Rate}}$$

Flow is defined as positive in the normal flow direction.

$$\alpha_N = \frac{N}{N_R} = \frac{\text{Pump Speed}}{\text{Rated Pump Speed}}$$

Speed is positive in the normal direction of pump rotation.

$$h = \frac{H}{H_R} = \frac{\text{Pump Head}}{\text{Rated Pump Head}}$$

Head is positive when pressure at the normal discharge side of the pump is greater than at the normal suction side.

Several definitions for pump head are used, and corresponding calculations are performed by the PSSR Code. They are:

1. Pump head, static leg to leg, based on upstream leg specific volume

2. Pump head, static leg to leg, based on local specific volumes

3. Pump head, total leg to leg, based on local specific volumes

4. Pump head, static flange to flange, based on local specific volumes

5. Pump head, total flange to flange, based on local specific volumes

The value for pump head based on definition 1 is the one listed in the Summary Table and used in developing the initial pump performance maps.

The density-adjusted torque values in the initial data presentation are derived from:

$$\beta_h = \frac{T_h}{T_R} \frac{\rho_R}{1/v_{ave}} = \frac{\text{Pump Hydraulic Torque}}{\text{Rated Pump Torque}} \times \text{Rated Density} \times \begin{matrix}\text{Average}\\ \text{Specific}\\ \text{Volume}\end{matrix}$$

$$\beta_{sh} = \frac{T_{sh}}{T_R} \frac{\rho_R}{1/v_{ave}} = \beta_h \frac{T_{sh}}{T_h} = \beta_h \frac{\text{Pump Shaft Torque}}{\text{Pump Hydraulic Torque}}$$

in which

1. T_{sh} is the shaft torque driving the pump, measured by the torque meter in the drive shaft between the gear box and the pump, and is positive in the normal direction of pump rotation,

2. T_h is the hydraulic torque, defined as the torque exerted by the impeller on fluid in the impeller passages, and equal to $T_{sh} - T_{f\&w}$ which is positive in the direction of normal rotation.

3. $T_{f\&w}$ is the torque required to overcome rotational friction and windage in the pump and is in the same direction as the pump rotation, and therefore has the same sign as the pump speed.

4. v_{ave} is the average specific volume given by:

   $v_{ave} = (1/2)\ (v_{upstream} + v_{downstream})$

The above dimensionless quantities ν, h, β_h and β_{sh} are evaluated for specific volumes derived (1) from gamma-densitometer measurements and (2) from orifice measurements combined with measurements in the suction and discharge pipe legs through an energy balance. Orifice-based upstream fluid properties are derived by way of an energy balance from water and steam orifice mass flow measurements, a calculated heat loss from the piping between the orifices and the upstream leg, the measured upstream leg pressure and/or temperature, and the supposition of homogeneous non-slip flow. Orifice-based downstream properties are derived from orifice measurements, heat loss along the way to the upstream leg, pump work, and downstream leg pressure and/or temperature. See Section 5.1.

The pump rated operating conditions, for maximum efficiency, obtained from the manufacturer's cold water tests (Reference 2) are as follows:

Rated Head, H_R = 252 ft of water

Rated Flow Rate, Q_R = 3500 gpm

Rated Torque, T_R = 308 ft-lbf

Rated Speed, N_R = 4500 rpm

Water Density, ρ_R = 62.3 lbm/ft^3

4.2.2.1.2 Homologous ratios. The homologous ratios, defined on the basis of fluid dynamic similarity principles (Appendix A), are calculated by the PSSR code. They are:

$\frac{h}{\alpha_N^2}$ or $\frac{h}{\nu^2}$: homologous head ratio

$\frac{\beta_h}{\alpha_N^2}$ or $\frac{\beta_h}{\nu^2}$: homologous hydraulic torque ratio

$\frac{\nu}{\alpha_N}$ or $\frac{\alpha_N}{\nu}$

Homologous head ratios are calculated in the code using all the head values defined. These calculations are detailed below.

For values of homologous flow-to-speed ratio greater than 1.0 ($\nu/\alpha_N > 1$) it is common to use the alternate homologous ratios with ν in the denominator and so all the ratios h/α_N^2, h/ν^2, β_h/α_N^2 and β_h/ν^2 are calculated. When the flow-to-speed ratio is less than or equal to 1($\nu/\alpha_N \leq 1$), the only similarity ratios calculated are h/α_N^2 and β_h/α_N^2.

4.2.2.1.3 Static and total head calculations. The pressure drops and pressure rises were measured as shown in the schematic of the test loop facility (Figure 4-1). The pump heads defined above are calculated as follows:

Pump Head, Static Leg to Leg, Based on Upstream Leg Specific Volume

Here, "leg to leg" ΔP means ΔP in psi between the pump suction instrumentation spool (SIS) and pump discharge instrumentation spool (DIS), which are designated in the code as stations 1 and 2, respectively.

$$\left[H_S^{LL}\right]_{UPSv} = \Delta P_{12} \times v_1 \times 144 \times \frac{|g_s|}{g}, \text{ ft}$$

v_1: Representative specific volume at station 1, ft^3/lbm

$|g_s|/g = lbm/lbf \cong 1.$

This calculated pump head is used in the head parameters listed in the Summary Table and in the preparation of the initial pump performance maps.

Pump Head, Static Leg to Leg, Based on Local Specific Volumes

$$\left[H_S^{LL}\right]_{local\ v} = \left[(P_1 + \Delta P_{12})\ v_2 - P_1 \times v_1\right] \times 144 \times \frac{|g_s|}{g}, \text{ ft}$$

where

v_2 = Representative specific volume at station 2, ft^3/lbm.

Pump Head, Total Leg to Leg, Based on Local Specific Volumes

Total hydraulic head at any station =

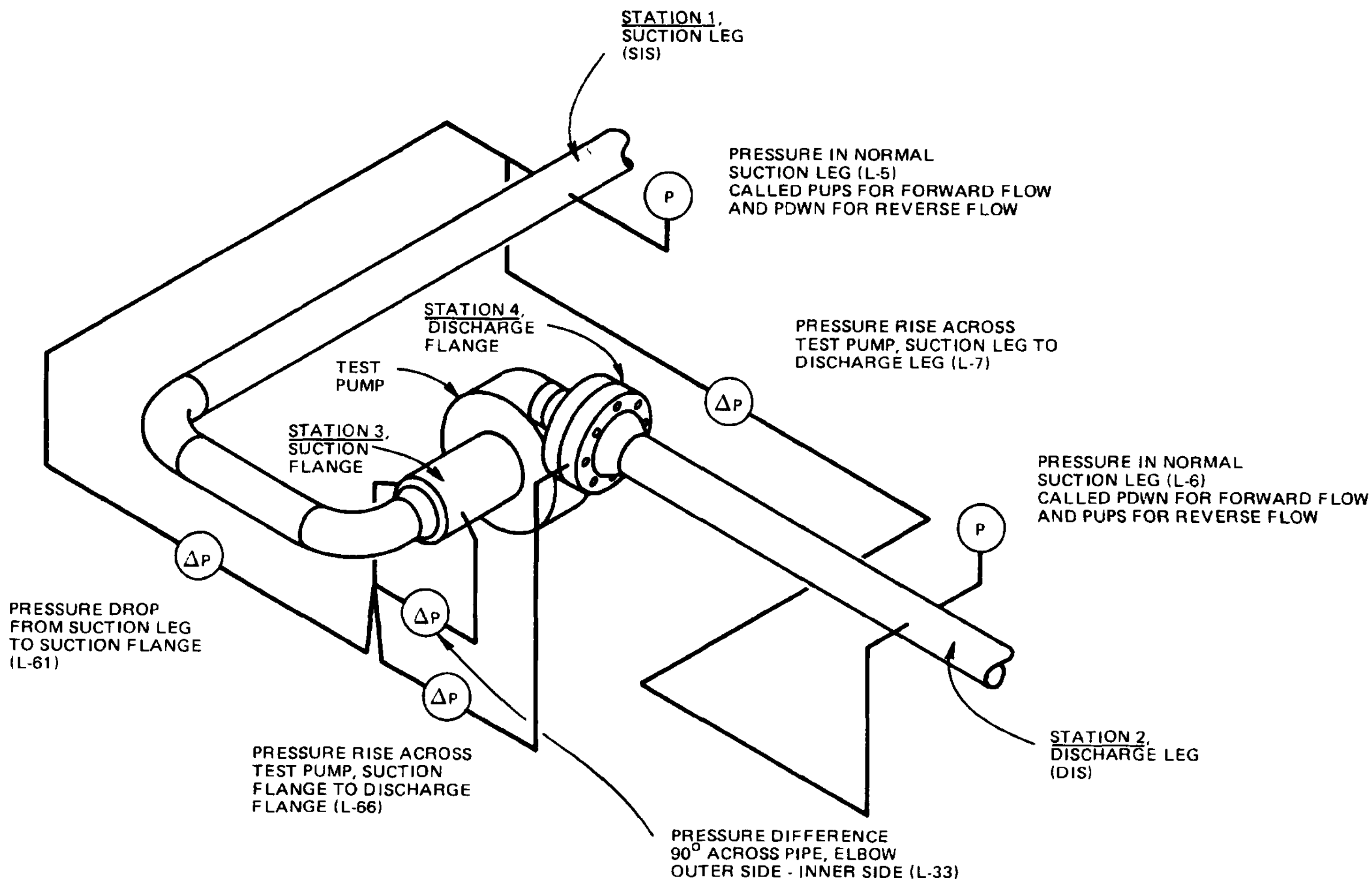


Figure 4-1. Test section pressure and differential pressure measurements.

$$\frac{P_{static}}{\rho} \times 144 \times \frac{|g_s|}{g} + \text{velocity head} + \text{elevation head.}$$

Applying this between stations 1 and 2,

$$\left[H_T^{LL}\right]_{local\ v} = \left[(P_1 + \Delta P_{12}) \times v_2 - P_1 \times v_1\right] \times 144 \times \frac{|g_s|}{g} +$$

$$\frac{V_2^2 - V_1^2}{2g} + (Z_2 - Z_1),\ \text{ft}$$

where

V_1 = Representative velocity of fluid at station 1, ft/sec

V_2 = Representative velocity of fluid at station 2, ft/sec

$(Z_2 - Z_1)$ = Difference in elevation between the normal discharge and suction lines of the test pump, 1.0 ft (actual).

Note that, in the above equation for H_T^{LL}, the absolute static pressure at station 2 is referenced with respect to the value at station 1 via ΔP_{12} even though the measured absolute at station 2 is available. This is because, in general, the direct measurement of ΔP is more accurate than taking the relatively small difference between the two large measured absolute pressures. Note also that the total hydraulic head function does not account for themodynmaic energy such as that associated with changes in temperature and change of state.

<u>Pump Head, Static Flange to Flange, Based on Local Specific Volumes</u>

$$\left[H_S^{FF}\right]_{local\ v} = \left[(P_1 - \Delta P_{13} + \Delta P_{34}) \times v_4 - (P_1 - \Delta P_{13}) \times\right.$$

$$\left. v_3\right] \times 144 \times \frac{|g_s|}{g},\ \text{ft}$$

where

v_4 = Representative specific volume at station 4, (as first approximation assumed equal to v_2), ft^3/lbm

v_3 = Representative specific volume at station 3, (assumed equal to v_1), ft^3/lbm

ΔP_{34} = Flange-to-flange pressure rise across the pump, psi

ΔP_{13} = Pressure drop between stations 1 and 3, psi

For reverse flow, the equivalent equation is

$$\left[H_S^{FF}\right]_{local\ v} = \left[(P_1 + \Delta P_{31} + \Delta P_{34}) \times v_4 - (P_1 + \Delta P_{31}) \times v_3\right] \times 144 \times \frac{|g_s|}{g}, \text{ ft}$$

Pump Head, Total Flange to Flange, Based on Local Specific Volumes

$$\left[H_T^{FF}\right]_{local\ v} = \left[H_S^{FF}\right]_{local\ v} + \frac{V_4^2 - V_3^2}{2g} + (Z_4 - Z_3), \text{ ft}$$

where V_4 and V_3 are the representative velocities at stations 4 and 3, approximated as equal to those at stations 2 and 1 respectively (ft/sec).

4.2.2.1.4 K-Factor calculations. The code calculates K-factor data from the static pressure drop measurements for single and two-phase fluid flows in the pump suction and discharge test section legs.

The relationship between K-factor and pressure drop is given by

$$\Delta P = K \times \frac{\rho V^2}{2|g_s| \times 144}$$

From this equation, K-factors are evaluated for the values of ΔP_{13} and ΔP_{42} derived from measurements:

$$K \text{ (for suction leg 1-3)} = \frac{\Delta P_{13} \times v_1 \ (2|g_s| \times 144)}{V_2^2}$$

$$K \text{ (for discharge leg 4-2)} = \frac{\Delta P_{42} \times v_2 \,(2|g_s| \times 144)}{V_2^2}$$

where,

$\Delta P_{42} = [(-\Delta P_{12}) - \Delta P_{13} - (-\Delta P_{34})]$ is the pressure drop due to mixing and friction between 4 and 2, psi.

For reverse flow steady state tests, the pressure drop ΔP_{24} is given by:

$$\Delta P_{24} = (\Delta P_{12} - \Delta P_{34} - \Delta P_{31}),\ \text{psi}$$

Also, for comparison, ΔP's are calculated using handbook single-phase K values of 0.69 for the suction leg (1 to 3) and 0.15 for the discharge leg (4 to 2).

4.2.2.1.5 Efficiency calculations. Pump efficiency is defined in several forms. They are hydraulic efficiency, mechanical efficiency and total efficiency.

Hydraulic efficiency is given by:

$$\eta_h = \frac{WH}{T_h \omega}$$

where

- W : weight flow rate, lbf/sec
- H : head developed by the pump, ft
- T_h: hydraulic torque, ft-lbf
- ω : pump speed, radians/sec

Representing the above in terms of reduced data quantities Q (volumetric flow rate, gal/min), v (specific volume, ft^3/lbm), H(head,ft), T_h (hydraulic torque, ft-lbf), and N (pump speed, rpm), η_h =

$$\frac{\frac{Q[gpm]}{60[sec/min]} \times \frac{1}{7.48}\left[\frac{ft^3}{gal}\right] \times \frac{1}{(v)_{Q,\nu}}\left[\frac{lbm}{ft^3}\right] \times \frac{g}{|g_s|}\left[\frac{lbf}{lbm}\right] \cdot \times (H_{static} + H_{elev})\ [ft]}{T_h\ [ft\text{-}lbf] \times \frac{2\ \pi\ N}{60}\ \frac{rad}{rev}\ [rpm]\ \frac{min}{sec}}$$

Introducing the rated quantities Q_R, H_R, N_R, T_R and non dimensionalizing,

$$\eta_h = 0.84355\ \frac{\nu}{\alpha_N} \times \frac{h + \frac{1.0}{H_R}}{\beta_h} \times \frac{(v)_{\beta_h}}{(v)_{Q,\nu}} \tag{4-1}$$

where

$$\beta_h = \frac{T_h}{T_R} \times (62.3) \times (v)_{\beta_h}$$

$$\nu \equiv \frac{Q}{Q_R},\ \alpha_N \equiv \frac{N}{N_R},\ h \equiv \frac{H}{H_R},\ \text{and}\ \frac{g}{|g_s|} \cong 1\ \frac{lbf}{lbm},\ \text{and}$$

$(v)_{\beta_h}$ and $(v)_{Q,\nu}$ should be the specific volumes used in deriving β_h and Q(or ν), respectively, which for initial data presentation were v_{ave} and v_1, respectively. However, the existing version of the PSSR code applied Equation 4-1 with $(v)_{Q,\nu}$ taken as v_{ave}, so the factor $(v)_{\beta_h}/(v)_{Q,\nu}$ was effectively unity. Efficiencies derived by either formulation were adequate for their use in checking consistency of test data.

ii) Mechanical efficiency is the ratio of hydraulic to shaft torques:

$$\eta_{mech} = \frac{T_h}{T_{sh}}$$

iii) Total efficiency or the overall efficiency is the product of hydraulic and mechanical efficiencies:

$$\eta_{total} = \eta_h \times \eta_{mech}$$

Turbining efficiencies are the inverse of the pumping efficiencies.

4.2.2.2 Code Versions, Parameters, Structure and Operation. Two versions of the PSSR Code were developed, one to handle forward flow steady-state test data and one to handle reverse flow steady-state test data. Volume VIII gives details of the coding, code parameters, input and output structure, and operating controls. Both forward and reverse flow PSSR Code output are handled by the one version of the Summary Table Code, which is also detailed in Volume VIII.

The PSSR Code can be set up by the user to access and process the reduced data from any or all of the tests covered by a given output file from the SSDR Code by inputting the appropriate test numbers.

4.2.2.2.1 Output. The output from the PSSR Code is in two forms: one is a detailed review of many test parameters for each steady state test, and the other is a summary table of key parameters for all the tests.

For each test, the PSSR Code output provides a detailed display of all the reduced test data parameters used as input, the code-calculated five-scan averages, K-factors, homologous ratios for head and torque and the pump efficiencies, as shown in Volume VIII for a sample test.

After all the tests of interest have been processed, a summary table for those tests is generated by the Summary Table Code to include the key test parameters and the corresponding homologous ratios for pump flow-to-speed, head, and hydraulic torque. A description of the Summary Table output is included in the next section.

4.3 DATA FORMAT

4.3.1 One Page Printouts

The Steady-State Data Reduction Code (discussed in Section 4.2.1 and Volume VIII Section 1.2) uses the raw data from each test point to calculate the desired quantities for the analysis of test pump performance. The output from this code is discussed briefly in this section. A more detailed treatment along with the output from each reducible steady state test appears in Volume V, Steady-State Data.

The output from the Steady-State Data Reduction Code originally appeared in a ten-page format. For publication purposes this ten-page format was reduced to a one-page format (as used in Volume V). The primary difference between the two is the inclusion in the ten-page printout of the averaged raw data for each instrument and the output values for all five scans for certain instruments and derived parameters. Only averages over five scans appear in the one-page form. Nor do any raw data values (voltages) appear in the one-page form.

Table 4-2 is a sample one-page printout. It is divided into a heading and three main sections. The heading gives the test number and time/date the data was acquired.

The top section gives performance data based on an average of the values calculated for each of the five instrument scans that comprise the test data. The use of five data scans for each test point allows the calculation of the drift per minute and standard deviation of the quantity.

The drift per minute is calculated by a regression analysis which seeks the best fit to a linear function of the parameter versus time. A completely stable test point would have drifts of zero for all parameters. The standard deviation is calculated from the scatter of each parameter about the best linear fit of the data as a function of time. The headings "Suction" and "Discharge" refer, respectively to the normal suction and discharge sides of the test pump.

The short middle section summarizes the mass flow rates for the water orifice, steam orifice, seal injection inlet orifice, and seal injection outlet flowmeter. All flows were measured with orifices except the seal injection outlet flow which was measured with a magnetic flowmeter.

The bottom section presents the output in engineering units from all steady-state instruments. A string of asterisks indicates an instrument that was disconnected or otherwise non-functional during the test. The output is presented in English and metric units.

Associated with each instrument is a location or "L" number. This number specifies a physical instrument location on the test loop. Figure 4-2, Piping and Instrumentation Diagram (P&ID) for the test facility, shows all L numbers

TABLE 4-2

SAMPLE STEADY-STATE DATA ONE PAGE PRINT OUT

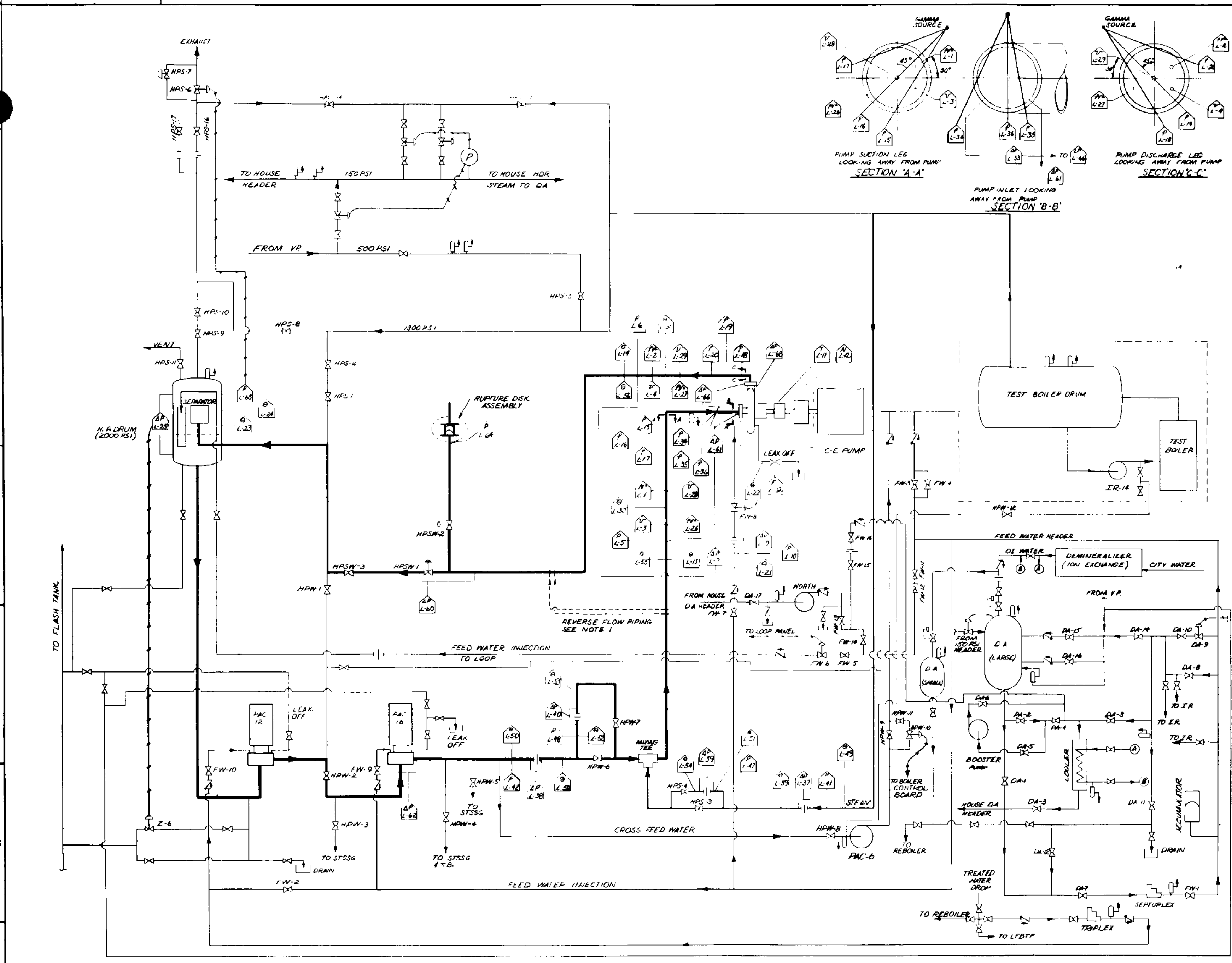
STEADY STATE TEST RESULTS FOR TEST 513 DATE 3/21/77 TIME 1320.00

PERFORMANCE DATA

PARAMETER	UNITS	SUCTION VALUE	SUCTION DRIFT/MIN	SUCTION STD. DEV.	DISCHARGE VALUE	DISCHARGE DRIFT/MIN	DISCHARGE STD. DEV.
PRESSURE	PSIA-BAR	1211./83.49	1./ .07	3./ .19	1210./83.43	0./ .02	2./ .17
VOLUME FLOW	GPM-M3/S	-533./-.0336	0./.0000	2./.0001	-548./-.0346	0./.0000	2./.0001
VOID-ENERGY BAL		0.000/0.000	0.000/.000	0.000/.000	0.000/0.000	0.000/.000	0.000/.000
VOID-GAMMA DENS		0.000/0.000	0.000/.000	0.000/.000	0.000/0.000	0.000/.000	0.000/.000
SPEED	RPM-RPM	-406./ -406.	2./ 2.	3./ 3.	-406./ -406.	2./ 2.	3./ 3.
L-L HEAD-EGY BAL	FT-M	5.4/ 1.6	.0/ .0	.1/ .0	5.4/ 1.6	.0/ .0	.0/ .0
L-L HEAD-GAMMA D	FT-M	5.3/ 1.6	.0/ .0	.1/ .0	5.3/ 1.6	.1/ .0	.0/ .0
HYDRAULIC TORQUE	FTLB-NM	6.7/ 9.1	.1/ .2	.2/ .2	6.7/ 9.1	.1/ .2	.2/ .2
FRICTION TORQUE	FTLB-NM	-4.5/ -6.1	.0/ .0	.0/ .0	-4.5/ -6.1	.0/ .0	.0/ .0
TEMPERATURE	DEG F-DEG C	564.6/ 295.9	.3/ .2	.1/ .0	565.0/ 296.1	.3/ .1	.1/ .0
EGY BAL DENSITY	LB/FT3-KG/M3	44.995/2.8050	.023/ .0014	.003/ .0002	44.960/2.8028	.018/ .0011	.006/ .0004
MOMENTUM FLUX	LB/FTS2-KG/MS2	1939./ 2885.	2./ 3.	16./ 23.	2048./ 3047.	2./ 3.	18./ 25.
VELOCITY	FT/S2-M/S2	6.56/ 2.00	.00/ .00	.03/ .01	6.75/ 2.06	.00/ .00	.03/ .01
TOTAL MASS FLOW	LB/S-KG/S	53./ 24.	0./ 0.	0./ 0.	55./ 25.	0./ 0.	0./ 0.

PARAMETER	UNITS	VALUE	DRIFT/MIN	STD. DEV.
ORIFICE WATER FLOW	LB/S - KG/S	54.92/ 24.91	.04/ .02	.24/ .11
ORIFICE STEAM FLOW	LB/S - KG/S	0.00/ 0.00	0.00/ 0.00	0.00/ 0.00
SEAL INJECTION IN	LB/S - KG/S	8.13/ 3.69	.01/ .01	.01/ .01
SEAL INJECTION OUT	LB/S - KG/S	9.58/ 4.35	.01/ .00	.02/ .01

DEVICE	UNITS	LOC	VALUE	LOC	VALUE	LOC	VALUE	LOC	VALUE
THERMOCOUPLE	DEG F-DEG C	L-13	566.8/297.1	L-14	564.5/295.9	L-21	161.4/ 71.9	L-22	186.8/ 86.0
THERMOCOUPLE	DEG F-DEG C	L-23	564.5/295.9	L-24	567.3/297.4	L-30	559.5/293.1	L-31	561.6/294.2
THERMOCOUPLE	DEG F-DEG C	L-49	567.5/297.5	L-50	565.1/296.2	L-51	405.9/207.7	L-52	556.3/291.3
THERMOCOUPLE	DEG F-DEG C	L-57	81.6/ 27.6						
PRESSURE CELL	PSIA-BAR	L-5	1210.8/83.49	L-6	1210.0/83.43	L-10	1461.1/100.75	L-41	1207.5/83.26
PRESSURE CELL	PSIA-BAR	L-42	1270.4/87.59	L-47	1209.3/83.38	L-48	1263.3/87.14	L-64	1206.8/83.21
PRESSURE CELL	PSIA-BAR	L-65	1205.5/83.12						
D. P. CELL	PSID-BAR	L-7H	2.24/ .154	L-7L	1.67/ .115	L-9	23.51/ 1.621	L-25	1.136/ .0784
D. P. CELL	PSID-BAR	L-33	-.136/ -.0094	L-37L	.004/ .0003	L-38L	.533/ .0367	L-39L	-.002/ -.0001
D. P. CELL	PSID-BAR	L-40L	.001/ .0000	L-37H	-.111/ -.0076	L-38H	.537/ .0370	L-39H	-.000/ -.0000
D. P. CELL	PSID-BAR	L-40H	-.002/ -.0001	L-60	2.73/ .188	L-61	-.021/ -.0015	L-62	.51/ .035
D. P. CELL	PSID-BAR	L-66	1.450/ .1000	L-68	.92/ .064	L-38H	.634/ .0437		
R. T. D.	DEG F-DEG C	L-53	552.7/289.3	L-54	396.7/202.6	L-55	564.5/295.9	L-56	565.0/296.1
R. T. D.	DEG F-DEG C	L-58	565.5/296.4	L-59	566.1/296.7				
TORQUE METER	FTLB-NM	L-11	2.2/ 3.0						
DRAG DISC	LB/FTS2-KG/MS2	L-1	-17328./ -25784.	L-2	440./ 655.	L-26	72152./ 107362.	L-27	********/********
TURBINE METER	FT/S-M/S	L-3	********/*****	L-4	********/*****	L-28	********/*****	L-29	********/*****
SPEED METER	RPM-RPM	L-12	-405.8/ -405.8						
DENSITOMETER	LB/FT3-KG/M3	L-15	45.327/ 726.0	L-16	45.429/ 727.7	L-17	45.798/ 733.6		
DENSITOMETER	LB/FT3-KG/M3	L-18	46.033/ 737.4	L-19	45.577/ 730.1	L-20	47.143/ 755.2		
DENSITOMETER	LB/FT3-KG/M3	L-34	45.013/ 721.0	L-35	45.377/ 726.8	L-36	45.153/ 723.3		
MAG FLOW METER	GPM-M3/HR	L-32	71.2/ 16.2						



INSTRUMENTATION

P - PRESSURE CELL
ΔP - DIFFERENTIAL PRESSURE
θ - TEMPERATURE
T - TURBINE METER
DD - DRAG DISK
ρ - DENSITOMETER
—•— - PNEUMATIC SIGNAL

LO - LUBRICATION OIL
F - MAGNETIC FLOW METER
T - TORQUE METER
N - SPEED METER
TC - THRUST PAD
SG - THRUST PADS

LOCATION No.	DESCRIPTION	RANGE	[illegible]	
L-1	SUCTION LEG DRAG DISK (HI)	VARIED	S-1	
L-2	DISCHARGE LEG DRAG DISK (HI)	VARIED	S-2	
L-3	SUCTION LEG TURBINE METER (LO)	VARIED	S-3	S-28*
L-4	DISCHARE LEG TURBINE METER (LO)	VARIED	S-4	S-29**
L-5	SUCTION LEG PRESURE CELL	0-1500 PSI	S-5	
L-6	DISCHARGE LEG PRESURE CELL	0-1500 PSI	S-6	
L-7H	PUMP LEG-TO-LEG ΔP CELL (BLH)	± 500 PSID	S-7	
L-7H	PUMP LEG-TO-LEG ΔP CELL	VARIED	S-7A	
L-7L	PUMP LEG-TO-LEG ΔP CELL (BLH)	± 200 PSID	S-8	
L-7	PUMP LEG-TO-LEG ΔP CELL	VARIED	S-8A	
L-9	PUMP INJECTION INLET ΔP CELL	0-25 PSID	S-9	
L-10	PUMP INJECTION INLET PRESURE CELL	0-1500 PSID	S-10	
L-11	PUMP TORQUE METER	0-200/0-1200 ft-lb	S-11	
L-12	PUMP SPEED METER	0-10,000 RPM	S-12	
L-13	SUCTION LEG THEMOCOUPLE	0-600°F	S-13	
L-14	DISCHARE LEG THEMOCOUPLE	0-600	S-14	
L-15	SUCTION LEG DENSITOMETER, BEAM 1	0-62.4 lb/ft³	S-15	
L-16	SUCTION LEG DENSITOMETER, BEAM 2	0-62.4 lb/ft³	S-16	
L-17	SUCTION LEG DENSITOMETER BEAM 3	0-62.4 lb/ft³	S-17	
L-18	DISCHARGE LEG DENSITOMETER, BEAM 1	0-62.4 lb/ft³	S-18	
L-19	DISCHARGE LEG DENSITOMETER, BEAM 2	0-62.4 lb/ft³	S-19	
L-20	DISCHARGE LEG DENSITOMETER, BEAM 3	0-62.4 lb/ft³	S-20	
L-21	PUMP INJECTION INLET THERMOCOUPLE	0-600°F	S-21	
L-22	PUMP INJECTION OUTLET THERMOCOUPLE	0-600°F	S-22	
L-23	HIGH PRESURE DRUM ID THERMOCOUPLE	0-600°F	S-23	
L-24	HIGH PRESURE DRUM OD THERMOCOUPLE	0-600°F	S-24	
L-25	HIGH PRESURE DRUM LEVEL ΔP CELL	0-2.5 PSID	S-25	
L-26	SUCTION LEG DRAG DISK (LOWER)	VARIED	S-26	
L-27	DISCHARGE LEG DRAG DISK (LOWER)	VARIED	S-27	
L-28	SUCTION LEG TURBINE METER	VARIED *	S-28	S-3*
L-29	DISCHARGE LEG TURBINE METER	VARIED **	S-29	S-4**
L-30	SUCTION LEG DRAG DISK THERMOCOUPLE	0-600°F	S-30	
L-31	DISCHARGE LEG DRAG DISK THERMOCOUPLE	0-600°F	S-31	
L-32	PUMP INJECTION OUTLET FLOW	VARIED	S-32	
L-33	INLET ACROSS PIPE ΔP	± 500 in.	S-33	
L-34	INLET DENSITOMETER, BEAM 3	0-62.4 lb/ft³	S-34	
L-35	INLET DENSITOMETER, BEAM 1	0-62.4 lb/ft³	S-35	
L-36	INLET DENSITOMETER, BEAM 2	0-62.4 lb/ft³	S-36	
L-37L	MAIN STEAM ORIFICE ΔP CELL	0-3.5 PSID	S-37	
L-37H	MAIN STEAM ORIFICE ΔP CELL	0-25 PSID	S-43	
L-38L	MAIN WATER ORIFICE ΔP CELL	0-3.5 PSID	S-38	
L-38M	MAIN WATER ORIFICE ΔP CELL	0-25 PSID	S-44	
L-38H	MAIN WATER ORIFICE ΔP CELL	VARIED	S-69	
L-39L	BYPASS STEAM ORIFICE ΔP CELL	0-3.5 PSID	S-39	
L-39H	BYPASS STEAM ORIFICE ΔP CELL	0-25 PSID	S-45	
L-40L	BYPASS WATER ORIFICE ΔP CELL	0-3.5 PSID	S-40	
L-40H	BYPASS WATER ORIFICE ΔP CELL	0-25 PSID	S-46	
L-41	MAIN STEAM ORIFICE PRESURE CELL	0-1500 PSI	S-41	
L-42	MAIN WATER ORIFICE PRESURE CELL	0-1500 PSI	S-42	
L-47	BYPASS STEAM ORIFICE PRESURE CELL	0-1500 PSI	S-47	
L-48	BYPASS STEAM ORIFICE PRESURE CELL	0-1500 PSI	S-48	
L-49	MAIN STEAM ORIFICE THERMOCOUPLE	0-600°F	S-49	
L-50	MAIN WATER ORIFICE THERMOCOUPLE	0-600°F	S-50	
L-51	BYPASS STEAM ORIFICE THERMOCOUPLE	0-600°F	S-51	
L-52	BYPASS WATER ORIFICE THERMOCOUPLE	0-600°F	S-52	
L-53	BYPASS WATER ORIFICE RTD	0-600°F	S-53	
L-54	BYPASS STEAM ORIFICE RTD	0-600°F	S-54	
L-55	SUCTION LEG RTD	0-600°F	S-55	
L-56	DISCHARGE LEG RTD	0-600°F	S-56	
L-57	AMBIENT TEMPERATURE THERMOCOUPLE	0-200°F	S-57	
L-58	MAIN WATER ORIFICE RTD	0-600°F	S-58	
L-59	MAIN STEAM ORIFICE RTD	0-600°F	S-59	
L-60	LOOP FLOW CONTROL VALVE ΔP CELL	0-200 PSID	S-60	
L-61	SUCTION LEG TO INLET FLANGE ΔP CELL	0-10 PSID	S-61	
L-62	PAC 16 ΔP CELL	0-200 PSID	S-62	
L-64	BLOWDOWN LEG PRESSURE CELL	0-1500 PSI	S-64	
L-65	H.P. DRUM PRESSURE CELL	0-1500 PSI	S-65	
L-66	TEST PUMP FLANGE TO FLANGE ΔP CELL	VARIED	S-66	
L-68	PUMP VOLUTE TO IMPELLER BACK ΔP CELL	0-25 PSID	S-68	

* FOR TESTS 209→243 and 298→453

** FOR TESTS 209 → 609

VALVE IDENTIFICATION

VALVE No.	DESCRIPTION
DA-1	COOLER BYPASS VALVE
DA-2	COOLER INLET VALVE
DA-3	COOLER OUTLET VALVE
DA-4	BOOSTER PUMP BYPASS VALVE
DA-5	BOOSTER PUMP INLET VALVE
DA-6	BOOSTER PUMP OUTLET VALVE
DA-7	SEPTUPLEX INLET (SUCTION) VALVE
DA-8	MANUAL DA RETURN
DA-9	PNEUMATIC DA RETURN
DA-10	ISOLATION - PNEUMATIC DA RETURN
DA-11	RETURN TO SEPTUPLEX SUCTION (IN SERIES W/DA-12)
DA-12	RETURN TO SEPTUPLEX
DA-13	RETURN TO COOLER
DA-14	RETURN TO DA
DA-15	RETURN INTO UPPER PLENUM OF DA
DA-16	RETURN INTO LOWER PLENUM OF DA
DA-17	WORTHINGTON CENTRIFUGAL INLET VALVE

VALVE No.	DESCRIPTION
HPS-1	BOILER DRUM TO H.P. DRUM ISOLATION VALVE
HPS-2	BOILER DRUM TO H.P. DRUM ISOLATION VALVE
HPS-3	MAIN STEAM FLOW VALVE (6" ANGLE VALVE)
HPS-4	STEAM BYPASS VALVE
HPS-5	VP BOILER TO LOOP ISOLATION VALVE (CROSS TIE SYSTEM)
HPS-6	PNEUMATIC VENT FOR TEST BOILER AND LOOP
HPS-7	PNEUMATIC VENT FOR TEST BOILER AND LOOP
HPS-8	TEST BOILER TO VENT ISOLATION VALVE
HPS-9	H.P. DRUM TO VENT ISOLATION VALVE
HPS-10	H.P. DRUM TO VENT ISOLATION VALVE
HPS-11	2" VENT ON TOP OF H.P. DRUM
HPS-14	LOOP STEAM TO HOUSE HEADER
HPS-15	BOILER STEAM TO HOUSE HEADER
HPS-16	MAIN MANUAL VENT VALVES
HPS-17	BYPASS MANUAL VENT VALVES

VALVE No.	DESCRIPTION
HPW-1	DRUM INTERNAL ISOLATION VALVE
HPW-2	LOOP ISOLATION VALVE
HPW-3	STSSG ISOLATION VALVE
HPW-4	STSSG ISOLATION VALVE
HPW-5	STSSG ISOLATION VALVE
HPW-6	MAIN WATER FLOW CONTROL VALVE
HPW-7	BYPASS WATER FLOW CONTROL VALVE
HPW-8	PAC 6 SUCTION VALVE
HPW-9	PAC 6 MAIN FLOW CONTROL VALVE
HPW-10	PAC 6 PNEUMATIC BYPASS CONTROL VALVE
HPW-11	PAC 6 MANUAL BYPASS SHUT-OFF VALVE
HPW-12	PAC 6 BLOWDOWN CIRCULATION VALVE

VALVE No.	DESCRIPTION
FW-1	SEPTUPLEX OUTLET VALVE
FW-2	TRIPLEX OUTLET VALVE (LOCATED AT MEZZANINE LEVEL)
FW-3	LARGE BOILER FEED VALVE
FW-4	SMALL BOILER FEED VALVE
FW-5	MANUAL LOOP FEEDWATER VALVE
FW-6	PNEUMATIC LOOP FEEDWATER VALVE
FW-7	TEST PUMP INJECTION MANUAL SHUT-OFF
FW-8	TEST PUMP INJECTION CONTROL VALVE
FW-9	PAC-16 SEAL INJECTION VALVE
FW-10	PAC-12 SEAL INJECTION VALVE
FW-11	SEPTUPLEX LOOP FEEDWATER VALVE
FW-12	SEPTUPLEX LOOP FEEDWATER VALVE
FW-13	WORTHINGTON CENTRIFUGAL OUTLET VALVE
FW-14	WORTHINGTON CENTRIFUGAL LOOP FEEDWATER VALVE
FW-15	WORTHINGTON CENTRIFUGAL OUTLET BYPASS
FW-16	WORTHINGTON CENTRIFUGAL OUTLET BYPASS

VALVE No.	DESCRIPTION
HPSW-1	TPPP LOOP FLOW CONTROL VALVE
HPSW-2	TPPP BLOWDOWN VALVE
HPSW-3	TPPP ISOLATION VALVE

NOTES:

1) FOR REVERSE FLOW TESTING, PIPING SWITCH IS MADE AS INDICATED

2) DIFFERENTIAL PRESSURE CELLS ARE INSTALLED SO THAT A PRESSURE RISE IN POSITIVE FLOW DIRECTION, AS INDICATED BY THE ARROWS IS DEFINED AS POSITIVE. FOR REVERSE FLOW TESTING, THE DIFFERENTIAL PRESSURE CELL AT LOCATION L-61 IS REVERSED

PIPING & INSTRUMENTATION DIAGRAM

CE / EPRI PUMP TEST FACILITY

C-E POWER SYSTEMS
COMBUSTION ENGINEERING, INC.

Scale: N/A
Drawn By: [signature] Date: 7-22-78
Checked By: [signature] Date: 9-14-77
Approved By: [signature] Date: 7-30-78
Comp. Code:
Drawing No.:
Rev. O

Figure 4-2. Piping and instrumentation diagram and their position in the test loop. Instrumentation is discussed in greater detail in Section 4 of Volume VII, Test Facility Description.

4.3.2 Summary Table

The Summary Table Code extracts information from the output of the PSSR Code (Section 4-2) and prints out a compact table of key pump operating conditions and performance parameters. A sample page of the summary table is exhibited at Table 4-3. The one-line-per-test format results in a columnar array which facilitates rapid visual access, sorting, and extraction of results. Since the PSSR Code has different versions for forward and reverse flow tests, the summary tables have separate groups of tests for the forward and reverse flow.

The left portion of the columns list the pump operating conditions and associated pressure changes, while the remaining columns list the normalized performance parameters and homologous ratios, plus upstream density. Meanings of the individual column headings are listed in Table 4-4. Asterisks in a column signify a number too large to fit the alloted space in the table.

TABLE 4-3

SAMPLE STEADY-STATE DATA SUMMARY TABLE

GE/EPRI TWO PHASE PUMP STEADY STATE TESTS PAGE-- 6

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LE)	DP (FE)	DP (TS-MS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ.B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
1091	10/13/77	FWD	58	1.000	-4.56	-3.88	.23	3.684	.220	16.734	.060	-20.488	-20.903	*******	-1.509	*******	-1.540	.127
1092	10/13/77	FWD	57	1.000	-4.96	-4.23	.24	3.858	.221	17.467	.057	-22.665	-20.445	*******	-1.522	*******	-1.373	.125
1093	10/13/77	FWD	59	1.000	-5.74	-4.93	.28	4.364	.552	7.910	.126	-25.285	-21.603	-83.068	-1.328	-70.972	-1.134	.130
1095	10/13/77	FWD	54	1.000	-.27	-.15	.12	1.503	.552	2.723	.367	-1.266	-5.589	-4.156	-.560	-18.341	-2.473	.121
1096	10/13/77	FWD	55	1.000	-1.25	-1.03	.16	2.570	.551	4.662	.215	-5.917	-7.252	-19.463	-.895	-23.854	-1.098	.120
1097	10/13/77	FWD	56	1.000	-1.93	-1.65	.19	3.029	.552	5.493	.182	-9.061	-14.285	-29.788	-.987	-46.964	-1.557	.122
1098	10/13/77	FWD	56	1.000	-2.55	-2.23	.21	3.409	.551	6.183	.162	-11.858	-13.615	-39.004	-1.020	-44.783	-1.171	.123
1099	10/13/77	FWD	60	1.000	-3.61	-3.18	.24	3.768	.552	6.830	.146	-15.746	-17.580	-51.740	-1.109	-57.767	-1.238	.131
1100	10/13/77	FWD	60	1.000	-5.64	-4.98	.33	4.826	.886	5.448	.184	-24.536	-20.043	-31.265	-1.053	-25.540	-.860	.131
1102	10/13/77	FWD	54	1.000	-1.11	-.85	.20	2.093	.698	3.000	.333	-5.328	-1.852	-5.352	-.595	-1.861	-.207	.119
1112	10/18/77	FWD	951	.266	22.96	35.85	6.04	1.077	1.007	1.069	.935	.376	.722	.371	.324	.711	.622	34.863
1113	10/18/77	FWD	936	.219	36.27	45.40	6.23	1.053	1.008	1.045	.957	.559	.730	.551	.505	.719	.659	37.051
1114	10/18/77	FWD	958	.203	40.21	50.54	6.89	1.045	1.007	1.038	.964	.610	.770	.602	.559	.759	.705	37.651
1115	10/18/77	FWD	955	.187	46.53	54.22	6.07	1.033	1.002	1.031	.970	.694	.901	.691	.650	.897	.844	38.344
1116	10/18/77	FWD	951	.187	44.61	56.49	6.13	1.036	1.001	1.036	.966	.669	.876	.658	.623	.876	.817	38.370
1118	10/20/77	FWD	45	1.000	-2.67	-2.19	.26	4.706	1.625	2.896	.345	-15.304	-4.956	-5.796	-.691	-1.877	-.224	.098
1119	1/20/77	FWD	50	1.000	-3.01	-2.46	.29	4.825	1.625	2.969	.337	-15.825	-5.431	-5.991	-.680	-2.056	-.233	.109
1120	10/20/77	FWD	51	1.000	-4.08	-3.58	.29	4.798	1.155	4.153	.241	-21.089	-13.069	-15.798	-.916	-9.790	-.568	.111
1121	10/20/77	FWD	49	1.000	-.34	-.17	.14	2.343	1.154	2.031	.492	-1.782	3.375	-1.339	-.325	2.535	.615	.109
1122	10/20/77	FWD	482	.989	1.55	1.78	.15	.917	.997	.920	1.087	.565	1.211	.569		1.219		1.572
1123	10/20/77	FWD	482	.988	-.36	-.14	.15	.883	.498	1.772	.564	-.124	.107	-.499	-.159	.429	.137	1.652
1124	10/20/77	FWD	483	.990	-1.83	-1.50	.20	1.130	.349	3.243	.308	-.682	-.412	-5.611	-.533	-3.391	-.322	1.536
1125	10/20/77	FWD	483	.991	-2.34	-1.93	.22	1.229	.348	3.527	.284	-.889	-.371	-7.323	-.589	-3.051	-.245	1.501
1126	10/20/77	FWD	484	.991	-2.38	-2.00	.22	1.219	.330	3.694	.271	-.903	-.491	-8.288	-.607	-4.508	-.330	1.509
1133	10/21/77	FWD	251	0.000	-7.63	-4.75	.69	.428	.186	2.300	.435	-.071	-.049	-2.058	-.389	-1.420	-.268	61.237
1134	10/21/77	FWD	308	0.000	-60.46	-55.57	2.47	.863	.192	4.504	.222	-.565	-.709	-15.389	-.758	-19.295	-.951	61.110
1135	10/21/77	FWD	225	0.000	40.40	58.91	7.14	1.495	1.084	1.378	.725	.379	.971	.323	.170	.826	.435	60.864
1136	10/21/77	FWD	211	.100	24.26	23.16	-1.37	-.009	.406	-.023	-44.274	.270	.135	1.642		.823		51.319
1137	10/21/77	FWD	171	0.000	-26.50	-19.64	2.42	.899	.409	2.200	.455	-.263	-.028	-1.578	-.326	-.168	-.035	57.504
1138	10/21/77	FWD	431	.041	25.05	21.95	-1.37	-.009	.406	-.021	-47.373	.283	.143	1.718		.865		50.515
1139	10/21/77	FWD	425	0.000	-31.81	-23.86	2.39	.949	.410	2.315	.432	-.346	-.072	-2.062	-.385	-.430	-.080	52.515
1140	10/21/77	FWD	914	0.000	22.24	20.20	-1.37	.013	.406	.031	31.794	.265	.149	1.613		.904		47.874
1141	10/21/77	FWD	917	0.000	-29.04	-23.63	2.32	.984	.409	2.405	.416	-.348	-.099	-2.081	-.360	-.591	-.102	47.615
1145	10/22/77	FWD	889	0.000	-26.55	-23.56	2.33	.979	.409	2.394	.417	-.317	-.082	-1.895	-.330	-.493	-.086	47.893
1146	10/22/77	FWD	863	0.000	39.15	56.94	5.69	1.501	1.164	1.290	.775	.471	1.167	.348	.209	.861	.518	47.515
1147	10/22/77	FWD	866	0.000	-7.76	6.40	3.72	1.272	.794	1.603	.624	-.093	.459	-.147	-.057	.729	.284	47.742
1148	10/22/77	FWD	878	0.000	-6.69	-4.47	.63	.492	.221	2.225	.449	-.080	.013	-1.637	-.331	.262	.053	47.851
1149	10/22/77	FWD	893	0.000	-3.98	-3.90	.49	.430	.186	2.306	.434	-.048	.009	-1.370	-.258	.247	.046	47.824
1151	10/22/77	FWD	914	0.000	-14.85	-9.31	2.29	.941	.471	1.998	.501	-.178	.064	-.801	-.201	.288	.072	47.724
1152	10/22/77	FWD	876	0.000	27.21	38.73	3.33	1.209	.903	1.338	.747	.326	.735	.399	.223	.902	.504	47.755

TABLE 4-4

KEY TO SUMMARY TABLE COLUMN HEADINGS AND ABBREVIATIONS

Column Heading	Meaning
TEST	Steady state test number
DATE	Date of test
TYP	Type of test FWD = forward flow test REV = reverse flow test
PRES PSIA	Upstream instrument spool static pressure, psia. L-5 for forward flow, L-6 for reverse flow
VOID FRAC	Upstream void fraction obtained from orifice measurements, upstream instrument measurements, and piping heat loss combined in an energy balance.
DP (LL)	Static ΔP, suction instrument spool (SIS) to discharge instrument spool (DIS), (psi).
DP (FF)	Static ΔP, suction flange to discharge flange, (psi).
DP (TS-NS)	Static ΔP, suction instrument spool to suction flange, (psi).
NU	$\equiv \nu$. Normalized upstream volumetric flow rate Q/Q_{rated}, calculated from orifice-measured flow rate and orifice-based upstream specific volume.
ALN	Normalized pump speed, $\alpha_N = N/N_R$
NU/ALN	Homologous flow-to-speed ratio, ν/α_N
ALN/NU	Homologous speed-to-flow ratio, α_N/ν
NORMALIZED H	Normalized SIS to DIS static pump head, $h \equiv H/H_R$ in feet of fluid having orfice-based upstream density.
NORMALIZED HYTRQ,B	Normalized hydraulic torque, $\beta_H = (T_h/T_R)(\rho_R \cdot v_{ave})$, including adjustment to average density across the pump, which is evaluated as the reciprocal of average specific volume. See Volume VIII for details.
H/ALN2	Homologous head ratio, h/α_N^2 for $\nu/\alpha_N \leq 1$
H/NU2	Alternate homologous head ratio, h/ν^2 for $\nu/\alpha_N > 1$.
B/ALN2	Homologous hydraulic torque ratio, β_H/α_N^2 for $\nu/\alpha_N \leq 1$.

B/NU2 — Alternate homologous hydraulic torque ratio, β_H/ν^2 for $\nu/\alpha_N > 1$.

DENSITY UPSTRM — Orifice-based upstream density derived as the reciprocal of the five-scan average of orifice-based upstream specific volume.

4.3.3 Extent of Data in Report vs Data Available

A variety of steady state data compilations have been described above and some others will accompany the analysis given below. A list of which types of data compilation are included in this report and which are otherwise available is given Table 4-5. Examination of the extent of these various data presentations shows that a large percentage of the data is included in the report.

A more detailed list of data that is not in the report but available in EPRI files is as follows:

1. Raw scanner voltages for the five scans of each measured quantity in each test.
2. Raw FM analog signals from each test to record gamma densitometer outputs, and at the same time include the other instrument outputs. This data has not been reduced.
3. Reduced data items
   - -- Individual scan values in engineering units for all measured quantities except orifice pressure drops, pressure levels and temperatures. The derived orifice flows are available for each scan.
   - -- Drift in the least-squares mean value of operating conditions during the five scan period.
   - -- Deviation of operating conditions from the specified set point.
   - -- Instrument measurement uncertainties.
   - -- Normalized performance parameters based on densities measured by gamma densitometers. Samples are covered in analysis, however.
   - -- Performance values based on average density (reciprocal of average of upstream and downstream specific volumes) except that the average density hydraulic torque functions are reported.
   - -- Static $P_{discharge} - P_{suction}$ for comparison with directly measured ΔP.
   - -- Upstream superficial velocities (Q/A_{pipe}) for water and for steam.

-- Steam table saturation properties at suction and discharge legs,(SIS and DIS), water and steam orifices, and high-pressure separator drum.

-- Net seal injection leakage flow.

Items calculated by the PSSR Code (Section 4.2.2) but not in the Summary Table and available only through samples given in data analysis comprise the following:

1. Alternate pump head functions, i.e. other than static pressure head based on upstream orifice-based density.

2. Homologous parameters based on densities from gamma densitometer measurements.

3. Suction and discharge piping pressure loss characteristics.

   -- Handbook pressure drops

   -- Experimental combined pressure drop

   -- Test-derived K factors for suction and discharge sections

4. Pump efficiencies.

Details of these parameters were described in Section 4.2 above.

TABLE 4-5

AVAILABILITY OF STEADY STATE DATA COMPILATIONS

Included in Report (Volume/Section No.)		Available in EPRI Files
Chronological table of tests	(V/2)	Raw scanner data for individual scans
Matrix table of tests	(II/3.3)	Supplementary raw FM data
One-page printout per test	(V/3)	Ten-page reduced data printout per test
Summary table of key data	(II/4.4)	
Performance curves	(II/5.2)	
Special Topics curves	(II.5.4)	**Partially Available**
Friction and windage torque	(II/4.5)	Full output of the PSSR Code was not requested for EPRI files but portions are available in the Summary Table and in excerpts in Special Topics (Section 5.4)
Comparisons with transient performance (alternate measurements)	(IV/2)	

4.4 SUMMARY OF STEADY-STATE TEST DATA

A compact summary of key data from all steady-state pump performance tests is presented here in tabular form. Detailed data listings can be found in the one-page-per-test printouts in Volume V and in the ten-page printouts stored at EPRI, as described in Section 4.3. Graphical presentations will be provided below as a part of Section 5, Data Analysis.

4.4.1 Summary Table Code Output

Key pump operating conditions and performance parameters for the steady-state pump performance tests are presented in Table 4-6. This table contains processed data compiled by the Summary Table Code, with format, definitions and methods described above (Section 4.2 and 4.3). Certain entries, identified in the table and detailed in Section 5.3.3 below, have been modified by hand to remedy obvious errors (e.g. a few reversed signs) and thereby simplify and enhance further processing and use of the data. The data contained in the one-page printouts in Volume V have not been modified. Therefore some inconsistencies may be found in comparing the summary data in Table 4-6 with the one-page data contained in Volume V. For convenience, the tests in Table 4-6 are grouped separately for forward and reverse flow and for Phases I and II. Within these groups the tests are listed in numerical order by test number.

For further indexing of the tests by purpose, see the Chronological Steady-State Test List (Volume V), which gives the nominal purpose and intended operating conditions for each test, and see Table 3-1, which lists the performance tests in groups according to purpose.

4.5 DATA FOR SPECIAL CONSIDERATIONS

4.5.1 Friction and Windage Tests of Model Pump

Because the torque meter used in the test program was located on the test pump shaft, it did not measure hydraulic torque directly. Rather it measured a "shaft" torque which can be related to hydraulic torque by the equation:

$$T_h = T_{sh} - T_{f\&w}$$

where;

T_h = Hydraulic torque (ft-lbf)

T_{sh} = Shaft torque (ft-lbf)

$T_{f\&w}$ = Friction and windage torque (ft-lbf)
(sign of $T_{f\&w}$ same as that of pump speed)

It is assumed that the friction torque is made up of two independent components, one due to test pump speed and the other due to system pressure within the pump casing. Tests were performed to determine the contribution of each of these components. To test the effect of speed, the pump was operated with the test loop filled with air. Test pump speed was varied from -9000 to +9000 rpm in steps. At each step, the speed was held constant and the torque was recorded manually from the digital voltmeter on the data scanner. To check the effect of pressure, the test pump impeller was removed and the system filled with water at ambient temperature. Shaft torque was then recorded manually from the digital voltmeter on the data scanner at different system pressures while the pump was rotated at near-zero speed. These procedures covered the windage of the rotating parts in air but neglected water/ steam windage on the outside of the impeller. The data obtained was fit to the equation below with a regression analysis;

$$T_{f\&w} = [A_1(P - P_{ABS}) + A_2(P - P_{ABS})^2 + A_3\ |N| + A_4N^2]\ /12$$

in which

P = upstream pressure (psia)

P_{ABS} = atmospheric pressure (psia)

N = pump speed (rpm)

The best fit constants to the above equation, based on the friction and windage test data, were:

$A_1 = -1.8 \times 10^{-2}$

$A_2 = +3.05 \times 10^{-5}$

$A_3 = +8.0197 \times 10^{-2}$

$A_4 = -3.5856 \times 10^{-6}$

These constants were used in the above equation to calculate friction and windage torque for all steady-state test points. A tabulation of the friction and windage data may be found in Appendix B along with notes on the analysis of these data.

Table 4-6

STEADY-STATE DATA SUMMARY TABLE

SUMMARY TABLE Phase I Forward Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS PAGE-- 1

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ.B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM	Note
209	1/21/77	FWD	1017	0.000	100.95	101.33	.62	.442	.999	.442	2.260	1.225	.897	1.226		.898		47.085	
210	1/12/77	FWD	991	0.000	88.00	90.56	1.52	.830	.997	.832	1.202	1.073	.977	1.079		.982		46.852	
211	1/12/77	FWD	993	0.000	72.94	77.47	2.24	.994	.997	.997	1.003	.893	.982	.899		.988		46.659	
212	1/21/77	FWD	1012	0.000	57.60	64.83	2.83	1.141	.998	1.143	.875	.702	.966	.705	.539	.970	.742	46.887	
213	1/21/77	FWD	1010	0.000	33.04	43.09	3.87	1.354	1.001	1.353	.739	.405	.871	.404	.221	.870	.476	46.664	
214	1/21/77	FWD	1007	0.000	98.84	99.51	.65	.470	1.000	.470	2.126	1.197	.892	1.197		.891		47.179	
215	1/21/77	FWD	991	.112	59.85	68.03	5.43	1.053	1.000	1.053	.950	.826	.983	.826	.745	.983	.887	41.391	
216	1/21/77	FWD	999	.224	34.80	42.06	5.70	1.035	1.003	1.031	.970	.546	.790	.542	.510	.785	.738	36.406	
217	1/22/77	FWD	902	.380	31.97	34.66	.96	.629	1.020	.617	1.621	.610	.652	.587		.627		29.958	
219	1/25/77	FWD	1005	.074	-23.970	-28.63	2.86	1.006	.501	2.006	.499	-0.318	-.031	-1.270	-0.318	-.122	-.030	42.989	a
220	1/25/77	FWD	1008	.083	-26.682	-28.81	3.18	1.016	.500	2.030	.493	-0.356	-.057	-1.426	-0.349	-.229	-.056	42.571	a
221	1/25/77	FWD	1004	.165	-25.710	-28.63	4.40	.989	.501	1.976	.506	-0.377	-.069	-1.501	-0.384	-.276	-.071	38.995	a
222	1/25/77	FWD	1006	.160	-27.130	-28.81	5.06	1.005	.501	2.007	.498	-0.405	-.083	-1.610	-0.397	-.330	-.082	38.349	a
223	1/25/77	FWD	991	.137	67.19	72.03	3.74	.974	.994	.980	1.020	.953	1.007	.965		1.020		40.300	
224	1/25/77	FWD	986	.366	14.57	25.25	6.56	1.135	.998	1.137	.880	.275	.744	.276	.214	.746	.578	30.230	
225	1/25/77	FWD	992	.429	32.21	32.52	1.97	.722	.987	.732	1.366	.672	.746	.690		.766		27.427	
226	1/25/77	FWD	976	.481	48.63	44.13	2.87	.811	1.221	.664	1.505	1.104	1.004	.741		.673		25.184	
228	1/26/77	FWD	992	.485	12.65	11.96	.60	.396	.700	.566	1.767	.290	.317	.591		.647		24.968	
229	1/26/77	FWD	986	.468	30.45	32.44	.61	.409	.993	.412	2.427	.703	.627	.714		.636		24.781	
230	1/26/77	FWD	985	.428	-15.516	-13.97	4.12	.943	.498	1.893	.528	-0.324	-.039	-1.302	-0.361	-.159	-.044	27.509	a
231	1/26/77	FWD	992	.415	-21.195	-27.61	4.84	.984	.499	1.971	.507	-0.433	-.114	-1.730	-0.444	-.459	-.118	28.033	a
232	1/26/77	FWD	989	.317	23.46	32.07	5.69	1.057	.998	1.059	.945	.414	.766	.416	.371	.769	.686	32.365	
233	1/26/77	FWD	998	.387	18.88	26.60	5.15	1.017	1.003	1.015	.986	.369	.713	.367	.356	.709	.689	29.255	
234	1/26/77	FWD	998	.416	20.35	26.27	4.67	.965	.997	.967	1.034	.416	.723	.418		.727		27.963	
235	1/26/77	FWD	994	.458	20.02	22.52	3.85	.904	.998	.906	1.104	.438	.697	.439		.699		26.121	
236	1/26/77	FWD	990	.544	17.19	18.20	1.73	.692	.999	.693	1.443	.442	.630	.443		.630		22.228	
237	1/26/77	FWD	985	.514	25.20	26.55	1.36	.656	1.001	.655	1.526	.608	.690	.606		.688		23.692	
238	1/26/77	FWD	992	.497	.02	1.78	1.31	.594	.499	1.190	.840	.001	.141	.002	.002	.564	.398	24.434	
239	1/26/77	FWD	981	.471	25.71	27.65	2.21	.711	.999	.712	1.405	.574	.688	.576		.690		25.577	
240	1/26/77	FWD	985	.442	-.85	1.52	1.68	.631	.498	1.268	.789	-.018	.149	-.073	-.046	.602	.374	26.851	
241	1/26/77	FWD	990	.408	-1.81	1.22	1.94	.682	.498	1.369	.730	-.037	.143	-.147	-.079	.578	.308	28.353	
242	1/26/77	FWD	985	.427	27.10	30.09	3.47	.766	.990	.774	1.293	.563	.775	.574		.790		27.528	
243	1/26/77	FWD	980	.366	26.15	31.16	4.44	.932	.999	.933	1.072	.494	.717	.494		.719		30.270	
246	1/28/77	FWD	1098	.003	-.16	-.71	.04	-.064	.000	*******	-.006	-.002	-.438	*******	-.478	*******	*******	45.290	
251	1/29/77	FWD	922	0.000	52.36	56.95	3.96	.669	1.002	.667	1.498	.639	.700	.636		.696		46.790	
255	1/30/77	FWD	56	0.000	110.88	114.77	1.93	.792	.989	.801	1.248	1.038	.934	1.061		.955		61.050	
256	1/30/77	FWD	102	0.000	127.32	129.44	.73	.431	.990	.435	2.300	1.194	.854	1.218		.871		60.901	
257	1/30/77	FWD	107	0.000	-.64	5.75	2.55	.913	.579	1.577	.634	-.006	.229	-.018	-.007	.683	.275	61.162	
258	1/30/77	FWD	106	0.000	-36.509	-28.63	2.60	.919	.409	2.244	.446	-0.343	-.096	-2.042	-0.406	-.573	-.114	61.013	a
259	1/30/77	FWD	106	0.000	-38.713	-28.61	2.60	.919	.402	2.286	.437	-0.366	-.110	-2.241	-0.425	-.681	-.130	60.938	a

a) DP(LL) based on SIS and DIS readings are used to determine pump DP because of erroneous DP sensor output. Hand corrections made to DP(LL), H, H/ALN2, and H/NU2.

SUMMARY TABLE Phase I Forward Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PHFS PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
260	1/30/77	FWD	105	0.000	-29.950	-28.66	2.60	.926	.446	2.074	.482	-0.281	-.024	-1.413	-0.325	-.119	-.028	60.864 a
263	1/31/77	FWD	482	.770	-4.11	-3.56	1.62	.889	.500	1.780	.562	-.188	.125	-.754	-.238	.501	.158	12.473
264	1/31/77	FWD	478	.788	.27	2.92	1.72	.935	1.000	.935	1.070	.013	.588	.013		.588		11.611
265	1/31/77	FWD	521	.876	-2.64	-1.32	.86	.790	.499	1.584	.631	-.209	.201	-.839	-.334	.808	.322	7.224
266	1/31/77	FWD	481	.946	-2.74	-1.76	.69	.962	.500	1.927	.519	-.418	.221	-1.676	-.451	.888	.239	3.742
267	1/31/77	FWD	477	1.000	-.49	-.71	.17	1.012	.500	2.025	.494	-.271	.453	-1.088	-.265	1.815	.442	1.037
268	1/31/77	FWD	477	1.000	1.52	1.27	.17	1.017	.999	1.019	.982	.841	2.129	.844	.813	2.134	2.057	1.035
269	1/31/77	FWD	846	.795	2.56	5.13	1.69	.962	.995	.967	1.034	.130	.697	.131		.704		11.237
270	1/31/77	FWD	844	.798	17.02	19.49	2.01	.986	1.506	.655	1.527	.878	1.357	.387		.598		11.072
271	1/31/77	FWD	847	.795	37.61	38.48	1.88	.996	1.909	.522	1.916	1.915	2.254	.526		.619		11.236
273	2/ 1/77	FWD	842	.811	1.20	1.10	.29	.360	.500	.721	1.386	.065	.147	.262		.590		10.483
274	2/ 1/77	FWD	846	.811	-.52	-.57	.26	.356	.249	1.428	.700	-.029	.102	-.459	-.225	1.637	.802	10.508
275	2/ 1/77	FWD	839	.813	7.95	7.70	.26	.353	.999	.354	2.827	.436	.530	.437		.531		10.418
276	2/ 1/77	FWD	856	.816	20.05	18.87	.27	.371	1.496	.248	4.028	1.117	1.206	.499		.539		10.260
277	2/ 1/77	FWD	844	.852	18.26	17.83	.42	.440	1.495	.294	3.398	1.210	1.248	.541		.558		8.625
278	2/ 1/77	FWD	982	.234	42.94	46.96	5.97	1.007	.992	1.015	.985	.680	.836	.691	.671	.849	.824	36.072
279	2/ 1/77	FWD	987	.230	57.20	62.46	5.21	.973	1.041	.935	1.070	.903	.963	.834		.889		36.203
280	2/ 1/77	FWD	991	.429	-2.73	.36	2.21	.719	.503	1.428	.700	-.057	.148	-.224	-.110	.582	.285	27.435
281	2/ 1/77	FWD	979	.501	42.21	43.91	2.49	.796	1.239	.643	1.556	1.002	.980	.653		.639		24.198
283	2/ 2/77	FWD	992	.456	5.10	5.11	.51	.373	.499	.747	1.338	.111	.160	.446		.643		26.204
284	2/ 2/77	FWD	993	.369	22.94	18.42	.61	.358	.699	.512	1.952	.436	.375	.893		.768		30.052
285	2/ 2/77	FWD	1004	.385	49.74	52.93	1.00	.356	1.007	.354	2.825	.969	.825	.957		.814		29.307
286	2/ 2/77	FWD	1000	.411	53.60	55.73	.96	.384	1.103	.348	2.870	1.086	.976	.893		.803		28.207
287	2/ 2/77	FWD	997	.421	24.79	22.93	-.40	.052	.499	.105	9.510	.510	.382	2.048		1.532		27.733
289	2/ 2/77	FWD	972	.565	85.16	82.63	-1.30	.063	.996	.063	15.903	2.271	1.526	2.287		1.537		21.436
290	2/ 2/77	FWD	1002	.397	-8.96	-7.12	.43	.350	-.000	*******	-.000	-.178	-.002	*******	-1.449	*******	-.012	28.784
291	2/ 2/77	FWD	1007	.430	-34.95	-29.40	1.88	.684	-.000	*******	-.000	-.731	.007	*******	-1.563	*******	.015	27.316
292	2/ 2/77	FWD	991	.422	-2.81	1.65	2.07	.715	.500	1.431	.699	-.058	.130	-.232	-.113	.523	.255	27.741
293	2/ 2/77	FWD	999	.407	-26.50	-17.81	4.49	.984	.502	1.960	.510	-.534	-.129	-2.121	-.552	-.511	-.133	28.351
294	2/ 2/77	FWD	992	.276	-37.09	-26.19	5.67	1.014	.502	2.022	.495	-.620	-.190	-2.464	-.603	-.753	-.184	34.165
296	2/ 3/77	FWD	840	.059	-27.65	-19.99	2.42	.966	.498	1.938	.516	-.352	-.013	-1.420	-.378	-.052	-.014	44.835
297	2/ 3/77	FWD	834	.155	-22.02	-13.45	4.44	.862	.501	1.721	.581	-.313	.003	-1.245	-.420	.010	.003	40.206
299	2/ 8/77	FWD	994	.414	-56.29	-42.03	6.00	1.217	.508	2.395	.417	-1.145	-.599	-4.440	-.774	-2.323	-.405	28.082
300	2/ 8/77	FWD	990	1.000	-.41	-.16	.21	.897	.503	1.782	.561	-.104	.144	-.410	-.129	.567	.178	2.234
301	2/ 8/77	FWD	993	1.000	-.92	-.62	.24	.990	.504	1.964	.509	-.236	.100	-.928	-.241	.392	.102	2.241
302	2/ 9/77	FWD	1185	1.000	.10	.23	.20	.781	.504	1.551	.645	.020	.228	.081	.034	.898	.373	2.742
305	2/ 9/77	FWD	990	.875	-18.56	-13.95	1.99	1.442	.504	2.860	.350	-1.365	-.543	-5.366	-.656	-2.135	-.261	7.767
306	2/ 9/77	FWD	1003	1.000	-2.07	-1.55	.31	1.175	.504	2.334	.428	-.521	-.134	-2.056	-.377	-.529	-.097	2.266
307	2/ 9/77	FWD	990	1.000	-2.37	-1.79	.33	1.200	.504	2.384	.420	-.605	-.116	-2.387	-.420	-.456	-.080	2.234
308	2/ 9/77	FWD	996	1.000	-4.90	-3.91	.52	1.436	.504	2.850	.351	-1.245	-.674	-4.907	-.604	-2.658	-.327	2.248

a)DP(LL) based on SIS and DIS readings are used to determine pump DP because of erroneous DP sensor output. Hand corrections made to DP(LL), H, H/ALN2, and H/NU2.

SUMMARY TABLE Phase I Forward Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
309	2/ 9/77	FWD	990	1.000	.86	1.68	.46	1.421	.998	1.423	.703	.221	1.443	.222	.109	1.448	.715	2.233
310	2/10/77	FWD	1194	0.000	-35.72	-28.63	2.54	1.132	.500	2.264	.442	-.451	-.118	-1.801	-.352	-.471	-.092	45.294
311	2/10/77	FWD	1205	0.000	-13.48	-8.47	1.86	.968	.498	1.942	.515	-.170	.063	-.685	-.182	.253	.067	45.314
312	2/10/77	FWD	998	.424	-22.51	-16.23	3.89	1.006	.499	2.015	.496	-.466	-.092	-1.870	-.461	-.369	-.091	27.603
313	2/10/77	FWD	984	.420	14.44	21.17	4.65	1.008	.997	1.011	.989	.297	.668	.299	.292	.672	.657	27.835
314	2/10/77	FWD	994	.424	-23.07	-5.74	9.55	1.482	.999	1.483	.674	-.478	.554	-.479	-.218	.555	.252	27.609
315	2/12/77	FWD	447	1.000	-3.02	-1.95	.51	2.173	1.005	2.162	.463	-1.784	1.535	-1.766	-.378	1.520	.325	.969
316	2/12/77	FWD	440	1.000	-8.01	-7.07	.61	2.249	.499	4.508	.222	-4.798	-3.105	-19.277	-.949	-12.475	-.614	.955
317	2/12/77	FWD	440	1.000	-6.22	-5.44	.47	2.080	.499	4.169	.240	-3.752	-2.637	-15.067	-.867	-10.589	-.609	.947
318	2/12/77	FWD	437	1.000	-4.07	-3.10	.58	2.353	.998	2.358	.424	-2.452	-.245	-2.464	-.443	-.247	-.044	.949
319	2/10/77	FWD	448	1.000	-5.73	-4.49	.66	2.558	.998	2.564	.390	-3.380	.331	-3.395	-.517	.333	.051	.969
320	2/10/77	FWD	458	1.000	-9.46	-8.59	.58	2.400	.497	4.832	.207	-5.462	-3.831	-22.138	-.948	-15.526	-.665	.989
321	2/11/77	FWD	115	0.000	67.93	79.96	4.23	1.168	.996	1.173	.853	.637	.920	.643	.467	.928	.674	60.901
322	2/11/77	FWD	100	0.000	42.74	56.22	4.85	1.238	.997	1.242	.805	.402	.850	.404	.262	.855	.554	60.827
323	2/11/77	FWD	147	0.000	107.16	115.94	2.39	.852	.995	.857	1.167	1.009	.946	1.020		.956		60.702
324	2/11/77	FWD	166	0.000	115.64	122.77	1.36	.627	.997	.629	1.590	1.090	.909	1.097		.915		60.643
325	2/11/77	FWD	170	0.000	138.56	142.68	2.05	.309	.998	.309	3.235	1.307	.829	1.312		.832		60.606
326	2/11/77	FWD	187	0.000	160.75	150.77	-1.37	.045	.998	.045	22.034	1.514	.735	1.520		.738		60.680
327	2/11/77	FWD	112	.028	163.79	149.96	-1.37	.014	.999	.014	72.697	1.589	.746	1.592		.748		58.921
330	2/14/77	FWD	963	.404	-17.29	.03	10.93	1.412	.998	1.415	.707	-.345	.612	-.347	-.173	.614	.307	28.619
331	2/14/77	FWD	986	.396	-15.91	1.01	10.73	1.402	.996	1.407	.711	-.315	.657	-.317	-.160	.662	.334	28.880
332	2/14/77	FWD	989	.427	24.36	45.96	14.48	1.642	1.495	1.098	.911	.506	1.555	.226	.188	.695	.577	27.522
333	2/14/77	FWD	990	.432	43.51	67.94	16.46	1.797	1.721	1.044	.957	.911	2.003	.308	.282	.676	.620	27.288
334	2/14/77	FWD	986	.432	92.23	106.09	9.23	1.328	1.628	.815	1.227	1.930	2.061	.728		.777		27.304
335	2/15/77	FWD	1197	0.000	58.88	72.42	4.98	1.429	1.193	1.198	.835	.751	1.270	.528	.368	.893	.622	44.819
336	2/15/77	FWD	1202	0.000	208.80	193.12	-1.33	.014	1.291	.011	91.462	2.520	1.233	1.512		.740		47.353
337	2/15/77	FWD	972	.539	45.38	52.13	5.78	1.223	1.610	.760	1.316	1.148	2.021	.443		.780		22.558
338	2/15/77	FWD	990	.436	37.41	48.20	5.52	1.049	1.219	.861	1.161	.789	1.099	.531		.740		27.090
339	2/15/77	FWD	987	.426	25.16	31.09	2.05	.716	1.007	.710	1.408	.521	.745	.514		.734		27.544
342	2/16/77	FWD	1211	0.000	-25.76	-18.80	2.49	1.061	.503	2.110	.474	-.327	-.032	-1.291	-.290	-.125	-.028	45.049
343	2/16/77	FWD	1188	0.000	29.88	40.64	3.81	1.325	1.000	1.325	.755	.380	.852	.381	.217	.853	.486	44.883
344	2/17/77	FWD	989	.447	10.49	16.02	6.11	1.054	1.001	1.053	.950	.225	.658	.225	.203	.657	.593	26.641
345	2/17/77	FWD	1001	.655	-12.97	-8.00	3.00	.989	.499	1.982	.504	-.425	.007	-1.706	-.434	.029	.007	17.451
346	2/17/77	FWD	996	.633	6.40	10.90	3.18	.970	.999	.971	1.030	.198	.714	.199		.715		18.430
347	2/17/77	FWD	1006	.801	3.53	6.63	1.85	.975	1.002	.973	1.028	.183	.843	.183		.840		11.027
348	2/17/77	FWD	1003	.799	-8.96	-5.14	1.97	.996	.500	1.992	.502	-.462	.062	-1.848	-.466	.247	.062	11.085
349	2/17/77	FWD	999	.092	-24.04	-16.91	2.87	.978	.499	1.959	.510	-.325	.015	-1.306	-.340	.060	.016	42.226
350	2/17/77	FWD	989	.176	51.18	60.41	5.34	1.057	.995	1.063	.941	.757	.930	.766	.678	.940	.832	38.613
351	2/17/77	FWD	994	.220	-30.16	-20.61	5.53	.974	.503	1.935	.517	-.471	-.083	-1.859	-.496	-.329	-.088	36.609
352	2/17/77	FWD	993	.214	-39.88	-30.49	5.36	.973	.450	2.164	.462	-.618	-.246	-3.056	-.653	-1.218	-.260	36.865

SUMMARY TABLE Phase I Forward Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
353	2/17/77	FWD	998	.947	-2.95	-1.63	.71	.949	.499	1.902	.526	-.367	.147	-1.472	-.407	.592	.164	4.606
354	2/17/77	FWD	994	.947	3.55	4.80	.74	.956	.998	.958	1.044	.444	1.167	.446		1.172		4.565
355	2/17/77	FWD	996	.908	3.58	5.37	1.01	.958	.998	.960	1.042	.325	.975	.326		.978		6.307
356	2/17/77	FWD	994	.906	-4.57	-2.49	1.05	.967	.500	1.936	.517	-.410	.073	-1.642	-.438	.292	.078	6.368
357	2/17/77	FWD	995	1.000	-.89	-.56	.30	.960	.500	1.920	.521	-.225	.340	-.901	-.245	1.359	.369	2.249
358	2/17/77	FWD	996	1.000	3.53	3.82	.29	.954	.998	.955	1.047	.898	1.555	.901		1.560		2.249
359	2/18/77	FWD	991	.415	66.27	79.22	9.66	1.319	1.482	.890	1.124	1.351	1.523	.615		.693		28.022
360	2/18/77	FWD	985	.411	-2.76	10.80	9.14	1.303	.999	1.304	.767	-.056	.687	-.056	-.033	.688	.405	28.209
361	2/18/77	FWD	999	.404	40.93	45.07	5.40	.997	1.148	.868	1.152	.820	1.078	.621		.818		28.506
362	2/18/77	FWD	1003	.399	24.52	21.22	.37	.342	.833	.410	2.437	.487	.452	.702		.651		28.686
363	2/18/77	FWD	998	.389	10.16	11.36	.64	.337	.550	.613	1.632	.199	.240	.659		.793		29.151
364	2/18/77	FWD	1211	.102	-22.41	-15.85	2.72	.985	.499	1.976	.506	-.317	.005	-1.275	-.327	.021	.005	40.401
365	2/21/77	FWD	14	0.000	29.84	29.31	-.22	.043	.498	.086	11.635	.277	.172	1.117		.696		61.614
366	2/21/77	FWD	31	0.000	30.11	31.00	.28	.297	.498	.598	1.674	.280	.224	1.130		.905		61.501
367	2/21/77	FWD	71	0.000	17.09	19.78	.95	.588	.498	1.182	.846	.159	.227	.643	.460	.918	.657	61.387
368	2/21/77	FWD	107	0.000	-6.64	-1.45	1.84	.859	.499	1.721	.581	-.062	.167	-.249	-.084	.671	.227	61.200
369	2/21/77	FWD	94	0.000	-50.68	-43.58	2.41	.998	.504	1.981	.505	-.474	-.132	-1.870	-.477	-.520	-.132	61.050
370	2/21/77	FWD	91	0.000	-.63	-.65	.01	.042	.000	497.845	.002	-.006	-.090	*******	-3.343	*******	-51.047	61.050
371	2/21/77	FWD	99	0.000	-14.09	-13.38	-.13	.303	.000	*******	.000	-.132	-.208	*******	-1.440	*******	-2.269	61.050
377	2/23/77	FWD	1187	.102	67.35	72.71	2.98	.977	.997	.980	1.021	.949	.995	.955		1.002		40.535
378	2/23/77	FWD	1193	.214	-22.32	-15.39	4.22	.982	.499	1.967	.509	-.356	-.012	-1.429	-.370	-.048	-.013	35.786
379	2/23/77	FWD	1198	.196	46.28	52.79	4.41	1.055	.996	1.059	.945	.723	.897	.729	.650	.904	.806	36.550
380	2/23/77	FWD	1195	.253	-20.84	-14.35	3.95	.993	.502	1.978	.506	-.349	-.010	-1.385	-.354	-.041	-.011	34.165
381	2/23/77	FWD	1190	.274	40.90	50.45	4.59	1.017	1.001	1.016	.984	.701	.942	.700	.678	.941	.911	33.318
382	2/23/77	FWD	1190	.409	-21.36	-14.85	3.90	.989	.498	1.985	.504	-.442	-.017	-1.784	-.453	-.069	-.018	27.601
383	2/23/77	FWD	1196	.786	-7.41	-4.91	1.37	.980	.498	1.970	.508	-.361	.069	-1.460	-.376	.278	.072	11.744
384	2/23/77	FWD	850	.716	-2.89	-.72	1.08	.776	.497	1.561	.641	-.111	.183	-.450	-.185	.743	.305	14.849
386	2/24/77	FWD	845	.792	-5.83	-3.25	.97	.963	.499	1.929	.518	-.293	.118	-1.175	-.316	.473	.127	11.377
387	2/24/77	FWD	841	.794	3.20	5.76	1.24	.975	.999	.976	1.024	.162	.661	.163		.662		11.272
388	2/24/77	FWD	845	.430	-22.80	-16.93	3.22	1.007	.500	2.015	.496	-.468	-.104	-1.874	-.462	-.418	-.103	27.860
389	2/24/77	FWD	843	.253	-36.69	-29.61	4.61	.997	.501	1.991	.502	-.583	-.175	-2.324	-.586	-.697	-.176	35.961
390	2/24/77	FWD	843	.122	-38.20	-29.79	4.65	1.003	.500	2.008	.498	-.520	-.138	-2.083	-.517	-.552	-.137	41.964
566	3/28/77	FWD	1015	.361	-84.42	-77.31	3.31	.947	-.000	*******	-.000	-1.590	-1.669	*******	-1.774	*******	-1.861	30.312
569	3/29/77	FWD	1210	.052	17.06	21.02	1.45	.934	.701	1.333	.750	.229	.444	.467	.263	.904	.509	42.528
570	3/29/77	FWD	1218	.064	-24.18	-15.96	3.07	1.265	.702	1.803	.555	-.329	.206	-.669	-.206	.418	.129	41.964
571	3/29/77	FWD	1111	.235	100.63	100.86	6.00	1.165	1.301	.895	1.117	1.626	1.453	.961		.859		35.363
572	3/29/77	FWD	1117	.041	78.00	81.87	1.22	.943	.998	.944	1.059	1.020	1.041	1.024		1.045		43.676
573	3/29/77	FWD	1125	.056	102.50	107.04	1.29	.933	1.112	.839	1.192	1.363	1.274	1.101		1.030		42.941
578	3/29/77	FWD	869	0.000	24.09	24.62	.19	.315	.500	.630	1.587	.279	.248	1.117		.993		49.295
579	3/30/77	FWD	869	0.000	15.11	16.60	.50	.573	.499	1.150	.870	.177	.246	.712	.538	.989	.748	48.804

SUMMARY TABLF Phase I Forward Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS PAGE-- 5

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
580	3/30/77	FWD	867	0.000	24.38	24.82	.16	.290	.499	.582	1.718	.282	.229	1.135		.921		49.383
581	3/30/77	FWD	862	0.000	3.96	6.94	.89	.763	.499	1.529	.654	.047	.181	.187	.080	.729	.311	48.610
582	3/30/77	FWD	960	0.000	-11.22	-6.60	1.34	.960	.501	1.916	.522	-.135	.089	-.537	-.146	.354	.097	47.551
583	3/30/77	FWD	425	0.000	-10.91	-6.44	1.36	.930	.498	1.868	.535	-.118	.098	-.477	-.137	.395	.113	52.687
584	3/30/77	FWD	178	0.000	-8.63	-3.42	1.45	.891	.497	1.793	.558	-.086	.113	-.349	-.108	.456	.142	57.307
585	3/30/77	FWD	172	0.000	-14.33	-9.61	1.50	.941	.501	1.878	.532	-.143	.087	-.569	-.161	.348	.099	57.307
586	3/30/77	FWD	166	0.000	-25.25	-18.99	1.76	.986	.501	1.970	.508	-.252	.028	-1.004	-.259	.112	.029	57.307
587	3/30/77	FWD	84	0.000	-42.68	-36.56	1.74	.948	.503	1.883	.531	-.402	-.068	-1.587	-.448	-.268	-.076	60.643
588	3/30/77	FWD	96	0.000	-50.25	-46.21	1.85	.990	.500	1.979	.505	-.474	-.146	-1.893	-.483	-.583	-.149	60.643
591	3/31/77	FWD	45	1.000	-19.56	-17.57	.41	8.201	1.479	5.547	.180	*******	164.330	-52.144	-1.695	75.167	2.443	.098
592	3/31/77	FWD	48	1.000	-7.51	-6.87	.25	5.587	.602	9.287	.108	-40.850	184.642	*******	-1.309	510.101	5.914	.105
593	4/ 1/77	FWD	50	1.000	-24.05	-22.52	.40	7.815	-.000	*******	-.000	*******	*******	*******	-2.072	*******	-7.758	.109
594	4/ 1/77	FWD	48	1.000	-23.51	-22.03	.39	7.925	-.000	*******	-.000	*******	*******	*******	-2.048	*******	-7.991	.104
595	4/ 1/77	FWD	34	1.000	-14.03	-13.11	.30	7.555	-.000	*******	-.000	*******	*******	*******	-1.899	*******	-2.644	.074
596	4/ 1/77	FWD	26	1.000	-7.68	-7.05	.22	6.543	-.000	*******	-.000	-77.986	-45.796	*******	-1.821	*******	-1.070	.056
597	4/ 1/77	FWD	32	1.000	-2.31	-2.00	.13	3.554	-.000	*******	-.000	-19.120	149.160	*******	-1.514	*******	11.812	.069
598	4/ 1/77	FWD	30	1.000	-4.63	-4.20	.18	4.970	-.000	*******	-.000	-40.444	118.487	*******	-1.637	*******	4.797	.065
602	4/ 1/77	FWD	1213	0.000	-2.93	-3.09	.07	.153	-.000	*******	-.001	-.037	-.071	*******	-1.583	*******	-3.065	45.310
603	4/ 1/77	FWD	1211	0.000	-1.91	-2.11	.05	.122	-.000	*******	-.002	-.024	-.065	*******	-1.616	*******	-4.422	45.712
604	4/ 1/77	FWD	1220	0.000	-1.46	-1.65	.05	.103	-.000	*******	-.002	-.018	-.059	*******	-1.730	*******	-5.643	45.981
605	4/ 1/77	FWD	1214	0.000	-.89	-1.08	.04	.074	-.000	*******	-.003	-.011	-.058	*******	-1.983	*******	-10.465	46.070
606	4/ 1/77	FWD	1213	0.000	-.59	-.79	.03	.053	-.000	*******	-.004	-.007	-.057	*******	-2.589	*******	-20.375	46.266
615	4/ 6/77	FWD	27	.176	-.34	-.38	-.01	-.011	-.000	29.136	.034	-.004	.006	*******	-31.575	*******	51.728	50.135
616	4/ 6/77	FWD	90	0.000	-48.58	-39.98	3.14	.970	.499	1.944	.514	-.456	-.083	-1.833	-.485	-.336	-.089	60.901
617	4/ 6/77	FWD	141	0.000	-33.00	-25.38	2.67	.965	.498	1.938	.516	-.329	.006	-1.328	-.353	.025	.007	57.307
618	4/ 6/77	FWD	403	0.000	-13.47	-6.87	2.40	.915	.497	1.841	.543	-.146	.130	-.592	-.174	.527	.155	52.715
619	4/ 6/77	FWD	400	0.000	-14.86	-8.16	2.42	.929	.497	1.869	.535	-.161	.110	-.652	-.187	.445	.127	52.715
623	4/ 6/77	FWD	868	0.000	1.16	5.88	1.62	.771	.499	1.546	.647	.014	.206	.055	.023	.830	.347	48.193
624	4/ 6/77	FWD	875	0.000	13.27	16.05	.93	.578	.498	1.161	.861	.157	.258	.632	.469	1.039	.771	48.370
625	4/ 6/77	FWD	871	0.000	23.67	24.39	.25	.289	.499	.580	1.724	.278	.263	1.117		1.057		48.709
627	4/ 7/77	FWD	1137	0.000	1.37	5.64	1.57	.770	.499	1.543	.648	.017	.199	.069	.029	.799	.336	45.876
628	4/ 7/77	FWD	1146	0.000	68.27	75.57	2.60	1.005	-.000	*******	-.000	.855	1.111	*******	.848	*******	1.101	45.600
636	4/28/77	FWD	25	0.000	38.80	36.69	-1.14	.052	.497	.105	9.561	.360	.188	1.458		.760		61.576
637	4/28/77	FWD	25	0.000	157.17	149.87	-1.34	.098	.995	.099	10.124	1.460	.796	1.474		.804		61.538
638	4/28/77	FWD	20	0.000	143.76	143.34	-1.33	.231	.994	.232	4.311	1.336	.830	1.353		.840		61.463
639	4/28/77	FWD	166	0.000	-2.38	-1.84	.14	.174	.060	2.901	.345	-.024	-.015	-6.613	-.786	-4.077	-.484	57.274
642	4/28/77	FWD	821	0.000	-1.67	-1.12	.04	.078	.002	41.035	.024	-.019	-.000	*******	-3.100	*******	-.060	50.363
643	4/28/77	FWD	718	0.000	-8.10	-8.72	.55	.440	.177	2.482	.403	-.094	-.022	-2.978	-.483	-.711	-.115	49.480
648	4/28/77	FWD	865	0.000	25.90	25.06	.24	.289	.503	.575	1.739	.302	.237	1.193		.938		49.058
649	4/28/77	FWD	866	0.000	26.21	25.10	.23	.281	.501	.561	1.783	.305	.234	1.217		.932		49.116

SUMMARY TABLE Phase I Forward Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
650	4/28/77	FWD	865	0.000	14.18	16.43	.88	.578	.501	1.153	.867	.168	.256	.668	.502	1.022	.768	48.356
661	5/ 9/77	FWD	98	0.000	-1.78	-1.46	.11	.161	.057	2.845	.351	-.018	.008	-5.550	-.686	2.549	.315	57.176
663	5/ 9/77	FWD	387	0.000	-1.85	-2.03	.16	.215	.075	2.878	.347	-.020	-.011	-3.578	-.432	-1.931	-.233	52.826
668	5/10/77	FWD	869	0.000	23.95	24.23	.26	.287	.498	.577	1.734	.282	.227	1.138		.915		48.520
669	5/10/77	FWD	863	0.000	-.25	15.88	.94	.579	.498	1.163	.860	-.003	.235	-.012	-.009	.947	.701	48.137
670	5/10/77	FWD	853	0.000	-.30	4.67	1.75	.789	.498	1.584	.631	-.004	.174	-.014	-.006	.700	.279	47.971
671	5/10/77	FWD	858	0.000	13.27	15.63	.95	.587	.498	1.178	.849	.158	.232	.637	.459	.936	.674	48.003
672	5/10/77	FWD	851	0.000	.01	5.31	1.64	.780	.500	1.562	.640	.000	.174	.000	.000	.698	.286	47.884
673	5/10/77	FWD	846	0.000	-18.73	-10.85	2.66	.980	.502	1.952	.512	-.222	.062	-.880	-.231	.247	.065	48.286
674	5/10/77	FWD	852	0.000	-7.52	-2.30	2.24	.889	.501	1.775	.564	-.089	.123	-.354	-.112	.490	.155	48.421
675	5/10/77	FWD	1109	0.000	-19.67	-13.21	2.66	1.001	.501	1.997	.501	-.245	.033	-.974	-.244	.130	.032	45.952
676	5/10/77	FWD	963	0.000	56.09	63.57	4.58	.667	1.018	.655	1.527	.689	.730	.665		.704		46.486
688	5/11/77	FWD	145	0.000	-2.64	-2.09	.1+	.226	.089	2.546	.393	-.027	-.010	-3.363	-.519	-1.215	-.187	56.922
689	5/11/77	FWD	371	0.000	-18.01	-15.73	1.74	.788	.360	2.189	.457	-.195	-.040	-1.507	-.315	-.309	-.065	52.715
695	5/12/77	FWD	867	0.000	24.63	24.26	.25	.292	.498	.585	1.708	.290	.218	1.170		.879		48.464
696	5/12/77	FWD	857	0.000	13.21	16.02	.85	.577	.498	1.159	.863	.157	.226	.632	.470	.910	.677	48.132
697	5/12/77	FWD	868	0.000	.35	5.68	1.51	.775	.498	1.555	.643	.004	.172	.017	.007	.693	.286	47.916
698	5/12/77	FWD	860	0.000	-5.92	-.97	1.83	.866	.499	1.735	.576	-.071	.130	-.284	-.094	.520	.173	47.856
699	5/12/77	FWD	871	0.000	-12.87	-9.31	2.39	.976	.501	1.948	.513	-.152	.062	-.607	-.160	.246	.065	48.235
700	5/12/77	FWD	1130	0.000	-20.10	-11.82	2.33	1.002	.500	2.003	.499	-.250	.037	-.998	-.249	.147	.037	45.960
701	5/12/77	FWD	982	0.000	52.95	68.75	3.66	.715	.996	.718	1.393	.652	.755	.657		.760		46.369
717	5/18/77	FWD	1015	0.000	87.66	83.71	-1.37	.098	.860	.114	8.785	1.079	.541	1.460		.732		46.434
718	5/18/77	FWD	964	.253	12.00	13.94	1.33	.551	.573	.962	1.040	.193	.233	.588		.710		35.453
719	5/18/77	FWD	966	.195	8.15	9.27	1.29	.485	.573	.847	1.181	.123	.181	.373		.551		37.997
720	5/18/77	FWD	966	.175	9.59	10.88	1.39	.495	.572	.865	1.156	.141	.201	.431		.614		38.898
721	5/18/77	FWD	968	.297	9.05	10.75	1.30	.568	.571	.993	1.007	.154	.226	.473		.693		33.463
722	5/18/77	FWD	958	.294	8.06	10.16	1.28	.574	.557	1.029	.972	.137	.212	.441	.416	.682	.644	33.636
723	5/18/77	FWD	961	.265	9.52	11.58	1.40	.581	.561	1.036	.966	.156	.204	.495	.462	.650	.606	34.904
724	5/18/77	FWD	959	.268	10.49	10.55	1.62	.593	.570	1.039	.962	.172	.226	.529	.490	.696	.644	34.797
725	5/18/77	FWD	957	.261	10.95	12.77	1.39	.561	.568	.987	1.013	.178	.246	.551		.762		35.127
726	5/18/77	FWD	949	.361	-2.20	1.25	2.21	.719	.503	1.430	.699	-.041	.123	-.162	-.079	.488	.238	30.679
736	5/19/77	FWD	948	.065	18.63	19.78	.36	.523	.500	1.047	.955	.240	.250	.960	.876	1.001	.913	44.385
737	5/19/77	FWD	942	.414	-4.76	-.84	2.46	.792	.500	1.583	.632	-.096	.109	-.384	-.153	.436	.174	28.322
738	5/19/77	FWD	936	.340	-.57	2.79	1.93	.700	.499	1.405	.712	-.010	.141	-.041	-.021	.565	.287	31.654
739	5/19/77	FWD	940	.394	-1.16	1.63	1.75	.692	.500	1.386	.722	-.023	.134	-.091	-.047	.537	.280	29.218
740	5/19/77	FWD	904	.449	-1.12	5.71	4.09	1.034	.765	1.351	.740	-.024	.372	-.041	-.022	.635	.348	26.883
741	5/19/77	FWD	868	.453	4.70	9.58	4.14	1.073	.865	1.241	.806	.100	.482	.134	.087	.645	.419	26.802
742	5/19/77	FWD	868	.503	-.78	6.12	4.39	1.126	.864	1.304	.767	-.018	.426	-.025	-.015	.571	.336	24.517
743	5/19/77	FWD	869	.440	-41.21	-31.88	6.05	1.191	.582	2.047	.489	-.860	-.308	-2.540	-.606	-.910	-.217	27.394
744	5/19/77	FWD	870	.450	-41.67	-33.12	6.05	1.208	.582	2.077	.482	-.884	-.313	-2.615	-.606	-.925	-.215	26.957

SUMMARY TABLE Phase I Forward Flow Tests

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ.B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
745	5/19/77	FWD	888	.448	-42.86	-35.36	5.92	1.196	.541	2.212	.452	-.908	-.411	-3.106	-.635	-1.407	-.288	26.973
746	5/19/77	FWD	940	.367	-50.54	-39.95	6.04	1.136	.500	2.273	.440	-.949	-.438	-3.801	-.736	-1.755	-.340	30.427
747	5/19/77	FWD	839	.558	-22.83	-16.04	3.32	1.006	.446	2.256	.443	-.590	-.183	-2.972	-.584	-.923	-.181	22.097
748	5/19/77	FWD	841	.557	-21.36	-16.10	3.23	1.001	.445	2.253	.444	-.552	-.186	-2.794	-.550	-.941	-.185	22.137
749	5/19/77	FWD	836	.550	-22.42	-17.15	3.24	1.001	.450	2.226	.449	-.571	-.201	-2.825	-.570	-.992	-.200	22.430
750	5/19/77	FWD	838	.544	-19.31	-15.04	3.06	.985	.450	2.189	.457	-.485	-.159	-2.393	-.499	-.787	-.164	22.731
751	5/19/77	FWD	841	.510	-20.99	-16.50	3.29	.973	.450	2.163	.462	-.493	-.179	-2.437	-.521	-.882	-.188	24.303
752	5/19/77	FWD	808	.619	-20.89	-14.37	3.17	1.035	.455	2.277	.439	-.618	-.162	-2.989	-.576	-.784	-.151	19.329
753	5/19/77	FWD	807	.618	-19.99	-14.71	3.04	1.030	.455	2.264	.442	-.589	-.184	-2.846	-.555	-.889	-.174	19.399
754	5/19/77	FWD	818	.609	-18.34	-14.23	3.12	1.017	.455	2.237	.447	-.530	-.183	-2.562	-.512	-.883	-.176	19.795
755	5/19/77	FWD	796	.637	-28.88	-24.96	3.33	1.086	.371	2.926	.342	-.891	-.474	-6.469	-.755	-3.445	-.402	18.536
756	5/20/77	FWD	806	.633	-23.16	-16.95	3.47	1.099	.479	2.293	.436	-.708	-.220	-3.079	-.586	-.956	-.182	18.706
757	5/20/77	FWD	802	.635	-22.74	-17.50	3.55	1.104	.480	2.302	.434	-.698	-.209	-3.035	-.573	-.909	-.172	18.603
761	5/20/77	FWD	756	.674	-19.61	-13.02	3.05	1.098	.500	2.197	.455	-.664	-.154	-2.660	-.551	-.617	-.128	16.862
762	5/20/77	FWD	754	.718	-17.59	-12.40	3.04	1.125	.500	2.248	.445	-.678	-.176	-2.712	-.536	-.703	-.139	14.823
763	5/20/77	FWD	753	.703	-18.49	-12.52	3.08	1.128	.500	2.256	.443	-.681	-.175	-2.725	-.535	-.702	-.138	15.513
765	5/20/77	FWD	703	.725	-17.45	-13.42	3.13	1.163	.509	2.285	.438	-.688	-.206	-2.655	-.509	-.796	-.153	14.516
766	5/20/77	FWD	707	.745	-20.08	-13.43	3.26	1.212	.509	2.380	.420	-.847	-.261	-3.267	-.577	-1.007	-.178	13.551
767	5/20/77	FWD	636	.793	-18.46	-13.55	2.97	1.275	.508	2.508	.399	-.931	-.307	-3.602	-.572	-1.189	-.189	11.329
769	5/20/77	FWD	639	.802	-21.97	-15.28	3.33	1.354	.520	2.607	.384	-1.157	-.396	-4.287	-.631	-1.466	-.216	10.851
770	5/20/77	FWD	638	.802	-20.88	-15.32	3.23	1.337	.520	2.573	.389	-1.095	-.377	-4.056	-.613	-1.395	-.211	10.897
771	5/20/77	FWD	841	.579	-28.00	-23.21	3.58	1.111	.451	2.465	.406	-.758	-.328	-3.731	-.614	-1.617	-.266	21.121
772	5/20/77	FWD	844	.539	-24.68	-18.32	3.48	1.015	.449	2.258	.443	-.615	-.206	-3.042	-.597	-1.018	-.200	22.964
773	5/20/77	FWD	952	.263	-11.63	-4.62	4.38	.972	.568	1.712	.584	-.190	.140	-.589	-.201	.434	.148	35.016
777	5/20/77	FWD	948	0.000	20.00	21.87	.57	.635	.566	1.123	.891	.238	.293	.743	.590	.915	.726	48.077
778	5/20/77	FWD	935	0.000	13.19	15.87	.74	.751	.566	1.327	.754	.157	.267	.490	.278	.833	.473	48.012
779	5/20/77	FWD	909	0.000	-4.75	-.14	1.33	.984	.567	1.734	.577	-.057	.159	-.176	-.058	.495	.165	47.925
780	5/20/77	FWD	868	0.000	31.81	32.50	.17	.291	.566	.514	1.947	.375	.273	1.170		.851		48.492
781	5/21/77	FWD	300	.968	-2.37	-1.34	.56	1.137	.500	2.275	.440	-.580	-.015	-2.320	-.448	-.058	-.011	2.333
782	5/21/77	FWD	293	.968	-2.67	-1.55	.56	1.159	.500	2.320	.431	-.671	-.056	-2.687	-.499	-.224	-.042	2.275
783	5/21/77	FWD	274	.985	-2.76	-1.68	.46	1.417	.500	2.834	.353	-1.162	-.654	-4.648	-.579	-2.616	-.326	1.359
784	5/21/77	FWD	278	.985	-1.80	-1.11	.39	1.254	.500	2.509	.399	-.734	-.389	-2.940	-.467	-1.560	-.248	1.405
785	5/21/77	FWD	278	.988	-1.81	-1.21	.36	1.288	.497	2.590	.386	-.848	-.335	-3.426	-.511	-1.355	-.202	1.218
786	5/21/77	FWD	277	.987	-1.45	-.85	.36	1.270	.551	2.307	.434	-.666	-.490	-2.197	-.413	-1.616	-.304	1.247
795	5/23/77	FWD	873	0.000	-3.35	-2.96	.25	.296	.107	2.759	.362	-.040	-.021	-3.477	-.457	-1.841	-.242	47.870
796	5/23/77	FWD	871	0.000	-9.98	-7.63	.88	.587	.249	2.361	.424	-.119	-.039	-1.931	-.346	-.626	-.112	47.815
797	5/23/77	FWD	871	0.000	-16.61	-12.62	1.56	.780	.343	2.278	.439	-.198	-.047	-1.688	-.325	-.397	-.077	47.893
798	5/23/77	FWD	873	0.000	-24.21	-18.39	2.40	.970	.437	2.219	.451	-.287	-.059	-1.501	-.305	-.308	-.063	48.216
799	5/23/77	FWD	869	0.000	-20.36	-15.57	1.93	.880	.388	2.270	.441	-.242	-.051	-1.607	-.312	-.339	-.066	48.146
800	5/23/77	FWD	971	.230	-28.58	-19.73	5.33	1.006	.500	2.010	.497	-.448	-.063	-1.791	-.443	-.251	-.062	36.414

SUMMARY TABLE Phase I Forward Flow Tests

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
801	5/23/77	FWD	971	.223	-28.18	-19.41	5.39	1.005	.501	2.006	.498	-.439	-.073	-1.746	-.434	-.291	-.072	36.716
802	5/23/77	FWD	972	.194	-48.23	-36.93	6.66	1.096	.504	2.175	.460	-.726	-.264	-2.858	-.604	-1.041	-.220	37.982
803	5/23/77	FWD	951	.328	-60.63	-50.28	6.70	1.147	.466	2.463	.406	-1.078	-.596	-4.972	-.820	-2.750	-.453	32.144
804	5/23/77	FWD	946	.288	-61.84	-50.49	6.38	1.100	.437	2.518	.397	-1.041	-.600	-5.455	-.860	-3.143	-.495	33.942
805	5/24/77	FWD	845	.554	-28.02	-21.92	3.57	1.163	.499	2.331	.429	-.718	-.238	-2.887	-.531	-.955	-.176	22.276
806	5/24/77	FWD	914	.433	-50.20	-41.04	6.10	1.229	.499	2.461	.406	-1.040	-.467	-4.170	-.689	-1.873	-.309	27.589
807	5/24/77	FWD	893	.470	-41.18	-34.43	5.18	1.203	.498	2.414	.414	-.905	-.418	-3.645	-.625	-1.684	-.289	25.996
808	5/24/77	FWD	856	.525	-33.14	-23.67	4.65	1.199	.497	2.411	.415	-.803	-.305	-3.247	-.559	-1.231	-.212	23.577
809	5/24/77	FWD	846	.554	-28.02	-21.92	3.57	1.163	.499	2.331	.429	-.718	-.238	-2.887	-.531	-.955	-.176	22.276
810	5/24/77	FWD	848	.618	-21.25	-15.33	3.08	1.147	.499	2.300	.435	-.629	-.160	-2.528	-.478	-.643	-.121	19.315
811	5/24/77	FWD	797	.648	-19.11	-12.25	2.91	1.144	.499	2.294	.436	-.606	-.154	-2.437	-.463	-.618	-.118	18.010
812	5/24/77	FWD	745	.676	-18.07	-11.36	2.61	1.136	.500	2.274	.440	-.614	-.119	-2.459	-.476	-.478	-.092	16.808
813	5/24/77	FWD	742	.732	-14.86	-10.29	2.29	1.158	.501	2.312	.433	-.600	-.088	-2.390	-.447	-.352	-.066	14.174
814	5/24/77	FWD	740	.762	-13.80	-9.20	2.10	1.174	.500	2.346	.426	-.619	-.122	-2.471	-.449	-.488	-.089	12.747
815	5/24/77	FWD	645	.811	-12.27	-8.04	2.02	1.183	.500	2.364	.423	-.671	-.068	-2.679	-.479	-.273	-.049	10.456
816	5/24/77	FWD	645	.810	-12.29	-8.00	2.05	1.179	.500	2.358	.424	-.670	-.077	-2.681	-.482	-.307	-.055	10.495
817	5/24/77	FWD	302	.980	-3.57	-2.29	.75	1.415	.500	2.832	.353	-1.198	-.060	-4.801	-.599	-.241	-.030	1.702
818	5/24/77	FWD	302	.980	-3.66	-2.30	.74	1.426	.500	2.854	.350	-1.242	-.245	-4.973	-.611	-.979	-.120	1.683
819	5/24/77	FWD	301	.989	-2.98	-1.96	.67	1.459	.500	2.918	.343	-1.381	-.656	-5.526	-.649	-2.625	-.308	1.232
820	5/24/77	FWD	305	.992	-3.03	-2.05	.63	1.508	.500	3.017	.331	-1.660	-.519	-6.645	-.730	-2.076	-.228	1.049
821	5/24/77	FWD	303	.992	-3.24	-2.15	.65	1.537	.500	3.072	.326	-1.786	-.558	-7.138	-.757	-2.230	-.236	1.037
822	5/24/77	FWD	301	1.000	-1.56	-1.20	.21	1.577	.500	3.155	.317	-1.396	-.686	-5.585	-.561	-2.747	-.276	.639
830	5/25/77	FWD	160	0.000	-2.82	-2.46	.25	.258	.098	2.626	.381	-.028	-.015	-2.907	-.422	-1.503	-.218	57.169
832	5/25/77	FWD	440	0.000	-4.14	-2.63	.26	.280	-.001	*******	-.004	-.045	-.002	*******	-.576	*******	-.023	52.576
838	5/25/77	FWD	873	0.000	-3.49	-2.98	.24	.288	.105	2.746	.364	-.041	-.013	-3.758	-.498	-1.200	-.159	48.239
839	5/25/77	FWD	867	0.000	-8.93	-7.22	.85	.552	.233	2.374	.421	-.106	-.028	-1.963	-.349	-.516	-.092	47.998
840	5/25/77	FWD	863	0.000	-18.06	-13.21	1.58	.786	.346	2.274	.440	-.216	-.041	-1.805	-.349	-.342	-.066	47.819
841	5/25/77	FWD	877	0.000	-21.52	-15.34	1.99	.874	.389	2.248	.445	-.255	-.047	-1.686	-.334	-.309	-.061	48.193
842	5/25/77	FWD	868	0.000	-26.78	-20.09	2.56	1.004	.453	2.215	.452	-.318	-.053	-1.547	-.315	-.256	-.052	48.132
843	5/25/77	FWD	873	0.000	-22.58	-13.36	2.59	1.010	.499	2.025	.494	-.269	.035	-1.080	-.263	.140	.034	48.045
844	5/26/77	FWD	858	0.000	-18.78	-10.63	2.47	.988	.500	1.976	.506	-.222	.048	-.887	-.227	.192	.049	48.342
845	5/26/77	FWD	1061	0.000	68.62	76.69	2.39	1.009	.998	1.011	.990	.854	.966	.857	.839	.970	.950	45.943
846	5/26/77	FWD	969	0.000	65.43	66.23	3.92	.693	1.002	.692	1.445	.806	.792	.803		.788		46.386

SUMMARY TABLE Phase II Forward Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

PAGE-- 1

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LI)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
856	9/20/77	FWD	79	0.000	-23.44	-13.47	3.63	1.257	.983	1.279	.782	-.222	.488	-.230	-.140	.505	.309	60.401
857	9/20/77	FWD	90	0.000	-37.15	-29.69	3.22	1.207	.833	1.448	.691	-.352	.282	-.507	-.242	.406	.194	60.285
858	9/20/77	FWD	236	0.000	-58.91	-51.14	2.61	1.095	.594	1.845	.542	-.559	-.096	-1.587	-.467	-.271	-.080	60.205
859	9/20/77	FWD	126	0.000	-15.65	-10.12	1.97	.950	.494	1.923	.520	-.149	.114	-.610	-.165	.469	.127	60.132
860	9/20/77	FWD	137	0.000	-4.45	.09	1.62	.846	.492	1.721	.581	-.042	.173	-.175	-.059	.715	.241	60.096
861	9/20/77	FWD	73	0.000	8.92	12.34	1.12	.688	.491	1.401	.714	.085	.221	.351	.179	.917	.467	60.132
862	9/20/77	FWD	92	0.000	24.30	25.74	.54	.457	.491	.932	1.073	.231	.251	.958		1.041		60.168
863	9/20/77	FWD	106	0.000	32.33	32.31	.09	.188	.491	.384	2.608	.307	.232	1.272		.962		60.234
864	9/21/77	FWD	87	0.000	-20.34	-5.65	5.69	1.321	.998	1.323	.756	-.194	.580	-.195	-.111	.582	.333	59.880
865	9/21/77	FWD	93	0.000	-32.06	-17.85	5.17	1.228	.874	1.405	.712	-.305	.391	-.400	-.203	.512	.259	59.952
866	9/21/77	FWD	108	0.000	-53.76	-40.83	4.41	1.120	.643	1.742	.574	-.512	-.009	-1.239	-.408	-.021	-.007	60.038
867	9/21/77	FWD	121	0.000	-77.35	-67.55	3.40	.996	.358	2.780	.360	-.734	-.699	-5.715	-.740	-5.450	-.705	60.263
868	9/21/77	FWD	55	0.000	-18.41	-11.62	2.53	.846	.541	1.563	.640	-.174	.145	-.594	-.243	.497	.203	60.423
869	9/21/77	FWD	68	0.000	-35.04	-29.84	1.94	.723	.276	2.622	.381	-.331	-.134	-4.348	-.632	-1.762	-.256	60.569
870	9/21/77	FWD	93	0.000	-6.48	-4.86	.77	.425	.183	2.319	.431	-.061	.006	-1.820	-.338	.190	.035	60.643
871	9/21/77	FWD	104	0.000	-2.36	-2.11	.17	.163	.069	2.639	.379	-.022	.017	-4.618	-.663	3.510	.504	60.716
872	9/21/77	FWD	111	0.000	-73.70	-68.76	1.63	.691	.003	256.396	.004	-.708	-.665	*******	-1.484	*******	-1.394	59.517
873	9/22/77	FWD	36	1.000	-2.76	-2.46	.21	4.658	.997	4.670	.214	-20.102	7.400	-20.210	-.927	7.440	.341	.079
874	9/22/77	FWD	38	1.000	-1.57	-1.42	.13	3.819	.997	3.830	.261	-11.357	11.203	-11.423	-.779	11.269	.768	.084
875	9/22/77	FWD	34	1.000	-1.33	-1.07	.16	3.661	.997	3.672	.272	-10.217	11.884	-10.275	-.762	11.952	.887	.074
876	9/22/77	FWD	33	1.000	-.65	-.53	.14	2.941	.997	2.950	.339	-5.133	16.487	-5.165	-.594	16.589	1.906	.073
877	9/22/77	FWD	33	1.000	-.29	-.27	.11	2.368	.997	2.375	.421	-2.196	27.711	-2.210	-.392	27.889	4.944	.074
878	9/22/77	FWD	26	1.000	-.25	-.25	.11	2.144	.997	2.151	.465	-2.443	31.073	-2.459	-.532	31.272	6.760	.057
879	9/22/77	FWD	28	1.000	-.17	-.33	.10	1.013	.218	4.646	.215	-1.542	23.454	-32.461	-1.504	493.732	22.871	.065
880	9/22/77	FWD	508	.353	-26.74	-5.74	10.90	1.254	1.001	1.252	.799	-.462	.547	-.461	-.294	.546	.348	33.049
881	9/22/77	FWD	465	.218	18.55	30.14	7.33	1.001	1.004	.997	1.003	.265	.564	.263		.560		40.045
885	9/23/77	FWD	811	.657	-40.54	-31.90	2.62	1.001	.049	20.362	.049	-1.326	-2.241	*******	-1.324	*******	-2.237	17.468
886	9/23/77	FWD	782	.621	-40.55	-35.07	2.35	.893	.029	31.048	.032	-1.206	-1.865	*******	-1.511	*******	-2.337	19.159
887	9/23/77	FWD	868	.799	-52.95	-43.41	2.55	1.406	-.001	*******	-.000	-2.742	-2.291	*******	-1.387	*******	-1.159	11.036
888	9/23/77	FWD	994	.253	63.26	65.28	2.00	.646	.991	.652	1.534	1.025	.859	1.045		.875		35.256
898	9/28/77	FWD	1045	.421	-9.65	-8.84	.38	.361	-.001	*******	-.002	-.199	-.187	*******	-1.534	*******	-1.440	27.643
899	9/29/77	FWD	1027	.422	-9.80	-9.06	.36	.363	-.001	*******	-.002	-.202	-.191	*******	-1.539	*******	-1.452	27.667
900	9/29/77	FWD	1002	.167	-4.00	3.54	4.74	1.063	.702	1.514	.661	-.059	.294	-.119	-.052	.596	.260	39.014
901	9/29/77	FWD	996	.231	-2.43	4.87	4.24	1.028	.702	1.465	.683	-.038	.291	-.078	-.036	.592	.276	36.198
902	9/29/77	FWD	996	.359	-4.89	1.67	3.49	1.041	.703	1.480	.676	-.091	.266	-.185	-.084	.538	.246	30.564
903	9/29/77	FWD	1001	.248	9.48	16.82	4.65	1.068	.834	1.281	.781	.153	.501	.220	.134	.719	.439	35.451
904	9/29/77	FWD	1005	.667	-3.16	.06	1.52	1.052	.704	1.494	.669	-.107	.322	-.216	-.097	.649	.291	16.906
907	9/29/77	FWD	861	0.000	-59.01	-53.92	1.19	.988	.249	3.967	.252	-.697	-.514	-11.247	-.715	-8.294	-.527	48.356
908	9/30/77	FWD	834	.517	-65.00	-62.11	2.91	1.199	.277	4.329	.231	-1.550	-1.211	-20.209	-1.078	-15.780	-.842	23.990
909	9/30/77	FWD	846	.660	-33.81	-30.19	1.75	1.145	.269	4.252	.235	-1.110	-.931	-15.304	-.846	-12.836	-.710	17.405

SUMMARY TABLE Phase II Forward Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

PAGE-- 2

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRO.B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
910	9/30/77	FWD	847	.664	-33.00	-28.32	1.97	1.151	.278	4.147	.241	-1.097	-.690	-14.229	-.827	-8.949	-.520	17.198
911	9/30/77	FWD	853	.640	5.26	7.90	1.39	.983	.998	.985	1.015	.165	.547	.166		.550		18.155
912	9/30/77	FWD	843	.659	-9.52	-6.76	1.18	.983	.498	1.973	.507	-.312	.035	-1.256	-.323	.140	.036	17.433
913	9/30/77	FWD	849	.798	-28.56	-23.33	1.78	1.397	.350	3.996	.250	-1.470	-.971	-12.026	-.753	-7.942	-.497	11.097
914	9/30/77	FWD	843	.904	-18.97	-15.75	1.53	1.454	.348	4.176	.239	-1.737	-1.024	-14.334	-.822	-8.451	-.485	6.240
915	9/30/77	FWD	854	.951	-12.57	-10.55	1.02	1.440	.348	4.140	.242	-1.748	-1.072	-14.452	-.843	-8.864	-.517	4.106
916	9/30/77	FWD	846	1.000	-.78	-.54	.19	1.041	.499	2.087	.479	-.239	.042	-.961	-.221	.170	.039	1.855
917	9/30/77	FWD	849	.900	-4.03	-2.59	.76	1.029	.498	2.064	.485	-.358	.097	-1.442	-.338	.390	.091	6.421
918	9/30/77	FWD	848	.951	2.97	3.90	.47	1.012	.998	1.014	.986	.415	1.018	.417	.405	1.021	.993	4.090
919	9/30/77	FWD	849	.801	.29	2.75	1.03	1.022	.847	1.207	.828	.015	.498	.021	.015	.694	.476	10.950
920	9/30/77	FWD	847	.817	10.06	9.84	-.02	.095	.999	.095	10.481	.564	.730	.566		.732		10.165
921	9/30/77	FWD	1006	.472	29.13	29.17	.07	.110	.995	.110	9.084	.652	.726	.658		.733		25.530
922	9/30/77	FWD	1013	.425	33.58	36.53	.22	.267	.996	.268	3.727	.701	.680	.707		.685		27.444
928	10/ 3/77	FWD	78	0.000	-11.78	-7.16	1.51	.842	.472	1.784	.560	-.110	.117	-.494	-.155	.524	.165	61.125
929	10/ 3/77	FWD	79	0.000	-12.16	-7.18	1.57	.841	.472	1.782	.561	-.114	.119	-.511	-.161	.532	.168	61.087
930	10/ 3/77	FWD	78	0.000	-11.73	-6.79	1.57	.840	.472	1.779	.562	-.110	.116	-.493	-.156	.519	.164	61.087
931	10/ 3/77	FWD	94	0.000	6.19	9.25	1.15	.694	.471	1.473	.679	.058	.165	.261	.120	.746	.344	61.028
932	10/ 3/77	FWD	95	0.000	6.01	9.46	1.13	.695	.471	1.475	.678	.056	.166	.254	.117	.747	.344	61.013
933	10/ 3/77	FWD	94	0.000	6.05	9.36	1.06	.694	.471	1.473	.679	.057	.164	.256	.118	.740	.341	61.013
934	10/ 3/77	FWD	114	0.000	21.16	22.81	.53	.462	.470	.983	1.017	.198	.198	.896		.896		60.976
935	10/ 3/77	FWD	114	0.000	21.47	22.76	.54	.462	.470	.981	1.019	.201	.203	.910		.916		60.938
936	10/ 3/77	FWD	114	0.000	21.30	22.73	.54	.462	.470	.983	1.017	.200	.203	.903		.919		60.938
937	10/ 3/77	FWD	93	0.000	-15.84	-5.79	3.19	1.315	1.000	1.315	.761	-.151	.546	-.151	-.087	.545	.315	59.981
938	10/ 3/77	FWD	92	0.000	-17.34	-6.27	3.28	1.320	1.000	1.320	.757	-.166	.535	-.166	-.095	.535	.307	59.837
939	10/ 3/77	FWD	92	0.000	-17.25	-6.43	3.20	1.311	1.000	1.311	.763	-.165	.524	-.165	-.096	.523	.305	59.709
940	10/ 3/77	FWD	119	0.000	-30.44	-24.34	1.82	.932	.431	2.165	.462	-.290	-.054	-1.566	-.334	-.290	-.062	59.895
941	10/ 3/77	FWD	110	0.000	-24.67	-19.52	1.74	.896	.431	2.081	.480	-.235	-.019	-1.269	-.293	-.103	-.024	59.880
942	10/ 3/77	FWD	102	0.000	-22.43	-16.85	1.61	.875	.430	2.033	.492	-.214	-.004	-1.156	-.280	-.024	-.006	59.844
943	10/ 3/77	FWD	113	0.000	-65.99	-58.93	2.15	1.056	.516	2.047	.489	-.629	-.244	-2.364	-.564	-.917	-.219	59.952
944	10/ 3/77	FWD	161	0.000	-30.93	-24.09	2.20	1.038	.492	2.110	.474	-.294	-.020	-1.217	-.273	-.084	-.019	60.010
945	10/ 4/77	FWD	163	0.000	-30.33	-23.20	2.20	1.031	.491	2.098	.477	-.288	-.016	-1.194	-.271	-.067	-.015	60.132
946	10/ 4/77	FWD	148	0.000	-39.31	-31.16	2.68	1.156	.596	1.939	.516	-.373	.033	-1.051	-.279	.093	.025	60.168
947	10/ 4/77	FWD	148	0.000	-38.52	-30.86	2.69	1.159	.596	1.943	.515	-.366	.034	-1.028	-.272	.096	.025	60.205
948	10/ 4/77	FWD	148	0.000	-38.75	-30.34	2.73	1.160	.596	1.947	.514	-.368	.036	-1.036	-.273	.101	.027	60.212
949	10/ 4/77	FWD	133	0.000	-17.14	-8.69	3.01	1.261	.786	1.604	.623	-.163	.361	-.263	-.102	.585	.227	60.205
950	10/ 4/77	FWD	133	0.000	-17.28	-9.13	3.10	1.249	.787	1.588	.630	-.164	.357	-.265	-.105	.577	.229	60.205
951	10/ 4/77	FWD	133	0.000	-17.31	-8.10	3.08	1.257	.786	1.599	.625	-.164	.364	-.266	-.104	.589	.230	60.205
952	10/ 4/77	FWD	119	0.000	5.14	16.35	3.52	1.341	.979	1.371	.730	.049	.672	.051	.027	.702	.373	60.168
953	10/ 4/77	FWD	118	0.000	4.79	16.54	3.44	1.356	.978	1.386	.721	.046	.675	.048	.025	.705	.367	60.132
954	10/ 4/77	FWD	119	0.000	4.92	16.81	3.39	1.355	.977	1.387	.721	.047	.669	.049	.025	.700	.364	60.096

SUMMARY TABLE Phase II Forward Flow Tests

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
958	10/ 4/77	FWD	998	.794	-1.03	1.06	1.03	.985	.704	1.399	.715	-.052	.343	-.104	-.053	.692	.353	11.341
959	10/ 4/77	FWD	1004	.434	.51	.56	.17	.224	.250	.895	1.118	.011	.026	.172		.408		27.187
960	10/ 5/77	FWD	1176	.496	9.33	15.96	3.54	1.140	.999	1.141	.877	.222	.704	.223	.171	.705	.542	24.004
961	10/ 5/77	FWD	1106	.423	18.74	24.30	3.73	1.043	.998	1.045	.957	.392	.721	.394	.361	.724	.663	27.299
962	10/ 5/77	FWD	505	.018	-26.35	-20.30	1.20	.937	.498	1.879	.532	-.303	.032	-1.218	-.345	.130	.037	49.756
963	10/ 5/77	FWD	484	.218	-66.33	-53.63	4.55	.921	.463	1.990	.503	-.949	-.594	-4.432	-1.120	-2.777	-.702	39.946
964	10/ 5/77	FWD	485	.043	-66.61	-56.30	3.21	.801	.427	1.876	.533	-.807	-.544	-4.428	-1.258	-2.984	-.847	48.563
965	10/ 5/77	FWD	481	0.000	-60.12	-51.81	.91	.819	.427	1.917	.522	-.676	-.394	-3.705	-1.009	-2.160	-.588	50.839
966	10/ 5/77	FWD	472	.349	-35.69	-27.50	3.41	.935	.500	1.870	.535	-.608	-.191	-2.430	-.695	-.764	-.218	33.566
967	10/ 5/77	FWD	482	.371	12.36	18.01	4.24	.965	.999	.967	1.035	.218	.515	.219		.517		32.362
971	10/ 6/77	FWD	712	0.000	-38.48	-32.14	1.77	1.119	.498	2.246	.445	-.446	-.136	-1.800	-.357	-.547	-.109	49.324
972	10/ 6/77	FWD	841	0.000	-37.73	-31.54	1.74	1.116	.498	2.242	.446	-.448	-.120	-1.806	-.359	-.483	-.096	48.170
973	10/ 6/77	FWD	837	0.000	-26.34	-20.70	1.62	1.066	.497	2.144	.466	-.311	-.031	-1.259	-.274	-.125	-.027	48.323
974	10/ 6/77	FWD	845	0.000	-20.06	-14.36	1.59	1.014	.497	2.039	.491	-.237	.020	-.957	-.230	.080	.019	48.305
975	10/ 6/77	FWD	850	0.000	-12.32	-7.70	1.31	.959	.496	1.932	.518	-.146	.069	-.591	-.158	.281	.075	48.314
976	10/ 6/77	FWD	837	0.000	-5.21	-1.43	1.14	.888	.498	1.782	.561	-.061	.120	-.248	-.078	.484	.152	48.501
977	10/ 6/77	FWD	855	0.000	.64	3.80	.93	.811	.498	1.631	.613	.008	.158	.031	.012	.638	.240	48.440
978	10/ 6/77	FWD	843	0.000	5.67	8.36	.81	.739	.499	1.483	.675	.067	.189	.268	.122	.761	.346	48.577
979	10/ 6/77	FWD	836	0.000	11.26	13.19	.62	.639	.498	1.283	.779	.134	.217	.538	.327	.876	.532	48.207
980	10/ 6/77	FWD	847	0.000	18.93	20.02	.40	.501	.500	1.001	.999	.224	.239	.894	.892	.954	.952	48.305
981	10/ 6/77	FWD	833	0.000	23.52	24.24	.21	.315	.500	.629	1.590	.277	.227	1.108		.907		48.497
982	10/ 6/77	FWD	841	0.000	28.03	28.71	.30	.147	.501	.294	3.399	.329	.205	1.309		.817		48.738
983	10/ 6/77	FWD	848	0.000	23.68	23.76	.23	.337	.501	.673	1.485	.279	.232	1.115		.925		48.431
984	1/ 6/77	FWD	849	0.000	11.09	20.46	2.36	1.400	.943	1.484	.674	.133	.677	.149	.068	.760	.345	47.801
986	10/ 6/77	FWD	487	.655	-14.32	-6.55	1.64	1.029	.499	2.066	.484	-.449	-.061	-1.812	-.425	-.245	-.057	18.208
987	10/ 6/77	FWD	482	.688	-.91	3.12	2.21	1.129	1.001	1.128	.887	-.028	.542	-.028	-.022	.541	.426	16.590
988	10/ 6/77	FWD	487	.613	3.42	6.16	1.37	.901	1.000	.901	1.110	.096	.505	.096		.505		20.300
989	0/ 6/77	FWD	479	.651	1.43	5.03	1.66	.994	1.000	.994	1.006	.044	.496	.044		.496		18.486
990	10/ 6/77	FWD	476	.197	18.81	24.27	6.80	1.035	.994	1.041	.960	.262	.542	.265	.244	.549	.506	41.068
991	10/ 6/77	FWD	479	.209	17.34	26.80	6.42	1.042	.993	1.049	.953	.245	.553	.249	.226	.561	.509	40.538
992	10/ 6/77	FWD	474	.216	16.67	24.86	6.49	1.050	.996	1.054	.949	.223	.522	.225	.203	.526	.474	40.128
993	10/ 6/77	FWD	475	.917	-.05	2.31	1.02	1.049	1.001	1.048	.954	-.003	.580	-.003	-.003	.578	.527	10.127
994	10/ 6/77	FWD	481	.901	1.00	2.29	.59	1.008	1.000	1.007	.993	.096	.765	.096	.094	.764	.753	5.959
995	10/ 6/77	FWD	479	.948	1.29	2.28	.42	1.022	1.001	1.021	.980	.205	1.017	.205	.197	1.015	.974	3.595
996	10/ 7/77	FWD	485	.901	-3.72	-1.45	.60	1.010	.501	2.018	.496	-.356	.037	-1.422	-.349	.146	.036	5.963
1003	10/11/77	FWD	55	0.000	3.74	21.26	6.44	1.387	1.288	1.077	.929	.035	.850	.021	.018	.512	.441	60.350
1004	10/11/77	FWD	186	0.000	29.55	51.40	7.73	1.509	1.106	1.364	.733	.280	.998	.229	.123	.815	.438	60.343
1005	10/11/77	FWD	199	0.000	54.15	72.50	6.56	1.421	1.097	1.296	.772	.518	1.053	.431	.257	.875	.521	59.701
1006	10/11/77	FWD	228	0.000	25.39	41.07	5.71	1.318	.939	1.403	.713	.244	.720	.277	.141	.816	.414	59.418
1007	10/11/77	FWD	252	0.000	43.06	56.30	4.73	1.216	.939	1.296	.772	.416	.772	.473	.281	.876	.522	59.081

SUMMARY TABLE Phase II Forward Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

PAGE-- 4

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
1008	10/11/77	FWD	262	0.000	58.74	69.49	4.02	1.091	.937	1.164	.859	.571	.817	.650	.480	.930	.686	58.768
1009	10/11/77	FWD	227	0.000	81.01	89.77	2.34	.939	.953	.986	1.015	.791	.870	.872		.958		58.486
1010	10/11/77	FWD	232	0.000	93.67	100.67	2.26	.825	.953	.866	1.155	.916	.866	1.009		.953		58.411
1011	10/11/77	FWD	231	0.000	58.97	103.87	1.65	.690	.945	.730	1.369	.969	.830	1.085		.929		58.377
1012	10/11/77	FWD	292	0.000	21.83	24.45	.04	.517	.507	1.020	.980	.213	.250	.829	.797	.972	.934	58.486
1013	10/11/77	FWD	286	0.000	31.06	32.15	.25	.233	.508	.459	2.177	.303	.221	1.175		.856		58.624
1014	10/11/77	FWD	270	.113	40.36	37.05	-1.37	-.007	.508	-.015	-68.264	.445	.221	1.720		.856		51.959
1015	10/11/77	FWD	276	0.000	31.15	32.38	.25	.235	.508	.463	2.161	.302	.221	1.171		.854		58.879
1016	10/11/77	FWD	343	0.000	22.19	24.84	.92	.512	.508	1.008	.992	.215	.246	.834	.920	.954	.938	58.976
1017	10/11/77	FWD	312	0.000	111.34	106.38	1.59	.682	.948	.719	1.391	.983	.833	1.094		.927		58.928
1018	10/11/77	FWD	316	0.000	93.01	99.52	2.24	.824	.947	.871	1.149	.904	.855	1.008		.953		58.789
1019	10/11/77	FWD	313	0.000	79.03	88.11	2.93	.941	.947	.994	1.006	.778	.856	.868		.955		58.679
1020	10/11/77	FWD	359	0.000	53.43	64.33	3.85	1.089	.919	1.185	.844	.523	.778	.619	.440	.921	.656	58.432
1021	10/11/77	FWD	354	0.000	37.53	51.51	4.89	1.217	.923	1.319	.758	.370	.738	.434	.250	.866	.498	57.984
1022	10/11/77	FWD	358	0.000	18.22	34.60	5.87	1.338	.922	1.450	.690	.183	.660	.215	.102	.776	.369	56.928
1023	10/11/77	FWD	347	0.000	31.13	50.13	6.71	1.457	1.042	1.398	.715	.315	.891	.290	.148	.821	.420	56.536
1024	10/11/77	FWD	339	0.000	37.84	58.52	7.54	1.554	1.130	1.375	.727	.386	1.073	.302	.160	.840	.444	56.066
1026	10/11/77	FWD	334	0.000	1.55	1.94	.23	.235	.185	1.269	.788	.015	.023	.427	.265	.676	.420	60.496
1027	10/11/77	FWD	333	0.000	2.24	4.50	.92	.500	.339	1.475	.678	.021	.084	.184	.085	.732	.336	60.459
1028	10/11/77	FWD	311	0.000	71.34	75.74	1.60	.674	.804	.839	1.192	.675	.604	1.045		.935		60.386
1029	10/11/77	FWD	305	0.000	57.95	54.30	2.20	.809	.803	1.007	.993	.549	.628	.851	.839	.973	.960	60.299
1030	10/12/77	FWD	275	0.000	44.86	53.08	2.89	.931	.803	1.159	.863	.426	.598	.660	.491	.927	.689	60.096
1031	10/12/77	FWD	269	0.000	32.59	43.20	3.55	1.073	.824	1.301	.768	.310	.589	.457	.270	.867	.512	60.002
1032	10/12/77	FWD	256	0.000	40.93	53.83	4.42	1.199	.922	1.301	.769	.390	.763	.459	.271	.898	.531	59.895
1033	10/12/77	FWD	239	0.000	64.08	80.38	5.56	1.316	1.062	1.239	.807	.612	1.020	.543	.354	.904	.589	59.787
1034	10/12/77	FWD	292	0.000	7.27	25.44	6.56	1.418	.933	1.520	.658	.070	.630	.080	.035	.724	.313	59.573
1035	10/12/77	FWD	277	0.000	42.16	52.79	7.49	1.515	1.081	1.402	.713	.310	.941	.265	.135	.806	.410	59.305
1036	10/12/77	FWD	288	0.000	29.76	47.83	6.40	1.424	1.014	1.405	.712	.289	.838	.281	.143	.816	.413	58.844
1037	10/12/77	FWD	291	0.000	57.55	73.54	5.61	1.323	1.047	1.263	.791	.561	.971	.512	.321	.886	.555	58.596
1038	10/12/77	FWD	301	0.000	58.21	71.50	4.59	1.221	.997	1.225	.817	.569	.899	.572	.382	.905	.603	58.466
1039	10/12/77	FWD	297	0.000	84.75	96.50	3.74	1.095	1.030	1.063	.941	.831	1.003	.783	.693	.945	.837	58.275
1040	10/12/77	FWD	259	0.000	103.83	111.71	2.89	.947	1.029	.920	1.086	1.013	1.016	.957		.960		58.119
1041	10/12/77	FWD	267	0.000	100.43	106.88	2.21	.825	.975	.847	1.181	.989	.899	1.040		.946		58.059
1042	10/12/77	FWD	264	0.000	112.48	117.32	1.64	.690	1.009	.684	1.461	1.108	.943	1.089		.926		58.005
1043	10/12/77	FWD	262	0.000	125.62	129.60	.98	.513	1.032	.497	2.012	1.238	.930	1.164		.874		57.971
1044	10/12/77	FWD	245	0.000	187.71	186.40	-1.37	.233	1.152	.202	4.947	1.851	1.028	1.393		.774		57.964
1046	10/12/77	FWD	269	0.000	14.83	15.49	.20	.234	.366	.641	1.559	.146	.120	1.090		.901		58.173
1047	10/12/77	FWD	260	0.000	31.99	34.64	.38	.518	.570	.908	1.102	.314	.313	.964		.961		58.241
1048	10/12/77	FWD	245	0.000	58.28	63.04	1.52	.692	.765	.904	1.106	.571	.557	.975		.951		58.275
1049	10/12/77	FWD	256	0.000	56.16	62.12	2.10	.826	.808	1.022	.978	.551	.626	.843	.807	.958	.917	58.309

SUMMARY TABLE Phase II Forward Flow Tests

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-TS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
1050	10/12/77	FWD	305	0.000	50.63	58.50	2.75	.939	.837	1.121	.892	.497	.664	.709	.564	.947	.754	58.187
1051	10/12/77	FWD	296	0.000	41.06	51.84	3.63	1.095	.872	1.257	.796	.404	.683	.532	.337	.899	.570	58.086
1052	10/12/77	FWD	293	0.000	38.94	52.10	4.60	1.219	.928	1.313	.762	.384	.752	.446	.258	.873	.507	57.958
1053	10/12/77	FWD	284	0.000	33.57	46.63	5.40	1.330	.972	1.368	.731	.332	.796	.351	.188	.843	.450	57.824
1054	10/12/77	FWD	276	0.000	28.12	46.31	6.04	1.440	1.019	1.413	.708	.279	.849	.268	.134	.817	.409	57.663
1055	10/12/77	FWD	242	0.000	36.06	58.00	6.97	1.525	1.124	1.356	.737	.368	1.046	.291	.158	.828	.450	57.386
1056	10/12/77	FWD	256	0.000	17.32	34.30	6.13	1.440	.998	1.442	.693	.173	.776	.174	.083	.779	.374	57.195
1057	10/12/77	FWD	259	0.000	36.51	51.91	5.32	1.341	.997	1.345	.743	.368	.850	.371	.205	.855	.472	56.644
1058	10/12/77	FWD	268	0.000	52.48	65.96	4.49	1.245	.997	1.249	.801	.532	.893	.536	.343	.898	.576	56.319
1059	10/12/77	FWD	282	0.000	69.04	80.35	3.55	1.121	.996	1.126	.888	.703	.930	.709	.559	.939	.740	56.129
1060	10/12/77	FWD	242	0.000	96.77	94.99	2.73	.964	.992	.972	1.029	.885	.950	.900		.966		56.022
1061	10/12/77	FWD	246	0.000	100.67	106.50	2.02	.841	.993	.848	1.180	1.027	.939	1.043		.953		55.991
1062	10/12/77	FWD	245	0.000	105.91	111.55	1.53	.705	.993	.709	1.410	1.080	.917	1.095		.929		56.022
1063	10/12/77	FWD	252	0.000	110.60	114.24	.92	.532	.992	.536	1.865	1.129	.875	1.147		.889		56.066
1064	10/12/77	FWD	250	0.000	131.28	132.30	-.39	.253	.996	.254	3.931	1.336	.795	1.350		.803		56.142
1066	10/12/77	FWD	286	0.000	76.23	79.72	.66	.252	.772	.327	3.058	.772	.484	1.296		.813		56.402
1067	10/12/77	FWD	297	0.000	63.57	67.16	.90	.524	.771	.685	1.459	.644	.540	1.083		.908		56.402
1068	10/12/77	FWD	269	0.000	106.72	111.42	1.53	.700	.994	.704	1.420	1.082	.916	1.095		.926		56.338
1069	10/12/77	FWD	269	0.000	101.43	107.86	2.13	.841	.993	.847	1.181	1.030	.934	1.045		.947		56.243
1070	10/11/77	FWD	254	0.000	87.07	95.34	2.75	.972	.992	.980	1.020	.887	.962	.902		.978		56.085
1071	10/12/77	FWD	288	0.000	67.65	76.70	3.64	1.125	.993	1.132	.883	.693	.922	.703	.548	.934	.729	55.785
1072	10/12/77	FWD	285	0.000	50.93	63.47	4.36	1.237	.996	1.243	.805	.525	.904	.530	.343	.912	.591	55.389
1073	10/12/77	FWD	282	0.000	21.61	37.90	5.64	1.366	.996	1.372	.729	.225	.806	.227	.120	.813	.432	54.951
1074	10/12/77	FWD	352	0.000	26.40	45.36	6.02	1.493	1.069	1.393	.718	.277	.920	.244	.126	.811	.418	54.460
1075	10/12/77	FWD	364	0.000	36.66	57.06	6.95	1.564	1.156	1.352	.739	.386	1.094	.289	.158	.818	.447	54.242
1076	10/13/77	FWD	68	1.000	-7.70	-7.04	.34	4.682	.497	9.420	.106	-29.424	-31.912	********	-1.342	********	-1.456	.149
1077	10/13/77	FWD	64	1.000	-.35	-.28	.11	.985	-.001	********	-.001	-1.390	-4.433	********	-1.432	********	-4.569	.144
1078	10/13/77	FWD	54	1.000	-.65	-.55	.12	1.499	-.000	********	-.000	-3.030	-5.278	********	-1.350	********	-2.351	.122
1079	10/13/77	FWD	54	1.000	-1.34	-1.20	.14	2.137	.087	24.658	.041	-6.305	-11.435	********	-1.381	********	-2.505	.121
1080	10/13/77	FWD	55	1.000	-1.98	-1.77	.18	2.709	.227	11.906	.084	-9.191	-14.672	********	-1.253	********	-2.000	.123
1081	10/13/77	FWD	53	1.000	-2.35	-2.13	.19	3.000	.228	13.173	.076	-11.523	-16.241	********	-1.280	********	-1.804	.117
1082	10/13/77	FWD	60	1.000	-4.60	-4.19	.26	3.750	.228	16.472	.061	-19.455	-27.337	********	-1.419	********	-1.944	.132
1083	10/13/77	FWD	60	1.000	-6.29	-5.75	.30	4.318	.267	16.180	.062	-27.245	-31.942	********	-1.461	********	-1.713	.132
1084	10/13/77	FWD	73	1.000	-7.63	-6.87	.35	4.648	.608	7.644	.131	-27.379	-28.120	-74.048	-1.267	-76.051	-1.301	.159
1085	10/13/77	FWD	53	1.000	-1.66	-1.38	.19	2.685	.431	6.223	.161	-8.374	-11.710	-44.993	-1.162	-62.918	-1.625	.115
1086	10/13/77	FWD	54	1.000	-.56	-.47	.11	1.327	.031	42.547	.024	-2.708	-6.611	********	-1.539	********	-3.756	.119
1087	10/13/77	FWD	53	1.000	-.84	-.70	.12	1.640	.030	55.207	.018	-4.071	-6.882	********	-1.514	********	-2.559	.118
1088	10/13/77	FWD	56	1.000	-1.81	-1.54	.15	2.401	.114	21.141	.047	-8.425	-11.336	********	-1.462	********	-1.967	.123
1089	10/13/77	FWD	56	1.000	-2.43	-2.09	.15	2.456	.221	12.948	.077	-11.162	-6.124	********	-1.369	********	-.751	.124
1090	10/13/77	FWD	56	1.000	-3.12	-2.70	.20	3.188	.220	14.480	.069	-14.494	-16.146	********	-1.427	********	-1.589	.123

SUMMARY TABLE Phase II Forward Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (II)	DP (FF)	DP (TS-DS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
1091	10/13/77	FWD	58	1.000	-4.56	-3.88	.23	3.684	.220	16.734	.060	-20.488	-20.903	*******	-1.509	*******	-1.540	.127
1092	10/13/77	FWD	57	1.000	-4.96	-4.23	.24	3.858	.221	17.467	.057	-22.665	-20.445	*******	-1.522	*******	-1.373	.125
1093	10/13/77	FWD	59	1.000	-5.74	-4.93	.28	4.364	.552	7.910	.126	-25.285	-21.603	-83.068	-1.328	-70.972	-1.134	.130
1095	10/13/77	FWD	54	1.000	-.27	-.15	.12	1.503	.552	2.723	.367	-1.266	-5.589	-4.156	-.560	-18.341	-2.473	.121
1096	10/13/77	FWD	55	1.000	-1.25	-1.03	.16	2.570	.551	4.662	.215	-5.917	-7.252	-19.463	-.895	-23.854	-1.098	.120
1097	10/13/77	FWD	56	1.000	-1.93	-1.65	.19	3.029	.552	5.493	.182	-9.061	-14.285	-29.788	-.987	-46.964	-1.557	.122
1098	10/13/77	FWD	56	1.000	-2.55	-2.23	.21	3.409	.551	6.183	.162	-11.858	-13.615	-39.004	-1.020	-44.783	-1.171	.123
1099	10/13/77	FWD	60	1.000	-3.61	-3.18	.24	3.768	.552	6.830	.146	-15.746	-17.580	-51.740	-1.109	-57.767	-1.238	.131
1100	10/13/77	FWD	60	1.000	-5.64	-4.98	.33	4.826	.886	5.448	.184	-24.536	-20.043	-31.265	-1.053	-25.540	-.860	.131
1102	10/13/77	FWD	54	1.000	-1.11	-.85	.20	2.993	.998	3.000	.333	-5.328	-1.852	-5.352	-.595	-1.861	-.207	.119
1112	10/18/77	FWD	951	.266	22.96	35.85	6.04	1.077	1.007	1.069	.935	.376	.722	.371	.324	.711	.622	34.863
1113	10/18/77	FWD	936	.219	36.27	45.40	6.29	1.053	1.008	1.045	.957	.559	.730	.551	.505	.719	.659	37.051
1114	10/18/77	FWD	958	.203	40.21	50.54	6.89	1.045	1.007	1.038	.964	.610	.770	.602	.559	.759	.705	37.651
1115	10/18/77	FWD	955	.187	46.53	54.22	6.07	1.033	1.002	1.031	.970	.694	.901	.691	.650	.897	.844	38.344
1116	10/18/77	FWD	951	.187	44.91	56.49	6.13	1.036	1.001	1.036	.966	.669	.878	.668	.623	.876	.817	38.370
1118	10/20/77	FWD	45	1.000	-2.63	-2.19	.26	4.706	1.625	2.896	.345	-15.304	-4.956	-5.796	-.691	-1.877	-.224	.098
1119	1/20/77	FWD	50	1.000	-3.01	-2.46	.29	4.825	1.625	2.969	.337	-15.825	-5.431	-5.991	-.680	-2.056	-.233	.109
1120	10/20/77	FWD	51	1.000	-4.08	-3.58	.29	4.798	1.155	4.153	.241	-21.089	-13.069	-15.798	-.916	-9.790	-.568	.111
1121	10/20/77	FWD	49	1.000	-.34	-.17	.14	2.343	1.154	2.031	.492	-1.782	3.375	-1.339	-.325	2.535	.615	.109
1122	10/20/77	FWD	482	.989	1.55	1.79	.15	.917	.947	.920	1.087	.565	1.211	.569		1.219		1.572
1123	10/20/77	FWD	482	.988	-.36	-.14	.16	.883	.498	1.772	.564	-.124	.107	-.499	-.159	.429	.137	1.652
1124	10/20/77	FWD	483	.990	-1.83	-1.50	.20	1.130	.349	3.243	.308	-.682	-.412	-5.611	-.533	-3.391	-.322	1.536
1125	10/20/77	FWD	483	.991	-2.34	-1.43	.22	1.229	.348	3.527	.284	-.889	-.371	-7.323	-.589	-3.051	-.245	1.501
1126	10/20/77	FWD	484	.991	-2.38	-2.00	.22	1.219	.330	3.694	.271	-.903	-.491	-8.288	-.607	-4.508	-.330	1.508
1133	10/21/77	FWD	251	0.000	-7.63	-4.75	.69	.428	.186	2.300	.435	-.071	-.049	-2.058	-.389	-1.420	-.268	61.237
1134	10/21/77	FWD	308	0.000	-60.46	-55.57	2.47	.863	.192	4.504	.222	-.565	-.709	-15.389	-.758	-19.295	-.951	61.110
1135	10/21/77	FWD	225	0.000	40.40	58.91	7.14	1.495	1.084	1.378	.725	.379	.971	.323	.170	.826	.435	60.864
1136	10/21/77	FWD	211	.100	24.26	23.16	-1.37	-.009	.406	-.023	-44.274	.270	.135	1.642		.823		51.319
1137	10/21/77	FWD	171	0.000	-26.50	-19.64	2.42	.899	.409	2.200	.455	-.263	-.028	-1.578	-.326	-.168	-.035	57.504
1138	10/21/77	FWD	431	.041	25.05	21.95	-1.37	-.009	.406	-.021	-47.373	.283	.143	1.718		.865		50.515
1139	10/21/77	FWD	425	0.000	-31.81	-23.86	2.39	.949	.410	2.315	.432	-.346	-.072	-2.062	-.385	-.430	-.080	52.515
1140	10/21/77	FWD	914	0.000	22.24	20.20	-1.37	.013	.406	.031	31.794	.265	.149	1.613		.904		47.874
1141	10/21/77	FWD	917	0.000	-29.04	-23.63	2.32	.984	.409	2.405	.416	-.348	-.099	-2.081	-.360	-.591	-.102	47.615
1145	10/22/77	FWD	889	0.000	-26.55	-23.66	2.33	.979	.409	2.395	.417	-.317	-.082	-1.895	-.330	-.493	-.086	47.893
1146	10/22/77	FWD	863	0.000	39.15	56.84	5.69	1.501	1.164	1.290	.775	.471	1.167	.348	.209	.861	.518	47.515
1147	10/22/77	FWD	866	0.000	-7.76	6.40	3.72	1.272	.794	1.603	.624	-.093	.459	-.147	-.057	.729	.284	47.742
1148	10/22/77	FWD	878	0.000	-6.69	-4.47	.63	.492	.221	2.225	.449	-.080	.013	-1.637	-.331	.262	.053	47.851
1149	10/22/77	FWD	883	0.000	-3.98	-3.90	.49	.430	.186	2.306	.434	-.048	.009	-1.370	-.258	.247	.046	47.824
1151	10/22/77	FWD	914	0.000	-14.85	-9.31	2.20	.941	.471	1.998	.501	-.178	.064	-.801	-.201	.288	.072	47.724
1152	10/22/77	FWD	876	0.000	27.21	38.73	3.33	1.209	.903	1.338	.747	.326	.736	.399	.223	.902	.504	47.755

SUMMARY TABLE Phase II Forward Flow Tests

GE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ.B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
1153	10/22/77	FWD	841	0.000	29.61	44.39	4.81	1.441	1.070	1.347	.743	.354	.998	.309	.171	.871	.480	47.746
1155	10/22/77	FWD	1121	0.000	69.02	77.48	2.30	.996	.999	.996	1.004	.858	.994	.859		.995		45.985
1156	10/22/77	FWD	948	0.000	56.65	61.57	3.66	.624	1.009	.619	1.617	.694	.762	.682		.748		46.620
1164	10/25/77	FWD	162	0.000	-26.44	-19.70	2.45	.889	.405	2.196	.455	-.263	-.052	-1.602	-.332	-.320	-.066	57.537
1165	10/25/77	FWD	340	0.000	-6.30	-4.89	.66	.431	.186	2.311	.433	-.060	-.023	-1.717	-.322	-.662	-.124	60.241
1166	10/25/77	FWD	318	0.000	-13.65	-6.66	2.40	.867	.453	1.913	.523	-.129	.093	-.628	-.172	.455	.124	60.503
1167	10/25/77	FWD	269	0.000	34.90	57.12	7.26	1.518	1.086	1.398	.715	.330	.958	.280	.143	.813	.416	60.430
1168	10/25/77	FWD	439	.038	5.55	4.66	-.45	-.009	.192	-.049	-20.617	.062	.014	1.690		.380		50.885
1169	10/25/77	FWD	450	0.000	-68.75	-64.39	2.29	.935	.199	4.696	.213	-.749	-.625	-18.884	-.856	-15.761	-.715	52.427
1170	10/25/77	FWD	894	0.000	17.24	19.27	.62	.506	.499	1.014	.986	.207	.242	.832	.809	.975	.948	47.660
1171	10/25/77	FWD	925	0.000	-17.04	-10.35	2.39	.993	.502	1.979	.505	-.205	.053	-.813	-.208	.212	.054	47.574
1172	10/25/77	FWD	855	0.000	45.93	61.51	5.64	1.531	1.196	1.280	.781	.551	1.222	.385	.235	.854	.521	47.551
1173	10/25/77	FWD	918	.043	32.41	29.62	-1.38	-.006	.496	-.011	-88.645	.405	.193	1.647		.785		45.804
1178	10/26/77	FWD	1025	0.000	69.70	76.63	2.31	1.005	.998	1.007	.993	.861	.929	.864	.853	.933	.921	46.262
1179	10/26/77	FWD	984	0.000	65.33	78.66	2.92	.677	1.009	.671	1.491	.806	.584	.792		.574		46.318
1186	10/27/77	FWD	291	0.000	-7.84	-4.84	.74	.431	.186	2.316	.432	-.073	-.009	-2.119	-.395	-.256	-.048	61.125
1187	10/27/77	FWD	272	0.000	-19.09	-11.25	2.51	.855	.416	2.056	.486	-.179	.030	-1.033	-.244	.171	.041	61.087
1188	10/27/77	FWD	264	0.000	19.60	39.27	6.80	1.476	1.015	1.454	.688	.184	.824	.179	.085	.800	.378	60.879
1189	10/27/77	FWD	283	0.000	-8.45	-5.60	.80	.443	.186	2.388	.419	-.080	-.017	-2.314	-.406	-.488	-.086	60.643
1190	10/27/77	FWD	253	0.000	.34	9.16	3.36	.976	.613	1.592	.628	.003	.295	.009	.003	.785	.310	60.643
1191	10/27/77	FWD	305	0.000	-60.24	-47.89	4.25	1.105	.416	2.659	.376	-.568	-.271	-3.291	-.465	-1.567	-.222	60.555
1192	10/27/77	FWD	285	0.000	-26.71	-13.12	5.42	1.269	.683	1.857	.539	-.253	.189	-.541	-.157	.405	.118	60.423
1193	10/27/77	FWD	264	0.000	9.06	29.70	6.93	1.436	.957	1.500	.666	.086	.690	.094	.042	.754	.335	60.183
1194	10/27/77	FWD	268	0.000	-26.76	-19.63	2.27	.806	.332	2.426	.412	-.254	-.076	-2.303	-.391	-.685	-.116	60.205
1197	10/27/77	FWD	172	0.000	-26.94	-19.80	2.66	.897	.409	2.193	.456	-.268	-.017	-1.602	-.333	-.102	-.021	57.445
1199	10/27/77	FWD	417	0.000	-28.83	-19.80	2.56	.948	.432	2.194	.456	-.313	-.038	-1.675	-.348	-.204	-.042	52.715
1203	10/28/77	FWD	885	0.000	-9.74	-6.87	.74	.518	.209	2.479	.403	-.116	-.031	-2.664	-.434	-.699	-.114	47.778
1204	10/28/77	FWD	919	0.000	-40.85	-35.77	1.96	.864	.242	3.564	.281	-.489	-.326	-8.322	-.655	-5.551	-.437	47.765
1205	10/28/77	FWD	886	0.000	-39.38	-30.45	3.12	1.113	.488	2.279	.439	-.471	-.100	-1.974	-.380	-.418	-.080	47.824
1206	10/28/77	FWD	862	0.000	-7.88	4.44	4.21	1.306	.816	1.601	.624	-.094	.466	-.142	-.055	.700	.273	47.819
1207	10/28/77	FWD	836	0.000	24.65	41.23	5.42	1.479	1.088	1.360	.735	.295	.997	.249	.135	.842	.456	47.806
1208	10/28/77	FWD	826	0.000	37.55	56.56	6.07	1.549	1.203	1.287	.777	.449	1.214	.310	.187	.838	.506	47.801
1210	10/28/77	FWD	1024	0.000	72.59	69.82	2.24	.984	.999	.985	1.016	.886	.993	.888		.995		46.803
1211	10/28/77	FWD	1022	0.000	66.69	76.99	3.62	.684	.994	.688	1.453	.827	.870	.837		.881		46.079
1213	10/28/77	FWD	240	0.000	14.86	28.57	3.79	1.459	.964	1.513	.661	.139	.715	.150	.065	.769	.336	60.968
1214	10/28/77	FWD	249	0.000	-1.73	10.68	3.27	1.387	.856	1.620	.617	-.016	.705	-.022	-.008	.962	.367	60.827
1215	10/28/77	FWD	259	0.000	-19.59	-8.65	3.10	1.308	.726	1.800	.556	-.184	.345	-.349	-.108	.654	.202	60.753
1216	10/28/77	FWD	270	0.000	-39.82	-30.38	2.56	1.213	.565	2.145	.466	-.375	-.011	-1.173	-.255	-.036	-.008	60.680
1217	10/28/77	FWD	280	0.000	-30.03	-23.71	2.42	1.121	.526	2.131	.469	-.283	.002	-1.023	-.225	.008	.002	60.606
1218	10/28/77	FWD	284	0.000	-13.90	-8.15	1.92	1.042	.549	1.899	.527	-.131	.156	-.435	-.121	.518	.144	60.555

SUMMARY TABLE Phase II Forward Flow Tests

GE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
1219	10/28/77	FWD	234	0.000	4.62	9.48	1.64	.912	.576	1.583	.632	.044	.249	.132	.053	.751	.300	60.533
1220	10/28/77	FWD	241	0.000	14.24	18.93	1.27	.792	.575	1.378	.726	.134	.293	.407	.214	.887	.468	60.533
1221	10/28/77	FWD	250	0.000	13.78	16.30	.87	.663	.503	1.319	.758	.130	.238	.515	.296	.941	.541	60.533
1222	10/28/77	FWD	262	0.000	26.45	28.36	.47	.455	.504	.904	1.106	.250	.254	.984		1.001		60.533
1231	10/31/77	FWD	278	0.000	-6.34	-3.14	1.02	.558	.287	1.946	.514	-.059	.029	-.719	-.190	.350	.093	61.162
1232	10/31/77	FWD	261	0.000	8.49	13.82	1.95	.811	.555	1.461	.684	.079	.249	.258	.121	.808	.379	61.125
1233	10/13/77	FWD	250	0.000	4.40	11.71	2.71	.969	.621	1.559	.641	.041	.274	.107	.044	.708	.291	61.087
1234	10/31/77	FWD	299	0.000	-20.67	-9.51	3.63	1.124	.599	1.875	.533	-.194	.135	-.540	-.153	.376	.107	60.938
1235	10/31/77	FWD	285	0.000	-31.34	-17.64	4.42	1.257	.653	1.925	.520	-.294	.094	-.690	-.186	.221	.060	60.827
1236	10/31/77	FWD	270	0.000	-3.78	12.47	5.28	1.380	.858	1.608	.622	-.036	.495	-.048	-.019	.672	.260	60.687
1245	11/ 2/77	FWD	292	0.000	36.39	37.74	1.00	.559	.591	.945	1.059	.340	.348	.971		.995		61.237
1246	11/ 2/77	FWD	278	0.000	15.95	20.94	1.84	.802	.592	1.356	.738	.149	.310	.426	.232	.887	.482	61.162
1247	11/ 2/77	FWD	266	0.000	8.42	15.98	2.58	.972	.642	1.515	.660	.079	.326	.191	.083	.791	.345	61.125
1248	11/ 2/77	FWD	313	0.000	-7.55	1.85	3.46	1.124	.652	1.724	.580	-.071	.594	-.166	-.056	1.398	.470	60.998
1249	11/ 2/77	FWD	302	0.000	-29.30	-14.67	4.24	1.258	.664	1.895	.528	-.275	.156	-.624	-.174	.355	.099	60.901
1250	11/ 2/77	FWD	287	0.000	-4.52	11.65	5.04	1.373	.847	1.620	.617	-.042	.981	-.059	-.023	1.367	.521	60.753
1251	11/ 2/77	FWD	179	.033	16.65	15.56	-1.38	-.013	.331	-.039	-25.511	.172	.002	1.569		.019		55.243
1252	11/ 2/77	FWD	189	0.000	-36.94	-31.09	1.97	.903	.349	2.589	.386	-.371	-.093	-3.050	-.455	-.766	-.114	56.980
1254	11/ 3/77	FWD	437	0.000	-67.30	-61.94	1.73	.916	.191	4.788	.209	-.731	-.617	-19.967	-.871	-16.842	-.735	52.615
1258	11/ 3/77	FWD	926	0.000	-32.20	-24.22	2.25	1.099	.490	2.242	.446	-.386	-.057	-1.606	-.319	-.239	-.048	47.651
1259	11/ 3/77	FWD	941	0.000	-22.14	-17.11	1.71	.940	.411	2.284	.438	-.265	-.050	-1.566	-.300	-.296	-.057	47.710
1260	11/ 3/77	FWD	966	0.000	-12.06	-8.58	.80	.619	.258	2.395	.417	-.144	-.029	-2.160	-.377	-.441	-.077	47.829
1263	11/ 3/77	FWD	869	0.000	-15.28	-3.45	3.21	1.284	.748	1.716	.583	-.182	.342	-.325	-.110	.610	.207	47.948
1264	11/ 3/77	FWD	892	0.000	10.18	24.48	3.65	1.430	.965	1.481	.675	.122	.769	.131	.060	.825	.376	47.574
1265	11/ 3/77	FWD	857	0.000	40.14	58.09	4.45	1.566	1.194	1.311	.763	.480	1.232	.337	.196	.864	.502	47.751
1266	11/ 3/77	FWD	1140	0.000	-74.63	-72.02	1.35	.835	-.001	*******	-.001	-1.007	-.935	*******	-1.446	*******	-1.342	45.183
1267	11/ 3/77	FWD	1022	.013	-.58	-.60	.02	-.003	-.001	2.311	.433	-.007	-.019	*******	*******	*******	*******	45.645
1274	11/ 4/77	FWD	240	0.000	-17.33	-13.90	1.02	.553	.185	2.983	.335	-.162	-.229	-4.698	-.528	-6.668	-.749	61.275
1275	11/ 4/77	FWD	227	0.000	-25.21	-19.10	1.90	.796	.324	2.457	.407	-.235	-.146	-2.240	-.371	-1.389	-.230	61.237
1276	11/ 4/77	FWD	284	0.000	-83.58	-73.45	2.73	.974	.211	4.611	.217	-.782	-1.647	-17.504	-.823	-36.871	-1.734	61.087
1277	11/ 4/77	FWD	265	0.000	-58.07	-45.73	3.54	1.129	.440	2.565	.390	-.544	-.631	-2.805	-.426	-3.257	-.495	61.013
1278	11/ 4/77	FWD	245	0.000	-29.47	-13.71	4.53	1.273	.687	1.853	.540	-.276	.661	-.586	-.171	1.400	.408	60.938
1279	11/ 4/77	FWD	230	0.000	-5.93	11.76	5.00	1.377	.863	1.595	.627	-.056	1.512	-.075	-.029	2.030	.798	60.798
1280	11/ 4/77	FWD	200	0.000	-4.67	12.68	5.06	1.380	.881	1.565	.639	-.044	1.333	-.056	-.023	1.715	.700	60.835
1282	11/ 5/77	FWD	174	0.000	-27.47	-20.63	2.11	.905	.407	2.224	.450	-.274	-.108	-1.658	-.335	-.651	-.132	57.234
1284	11/ 5/77	FWD	441	0.000	-27.33	-19.35	1.91	.937	.414	2.265	.442	-.298	-.046	-1.741	-.339	-.266	-.052	52.405
1296	11/ 7/77	FWD	226	0.000	-7.65	-4.93	1.04	.559	.270	2.074	.482	-.071	.007	-.979	-.228	.102	.024	61.425
1297	11/ 7/77	FWD	218	0.000	-23.13	-17.60	1.94	.790	.328	2.411	.415	-.215	-.068	-2.006	-.345	-.635	-.109	61.387
1298	11/ 7/77	FWD	260	0.000	-52.91	-44.34	2.81	.975	.331	2.945	.340	-.493	-.274	-4.495	-.518	-2.496	-.288	61.335
1299	11/ 7/77	FWD	255	0.000	-56.04	-47.05	3.47	1.118	.429	2.608	.383	-.523	-.240	-2.843	-.418	-1.307	-.192	61.275

SUMMARY TABLE Phase II Forward Flow Tests

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LI)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRO.B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
1300	11/ 7/77	FWD	234	0.000	-31.13	-17.14	4.18	1.256	.666	1.886	.530	-.291	.230	-.656	-.184	.518	.146	61.200
1301	11/ 7/77	FWD	215	0.000	-6.81	13.19	5.01	1.379	.876	1.575	.635	-.064	1.175	-.083	-.033	1.533	.618	61.095
1302	11/ 8/77	FWD	297	0.000	-14.99	-11.90	.96	.534	.185	2.884	.347	-.140	-6.200	-4.082	-.491	*******	-21.735	61.207
1303	11/ 8/77	FWD	318	0.000	-47.34	-36.48	3.68	1.124	.469	2.397	.417	-.443	-10.053	-2.015	-.351	-45.727	-7.961	61.080
1304	11/ 8/77	FWD	186	0.000	-62.61	-57.99	1.83	.873	.204	4.275	.234	-.628	-.878	-15.059	-.824	-21.046	-1.151	56.948
1307	11/ 8/77	FWD	414	0.000	-72.99	-64.58	1.93	.933	.206	4.519	.221	-.791	-.680	-18.554	-.908	-15.958	-.781	52.726
1311	11/ 9/77	FWD	847	0.000	-11.28	-8.43	.83	.629	.267	2.351	.425	-.134	-.034	-1.868	-.338	-.473	-.086	48.272
1313	11/ 9/77	FWD	857	0.000	-56.54	-50.78	1.69	.901	.189	4.754	.210	-.667	-.530	-18.590	-.822	-14.762	-.653	48.431
1314	11/ 9/77	FWD	860	0.000	-23.31	-16.20	2.40	1.098	.541	2.031	.492	-.277	.034	-.946	-.229	.117	.028	48.156
1315	11/ 9/77	FWD	852	0.000	-5.07	2.11	3.15	1.289	.781	1.651	.606	-.060	.396	-.099	-.036	.650	.238	48.012
1316	11/ 9/77	FWD	853	0.000	15.42	30.02	3.69	1.432	.988	1.449	.690	.184	.794	.189	.090	.813	.387	47.810
1317	11/ 9/77	FWD	839	0.000	43.04	59.54	4.44	1.559	1.181	1.320	.758	.515	1.201	.369	.212	.861	.494	47.733
1318	11/ 9/77	FWD	985	0.000	41.47	52.65	4.25	1.180	1.000	1.181	.847	.509	.886	.510	.366	.887	.636	46.512
1319	11/ 9/77	FWD	985	0.000	44.14	53.29	3.96	.723	.995	.726	1.377	.542	.717	.548		.724		46.529
1326	11/10/77	FWD	322	0.000	-15.84	-13.75	1.03	.552	.185	2.977	.336	-.148	-.052	-4.290	-.484	-1.509	-.170	61.350
1327	11/10/77	FWD	308	0.000	-24.19	-18.62	1.96	.791	.325	2.431	.411	-.225	-.062	-2.127	-.360	-.583	-.099	61.350
1328	11/10/77	FWD	289	0.000	-.26	8.25	2.85	.970	.601	1.615	.619	-.002	.256	-.007	-.003	.709	.272	61.290
1329	11/10/77	FWD	295	0.000	26.45	37.79	3.71	1.130	.816	1.384	.722	.247	.581	.371	.193	.871	.454	61.200
1330	11/10/77	FWD	268	0.000	7.36	21.45	4.43	1.259	.817	1.540	.649	.069	.505	.103	.043	.755	.318	60.953
1331	11/10/77	FWD	287	0.000	2.78	18.99	5.18	1.382	.880	1.571	.637	.026	.559	.034	.014	.722	.293	60.672
1333	11/10/77	FWD	177	0.000	-27.95	-26.73	2.24	.914	.415	2.201	.454	-.279	-.024	-1.615	-.334	-.140	-.029	57.307
1335	11/10/77	FWD	420	0.000	-71.85	-66.17	2.03	.942	.208	4.532	.221	-.779	-.656	-18.040	-.878	-15.201	-.740	52.731
1340	11/10/77	FWD	983	0.000	21.68	23.86	.52	.487	.530	.919	1.088	.261	.310	.931		1.105		47.456
1341	11/10/77	FWD	868	0.000	37.48	55.02	4.74	1.566	1.198	1.307	.765	.451	1.233	.314	.184	.859	.503	47.492
1342	11/10/77	FWD	898	0.000	15.60	26.81	3.75	1.444	.990	1.458	.686	.188	.818	.192	.090	.835	.393	47.375
1343	11/10/77	FWD	906	0.000	-12.73	-2.14	3.23	1.297	.767	1.690	.592	-.153	.386	-.260	-.091	.656	.230	47.474
1344	11/10/77	FWD	920	0.000	-45.14	-33.49	2.45	1.117	.464	2.406	.416	-.543	-.133	-2.517	-.435	-.617	-.107	47.547
1345	11/10/77	FWD	941	0.000	-60.19	-54.76	1.65	.923	.190	4.864	.206	-.723	-.551	-20.101	-.850	-15.314	-.647	47.542
1346	11/10/77	FWD	902	0.000	-24.35	-20.57	.83	.661	.186	3.547	.282	-.293	-.163	-8.415	-.669	-4.676	-.372	47.547
1349	11/11/77	FWD	1019	0.000	73.23	78.62	1.94	1.006	.998	1.008	.992	.894	1.003	.897	.884	1.007	.992	46.816
1350	11/11/77	FWD	1027	0.000	24.69	30.30	1.67	.954	.750	1.272	.786	.301	.539	.535	.331	.958	.592	46.812
1351	11/11/77	FWD	1014	0.000	38.63	46.54	1.72	.496	.756	.656	1.524	.478	.468	.836		.819		46.224
1358	11/14/77	FWD	242	0.000	-1.21	-.23	.42	.323	.186	1.740	.575	-.011	.036	-.325	-.107	1.045	.345	61.455
1359	11/14/77	FWD	228	0.000	-8.85	-6.95	.82	.468	.186	2.514	.398	-.082	-.039	-2.378	-.376	-1.124	-.178	61.425
1360	11/14/77	FWD	256	0.000	-17.43	-14.47	1.17	.561	.187	3.007	.333	-.162	-.115	-4.656	-.515	-3.308	-.366	61.425
1361	11/14/77	FWD	252	0.000	-26.68	-22.96	1.44	.643	.188	3.426	.292	-.248	-.183	-7.050	-.601	-5.202	-.443	61.387
1362	11/14/77	FWD	255	0.000	-33.89	-28.67	1.81	.723	.215	3.366	.297	-.316	-.208	-6.834	-.603	-4.512	-.398	61.387
1363	11/14/77	FWD	251	0.000	-25.79	-19.61	2.06	.795	.320	2.487	.402	-.240	-.098	-2.348	-.380	-.959	-.155	61.350
1364	11/14/77	FWD	119	0.000	162.31	-10.54	1.90	.829	.502	1.651	.606	1.624	.099	6.445	2.363	.394	.145	57.110
1366	11/14/77	FWD	352	0.000	162.18	.94	1.75	.847	.511	1.660	.603	1.751	.164	6.715	2.438	.627	.228	52.932

SUMMARY TABLE Phase II Forward Flow Tests

GE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
1371	11/14/77	FWD	846	0.000	1.32	6.74	1.74	.905	.575	1.573	.636	.016	.238	.048	.019	.718	.290	47.906
1372	11/14/77	FWD	868	0.000	2.86	5.88	1.20	.742	.479	1.550	.645	.034	.169	.149	.062	.738	.307	47.833
1373	11/14/77	FWD	863	0.000	29.60	33.45	.91	.634	.642	.989	1.011	.353	.404	.857		.982		47.962
1375	11/14/77	FWD	884	0.000	-.23	.82	.37	.397	.242	1.642	.609	-.003	.041	-.047	-.017	.706	.262	47.916
1376	11/14/77	FWD	876	0.000	23.11	25.52	.63	.524	.550	.953	1.049	.276	.298	.910		.984		47.934
1377	11/14/77	FWD	845	0.000	15.62	20.65	1.46	.823	.631	1.305	.766	.186	.355	.468	.275	.892	.524	47.962
1379	11/14/77	FWD	1094	0.000	97.45	101.42	.53	.415	.996	.417	2.399	1.204	.868	1.213		.874		46.249
1380	11/14/77	FWD	986	0.000	85.40	93.56	.42	.287	1.003	.286	3.493	1.051	.671	1.046		.667		46.412
1384	11/16/77	FWD	580	0.000	-4.09	-3.29	.25	.325	.125	2.605	.384	-.046	-.018	-2.965	-.437	-1.174	-.173	50.607
1385	11/16/77	FWD	557	.891	-29.51	-16.86	6.23	2.179	.991	2.199	.455	-2.585	.051	-2.633	-.544	.052	.011	6.520
1386	11/16/77	FWD	461	.930	-34.34	-20.63	6.20	2.553	.992	2.573	.389	-4.961	-.753	-5.041	-.761	-.765	-.116	3.962
1387	11/16/77	FWD	491	.912	-33.14	-19.07	6.25	2.394	.993	2.412	.415	-3.717	-.456	-3.773	-.648	-.462	-.079	5.091
1388	11/16/77	FWD	480	.926	-32.41	-20.55	6.67	2.467	.991	2.490	.402	-3.931	-.410	-4.007	-.646	-.418	-.067	4.714
1389	11/16/77	FWD	477	.919	-32.17	-18.96	6.74	2.415	.992	2.435	.411	-3.656	-.370	-3.718	-.627	-.376	-.063	5.028
1390	11/16/77	FWD	557	.891	-29.51	-16.96	6.23	2.179	.991	2.199	.455	-2.585	.051	-2.633	-.544	.052	.011	6.520
1391	11/16/77	FWD	497	.781	-50.54	-28.38	6.99	2.145	1.155	1.857	.538	-2.419	.183	-1.814	-.526	.138	.040	11.933
1392	11/16/77	FWD	991	.317	-67.57	-54.17	5.39	1.079	.352	3.065	.326	-1.190	-.826	-9.609	-1.023	-6.670	-.710	32.434
1393	35/17/77	FWD	1012	.438	-75.01	-62.91	4.83	1.170	.282	4.145	.241	-1.587	-1.187	-19.920	-1.159	-14.896	-.867	27.007
1394	11/17/77	FWD	964	.435	-45.11	-28.13	7.87	1.441	.817	1.764	.567	-.944	.041	-1.415	-.455	.062	.020	27.310
1395	11/17/77	FWD	946	.418	-45.21	-28.04	7.81	1.406	.792	1.776	.563	-.918	-.005	-1.465	-.465	-.008	-.003	28.137
1396	11/17/77	FWD	946	.414	-46.44	-31.02	7.72	1.392	.762	1.828	.547	-.937	-.064	-1.615	-.483	-.111	-.033	28.317
1397	11/17/77	FWD	777	.579	-9.53	-3.58	3.05	1.051	.659	1.594	.627	-.260	.210	-.599	-.236	.482	.190	21.182
1401	11/18/77	FWD	856	0.000	-15.64	-9.66	1.88	.988	.499	1.978	.506	-.185	.058	-.742	-.190	.233	.059	48.291
1403	11/18/77	FWD	279	.979	-37.51	-27.75	4.93	3.367	.598	5.625	.178	-12.769	-7.411	-35.647	-1.127	-20.690	-.654	1.679
1404	11/18/77	FWD	312	.979	-36.70	-28.23	4.46	3.113	.407	7.654	.131	-11.773	-7.932	-71.175	-1.215	-47.953	-.818	1.782
1405	11/18/77	FWD	283	.980	-37.97	-28.96	4.60	3.248	.407	7.984	.125	-13.041	-9.096	-78.786	-1.236	-54.953	-.862	1.664
1406	11/18/77	FWD	427	.982	-37.55	-30.46	3.24	3.076	.449	6.857	.146	-11.663	-8.076	-57.961	-1.233	-40.135	-.854	1.840
1407	11/18/77	FWD	417	.964	-65.48	-50.59	6.73	3.094	.455	6.797	.147	-11.562	-7.755	-55.789	-1.208	-37.418	-.810	3.236
1408	11/18/77	FWD	409	.981	-32.63	-25.41	3.36	3.139	.685	4.579	.218	-10.212	-6.066	-21.734	-1.037	-12.909	-.616	1.826
1409	11/18/77	FWD	533	.881	-17.30	-12.12	2.07	1.323	.295	4.489	.223	-1.417	-.791	-16.312	-.809	-9.102	-.452	6.976
1410	11/18/77	FWD	553	.806	-20.87	-13.57	2.59	1.339	.477	2.810	.356	-1.118	-.411	-4.919	-.623	-1.806	-.229	10.668
1411	11/19/77	FWD	769	.611	-27.83	-20.09	3.17	1.195	.528	2.263	.442	-.805	-.196	-2.885	-.563	-.703	-.137	19.754
1412	11/19/77	FWD	790	.622	-27.35	-19.01	3.29	1.218	.529	2.303	.434	-.812	-.199	-2.904	-.547	-.712	-.134	19.258
1413	11/19/77	FWD	798	.654	-33.06	-26.42	3.63	1.328	.529	2.513	.398	-1.063	-.402	-3.807	-.603	-1.440	-.228	17.758
1414	11/19/77	FWD	782	.674	-20.77	-13.03	3.07	1.270	.657	1.933	.517	-.706	.016	-1.634	-.438	.036	.010	16.821
1415	11/19/77	FWD	959	.260	-8.70	1.61	6.04	1.106	.746	1.483	.674	-.142	.326	-.256	-.116	.585	.266	35.088
1416	11/19/77	FWD	964	.225	-7.36	3.25	6.27	1.102	.745	1.478	.676	-.123	.333	-.221	-.101	.600	.275	36.678
1417	11/19/77	FWD	988	.478	5.95	5.90	.06	.053	.497	.106	9.411	.134	.168	.543		.679		25.309
1418	11/19/77	FWD	989	.552	5.01	5.47	.05	.054	.497	.108	9.231	.130	.163	.526		.658		22.024
1419	11/19/77	FWD	991	.556	4.65	4.91	.06	.054	.498	.109	9.141	.122	.167	.491		.673		21.808

SUMMARY TABLE Phase II Forward Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRO.B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
1420	11/19/77	FWD	991	.386	4.99	5.10	.06	.039	.498	.079	12.619	.100	.123	.402		.498		29.033
1421	11/19/77	FWD	989	.576	5.86	6.13	.05	.058	.497	.117	8.539	.160	.183	.647		.740		20.966
1422	11/19/77	FWD	984	.745	13.25	12.75	.10	.097	.496	.195	5.135	.562	.419	2.284		1.704		13.479
1423	11/19/77	FWD	968	.655	29.98	28.68	-1.38	.070	.495	.141	7.102	.981	.520	3.994		2.119		17.473
1424	11/19/77	FWD	985	.648	29.98	28.11	-1.38	.069	.496	.138	7.224	.963	.532	3.921		2.168		17.790
1425	11/19/77	FWD	990	.652	29.60	27.96	-1.39	.069	.496	.139	7.175	.960	.545	3.909		2.219		17.622
1426	11/19/77	FWD	996	.646	17.81	17.40	.00	.066	.496	.134	7.479	.570	.388	2.319		1.577		17.857
1427	11/19/77	FWD	996	.639	18.59	16.35	-.01	.064	.496	.130	7.697	.585	.392	2.380		1.595		18.169
1428	11/19/77	FWD	997	.619	16.99	17.36	.00	.060	.496	.121	8.260	.510	.377	2.073		1.532		19.046
1429	11/19/77	FWD	1000	.618	13.74	13.21	.04	.060	.496	.122	8.199	.412	.349	1.675		1.419		19.080
1430	11/19/77	FWD	477	.005	-14.64	-8.01	2.35	.816	.498	1.640	.610	-.165	.103	-.666	-.248	.416	.155	50.710
1431	11/19/77	FWD	482	.017	-29.23	-19.72	2.31	.816	.502	1.626	.615	-.334	.002	-1.324	-.501	.006	.002	50.050
1432	11/19/77	FWD	476	.031	-40.57	-29.48	3.11	.783	.501	1.565	.639	-.470	-.111	-1.875	-.766	-.442	-.181	49.349
1433	11/19/77	FWD	484	.217	-49.14	-34.74	4.97	.878	.501	1.754	.570	-.701	-.271	-2.798	-.910	-1.081	-.352	40.032
1434	11/19/77	FWD	489	.439	-56.46	-40.30	4.96	1.090	.502	2.169	.461	-1.115	-.517	-4.417	-.939	-2.048	-.435	28.928
1435	11/19/77	FWD	482	.207	-60.00	-43.44	5.33	.893	.501	1.780	.562	-.846	-.422	-3.364	-1.062	-1.678	-.530	40.532

SUMMARY TABLE Phase I Reverse Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
393	3/ 2/77	REV	41	0.000	10.87	13.30	.45	-.257	-.499	.516	1.938	.102	-.031	.409		-.123		61.050
394	3/ 2/77	REV	58	0.000	26.12	24.09	1.86	-.505	-.500	1.009	.991	.245	.164	.977	.959	.657	.645	61.050
395	3/ 2/77	REV	91	0.000	58.70	56.36	2.46	-.515	-1.000	.515	1.942	.550	-.150	.551		-.150		60.938
396	3/ 2/77	REV	110	0.000	70.71	68.20	3.95	-.770	-1.001	.770	1.299	.663	.202	.662		.202		60.901
397	3/ 2/77	REV	70	0.000	41.96	38.37	4.38	-.051	.499	-.103	-9.703	.393	.192	1.579		.773		61.087
398	3/ 2/77	REV	27	0.000	.03	.08	.01	-.052	-.000	*******	.001	.000	-.005	*******	.114	*******	-1.741	61.125
399	3/ 2/77	REV	40	0.000	10.95	11.36	.30	-.283	-.000	*******	.000	.102	.054	*******	1.279	*******	.674	61.087
401	3/ 3/77	REV	1210	0.000	63.84	60.34	4.00	-.921	-.799	1.153	.868	.803	.610	1.257	.946	.955	.719	45.450
402	3/ 3/77	REV	1255	0.000	63.32	59.94	3.93	-.920	-.799	1.151	.868	.803	.610	1.257	.948	.955	.720	45.069
403	3/ 3/77	REV	1012	.041	38.96	36.47	3.00	-.703	-.499	1.408	.710	.501	.460	2.010	1.014	1.844	.930	44.429
404	3/ 3/77	REV	1002	.220	34.40	32.29	1.67	-.704	-.498	1.413	.708	.537	.469	2.164	1.083	1.887	.945	36.584
405	3/ 3/77	REV	990	.398	26.06	23.81	1.70	-.689	-.497	1.386	.722	.517	.400	2.089	1.088	1.616	.841	28.808
406	3/ 3/77	REV	996	.791	9.28	8.58	.48	-.677	-.495	1.369	.731	.463	.253	1.891	1.010	1.033	.551	11.456
407	3/ 3/77	REV	999	.358	77.10	77.03	-1.34	-1.057	-.499	2.117	.472	1.444	1.473	5.797	1.293	5.911	1.319	30.506
408	3/ 3/77	REV	1005	.387	75.47	67.88	7.55	-1.101	-1.000	1.101	.908	1.476	1.025	1.476	1.217	1.024	.845	29.211
409	3/ 3/77	REV	1001	.412	80.72	76.03	5.29	-1.061	-1.498	.708	1.412	1.639	.283	.731		.126		28.133
411	3/ 4/77	REV	1005	.302	26.90	26.67	-1.30	-.213	-.999	.213	4.701	.467	-.599	.468		-.600		32.953
412	3/ 4/77	REV	1005	.398	6.57	6.59	-.26	-.096	-.499	.192	5.212	.131	-.202	.525		-.809		28.721
413	3/ 4/77	REV	1003	.101	36.06	32.16	3.33	-.686	-.698	.983	1.017	.493	.287	1.010		.588		41.813
414	3/ 4/77	REV	1003	.395	26.56	23.28	2.51	-.682	-.698	.977	1.024	.525	.227	1.078		.466		28.878
415	3/ 4/77	REV	998	.795	10.02	9.83	.48	-.695	-.699	.994	1.006	.508	.077	1.040		.158		11.266
416	3/ 4/77	REV	1012	.094	32.42	33.51	-1.31	-.181	.499	-.362	-2.764	.440	.302	1.767		1.214		42.091
417	3/ 4/77	REV	1010	.250	28.96	29.50	-1.10	-.182	.498	-.365	-2.738	.470	.320	1.891		1.289		35.206
418	3/ 4/77	REV	996	.792	17.64	18.21	-.11	-.270	.499	-.540	-1.852	.887	.642	3.556		2.575		11.371
419	3/ 4/77	REV	1005	.415	76.96	79.66	-1.34	-.922	.235	-3.915	-.255	1.569	1.654	28.320	1.848	29.851	1.948	28.019
420	3/ 4/77	REV	1010	.390	25.22	26.66	-1.35	-.492	.197	-2.498	-.400	.496	.463	12.783	2.048	11.936	1.912	29.078
421	3/ 5/77	REV	997	0.000	37.36	35.75	1.53	-.685	-.499	1.375	.727	.452	.397	1.817	.961	1.599	.846	47.281
422	3/ 5/77	REV	1000	0.000	36.43	34.14	2.29	-.685	-.700	.980	1.021	.440	.270	.899		.552		47.295
423	3/ 5/77	REV	1000	.139	37.36	34.99	1.83	-.712	-.499	1.426	.701	.531	.480	2.131	1.048	1.927	.948	40.193
424	3/ 5/77	REV	998	.428	33.96	30.71	1.57	-.713	-.996	.715	1.398	.708	.034	.713		.034		27.438
425	3/ 5/77	REV	1001	.399	60.81	62.88	-1.25	-.690	-1.489	.463	2.158	1.210	-.633	.546		-.285		28.717
426	3/ 5/77	REV	1000	.586	18.14	15.89	1.68	-.685	-.499	1.374	.728	.506	.345	2.034	1.078	1.386	.735	20.500
427	3/ 5/77	REV	1009	.387	8.27	8.28	.17	-.346	-.498	.695	1.439	.162	.001	.652		.005		29.236
428	3/ 5/77	REV	997	1.000	1.92	1.75	-.03	-.703	-.498	1.413	.708	.490	.304	1.978	.991	1.227	.615	2.234
430	3/ 9/77	REV	80	0.000	55.58	48.96	6.25	-.256	.498	-.514	-1.945	.515	.293	2.075		1.180		61.652
431	3/ 9/77	REV	120	0.000	90.29	77.80	12.49	-.521	.497	-1.048	-.954	.840	.615	3.402	3.097	2.489	2.266	61.425
432	3/ 9/77	REV	193	0.000	167.64	153.58	13.34	-.073	.992	-.074	-13.573	1.567	.780	1.593		.793		61.125
433	3/ 9/77	REV	67	0.000	38.05	37.18	.62	-.520	-.000	*******	.000	.356	.374	*******	1.317	*******	1.385	61.162
434	3/10/77	REV	119	0.000	85.06	84.01	.34	-.769	-.000	*******	.000	.795	.821	*******	1.345	*******	1.388	61.117
436	3/10/77	REV	989	0.000	42.20	38.65	3.45	-.249	.499	-.499	-2.003	.520	.306	2.085		1.225		46.386

SUMMARY TABLE Phase I Reverse Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
437	3/10/77	REV	995	.281	36.22	37.58	-1.36	-.297	.498	-.595	-1.679	.612	.459	2.465		1.850		33.804
438	3/10/77	REV	997	.071	71.15	75.02	-1.38	-.555	.477	-1.164	-.859	.942	.865	4.139	3.054	3.802	2.806	43.163
439	3/10/77	REV	1193	.096	67.10	69.82	-1.39	-.571	.478	-1.197	-.836	.940	.844	4.123	2.880	3.699	2.583	40.773
441	3/11/77	REV	1000	.385	84.10	86.40	-1.36	-1.009	-.000	*******	.000	1.638	1.123	*******	1.609	*******	1.104	29.348
442	3/11/77	REV	996	.376	36.40	36.53	-1.36	-.689	-.000	*******	.000	.699	.987	*******	1.474	*******	2.080	29.727
443	3/11/77	REV	998	.132	81.28	86.10	-1.37	-.840	-.000	*******	.000	1.148	1.293	*******	1.626	*******	1.831	40.463
444	3/11/77	REV	997	.391	5.93	5.82	-.38	-.299	-.000	*******	.001	.117	.252	*******	1.305	*******	2.822	29.083
445	3/11/77	REV	996	.346	5.85	5.72	-.41	-.281	-.000	916.896	.001	.108	.233	*******	1.362	*******	2.944	31.052
446	3/11/77	REV	1197	0.000	1.99	1.70	-.02	-.147	-.000	543.989	.002	.025	.107	*******	1.129	*******	4.927	46.361
447	3/11/77	REV	1199	0.000	1.26	.92	-.02	-.117	-.000	453.745	.002	.015	.109	*******	1.127	*******	7.953	46.581
448	3/11/77	REV	1197	0.000	.81	.49	-.02	-.099	-.000	569.789	.002	.010	.102	*******	1.009	*******	10.406	46.816
449	3/11/77	REV	1200	0.000	.29	-.04	-.02	-.070	-.000	321.402	.003	.003	.103	*******	.710	*******	20.926	47.326
450	3/11/77	REV	1199	0.000	-.03	-.27	-.03	-.049	-.000	233.279	.004	-.000	.097	*******	-.169	*******	41.045	48.962
451	3/12/77	REV	846	.413	86.03	87.58	-.59	-1.008	-.000	*******	.000	1.715	1.866	*******	1.689	*******	1.838	28.657
452	3/12/77	REV	844	.608	83.70	86.35	.80	-1.259	-.000	*******	.000	2.423	2.622	*******	1.529	*******	1.655	19.746
453	3/12/77	REV	846	.738	89.41	84.91	2.60	-1.598	-.000	*******	.000	3.701	3.717	*******	1.449	*******	1.456	13.806
462	3/14/77	REV	137	0.000	102.56	-184.08	.95	-.846	-.000	*******	.000	.957	.965	*******	1.336	*******	1.347	61.222
463	3/14/77	REV	207	0.000	44.55	43.14	.94	-.577	-.000	*******	.000	.443	.467	*******	1.330	*******	1.402	57.504
464	3/14/77	REV	492	0.000	40.37	39.06	.94	-.575	-.000	*******	.000	.440	.462	*******	1.332	*******	1.397	52.383
465	3/14/77	REV	912	0.000	35.71	35.14	1.21	-.576	-.000	*******	.000	.426	.485	*******	1.286	*******	1.462	47.847
468	3/14/77	REV	842	0.000	80.87	78.60	2.02	-.851	-.000	*******	.000	.949	.990	*******	1.312	*******	1.368	48.695
469	3/14/77	REV	835	0.000	51.04	38.52	1.29	-.668	-.000	*******	.000	.595	.616	*******	1.335	*******	1.380	48.991
470	3/14/77	REV	847	0.000	7.65	6.86	.21	-.261	-.000	*******	.001	.089	.191	*******	1.303	*******	2.805	49.135
471	3/14/77	REV	1161	0.000	37.23	35.44	1.39	-.598	-.000	*******	.000	.465	.487	*******	1.301	*******	1.363	45.800
473	3/15/77	REV	1109	1.000	37.35	34.93	1.27	-.039	-.000	127.739	.008	8.474	5.120	*******	*******	*******	*******	2.519
474	3/15/77	REV	1164	0.000	35.29	35.08	1.46	-.590	-.000	*******	.000	.443	.507	*******	1.275	*******	1.459	45.488
475	3/15/77	REV	1171	0.000	.65	-.17	-.05	-.043	-.000	87.574	.011	.008	.231	*******	4.522	*******	125.830	44.875
486	3/16/77	REV	15	0.000	54.85	51.31	2.24	-.560	.172	-3.261	-.307	.515	.502	17.497	1.645	17.031	1.601	60.805
487	3/16/77	REV	143	0.000	50.53	47.65	2.54	-.558	.172	-3.236	-.309	.505	.494	16.988	1.622	16.602	1.585	57.136
488	3/16/77	REV	414	0.000	45.89	43.52	3.16	-.564	.173	-3.269	-.306	.500	.501	16.769	1.569	16.793	1.571	52.460
489	3/16/77	REV	948	0.000	41.41	38.60	2.91	-.569	.174	-3.276	-.305	.501	.505	16.626	1.549	16.774	1.563	47.259
492	3/16/77	REV	846	0.000	82.87	79.81	3.44	-.817	.164	-4.978	-.201	.978	1.008	36.287	1.464	37.382	1.508	48.407
493	3/16/77	REV	841	0.000	54.94	51.52	3.35	-.650	.170	-3.815	-.262	.645	.654	22.245	1.528	22.525	1.548	48.643
494	3/16/77	REV	843	0.000	32.49	29.83	2.64	-.487	.175	-2.783	-.359	.386	.394	12.594	1.626	12.876	1.662	48.151
495	3/16/77	REV	842	0.000	13.36	10.08	1.84	-.251	.179	-1.398	-.715	.158	.132	4.910	2.511	4.095	2.094	48.328
496	3/17/77	REV	1152	0.000	39.68	36.44	2.87	-.557	.175	-3.191	-.313	.497	.490	16.296	1.601	16.062	1.578	45.604
497	3/17/77	REV	1133	.047	12.40	11.87	-.37	.004	.995	.004	275.801	.161	.219	.163		.221		43.972
502	3/18/77	REV	934	0.000	95.25	104.97	-1.15	.098	.988	.099	10.117	1.162	.706	1.190		.723		46.825
503	3/18/77	REV	995	.401	36.41	38.36	-1.29	-.777	-.252	3.087	.324	.726	.764	11.448	1.201	12.054	1.265	28.658
504	3/18/77	REV	998	.409	37.08	38.91	-1.31	-.787	-.252	3.126	.320	.750	.772	11.841	1.212	12.201	1.248	28.273

SUMMARY TABLE Phase I Reverse Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
505	3/18/77	REV	996	.411	11.19	12.27	-1.34	-.246	.249	-.989	-1.011	.227	.195	3.656		3.150		28.209
506	3/18/77	REV	1003	.362	14.96	16.22	-1.37	-.277	.287	-.966	-1.036	.282	.257	3.426		3.122		30.351
507	3/18/77	REV	1000	.383	21.77	22.59	-1.39	-.339	.344	-.985	-1.015	.423	.355	3.578		3.004		29.429
508	3/18/77	REV	998	.385	75.66	79.43	-1.38	-.623	.629	-.991	-1.010	1.476	1.204	3.728		3.040		29.291
511	3/21/77	REV	1202	0.000	376.69	1.59	-.02	-.158	-.095	1.657	.604	4.751	.030	525.685	191.466	3.370	1.227	45.306
512	3/21/77	REV	1212	0.000	1.06	.92	-.04	-.124	-.063	1.976	.506	.013	.025	3.435	.879	6.465	1.655	45.029
513	3/21/77	REV	1210	0.000	1.67	1.45	-.02	-.157	-.090	1.737	.576	.021	.030	2.615	.866	3.695	1.224	44.956
514	3/21/77	REV	1207	0.000	.67	.46	-.06	-.102	-.029	3.531	.283	.009	.016	10.291	.826	18.902	1.516	45.017
515	3/21/77	REV	1207	0.000	.25	.04	-.05	-.070	-.000	186.704	.005	.003	.010	*******	.653	*******	1.979	45.237
516	3/21/77	REV	1208	0.000	-.01	-.21	-.05	-.049	-.002	29.795	.034	-.000	.010	-54.295	-.061	*******	4.103	45.282
517	3/20/77	REV	997	.950	3.84	3.45	.24	-.693	-.496	1.396	.717	.494	.346	2.005	1.030	1.403	.720	4.441
518	3/21/77	REV	999	1.000	1.85	1.72	.01	-.699	-.700	.999	1.001	.470	.238	.961		.485		2.250
521	3/22/77	REV	1006	.390	30.14	30.94	-1.32	-.297	-1.047	.284	3.524	.592	-.594	.540		-.543		29.095
522	3/22/77	REV	1004	.035	40.45	40.96	-1.32	-.261	.496	-.526	-1.902	.518	.359	2.107		1.461		44.647
523	3/22/77	REV	1000	.372	32.03	32.09	-1.29	-.276	.497	-.555	-1.800	.616	.435	2.497		1.764		29.721
524	3/22/77	REV	997	1.000	2.91	2.56	.10	-.273	.500	-.546	-1.832	.738	.764	2.958		3.061		2.248
525	3/22/77	REV	1042	.357	81.71	84.97	-1.36	-.985	.002	*******	-.002	1.536	1.660	*******	1.583	*******	1.710	30.379
526	3/22/77	REV	1093	.510	82.22	86.95	-1.34	-1.124	.000	*******	-.000	1.992	2.029	*******	1.576	*******	1.605	23.594
527	3/22/77	REV	1123	.151	79.89	85.07	-1.36	-.862	.001	*******	-.002	1.174	1.295	*******	1.579	*******	1.741	38.883
528	3/22/77	REV	1127	.133	71.08	75.67	-1.36	-.814	.001	*******	-.001	1.025	1.162	*******	1.545	*******	1.752	39.638
529	3/22/77	REV	1129	.119	73.03	78.44	-1.36	-.819	.000	*******	-.000	1.037	1.150	*******	1.546	*******	1.715	40.245
530	3/22/77	REV	1130	.110	73.62	79.46	-1.36	-.820	.005	*******	-.006	1.036	1.154	*******	1.541	*******	1.716	40.588
531	3/22/77	REV	1131	.085	73.04	78.88	-1.36	-.812	.000	*******	-.000	1.001	1.135	*******	1.518	*******	1.720	41.684
532	3/23/77	REV	660	.639	81.13	80.88	1.72	-1.251	.000	*******	-.000	2.483	2.425	*******	1.587	*******	1.550	18.669
533	3/23/77	REV	657	.641	81.41	79.56	1.80	-1.234	.000	*******	-.000	2.509	2.419	*******	1.649	*******	1.589	18.539
534	3/23/77	REV	456	.899	37.63	34.08	2.12	-1.686	.001	*******	-.001	3.570	2.776	*******	1.255	*******	.976	6.025
535	3/23/77	REV	445	.926	27.97	27.58	1.50	-1.697	.000	*******	-.000	3.413	3.479	*******	1.185	*******	1.207	4.682
538	3/23/77	REV	952	.092	84.54	90.48	-1.37	-.469	.654	-.718	-1.393	1.135	.986	2.655		2.307		42.571
539	3/23/77	REV	947	.188	92.61	97.94	-1.37	-.767	.390	-1.966	-.509	1.381	1.438	9.062	2.346	9.436	2.442	38.329
540	3/23/77	REV	948	.158	92.81	99.25	-1.37	-.745	.384	-1.939	-.516	1.337	1.413	9.052	2.408	9.572	2.547	39.670
541	3/23/77	REV	934	.266	76.50	79.21	-1.38	-.984	-.482	2.043	.489	1.254	1.304	5.405	1.295	5.619	1.346	34.863
542	3/23/77	REV	921	.318	59.19	53.09	5.68	-.916	-.998	.918	1.089	1.036	.520	1.041		.522		32.643
543	3/23/77	REV	904	.624	41.18	37.61	2.94	-1.050	-1.089	.964	1.037	1.242	.431	1.047		.363		18.945
544	3/23/77	REV	847	.737	39.03	37.89	2.71	-1.184	-1.215	.974	1.027	1.607	.515	1.088		.349		13.878
558	3/24/77	REV	538	.784	28.40	27.62	2.95	-1.166	-.930	1.253	.798	1.382	.542	1.596	1.017	.626	.398	11.752

SUMMARY TABLE Phase II Reverse Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ,B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
1441	11/28/77	REV	142	0.000	101.16	100.45	-.14	-.846	-.001	776.947	.001	.955	.990	*******	1.334	*******	1.383	60.562
1442	11/28/77	REV	150	0.000	85.33	83.66	1.48	-.782	-.001	837.380	.001	.806	.825	*******	1.319	*******	1.350	60.496
1443	11/28/77	REV	178	0.000	68.59	65.62	1.82	-.694	-.001	758.438	.001	.648	.658	*******	1.344	*******	1.364	60.496
1444	11/28/77	REV	188	0.000	48.25	49.68	1.31	-.605	-.001	647.819	.002	.456	.508	*******	1.247	*******	1.389	60.459
1445	11/28/77	REV	196	0.000	31.77	32.74	.88	-.494	-.001	507.327	.002	.300	.336	*******	1.232	*******	1.379	60.459
1446	11/28/77	REV	205	0.000	18.02	17.18	.60	-.360	-.001	373.579	.003	.170	.186	*******	1.312	*******	1.436	60.459
1449	11/29/77	REV	145	0.000	12.17	10.88	.37	-.293	-.001	296.597	.003	.121	.127	*******	1.410	*******	1.479	57.584
1450	11/29/77	REV	182	0.000	93.44	92.16	.21	-.833	-.001	844.210	.001	.928	.965	*******	1.337	*******	1.391	57.537
1452	11/29/77	REV	391	0.000	11.52	11.04	.29	-.308	-.001	301.711	.003	.124	.137	*******	1.304	*******	1.445	53.079
1453	11/29/77	REV	427	0.000	85.29	82.97	1.52	-.831	-.001	721.844	.001	.922	.951	*******	1.336	*******	1.377	52.837
1454	11/29/77	REV	395	0.000	-.03	-.30	-.02	-.021	-.001	17.297	.058	-.000	.033	*******	-.791	*******	72.955	52.910
1458	11/29/77	REV	911	0.000	16.26	15.82	.34	-.392	-.001	300.194	.003	.194	.219	*******	1.263	*******	1.421	47.833
1459	11/29/77	REV	919	0.000	1.23	-.32	-.03	-.025	-.001	19.045	.053	.015	.035	*******	23.421	*******	55.151	47.925
1460	11/29/77	REV	904	0.000	34.45	32.75	.81	-.554	-.001	439.286	.002	.412	.427	*******	1.341	*******	1.390	47.733
1461	11/29/77	REV	960	0.000	51.49	50.34	1.15	-.687	-.001	540.768	.002	.617	.670	*******	1.306	*******	1.419	47.669
1462	11/29/77	REV	952	0.000	67.24	65.80	1.62	-.785	-.001	712.221	.001	.806	.844	*******	1.308	*******	1.369	47.660
1463	11/29/77	REV	947	0.000	81.26	76.23	1.94	-.846	-.001	677.406	.001	.973	.972	*******	1.360	*******	1.358	47.710
1464	11/29/77	REV	1099	0.000	75.43	74.76	1.92	-.848	-.001	621.505	.002	.927	.979	*******	1.289	*******	1.361	46.486
1466	12/ 1/77	REV	999	.240	82.83	84.46	-1.40	-.885	-.002	579.062	.002	1.323	1.454	*******	1.689	*******	1.855	35.768
1467	12/ 1/77	REV	1001	.203	82.91	84.44	-1.40	-.864	-.001	623.318	.002	1.266	1.387	*******	1.695	*******	1.857	37.414
1468	12/ 1/77	REV	980	0.000	54.45	45.59	8.94	-.516	.397	-1.298	-.770	.656	.512	4.160	2.469	3.246	1.927	47.402
1469	12/ 1/77	REV	1002	0.000	55.97	45.89	8.91	-.522	.401	-1.303	-.768	.676	.530	4.211	2.482	3.302	1.946	47.313
1470	12/ 1/77	REV	1006	.104	50.63	51.35	-.36	-.509	.401	-1.269	-.788	.693	.575	4.307	2.673	3.572	2.216	41.743
1471	12/ 1/77	REV	1011	.229	54.33	57.76	-1.42	-.568	.401	-1.416	-.706	.858	.778	5.338	2.662	4.841	2.414	36.182
1472	12/ 1/77	REV	1003	.225	72.09	76.11	-1.42	-.765	.225	-3.397	-.294	1.132	1.142	22.328	1.935	22.543	1.954	36.403
1473	12/ 1/77	REV	1001	.503	46.94	50.76	-.21	-.123	.800	-.154	-6.511	1.124	.736	1.757		1.150		23.802
1474	12/ 1/77	REV	1000	.466	54.04	53.37	-.25	-.118	.799	-.147	-6.784	1.200	.765	1.877		1.196		25.739
1475	12/ 1/77	REV	998	.464	52.22	51.37	-.20	-.116	.802	-.145	-6.914	1.153	.741	1.793		1.152		25.857
1476	12/ 1/77	REV	1001	.384	53.13	52.44	-.19	-.102	.802	-.127	-7.888	1.032	.691	1.605		1.075		29.388
1477	12/ 1/77	REV	855	.811	63.19	62.03	-.38	-.259	.998	-.260	-3.847	3.437	2.386	3.450		2.395		10.500
1478	12/ 1/77	REV	887	.200	92.78	89.91	6.36	-.025	.997	-.025	-40.659	1.584	1.386	1.595		1.395		34.953
1479	12/ 1/77	REV	869	.814	65.76	65.04	-.34	-.120	.995	-.121	-8.263	3.639	2.823	3.674		2.851		10.318
1480	12/ 1/77	REV	851	.829	62.15	63.81	-.30	-.119	.995	-.119	-8.388	3.674	2.999	3.709		3.028		9.668
1486	12/ 2/77	REV	250	0.000	89.45	80.26	6.95	-.912	-.908	1.005	.995	.838	.525	1.018	1.009	.638	.632	60.976
1487	12/ 2/77	REV	256	0.000	75.68	68.77	6.00	-.846	-.764	1.106	.904	.709	.503	1.214	.992	.862	.704	60.953
1488	12/ 2/77	REV	242	0.000	63.01	57.34	4.56	-.771	-.839	.918	1.089	.591	.316	.839		.448		60.938
1489	12/ 1/77	REV	239	0.000	49.83	43.72	3.92	-.676	-.609	1.110	.901	.468	.322	1.261	1.023	.867	.704	60.901
1490	12/ 1/77	REV	218	0.000	32.90	29.98	2.71	-.559	-.516	1.083	.923	.309	.223	1.158	.987	.835	.712	60.864
1491	12/ 2/77	REV	313	0.000	21.53	18.73	1.75	-.444	-.402	1.105	.905	.202	.141	1.253	1.026	.874	.716	60.864
1494	12/ 2/77	REV	207	0.000	32.14	31.06	2.70	-.590	-.529	1.116	.896	.319	.256	1.142	.917	.914	.734	57.504

SUMMARY TABLE Phase II Reverse Flow Tests

CE/EPRI TWO PHASE PUMP STEADY STATE TESTS   SUMMARY TABLE Phase II Reverse Flow Tests   PAGE-- 2

TEST	DATE	TYP	PRES PSIA	VOID FRAC	DP (LL)	DP (FF)	DP (TS-NS)	NU	ALN	NU/ALN	ALN/NU	NORMALIZED H	HYTRQ.B	H/ALN2	H/NU2	B/ALN2	B/NU2	DENSITY UPSTRM
1496	12/ 2/77	REV	434	0.000	15.97	15.27	1.33	-.432	-.386	1.119	.894	.171	.136	1.150	.918	.915	.730	53.259
1498	12/ 3/77	REV	502	0.000	72.57	66.87	5.15	-.906	-.977	.927	1.079	.801	.443	.838		.464		51.781
1503	12/ 3/77	REV	889	0.000	68.24	63.23	5.17	-.922	-.903	1.022	.978	.811	.526	.996	.953	.646	.619	48.082
1504	12/ 3/77	REV	896	0.000	57.99	52.24	4.04	-.836	-.900	.928	1.077	.688	.366	.849		.452		48.137
1505	12/ 3/77	REV	863	0.000	30.76	28.63	3.88	-.372	-.893	.417	2.401	.363	-.187	.456		-.235		48.379
1506	12/ 3/77	REV	855	0.000	37.87	36.31	.63	-.521	-.895	.583	1.716	.448	-.047	.560		-.059		48.263
1507	12/ 3/77	REV	912	0.000	39.80	40.28	1.47	-.643	-.896	.717	1.395	.472	.096	.588		.120		48.193
1508	12/ 3/77	REV	902	0.000	46.27	44.79	3.30	-.749	-.898	.834	1.200	.549	.237	.681		.294		48.146
1509	12/ 3/77	REV	1001	0.000	80.40	75.49	5.35	-.810	.169	-4.779	-.209	.971	.976	33.820	1.481	33.960	1.487	47.290
1511	12/ 3/77	REV	1074	.009	6.49	6.90	-.05	-.004	.422	-.010	-96.356	.082	.536	.461		3.006		45.151

NOTES

DP(LL)..... LEG TO LEG PRESSURE RISE.PSI

DP(FF)..... FLANGE TO FLANGE PRESSURE RISE.PSI

DP(TS-NS)..FOR FWD FLOW.PRESSURE DROP IS FROM SUCTION LEG TO SUCTION FLANGE. FOR REV FLOW. THE PRESSURE DROP IS FROM SUCTION FLANGE TO SUCTION LEG.PSI

NU......... NORMALIZED VOLUME FLOW RATE (TEST/RATED)

ALN........ NORMALIZED PUMP SPEED(TEST/RATED)

H .... NORMALIZED LEG TO LEG PUMP HEAD(TEST/RATED)

B.......... DENSITY CORRECTED NORMALIZED HYDRAULIC TORQUE((HYD TRQ/RATED).(62.3).(AVE SPEC VOL))

DENSITY UPSTRM...FOR FWD FLOW IT IS THE SUCTION LEG VALUE
FOR REV FLOW IT IS THE DISCHARGE LEG VALUE.LBM/CFT

RATED FLOW RATE, GPM , 3500
RATED SPEED , RPM , 4500
RATED TORQUE, FT-LB, 308
RATED HEAD , FT , 252
AVE SPEC VOL.CFT/LBM , AVERAGE OF UPSTREAM AND DOWNSTREAM SPEC VOLS
VOID FRAC AND SPEC VOLS ARE BASED ON ORIFICE MEASUREMENTS

...THIS SUMMARY TABLE IS BASED ON ANALYSIS OF REDUCED DATA BY PSSR PROGRAMS PSSRFORWARD AND PSSRREVERSE...

Section 5

DATA ANALYSIS

Steady-state data analysis in this report is aimed at providing an orderly presentation of the data, an initial assessment of data consistency, and comments on whether the data appears amenable to reasonably simple representation in mathematical formulations. The analysis also includes observations on overall trends, special effects, and some possibilities for further analysis.

A limited scope of analysis was included in this project, and what is presented in this section is one initial way of looking at the data. Using the data produced here, a large amount of additional analysis and interpretation can be performed in several different ways.

5.1 SELECTION OF CORRELATION PARAMETERS

The correlation parameters used in this report are those chosen as key parameters for describing and interrelating pump operating conditions and performance and for indicating flow similarity. These include normalized and homologous parameters which facilitate scaling the model test results to full size pumps and scaling to hydraulically similar operating conditions outside the range of testing. Such key parameters have already been identified in general terms in Volume 1, Section 2.2, on Basic Parameters, and the rationale of their development is described in some detail in Appendix A. However, there are alternate versions of these key parameters to choose from, and the initial selections for use in this report are indicated here.

As stated before, single-phase pump performance is generally measured and described in terms of head and torque for a given speed, volumetric flow rate, and fluid density. For two-phase conditions pressure, void fraction and, to some extent, flow regime are also included.

The resulting key parameters for indicating pump operating conditions (using normalized forms as derived in Appendix A) are pressure (P), void fraction (α_F), volumetric flow rate (ν), speed (α_N) and associated density (ρ). The primary criterion for having similarity in flow patterns is matching the ratio of fluid speed to pump speed, as indicated by matching ν/α_N. The parameters for pump performance are head and torque, expressed in normalized form as h and β, or in homologous form as h/α_N^2 or h/ν^2 and β/α_N^2 or β/ν^2.

The process of specifying representative fluid properties is complicated by the fact that pressure, void fraction, and density commonly vary with position throughout the test section. Also it is possible to define head in different ways, such as static or total head. Thus there are choices to be made as to which parameter definitions and which test section locations to use in quantifying the key correlation parameters. The selections made for this report are not purported to be the best or final. Rather they are considered as workable initial selections, for trial, which are reasonable on the basis of relation to current practice and physical reasoning. Also, it is considered desirable to start out simplistically and get a first assessment of correlations, leaving more extensive evaluation of alternates and potential refinements as follow-on work, which is beyond the defined scope of this project.

The first decision was to make the routine presentations of pump head on a test section leg-to-leg basis. This means using head changes between the suction and discharge piping legs which were equipped as measuring stations with instrument spools (See Figures 2-2 and 4-1). Such heads include the losses in the two suction pipe elbows. Thus the decision was, in effect, to derive and present performance for the combination of pump and adjacent piping including the two suction elbows. There are two reasons for this decision. First, in LOCA analysis, head data is required and applied for pump paths which ordinarily include (or can conveniently include) two suction elbows, and it is beneficial to incorporate directly the experimentally determined piping losses. The test system was designed to provide generally typical piping geometry adjacent to the pump, including the two elbows, and thereby appropriately model the pump and piping interaction and piping losses. Secondly, the suction and discharge legs were where the complete arrays of instrument sensors were located and provided the best knowledge of suction and discharge conditions. This was done because straight piping runs of several pipe diameters are required for good measurements. How well the head data for a variety of operating conditions does correlate when the piping losses are included is commented upon below where the head curves are reviewed.

Pressure taps were also provided closer to the pump at the suction and discharge flange locations, and some of the processed data tables provide resulting information on the flange-to-flange pressure rise and piping leg pressure drops. These additional ΔP's can be used to supplement the leg-to-leg head presentations, but some assumptions are required about fluid properties not measured at the flanges (See Section 4.2.2).

A second decision for the routine presentation of pump head was to select the version of head based on static pressure rise. Static pressure head is the simplest to derive from the measurements. It was reported from the Semiscale tests (Reference 3), and has been used in blowdown analysis. Some comments are offered below on the possibility of using total head as an alternate.

Another decision was to use upstream fluid conditions (in the suction leg for forward flow or the discharge leg for reverse flow) as the basis for specifying and/or describing pump operating conditions of fluid pressure, void fraction, density, and volumetric flow rate. In the Preliminary Test Plan (Reference 1) it was recognized that pump path average conditions might be considered more representative of fluid inside the pump, but that upstream conditions were possible alternates. The dominant reason for choosing to use upstream conditions in this test program was operating convenience and practicability in setting a point.

It was recognized that interpolation of results would be involved if correlation on the basis of pump average conditions were desired later. One aspect of pump fluid mechanics which favors the use of upstream volumetric flow rate is the sensitivity of impeller flow patterns to the angle at which the fluid enters the passages. This angle in turn is a result of the ratio of the entering fluid velocity to impeller velocity, which in turn is proportional to the volumetric flow rate-to-speed ratio ν/α_N. As a first approximation, the volumetric flow rate entering the impeller is considered to be the same as that in the upstream leg, i.e. ν upstream.

Among the alternate ways of deriving upstream ν from the measurements, the one selected for use in initial data correlations is the method which calculates mass flow rates through the water and steam orifices, applies an energy balance including heat losses along the way to the upstream leg, and then determines fluid specific volume from the ASME steam tables at upstream enthalpy plus temperature and/or pressure. (See Volume VIII for details). For the steady-state testing this is a generally basic approach with relatively good certainty.

Upstream void fraction is by definition the fraction of the upstream pipe leg cross sectional area which is occupied by steam flow. For a given combination of steam and water volumetric flow rates, such as determined by the orifice readings plus energy balance method in the previous paragraph, the void fraction would vary depending on the relative steam and water velocities, i.e. on slip. Evidence of the actual void fraction was given by the three-beam gamma densitometer readings, but interpretation is complicated by the fact that a given set of beam readings could indicate a variety of phase distributions across the pipe. Also, there is the important concept that the pump tends to be a volumetric flow machine. That is, more influenced simply by the water and steam volumetric flow rates (gpm) rather than by relative phase velocities and fractions of pipe area occupied, especially considering that the two elbows just ahead of the pump will alter the upstream flow distribution and tend to stir up the phases, and the rotation of the impeller blades will tend to "chop" across and further mix any distribution. For these reasons the selected method of deriving void fraction as a key parameter was to assume a uniform non-slip, homogeneous flow of the phases and use the volumetric flows from the orifice readings combined with an energy balance. This is equivalent to using a flow rate void fraction rather than a pipe area void fraction and appears to lead to a result similar to the Semiscale method of deriving an effective density by factoring out slip (Reference 3).

Converting pump ΔP measurements to head in feet of fluid involves selecting a representative (or at least a reference) density. Since pressure and density changes occur throughout the flow path, there is no one density which is really representative of the whole process. More is written below (Section 5.4.2) about alternate forms of pump head and representative densities. It was decided for the initial data presentations to use static pressure head based on upstream density. This form of head has been used in other presentations, including Semiscale data (Reference 3), and comparisons will be facilitated. This form is simpler to derive and it is of interest to present this data so its adequacy can be assessed. If refinement beyond this form were to be investigated, this initial presentation would serve as a basis for evaluating the alternate versions.

The torque to be correlated with the effects of two-phase flow is the hydraulic torque. This is because it characterizes the hydraulic performance to be scaled from the pump model to full sized pumps. Hydraulic torque is the torque exerted by the impeller on the fluid flowing through the impeller passages, and is obtained by subtracting the friction and windage torque from the measured shaft (input) torque (Section 4.5.1). Normalization of the model pump hydraulic torque (yielding β_h) involves ratioing from test density to rated (cold water) density. As with head and other parameters above, the question arises as to what density in the test section to select as representative. Since hydraulic torque generation is localized to the impeller passages, densities outside the impeller seem extraneous and it was decided to approximate the impeller fluid density by using an average density. This average density is the inverse of the average of specific volumes in the suction and discharge legs calculated by the orifice-flow plus energy-balance method discussed above. It is recognized that this is a different choice than was made for head, but it was felt that the choice for torque could focus more directly on a limited region of the pump path, i.e. the impeller. Whether this appears to be a necessary distinction for workable data correlation and whether any alternate choice might prove of interest would come from follow-on analysis beyond this project, but some preliminary observations are made in Special Topics (Section 5.4.2).

As fluid flows through the test section and pump and experiences pressure changes, there are corresponding changes in fluid properties, especially density and void fraction. It is expected that for a given head these property changes are accentuated when operating at lower pressure levels. However, relating to LOCA blowdown conditions, lower pressure levels occur when void fractions are already high. To find out whether pressure level effects are very significant in two-phase pump performance, pressure level is treated as a correlation parameter in the data presentation. Upstream pressure was selected as the parameter for initial presentation.

The selected correlation parameters which have been explained here are the ones which are used in the Summary Table as described in Section 4.3.3 and in the routine graphical presentations in Section 5.2 which follows.

5.2 PRESENTATION OF PERFORMANCE RESULTS

In addition to various presentations of pump test data in tabular form above, a variety of graphical presentations are provided and discussed below. Comments are included on test range versus range of interest, overall performance trends, and general magnitudes of two-phase effects on performance.

5.2.1 Degradation Curves

Two broad questions of general interest to be answered by analysis of the pump test data are

a. Did two-phase operation appreciably degrade the pump performance compared to single-phase operation?

b. If there was appreciable degradation, what was its gross nature as to when it occurred, how much, and how it compares with previously available test data?

A set of degradation curves is a useful form of data presentation for answering these questions and also providing numerical details for closer follow-up analysis.

The term "degradation curve" is used here to designate a plot of homologous head ratio (h/α_N^2 or h/ν^2) or homologous hydraulic torque ratio (β_H/α_N^2 or β_H/ν^2) versus void fraction (α_F) for a constant flow-to-speed ratio (ν/α_N) and pressure (P) as shown in Figures 5-1 and 5-2. With ν/α_N constant and homologous ratios being plotted, the primary conditions for hydraulic similarity in single phase flow are satisfied. Thus, if the two-phase performance did not degrade from the single-phase performance, the homologous head and torque ratios would remain constant at the values for water while the void fraction ranged from 0 to 1.

It is readily apparent from Figure 5-1 and 5-2 that both the head and hydraulic torque degraded considerably for two-phase operation. These curves are for rated volumetric flow and speed, which produce the pump peak efficiency flow pattern for single-phase performance, but the two-phase effects result in considerable reduction in the pumping effectiveness.

Looking at the gross nature of the main curves at 1000 psia, little if any degradation occurred until after 0.10 void fraction. Then there was a steady decline until mid-to-upper range void fractions, followed by an increasingly

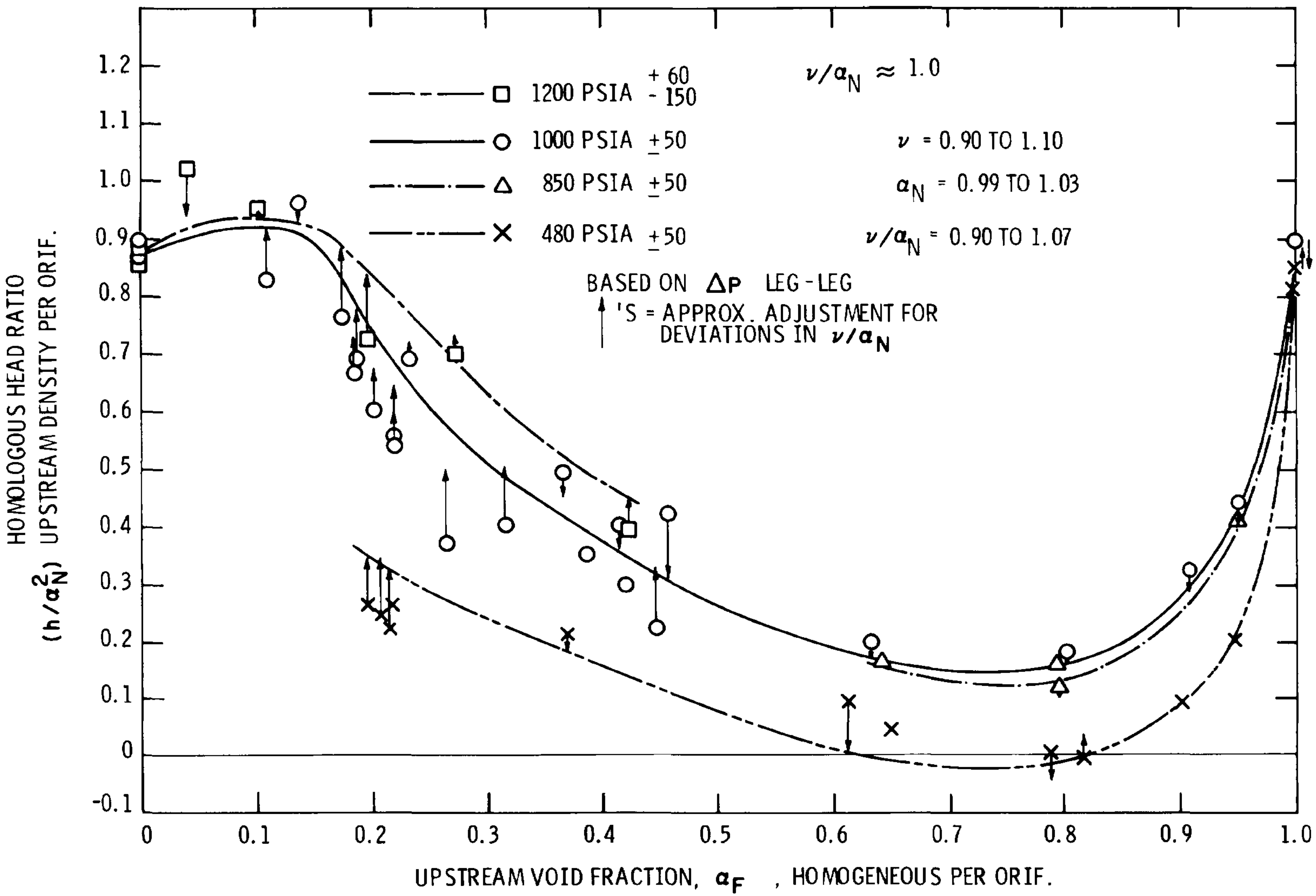


Figure 5-1. Effect of void fraction on homologous head ratio near rated flow and speed ($\nu/\alpha_N \approx 1.0$).

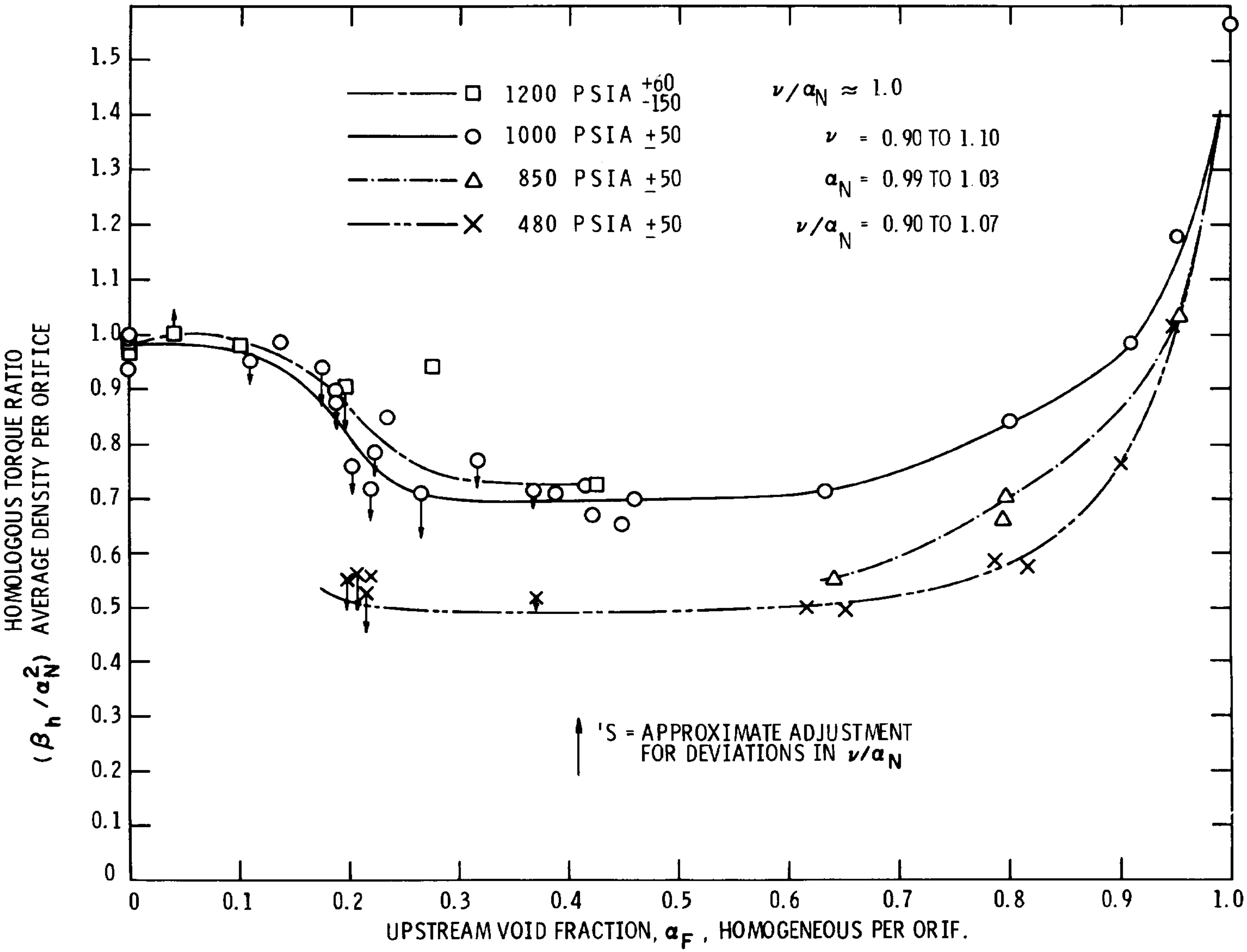


Figure 5-2. Effect of void fraction on homologous torque ratio near rated flow and speed ($\nu/\alpha_N \simeq 1.0$).

steep recovery to all-steam values at least equaling those for water. The minimum head was about 15 percent of the single-phase value, and occurred at a void fraction near 0.75. The decrease in hydraulic torque was considerably less than for the head, and this indicates a decrease also in hydraulic efficiency, which is proportional to (ν/α_N) (h/β_h). The performance fall-off with increasing void fraction appears more orderly and gradual and somewhat less drastic than indicated by previous data for a more highly centrifugal pump (Reference 3).

Ordinarily single-phase homologous head and torque ratios have a value of 1.0 when $\nu/\alpha_N = 1$, because this would correspond to pump rated operating condition for all parameters. However, the curves plotted here do not go through (1,1) because the parameters are normalized to rated values from the manufacturer's cold water tests which reported only shaft torque (with low-friction bearings) and flange-to-flange head with no elbows. It is to be expected that the parameters presented here with new allowances for friction and windage torque and extra head losses in piping elbows would tend to yield lower torque and head values at the maximum efficiency flow and speed. Also, some further secondary changes in head and torque would be expected from inlet flow distribution effects due to the two elbows. The resulting intercepts observed on the data curves at $\nu/\alpha_N = 1$ are at approximately 0.875 for head ratio and 0.98 for torque ratio. Renormalization to new values to yield intercepts at 1.0 would involve using a rated head of 0.875 times the manufacturer's cold water value and a rated hydraulic torque of 0.98 times the manufacturer's rated torque. Such renormalization is an easy step for the user to take later when actually applying the data, and the factors would be different if different definitions of head or effective density were chosen. For these reasons and to maintain consistency in all initial handling of both steady-state and transient test data, all data reduction, tables, and plots in this report use the manufacturer's cold water values for reference, i.e., head = 252 ft, flow = 3500 gpm, speed = 4500 rpm, and torque = 308 ft-lbf at 62.3 lbm/ft^3 density.

There is some scatter apparent in the plotted points in Figure 5-1, but much of this is eliminated when allowance is made for the fact that actual test ν/α_N's deviated somewhat from the nominal value of 1.0. The desired operating conditions were rated flow and speed, but the plot covers actual flows from 0.90 to 1.10 times rated and speeds from 0.95 to 1.03 times rated, with actual

ν/α_N's ranging from 0.90 to 1.07. The amount of shift in h/α_N^2 as ν/α_N departed from 1.0 was obtained from the slopes of the performance curves in the next section for several void fractions and plotted in Figure 5-3. Thus a correction to offset the shift in each homologous head point was calculated from

$$\Delta\left[\frac{h}{\alpha_N^2}\right]_{\text{correction}} \simeq \left[1 - \left[\frac{\nu}{\alpha_N}\right]_{\text{test point}}\right]\left[\frac{\partial\left[\frac{h}{\alpha_N^2}\right]}{\partial\left[\frac{\nu}{\alpha_N}\right]}\right]_{\text{slope, at } \nu/\alpha_N = 1}$$

These calculated corrections are shown in Figure 5-1 by the arrows, with the tips of the arrows indicating the adjusted head values. It is readily apparent that the adjustments bring the points into considerably better alignment and make evident good coherence of the measurement data.

Also discernable in Figures 5-1 and 5-2 is a general trend in performance with changing pressure level. Further discussion of this is given in Section 5.4, Special Topics, along with remarks on the small initial rise in head at low void fractions, and the question of apparent overshoot of torque recovery at the steam end to values higher than for all-water.

To cover a wide range of operating conditions comparable to those encountered in LOCA blowdown analysis, degradation curves were generated for several other values of ν/α_N for both forward and reverse flow and/or speed. The LOCA blowdown range of ν/α_N is indicated by the sample LOCA curves in Figures 5-4 and 5-5. See Volume I, Section 2.3 regarding types of breaks. By comparison, test data for degradation curves was obtained at ν/α_N's of 1.0, 1.42, 2.0, and 4.0 for forward flow and speed, 1.0 and 1.4 for reverse flow and speed, and -0.56 for reverse flow with forward speed. The results are displayed in Figures 5-1 and 5-2 (as above) plus Figures 5-6 through 5-17.

The homologous head and torque curves for ν/α_N near 1.42 in Figures 5-6 and 5-7 show relatively mild and roughly constant degradation over most of the void fraction range. Since the single-phase pumping head rise was small to start out with, the moderate amount of head degradation was enough to result in a head drop, so that the mode of operation became pumping dissipation. For this value

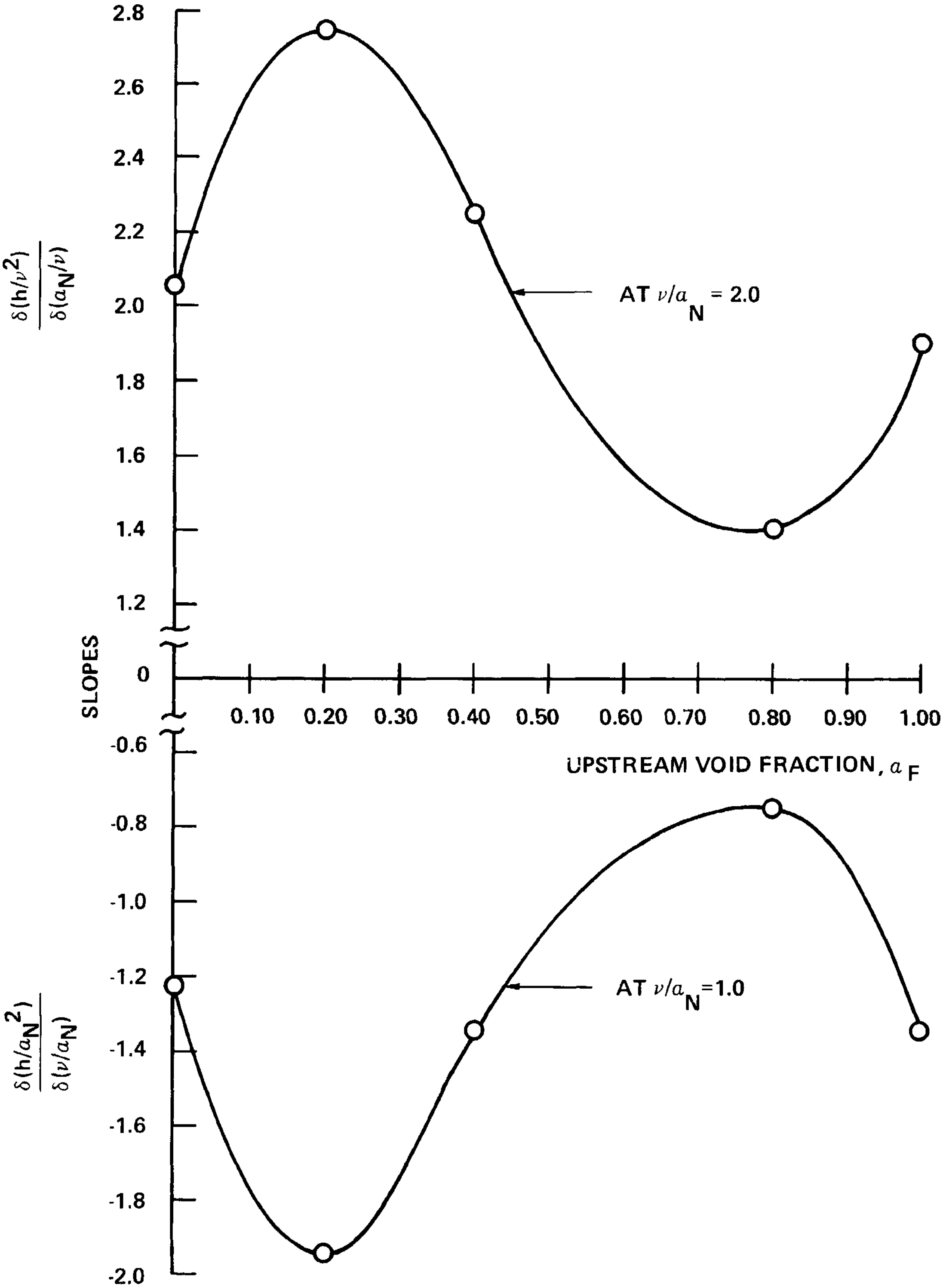


Figure 5-3. Slopes of homologous head performance curves.

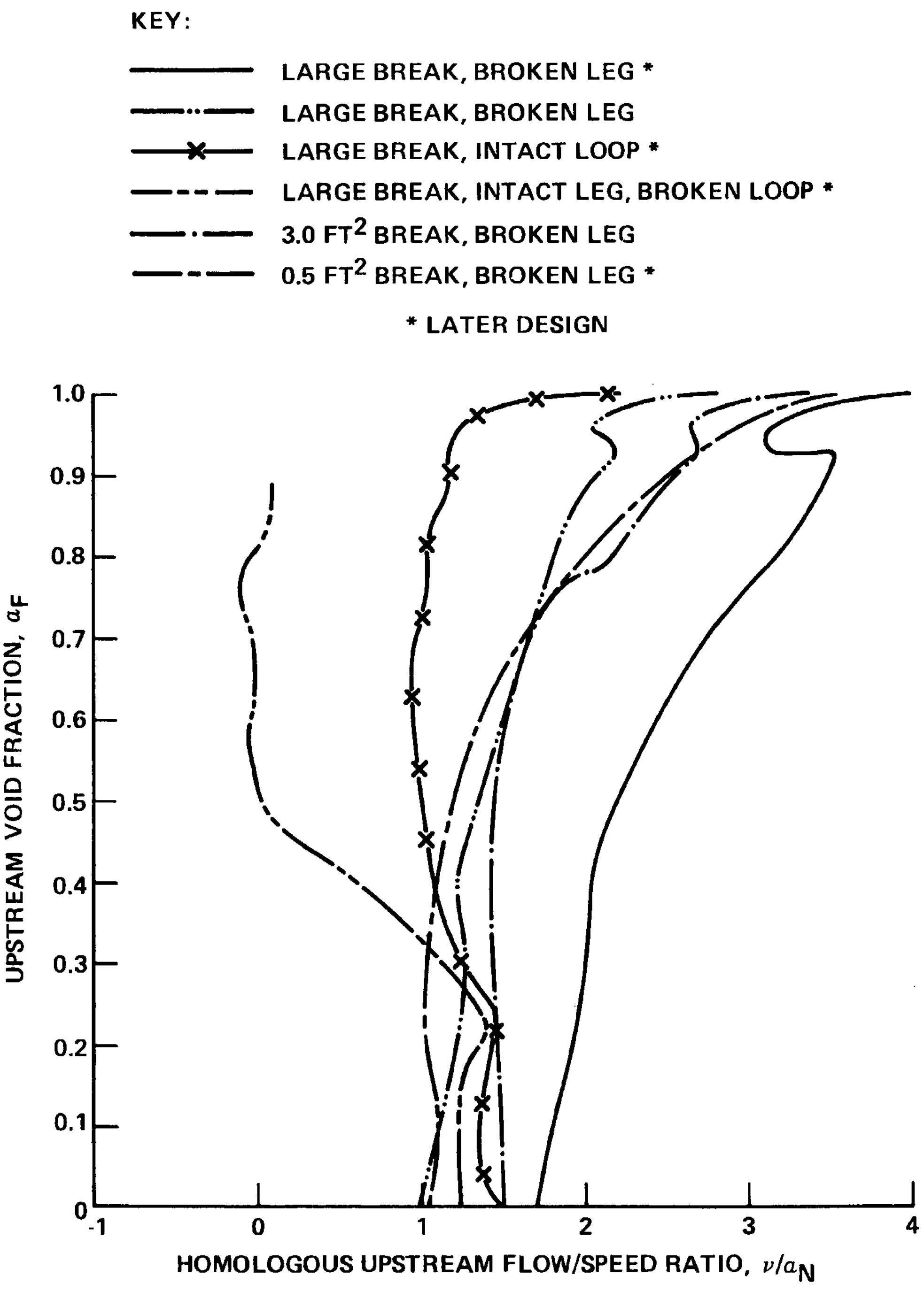


Figure 5-4. Typical NSSS blowdowns for discharge leg breaks, ν/α_N vs α_F.

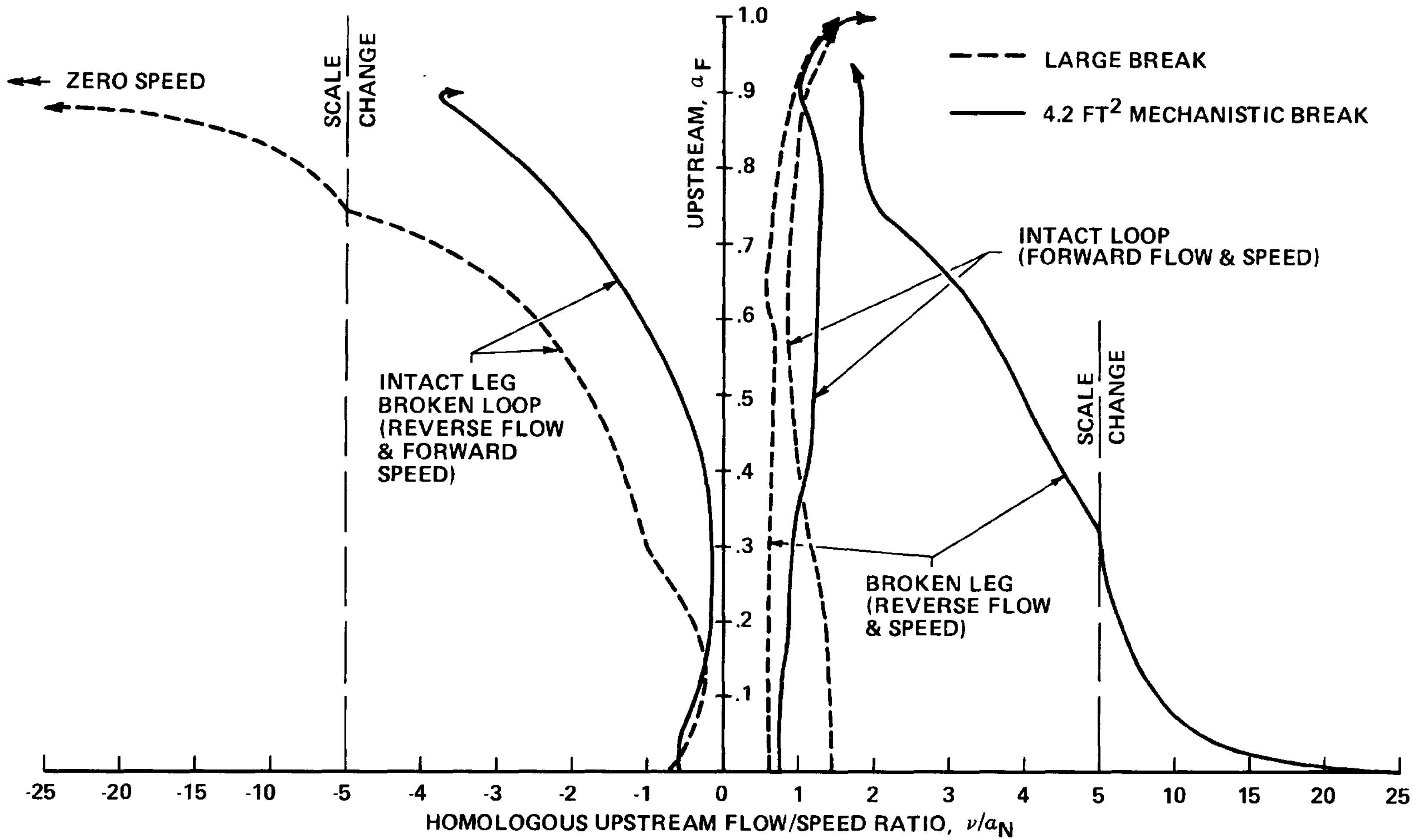


Figure 5-5. Typical NSSS blowdowns for suction leg breaks, ν/α_N vs α_F

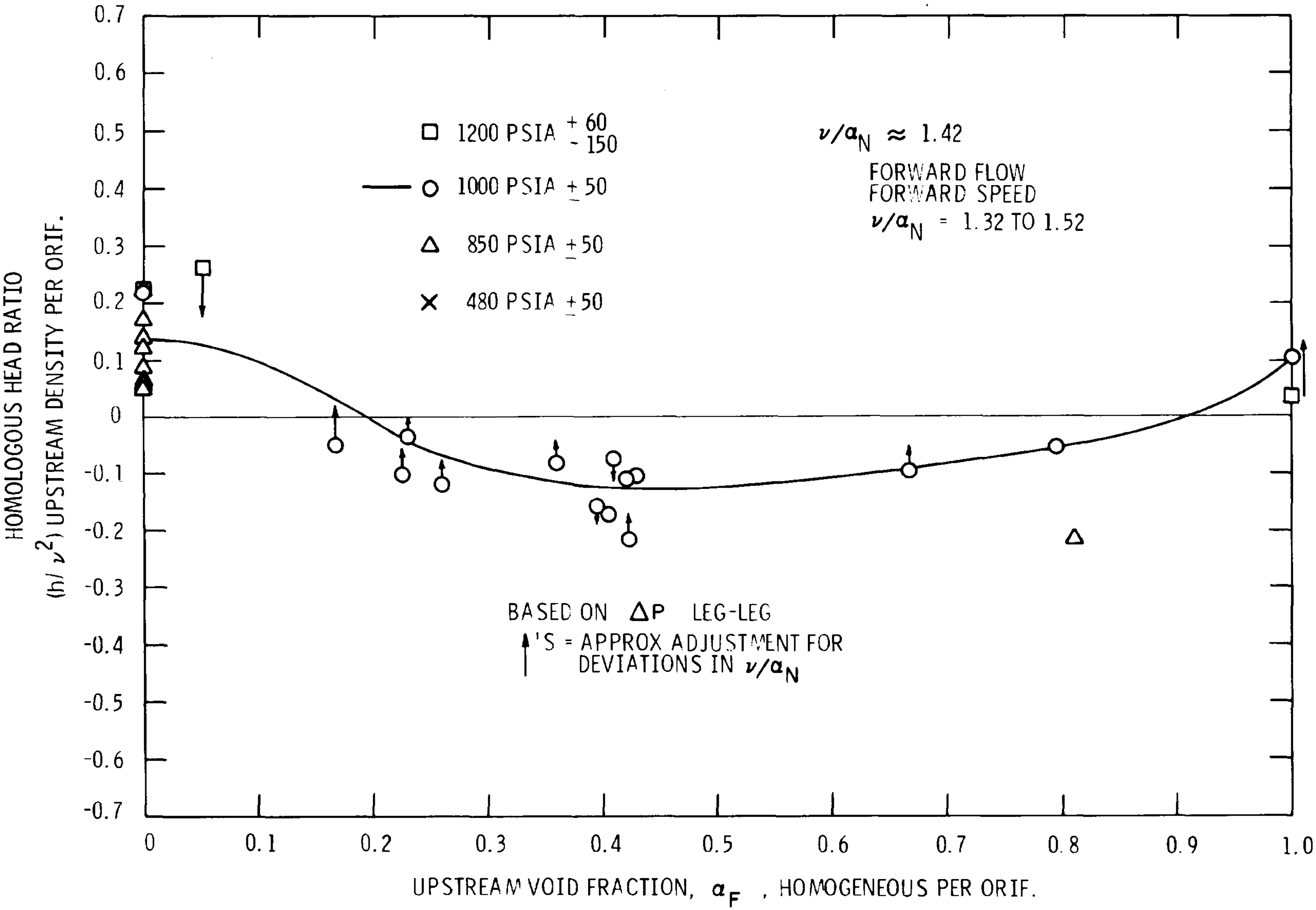


Figure 5-6. Effect of void fraction on homologous head ratio at $\nu/\alpha_N \approx 1.42$ (Forward)

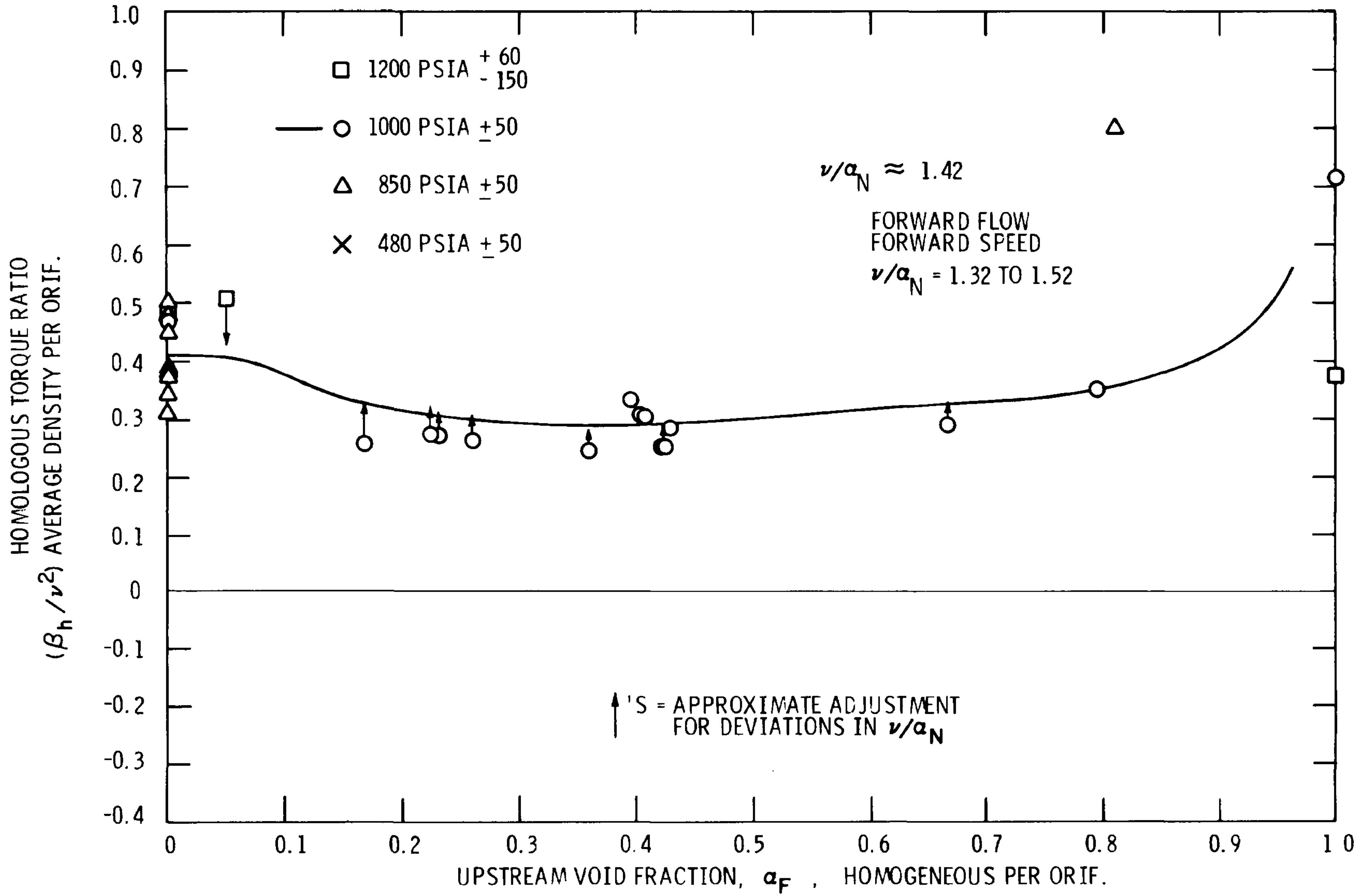


Figure 5-7. Effect of void fraction on homologous torque ratio at $\nu/\alpha_N \approx 1.42$ (Forward)

of ν/α_N nearly all the two-phase test points were run at one pressure level, i.e. near 1000 psia.

For ν/α_N near 2.0 in Figures 5-8 and 5-9 the head and torque at the higher pressures again showed the relatively shallow and flat-bottomed shape curves, except for some tilt-up in torques toward the steam region. Again the amounts of degradation at higher pressures were moderate compared to degradation for rated flow and speed, but sizable compared to the small single-phase values here. The heads were always negative, while the torques changed from slightly positive to negative for the mid-range void fractions. This corresponds to changing from pump dissipation to "reverse turbining", i.e. turbining with forward flow and speed with energy being furnished by the booster pumps, equivalent to blowdown pressure gradient. A considerable amount of data was obtained at several pressures. However, the 480 psia points at void fractions below 0.60 do not relate directly to LOCA blowdowns (See Figure 3-1 for range of P vs α_F). More is said about pressure effects in Section 5.4 below.

For ν/α_N near 4.0 as in Figures 5-10 and 5-11 there appears to be little effect of two-phase flow except possibly at the lower and mid-range α_F's where the data is incomplete. However, a ν/α_N of 4 does not occur in a NSSS pump until a high void fraction is reached and thus the data at high void fractions plus reference points for water are sufficient.

For reverse flow and speed, similar results were obtained for ν/α_N's of 1.0 and 1.4. These were both normal turbining operation with sizable reverse flow pressure drop and reverse speed shaft output torque. (Both the head and the torque at the torque meter were in the same direction as in normal pumping operation, and therefore were positive.) In Figures 5-12 to 5-15 it can be seen that two-phase flow resulted in slightly higher driving head. For the hydraulic torque ratio there was a smooth decline, starting at a void fraction of about 0.20, reaching significant amounts of degradation around α_F = 0.80, and then recovery as α_F approached 1.00.

Data for reverse flow and forward speed is shown in Figures 5-16 and 5-17 for ν/α_N near -0.56. The steam points were obtained from measurements at neighboring values of ν/α_N by interpolation along the performance curves presented in the next section. The data for these degradation curves is somewhat sparse but appears to indicate a rather strong increase in homologous head and torque at

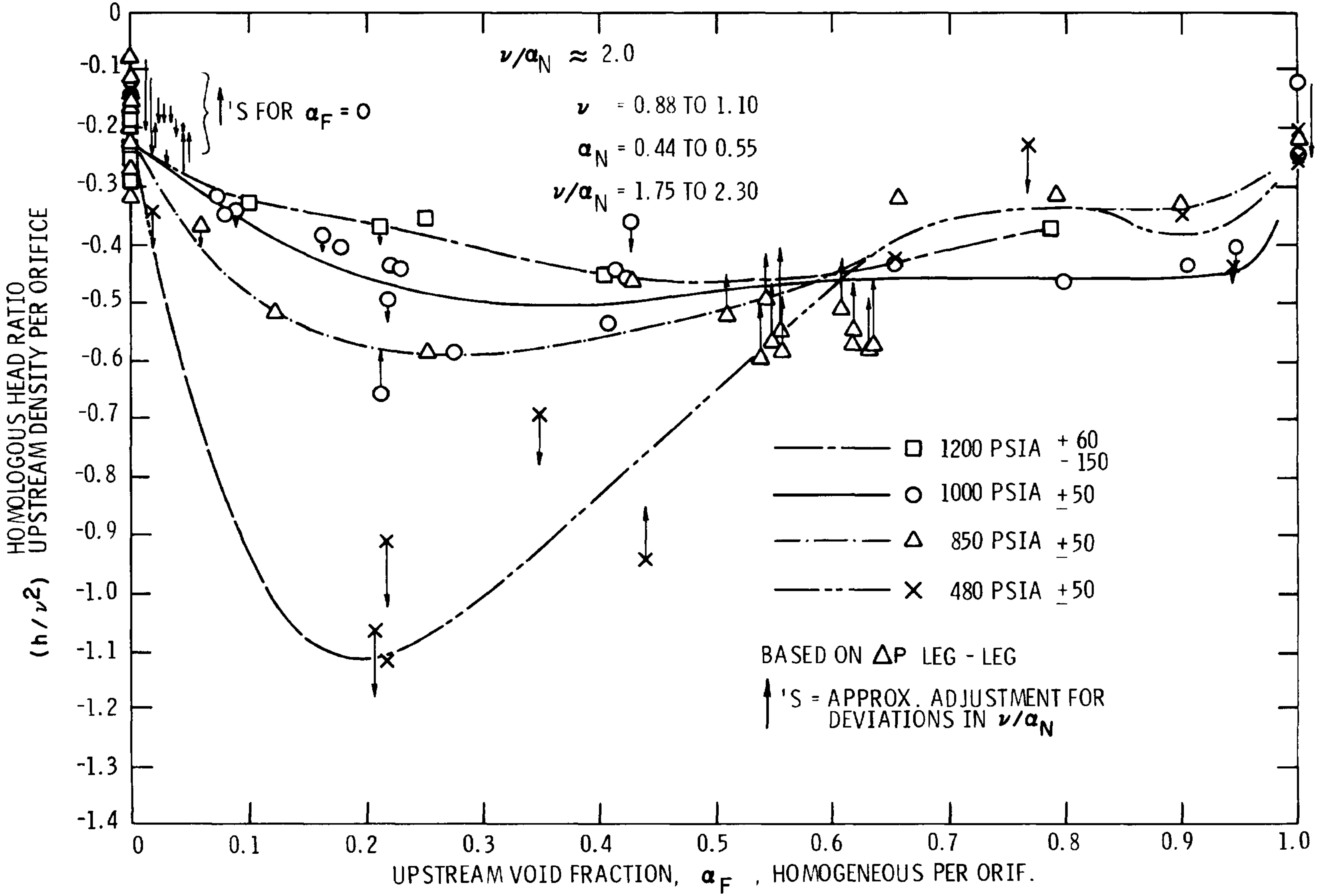


Figure 5-8. Effect of void fraction on homologous head ratio near rated flow and 1/2 rated speed ($\nu/\alpha_N \simeq 2.0$)

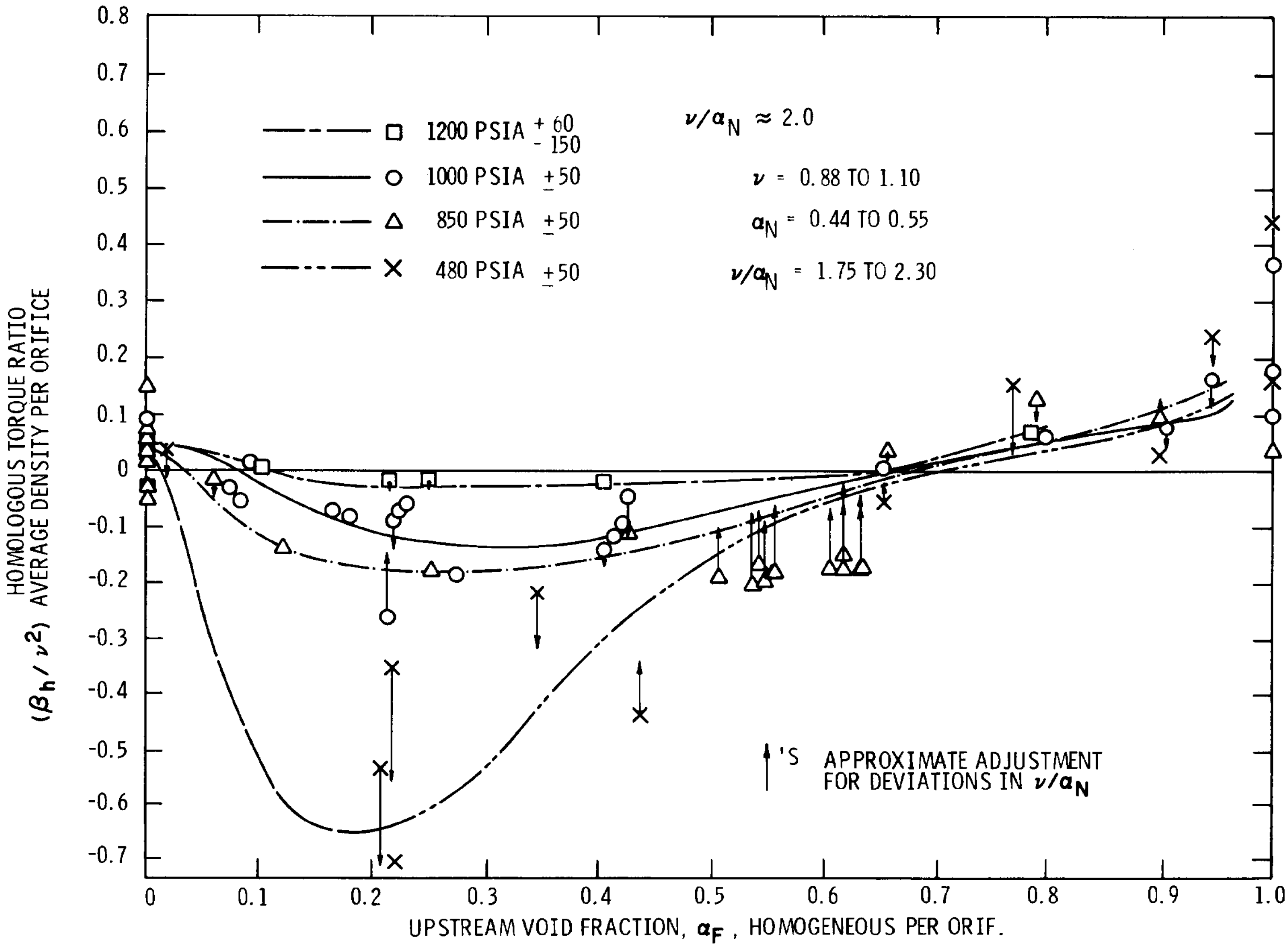


Figure 5-9. Effect of void fraction on homologous torque ratio near rated flow and 1/2 rated speed ($\nu/\alpha_N \approx 2.0$)

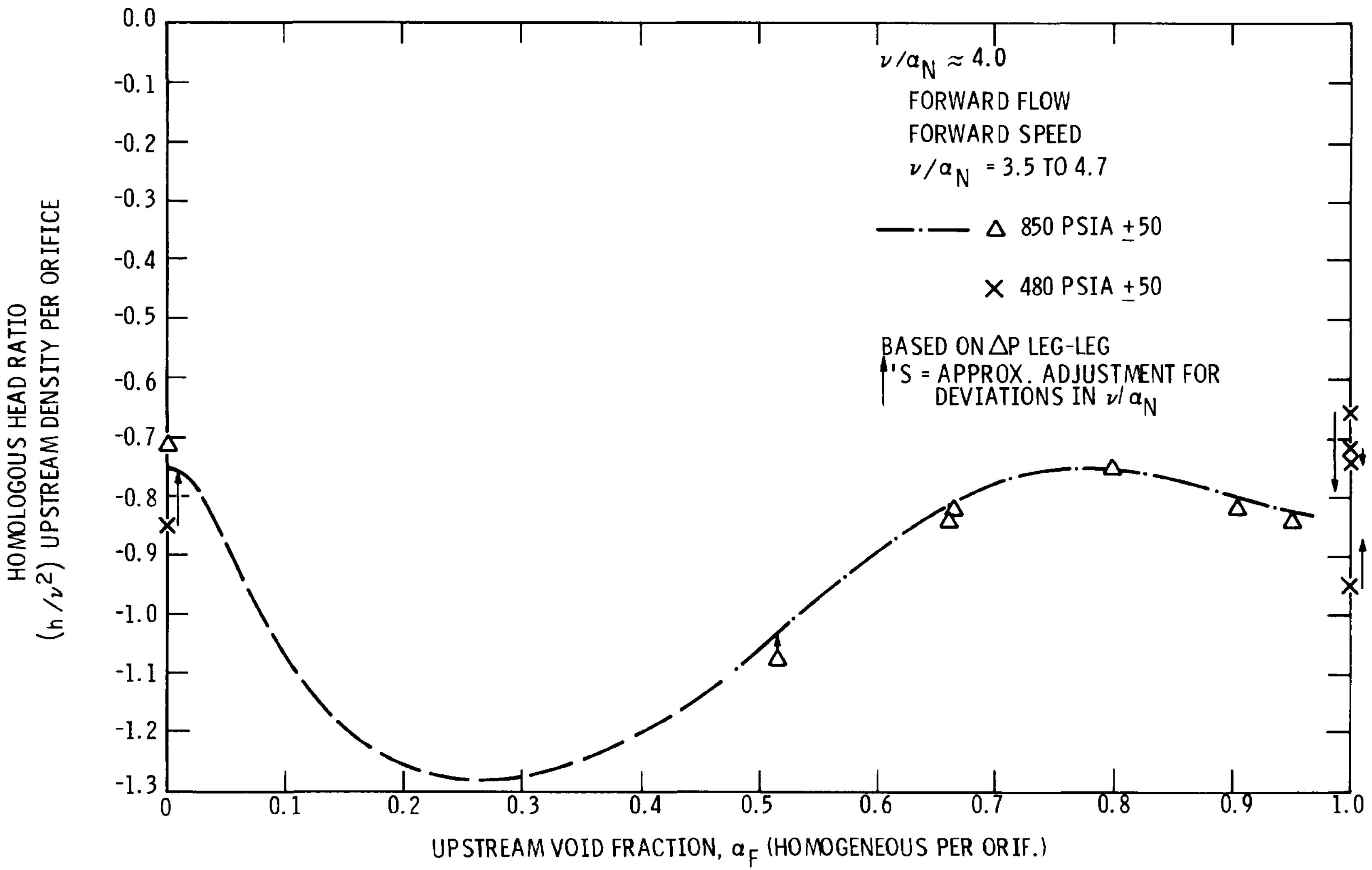


Figure 5-10. Effect of void fraction on homologous head ratio at $\nu/\alpha_N \approx 4.0$ (Forward)

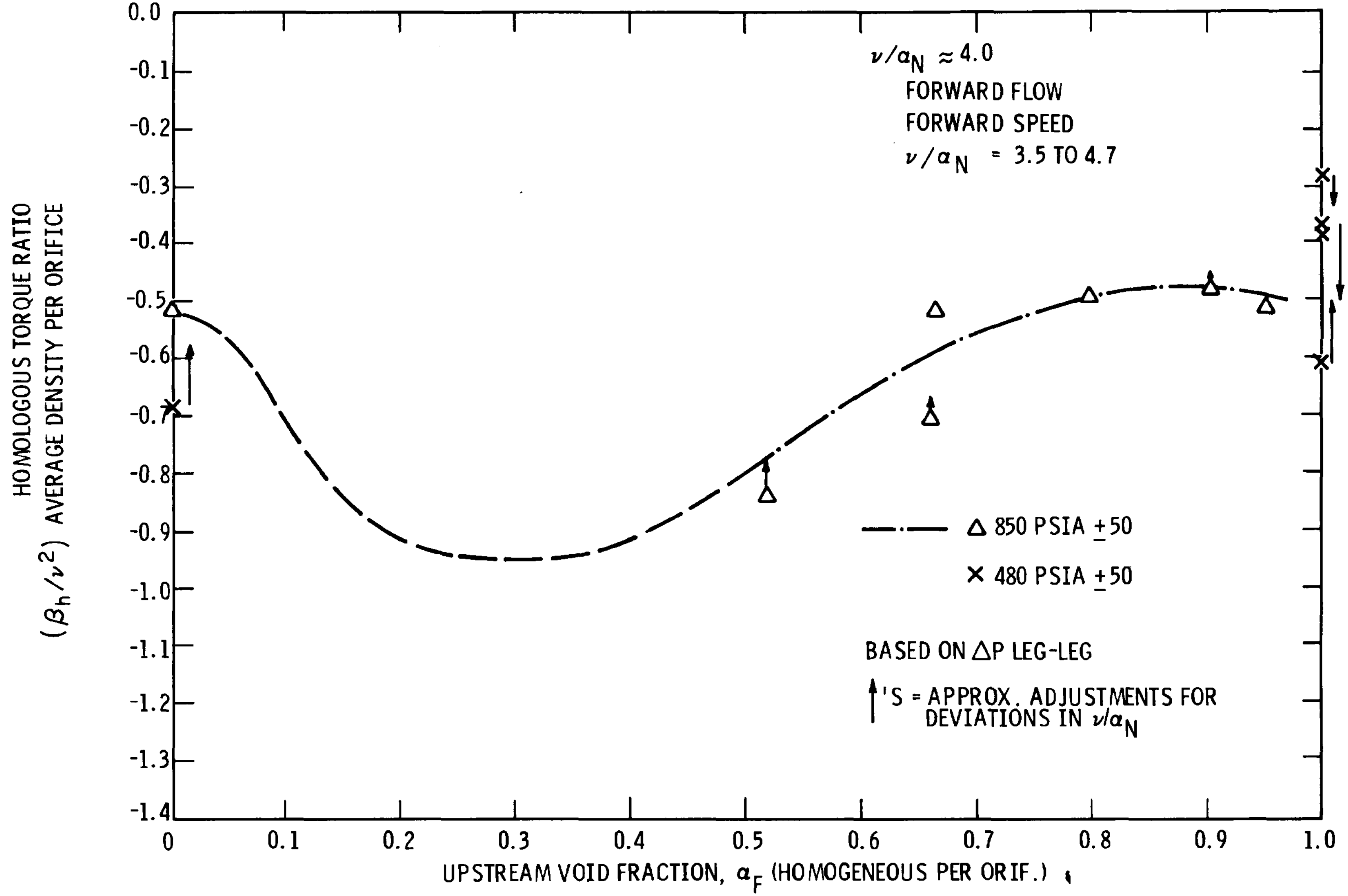


Figure 5-11. Effect of void fraction on homologous torque ratio at $\nu/\alpha_N \approx 4.0$ (Forward)

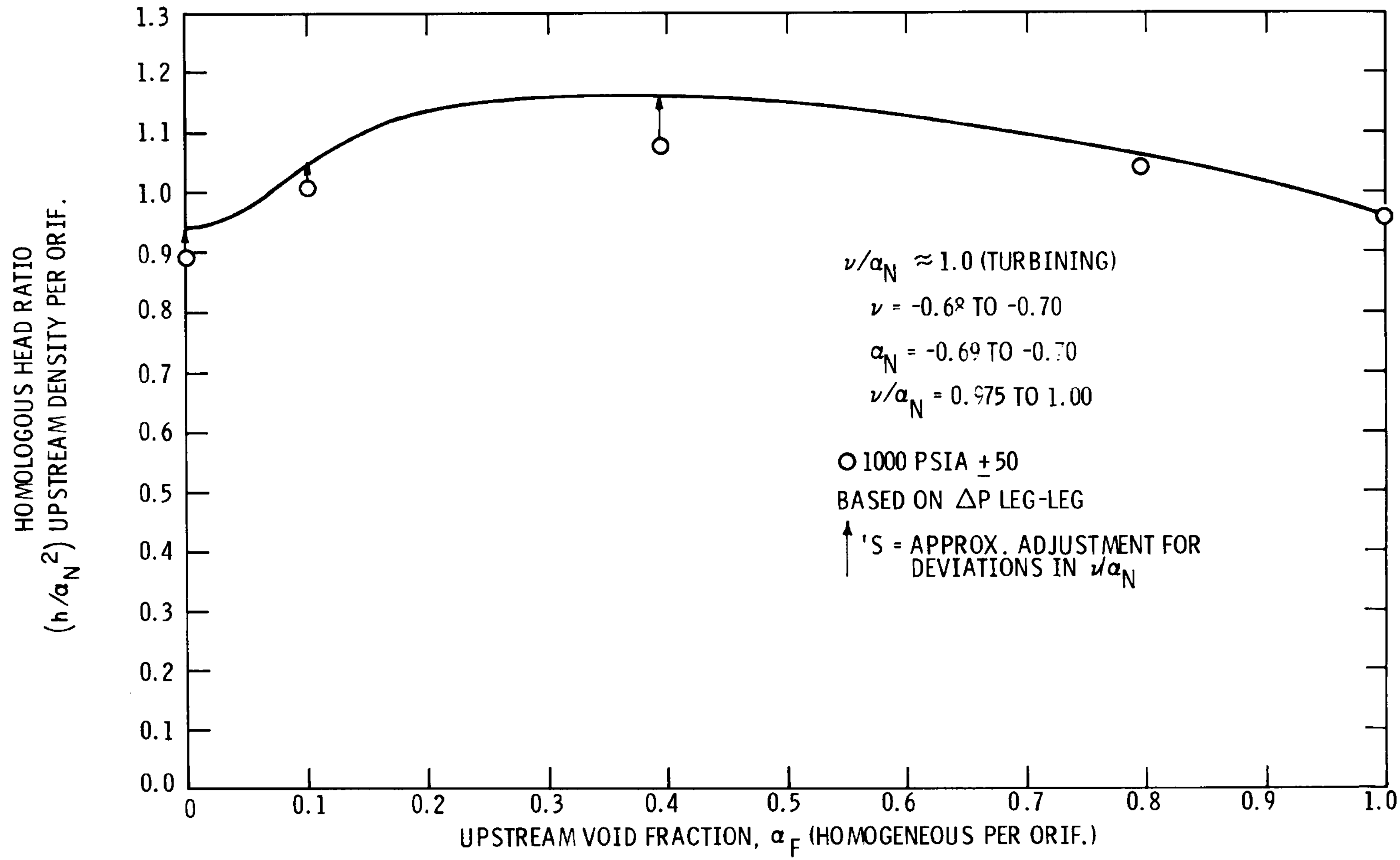


Figure 5-12. Effect of void fraction on homologous head ratio near -0.7 rated flow and speed ($\nu/\alpha_N \approx 1.0$ Reverse)

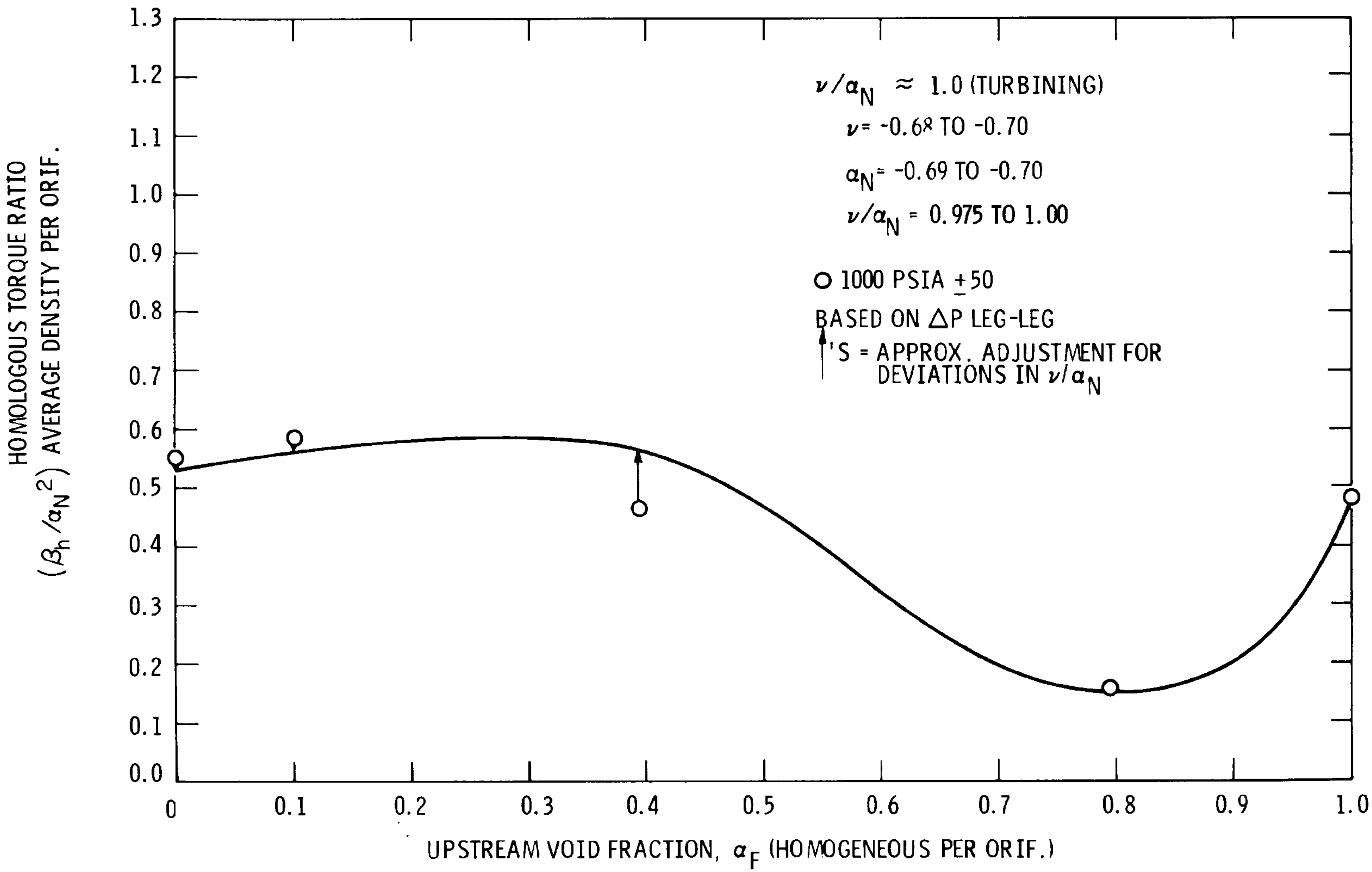


Figure 5-13. Effect of void fraction on homologous torque ratio near -0.7 rated flow and speed ($\nu/\alpha_N \approx 1.0$ Reverse)

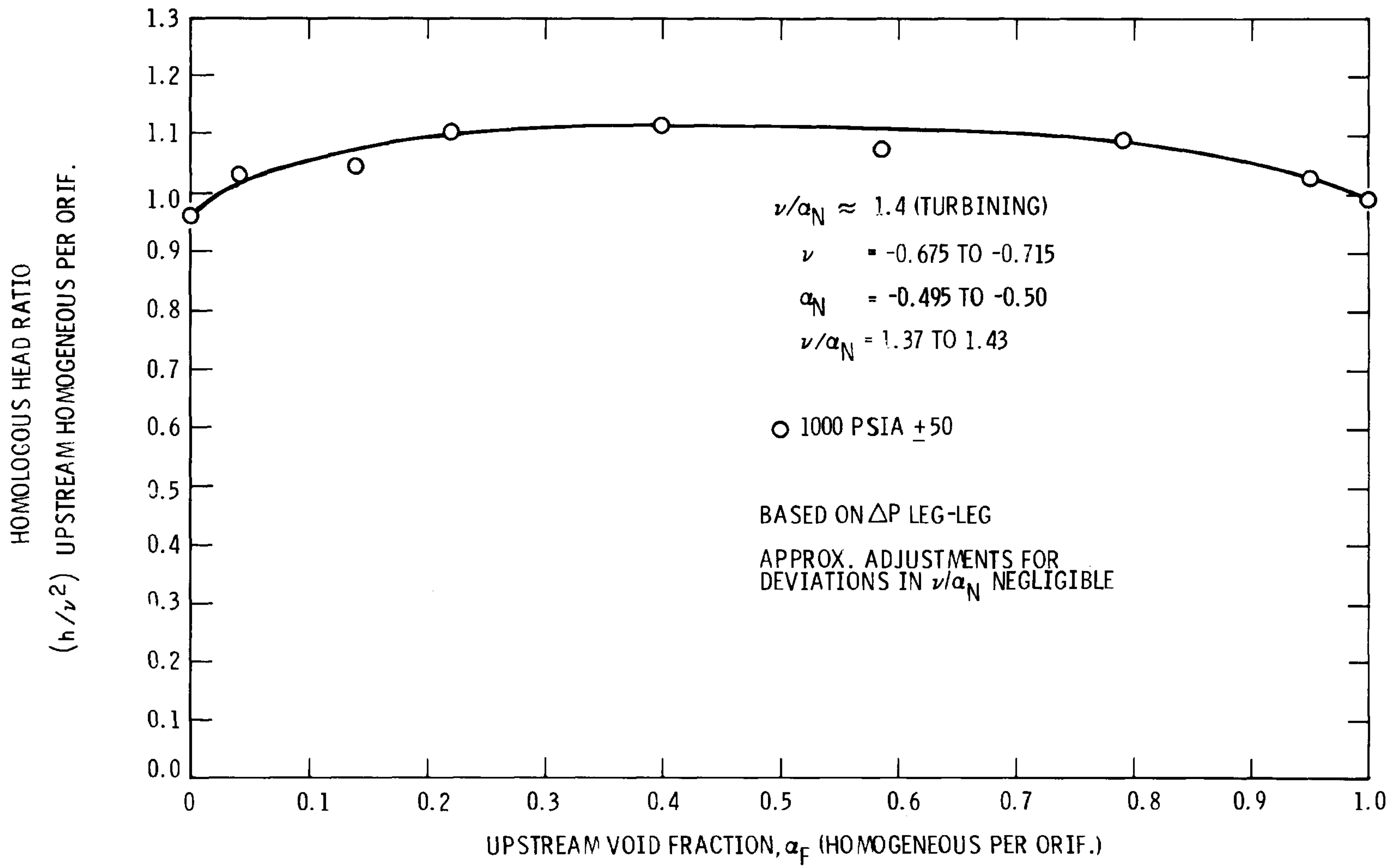


Figure 5-14. Effect of void fraction on homologous head ratio near -0.7 rated flow and -0.5 rated speed ($\nu/\alpha_N \approx 1.4$ Reverse)

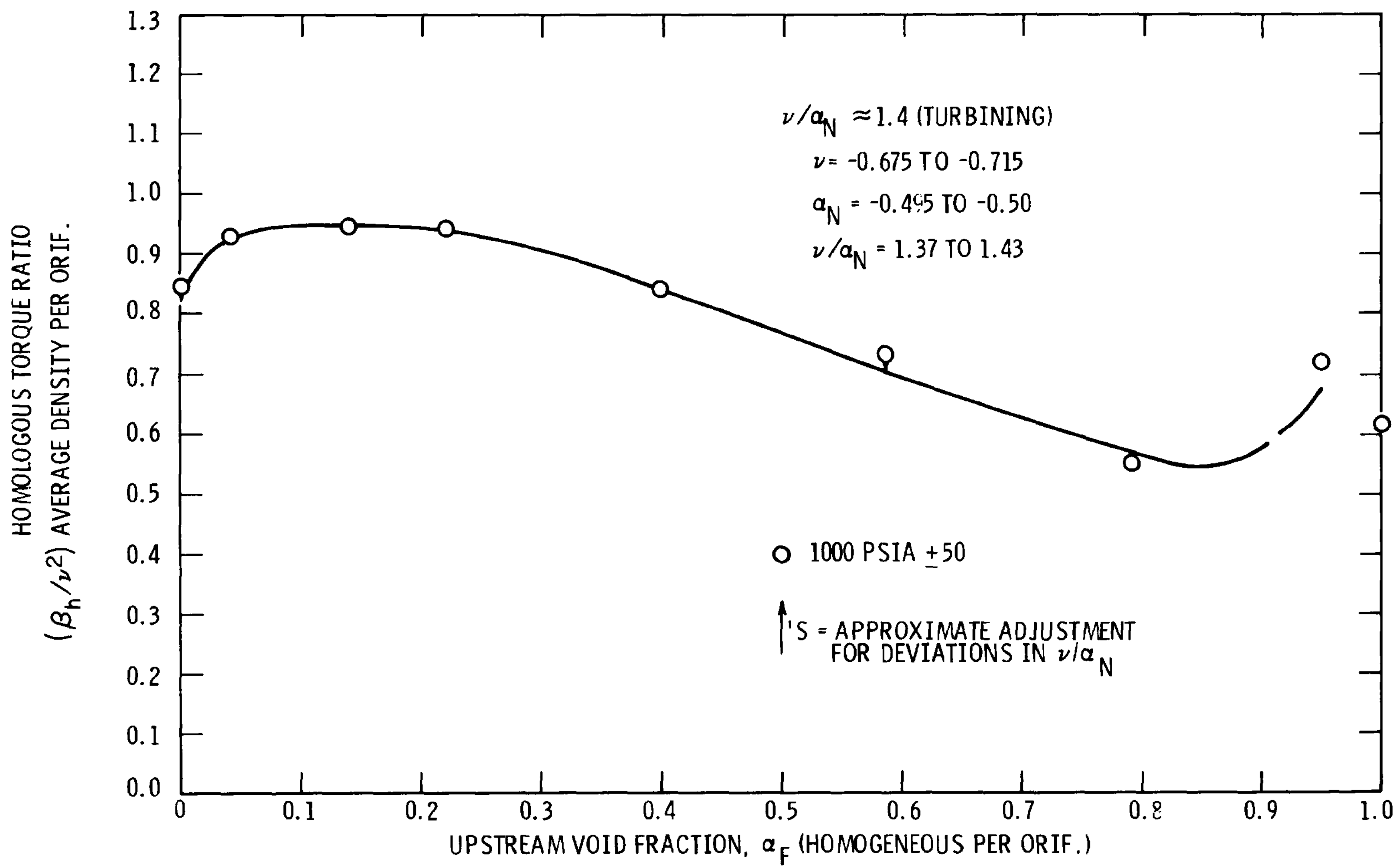


Figure 5-15. Effect of void fraction on homologous torque ratio near -0.7 rated flow and -0.5 rated speed ($\nu/\alpha_N \approx 1.4$ Reverse)

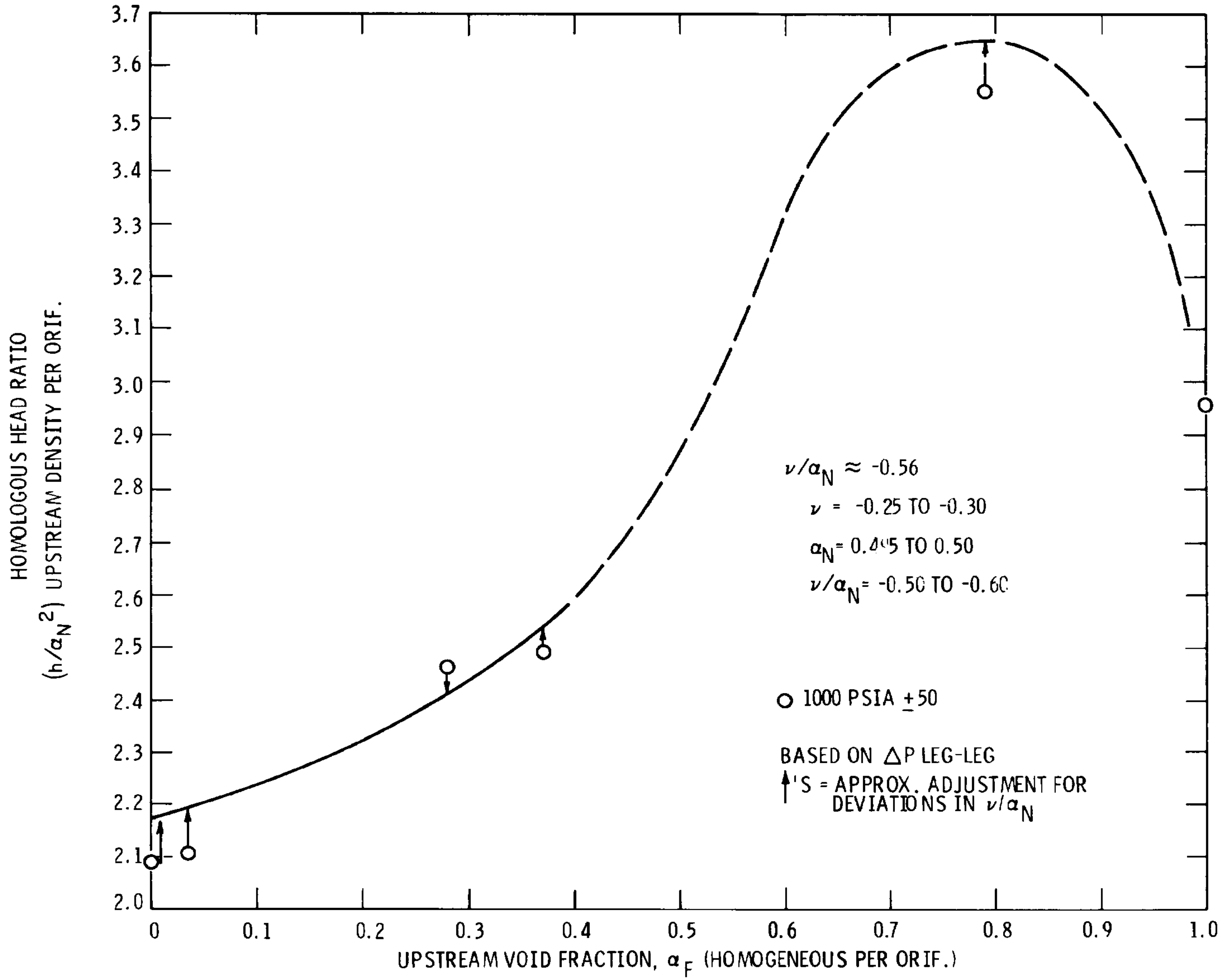


Figure 5-16. Effect of void fraction on homologous head ratio near -0.28 rated flow and 1/2 rated speed ($\nu/\alpha_N \simeq 0.56$)

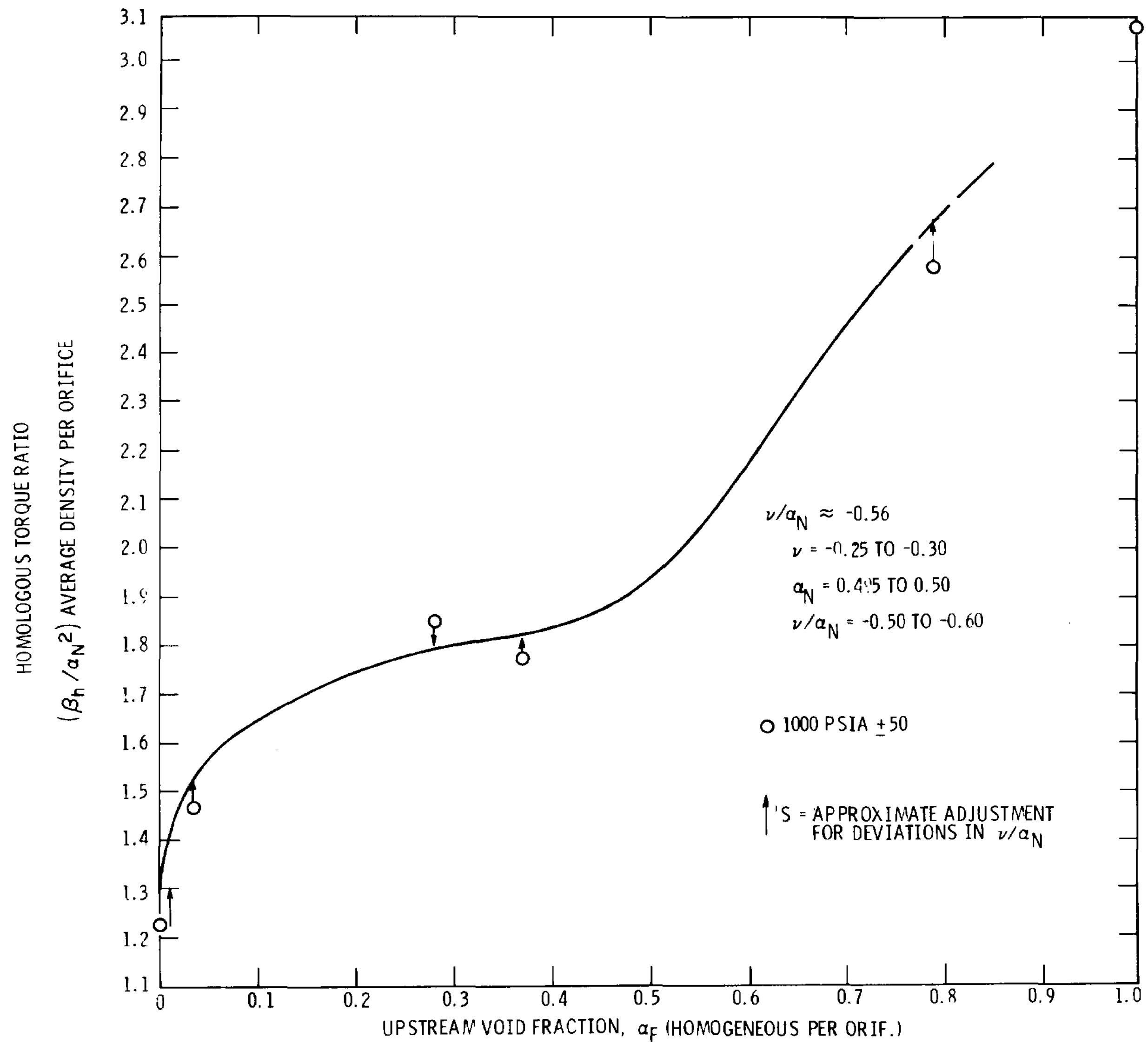


Figure 5-17. Effect of void fraction on homologous torque ratio near -0.28 rated flow and 1/2 rated speed ($\nu/\alpha_N \approx 0.56$)

high void fractions. Since the mode of pump operation here is pumping dissipation (flow opposite to head), the increase in two-phase head and torque means more dissipation.

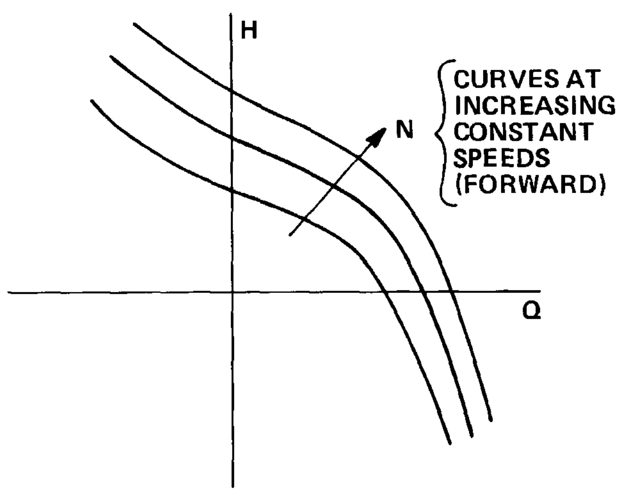
5.2.2 Single-Phase Homologous Curves

5.2.2.1 Graphic Form and Labeling. A common way of plotting single-phase pump performance on a dimensional basis is a family of head or torque vs volumetric flow rate at various constant speeds, as shown in Figure 5-18 for forward speed operation. Expressing each parameter non-dimensionally as a fraction of the rated (peak efficiency) value, as in Figure 5-19, would make the curves applicable to other pumps having similar hydraulic design but different absolute rated conditions. On this basis the model pump single-phase test curves would apply to the similar full-scale power plant pumps.

For more convenience in plotting, analyzing, and mathematically representing the data, the homologous parameters developed in Appendix A from similarity principles are used to further reduce the graphs as in Figure 5-20. Thus, to the extent that the similarity relationships hold (i.e., $\nu \sim \alpha_N$, $h \sim \alpha_N^2$, and $\beta_h \sim \alpha_N^2$), each family of head or torque can be represented by a single homologous curve. Further convenience in plotting data for large values of ν/α_N (especially as α_N approaches zero) is achieved by switching to mathematically equivalent inverse functions when $|\nu/\alpha_N|>1$, i.e., using $\alpha_N \sim \nu$, $h \sim \nu^2$ and $\beta_h \sim \nu^2$. This choice of parameters produces the foldback type of homologous curves shown in Figure 5-21. This figure also shows the branches of the curves for reverse speed operation.

For convenient identification of the various branches of the homologous curves, they are labeled HAN, HVN, etc. in accordance with the key shown in Figure 5-22. The simple diagram which is shown in this key is included in each report figure which presents such homologous curves. Again it may be mentioned that the tests and resulting curves in this program do not include the combination of reverse speed and forward flow because this operating realm is not significant in LOCA analysis. These curve labels (HAN, etc.) are simplistic representations of operating conditions, being based only on the directions of pump flow and speed.

For a more detailed understanding of pump performance it is well to recognize that dissipation can take place in portions of the normal pumping (N), and



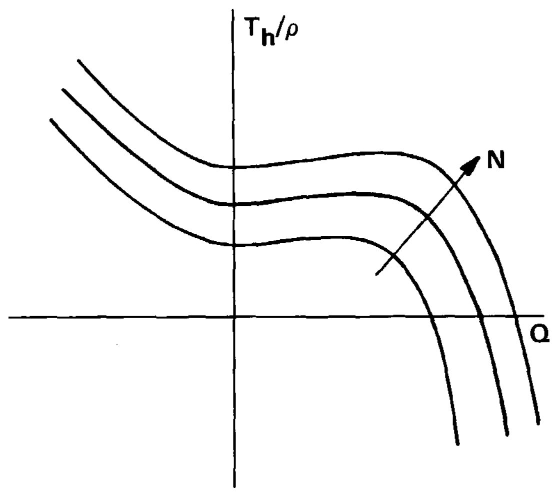


Figure 5-18. Dimensional pump head and torque performance curves (Sample)

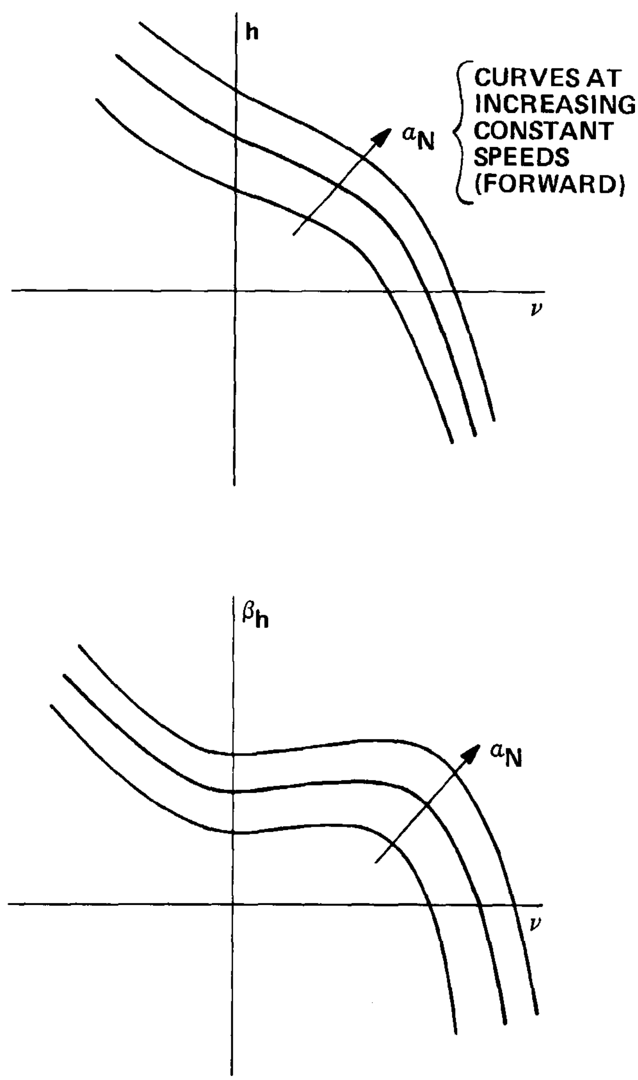


Figure 5-19. Pump head and torque performance as a fraction of rated values (Sample)

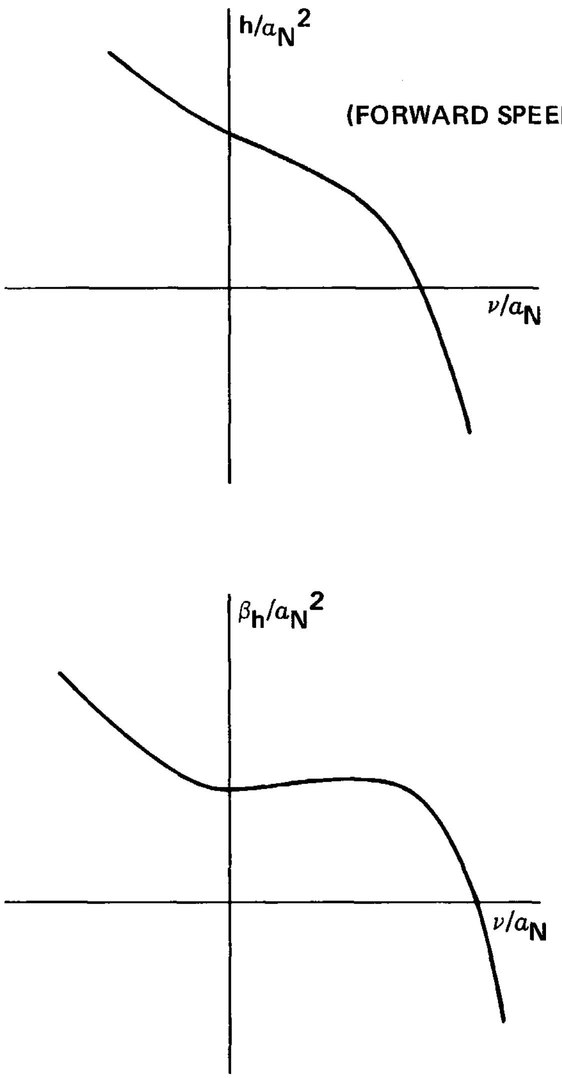


Figure 5-20. Pump homologous head and torque performance curves (Sample)

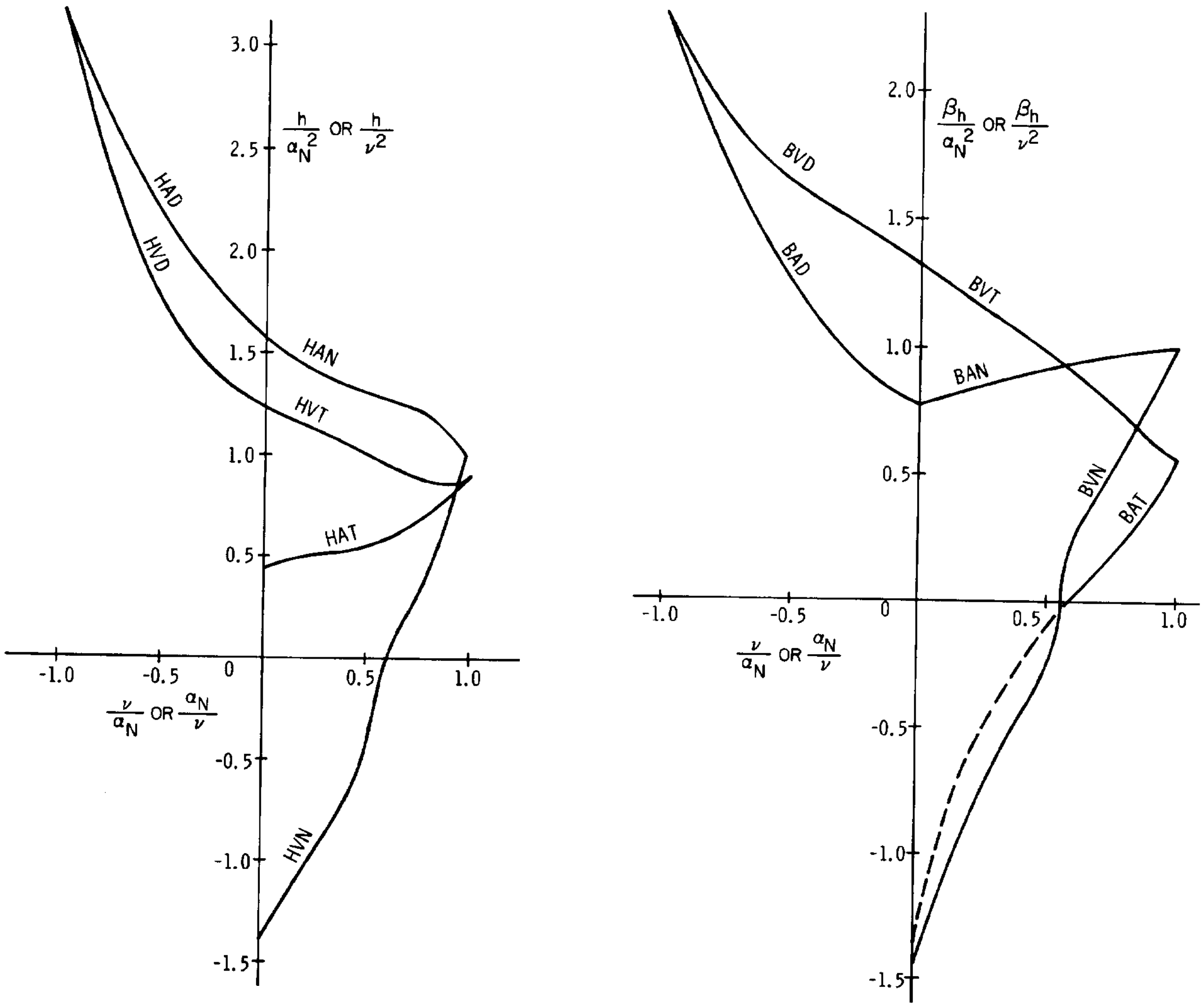
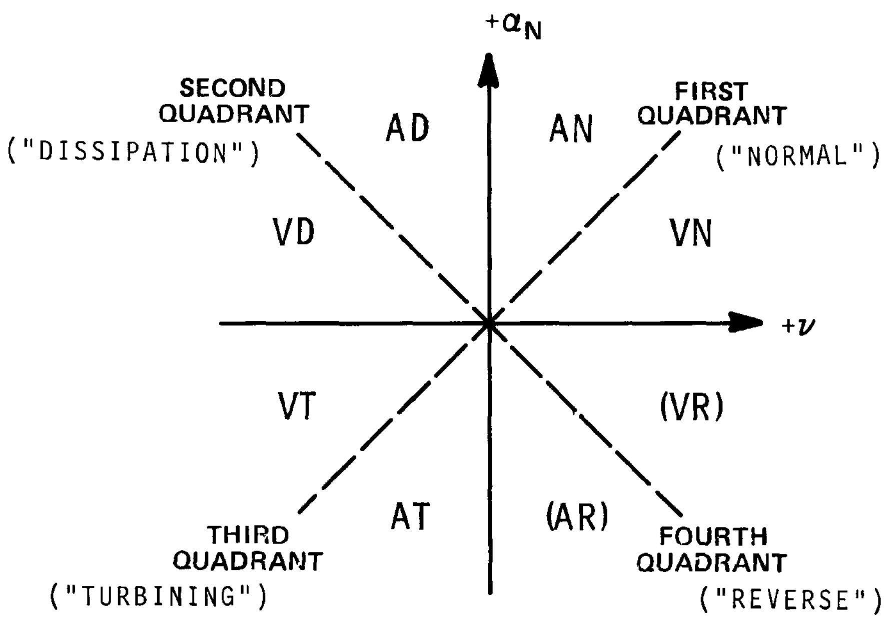


Figure 5-21. Typical reactor coolant pump homologous head and torque curves

Key to Labels HAN, HVN, etc. on Homologous Curves

H → Head function
B → Hydraulic torque function
A → Function with α_N in denominator
V → Function with ν in denominator, used when $|\nu/\alpha_N| > 1$
N Normal pumping quadrant with forward flow and speed
D Dissipation quadrant with reverse flow and forward speed
T Normal Turbining quadrant with reverse flow and speed
R Reverse pumping quadrant with forward flow and reverse speed



Examples:

HAN → h/α_N^2 vs ν/α_N for forward flow and speed

BVD → β_h/ν^2 vs α_N/ν for reverse flow and forward speed

Figure 5-22. Key to labels on homologous curves normal turbining (T), and reverse pumping (R) quadrants as well as everywhere in the dissipation (D) quadrant. This dissipation can be either hydraulic dissipation in the mainstream or dissipation due to friction and windage in bearings, seals, etc., or a combination of both.

Table 5-1 shows more details of operating modes and provides a quick reference for defining the signs of the parameters and showing which signs go with each operating mode. Other discussion of operating modes is included in Data Reduction and Processing Methods (Section 4.2) and in Volume VIII.

5.2.2.2 Extent of Single-Phase Data. One of the current and convenient ways of describing and using data to evaluate two-phase flow pump performance is to correlate and quantify the numerical differences between single-phase and two-phase performance. This, of course, requires single-phase performance data covering the ranges of flows and speeds which occur in LOCA analysis for two-phase flow as well as for single-phase flow. For flows and speeds not possible to be covered directly, the similarity ratio ν/α_N is matched.

5.2.2.3 Presentation of Results. Since there was so much test data obtained on water performance, two separate pairs of homologous head and torque plots are shown. Thus, one pair of plots are used to present Phase I forward flow data, and another pair to present representative Phase II forward flow data plus combined Phase I and II reverse flow data. These plots are shown in Figures 5-23 to 5-26. Roughly one-third of the Phase II forward flow points are not shown in the plots (Figures 5-25 and 5-26) because they fell essentially on top of points already plotted and would have prevented distinguishing the different kinds of symbols present in a given plot region. Omission of these points did not change the curves or the range of point location shown.

A high majority of the plot points fall close to the smooth curves which were manually drawn through the data. Deviation from the curves, which did occur for several points, can be attributed to side-effects such as incipient cavitation due to running some tests at unrealistically low pressure levels. More discussion of data consistency is presented in Section 5.3 below. The overall coherence of the water data appear to be good.

Identical head curves and torque curves are drawn through both the Phase I and Phase II forward flow data in Figures 5-23 to 5-26. The fact that data from

Table 5-1

SIGNS OF PUMP PARAMETERS FOR VARIOUS OPERATING MODES

Quadrant No.	Quadrant Label	Operating Mode	N	Q	H	T_h	$T_{f\&w}$	T_{sh}	
1	N	Normal Pumping	+	+	+	+	+	+	$T_{sh} > T_{f\&w}$
									← $H = 0$
		Pumping Dissipation	+	+	-	+	+	+	$T_{sh} > T_{f\&w}$
									← $T_h = 0$
		Reverse Turbining Dissipation	+	+	-	-	+	+	$T_{sh} < T_{f\&w}$: $\lvert T_h \rvert < T_{f\&w}$
									← $T_{sh} = 0$
		Reverse Turbining	+	+	-	-	+	-	$\lvert T_h \rvert > T_{f\&w}$
2	D	Counterflow Pumping Dissipation	+	-	+	+	+	+	
3	T	Normal Turbining	-	-	+	+	-	+	$\lvert T_h \rvert > T_{f\&w}$
									← $T_{sh} = 0$
		Turbining Dissipation	-	-	+	+	-	-	$\lvert T_h \rvert < T_{f\&w}$
									← $T_h = 0$
		Reverse Pumping Dissipation with reverse flow	-	-	+	-	-	-	
4	R	Reverse Pumping	-	+	+	-	-	-	
									← $H = 0$
		Reverse Pumping Dissipation	-	+	-	-	-	-	

Table 5-1 (Continued)

Parameter	Symbol	Definition	Sign
Hydraulic Torque	T_h	Torque exerted by impeller on fluid in impeller passage	Positive in the direction of normal pump rotation
Friction and Windage Torque	$T_{f\&w}$	Torque to overcome dynamic friction and windage outside of impeller passages	Positive in the direction of normal pump rotation
Shaft Torque	T_{sh}	Measured torque in the pump drive shaft, driving the pump	Positive in the direction of normal pump rotation
Pump Head	H	Pressure rise across the pump in feet of fluid	Positive indicates higher pressure at normal discharge
Pump Speed	N	Pump rotational speed	Positive in the direction of normal rotation
Volumetric Flow	Q	Volumetric flow through the pump	Positive in the direction of normal flow

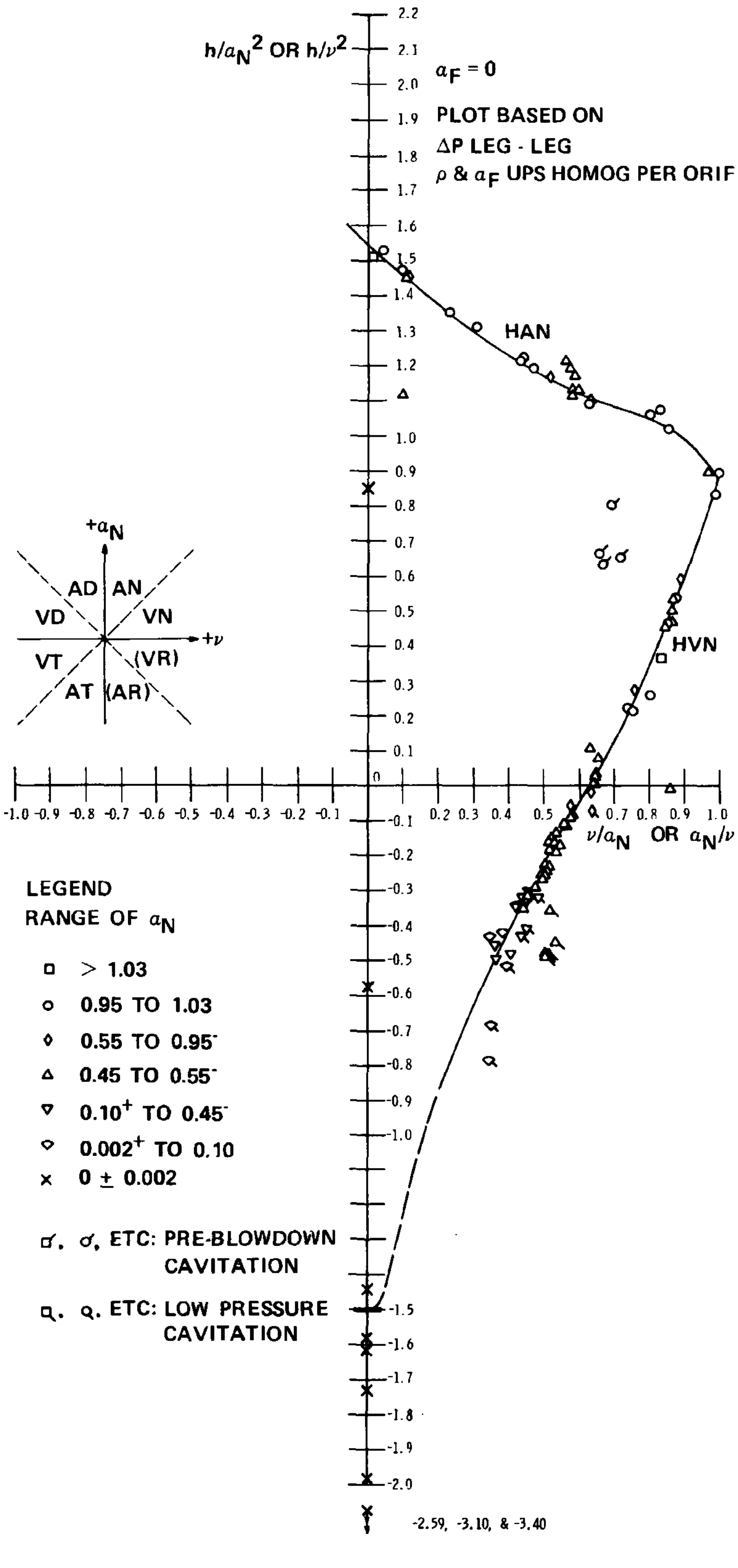


Figure 5-23. Homologous head curve for single-phase water, Phase I forward flow tests

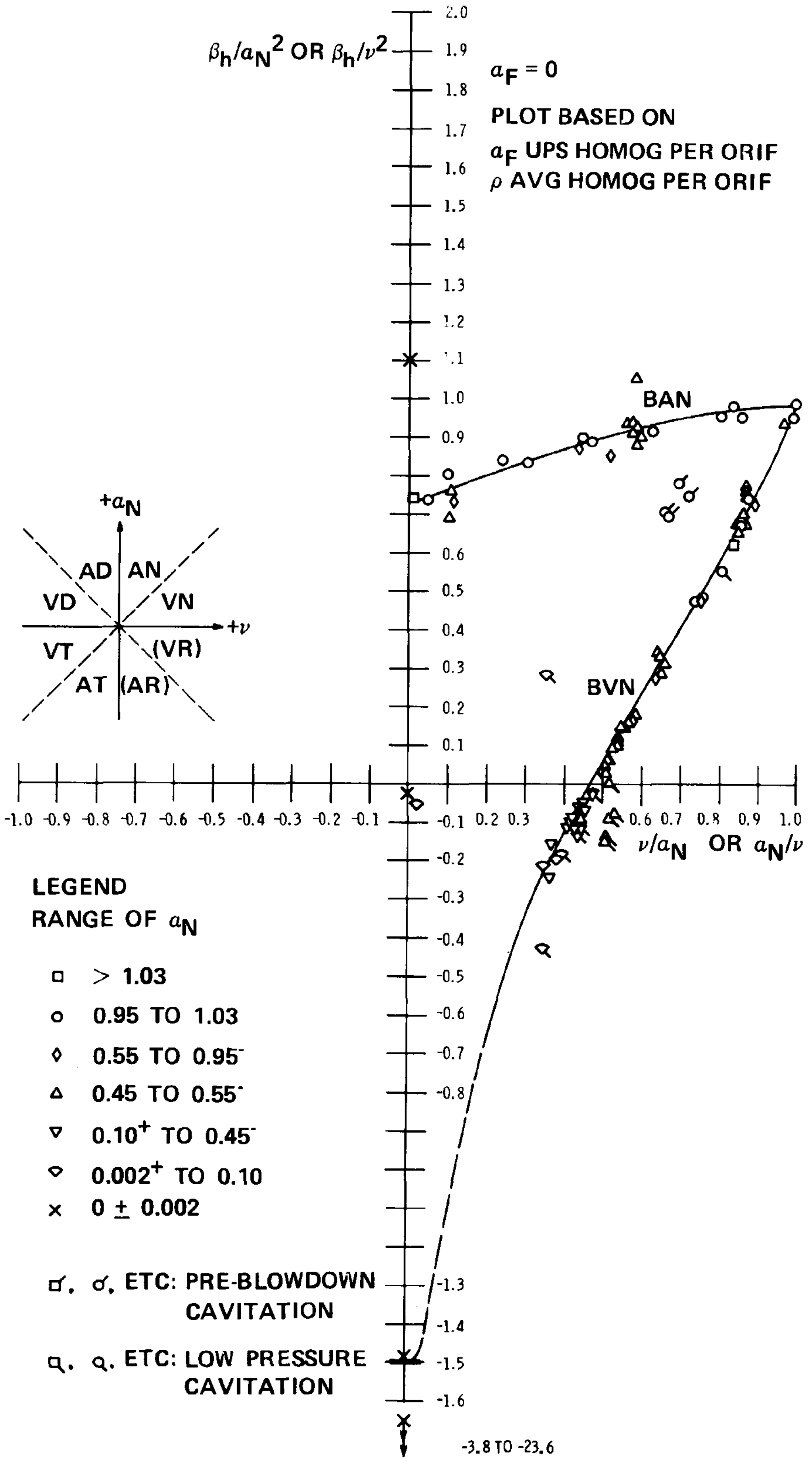


Figure 5-24. Homologous torque curve for single-phase water, Phase I forward flow tests

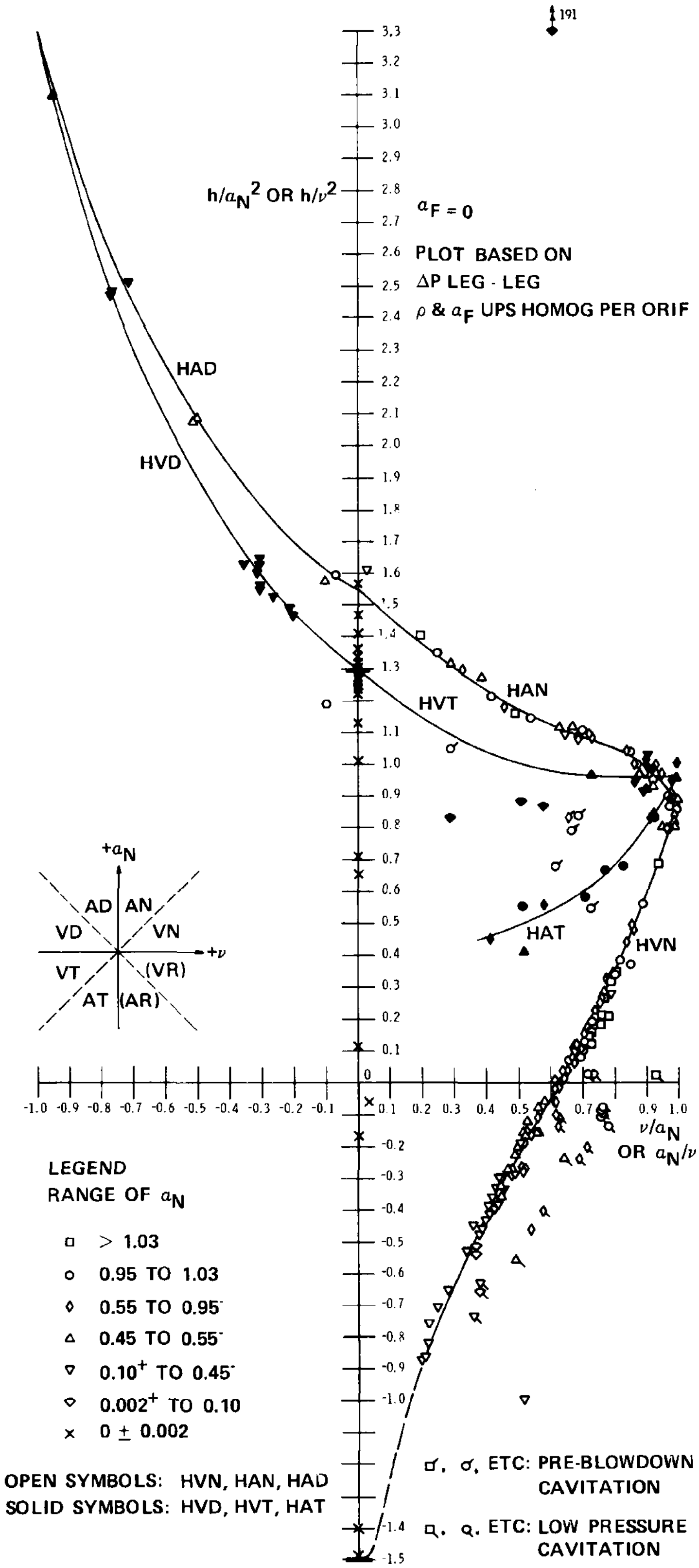


Figure 5-25. Homologous head curve for single-phase water, Phase II forward flow and all reverse flow tests

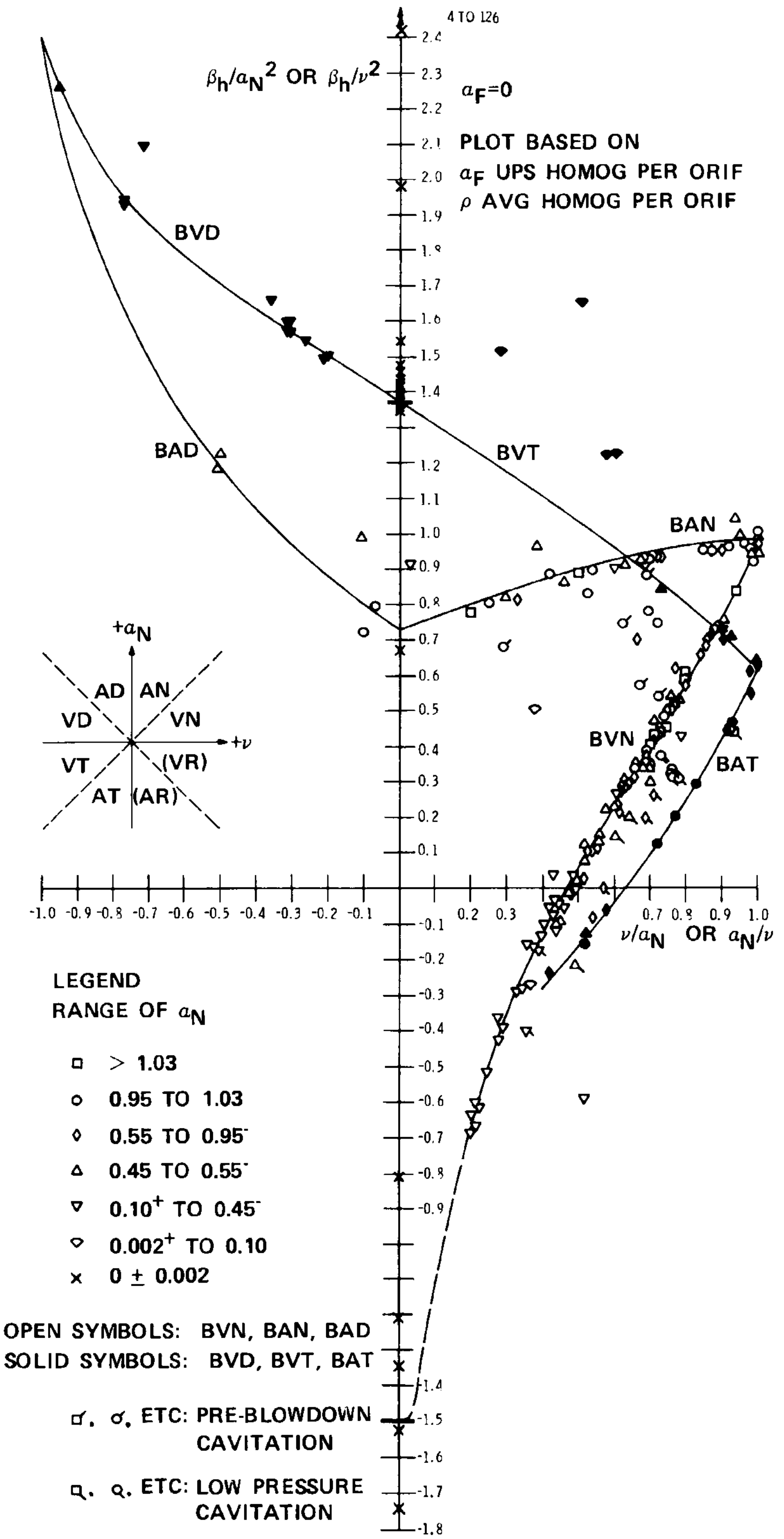


Figure 5-26. Homologous torque curve for single-phase water, Phase II forward flow and all reverse flow tests

Phase I and II agree shows good test reproducibility and negligible physical degradation of the test pump over an extended span of operation.

It is noticeable on these water curves, as well as curves for other void fractions, that the zero speed (locked rotor) points, represented by X's on the vertical axis, spread over a considerable range of head and torque ratios.

To determine the most representative values among these points they were plotted separately on auxiliary curves of h and β_h vs ν on log-log graphs as shown in Figure 5-27 and 5-28 for water. Assuming that the usual "k-factor" type of relationships ($h = k_1 \nu^2$ and $\beta_h = k_2\ \nu^2$) are valid for stationary pump geometry, the data was fitted with straight lines having a slope of two log cycles to one and favoring the higher flow data. The more notable deviations from the curves by some lower range points are commented upon in Section 5.3.2, Performance Data Scatter and Anomalies. These include the progressive rise of forward flow head points and fall of reverse flow head points away from the straight lines as flow decreases, torques for $|\beta_h| < 0.11$ not properly following flow changes, and generally erratic points at the low end of the range. These deviations are attributed to an apparent small (-0.2 psi) constant offset in $\Delta P_{leg-leg}$ measurements, torque hystereses due to static friction, and test measurements going below the range of good measurement accuracy. The k-factors derived from the fitted lines on the log-log plots constitute the zero-speed intercepts (i.e., $k_1 = h/\nu^2$ and $k_2 = \beta_h/\nu^2$) as marked on the homologous performance graphs by bars across the vertical axis.

The lack of water data between $\nu/\alpha_N \cong 5$ (i.e., $\alpha_N/\nu \cong 0.20$) and locked rotor is due to test equipment limitations which prevented higher water flows and/or torques and made speed impractical or unavailable below about 20% of rated speed (See Figure 3-2). This range was covered more extensively, however, by steam tests described next.

The homologous performance curves for all the steam tests are shown in Figures 5-29 and 5-30, and the auxiliary plot for locked rotor points is shown as Figure 5-31. The head curve in Figure 5-29 agrees rather well with the curves for water in Figures 5-23 and 5-25. This indicates close correlation of the single-phase head data on the basis of similarity scaling relationships.

The steam homologous torque curve in Figure 5-30, on the other hand, rises steadily above the water curves in Figures 5-24 and 5-25 as α_N/ν goes from 0.2 to 1 (i.e., ν/α_N goes from 5 down to 1). This is the same trend that showed before in the torque degration curves as an apparent overshoot in torque recovery as void fraction approached 1. At $\nu/\alpha_N = 1$ the excess of steam homologous torque ratio above the water values is in the range of 50 to 100 percent of the rated water value. However, because the density factor between rated (cold water) and steam conditions is so high, the absolute difference between the steam and water torques is only a few foot-pounds. Comments on possibilities for bias in friction and windage torque or other factors which could affect the steam torques by this amount are given in Section 5.4, Special Topics.

5.2.3 Two-Phase Homologous Curves

Homologous head and torque performance curves are presented here for two-phase steady-state tests at upstream void fractions of 0.20 and 0.40 with upstream pressure at 1000 psia, and at 0.80 void fraction with upstream pressure at 850 psia. These three combinations of void fraction and pressure were chosen for extensive performance mapping, as explained in Section 3.3. Operating conditions for the plotted points range around these nominal values as noted on the plots, and conditions in the pertinent individual tests are listed in Table 3-1.

The greatest two-phase testing emphasis was on the 0.40 void fraction, which was expected to be representative of mid-range conditions involving near-maximum degradation and not very strong performance changes with small variations in void fraction. Review of the degradation curves in Section 5.2.1 above showed that these expectations were fairly well fulfilled. However, for some combinations of speed and flow the curves had enough slope so that corrections to the performance curves below for deviations in α_F might be useful.

The homologous performance curves for $\alpha_F \cong 0.40$ are presented in Figures 5-32 and 5-33 and the auxiliary locked rotor curves are shown in Figures 5-34 and 5-35. These curves indicate two-phase degradation in both head and torque over essentially the whole operating range of ν/α_N. Coherence of the data appears to be generally good. Scatter is somewhat larger for the HAN and BAN branches of the curves where flow instabilities and inward leakage of seal injection water were sometimes encountered. More about these effects and consistency of similarity scaling is discussed in following sections.

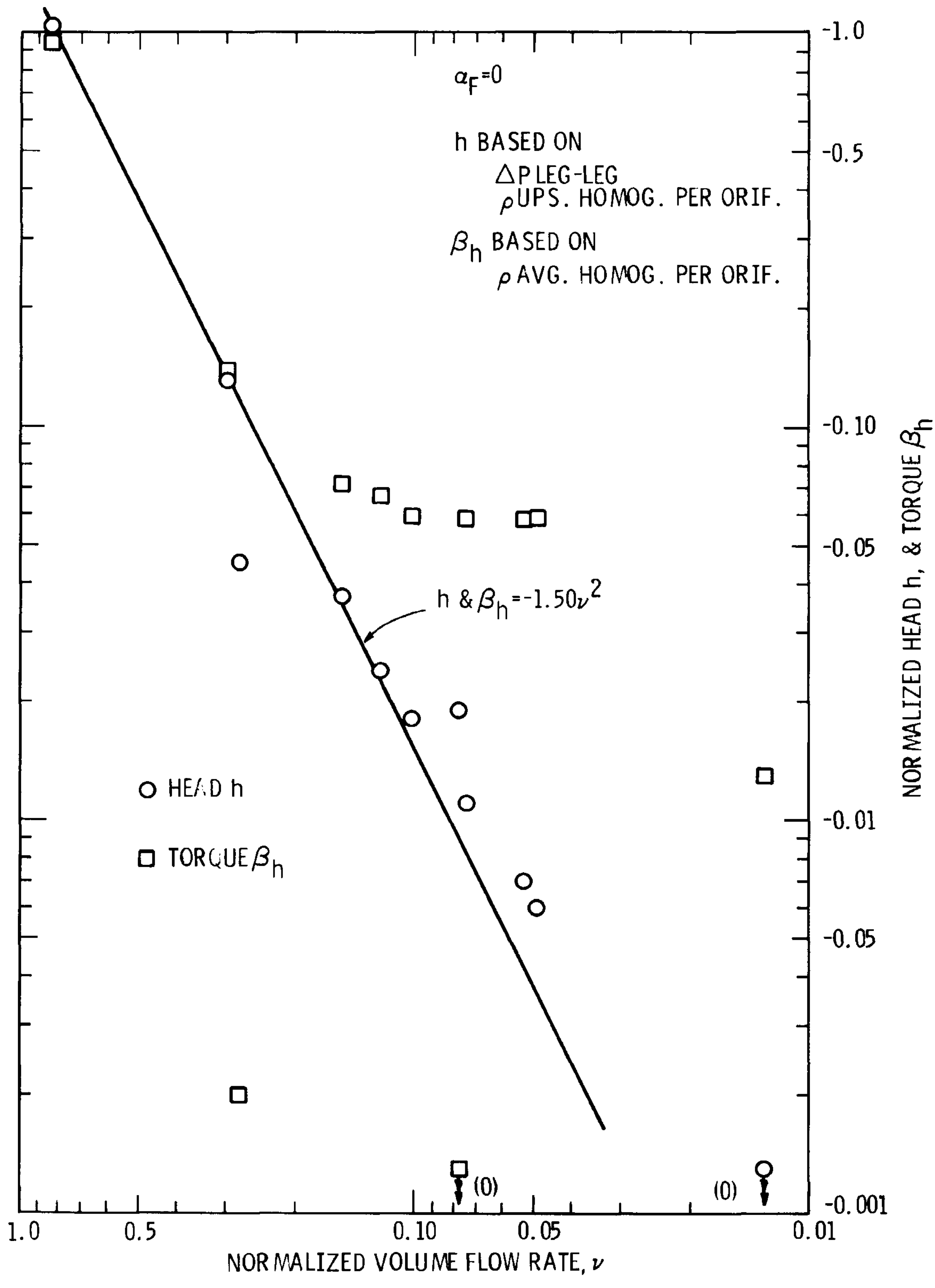


Figure 5-27. Locked rotor head and torque vs flow curves for single-phase forward flow water

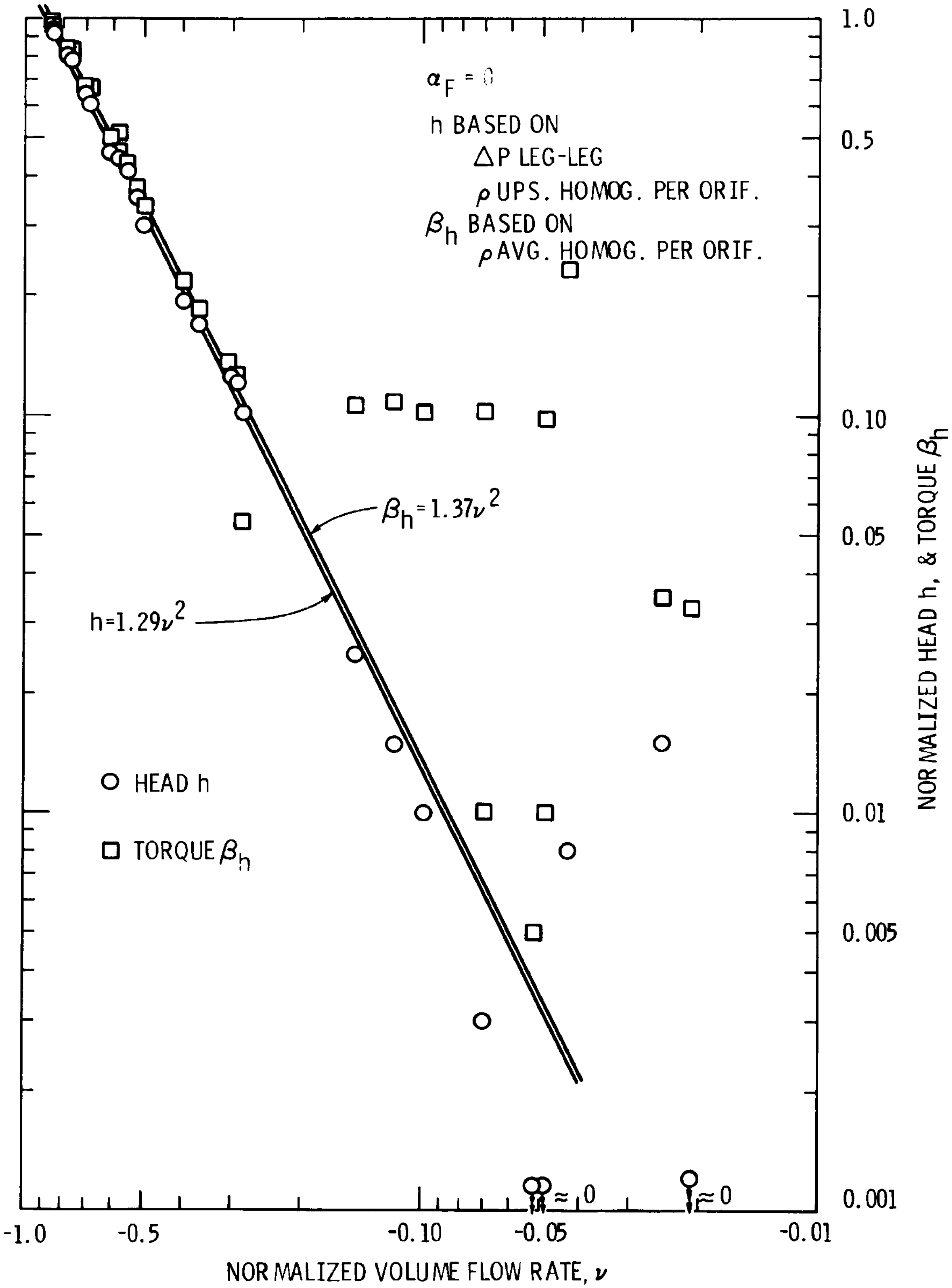


Figure 5-28. Locked rotor head and torque vs flow curves for single-phase reverse flow water

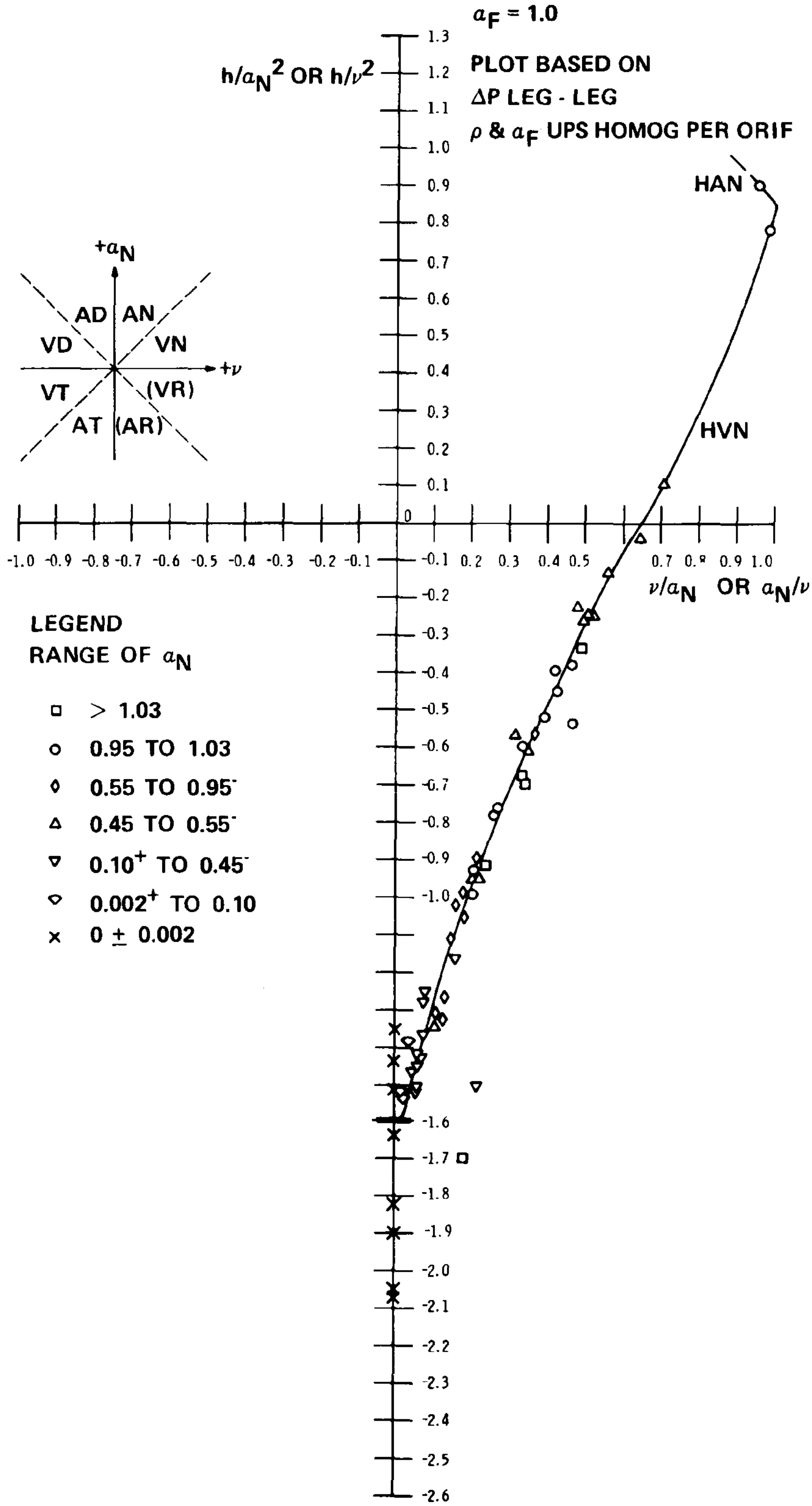


Figure 5-29. Homologous head curve for single-phase steam

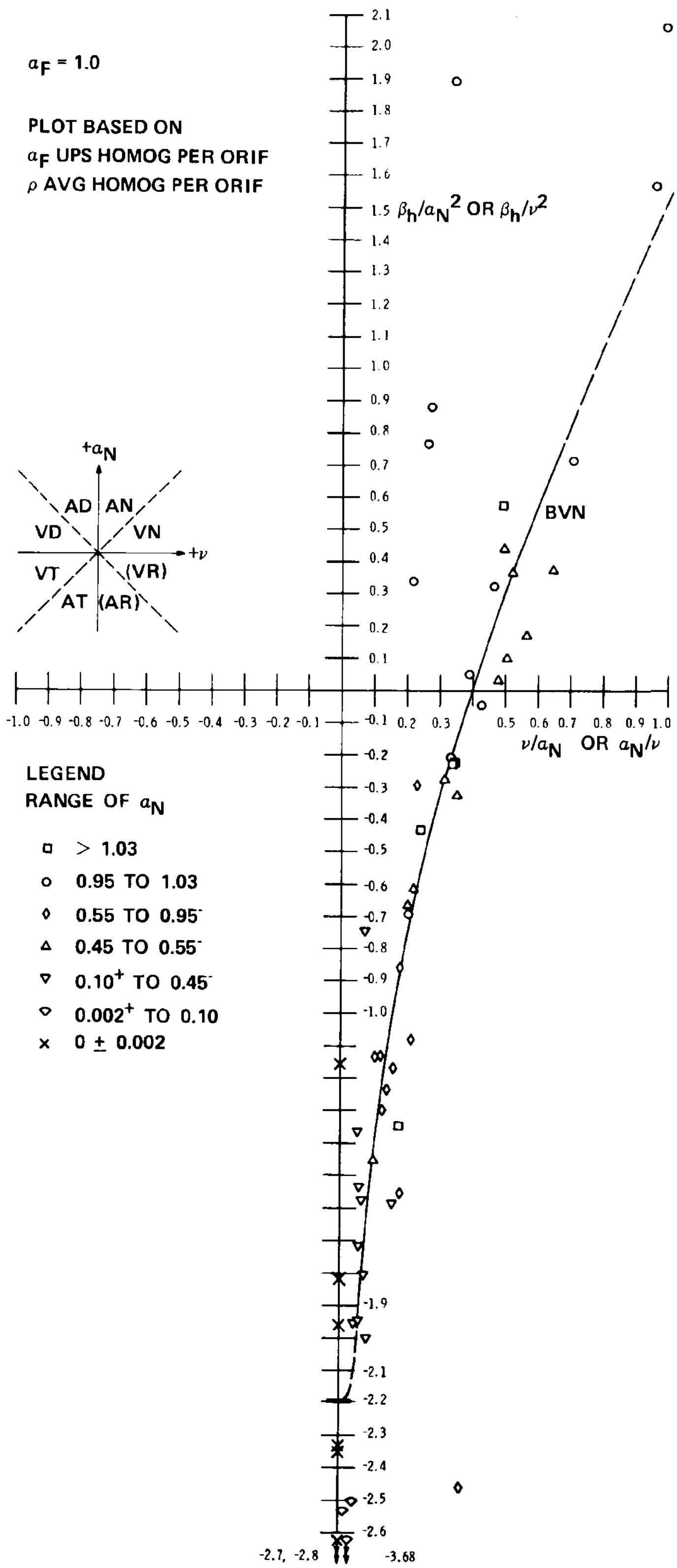


Figure 5-30. Homologous torque curve for single-phase steam

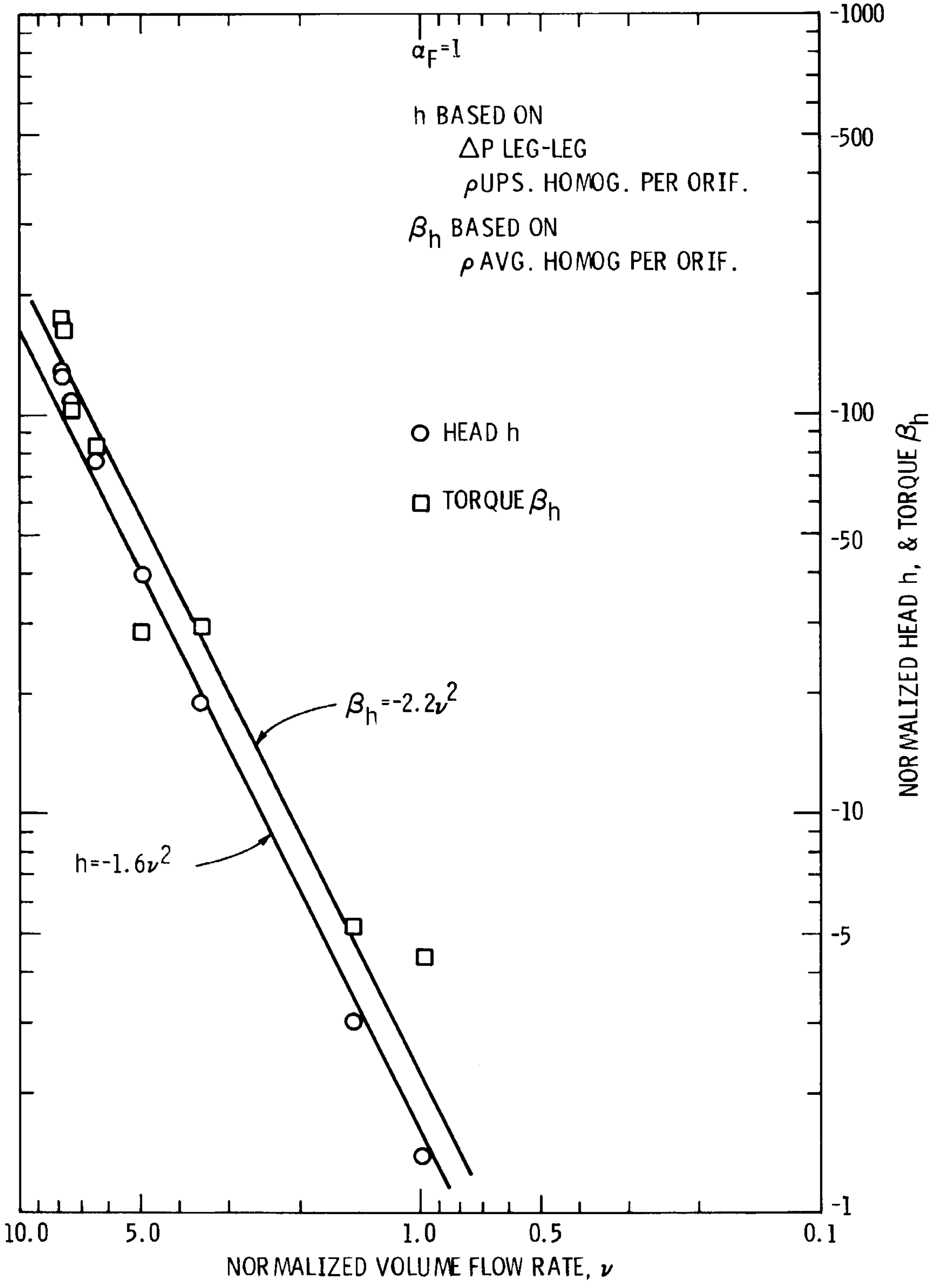


Figure 5-31. Locked rotor head and torque vs flow curves for single-phase forward flow steam

While there is some question as to just where the HAN and HAD curves reach the vertical zero flow axis, as indicated by the dashed lines in Figure 5-32, it seems most likely that there is a step change in homologous head ratio between forward and reverse flow. One factor involved is that when flow reverses, the specified upstream operating conditions -- pressure level, void fraction, and volume flow rate -- shift from being those at the normal suction leg to those at the normal discharge leg, with an accompanying shift in fluid conditions throughout the test section. Also, the plotted head is based on the shifting upstream density. The size of the step change in performance across the zero flow axis depends upon how sensitive the performance is to each of these changing parameters. Pressure effects at ν/α_N's approaching zero were not tested explicitly, but trends based on other tests are discussed in Section 5.4.1. The sensitivity of head to void fraction can be better appraised as the results at other void fractions are presented below.

The homologous torque curve is also expected to have some discontinuity at the flow reversal point (vertical axis). However, such a discontinuity would seem to be smaller for torque, judging from the plotted data and from the fact that the plotted torque parameter is normalized on the basis of average density (actually $1/v_{avg}$) between the suction and discharge legs. Also, the torque was generally less sensitive than head to changes in void fraction.

It should also be noted that steady-state two-phase tests with the main flow shut off were not attempted. Without significant flow the void fraction measured in the pipes could not be controlled or related to the conditions in the impeller with any certainty. Also, the shaft work continuously being dissipated in the fluid would tend to cause continuing vaporization, producing increasing void fractions limited only by heat removal by wall conduction and seal cooling flow.

Homologous performance curves for a nominal void fractions of 0.20 are shown in Figures 5-36 and 5-37. These indicate relatively mild degradation below the water curves except at high ν/α_N's and not much change in the shapes of the curves. Some tests were included in the dissipation (D) quadrant (reverse flow and forward speed) for high ν/α_N's approaching and including locked rotor. These were run to provide information for LOCA analysis of NSSS suction leg break blowdowns. For these breaks, some vaporization may occur at the pump just before the reverse flow brings the impeller to a stop and then holds it locked

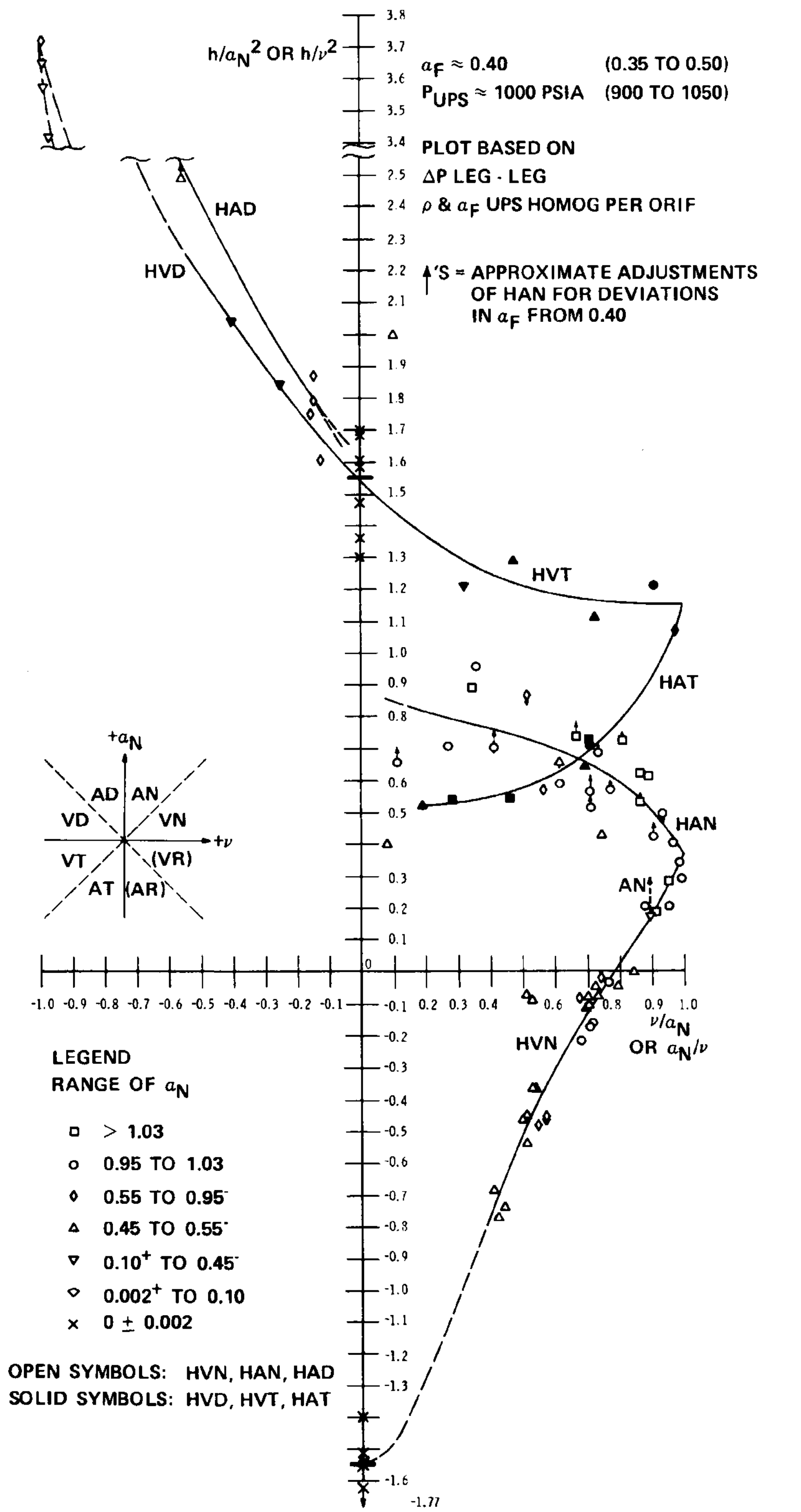


Figure 5-32. Homologous head curve for two-phase, $\alpha_F \approx 0.40$

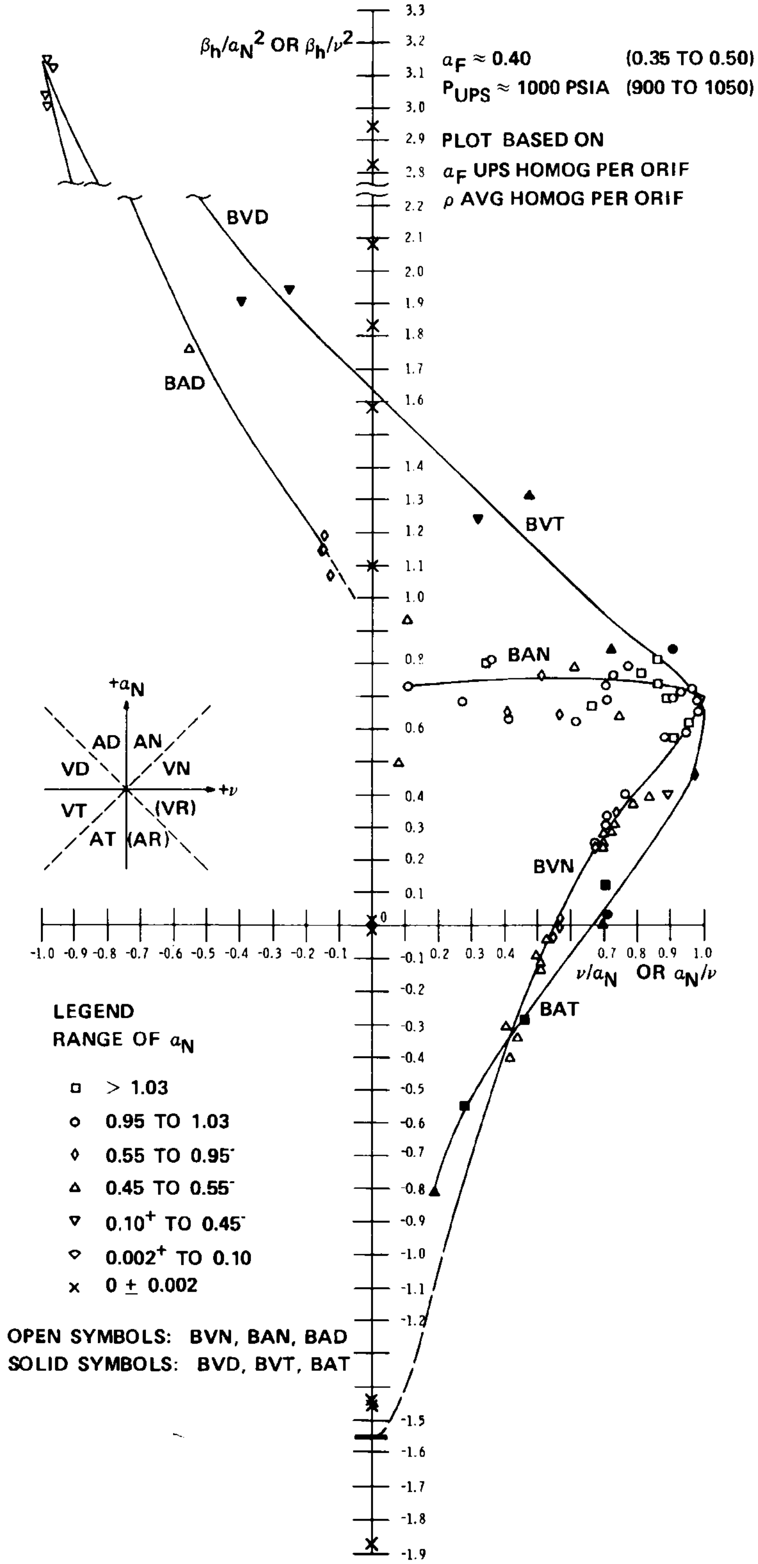


Figure 5-33. Homologous torque curve for two-phase, $\alpha_F \simeq 0.40$

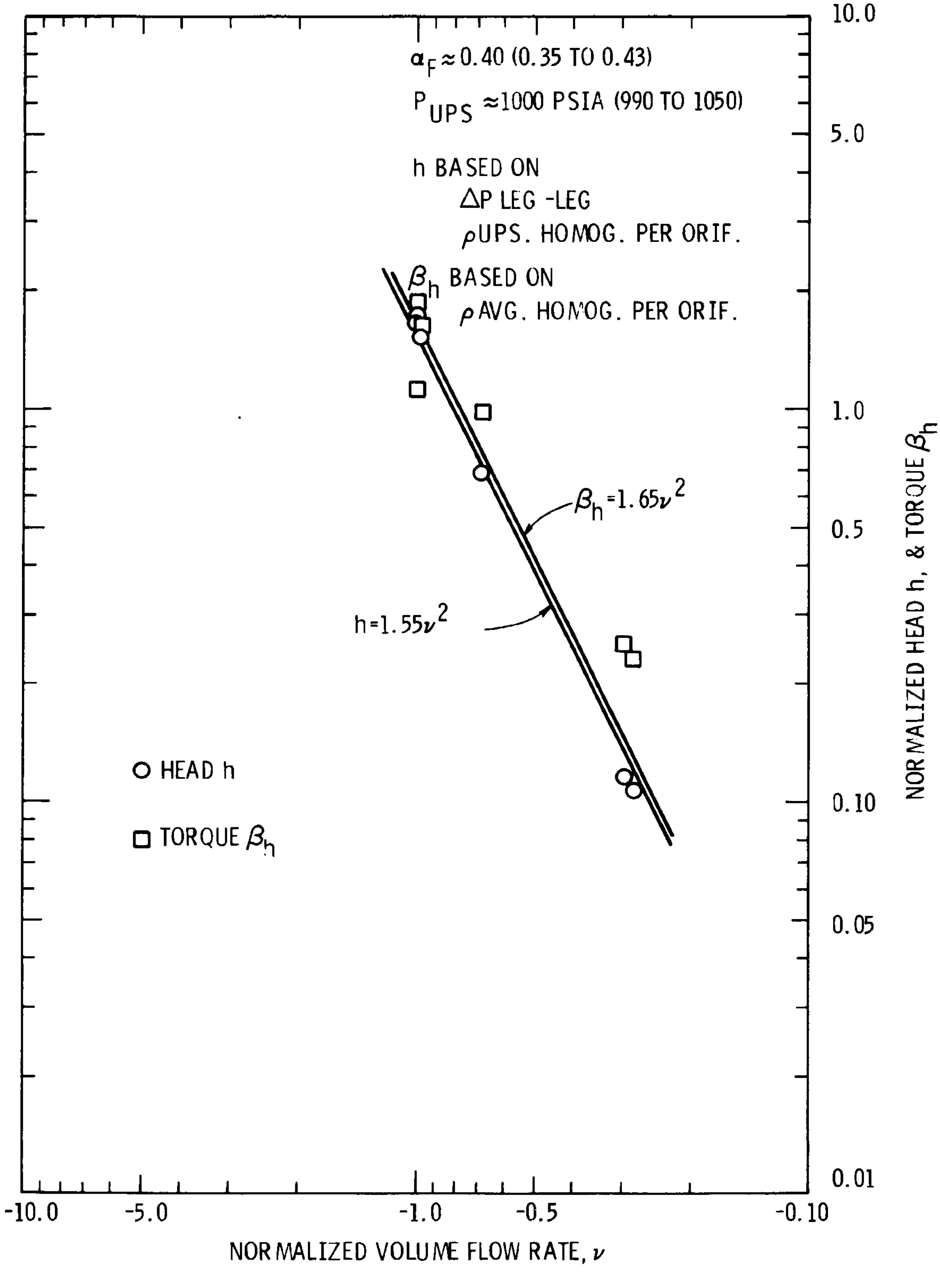


Figure 5-34. Locked rotor head and torque vs flow curves for two-phase forward flow, $\alpha_F \approx 0.40$

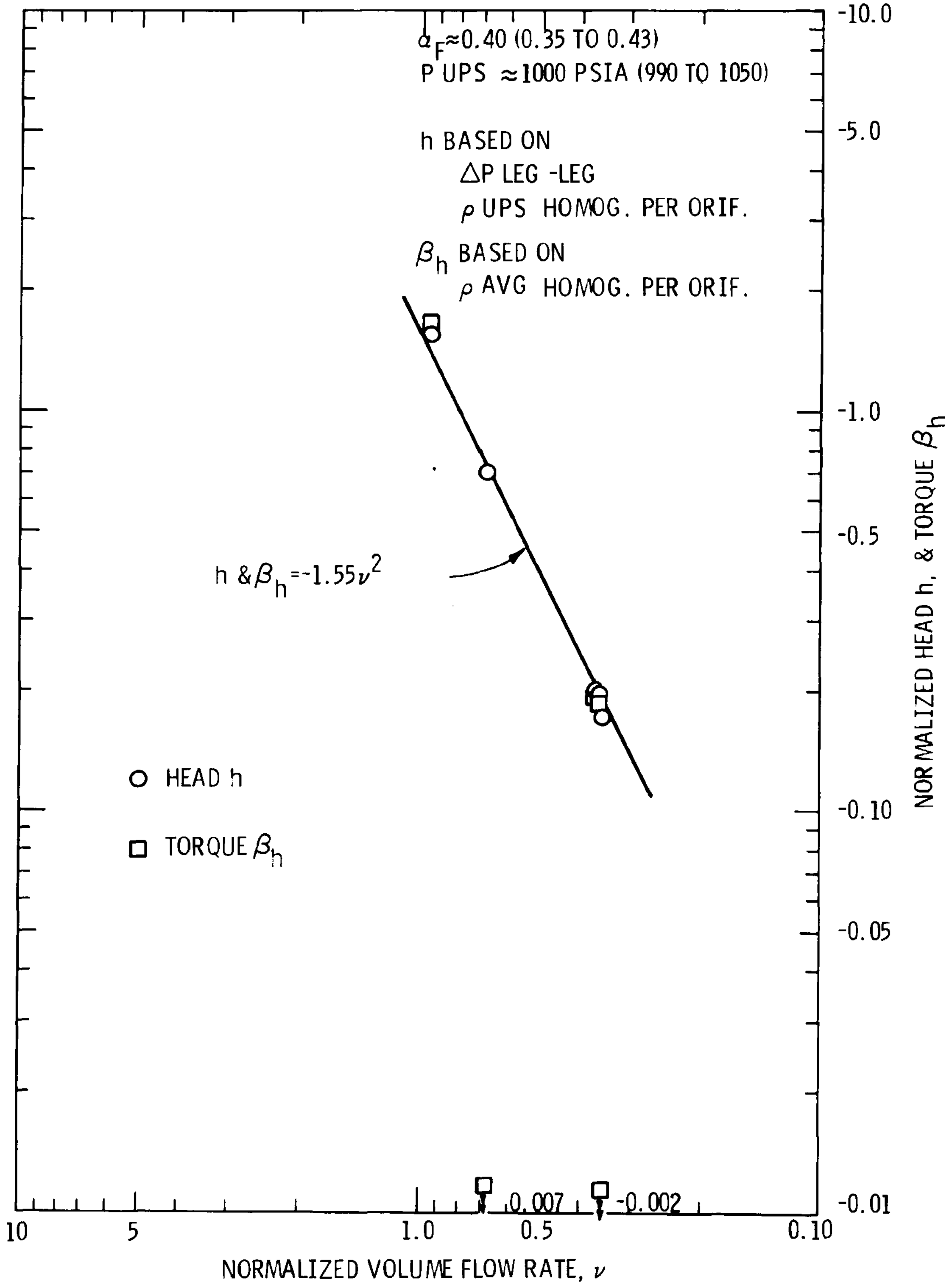


Figure 5-35. Locked rotor head and torque vs flow curves for two-phase reverse flow, $\alpha_F \approx 0.40$

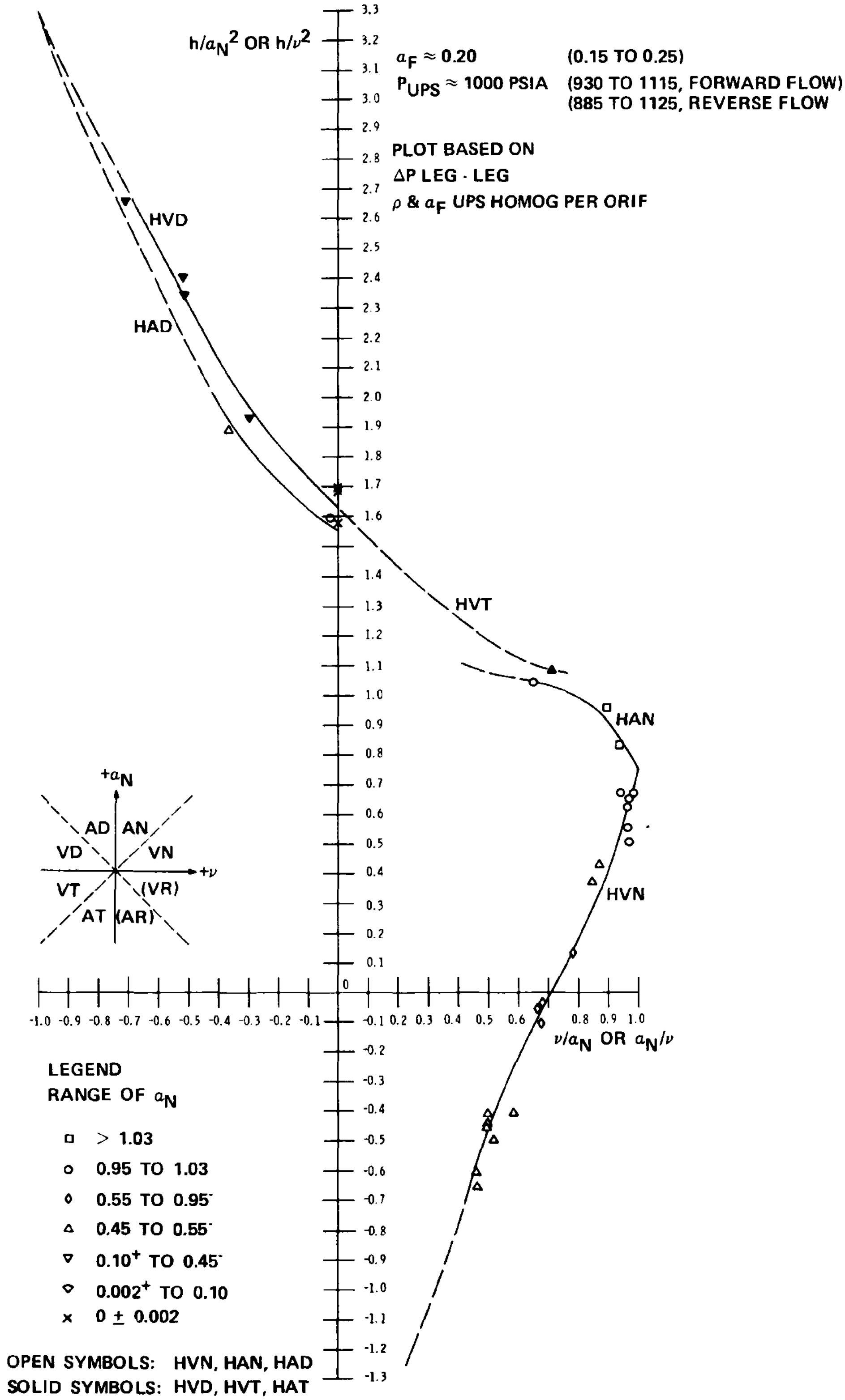


Figure 5-36. Homologous head curve for two-phase, $\alpha_F \approx 0.20$

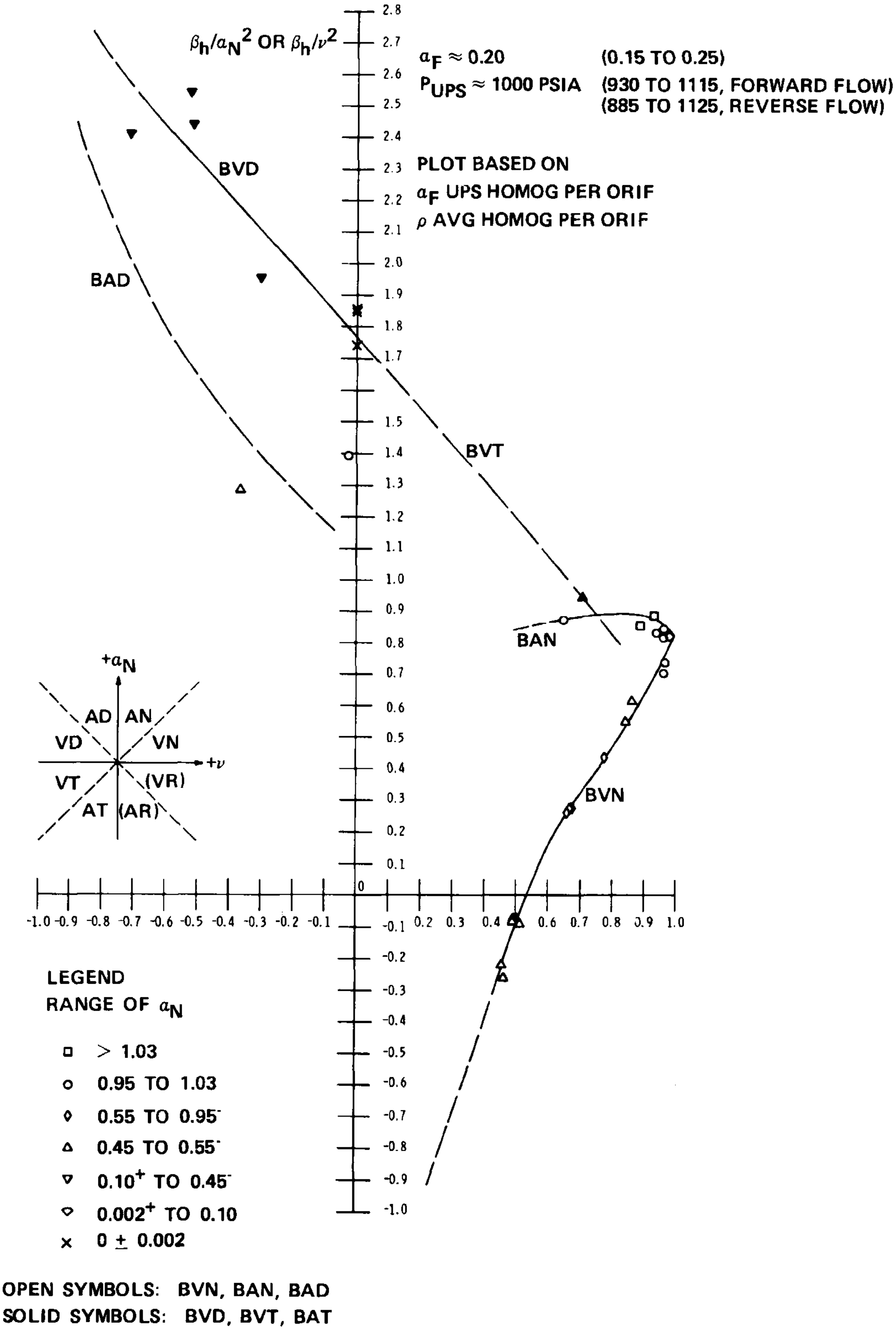


Figure 5-37. Homologous torque curve for two-phase, $\alpha_F \approx 0.20$

against the anti-reverse-rotation device. Step changes at flow reversal appear to be comparable or smaller than for 0.40 void fraction.

For a nominal void fraction 0.80 the homologous performance curves are presented in Figures 5-38 and 5-39. Heads were even more degraded than for 0.40 void fraction at ν/α_N's up to about 1.4, but the head recovered to single phase values by $\nu/\alpha_N = 3$. Torques similarly were lower than for 0.40 void fraction out to $\nu/\alpha_N = 1.0$ and then recovered to slightly lower than water values for ν/α_N above 1.6. Step changes at flow reversal appeared to be larger than for 0.40 void fraction.

For convenient overall comparison of two-phase and single-phase performance for forward flows, Figures 5-40 and 5-41 show composite sets of the above head and torque curves.

The discussion above about step changes in plotted performance at the vertical zero flow axis pointed out that one factor influencing the size of such a step is sensitivity to changes in void fraction. Figure 5-40 shows that for ν/α_N's approaching zero (i.e. zero flow), the head varies considerably with void fraction. On the other hand, in Figure 5-41, the torque curves appear to come closer together at low ν/α_N's and indicate less sensitivity to void fraction. The possibility of reducing or eliminating such steps in performance curves by using alternate versions of data presentation is commented upon further in Section 5.4.2 below.

5.3 DATA QUALIFICATION AND CONSISTENCY ANALYSIS

5.3.1 Comparison with Test Plan

In order to check that the steady-state tests carried out the intent of the test plan, the pump operating conditions that were actually achieved were compared against those specified in the test plan requests. The requests included set point tolerances indicating how closely the actual operating conditions should match the requested conditions to readily fulfuill the purposes of the tests. These set point tolerances varied somewhat, depending on the purposes of the tests and the ranges of the variable. Table 5-2 shows the set point tolerances used to guide most of the testing. In general, the tightness of the tolerances reflect:

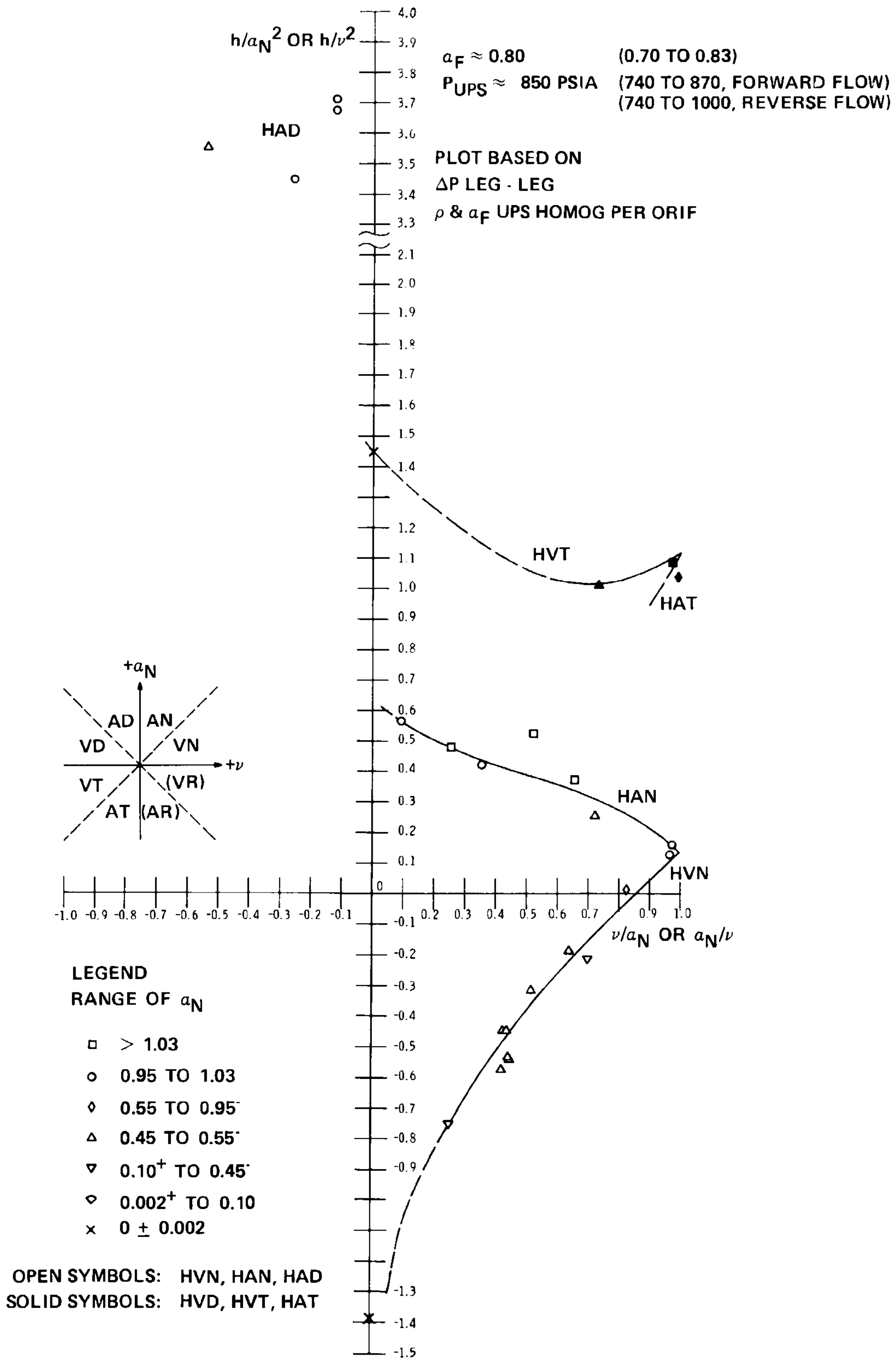


Figure 5-38. Homologous head curve for two-phase, $\alpha_F \approx 0.80$

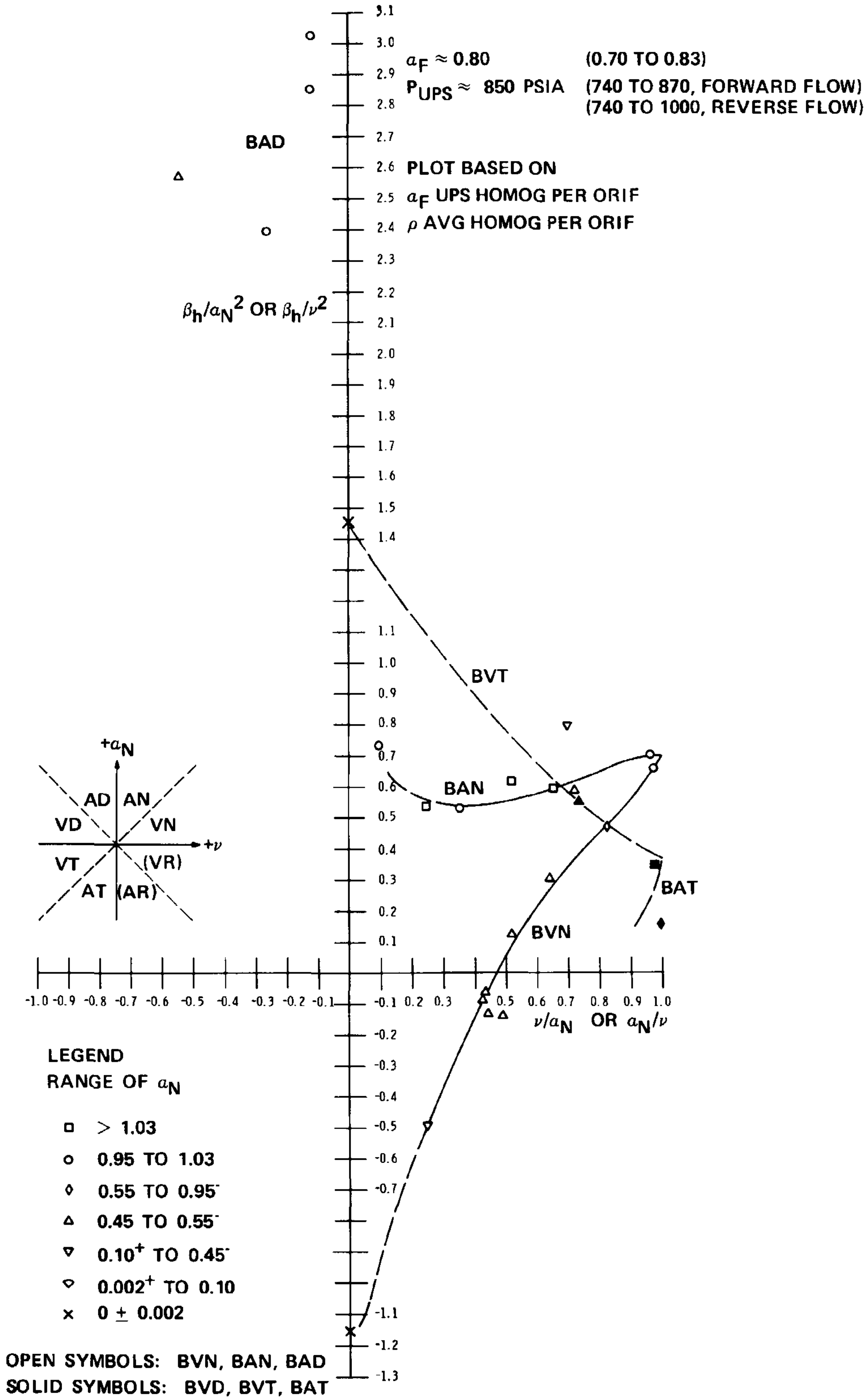


Figure 5-39. Homologous torque curve for two-phase, $\alpha_F \approx 0.80$

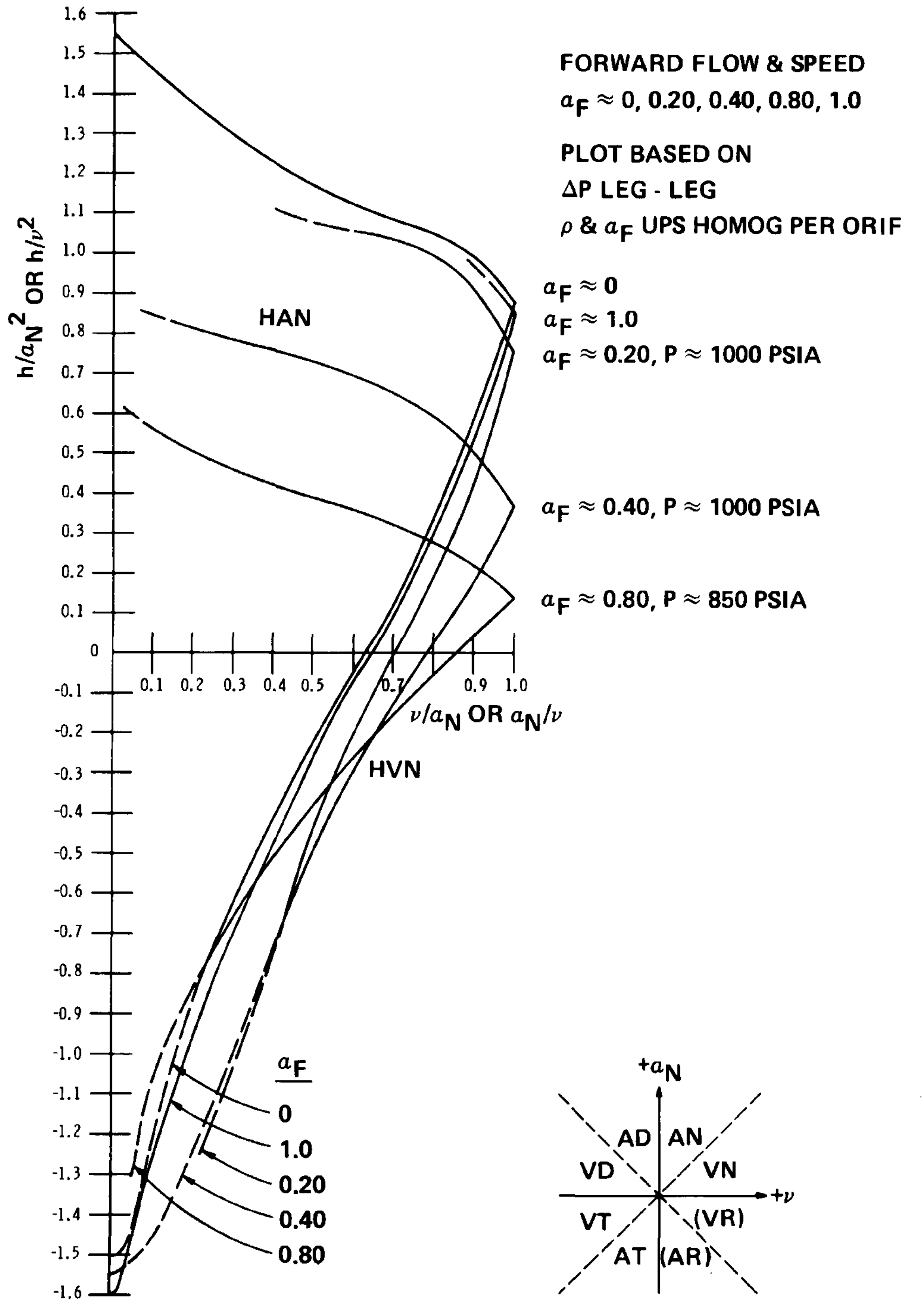


Figure 5-40. Homologous head curves for single and two-phase forward flow, $\alpha_F \approx 0$, 0.20, 0.40, 0.80 and 1.0

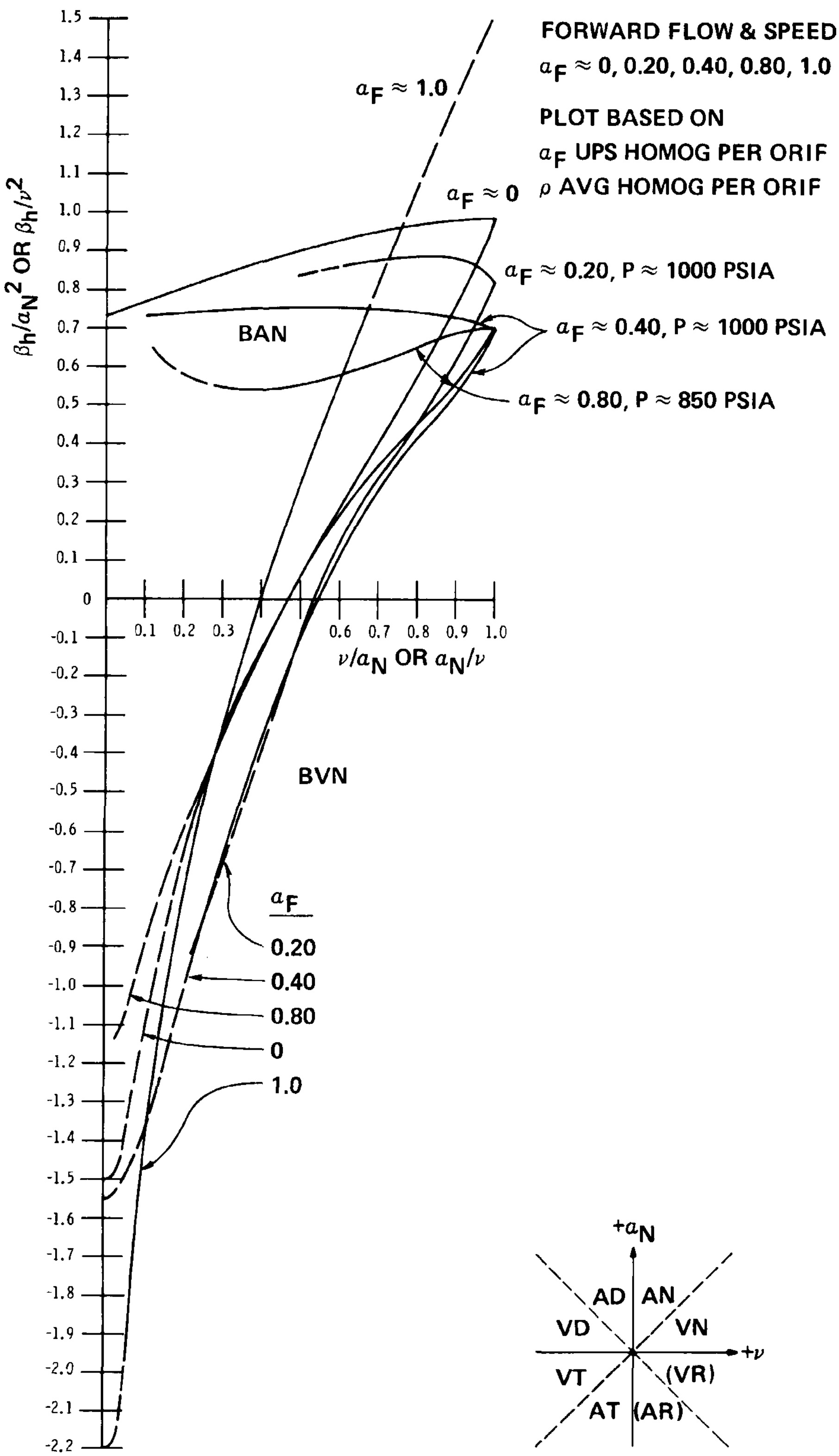


Figure 5-41. Homologous torque curves for single and two-phase forward flow, $\alpha_F \simeq$ 0, 0.20, 0.40, 0.80 and 1.0

1. the anticipated sensitivity of the pump performance to the particular parameter, and

2. the practical limits of operating control.

   Also for each type of testing,

3. tighter tolerances were placed on those parameters which were to be held constant and,

4. looser tolerances were allowed on those parameters that were varied to space the performance points along a curve.

For each test point the set point deviations were checked using preliminary data reduction methods immediately after recording the data in the laboratory. If the test conditions were not within the set point tolerances, adjustments were made in an effort to improve the test settings. Practical limitations on time, ease of control, flow stability, and test facility capacities resulted in some final deviations beyond the set point tolerances. Post-test reviews accounting for the actual shapes of the performance curves have refined the indications of whether a test can be considered appropriate for its original purpose. Even if beyond acceptance for the originally specified point, a test may constitute an acceptable alternate choice or contribute useful data for other purposes. The resulting matchups between tests and purposes are indicated in the groupings of tests by purpose in Table 3-1, Steady-State Test Matrix.

Thus the acceptance or utility of a test point for its original or an alternate purpose is a matter of degree depending on how sensitive the measured performance turned out to be to deviations from nominal operating conditions and how much scatter can be tolerated. These aspects are discussed in the next section on data scatter.

Another part of qualifying the accumulated data for adequacy was reviewing the resulting degradation and performance curves in preliminary form during the test program to see whether the actual shapes of the curves and locations of the measured points resulted in gaps or confusing relationships of the points. If this occurred in essential areas of interest, more tests were specified and run to provide better resolution of the performance.

5.3.2 Performance Data Scatter and Anomalies

Scatter pertains to data that is consistent with the overall trends but ranges within some band of fluctuations about the mean of the data. Anomalous points

Table 5-2

SETPOINT TOLERANCES FOR STEADY-STATE TESTS

Parameter	Nominal Set-Point Values	± Setpoint Tolerances For Various Types of Tests[a]		
		Sampling of α_F and P Degradation Effects	Performance Mapping of Head and Torque vs ν/α_N	Steady-State Comparison With Transients
Upstream Void Fraction (α_F)	.05-.25 .40 .65 .80 .90 .95	.01 .04 .05 .035 .017 .007	.02 .04 .05 .035 .017 .007	.01 .04 .05 .035 .017 .007
Upstream Volumetric Flow Rate (Q)		5% of value	15% of value	5% of value
Homologous Flow/Speed Ratio (ν/α_N)		1-2% of value by setting N as below after measuring Q	As results from Q and N	1-2% of value by setting N as below after measuring Q
Upstream Pressure (P)	1265 psia 850-1200 Psia 480 Psia	+0, -25, Psi 15 Psi 20 Psi	+0, -25 Psi 15 Psi 20 Psi	+0, -25 Psi 15 Psi 20 Psi
Speed (N)	>2500 RPM <2500 RPM	50 RPM[b] 2% of value[b]	50 RPM 2% of value	50 RPM[b] 2% of value[b]

[a] Setpoint tolerances are desired limits on deviations of sensor readings from requested points (i.e. sensor readings ignoring measurement uncertainties).

[b] Speed value in these cases is calculated from actual volumetric flow rate and required ν/α_N.

are those which are clearly inconsistent with the trends of the majority of data and/or conflict with designated modes of operation or physical reality.

5.3.2.1 Scatter. The primary means of observing performance data scatter is to see how widely the majority of the plotted points vary from smooth performance curves in the graphical presentations of Section 5.2 above.

Sources of data scatter can occur in the measurement processes and in the physical conditions being measured. Measurement scatter includes the effects of usual variability and uncertainties in sensor responses, calibrations, and outside influences (vibration, etc.). Scatter in physical conditions are real variations commonly occurring to some degree but not directly accounted for in the performance correlation as calculated from the measurements and plotted. Examples of such physical conditions are:

1. Two-phase flow bubbles and/or churning which cause time-varying signals from densitometers, turbine meters, etc., being recorded randomly in the five data scans made during each steady-state test.

2. Periodic gross flow variations such as slugging or oscillations which could be the consequence of two-phase flow regimes locally in the test section or could result from more overall pump/loop interaction peculiar to the test system configuration.

3. Side effects from variations in seal cooling water injection and net leakage -- normally out but sometimes into the main stream (See Special Topics, Section 5.4 below).

4. Set point deviations from nominal operating conditions (constant speed, void fraction, etc.), allowed in selecting points for the plot and not adjusted for in deriving the plotted values.

5. Performance deviations from similarity laws and other physical relationships assumed in the presentation models (See Special Topics below).

The extent of performance data scatter is observable directly from the performance plots in Section 5.2. Associated deviations from nominal operating conditions for individual plotted points can be derived from the conditions listed in Table 3-1, Steady-State Test Matrix, or the Summary Table (4-6). The sensitivity of performance results to such deviations in operating conditions can be deduced from performance cross-plots vs the deviating parameters (as illustrated below). Measurement uncertainties derived from instrument calibration data are listed in Volume VIII, Data Processing Methods, and in the 10-page data printouts on file at EPRI. Standard deviations indicating the variability of the five scan readings (relative to a straight line drift) are listed in the one page printouts in Volume V, Steady-State Data, and in the 10-page data printouts for the main derived parameters in each test. The general approach used in analyzing the scatter was to estimate point shifts that resulted from variations in physical conditions, as discussed next, and to consider measurement uncertainties as additional separate effects (See Special Topics below).

Inspection of the pump performance data plots in Section 5.2 shows that the overall coherence of the data as plotted is good and that for a high percentage of the points the scatter from the smooth curves drawn through the data is only a small fraction of rated performance values. This enhances confidence in the curves, especially in regions of main test emphasis.

Part of the scatter is the result of set point deviations not corrected for in data reduction and plotting. Since all test points deviated somewhat from nominal operating conditions, the points plotted for a given performance curve are those which fell within a selected range around the nominal conditions. These selection ranges are related to the set point tolerances but were tailored to be somewhat broader to include a maximum number of points useful for defining the curve while still avoiding too much scatter in performance values. Also it was desired for the initial data presentation to include some marginal points so as to further evaluate the sensitivity of performance to set point deviations and the choice of point selection ranges. The selection ranges used for the plots in Section 5.2 are indicated on the plots and are listed in Table 5-3 below.

The scatter due to a set point deviation can be corrected approximately by calculating and subtracting out the corresponding performance offset, based on a cross-plot of the performance vs the deviating parameter. This was done in Section 5.2.1 for Figure 5-1 which shows homologous head vs void fraction for ν/α_N nominally equal to 1. The correction needed to offset the shift in each head point for deviation in ν/α_N from 1 was calculated from:

$$\Delta\left[\frac{h}{\alpha_N^2}\right]_{\text{correction}} \cong \left[1-\left[\frac{\nu}{\alpha_N}\right]_{\text{test point}}\right]\left[\frac{\partial\left[\frac{h}{\alpha_N^2}\right]}{\partial\left[\frac{\nu}{\alpha_N}\right]}\right]_{\text{slope, at } \nu/\alpha_N = 1}$$

Table 5-3

SELECTION RANGES FOR PARAMETERS IN PLOTS OF PUMP TWO-PHASE TEST DATA

Plot Type	Figure No.	Y Coordinates	X Coordinates	Specified "Constant" Operating Conditions: Nominal	Specified "Constant" Operating Conditions: Selection Ranges Plotted
Two-Phase Performance	5-38	h/α_N^2 or h/ν^2	ν/α_N or α_N/ν	α_F = .20 P = 1000[a]	α_F = .15 to .25 P = 930 to 1115, forward flow P = 885 to 1125, reverse flow
	5-39	β_h/α_N^2 or β_h/ν^2			
Two-Phase Performance	5-34	h/α_N^2 or h/ν^2	ν/α_N or α_N/ν	α_F = .40 P = 1000	α_F = .35 to .50 P = 900 to 1050
	5-35	β_h/α_N^2 or β_h/ν^2			

[a]P's are in psia.

Table 5-3 (Continued)

SELECTION RANGES FOR PARAMETERS IN PLOTS OF PUMP TWO-PHASE TEST DATA

Plot Type	Figure No.	Y Coordinates	X Coordinates	Specified "Constant" Operating Conditions: Nominal	Specified "Constant" Operating Conditions: Selection Ranges Plotted
Two-Phase Performance	5-40	h/α_N^2 or h/ν^2	ν/α_N or α_N/ν	α_F = .80 P = 850[a]	α_F = .70 to .83 P = 740 to 870, forward flow P = 740 to 1000, reverse flow
	5-41	β_h/α_N^2 or β_h/ν^2			
Two-Phase Performance Locked Rotor Forward Flow	5-36	log h and log β_h	log ν^2	α_F = .40 P = 1000	α_F = .35 to .43 P = 990 to 1050
Reverse Flow	5-37				
Two-Phase Degradation Forward Flow	5-1	h/α_N^2	α_F	ν = 1.00 α_N = 1.00 ν/α_N = 1.00 (1)P = 1200 or 1000 or 850 or 480	ν = .90 to 1.10 α_N = .99 to 1.03 ν/α_N = .90 to 1.07 (2)P = 1050 to 1260 or 950 to 1050 or 800 to 900 or 430 to 530
	5-2	β_h/α_N^2			

[a]P's are in psia.

Table 5-3 (Continued)

SELECTION RANGES FOR PARAMETERS IN PLOTS OF PUMP TWO-PHASE TEST DATA

Plot Type	Figure No.	Y Coordinates	X Coordinates	Specified "Constant" Operating Conditions	
				Nominal	Selection Ranges Plotted
Two-Phase Degradation, Forward Flow	5-6	h/ν^2	α_F	$\nu/\alpha_N = 1.42$ P's as at (1) above	$\nu/\alpha_N = 1.32$ to 1.52 P's as at (2) above
	5-7	β_h/ν^2			
Two-Phase Degradation Forward Flow	5-8	h/ν^2	α_F	$\nu = 1.00$ $\alpha_N = .50$ $\nu/\alpha_N = 2.00$ P's as at (1) above	$\nu/\alpha_N = .88$ to 1.10 $\alpha_N = .44+$ to $.55$ $\nu/\alpha_N = 1.75$ to 2.30 P's as at (2) above
	5-9	β_h/ν^2			
Two-Phase Degradation, Forward Flow	5-10	h/ν^2	α_F	$\nu/\alpha_N = 4.00$ P's as at (1) above	$\nu/\alpha_N = 3.50$ to 4.70 P's at (2) above
	5-11	β_h/ν^2			
Two-Phase Degradation, Reverse Flow	5-12	h/α_N^2	α_F	$\nu = .70$ $\alpha_N = -.70$ $\nu/\alpha_N = 1.00$ P = 1200[a] or 1000 or 850 or 480	$\nu = -.68$ to $-.70$ $\alpha_N = -.69$ to $-.70$ $\nu/\alpha_N = .975$ to 1.00 P = 1050 to 1260 or 950 to 1050 or 800 to 900 or 430 to 530
	5-13	β_h/α_N^2			

[a]P's are in psia.

Table 5-3 (Continued)

SELECTION RANGES FOR PARAMETERS IN PLOTS OF PUMP TWO-PHASE TEST DATA

Plot Type	Figure No.	Y Coordinates	X Coordinates	Specified "Constant" Operating Conditions: Nominal	Specified "Constant" Operating Conditions: Selection Ranges Plotted
Two-Phase Degradation, Reverse Flow	5-14	h/ν^2	α_F	ν = -.70 α_N = -.50 ν/α_N = 1.40 P's as at (1) above	ν = -.675 to -.715 α_N = -.495 to -.50 ν/α_N = 1.37 to 1.43 P's as at (2) above
	5-15	β_h/ν^2			
Two-Phase Degradation, Reverse Flow	5-16	h/α_N^2	α_F	ν = -.28 α_N = .5 ν/α_N = -.56 P's as at (1) above	ν = -.25 to -.30 α_N = .495 to .50 ν/α_N = -.50 to -.60 P's as at (2) above.
	5-17	β_h/α_N^2			

[a]P's are in psia.

The slope for a given void fraction was taken from Figure 5-3 which was derived from the slopes at $\nu/\alpha_N = 1$ of the head performance curves for various void fractions (Figures 5-23, 5-25, 5-29, 5-32, 5-36, and 5-38). The calculated corrections are shown in Figure 5-1 by the arrows, with the tips of the arrows indicating the adjusted head values. The improved correlation with reduced scatter is apparent. Similar corrections are shown for at least part of the points in Figures 5-1, 5-6, 5-17, 5-32, 5-33 and 5-36 to 5-39. Corrections to curves of performance vs ν/α_N at nominally constant α_F and P, were derived from curves of performance degradation vs α_F at various P's and nominally constant ν/α_N, and vice versa. Thus a consistent corrected set of both kinds of curves involves some iterative interaction in the adjustments. In some cases (e.g. the HAN curve for $\alpha_F \cong 0.40$ in Figure 5-32) the effects of set point deviations happened to be predominantly in one direction, and the addition of correction arrows shifted the curve slightly. The calculated correction arrows exhibited in the plots discussed here are just key examples of this process for reducing scatter and improving correlations. These examples also serve to indicate for these cases the amount of scatter due to set point deviations.

Performance variations associated with changes in other operating conditions are discussed in Section 5.4, Special Topics.

5.3.2.2 Anomalies. A variety of consistency checks capable of detecting data and performance anomalies were made during the pump test program and data handling. Specific numerical checks were made on much of the data and included comparison of:

- pump head direct ΔP sensor readings vs calculated values of $P_{discharge} - P_{suction}$,
- two-phase pressures and temperatures vs steam table saturation values,
- algebraic signs of P's, friction torque, etc. vs flow and speed directions,
- general correspondence of specific volumes and void fractions derived from gamma densitometers vs orifice readings plus energy balance calculations, and
- thermocouple vs resistance temperature device readings.

Another key method was to look for uncommonly large deviations from the usual or expected operating conditions or performance results. This was sometimes done numerically, but also tended to stand out readily on the performance plots.

Observed inconsistencies included such items as a series of head or torque readings that did not change when the operating conditions were varied, overshoot of steam and near-steam torques to values considerably above the corresponding homologous water torques, and isolated points or series falling far from the curves which give good correlation for the rest of the data. It should be noted that for completeness and expediting such consistency comparisons, even extreme deviation points are shown (or indicated in the margin) in the plots.

Observation of anomalous deviations led to examining the test points in question to see which individual parameters did not fit into the usual pattern, and trying to diagnose the causes. Such examinations detected a variety of errors, not uncommon to such a complex test program, which were remedied in the course of methods review and data processing. These remedies have included correction of instrumentation hookups, range selections, data reduction formulas (signs, logic, etc.), hand plotting, etc. These activities in effect constituted part of the quality review and development of the data procurement and processing methods and results.

Most of the corrections for data processing have been incorporated into the methods, and the results have been revised accordingly. Some changes, such as substitution of $P_{disch} - P_{suction}$ for erroneous leg-to-leg ΔP's were not made in the basic raw data or resulting reduced data but were made and noted in Table 4-6, Summary Table.

Anomalies which remain in the data comprise those which have been diagnosed but are not readily correctable and those for which diagnosis is incomplete. An example of a non-correctable anomaly is some locked rotor torques which showed large hysteresis -- apparently due to sticking or binding in the non-rotating bearings or seals. An example of incomplete diagnosis is a series of consecutive torque readings which varied systematically in a typical pattern but far above the performance curve, and for which no explanation (such as wrong-range calibration constants) has been definitely identified. Observed remaining anomalies in the performance plots are listed with comments in Table 5-4 below. Observations on some special effects, including some which caused scatter and/or anomalies, are given in Section 5.4, Special Topics.

Table 5-4

COMMENTS ON DATA ANOMALIES IN PLOTTED POINTS

Figure No.	Test No.	Curve Segment	Approx. x, y Coord.	Comments
5-23 & 5-24	251 676 701 846	HAN BAN	.7, .7 .7, .75 Symbols with upper appendage.	These were pre-blowdown points with booster pumps locked and only the test pump running. Suction subcooling was not maintained and flashing occurred.
	257-260 322 369 587, 588 616, 617 639 661 688	HAN BVN	Below curves Point symbols with lower appendage.	At or below low side of scatter band. Low pressure effects -- apparently cavitation inside pump. Some tests were clearly below required net positive suction head (NPSH) per manufacturer. All were at suction pressure less than 150 psia.
	365	HAN BAN	.1, 1.1 .1, .7	Cavitation. Suction pressure was only approximately atmospheric.
	628	HAN BAN	0, .85 0, 1.1	Speed was not really zero and not properly recorded. Set point was 4500 rpm and speed recording was not operational.

Table 5-4

COMMENTS ON DATA ANOMALIES IN PLOTTED POINTS (Cont'd.)

Figure No.	Test No.	Curve Segment	Approx. x, y Coord.	Comments
5-23 & 5-24 Cont'd	669	HVN	.86, 0	Recorded $\Delta P_{leg-leg}$ not proper; not consistent with P_{DIS} - P_{SIS} or $\Delta P_{flange-flange}$. Using $P_{DIS} - P_{SIS}$ + 5psi for concurrent offset in P_{SIS}, would bring point to .86, .46 -- which is on curve.
	625	BAN	.6, 1.05	Torque somewhat high but no apparent reason observed.
	370,371 602-606 642 832	HVN BVN	Stray locked-rotor X's	For explanation see notes for Figure 5-27.
5-25 & 5-26	1156 1179 1211 1319 1351 1380	HAN BAN	Below curves. Symbols with upper appendage.	These were pre-blowdown points with booster pumps locked and only the test pump running. Suction subcooling was not maintained and flashing occurred.
	856, 857 864-869 937-939 943 949-953 1003	HAN BAN	Below curves. Symbols with lower appendage.	At or below low side of scatter band. Low pressure effects, apparently cavitation inside pump. Some tests were below required NPSH per manufacturer. All were at suction pressure less than 150 psia.

(Cont'd)

Table 5-4

COMMENTS ON DATA ANOMALIES IN PLOTTED POINTS (Cont'd.)

Figure No.	Test No.	Curve Segment	Approx. x, y Coord.	Comments
5-25 & 5-26 Cont'd.				Torques for points 856, 857, and 864-869 would fall somewhat lower yet if not affected by a positive offset in calibration (see re points 862 et al below).
	862 863 870 871	BAN BVN	.93, 1.04 .4, .96 .43, .03 .4, .5	These and others in test series 856-871 show higher torques than expected from the normal pattern -- apparently an improper offset of constant magnitude about 8 or 9 ft lbf, which is a large percentage for low torque points like 871. (See also comments on steam points for Figure 5-30.)
	965	HVN BVN	.5, -1 .5, -.6	Head and torque were very low. Suction pressure was 480 psia but conditions were at saturation, and large pressure drop resulted in cavitation plus flashing to 0.50 void fraction with two-phase degradation.
	858	HVN BVN	.7, -.2 .7, -.26	Low performance was similar to cavitation points but no specific reason was observed. Suction conditions (Cont'd.)

Table 5-4

COMMENTS ON DATA ANOMALIES IN PLOTTED POINTS (Cont'd.)

Figure No.	Test No.	Curve Segment	Approx. x, y Coord.	Comments
5-25 & 5-26 Cont'd.	858			were 236 psia and subcooled.
	1026	BVN	.79, .42	Low torque appears to be a consequence of drift in flow, and variable torque readings among 5 scans.
	1140	BAN	.03, .9	Torque high. Low flow and speed not favorable for scaling but no definite reason diagnosed.
	1364 1366	HVN	.6, 2.4	Head excessively high. $\Delta P_{leg-leg}$ measurements were not consistent with P_{DIS} - P_{SIS} which, if substituted, would bring points in line with others -- including cavitation effects for test 1364 which was run at 119 psia suction pressure.
	512-516	HVT BVT	0+, -.1& .8 .3 to .6, .9 0+, .23 &.5 .3 to .6, 1.2 to 1.8	These were very low reverse flow free-wheeling tests producing low speeds, ΔP's and torques with fair-poor accuracies for plotting.
	446-450	HVT	0, -.2 0, .8 to 1.2	These were very low reverse flow locked rotor tests (Cont'd)

Table 5-4

COMMENTS ON DATA ANOMALIES IN PLOTTED POINTS (Cont'd.)

Figure No.	Test No.	Curve Segment	Approx. x, y Coord.	Comments
5-25 & 5-26 Cont'd.	446-450	HVT	0, 5 to 50	producing low P's with poor accuracies for test 449 and and 450 heads. Torque involved apparent sticking. See comments on Figure 5-28.
	602-606	BVN	0, -3 to -20	Sticking bearings or seals. - See comments on Figure 5-27.
5-27	370 602-606	β_h vs ν	β_h's = -.06 to -.07	Torques for $\nu < 0.3$ do not follow flows as expected. These points and others for Figure 5-28 (See below) indicate consistent, torque hysteresis, with torque readings either too high or too low, depending on previous locked rotor torque levels. This suggests binding or sticking in bearings and/or seals for nonrotating conditions with the rotor locked at the outboard end of the motor shaft.
	370 602-606	h vs ν	ν's. 05 to .15 except .078	These heads rise increasingly in percentage above the straight line fit as flow drops. However, the absolute offset in h is approximately constant at -0.002, which corresponds to only -0.2 (Cont'd.)

Table 5-4

COMMENTS ON DATA ANOMALIES IN PLOTTED POINTS (Cont'd.)

Figure No.	Test No.	Curve Segment	Approx. x, y Coord.	Comments
5-27 Cont'd.	370 602-606			$^{+.06}_{-.08}$ psi offset in $\Delta P_{leg-leg}$ sensor calibration. The same offset is indicated in Figure 5-28 (See below).
	832 642 1202	h vs ν β_h vs ν	ν = .28 .078 .013	Irregularities not definitely diagnosed. Torques probably affected by hysteresis, but less predictably here since these points were not preceded by other locked rotor readings.
	628	h vs ν β_h vs ν	ν = 1.1	Not plotted in this figure because not a locked rotor test. Zero speed was recorded because the speed meter was nonoperational.
5-28	399 446-450 475 516 1447 1454 1459 515 398	β_h vs ν	All torques for ν < .3, except perhaps -.07, .01 & -.052, -.005	All these torque readings show hysteresis as described above for Figure 5-27. Points 515 and 398 listed as possible exceptions are probably affected by hysteresis too upon flow startup after installation of the rotor lock.
	446-449 510	h vs ν	ν's = .-14 to -.065	These heads which fall increasingly below the curve at lower (Cont'd.)

Table 5-4

COMMENTS ON DATA ANOMALIES IN PLOTTED POINTS (Cont'd.)

Figure No.	Test No.	Curve Segment	Approx. x, y Coord.	Comments
5-28 Cont'd	446-449 510			flows correspond to a small, approximately constant, offset of -0.2 psi in $\Delta P_{leg-leg}$ measurement, as for Figure 5-27 above.
	398 450	h vs ν	ν's = -.05 to -.02	In some cases, unsteadiness (fluctuations) were encountered.
	515 1447 1454 1459			All ΔP's for these points were so low that measurement uncertainties were large compared to the readings.
5-29 & 5-30	873-879	BVN	.2 to 5, > .3 Points with question marks.	Values way above curve. Probably calibration was off. Apparently there was a constant improper offset of 8 or 9 ft lbf in all readings. This also affected water tests in series 856-879 using the same calibration file. (See comments for Figure 5-25 & 26 above).
	879	HVN	.2, -1.5	Head considerably low. No definite reason diagnosed. $\Delta P_{leg-leg}$ was small (-.17 psi) and uncertainties from measurements and scatter in scans were comparable to discrepancy.
	591	HVN	.2, -1.7	Head low. Cause not diagnosed.

Table 5-4

COMMENTS ON DATA ANOMALIES IN PLOTTED POINTS (Cont'd.)

Figure No.	Test No.	Curve Segment	Approx. x, y Coord.	Comments
5-29 & 5-30 Cont'd	1095	BVN	.4, -2.5	Torque very far below curve. Reading was small and unsteady so uncertainties were comparable to reading.
	1079 1086, 1087	BVN		Torque far below curve. These were freewheeling tests with small torques (3 to 4 ft lbf) and relatively large uncertainties (near 1 ft lbf).
	268 358	BVN BAN	.98, 2.05 .96, 1.56	Inconsistent. Torque for 268 was high compared to homologous water curve. See Special Topics for discussion (Section 5.4.4).
	598 1077	β_h vs ν	X's on y axis	Locked rotor points. See comments re Figure 5-31 below.
5-31	595-598	β_h vs ν	ν's = 7.5, 6.5, 3.5, & 5	For each of these tests some of the 5 data scans showed seal injection water to be boiling and the discharge flow registered as zero even through steam may have been flowing through the magnetic flowmeter. In the data reduction calculation this resulted in presuming leakage into the main stream and quenching of (Cont'd.)

Table 5-4

COMMENTS ON DATA ANOMALIES IN PLOTTED POINTS (Cont'd.)

Figure No.	Test No.	Curve Segment	Approx. x, y Coord.	Comments
5-31 Cont'd.	595-598			the void. The resulting calculated pump discharge density, higher than actual, led to normalized torques lower than actual -- especially for Test 598, for which 4 out of 5 scans were affected. Torque for Test 597 was on the curve even though 2 scans were affected; probably hysteresis due to mechanical binding kept the reading from going lower (See comments for Figure 5-27 above).
	1076	β_h vs ν	$\nu = 1$	Torque above curve. No specific reason noted.
5-32 & 5-33	287	HAN BAN	.1, 2 .1, .94	Very high, especially head. This was a low flow test with seal in-leakage quenching voids. (See Special Topics, Section 5.4.1.)
	959	HAN BAN	.9, .17 .9, .4	Far below curves. Low speed and flow operation yielded low $\Delta P_{leg-leg}$ (0.5 psi). Also torque was unsteady (9 to 13.6 ft lbf). Uncertainties were higher than usual but no specific diagnosis made.

Table 5-4

COMMENTS ON DATA ANOMALIES IN PLOTTED POINTS (Cont'd.)

Figure No.	Test No.	Curve Segment	Approx. x, y Coord.	Comments
5-32 & 5-33 Cont'd	1420	HAN BAN	.08, .4 0.8, .5	Far below curves. Low flow. Possibly influenced by phase separation. No specific diagnosis.
	290,291	BVN	0,0	Locked rotor points. See comments re Figure 5-34 below.
5-34	290,291	BVN	0,0	These torque readings were not responsive to flow. Probably affected by hysteresis from bearing or seal binding. (See comments re Figure 5-27 above).
5-35	441, 442 444, 445	β_h vs ν	ν's = -1, .7, .3, .28	Deviations of torques from curve are noticeably greater than for heads and are consistent with presence of hysteresis due to binding (See comments re Figure 5-27 above).
5-36 & 5-37	719, 720	HAN BAN	.85, .4 .85, .6	Far below curves but no specific reason noted.
5-38 & 5-39	1422	HAN BAN	.2, 2.3 .2, 1.2	Far above curves. Seal in-leakage quenched fluid from 0.75 void fraction to 0.
	274	BVN	.7, .8	Far above curve. No specific reason noted.

5.4 SPECIAL TOPICS

5.4.1 Special Effects on Performance Variations

5.4.1.1 Pressure Level. Some of the degradation curves in Section 5.2.1 show homologous head and torque vs void fraction at constant ν/α_N for more than one pressure level. In particular for forward flow and speed with $\nu/\alpha_N \cong 1$ and 2, separate series of tests were run for pressures near 1200, 1000, 850 and 480 psia. The results are shown in Figures 5-1, 5-2, 5-8 and 5-9, with separate curves drawn through the data for the different pressure levels. Compared to the main data curves at 1000 psia, the higher pressures tended to suppress the two-phase effects somewhat, while lower pressures generally magnified the two-phase effects.

The greater two-phase effects at lower pressures were expected because at lower pressures there is more difference between steam and water densities. This not only promotes the two-phase mechanisms which arise from differences in density between the vapor bubbles and the liquid, but also results in greater changes in void fraction and mixture density for a given pressure change. For example, calculations using steam table properties (Reference 5) show that throttling losses associated with a moderate k factor and a given upstream velocity result in an increase in specific volume of the mixture which is about three times as large at 480 psia as at 1000 psia.

Also, there are factors which tend to make the low pressure effects greater at low void fractions. One factor is the higher mixture density at low void fractions, which means correspondingly greater ΔP for a given k factor and upstream velocity, since $\Delta P = k\rho V^2/2|g_s|$. Another factor is that a given amount of vaporization results in a relatively large percentage increase in void fraction if the void fraction is initially low. Such magnified low pressure effects at low void fractions are indeed in evidence in Figures 5-1 and 5-2 and even more so in Figures 5-8 and 5-9. However, pressures as low as 480 psia (or even 850 psia) at low void fractions are not involved in LOCA analysis (See Figure 3-1). The 480 psia tests at mid-range void fractions were run to identify and explore pressure effects by exaggeration, and were extended to low void fractions to produce complete curves to correlate with the current 1/20-scale model pump tests which are limited to 500 psia or less (Reference 6).

Inspection of the remaining regions of Figures 5-1, 5-2, 5-8 and 5-9 which are more pertinent to LOCA analysis, shows that at higher pressure levels, near 1000 psia, effects of a change of 100 psi were noticeable but not strong. In general, the spread in pressure across the LOCA band shown in Figure 3-1 appears to result in a spread in performance (h/α_N^2 or h/ν^2 and β/α_N^2 or β/ν^2) of the order of plus or minus 0.1 about the mean performance at each void fraction. Figures 5-1 and 5-2 represent forward flow and speed pumping operation, and Figures 5-8 and 5-9 represent forward flow and speed turbining (where torque is negative) or pumping dissipation (where torque is positive). Thus they show pressure effects in modes of operation of prime interest.

5.4.1.2 Cavitation. Related to pressure effects in two-phase tests is cavitation in single-phase water testing. It is a well known phenomenon that there is a pressure drop as the fluid speeds up coming into the impeller and that if the pressure falls below the vapor pressure there will be cavitation with an accompanying sharp drop in performance (References 2 and 4). The performance points which fall significantly below the HVN and BVN curves in Figures 5-23 to 5-26 are nearly all at low pressures -- generally well below 200 psia. Some of the points are within the range of conditions shown by the manufacturer's cold water tests (Reference 2) to fall below the net positive suction head (NPSH) necessary to avoid cavitation. Low pressure tests at other conditions not covered by the manufacturer's cavitation tests show similar degradation in amounts generally correlating with how low the pressure was. For operation with greater pressure rise and lower flow rates, less NPSH is required to avoid cavitation effects, and cold water points toward the left end of the HAN and BAN curves showed no significant cavitation effects even as low as 20 psia. However cold water Test 365 at $\nu/\alpha_N = 0.10$ with a pressure of only 14.3 psia did fall considerably below the curves in Figures 5-23 and 5-24.

After the extent of cavitation became more evident early in Phase II, the cold and warm water tests were normally run at pressures above 200 psia and hot tests were run above the corresponding saturation pressures.

5.4.1.3 Seal Leakage. To avoid excessive leakage of hot fluid from the main stream out through the model pump shaft seals with resulting overheating of the bearing oil, cool water was injected into the seal cavity behind the pump impeller.

The pressure in this seal cavity was controlled so that normally there was a small amount (about 1 lbm/sec) of mainstream fluid leaking from the impeller discharge into the injection water outflow. Such small loss of fluid downstream of the impeller had little effect on the mainstream fluid conditions (but was accounted for in reducing the data).

However, there were some tests in which the seal cavity pressure rose above mainstream pressure and cool seal water leaked into the main stream. The question arose whether this might be the cause of some unexpected head readings for two-phase tests at low flow rates (e.g. Test 287 in Figure 5-32 near ν/α_N =0.1 and h/α_N^2 = 2). To investigate seal leakage effects a special series of low-flow two-phase tests were run in which the seal leakage was allowed to range from the usual 1 lbm/sec out of the mainstream to nearly 2 lbm/sec into the mainstream. The results are presented in Figure 5-42 and Table 5-5.

Table 5-5

DATA FROM LOW-FLOW TESTS SHOWING EFFECTS OF SEAL LEAKAGE

Test No.	Net Seal Leakage lbm/sec*	Leakage % Of Main - Stream Flow	Upstream Void Fraction	Downstream Void Fraction	ν/α_N	h/α_N^2	β_h/α_N^2
1418	1.07	11.5	.55	.74	.108	.526	.658
1419	1.03	11.1	.56	.75	.109	.491	.673
1421	.62	6.6	.58	.70	.117	.647	.740
1423	-1.88	-20.5	.65	0	.141	3.994	1.304
1424	-1.94	-19.7	.65	0	.138	3.921	1.328
1425	-1.86	-19.6	.65	0	.139	3.909	1.354
1426	- .76	-8.2	.65	0	.134	2.319	1.026
1427	- .73	-8.0	.64	0	.130	2.380	1.027
1428	- .39	-4.4	.62	0	.121	2.073	.999
1429	- .09	- .94	.62	0	.122	1.675	.944
287	- .013	- .12	.42	0	.105	2.048	.932

* + = out of main stream; - = into main stream

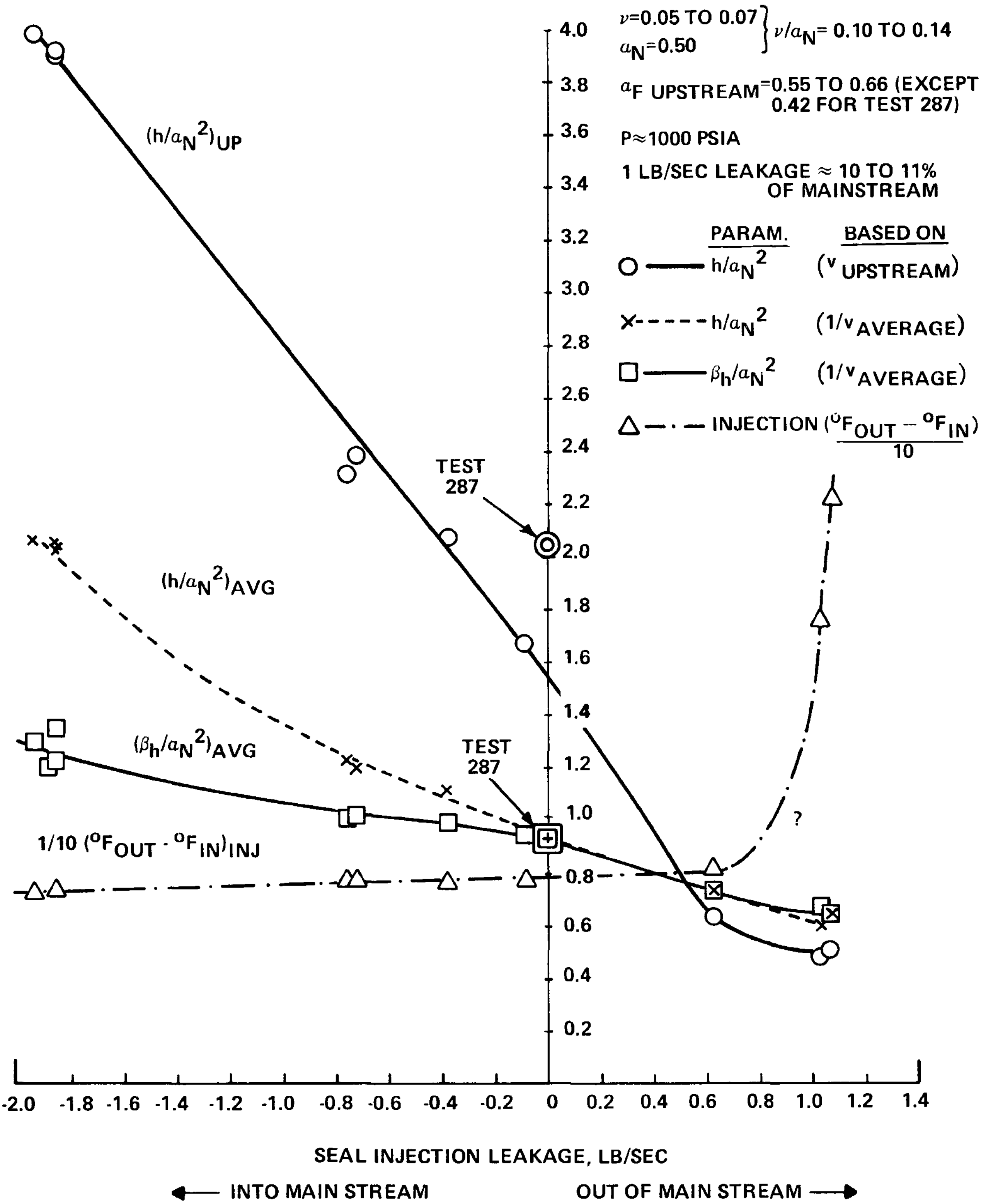


Figure 5-42. Effect of seal leakage on low-flow two-phase tests

The table and plots show that inflow of cool seal water quenched the steam at the discharge leg measuring station and that increasing amounts of cool inflow resulted in steadily increasing head and torque. Even when the head is plotted (like the torque) on the basis of average specific volume across the pump, the head shows considerable increase. These results seem to indicate that the cool in-leakage is affecting conditions in the impeller as well as beyond, and this implies that some of the cool water is recirculating down the front side of the impeller from the discharge and into the inlet. Such recirculation could occur when there is a pressure rise through the impeller (pumping mode) but would not be expected when there is a pressure drop between the suction and discharge sides. The curve of temperature rise between injection inflow and outflow seems to indicate that the heating effects of mainstream outflow are not felt until more than 0.6 lbm/sec leaks out, and the other curves seem to correlate with this. Whether this is real or there is some offset in zero seal leakage flow measurement can be questioned, but the calibrations of the flow measurements were checked and verified.

The effects displayed here are large, especially for head, and are sufficient to explain scatter in a low-flow test such as 287. For the special tests plotted in Figure 5-42 the mainstream flow was about 9.5 lbm/sec, and a leakage of 1 lbm/sec represented roughly 10 percent of the mainstream flow. For Test 287 the suction void fraction was somewhat lower (0.42) and the flow slightly higher (11.4 lbm/sec), but when plotted with the flows scaled by a factor of 9.5/11.4 to give the same percentage leakage in the graph, the head and torque points fall fairly close to the curves.

For tests with higher mainstream flow, small amounts of seal in-leakage did not seem to affect the performance much, perhaps because crossing the main stream to recirculate down the front side of the impeller would be less likely. For example, Test 228 had comparable seal in-leakage (0.43 lbm/sec) and upstream void fraction (0.48) but several times greater mainstream flow (77 lbm/sec) and showed very little lowering of discharge void fraction (0.47) and no evidence of enhanced head or torque. (See Table 4-3 and Figures 5-32 and 5-33) Most of the performance testing was at the higher mainstream flow rates, and seal leakage was normally maintained outward. Thus the leakage effects discussed here were not normally encountered and are presented to explain and assess some uncommon scatter.

5.4.1.4 Fluctuations and Flow Regimes. Increased scatter in the pumping heads and torques for 0.40 void fraction at mid-range ν/α_N's on the HAN and BAN curves (Figures 5-32 and 5-33) is in part attributed to somewhat unsteady flow conditions, as indicated by variations in the five data scan readouts for each test. For the most part the pump performance did not appear to be sensitive to moderate fluctuations in fluid conditions. Test points showing random variations of a few percent amoung the five scan readings usually averaged out near the smooth curves in the performance plots. Scan variations of several percent or more were necessary to cause more scatter, as for HAN in Figure 5-32 mentioned above.

Strong surging (periodic flow oscillations) and slugging (formation and passage of slugs of water) as evidenced by observations of flow, density, noise, and pipe motion during some of the early low-pressure shakedown runs and special low-pressure performance runs were much less in evidence in the usual higher pressure testing. The tendency for stronger surging and slugging seemed to be greatest in the mid-to-upper range of void fractions (0.40 to 0.80) at flow rates less than rated (again as for HAN in Figure 5-32). This combination of void fraction and flow rates somewhat corresponds to the slug flow region of the flow regime map for horizontal pipes accordings to Govier and associates (References 7 and 8). However, the subject is more complicated than indicated by this flow regime map because experience in this program has shown that the range of flow conditions over which surging and/or slugging are encountered is affected by both pressure and pump speed -- especially being milder at higher pressures. Such gross flow fluctuations could be the consequency of two-phase flow regimes locally in the test section or could result (especially for surging) from more overall pump and loop interaction peculiar to the test system configuration.

Test measurements under strong fluctuation conditions were not desirable or practical. Operations which encountered such conditions for a given test point were given a couple of tries to establish desired conditions, such as approaching the point from different directions. One method tried, in hopes of suppressing oscillations as well as promoting better mixing of the phases, was to insert a mixing plate ahead of the suction pipe leg (See Volume VII for details). Which tests used the mixing plate is indicated in the Table 3-1, Steady State Test Matrix. However, the mixing plate was not very effective in reducing fluid system instabilities. Therefore the use of the mixing plate was terminated midway through the program.

Indications of phase distributions in the test section pipes can be obtained from the three-beam gamma densitometer densities given in the one page printouts in Volume V. Also, the test points can be plotted, with precautions noted above, on a flow regime map such as shown in References 7 and 8 as a function of the steam and water superficial velocities, which are listed in the ten page printouts in EPRI files or easily calculated from the one page information using

$$V_{SG} = V_{S\ steam} = \alpha_F V_{mixture}$$

and

$$V_{SL} = V_{S\ water} = (1 - \alpha_F) V_{mixture}$$

These indications of flow regimes have not been analyzed in depth, but first impressions, based on scanning the data, are that the pump performance is not strongly affected by flow regime in the pipes as long as slugging or low-flow stratification at low pump speeds are not involved. Low-flow low-speed cases are discussed further in Section 5.4.4, Similarity Scaling. This low sensitivity to pipe flow regime is consistent with the concepts discussed in Section 5.1 that the suction elbows plus the impeller blade rotation tend to mix and "chop" across any phase distribution, and that the pump itself is most strongly influenced by the total volumetric flow and resulting internal flow angles as indexed by ν/α_N.

5.4.2 Alternate Forms of Performance Parameters

Section 5.1 and Appendix A present in some detail the identification and development of key parameters for describing and correlating pump operating conditions and performance and tell how initial choices were made among alternate forms of the parameters. The good overall coherence and correlation of the steady-state data in the performance plots in Section 5.2, using these initially selected parameters indicates that such homologous parameters are appropriate using methods described here. While there is the possibility of some refinements in the parameters and correlations such endeavors would be beyond the scope of this report. Some general observations and comments are provided here.

Section 5.2.3 (above) points out that two-phase head curves based on upstream fluid conditions have a step change where the flow reverses, because of such factors as the fluid conditions on the other side of the pump being different. When the step is real, there is nothing wrong with having it in the performance presentations as long as the presentations furnish information which can be used to develop the input required for applications of the data (e.g. LOCA analyses). If analysis using the pump data would accept or use the pump information more readily with values based on averages across the pump, that could provide incentive to modify the form of data presentation. Also, using average density might reduce some scatter which occurred in the correlation of heads for high and low flow points, in which the different absolute flow rates resulted in different ΔP's and therefore different changes in density and void fraction across the pump. Pump torques, as presented here, already use average density ($1/v_{avg}$) but would be included in considering possible use of averaged operating parameters also (e.g. P, ν, and α_F).

The use of total hydraulic head (based on local densities) in place of static head has been mentioned as a possibility and has been applied with some success in correlating two-phase pump test data in Reference 9. Certainly the changes in velocity and elevation heads across a pump need to be accounted for in any complete energy balance calculation for a path incorporating a pump. However, the appropriateness of using total hydraulic head for the data in Reference 9 depends on the fact that there was no change of phase (other than cavitation) in those tests, because they were run with air-water mixtures. In the present program with steam-water mixtures, even a small amount of flashing accompanying pressure drop in the pump could cause a large increase in velocity head, especially at low void fractions. This could result in a large change in total hydraulic head, masking the other hydraulic losses. Thus any energy balance for steam-water flow must account for the conversions between thermal and hydraulic energy. A simplified energy balance of this kind is used in reducing the steady-state data to calculate downstream void fraction and density (See Section 5.1 and Volume VIII).

A frequently used way to present two-phase degradation curves is to plot the degradation for a given ν/α_N as a function of α_F, with the degradation expressed as a fraction of the maximum. In this way the head and torque degradation curves for rated flow and speed at 1000 psia plotted in Figures 5-1 and 5-2 take the form shown in Figure 5-43. The functions plotted here are one type of "multiplier" parameter. Using them, the maximum degradation at the ν/α_N and pressure for which the curve is drawn is multiplied by the multiplier for a

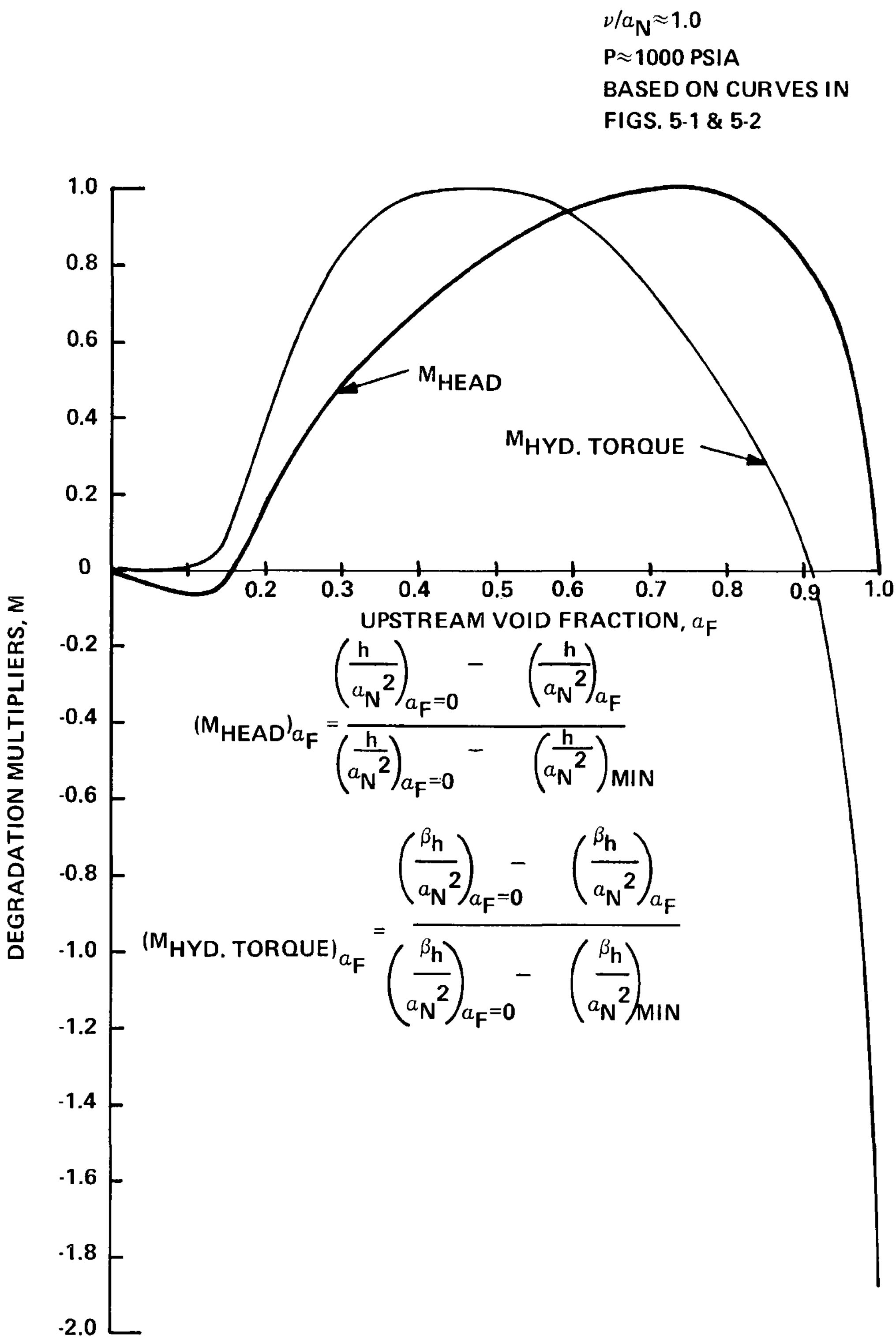


Figure 5-43. Effect of void fraction on homologous head and torque, shown in multiplier form

given void fraction to arrive at the degradation for that void fraction, ν/α_N, and pressure. This form of data presentation has been found useful in some mathematical pump performance models but is only one possibility. The specifics of the mathematical modeling is a matter for application by the user, which is beyond this report.

5.4.3 Uncertainties

As stated in Section 5.3.2, measurement uncertainties associated with instrumentation characteristics determined from calibrations are shown in Volume VIII (and in the 10 page printouts). If the instrument errors are random, then their effect is already visible as part of the scatter in the degradation and performance plots of Section 5.2. An example of such random uncertainties is the large scatter in h values in the log-log plot of h vs ν^2 in Figure 5-28 when h falls below 0.05 and the measurement uncertainty becomes comparable in magnitude. If the measurement uncertainties were systematic, then the performance points in a given region could be biased consistently in one direction to the extent of the combined uncertainties. However, because the plots use homologous parameters there are many points in juxtaposition which represent different ranges of measurements. Different sensors were used to cover different ranges of ΔP's and torques. Also there were redundant measurements and/or ways of deriving temperatures, densities, void fraction, saturation pressure, and head. These ways of comparing and cross checking made it likely that any significant consistent errors were visible. Examples of deviations attributed to such systematic errors are:

1. suction pressure readings which, during some test periods, consistently disagreed with $P_{discharge} - \Delta P_{leg-leg}$ and with P_{sat} derived from RTD temperature and steam tables, and

2. a series of steam orifice RTD temperature readings which disagreed with thermocouple readings by about three degrees and indicating subcooling (subsequently corrected).

5.4.4 Similarity Scaling

The validity and usefulness of flow similarity scaling based on matching the impeller flow angles (as indicated by matching ν/α_N) are demonstrated extensively in the performance plots of Section 5.2 by the common juxtaposition of test data symbols indicating absolute speeds (and flows) differing by factors of 2 or more. Another supportive aspect is the close agreement of the homologous head curves for single phase water and steam as shown in Figures 5-23, 5-25, 5-29, and 5-40 for a broad range of ν/α_N's and density ratios up to 60 or more.

Some significant deviations from similarity scaling did appear at low flows and for torques near all steam. The variability in two-phase performance at low flows can be seen at the left end of the HAN and BAN curves in Figures 5-32 and 5-33, and only some of the scatter is attributable to other factors such as seal injection leakage. Also in the middle of the HAN curve there appears to be some fairly consistent but small (less than or approximately equal to 0.1) separation of the points on the basis of speed and flow range.

The apparent overshoot of torque recovery as α_F approaches 1 in Figures 5-2, 5-7 and 5-9, and also seen in comparing the torque performance curves for water in Figure 5-24 or 5-26 with steam in Figure 5-30, is somewhat surprising in the light of the good agreement of the water and steam heads in corresponding Figures 5-1, 5-6 and 5-8 and 5-23, 5-25 and 5-29 plus Figure 5-40. The fact that the heads consistently agree and torques systematically disagree over a wide range of operating conditions seems to suggest that the measured steam densities are more appropriate for the heads. If there was a small amount of undetected water in the impeller passages and this water was not suspended as droplets but running as a film along the wall, it is possible that the water would not contribute to the head even though it affected the torque. Thus the recorded dry steam density would be appropriate for a steam curve and would scale with the head but be too low for the measured torque and give too high values of $\beta_h = (T_h/T_{rated})\ (\rho_{rated}/\rho_{test})$. It seems possible but not certain that an effect of this nature could be large enough to explain all of the torque overshoot, and attention still turns also to the torques as expressed directly in ft-lbf. Since steam densities are small, the torques are also small and the uncertainties in torque measurements could be significant. At rated flow and speed (the top points in Figure 5-30) the hydraulic torque is about 12 ft-lbf and the shaft torque measurement uncertainty is about 1 ft-lbf. Other uncertainties in friction and windage torques are discussed in the next section.

5.4.5 Friction and Windage Torque

Friction and windage torque measurements made before and after the test program showed no significant change (See Section 4.5). This indicated that no physical deterioration affecting bearing or seal friction or windage had occured during the performance testing.

The friction and windage tests showed that the effect of pressure was only a small part of the total, indicating that axial loading on the pressure-lubricated thrust bearings played a minor role. Therefore it was considered unnecessary to account for momentum thrust of the fluid flowing through the impeller in the torque data reduction.

Significant hysteresis in torque readings was encountered in some of the locked rotor tests, apparently due to sticking or binding of the non-rotating bearings or seals. Some check points were run later with the shaft rocked by hand to eliminate sticking.

The friction and windage torques were large compared to steam torques -- e.g. at rated speed and flow, 24 ft-lbf friction and windage compared to about 12 ft-lbf steam torque. The corresponding scatter uncertainty of about 2 ft-lbf in the friction and windage is significant but not enough to readily cover remaining questions about the steam homologous torques going considerably higher than for water as ν/α_N's go from about 3 down to 1 (as in Section 5.4.4 above).

Of course there was no practical way of completely simulating and/or isolating impeller windage under the whole range of operating conditions (See Appendix B) and there remains some additional friction and windage torque uncertainty from the necessarily limited range of calibration testing.

Section 6

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Appendix A

DYNAMIC SIMILARITY AND SCALING PARAMETERS

Single-phase pump performance is generally measured and described in terms of head and torques (hydraulic, friction and windage, and/or shaft) for a given speed, volumetric flow rate, and fluid density. For two-phase conditions pressure, void fraction and, to some degree, flow regime are also included. A straight empirical approach to performance testing would simply cover all combinations of these throughout the range of concern on a full-size pump. However, practical limitations require running the tests on a scaled-down model and obtaining as much information as possible from selected combinations of operating conditions within the capabilities of the test facility. This points to the need to understand the physical relationships among the parameters as a basis for scaling and to develop criteria for indicating the appropriateness of test conditions.

Flow paths and general dynamic phenomena in a given pump, or in scale model pumps, at different operating conditions with homogeneous fluids can be considered hydraulically similar when the vector diagrams relating fluid velocities to rotor velocities are geometrically similar (Ref. A-1). Since rotor velocities are proportional to ND (pump speed times impeller diameter) and fluid velocities are proportional to Q/D^2 (volumetric flow rate divided by area, or diameter squared), flow similarity is indicated by matching $(Q/D^2)/ND$ or Q/ND^3. This ratio is commonly normalized to rated conditions to give

$$\frac{Q/ND^3}{Q_r/N_R D^3} = \frac{Q/N}{Q_R/N_R} = \frac{Q/Q_R}{N/N_R} = \frac{\nu}{\alpha_N}$$

in which $\nu \equiv Q/Q_R$ and $\alpha_N \equiv N/N_R$ are called homologous flow and speed parameters, respectively. Thus, for the scale model test pump to be considered operating at the "same", or actually similar, hydraulic conditions as an NSSS pump, the model and NSSS values of ν/α_N, i.e., the indicator of ratio of fluid velocities to impeller velocities, should be matched.

Pump head H is the net result of fluid dynamic head and hydraulic losses, both of which are generally proportional to the square of fluid velocity i.e., $H \sim V^2$.

For hydraulically similar conditions when the ratios of fluid and impeller velocities are matched, H is also proportional to the square of the impeller velocity, i.e., $H \sim (ND)^2$.

Thus, the head H_p for the full-sized power plant pump can be obtained from a measurement of head H_m of a scale model at hydraulically similar flow conditions by ratioing in proportion to $(ND)^2$, i.e.,

$$H_p = H_m \frac{(N_p D_p)^2}{(N_m D_m)^2}$$

If these quantities are normalized to the rated conditions,

$$H/H_R \sim (N/N_R)^2$$

or

$$h \sim \alpha_N^2$$

and

$$h_p = h_m (\alpha_{Np}/\alpha_{Nm})^2,$$

in which $h \equiv H/H_R$ is called the homologous head parameter. This illustrates the significance and importance of using the fluid-to-impeller-speed parameter ν/α_N to indicate when test model operating conditions correspond to NSSS conditions.

In analogous fashion, hydraulic torque T_h which the impeller exerts on the fluid going through the passages is the result of causing momentum changes at each radius and is therefore proportional to mass flow rate, fluid velocities and impeller size, i.e.,

$$T_h \sim (\rho Q)\ (Q/D^2)\ (D)$$

For hydraulically similar conditions when the ratio of fluid and impeller velocities are matched, as indicated by matching ν/α_N,

$$Q/D^2 \sim ND$$

as above. This also can be expressed as

$$Q \sim ND^3.$$

Thus,

$$T_h \sim (\rho ND^3)\ (ND)\ (D)$$

or

$$T_h \sim \rho N^2 D^5.$$

Thus, the hydraulic torque T_{hp} for a full-size power plant pump can be determined by measurement of T_{hm} for the model at hydraulically similar conditions and then ratioing in proportion to $\rho N^2 D^5$, i.e.,

$$T_{hp} = T_{hm} \frac{(\rho N^2 D^5)_p}{(\rho N^2 D^5)_m}$$

If these quantities are normalized to rated conditions,

$$(T_h/T_{hR})/(\rho/\rho_R) \sim (N/N_R)^2$$

or

$$\beta_h \sim \alpha_N^2$$

and

$$\beta_{hp} = \beta_{hm} \frac{\alpha_{Np}^2}{\alpha_{Nm}^2}$$

in which $\beta_h \equiv (T_h/T_{hR})/(\rho/\rho_R)$ is called the homologous hydraulic torque parameter.

Hydraulic torque for the model is calculated from measured quantities as follows:

$$T_h = T_{shaft} - T_{f\&w} - \frac{I}{g_c} \frac{d\omega}{dt}$$

in which T_{shaft} is driving shaft torque, $T_{f\&w}$ is torque to overcome friction and windage, I is moment of inertia, and $d\omega/dt$ is angular acceleration.

The above discussion of hydraulic similarity and scaling and their application to head and hydraulic torque show that the similarity criterion parameter ν/α_N should be considered one of the test parameters.

It should be noted that head, torque, flow and speed expressed in percent of rated values are frequently used instead of the homologous parameters h, β, ν, and α_N, but the meaning is the same. Also, the names "similarity laws" and "affinity laws" are often given to relationships stated above as applying when hydraulic similarity exists, i.e.,

$$H \sim N^2D^2 \quad \text{or} \quad h \sim \alpha_N^2$$

$$Q \sim ND^3 \quad \text{or} \quad \nu \sim \alpha_N$$

and

$$T_h \sim \rho N^2D^5 \quad \text{or} \quad \beta \sim \alpha_N^2$$

Deviations from hydraulic similarity can occur when scale models are used if some flow phenomena do not scale geometrically and are not compensated readily by adjusting the mode of operation. Such distorting effects can come from gravity, Mach number, or certain Reynolds number effects such as variation in friction coefficients. For scaling down by a factor of only 5, and unless choking is present, such effects are expected to be of secondary importance provided the fluid is essentially homogeneous. If inhomogeneity occurs to a significant degree, which is possible for some two-phase flows, additional complication in scaling performance could result.

This pump test program is primarily concerned with how pump performance is affected by various two-phase mixtures of water and steam. The nature of a relatively uniform two-phase mixture is largely indicated if the void fraction α_F and density are specified. Tests were made over a range of pressure levels, and the main indicator of the nature of the fluid was assumed to be void fraction, α_F.

The effects on pump performance of having two-phase mixtures instead of a single phase are expected to be different if the two phases do not remain throughly mixed or homogeneous. The type of two-phase distribution pattern or "flow regime" which will exist in a horizontal pipe (such as ahead of the test pump) has been shown by various investigators to correlate approximately with the relative volumetric flow rates of the two phases. Govier and associates (References A-2 and A-3) recommend plotting superficial liquid velocity V_{SL} vs superficial gas velocity V_{SG} on a log-log plot showing empirical regions corresponding to various flow regimes. Superficial velocity is defined as volumetric flow rate of the phase divided by total pipe cross-sectional area. If the liquid velocities are high enough, the mixture will be uniform enough to behave more nearly as homogeneous.

Pump performance during a blowdown transient could differ from steady-state performance, even though the same inlet conditions exist momentarily, if inertial or nonequilibrium phase change effects are significant. Past experience in the field, (e.g., Reference A-4), indicates that for transients of interest, inertia effects are small and phase change effects are more likely to come into play. On this basis, the parameter chosen to indicate severity of a transient is the behavior of the pump average void fraction α_F vs time, from which the change in void fraction $d\alpha_F/dt$ can be inferred.

For pump flow conditions in two situations to be considered similar, all of the above comparison criteria, i.e., ν/α_N, α_F, $d\alpha_F/dt$, and flow regime should be matched simultaneously. Further comments on the significance of such comparison parameters are given in the data analysis in Section 5, Volume III Section 5, and in Volume IV.

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Appendix B

FRICTION AND WINDAGE TEST DATA AND ANALYSIS FOR MODEL PUMP

The torque meter used during the test program measured the shaft torque at the motor end of the test pump shaft. Hydraulic torque can be calculated by subtracting the friction torque due to the bearing assemblies and the windage on the rotating pump parts from the measured shaft torque. It was assumed that the friction and windage torque is made up of two independent components; one due to test pump speed and the other due to system pressure within the pump casing. Two types of tests were conducted to measure the contribution of each of these components. A brief description of the procedures used for each type of test along with the final results is reported in Section 4.5.1. In this appendix the data from each type of test will be presented along with the analysis used to produce the results appearing in Section 4.5.1.

To measure the contribution to friction and windage torque due to test pump speed the pump was operated in air at different speeds while shaft torque was recorded. The torque measured in this case includes windage drag due to rotation in air but does not cover steam/water windage on the outside of the impeller. The data from this test are recorded in Table B-1 and plotted in Figure B-1.

To measure the contribution of bearing friction torque due to thrust loading arising from system pressure the shaft torque required to rotate the pump at a very low, constant speed in water was measured for different system pressures. To avoid drag due to rotation of the impeller in water, the impeller was removed prior to this test. The data from this test are recorded in Table B-2 and plotted in Figure B-2.

A regression analysis was used to independently fit each set of data to a second order equation. The best fit equations for each set of data are:

$$T_{F1} = -16.44 + 8.0197 \times 10^{-2} |N| - 3.5856 \times 10^{-6} N^2$$

T_{F1} = friction torque due to speed (in - lbf)

N = test pump speed (rpm)

Table B-1

DATA FROM FRICTION TORQUE VS SPEED TEST

Forward Rotation		Reverse Rotation	
Speed (RPM)	Friction Torque (in-lbf)	Speed (RPM)	Friction Torque (in-lbf)
0	.38	1000	68.66
1000	59.19	2000	119.80
2000	143.57	3000	183.72
3000	207.50	4000	253.32
4000	271.42	5000	324.36
5000	327.68	6000	347.37
6000	348.13	7000	378.05
7000	378.82	8000	395.95
8000	391.60	8690	408.74
8680	401.83	8000	393.40
8000	378.82	7000	375.50
7000	363.48	6000	332.03
6000	322.56	5000	298.79
5000	289.32	4000	239.98
4000	220.28	3000	170.94
3000	161.47	2000	109.57
2000	110.33	1000	55.87
1000	59.19	0	2.94
800	33.62		

Table B-2

DATA FROM FRICTION TORQUE VS PRESSURE TEST

Forward Rotation		Reverse Rotation	
Pressure (psig)	Rolling Torque (in-lbf)	Pressure (psig)	Rolling Torque (in-lbf)
200	4.14	200	7.85
400	4.14	400	3.85
600	4.14	600	7.85
810	12.14	810	19.84
1010	20.14	1010	19.84
1215	32.13	1215	27.84
806	8.14	806	15.84
410	.15	410	11.84

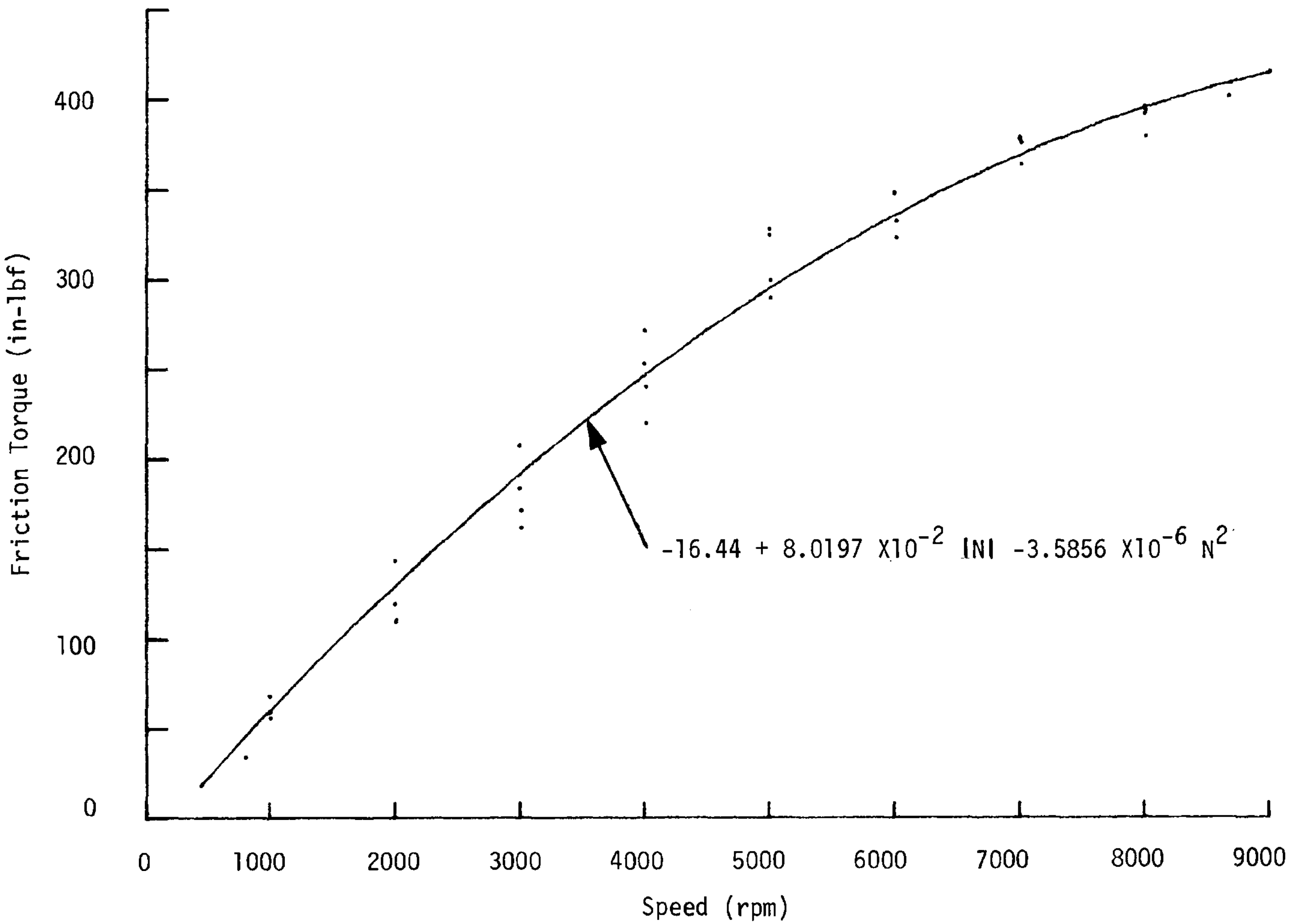

Figure B-1. Friction torque due to test pump speed

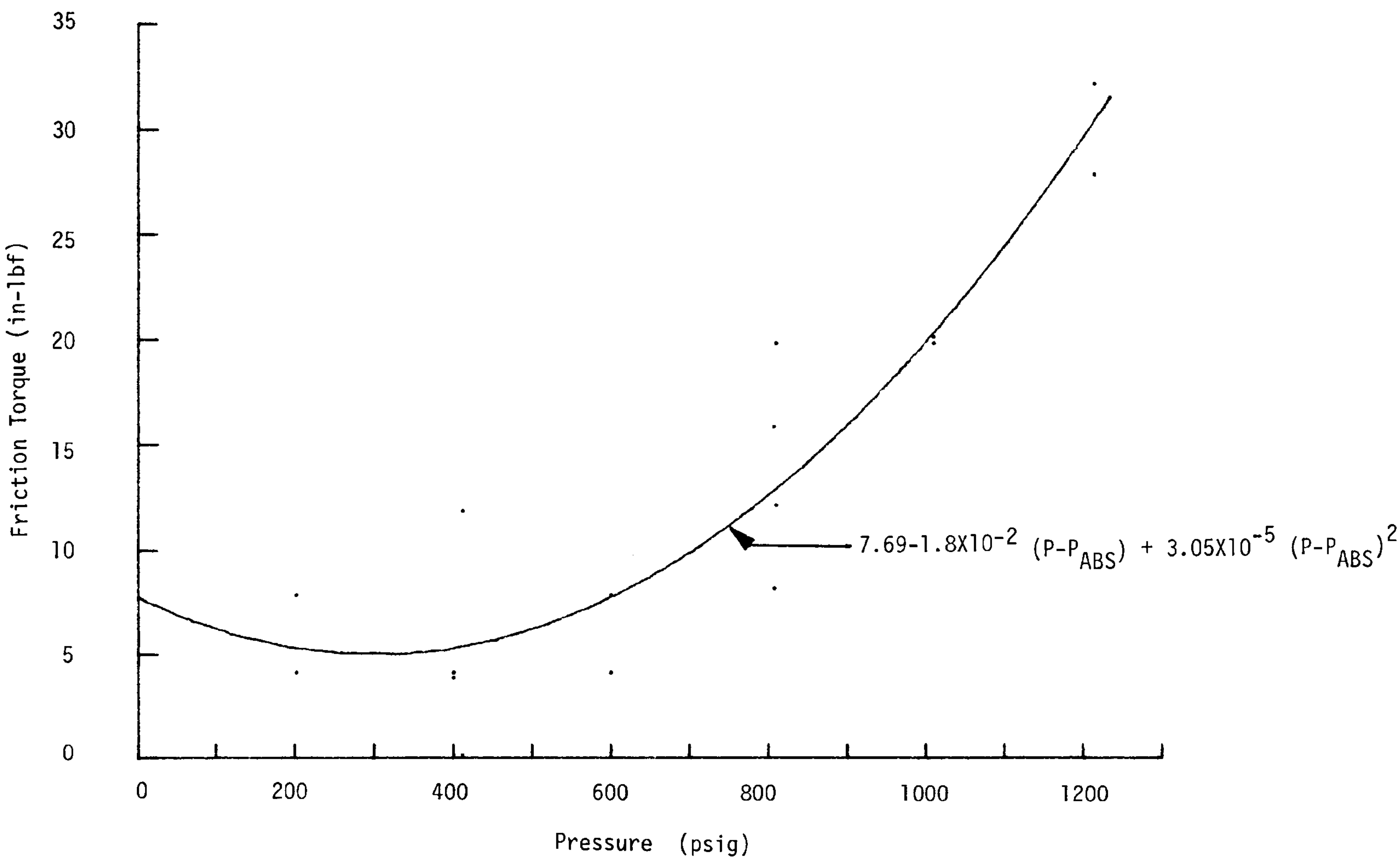

Figure B-2. Friction torque due to system pressure and

$$T_{F2} = 7.69 - 1.8 \times 10^{-2} (P - P_{ABS}) + 3.05 \times 10^{-5} (P - P_{ABS})^2$$

T_{F2} = friction torque due to system pressure (in - lbf)

P = upstream pressure (psia)

P_{ABS} = atmospheric pressure (psia)

Since friction torque should equal zero at zero speed and zero pressure, the small constant terms of the two relations above were set to zero. The final result is then

$$T_{f\&w} = -1.8 \times 10^{-2} (P - P_{ABS}) + 3.05 \times 10^{-5} (P - P_{ABS})^2$$
$$+ 8.0197 \times 10^{-2} |N| - 3.5856 \times 10^{-6} N^2$$

$T_{f\&w}$ = friction torque (in - lbf)