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CRITICAL HEAT FLUX EXPERIMENTS WITH A LOCAL HOT PATCH IN AN INTERNALLY HEATED ANNULUS

(LWBR Development Program)

E. P. MORTIMORE
S. G. BEUS

FEBRUARY 1979

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BETTIS ATOMIC POWER LABORATORY
WEST MIFFLIN, PENNSYLVANIA

Operated for the U. S. Department of Energy by
WESTINGHOUSE ELECTRIC CORPORATION

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BETTIS ATOMIC POWER LABORATORY WEST MIFFLIN, PENNSYLVANIA 15122

Operated by the U. S. Department of Energy
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FOREWORD

The Shippingport Atomic Power Station located in Shippingport, Pennsylvania was the first large-scale, central-station nuclear power plant in the United States and the first plant of such size in the world operated solely to produce electric power. This program was started in 1953 to confirm the practical application of nuclear power for large-scale electric power generation. It has provided much of the technology being used for design and operation of the commercial, central-station nuclear power plants now in use.

Subsequent to development and successful operation of the Pressurized Water Reactor in the DOE-owned reactor plant at the Shippingport Atomic Power Station, the Atomic Energy Commission in 1965 undertook a research and development program to design and build a Light Water Breeder Reactor core for operation in the Shippingport Station.

The objective of the Light Water Breeder Reactor (LWBR) program has been to develop a technology that would significantly improve the utilization of the nation's nuclear fuel resources employing the well-established water reactor technology. To achieve this objective, work has been directed toward analysis, design, component tests, and fabrication of a water-cooled, thorium oxide fuel cycle breeder reactor for installation and operation at the Shippingport Station. The LWBR core started operation in the Shippingport Station in the Fall of 1977 and is expected to be operated for about 3 to 4 years. At the end of this period, the core will be removed and the spent fuel shipped to the Naval Reactors Expended Core Facility for a detailed examination to verify core performance including an evaluation of breeding characteristics.

In 1976, with fabrication of the Shippingport LWBR core nearing completion, the Energy Research and Development Administration established the Advanced Water Breeder Applications (AWBA) program to develop and disseminate technical information which would assist U. S. industry in evaluating the LWBR concept for commercial-scale applications. The program will explore some of the problems that would be faced by industry in adapting technology confirmed in the LWBR program. Information to be developed includes concepts for commercial-scale prebreeder cores which would produce uranium-233 for light water breeder cores while producing electric power, improvements for breeder cores based on the technology developed to fabricate and operate the Shippingport LWBR core, and other information and technology to aid in evaluating commercial-scale application of the LWBR concept.

All three development programs (Pressurized Water Reactor, Light Water Breeder Reactor, and Advanced Water Breeder Applications) have been administered by the Division of Naval Reactors with the goal of developing practical improvements in the utilization of nuclear fuel resources for generation of electrical energy using water-cooled nuclear reactors.

Technical information developed under the Shippingport, LWBR, and AWBA programs has been and will continue to be published in technical memoranda, one of which is this present report.

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Critical heat flux experiments were conducted for upflow of water in a vertical 84 inch annular flow channel, 0.303 inch heated I.D. and 0.500 inch unheated O.D. Test data were obtained at pressures from 1200 to 2000 psia, mass velocities from 0.25×10^6 to 2.8×10^6 lb/hr-ft^2 and inlet temperatures ranging from 200 to 600°F. Three different test sections were employed with (1) axially uniform heat flux over the 84 inch length to serve as a no-hot-patch data base, (2) axially uniform heat flux over 82 inches with a 1.5 heat flux ratio hot patch over the last two inches, and (3) axially uniform heat flux over 82 inches with a 2.25 heat flux ratio hot patch over the last two inches. Comparisons of hot patch to no-hot-patch critical heat flux values were made indicating that for most cases a uniform two-inch exit hot patch does not cause a reduction in CHF at either hot patch ratio. However, there was a tendency for a CHF decrement to occur for the low inlet enthalpy runs at high mass velocity.

CRITICAL HEAT FLUX EXPERIMENTS WITH A LOCAL HOT PATCH IN AN INTERNALLY HEATED ANNULUS (LWBR Development Program)

I. INTRODUCTION

Local heat flux peaking can occur inadvertently in nuclear reactor cores having fuel rods due to the combined effects of fuel pellet eccentricity, non-uniform pellet porosity and potential fuel stack gaps created by densification during core power operation. Any one or combination of these conditions can produce a local region in a fuel rod which operates at a heat flux higher than that intended, thus increasing the chance for the occurrence of a critical heat flux (CHF) condition in that region.

The local conditions hypothesis of critical heat flux phenomena suggests that the increased heat flux over a region in a fuel rod could produce a CHF condition in the rod at a lower average rod heat flux compared to a fuel rod without local flux peaking. However, previous experimental evidence suggests that if the size of the region and/or the magnitude of the heat flux peak is small enough then the local flux peak region will have no effect on CHF (Reference 1).

Reference 1 reports results from an experiment conducted to determine the effect of a hot patch at the end of the heated length on CHF power levels. The test section was the same as that employed in the subject experiment except that the inner diameter of the electrically heated tube was reamed out for the last 1-1/4 inches to produce a circumferentially uniform hot patch with a heat flux 1.337 times the rod average surface heat flux. Direct comparison of the CHF power levels of this test section with those of a similar test section without the hot patch indicated that the hot patch did not affect the CHF power capability of the rod.

A comprehensive test program for hot patch effectiveness is discussed in Reference 2 which presents experimental data obtained over a range of hot patch lengths from 0.591 inches to 7.874 inches and with heat flux peaking factors of 1.5 and 2.0. The test sections employed in these tests were electrically heated 8 mm I.D. tubes with water flowing on the inside. The subject test program was undertaken to provide supplementary data concerning the effect of hot patches. In particular, available hot patch data in the literature were lacking at low qualities (less than 8%) where previous data obtained at Bettis indicated potential effects of hot patch on thermal performance.

II. TEST EQUIPMENT

The test equipment consisted of a high pressure water circulation loop, a D-C generator, the test section, local instrumentation and the data acquisition system. A Crocker-Wheeler direct current generator was used for test section electrical power with maximum ratings of 100 volts and 7500 amps. Additional test section current can be obtained by arranging up to four generators in parallel. The tests were performed in Bettis High Pressure Loop No. 29 shown schematically in Figure 1. The loop can circulate 50 gpm of water through 2 inch 316 stainless steel piping at pressures up to 2500 psia and 650°F using a single canned motor pump.

The test section was a 0.303 $\pm$ 0.001 inch O.D. stainless steel tube with a 0.035 inch thick wall, surrounded by a 0.500 inch I.D. ceramic tube contained within a 1 inch O.D. pipe (see Figure 2). An annular flow path exists between the inside 0.303 inch O.D. tube and the 0.500 inch

I.D. ceramic tube. The ceramic tube and outer pipe are in contact. The inside of the heated tube contains air at atmospheric pressure. The heated tube was centered within the ceramic tubing by seven spacers located at 12 inch intervals with the uppermost spacer located 9 inches before the end of the heated length. Each spacer consisted of three short tubing segments welded to the test section at 120° locations as can be seen in Figure 3. Copper terminals are attached to both ends of the tube and a heat flux is produced by DC resistance heating in the tube wall. Heat flux from the tube wall was uniform axially except for the increased heat flux in the 2 inch hot patch which was produced by reaming out the inside of the stainless steel tube to reduce the wall thickness to 0.026 inch at the end, thus increasing the electrical resistance locally.

Figure 2 shows an axial and cross-sectional view of the test section identifying the location of the outlet wall thermocouples and the dimensions of the annular flow channel. Figures 3 and 4 give partial and full length axial views of the disassembled test section. Figures 5 and 6 show detailed drawings of the inlet and exit regions of the test section showing the inlet pressure tap and the design of the heated tube and terminal connections. The test section was well insulated and heat losses were negligible throughout the full range of testing.

Stainless steel sheathed chromel-alumel thermocouples were used for water temperature indication. Four water thermocouples were positioned in the flow, two upstream and two downstream of the heated length. Two asbestos-insulated chromel-alumel wall thermocouples were spot welded inside the heated tube near the exit end of the test section as shown in Figure 6. Readouts from these thermocuples were displayed continuously on oscillograph charts and were used to indicate CHF. CHF was recognized by a 2 mm or greater rise of either CHF thermocouple oscillograph reading from its base line value corresponding to a temperature rise of 20°F.

Power measurements were recorded continuously as voltage drop across the test section terminals and current as measured by millivolt drop across a calibrated shunt. Voltage and current are estimated to be accurate to within ± 1.0% and ± 0.8% respectively.

High purity water was used in all tests with a pH near 7.0. The resistivity was maintained above 0.5 megohm-cm at room temperature and the oxygen concentration was maintained below 0.1 ppm.

The test section flow rate was measured with two orifices of the same size connected in series. Orifices of diameters 0.100, 0.300 and 0.435 inch were used in three parallel flow legs. The size used for a given test run depended on the flow rate. All orifice calibration constants were evaluated from tests with a weigh tank and flowrates calculated from the two orifices agreed within 2%. Water temperature at the orifices was measured by two thermocouples accurate to about $\pm$ 2^{o}F.

The mass velocities were calculated using the measured flowrates and the nominal flow area of the test section. There is a significant uncertainty (+6%, -34%) in local mass velocity due to the inner diameter tolerance of the ceramic tubing. This uncertainty is not present in the local enthalpy since this quantity is calculated from the test section power and flowrate determined from orifice readings.

The steady-state data acquisition system consisted of oscillograph recorders for CHF thermocouple monitoring and strip chart recorders for generator current and hub-to-hub test section voltage drop. The oscillographs were electrically coupled to the test section power supply such that test section power was automatically reduced by 44% when a CHF temperature excursion was indicated.

An Integrating Digital Voltmeter (IDVM) was used to measure all thermocouple and Differential Pressure (DP) cell readings. These readings were saved on magnetic tape recordings.

Water flow rates were determined as the numerical average of values calculated from the two orifices connected in series. The test section inlet mass velocity was determined by dividing the flowrate by the test section inlet flow area. The measurement error on the inlet temperature is estimated at $\pm$ 2^{o}F. For the system pressure, the estimated error is $\pm$ 3 psi while the heat flux and inlet mass velocity are each estimated to be accurate within $\pm$ 2%. These errors combined with the uncertainty inherent in identifying CHF lead to an estimated $\pm$ 10% allowed error band on a computed hot patch to no-hot-patch flux ratio.

III. TEST PROCEDURE

The test procedures for the no-hot-patch, 1.5 flux ratio hot patch and the 2.25 flux ratio hot patch CHF tests were identical and consisted of:

1. Establishing loop conditions of pressure, flowrate, chemistry (pH = 7.0) and test section inlet temperature.
2. Applying and increasing the test section power to an estimated value below CHF and increasing power in small increments until a CHF indication was obtained on either of the exit wall thermocouple oscillograph charts.
3. Recording all data.

Following a CHF run, the power was reset to approximately 98% of the CHF power level and a complete line of data recorded. These 98% runs served as a backup indication of nominal test section conditions for the CHF runs where a rapid CHF prevented the recording of a full line of data on the Integrating Digital Voltmeter (IDVM).

IV. DISCUSSION OF RESULTS

The data obtained at CHF and at 98% of CHF from the 1.5 Hot Patch Test are contained in Table 1. Comparable data for the 2.25 Hot Patch Test are contained in Table 2. The CHF data with no hot patch are shown for comparison in both tables. Each table lists the run number, run type, nominal system pressure, inlet mass velocity, inlet temperature, inlet enthalpy, calculated average exit enthalpy, average test section heat flux and the ratio of average heat fluxes with and without the hot patch. The quantities given in these tables are the actual test conditions.

The exit enthalpy was calculated from the equation:

$$H_{exit} \text{ (Btu/lb)} = H_{in} + \frac{Q'' A_h}{G A_f}$$

where

H_{in} = inlet enthalpy (Btu/lb)

Q'' = average heat flux (Btu/hr-ft^2)

G = test section mass velocity (lb/hr-ft^2)

A_h = test section heat transfer area = 0.5553 ft^2

A_f = test section annular flow area = 0.0008625 ft^2

Any effect of the hot patch on critical heat flux performance can be deduced by comparing the heat flux of pairs of runs in Tables 1 and 2. If the inlet fluid conditions for any pair of runs are very close then the heat fluxes can be compared directly. If the inlet fluid conditions for any pair of runs differ significantly, then allowance must be made for the different fluid conditions.

The heat flux ratios printed in these tables were used to develop plots discussed below. In some cases the 98% CHF points were used on the plots and these are indicated in the tables.

No comparison should be made between runs 34 and 158 at CHF or runs 35 and 159 at 98% CHF because runs 34 and 35 had $T_{in} \approx 200^{o}F$ while runs 158 and 159 had $T_{in} \approx 427^{o}F$ due to generator limitations which occurred during runs 158 and 159.

A. Hot Patch Data Comparison with Flux Ratio of 1.50

Figure 7 summarizes the results of the 1.5 flux ratio hot patch testing as compared to the no-hot-patch data base (referred to as "new") at 2000, 1600 and 1200 psia. The results are presented in tabular form in Table 1. The deviation of the hot patch CHF data from the no-hot-patch data base may be characterized by the CHF Ratio, defined as the ratio of the average heat flux at CHF with hot patch to the average heat flux at CHF without hot patch for the same pressure, mass velocity and inlet temperature. An examination of the data in Figure 7 shows that there is a decided mass velocity effect and that the CHF ratio is between 0.90 and 1.10 except for six of the 37 data points:

a. 2000 psia, $200^{o}F$, 0.25×10^{6} lb/hr-ft^{2}, Ratio = 1.12
b. 1600 psia, $400^{o}F$, 0.25×10^{6} lb/hr-ft^{2}, Ratio = 1.11
c. 1600 psia, $500^{o}F$, 0.25×10^{6} lb/hr-ft^{2}, Ratio = 1.11
d. 1200 psia, $200^{o}F$, 0.25×10^{6} lb/hr-ft^{2}, Ratio = 1.26
e. 1200 psia, $400^{o}F$, 0.25×10^{6} lb/hr-ft^{2}, Ratio = 1.17
f. 1200 psia, $500^{o}F$, 0.25×10^{6} lb/hr-ft^{2}, Ratio = 1.16

It is noted that all six of these points are at 0.25×10^6 $lb/hr\text{-}ft^2$ inlet mass velocity and the ratio is always greater than 1.00. Since it is not expected that the hot patch would cause an improvement in CHF at 0.25×10^6 $lb/hr\text{-}ft^2$ mass velocity, it is concluded that these points are probably in error. It may also be concluded from these comparisons that the 1.5 flux ratio hot patch does not result in earlier CHF.

Because of the unrealistic trend of the test results discussed above at low mass velocities, an alternate set of base case data obtained with a nominally identical test section in a previous test (as described in the Appendix)was utilized. Figure 8 summarizes the results of the 1.5 flux ratio hot patch testing at 2000 and 1200 psia using the alternate data base referred to in the Appendix as the "first assembly". Figure 8 shows that all the CHF ratios at 2000 psia are within the $\pm$ 10% experimental scatter band while three points at 1200 psia are outside the scatter band. Again, however, all of the CHF ratios outside of the scatter band are greater than 1.00 suggesting no hot patch CHF decrements.

Figure 9 compares the results of the 1.5 flux ratio hot patch testing at 2000, 1600 and 1200 psia, with a second alternate data set from a previous test. These data were obtained in a nominally identical test section referred to in the Appendix as the "second assembly". Figure 9 shows that all the CHF ratios at all pressures are within the $\pm$ 10% experimental scatter band.

Figures 10, 11 and 12 compare the results of the 1.5 heat flux hot patch testing to the no-hot-patch testing on the conventional flux-enthalpy plot at 2000, 1600 and 1200 psia, respectively. The 1.5 hot patch data are represented by open squares while the no-hot-patch data bases are represented by circles. An examination of these three figures shows that the 1.5 hot patch data generally lie very close to the no-hot-patch data and are consistently above and to the right of the no-hot-patch data at the lower mass velocities. A comparison of the old and new no-hot-patch data bases indicates a probable experimental bias between the two sets of data. The only known difference between the old no-hot-patch test section and the new no-hot-patch test section was the type of spacers used to center the stainless steel test tube in the two tests. The old test used "spring collar" spacers described in the Appendix while the new test section used small diameter open tubes which were located at the same axial locations as the spring collars thus yielding a nominally centered test tube in both cases. In both cases there was some unknown experimental tolerance in centering the tube, thus leading to the possibility that the one test section tube was more eccentric than the other. However, it is not known if differences in test section eccentricity could introduce the observed differences in the two data bases.

Two conclusions can be drawn from a comparison of the 1.5 CHF ratio data based on the new no-hot-patch data base vs. the same CHF ratio based on the old (Appendix) no-hot-patch data base:

1. The CHF ratio is sensitive to the data base used, especially at 0.25×10^6 lb/hr-ft^2.
2. The CHF ratio is never less than 0.9 irrespective of the no-hot-patch data base used, strongly suggesting that there is no-hot-patch CHF decrement over the range of variables tested.

B. Hot Patch Data Comparison with a Flux Ratio of 2.25

Figure 13 summarizes the results of the current 2.25 flux ratio hot patch testing at 2000, 1600 and 1200 psia, as compared with the new no-hot-patch data base. These data are tabulated in Table 2. An examination of these data shows that the hot patch to no-hot-patch CHF ratio is between 0.90 and 1.10 except for six of the 34 data points:

a. 2000 psia, 600°F, 0.25×10^6 lb/hr-ft^2, CHF Ratio = 1.15
b. 2000 psia, 200°F, 1.00×10^6 lb/hr-ft^2, CHF Ratio = 0.86
c. 2000 psia, 500°F, 2.00×10^6 lb/hr-ft^2, CHF Ratio = 0.88
d. 1200 psia, 200°F, 0.25×10^6 lb/hr-ft^2, CHF Ratio = 1.16
e. 1200 psia, 400°F, 2.00×10^6 lb/hr-ft^2, CHF Ratio = 0.80
f. 1200 psia, 500°F, 1.00×10^6 lb/hr-ft^2, CHF Ratio = 0.88

It is noted that the two points at 0.25×10^6 lb/hr-ft^2 are both greater than 1.10 while there are four data points for which a CHF decrement exists.

Figure 14 summarizes the results of current 2.25 hot patch testing at 2000 and 1200 psia, using the alternate data base. The no-hot-patch heat flux values used to compute the CHF ratios for these figures were taken from a previous test and were obtained on a nominally identical test section referred to in the Appendix as the "first assembly".

Figure 14 shows that all but one of the CHF ratios at 2000 psia are within the ± 10% scatter band while three points at 1200 psia are outside the scatter band. However, only one point is on the low side of the scatter band at conditions of 1200 psia, 400°F and 2.0 x 10^6 lb/hr-ft^2 where the CHF ratio is 0.87.

Figure 15 summarizes the results of current 2.25 hot patch testing at 2000, 1600 and 1200 psia, with a second alternate data base from a previous test. The no-hot-patch heat flux values used to compute the CHF ratios for these figures were obtained on a nominally identical test section referred to in the Appendix as the "second assembly". This comparison shows that all of the CHF ratios at all pressures are within the ± 10% experimental scatter band.

Figures 10, 11 and 12 compare the results of the 2.25 hot patch testing to the no-hot-patch testing results on the conventional flux-enthalpy plot at 2000, 1600 and 1200 psia, respectively. The 2.25 hot patch data are represented by open triangles while the no-hot-patch data base is represented by circles. An examination of these figures shows that the 2.25 hot patch data generally lie close to the no-hot-patch data and all but one (1200 psia, 400°F, 2.00 x 10^6 lb/hr-ft^2) of the 2.25 hot patch data points are judged to lie within the experimental scatter band of the comparable old no-hot-patch data point. At the higher mass velocities there appears to be a trend of the 2.25 hot patch data to lie below and to the left of the no-hot-patch data base and this may suggest a small CHF decrement at these conditions.

V. CONCLUSIONS

The 1.5 hot patch to no-hot-patch CHF ratio is always greater than 0.90, independently of the no-hot-patch data base (old and new) used to compute the CHF ratio. This result indicates that there is no hot patch

CHF decrement due to a 2 inch long 1.5 flux ratio hot patch over the range of variables and geometry tested.

The 2.25 hot patch to no-hot-patch CHF ratio, based on the new data base, is greater than 0.90 except for data at four conditions:

a. 2000 psia, 200^{o}F, 1,000,000 lb/hr-ft^2, CHF Ratio = 0.86
b. 2000 psia, 500^{o}F, 2,000,000 lb/hr-ft^2, CHF Ratio = 0.88
c. 1200 psia, 500^{o}F, 1,000,000 lb/hr-ft^2, CHF Ratio = 0.88
d. 1200 psia, 400^{o}F, 2,000,000 lb/hr-ft^2, CHF Ratio = 0.80

The 2.25 hot patch to no-hot-patch CHF ratio, based on the old (Appendix) data base, is greater than 0.90 except for data at one condition:

1200 psia, 400^{o}F, 2,000,000 x 10^6 lb/hr-ft^2, CHF Ratio = 0.87

These results indicate that there is no CHF decrement for most of the hot patch data with a heat flux ratio of 2.25 over the range of variables tested. However, there was a tendency for a CHF decrement to occur for the low inlet enthalpy runs at high mass velocity.

Based on a comparison of the new no-hot-patch data with the old no-hot-patch data (Appendix), the new no-hot patch data at 250,000 lb/hr-ft^2 mass velocity are probably in error. If these data are used, there is a consistent trend in both the hot patch data sets showing an improvement in CHF due to the hot patch at 250,000 lb/hr-ft^2. This trend is not evident if the old no-hot-patch data are used.

References

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2. V. N. Smolin, et al, "Departure from Nucleate Boiling in Channels with Heat Flux Peaking," Thermal Engineering, Vol. 17, No. 5, May 1970

3. WAPD-TM-1013, "Critical Heat Flux and Pressure Drop Tests in Bundles of Twenty Rods," B. W. LeTourneau, et al, January 1975

TABLE 1

Comparison of Data With and Without A Hot Patch - 1.5 Heat Flux Ratio

RUN NO.	*TYPE	PRES- (PSIA)	MASS VELOCITY X 10-5 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES
38	CHF W/O HP	2000	0.259	201.5	174.2	779.4	0.244	
82	CHF W HP	2000	0.253	199.8	172.4	856.4	0.269	1.10
36	CHF W/O HP	2000	0.499	201.4	174.1	706.8	0.413	
84	NO DATA							
34	CHF W/O HP	2000	0.991	200.7	173.4	635.3	0.711	
158	CHF W HP	2000	1.001	427.8	407.3	707.7	0.467	**
27	CHF W/O HP	2000	0.245	401.8	379.2	858.3	0.182	
85	CHF W HP	2000	0.253	400.5	377.8	889.3	0.201	1.11
29	CHF W/O HP	2000	0.500	401.7	379.1	783.8	0.314	
99	CHF W HP	2000	0.497	400.0	377.2	789.9	0.319	1.01
31	CHF W/O HP	2000	1.000	398.9	376.1	695.5	0.496	
122	CHF W HP	2000	0.978	400.0	377.3	692.1	0.478	.96
33	CHF W/O HP	2000	1.989	400.8	378.1	609.6	0.716	
124	CHF W HP	2000	2.002	400.0	377.3	610.0	0.723	1.01

*** W/O HP means without hot patch.**
W HP means with hot patch.

** Runs not comparable.

TABLE 1 (Continued)

Comparison of Data With and Without A Hot Patch - 1.5 Heat Flux Ratio

RUN NO.	TYPE	PRES- (PSIA)	MASS VELOCITY X 10-5 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES
25	CHF W/O HP	2000	0.244	501.4	489.3	885.7	0.150	
101	CHF W HP	2000	0.245	499.2	486.9	914.1	0.163	1.08
23	CHF W/O HP	2000	0.498	499.7	487.4	800.1	0.242	
108	CHF W HP	2000	0.502	499.6	487.3	808.4	0.250	1.04
21	CHF W/O HP	2000	1.000	500.4	488.2	747.3	0.402	
114	CHF W HP	2000	0.984	499.2	486.9	740.6	0.388	.96
19	CHF W/O HP	2000	1.990	500.2	488.0	690.2	0.625	
132	CHF W HP	2000	2.002	498.6	486.2	678.4	0.598	.96
18	CHF W/O HP	2000	2.682	501.1	489.0	660.1	0.713	
134	CHF W HP	2000	2.626	499.7	487.4	650.6	0.716	1.00
8	CHF W/O HP	2000	0.246	596.2	609.3	916.0	0.117	
144	CHF W HP	2000	0.254	600.1	615.2	940.3	0.128	1.10
10	CHF W/O HP	2000	0.493	599.7	614.6	822.8	0.159	
146	CHF W HP	2000	0.500	599.7	614.5	831.4	0.168	1.06
12	CHF W/O HP	2000	1.013	599.9	614.8	772.5	0.248	
148	CHF W HP	2000	1.020	600.7	616.0	770.3	0.244	.98
14	CHF W/O HP	2000	1.986	599.4	614.1	738.6	0.384	
150	CHF W HP	2000	1.995	599.4	614.1	735.8	0.377	.98
16	CHF W/O HP	2000	2.556	600.2	615.3	723.4	0.429	
152	CHF W HP	2000	2.754	599.5	614.2	716.8	0.439	1.02

TABLE 1 (Continued)

Comparison of Data With and Without A Hot Patch - 1.5 Heat Flux Ratio

RUN NO.	TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES
71	CHF W/O HP	1600	0.250	402.5	379.5	842.5	0.180	
90	CHF W HP	1600	0.252	398.8	375.6	881.2	0.198	1.10
73	CHF W/O HP	1600	0.501	401.3	378.3	728.3	0.272	
92	CHF W HP	1600	0.502	400.2	377.1	757.0	0.296	1.09
75	CHF W/O HP	1600	1.010	400.6	377.5	681.8	0.478	
125	CHF W HP	1600	0.988	400.1	377.0	377.0	----	0.
77	CHF W/O HP	1600	2.003	401.0	378.0	610.4	0.723	
131	CHF W HP	1600	2.030	400.1	377.0	607.2	0.726	1.00
69	CHF W/O HP	1600	0.250	499.3	486.9	868.4	0.148	
103	CHF W HP	1600	0.254	499.7	487.3	901.6	0.163	1.10
67	CHF W/O HP	1600	0.508	499.7	487.4	763.4	0.218	
110	CHF W HP	1600	0.500	498.8	486.3	778.9	0.227	1.04
65	CHF W/O HP	1600	0.997	499.7	487.3	708.2	0.342	
116	CHF W HP	1600	1.029	498.8	486.3	709.6	0.357	1.04
63	CHF W/O HP	1600	1.989	500.1	487.8	675.6	0.580	
136	CHF W HP	1600	2.001	499.4	487.0	670.3	0.570	.98
61	NO DATA							
142	CHF W HP	1600	2.852	499.0	486.6	642.2	0.689	0.

TABLE 1 (Continued)

Comparison of Data With and Without A Hot Patch - 1.5 Heat Flux Ratio

RUN NO.	TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES
40	CHF W/O HP	1200	0.245	200.2	171.1	704.3	0.203	
154	CHF W HP	1200	0.253	200.0	170.9	820.1	0.255	1.26
42	CHF W/O HP	1200	0.501	199.8	170.6	689.0	0.404	
156	CHF W HP	1200	0.501	200.4	171.2	698.2	0.410	1.02
44	CHF W/O HP	1200	0.247	401.0	377.5	814.3	0.167	
88	CHF W HP	1200	0.257	399.5	375.9	866.0	0.196	1.17
46	CHF W/O HP	1200	0.493	399.8	376.2	735.5	0.275	
94	CHF W HP	1200	0.500	400.2	376.7	731.3	0.276	1.00
48	CHF W/O HP	1200	0.921	400.5	377.0	681.4	0.435	
128*	NO DATA							
48A	CHF W/O HP	1200	0.987	400.7	377.2	684.6	0.471	
128*	NO DATA							Repeat
50	CHF W/O HP	1200	2.010	400.9	377.4	609.6	0.725	
130	CHF W HP	1200	1.973	399.4	375.8	614.6	0.732	1.01
51	CHF W/O HP	1200	0.248	501.0	489.0	837.4	0.134	
105	CHF W HP	1200	0.251	500.2	488.2	887.4	0.155	1.16
53	CHF W/O HP	1200	0.471	500.7	488.6	756.2	0.196	
112	CHF W HP	1200	0.498	500.1	488.0	761.4	0.212	1.08
55	CHF W/O HP	1200	1.083	500.2	488.0	723.0	0.366	
118	CHF W HP	1200	0.980	499.0	486.7	704.7	0.332	.91
57	CHF W/O HP	1200	2.014	500.2	488.1	667.5	0.562	
138	CHF W HP	1200	2.003	500.1	488.0	655.0	0.520	.93

* No data taken at CHF levels, see Run 129 at 98 CHF levels.

TABLE 1 (Continued)

Comparison of Data With and Without A Hot Patch - 1.5 Heat Flux Ratio

RUN NO.	*TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	Ratio of HEAT FLUXES
39	98 W/O HP	2000	0.258	201.6	174.3	769.8	0.239	
83	98 W HP	2000	0.253	199.7	172.4	844.6	0.265	1.11
37	98 W/O HP	2000	0.498	201.6	174.3	695.8	0.403	
35	98 W/O HP	2000	0.991	200.7	173.4	625.2	0.695	
159	98 W HP	2000	1.010	427.8	407.4	699.4	0.458	**
28	98 W/O HP	2000	0.244	401.5	378.9	848.5	0.178	
86	98 W HP	2000	0.254	400.7	378.0	878.2	0.197	1.11
30	98 W/O HP	2000	0.500	402.2	379.7	780.2	0.311	
100	98 W HP	2000	0.495	400.1	377.4	781.5	0.311	1.00
32	98 W/O HP	2000	1.000	399.0	376.2	691.8	0.490	
123	98 W HP	2000	0.985	400.0	377.3	687.2	0.474	.97

*** Type 98 W/O HP means a test run at 98% of CHF without hot patch.**

** Runs not comparable.

TABLE 1 (Continued)

Comparison of Data With and Without A Hot Patch - 1.5 Heat Flux Ratio

RUN NO.	TYPE			PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	Ratio of HEAT FLUXES
26	98	W/O	HP	2000	0.243	502.0	490.1	877.1	0.146	
102	98	W	HP	2000	0.246	499.0	486.6	901.8	0.158	1.08
24	98	W/O	HP	2000	0.495	499.6	487.3	794.8	0.237	
109	98	W	HP	2000	0.502	499.6	487.3	801.3	0.245	1.03
22	98	W/O	HP	2000	1.000	500.6	488.5	742.8	0.395	
115	98	W	HP	2000	0.984	499.0	486.7	736.5	0.382	.97
20	98	W/O	HP	2000	1.997	499.6	487.4	684.8	0.612	
133	98	W	HP	2000	2.000	498.5	486.0	674.7	0.586	.96
59 *	NO DATA									
135	98	W	HP	2000	2.823	499.3	487.0	648.5	0.708	0.
9	98	W/O	HP	2000	0.248	596.1	609.3	904.9	0.114	
145	98	W	HP	2000	0.255	600.0	614.9	929.5	0.125	1.09
11	98	W/O	HP	2000	0.492	599.6	614.4	818.9	0.156	
147	98	W	HP	2000	0.505	599.4	614.1	823.6	0.164	1.05
13	98	W/O	HP	2000	1.013	599.5	614.2	768.6	0.243	
149	98	W	HP	2000	1.019	600.6	615.8	767.1	0.239	.99
15	98	W/O	HP	2000	1.983	599.8	613.5	736.2	0.378	
151	98	W	HP	2000	1.998	599.3	613.9	731.6	0.365	.97
17	98	W/O	HP	2000	2.561	599.5	614.3	720.1	0.421	
153	98	W	HP	2000	2.758	599.0	613.4	712.8	0.426	1.01

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* No data taken at CHF levels, see Run 60 at 98 CHF levels.

TABLE 1 (Continued)

Comparison of Data With and Without A Hot Patch - 1.5 Heat Flux Ratio

RUN NO.		TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	Ratio of HEAT FLUXES	
72	98	W/O HP	1600	0.250	402.5	379.5	821.6	0.172		
91	98	W HP	1600	0.252	398.8	375.6	857.5	0.189	1.10	
74	98	W/O HP	1600	0.502	401.1	378.0	722.4	0.269		
93	98	W HP	1600	0.503	400.2	377.1	750.0	0.291	1.08	
76	98	W/O HP	1600	1.013	400.8	377.7	677.4	0.471		
126	98	W HP	1600	0.982	400.5	377.4	690.8	0.478	1.01	Used on Plot
70	98	W/O HP	1600	0.251	499.4	487.0	854.5	0.143		
104	98	W HP	1600	0.253	499.8	487.4	893.1	0.159	1.11	
68	98	W/O HP	1600	0.507	499.5	487.1	756.0	0.212		
111	98	W HP	1600	0.492	499.1	486.7	778.0	0.222	1.05	
66	98	W/O HP	1600	0.996	500.0	487.6	704.8	0.336		
117	98	W HP	1600	0.976	498.7	486.2	718.5	0.352	1.05	
64	98	W/O HP	1600	1.998	500.4	488.1	671.7	0.570		
137	98	W HP	1600	1.993	499.6	487.2	669.6	0.565	.99	
62	98	W/O HP	1600	2.562	499.7	487.4	660.6	0.690		
143	98	W HP	1600	2.847	498.3	485.7	645.7	0.707	1.03	Used on Plot

TABLE 1 (Continued)

Comparison of Data With and Without A Hot Patch - 1.5 Heat Flux Ratio

RUN NO.		TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	Ratio of HEAT FLUXES	
41	98	W/O HP	1200	0.245	200.2	171.0	677.3	0.193		
155	98	W HP	1200	0.253	200.1	170.9	806.9	0.250	1.29	
43	98	W/O HP	1200	0.501	200.0	170.8	682.0	0.398		
157	98	W HP	1200	0.501	200.2	171.1	686.7	0.401	1.01	
45	98	W/O HP	1200	0.246	400.7	377.2	803.5	0.163		
89	98	W HP	1200	0.257	399.3	375.7	841.7	0.186	1.14	
47	98	W/O HP	1200	0.494	399.8	376.3	729.1	0.271		
95	98	W HP	1200	0.499	400.3	376.8	723.5	0.269	.99	
49	98	W/O HP	1200	0.923	401.1	377.7	676.2	0.428		
129	98	W HP	1200	0.984	398.9	375.2	673.2	0.455	1.06	
49A	98	W/O HP	1200	0.989	401.1	377.6	678.6	0.462		
129	98	W HP	1200	0.984	398.9	375.2	673.2	0.455	.99	Used on Plot
52	98	W/O HP	1200	0.248	501.6	489.7	815.3	0.125		
106	98	W HP	1200	0.251	499.5	487.3	874.1	0.151	1.20	
54	98	W/O HP	1200	0.471	500.7	488.6	745.1	0.188		
113	98	W HP	1200	0.498	500.2	488.0	753.5	0.205	1.09	
56	98	W/O HP	1200	1.008	500.3	488.2	716.2	0.357		
119	98	W HP	1200	0.977	499.2	486.9	701.1	0.325	.91	
58	98	W/O HP	1200	2.021	500.7	488.6	665.9	0.556		
139	98	W HP	1200	2.019	499.8	487.7	651.3	0.513	.92	
60	98	W/O HP	1200	2.297	499.6	487.4	652.6	0.589		
141	98	W HP	1200	2.823	500.1	488.0	625.7	0.604	1.03	Used on Plot

TABLE 2

Comparison of Data With and Without A Hot Patch - 2.25 Heat Flux Ratio

RUN NO.	TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES
38	CHF W/O HP	2000	0.259	201.5	174.2	779.4	0.244	
209	CHF W 2.25 HP	2000	0.254	199.4	172.1	824.9	0.257	1.06
36	CHF W/O HP	2000	0.499	201.4	174.1	706.8	0.413	
211*	NO DATA							
34	CHF W/O HP	2000	0.991	200.7	173.4	635.3	0.711	
217*	NO DATA							
27	CHF W/O HP	2000	0.245	401.8	379.2	858.3	0.182	
175	CHF W 2.25 HP	2000	0.255	397.3	374.4	879.8	0.200	1.10
29	CHF W/O HP	2000	0.500	401.7	379.1	783.8	0.314	
173*	NO DATA							
31	CHF W/O HP	2000	1.000	398.9	376.1	695.5	0.496	
177	CHF W 2.25 HP	2000	0.998	400.8	378.2	676.3	0.462	.93
33**	CHF W/O HP	2000	1.989	400.8	378.1	609.6	0.716	
219**	NO DATA							
25	CHF W/O HP	2000	0.244	501.4	489.3	885.7	0.150	
181	CHF W 2.25 HP	2000	0.252	499.8	487.5	892.5	0.159	1.06
23	CHF W/O HP	2000	0.498	499.7	487.4	800.1	0.242	
191	CHF W 2.25 HP	2000	0.501	500.5	488.4	786.7	0.232	.96

* No data taken at CHF levels, see Runs 212, 218 and 174 at 98 CHF levels.

** **Maximum generator (no CHF) was** reached.

TABLE 2 (Continued)

Comparison of Data With and Without A Hot Patch - 2.25 Heat Flux Ratio

RUN NO.	TYPE	PRES-(PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES
21	CHF W/O HP	2000	1.000	500.4	488.2	747.3	0.402	
193	CHF W 2.25 HP	2000	1.000	500.1	487.9	723.6	0.366	.91
19*	CHF W/O HP	2000	1.990	500.2	488.0	690.2	0.625	
223	NO DATA							
18	CHF W/O HP	2000	2.682	501.1	489.0	660.1	0.713	
229	CHF W 2.25 HP	2000	2.810	499.7	487.5	639.9	0.666	.93
8	CHF W/O HP	2000	0.246	596.2	609.3	916.0	0.117	
205	CHF W 2.25 HP	2000	0.250	601.4	617.0	963.6	0.135	1.15
10	CHF W/O HP	2000	0.493	599.7	614.6	822.8	0.159	
207	CHF W 2.25 HP	2000	0.493	599.7	614.5	828.9	0.164	1.03
12	CHF W/O HP	2000	1.013	599.9	614.8	772.5	0.248	
199	CHF W 2.25 HP	2000	1.023	599.7	614.6	765.1	0.239	.96
14	CHF W/O HP	2000	1.986	599.4	614.1	738.6	0.384	
201	CHF W 2.25 HP	2000	2.007	599.9	614.8	731.4	0.364	.95
16	CHF W/O HP	2000	2.556	600.2	615.3	723.4	0.429	
203	CHF W 2.25 HP	2000	2.690	600.4	615.5	717.3	0.425	.99

* **No data taken at CHF level,** see Run 224 at 98 CHF level.

TABLE 2 (Continued)

Comparison of Data With and Without A Hot Patch - 2.25 Heat Flux Ratio

RUN NO.	TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES
71	CHF W/O HP	1600	0.250	402.5	379.5	842.5	0.180	
167	CHF W 2.25 HP	1600	0.249	400.4	377.3	847.6	0.182	1.01
73	CHF W/O HP	1600	0.501	401.3	378.3	728.3	0.272	
169	CHF W 2.25 HP	1600	0.499	400.5	377.4	740.7	0.281	1.03
75	CHF W/O HP	1600	1.010	400.6	377.5	681.8	0.478	
171	CHF W 2.25 HP	1600	0.998	400.2	377.1	685.5	0.478	1.00
77	CHF W/O HP	1600	2.003	401.0	378.0	610.4	0.723	
221	CHF W 2.25 HP	1600	1.987	400.7	377.6	606.3	0.706	.98
69	CHF W/O HP	1600	0.250	499.3	486.9	868.4	0.148	
183	CHF W 2.25 HP	1600	0.251	500.7	488.5	881.8	0.153	1.03
67	CHF W/O HP	1600	0.508	499.7	487.4	763.4	0.218	
189	CHF W 2.25 HP	1600	0.502	500.8	488.6	781.5	0.228	1.05
65	CHF W/O HP	1600	0.997	499.7	487.3	708.2	0.342	
195	CHF W 2.25 HP	1600	0.974	500.1	487.8	709.3	0.335	.98
63	CHF W/O HP	1600	1.989	500.1	487.8	675.6	0.580	
225	CHF W 2.25 HP	1600	1.969	500.0	487.6	667.4	0.550	.95
61*	NO DATA							
227	CHF W 2.25 HP	1600	2.772	500.5	488.2	632.1	0.620	

* No data taken at CHF level, see Run 62 at 98 CHF level.

TABLE 2 (Continued)

Comparison of Data With and Without A Hot Patch - 2.25 Heat Flux Ratio

RUN NO.	TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES	
40	CHF W/O HP	1200	0.245	200.2	171.1	704.3	0.203		
215	CHF W 2.25 HP	1200	0.255	200.8	171.6	765.9	0.236	1.16	
42	CHF W/O HP	1200	0.501	199.8	170.6	689.0	0.404		
213	CHF W 2.25 HP	1200	0.500	201.1	171.9	650.1	0.372	.92	
44	CHF W/O HP	1200	0.247	401.0	377.5	814.3	0.167		
160	CHF W 2.25 HP	1200	0.247	400.2	376.7	845.9	0.180	1.08	
46	CHF W/O HP	1200	0.493	399.8	376.2	735.5	0.275		
162	CHF W 2.25 HP	1200	0.497	400.1	376.6	730.9	0.274	.99	
48	CHF W/O HP	1200	0.921	400.5	377.0	681.4	0.435		
164	CHF W 2.25 HP	1200	0.989	400.5	377.0	663.2	0.440	1.01	
48A	CHF W/O HP	1200	0.987	400.7	377.2	684.6	0.471		
164	CHF W 2.25 HP	1200	0.989	400.5	377.0	663.2	0.440	.93	Repeat
50	CHF W/O HP	1200	2.010	400.9	377.4	609.6	0.725		
166	CHF W 2.25 HP	1200	1.991	400.6	377.1	565.4	0.582	.80	
51	CHF W/O HP	1200	0.248	501.0	489.0	837.4	0.134		
185	CHF W 2.25 HP	1200	0.251	497.3	484.8	863.6	0.148	1.10	
53	CHF W/O HP	1200	0.471	500.7	488.6	756.2	0.196		
187	CHF W 2.25 HP	1200	0.499	498.5	486.1	763.5	0.215	1.10	
55	CHF W/O HP	1200	1.003	500.2	488.0	723.0	0.366		
197	CHF W 2.25 HP	1200	1.011	499.3	487.1	693.4	0.324	.88	
57	CHF W/O HP	1200	2.014	500.2	488.1	667.6	0.562		

No 2.25 hot patch data taken due to generator limitations.

59* NO DATA

No 2.25 hot patch data taken due to generator limitations

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* No data taken at CHF level, see Table 6 (Run 60) at 98 CHF level.

TABLE 2 (Continued)

Comparison of Data With and Without A Hot Patch - 2.25 Heat Flux Ratio

RUN NO.		TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES	
39	98	W/O HP	2000	0.258	201.6	174.3	769.8	0.239		
210	98	W 2.25 HP	2000	0.254	199.4	172.0	809.2	0.252	1.05	
37	98	W/O HP	2000	0.498	201.6	174.3	695.8	0.403		
212	98	W 2.25 HP	2000	0.497	201.1	173.8	711.1	0.415	1.03	Used in Plot
35	98	W/O HP	2000	0.991	200.7	173.4	625.2	0.695		
218	98	W 2.25 HP	2000	1.002	200.6	173.2	559.9	0.601	.86	
28	98	W/O HP	2000	0.244	401.5	378.9	848.5	0.178		
176	98	W 2.25 HP	2000	0.254	399.4	376.6	860.8	0.191	1.08	
30	98	W/O HP	2000	0.500	402.2	379.7	780.2	0.311		
174	98	W 2.25 HP	2000	0.496	400.3	377.6	783.2	0.313	1.00	Used in Plot
32	98	W/O HP	2000	1.000	399.0	376.2	691.8	0.490		
178	98	W 2.25 HP	2000	0.998	401.2	378.6	673.4	0.457	.93	
26	98	W/O HP	2000	0.243	502.0	490.1	877.1	0.146		
182	98	W 2.25 HP	2000	0.255	499.8	487.5	874.2	0.153	1.05	
24	98	W/O HP	2000	0.495	499.6	487.3	794.8	0.237		
192	98	W 2.25 HP	2000	0.502	500.5	488.3	776.9	0.225	.95	

TABLE 2 (Continued)

Comparison of Data With and Without A Hot Patch - 2.25 Heat Flux Ratio

RUN NO.		TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES
22	98	W/O HP	2000	1.000	500.6	488.5	742.8	0.395	
194	98	W 2.25 HP	2000	1.000	500.2	487.9	717.2	0.356	.90
20	98	W/O HP	2000	1.997	499.6	487.4	684.8	0.612	
224	98	W 2.25 HP	2000	1.995	501.4	489.3	663.4	0.540	.88
9	98	W/O HP	2000	0.248	596.1	609.3	904.9	0.114	
206	98	W 2.25 HP	2000	0.251	600.9	616.3	953.5	0.132	1.15
11	98	W/O HP	2000	0.492	599.6	614.4	818.9	0.156	
208	98	W 2.25 HP	2000	0.492	599.7	614.5	824.3	0.160	1.03
13	98	W/O HP	2000	1.013	599.5	614.2	768.6	0.243	
200	98	W 2.25 HP	2000	1.019	599.6	614.3	760.0	0.231	.95
15	98	W/O HP	2000	1.983	599.0	613.5	736.2	0.378	
202	98	W 2.25 HP	2000	2.011	599.5	614.2	726.7	0.351	.93
17	98	W/O HP	2000	2.561	599.5	614.3	720.1	0.421	
204	98	W 2.25 HP	2000	2.694	600.0	615.0	713.2	0.411	.98

TABLE 2 (Continued)

Comparison of Data With and Without A Hot Patch - 2.25 Heat Flux Ratio

RUN NO.		TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES	
72	98	W/O HP	1600	0.250	402.5	379.5	821.6	0.172		
168	98	W 2.25 HP	1600	0.248	400.4	377.3	828.2	0.174	1.01	
74	98	W/O HP	1600	0.502	401.1	378.0	722.4	0.269		
170	98	W 2.25 HP	1600	0.499	400.5	377.4	727.3	0.271	1.01	
76	98	W/O HP	1600	1.013	400.8	377.7	677.4	0.471		
172	98	W 2.25 HP	1600	1.000	400.4	377.2	666.2	0.449	.95	
78	CHF	W/O HP	1600	1.985	400.1	376.6	612.9	0.728		
222	98	W 2.25 HP	1600	1.985	400.2	377.1	599.4	0.686	.94	
70	98	W/O HP	1600	0.251	499.4	487.0	854.5	0.143		
184	98	W 2.25 HP	1600	0.250	499.4	486.9	863.3	0.146	1.02	
68	98	W/O HP	1600	0.507	499.5	487.1	756.0	0.212		
190	98	W 2.25 HP	1600	0.502	500.5	488.2	772.7	0.222	1.05	
66	98	W/O HP	1600	0.996	500.0	487.6	704.8	0.336		
196	98	W 2.25 HP	1600	0.973	499.5	487.1	703.1	0.327	.97	
64	98	W/O HP	1600	1.998	500.4	488.1	671.7	0.570		
226	98	W 2.25 HP	1600	1.976	500.5	488.3	662.1	0.533	.94	
62	98	W/O HP	1600	2.562	499.7	487.4	660.6	0.690		
228	98	W 2.25 HP	1600	2.780	500.5	488.3	635.2	0.634	.92	Used In Plot

TABLE 2 (Continued)

Comparison of Data With and Without A Hot Patch - 2.25 Heat Flux Ratio

RUN NO.		TYPE	PRES- (PSIA)	MASS VELOCITY X 10-6 (LB/HR-FTSQ)	INLET TEMPER-ATURE (DEG.F.)	MEASURED INLET ENTHALPY (BTU/LB)	CALCU-LATED EXIT ENTHALPY (BTU/LB)	AVERAGE HEAT FLUX X 10-6 (BTU/HR-FTSQ)	RATIO OF CRITICAL HEAT FLUXES
41	98	W/O HP	1200	0.245	200.2	171.0	677.3	0.193	
216	98	W 2.25 HP	1200	0.255	200.7	171.5	746.2	0.228	1.18
43	98	W/O HP	1200	0.501	200.0	170.8	682.0	0.398	
214	98	W 2.25 HP	1200	0.500	201.0	171.8	634.6	0.359	.90
45	98	W/O HP	1200	0.246	400.7	377.2	803.5	0.163	
161	98	W 2.25 HP	1200	0.246	400.3	376.8	826.8	0.172	1.06
47	98	W/O HP	1200	0.494	399.8	376.3	729.1	0.271	
163	98	W 2.25 HP	1200	0.497	400.4	376.9	716.9	0.262	.97
49	98	W/O HP	1200	0.923	401.1	377.7	676.2	0.428	
165	98	W 2.25 HP	1200	0.988	400.2	376.6	655.1	0.427	1.00
49A	98	W/O HP	1200	0.989	401.1	377.6	678.6	0.462	
165	98	W 2.25 HP	1200	0.988	400.2	376.6	655.1	0.427	.92
52	98	W/O HP	1200	0.248	501.6	489.7	815.3	0.125	
186	98	W 2.25 HP	1200	0.251	499.6	487.4	842.8	0.139	1.11
54	98	W/O HP	1200	0.471	500.7	488.6	745.1	0.188	
188	98	W 2.25 HP	1200	0.495	500.4	488.3	759.6	0.209	1.11
56	98	W/O HP	1200	1.008	500.3	488.2	716.2	0.357	
198	98	W 2.25 HP	1200	1.015	499.2	486.9	686.4	0.315	.88
58	98	W/O HP	1200	2.021	500.7	488.6	665.9	0.556	

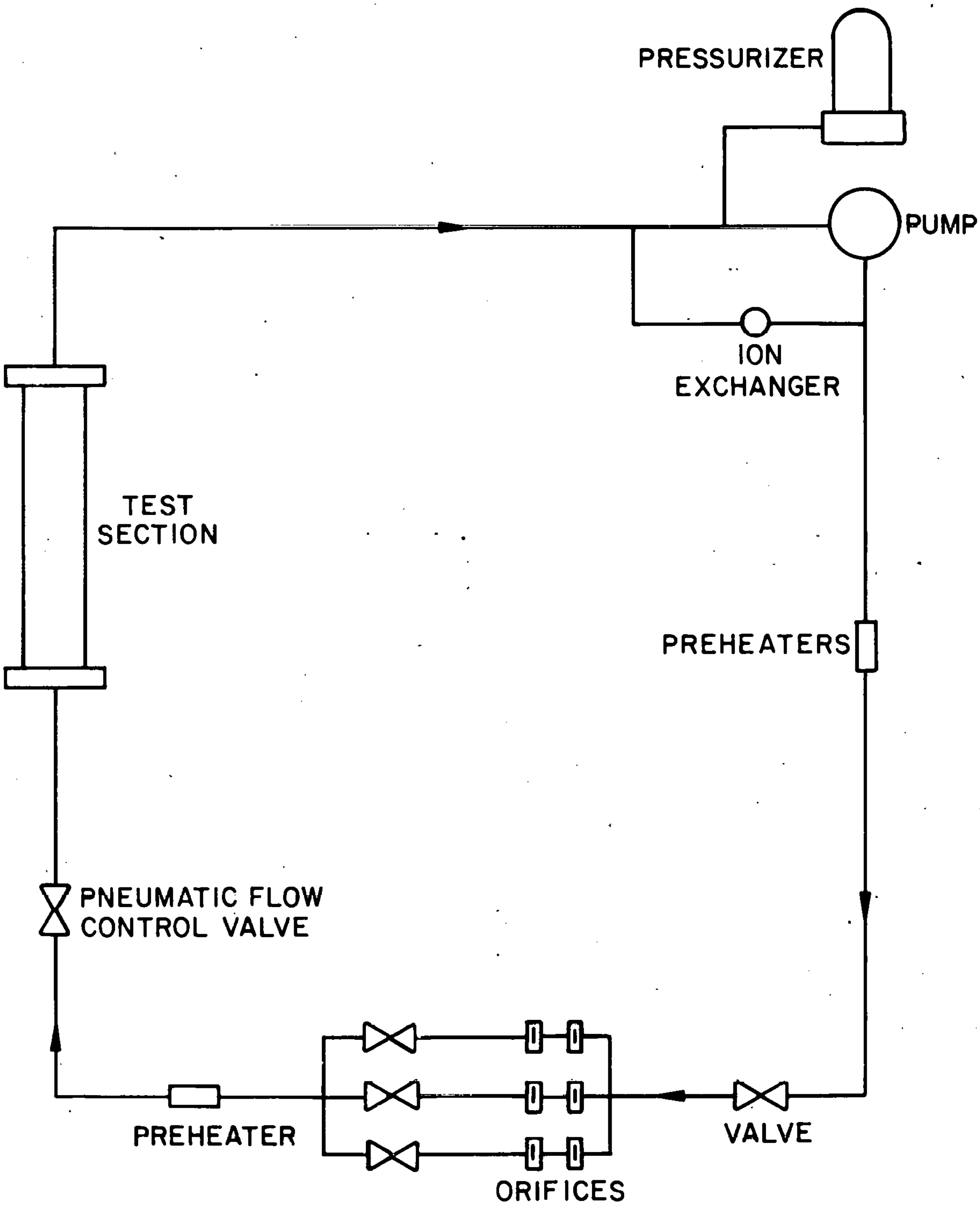


FIGURE I: SCHEMATIC DIAGRAM OF HOT PATCH TEST LOOP

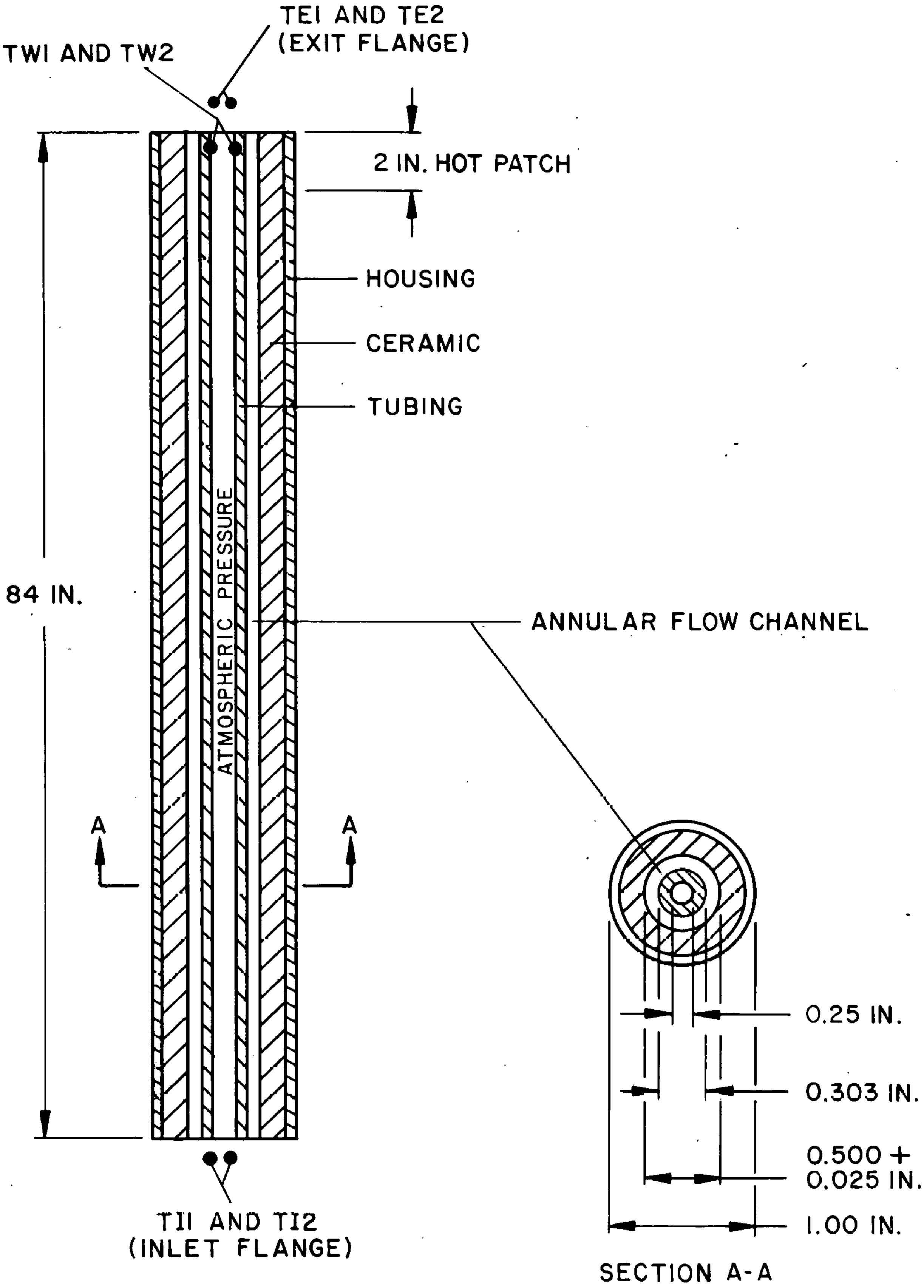


FIGURE 2: TEST SECTION AND INSTRUMENTATION

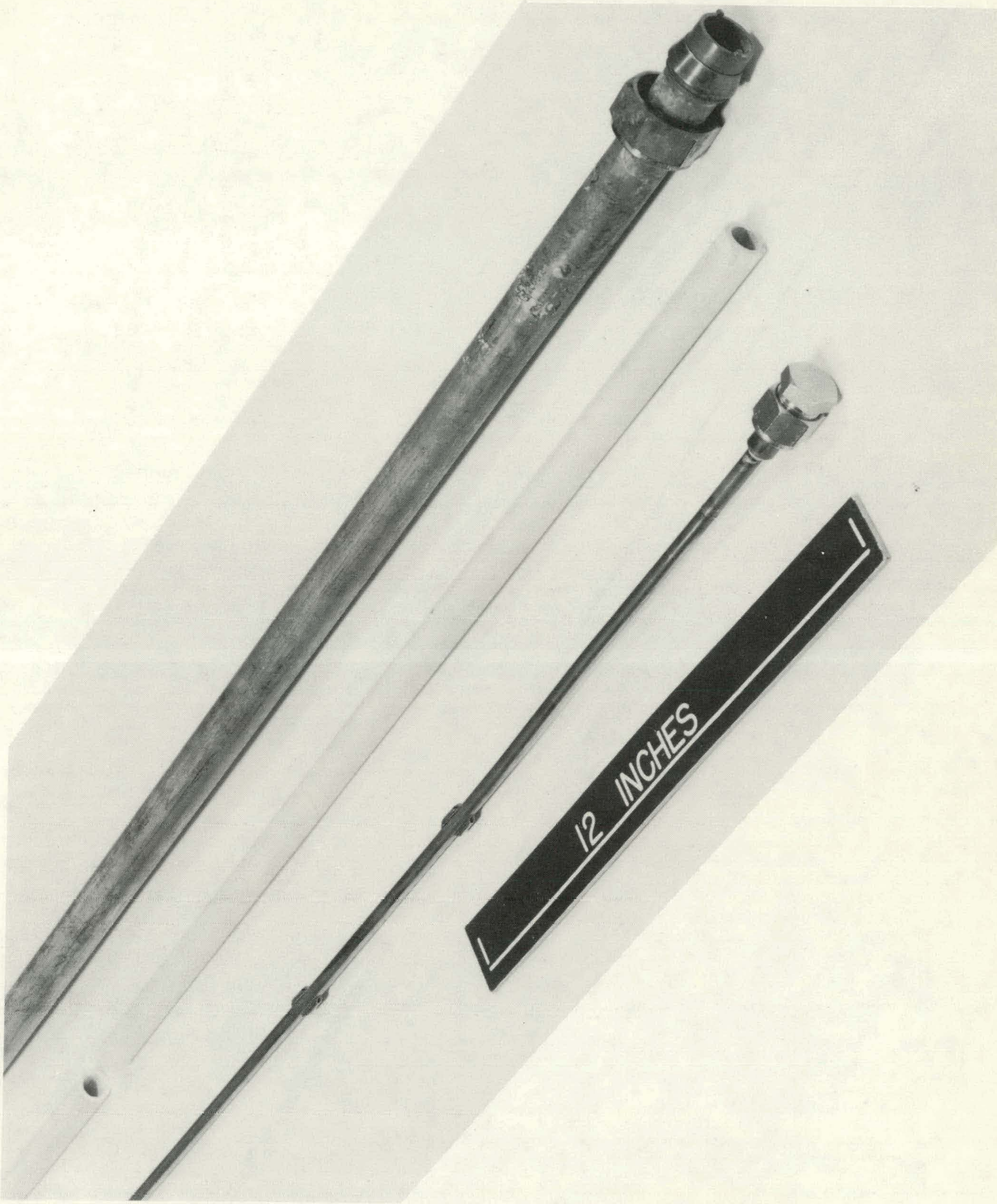


FIGURE 3: Partial Axial View of Hot Patch Test Section, Ceramic Housing and Backup Housing

Negative No. 51944-2

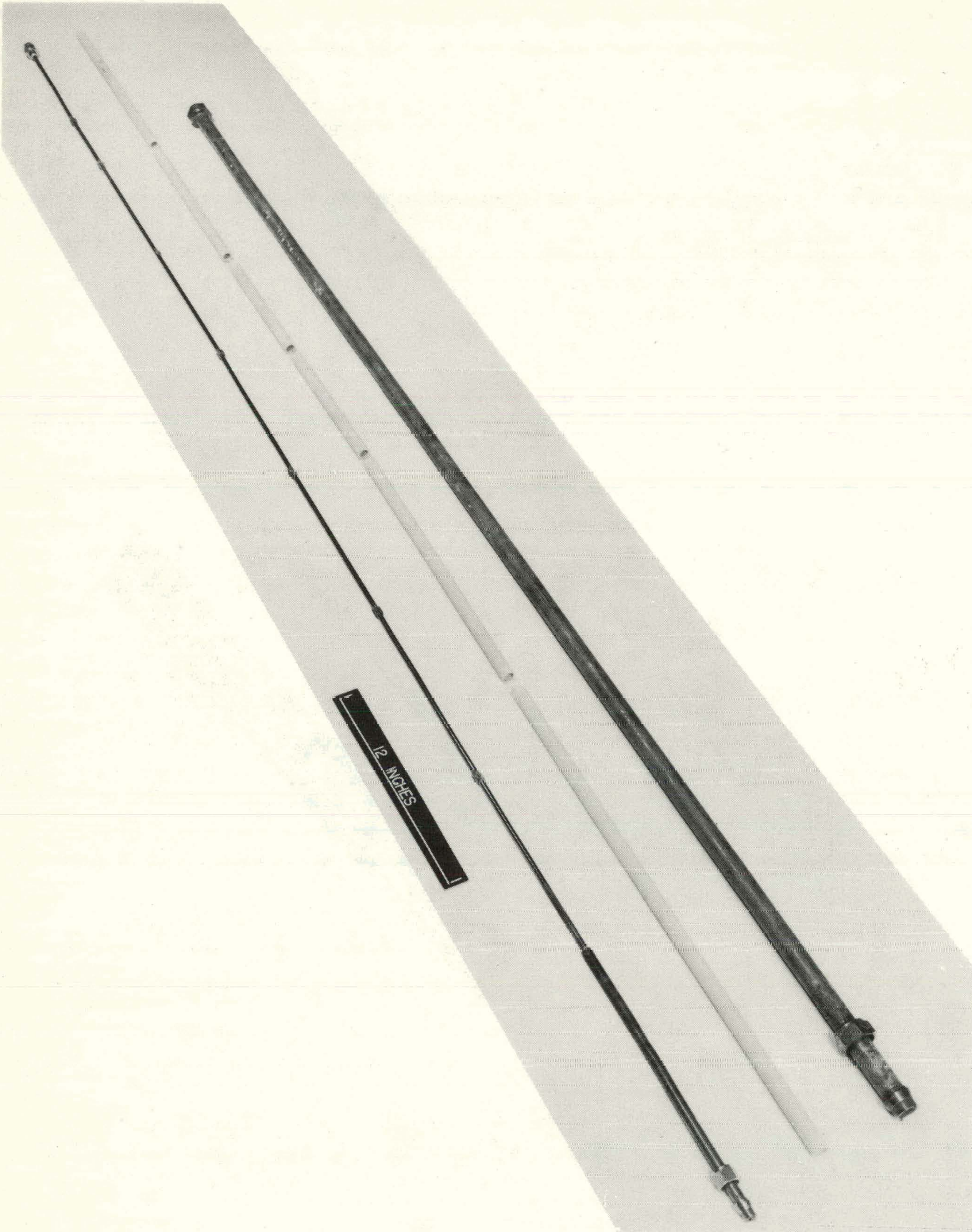


FIGURE 4. Full Axial View of Hot Patch Test Section, Ceramic Housing and Backup Housing

Negative No. 51944-3

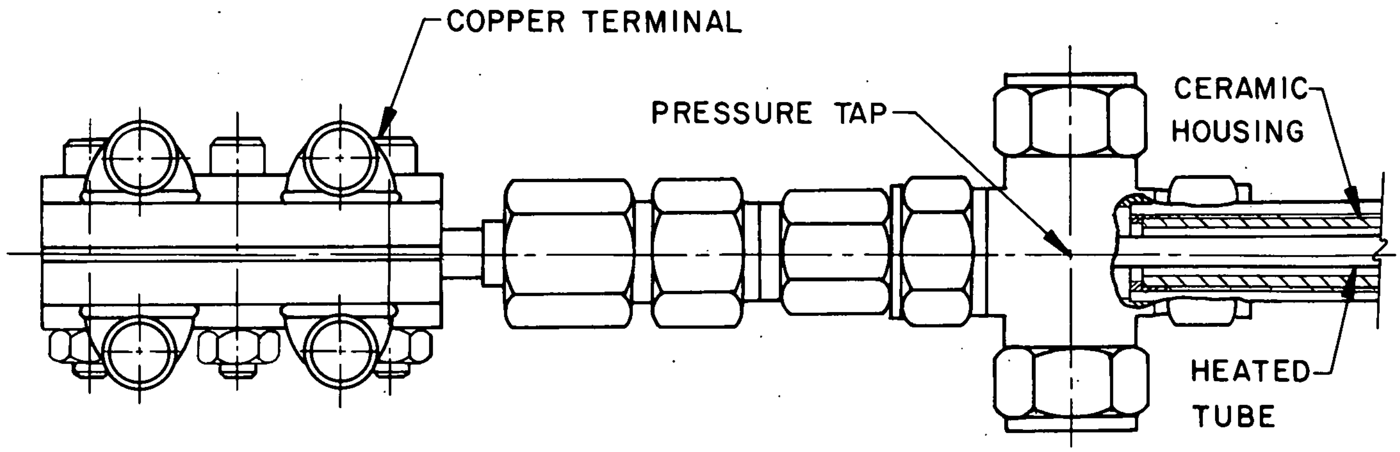


FIGURE 5. DETAILED SCHEMATIC OF INLET REGION OF HOT PATCH TEST SECTION

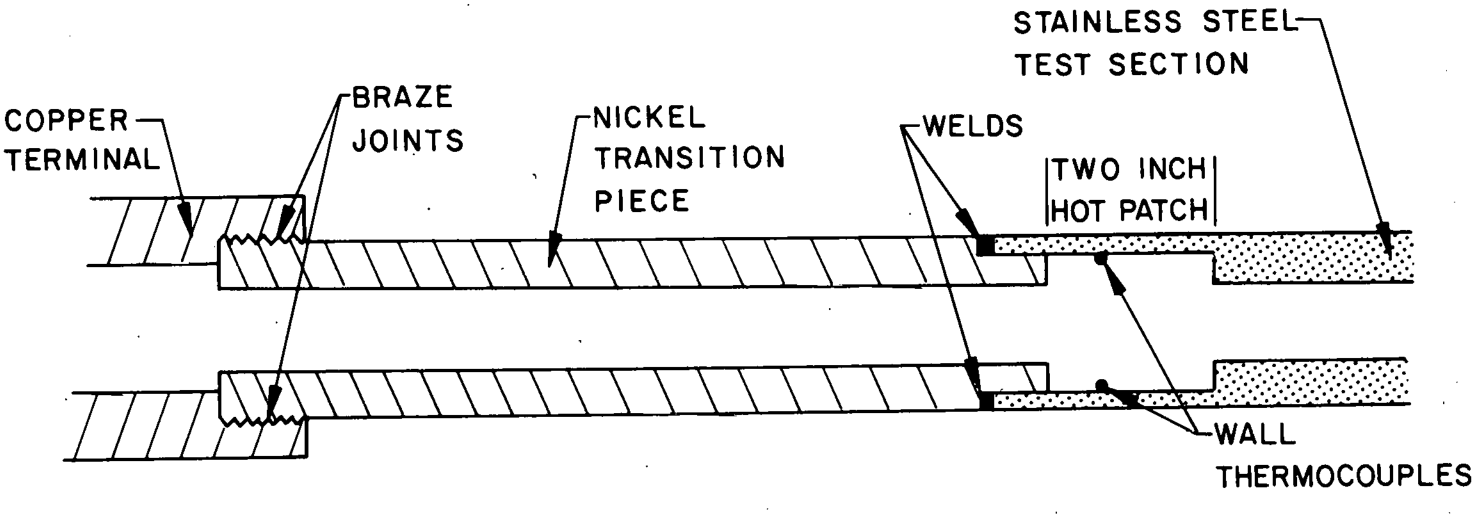


FIGURE 6. HEATED TUBE END CONNECTION DETAIL (NOT TO SCALE)

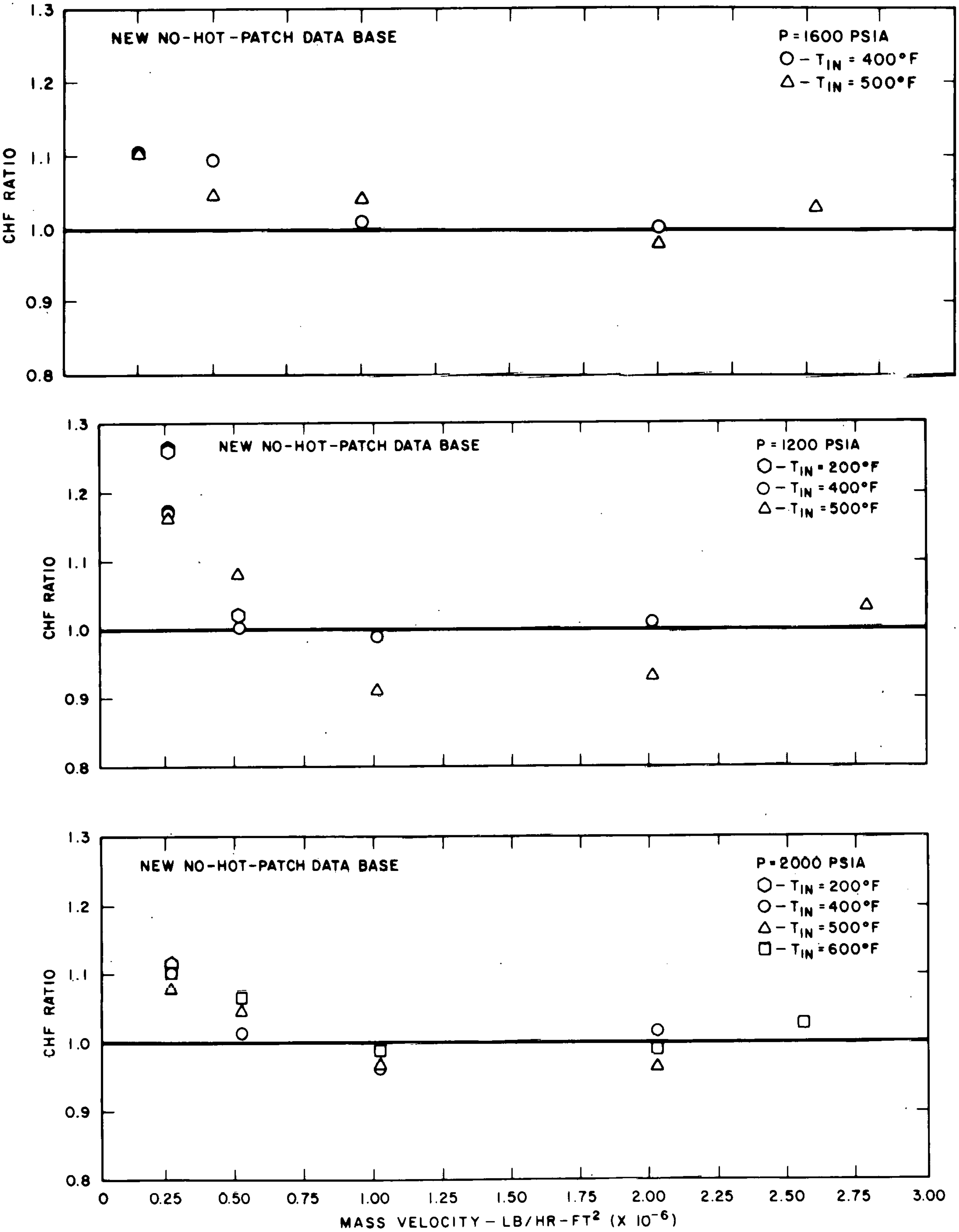
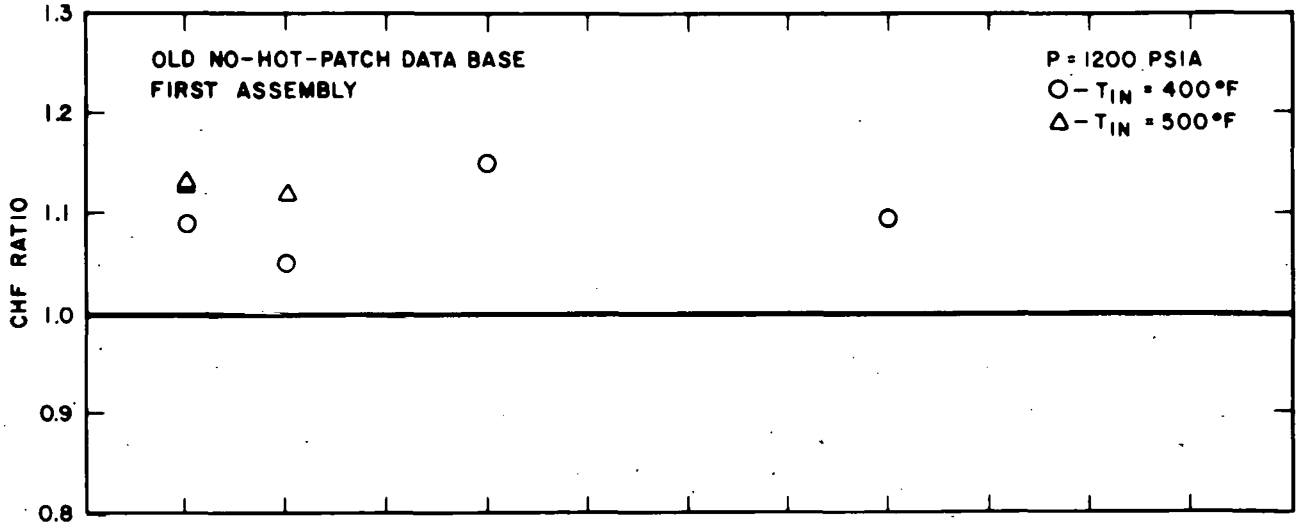


FIGURE 7: CHF RATIO DATA COMPARISON FOR HOT PATCH TEST WITH 1.5 HEAT FLUX RATIO



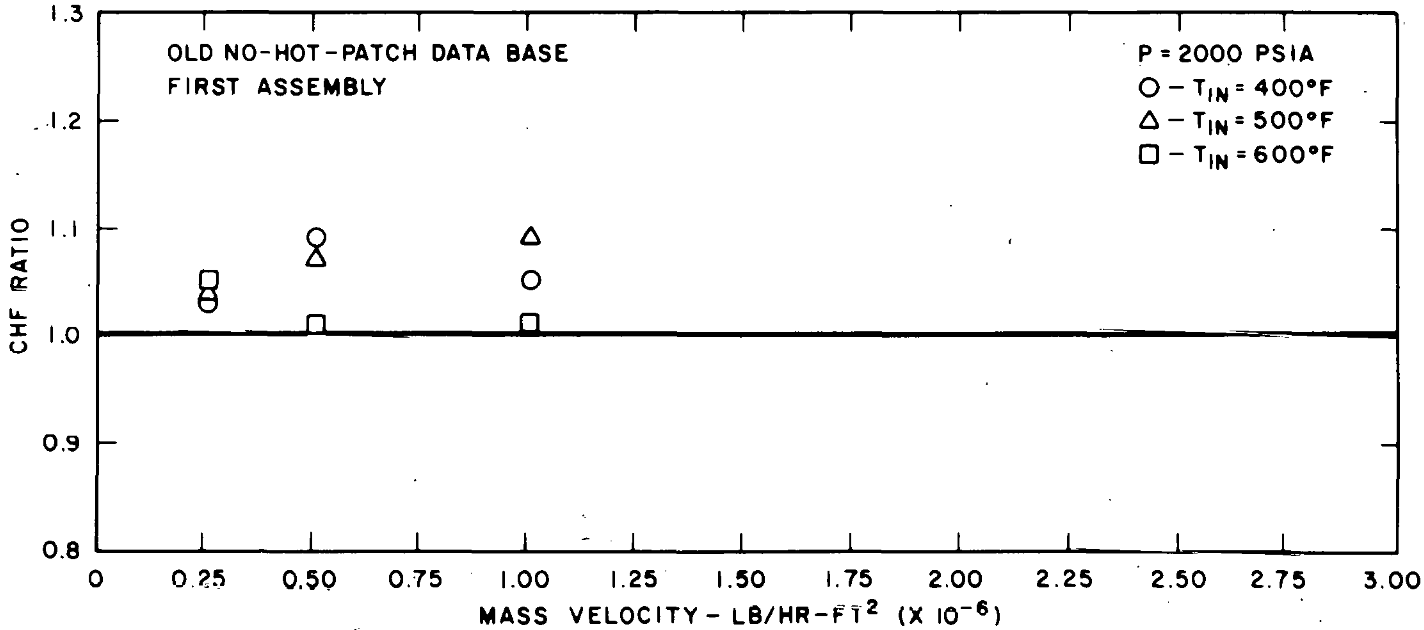


FIGURE 8: CHF RATIO DATA COMPARISON FOR 1.5 HOT PATCH TEST HEAT FLUX RATIO

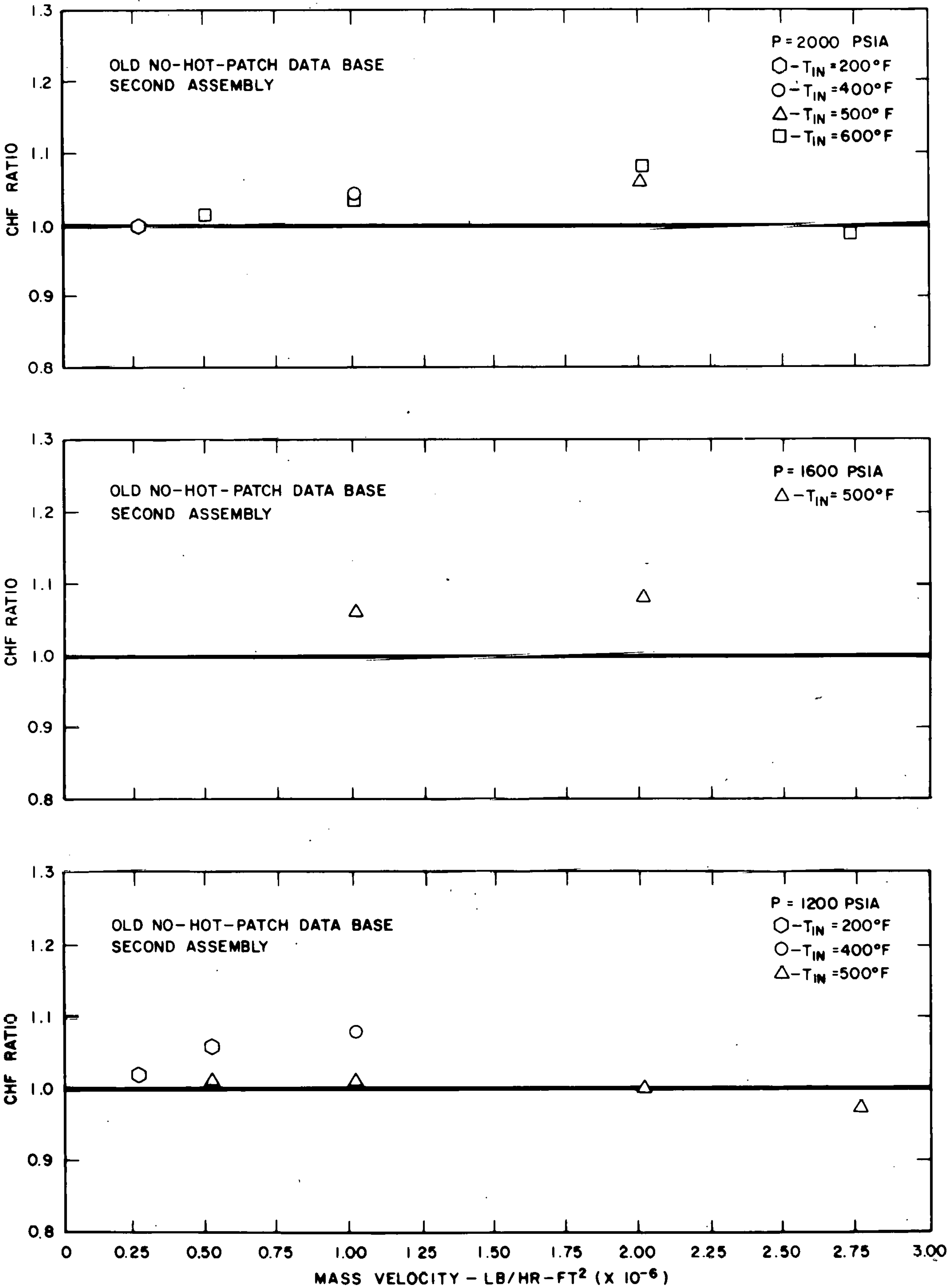


FIGURE 9. CHF RATIO DATA COMPARISON FOR 1.5 HOT PATCH TEST

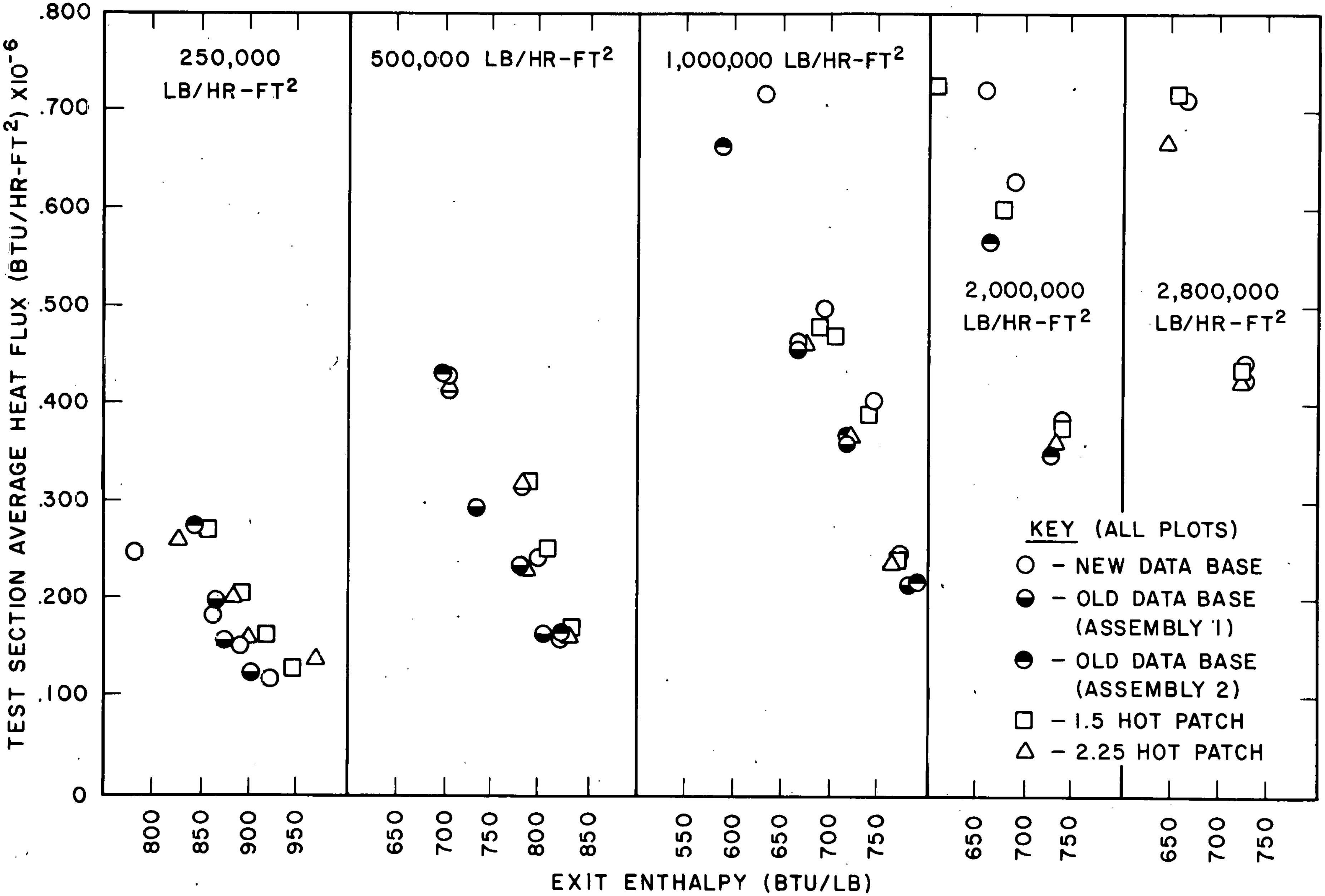


FIGURE 10: SUMMARY OF ALL CHF DATA AT 2000 PSIA

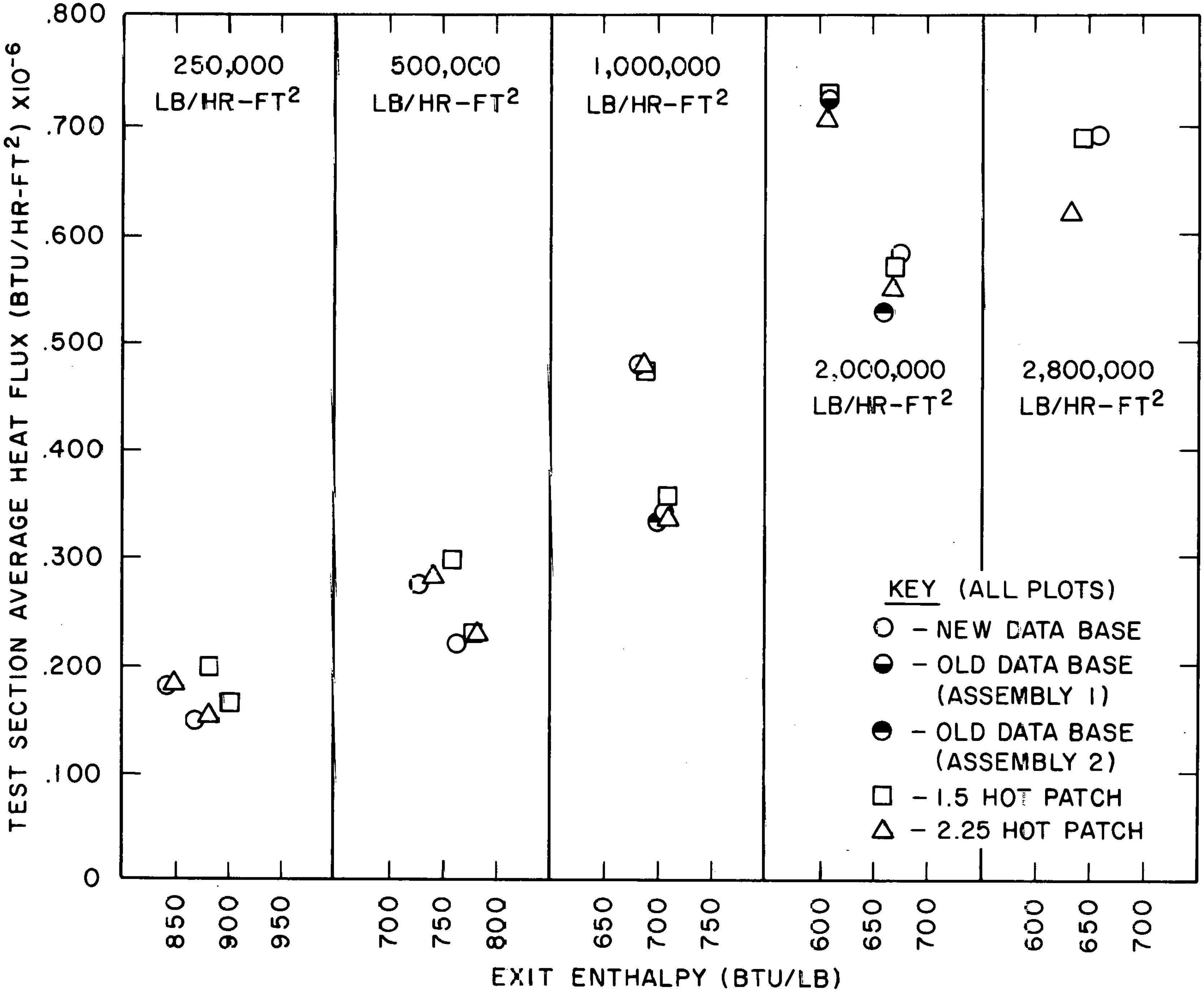


FIGURE 11: SUMMARY OF ALL CHF DATA AT 1600 PSIA

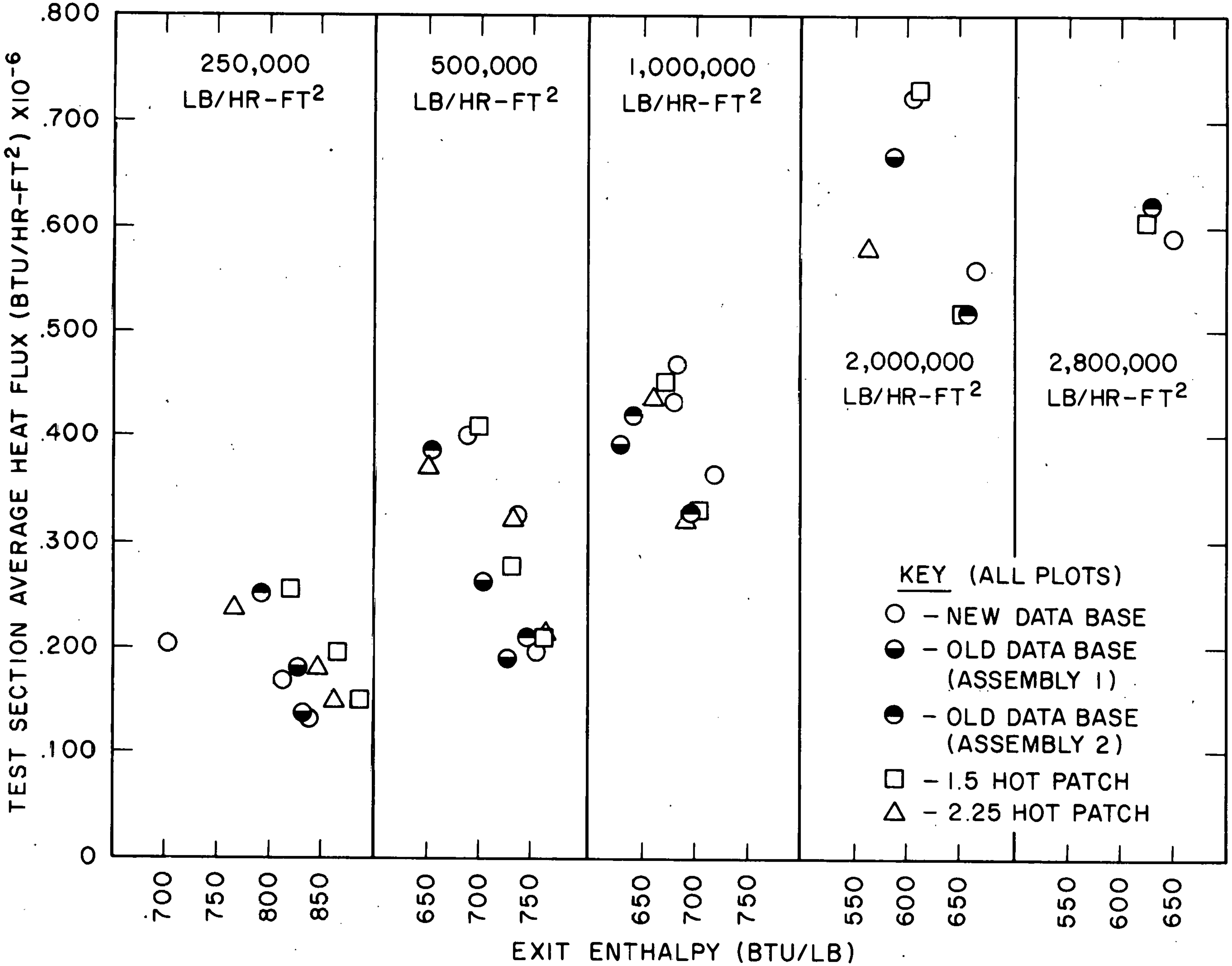


FIGURE 12: SUMMARY OF ALL CHF DATA AT 1200 PSIA

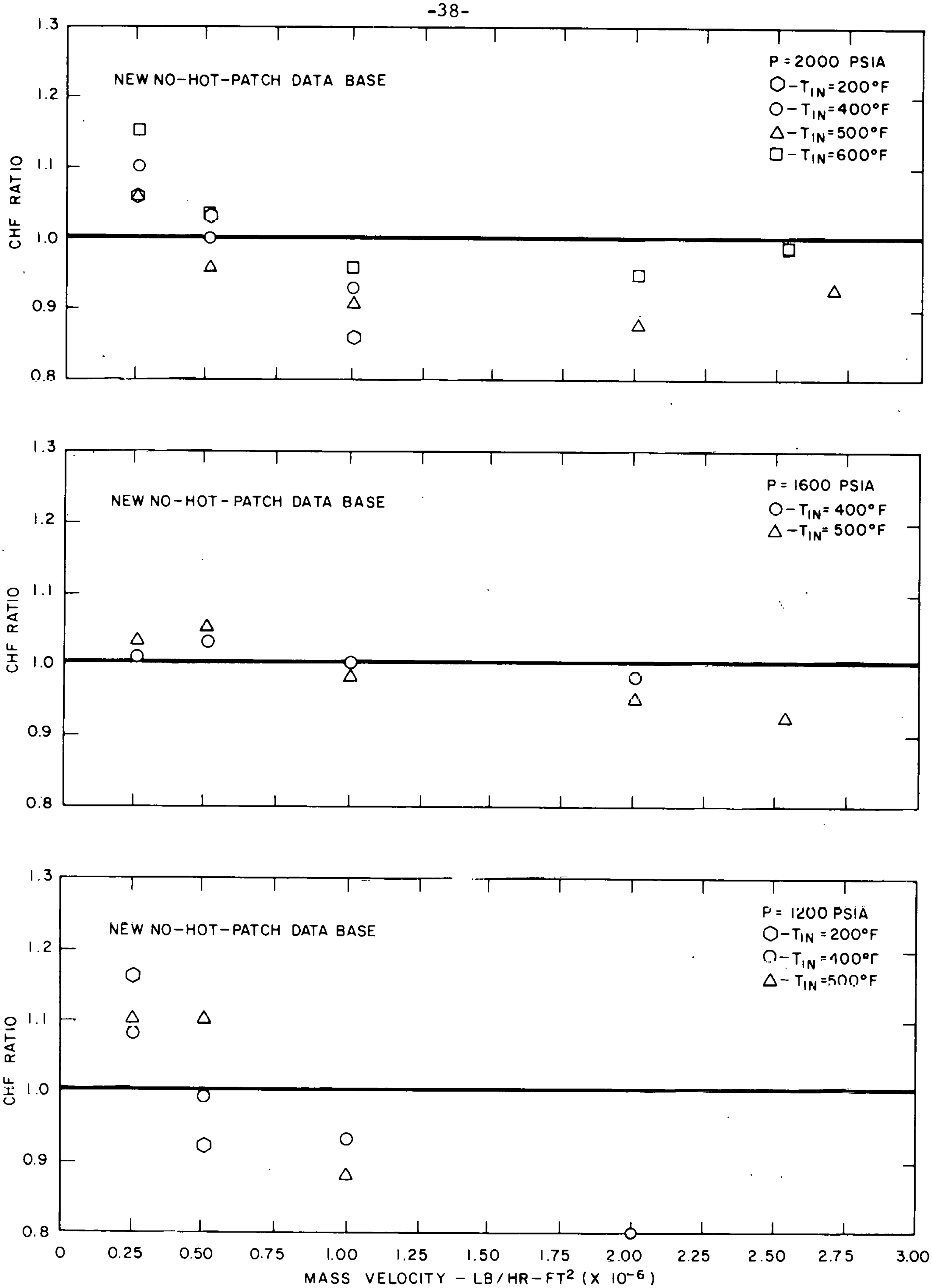


FIGURE 13. CHF RATIO DATA COMPARISON FOR 2.25 HOT PATCH TEST

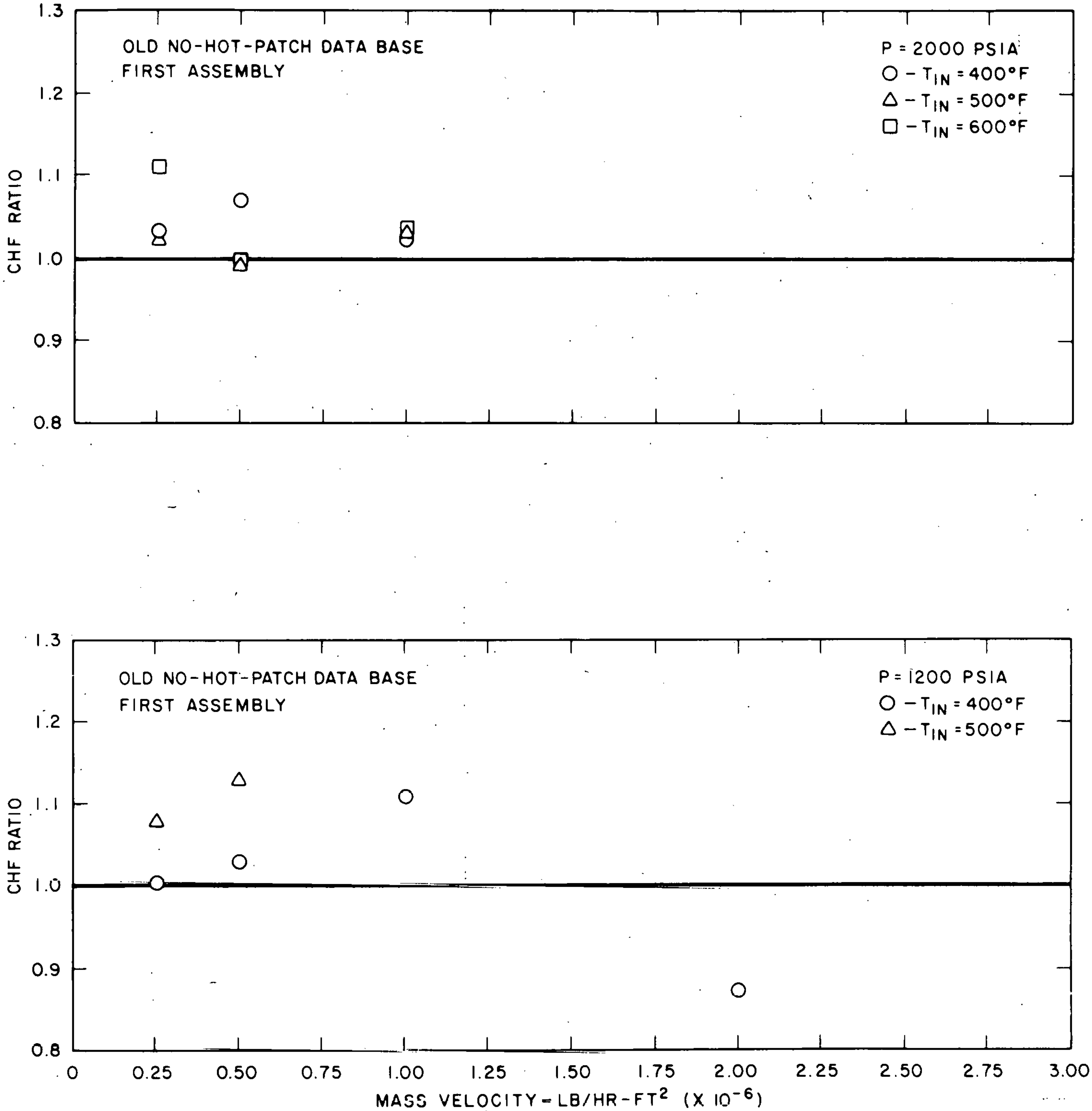


FIGURE 14: CHF RATIO DATA COMPARISON FOR 2.25 HOT PATCH TEST

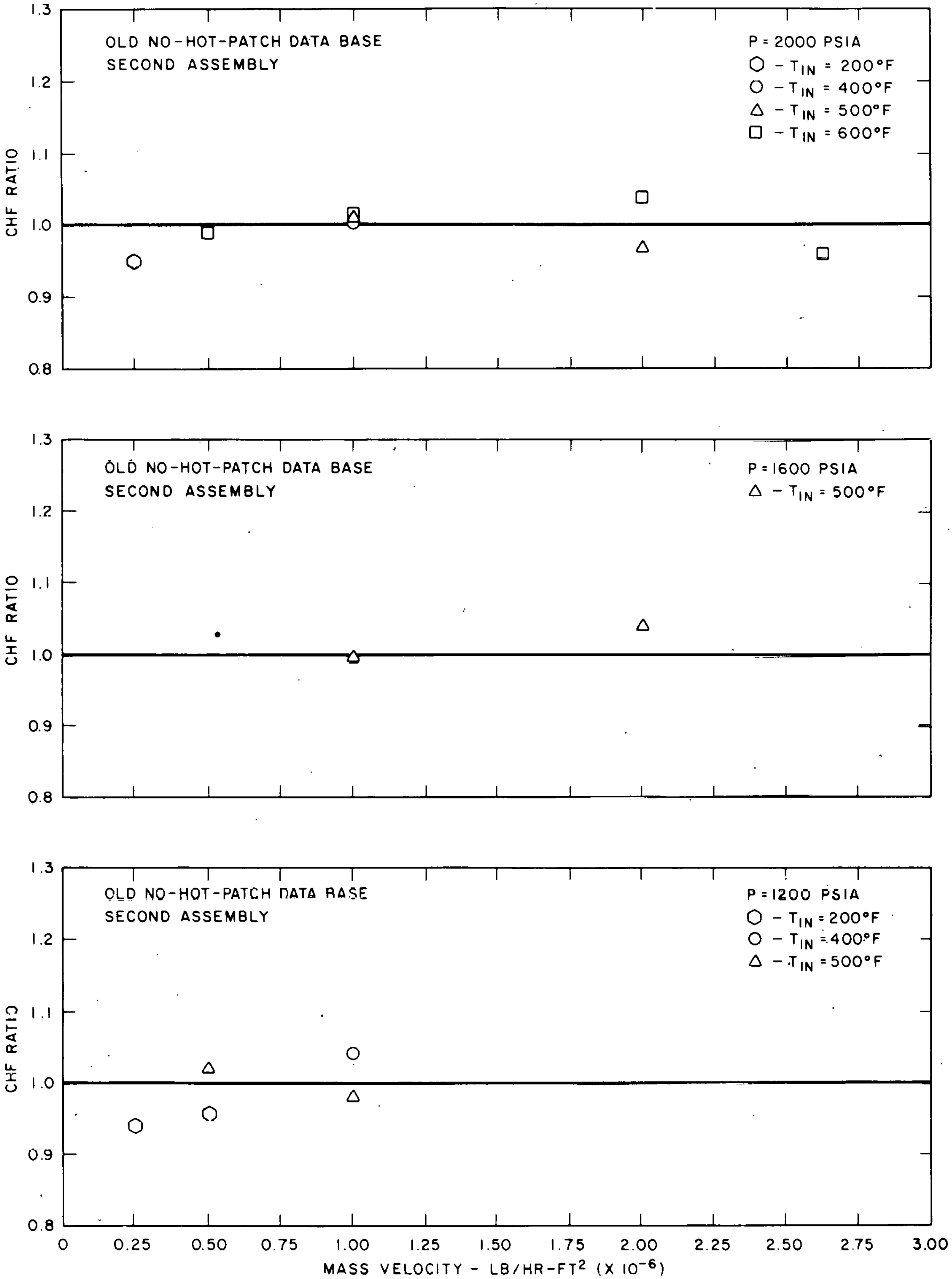


FIGURE 15: CHF RATIO DATA COMPARISON FOR 2.25 HOT PATCH TEST

Internally Heated Annulus CHF Experiments

This Appendix describes critical heat flux experiments conducted in 1969 in the Thermal and Hydraulics Laboratory at Bettis Atomic Power Laboratory in which a single rod was used as an internally heated annulus. Tests were conducted in two assemblies which were nominally identical to each other and to the no-hot-patch test assembly described in this report.

The test sections were comprised of a 0.303 inch stainless steel rod with a 84 inch heated length, located inside of ceramic tubes (alumina) with a nominal 0.50 inch I.D. with vertical upflow of water. The rod was centered inside the ceramic tubes by double window spring collars similar to those described in Reference (a). The last spacer was located 9 inches upstream from the end of the heated length and additional spacers were located every 12 inches upstream.

Data were obtained over the following range of variables:

Pressure: 800, 1200, 1600 and 2000 psia

Mass Velocity: 0.25×10^6 to 2.8×10^6 lb/hr-ft^2

Inlet Temperature: 200 to 600°F

Heat Flux: 0.12×10^6 to 0.71×10^6 Btu/hr-ft^2

Table A presents the CHF data for assemblies 1 and 2. The test section insulation was judged to be sufficient to prevent appreciable heat loss and so no heat loss corrections were applied to the data.

Reference

(a) WAPD-TM-1013, "Critical Heat Fux and Pressure Drop Testing in Bundles of Twenty Rods," B. W. LeTourneau, et al, January 1975

TABLE A

CHF Data With Last Spacer 9 Inches From the End of the Heated Length

Run No.	Pressure P (psia)	Mass Velocity $G \times 10^{-6}$ (lb/hr-ft^2)	Inlet Enthalpy H_{in} (Btu/lb)	Heat Flux $\emptyset \times 10^{-6}$ (Btu/hr-ft^2)	Exit Enthalpy H_{ex} (Btu/lb)
(FIRST ASSEMBLY)					
345-04-1	2000	0.259	378	0.195	862
345-02-1	2000	0.260	485	0.165	871
345-03-7	2000	0.261	597	0.122	899
345-04-3	2000	0.520	377	0.292	738
345-02-3	2000	0.518	486	0.234	777
345-03-5	2000	0.521	601	0.165	805
345-08-3	2000	1.003	377	0.454	669
345-03-1	2000	1.003	487	0.356	716
345-03-3	2000	1.006	614	0.233	763
345-08-5	2000	1.501	377	0.627	645
345-04-7	1200	0.258	379	0.180	828
345-05-1	1200	0.258	488	0.137	830
345-04-5	1200	0.519	376	0.264	704
345-05-3	1200	0.516	488	0.190	726
345-07-5	1200	1.003	377	0.395	630
345-07-7	1200	1.501	379	0.536	608
345-08-1	1200	2.001	376	0.668	591
345-06-6	800	0.257	376	0.153	759
347-07-1	800	0.413	376	0.195	681
345-06-1	800	0.516	376	0.221	650
345-05-7	800	0.619	375	0.247	632
345-05-5	800	0.776	377	0.285	613
345-07-3	800	1.002	376	0.349	600
(SECOND ASSEMBLY)					
345-20-5	2000	0.259	172	0.270	841
345-20-7	2000	0.519	173	0.425	701
345-18-1	2000	0.516	613	0.166	819
345-21-1	2000	1.004	171	0.658	592
345-19-4	2000	0.999	377	0.460	673
345-16-4	2000	1.005	490	0.362	721
345-17-7	2000	1.017	614	0.236	763
345-19-5	2000	1.506	377	0.616	641
345-16-5	2000	1.501	490	0.462	688
345-17-5	2000	1.522	613	0.304	741

TABLE A (Continued)

Run No.	Pressure P (psia)	Mass Velocity $G \times 10^{-6}$ ($lb/hr\text{-}ft^2$)	Inlet Enthalpy H_{in} (Btu/lb)	Heat Flux $\phi \times 10^{-6}$ ($Btu/hr\text{-}ft^2$)	Exit Enthalpy H_{ex} (Btu/lb)
345-16-7	2000	2.012	484	0.564	664
345-17-3	2000	2.024	615	0.350	727
345-17-1	2000	2.709	613	0.444	718
345-19-3	1600	1.002	484	0.336	700
345-19-2	1600	1.501	487	0.446	678
345-19-1	1600	1.998	490	0.528	660
345-20-1	1200	0.258	171	0.251	795
345-20-3	1200	0.516	172	0.387	654
345-18-2	1200	0.516	486	0.210	748
345-19-7	1200	1.004	374	0.422	644
345-18-3	1200	1.004	487	0.329	698
345-19-6	1200	1.503	374	0.560	614
345-18-4	1200	1.497	487	0.439	675
345-18-5	1200	1.999	488	0.520	656
345-18-6	1200	2.806	489	0.622	631

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