THE EFFECT OF NONUNIFORM AXIAL HEAT FLUX DISTRIBUTION

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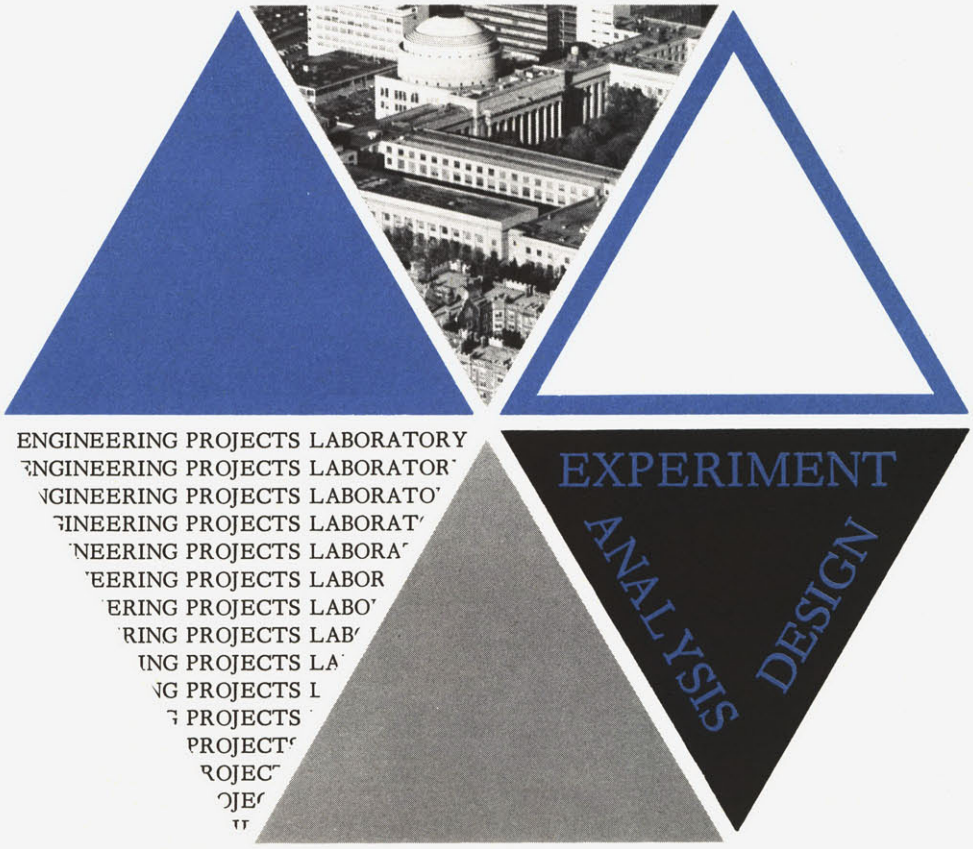

TECHNICAL REPORT
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THE EFFECT OF NONUNIFORM AXIAL HEAT FLUX DISTRIBUTION ON THE CRITICAL HEAT FLUX

by

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Abstract

A systematic experimental and analytic investigation of the effect of nonuniform axial heat flux distribution on critical heat flux was performed with water in the quality condition. Utilizing a model which ascribes the critical condition, to either a nucleation-induced disruption of the annular liquid film or annular film dryout, the experimental results taken at low pressures (50-200 psia) were confirmed. Application of this model to higher pressure conditions (500-2000 psia) indicated qualitative agreement with available data of other investigators.

Experimental data was obtained for flux distributions representing cosine, linear increasing and decreasing, inlet and exit peaked, spike and uniform shapes. These flux distributions were achieved by electrical resistance heating of test sections whose outside diameter had been machined to the required dimensions. In each case the critical location as well as the total critical power was obtained by testing the tubes in vertical upflow to failure.

The analytic prediction of the results for all flux shapes has been achieved by development of a model which considers the effect of nucleation within the annular film. It is shown that the occurrence of the critical condition is related to the local degree of nucleation (the ratio of the local flux to the flux required to cause nucleation at the local conditions) and the local film flow rate. Both the experimental total critical power and the critical location are confirmed by this model. The results indicate that the total critical power for the outlet peaked flux distributions tested (ratios of maximum to minimum flux of 2, 4, and 5.75 to 1) can be 15 to 30% lower than for uniform flux distributions at comparable hydrodynamic operating conditions. In addition, from this model for given operating conditions, a locus of critical conditions can be constructed from uniform flux distribution data which will enable prediction of the performance of nonuniform flux distributions at similar conditions of mass velocity, pressure and diameter.

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NOMENCLATURE

Symbol	Variable	Units
A_F	Flow cross sectional area	ft^2
A_S	Inside surface area	ft^2
A_X	Wall cross sectional area	ft^2
D_i	Inside diameter	inches
C_p	Specific heat at constant pressure	btu/lbm^oF
C_1	Constant associated with peaked inlet and outlet flux distributions defined by Eq. B-53	inches
C_7	Constant associated with spike (Cosine Shaped) flux distribution defined by Eq. B-85	inches
D_o	Outside diameter	inches
E	Test section voltage drop	volts
g	Acceleration due to gravity	ft/sec^2
g_o	Gravitational constant, 32.2	$\frac{lbm}{lbf}\frac{ft}{sec^2}$
G	Mass velocity	$lbm/hr\text{-}ft^2$
h	Heat transfer coefficient	$btu/hr\ ft^{2o}F$
H	Enthalpy	btu/lbm
I	Test section current	amperes
k	Thermal conductivity	$btu/hr\ ft^oF$
ℓ	Test section heated length	inches
ℓ'	Length of cosine portion of test section length or spike length (see Fig. 10)	inches
L	Half-wavelength of cosine test section which is truncated to length ℓ (see Fig. 10)	inches
L'	Half-wavelength of cosine portion of test section which is truncated to length ℓ' (see Fig. 10)	inches

Nomenclature (Continued)

Symbol	Variable	Units
$\mathscr{L}$	Length of test section for peaked and spiked flux distributions defined in Fig. 10.	inches
$L_{X=0}$	Location at which saturation condition is reached	inches
L_S	Length over which quality condition exists	inches
M	Ratio of maximum to minimum flux	dimensionless
P	Pressure	psia
P_r	Prandlt number	dimensionless
q/A, Ø	Heat flux	btu/hr-ft^2
Q	Integrated power input	btu/hr
r	Maximum cavity size required for nucleation	ft
R	Overall tube resistance	OHM
Re	Reynolds number	dimensionless
T	Temperature	^oF
X	Quality	$\frac{\text{lbm steam}}{\text{total lbm}}$
X_{tt}	Martinelli-Nelson Parameter	dimensionless
u,x,y,z	Axial position indices (see Fig. 10)	inches
v	Specific volume	ft^3/lbm
V	Velocity	ft/sec
W	Mass flow rate	lbm/hr

Subscripts

ANN	Tube length in annular flow condition
C	Critical location
CRIT	Critical condition
EXIT	Exit
f	Saturated liquid
fg	Liquid to vapor
film	Film
G	Gas
i	Required to initiate nucleation
IN	Inside, inlet
INLET	Inlet
L	Liquid
MAX	Maximum
MIN	Minimum
OUT	Outlet
p	Pump
S	Saturation location
SAT	Saturation condition
SUB	Subcooled
TOT	Total
TP	Two Phase
V	Vapor
WALL	Wall
u,x,y,z	Axial position indices

Greek Letters

ρ	Specific resistivity	ohm/ft
ξ	Constant associated with peaked flux distributions defined by Eqs. B-51 and B-73	dimensionless
σ	Surface tension	lb_f/ft
τ	Shear stress	lb_f/ft^2
μ	Viscosity	lbm/hr ft
γ	Kinematic viscosity	ft^2/hr
ϕ or q/A	Heat flux	$btu/hr\ ft^2$

CONVERSION OF UNITS

ENGLISH TO METRIC (MKS, CGS)

PRESSURE (P)	$kg/cm^2 = 0.0702 X psia$
UNIT MASS FLOW RATE (G)	$kg/m^2 sec = 1.361 X 10^{-3} X lb/hr\ ft^2$
	$g/cm^2 sec = 1.361 X 10^{-4} X lb/hr\ ft^2$
HEAT FLUX (Ø)	$watts/cm^2 = 3.15 X 10^{-4} X BTU/hr\ ft^2$
	$kJ/m^2 sec = 3.105 X 10^{-3} X BTU/hr\ ft^2$
DENSITY (ρ)	$gm/cm^3 = 62.4 X lb/ft^3$
KINEMATIC VISCOSITY (γ)	$cm^2/sec = 3.88 X ft^2/hr$
VISCOSITY (μ)	$gm/cm\ sec = 243 X lb(m)/hr\ ft$
LENGTH (l)	$mm = 25.4 X\ in$

METRIC TO ENGLISH

PRESSURE (P)	$psia = 14.25 X kg/cm^2$
UNIT MASS FLOW RATE (G)	$lb/hr\ ft^2 = 735 X kg/m^2 sec$
	$lb/hr\ ft^2 = 7350 X g/cm^2 sec$
HEAT FLUX (Ø)	$BTU/hr\ ft^2 = 3170 X watts/cm^2$
	$= 322 X kJ/m^2 sec$
DENSITY (ρ)	$lb/ft^3 = 0.016 X gm/cm^3$
KINEMATIC VISCOSITY (γ)	$ft^2/hr = 0.258 X cm^2/sec$
VISCOSITY (μ)	$lb(m)/hr\ ft = 0.00412 X gm/cm\ sec$
LENGTH (l)	$in = 0.0394 X mm$

CHAPTER I

INTRODUCTION

1.1 Background of the Problem

Forced convection boiling of water in axial flow is being utilized in pressurized and boiling water reactors and has been investigated as a means for cooling the nozzles of electro-thermal engines, electric-arc wind tunnels and nuclear rockets. One of the most important limits in the thermal performance of such systems is the so-called critical or burnout condition. This condition is characterized by a sharp reduction in ability to transfer heat from the heated surface. Much test data are available for uniform heat flux distributions along the test section and numerous correlations of these data have been proposed. However, in reactor systems as well as high temperature flow nozzles mentioned above, the heat flux distributions are inherently nonuniform and possess such large gradients that the existing uniform flux burnout correlations are not applicable. In addition, although interpretation of the limited data available on nonuniform heat flux distributions varies as discussed in the literature survey of section 1.3, the overall conclusion is that certain non-uniform heat flux distributions can significantly lower the critical heat flux compared to a uniform heat flux distribution under similar hydrodynamic operating conditions. Therefore, it is highly desirable for design purposes to have a satisfactory method for predicting the effect on the critical condition of nonuniform heat flux distributions which exist in practice.

In general three basic axial flux shapes exist:

(a) A reasonably symmetrical flux distribution with central peak, approximated by a "chopped" cosine. This corresponds to an end-of-core-life condition where the flux is not significantly perturbed by control rods or nonuniform burnup, or to a core with chemical control

(b) A flux distribution markedly peaked near the inlet of the channel, corresponding to a new, clean core with control rods in the upper part of the core (upflow); and

(c) A flux distribution markedly peaked near the exit of the channel, corresponding to a maximum xenon override condition where the control rods are withdrawn but the upper part of the core has had less burnup.

In addition to these macroscopic flux distributions, there may be superimposed microscopic flux peaks which may occur at any point along the channel. These flux peaks may be due to nuclear effects (fuel peaks or water holes) or manufacturing dimensional tolerances (fuel thickness or eccentricity) and are of some short but undefined axial extent. It is the purpose of this investigation to determine the effect of these types of axial flux distributions on the critical heat flux in the quality region by a systematic experimental and analytic investigation. The two quantities of interest are (1) the location of the critical condition and (2) the power input to the reactor channel required to cause the critical condition.

1.2 Scope of the Research

A comprehensive experimental program was undertaken to

investigate nonuniform axial flux distributions under bulk boiling conditions. In addition to the flux shapes of direct reactor interest, additional nonuniform as well as uniform shapes were tested to permit more thorough analysis of the fundamental nature of the critical condition. Also the flux gradient was varied for several of the distributions tested as tabulated below to bracket and extend data available in the literature.

Flux Distribution	Approximate Ratio Maximum Flux / Minimum Flux
Uniform	1.0
Cosine	2.27, 4.03, 5.75
Linear Increasing	2.27, 5.75
Linear Decreasing	2.27, 5.75
Peak Inlet	5.75
Peak Outlet	5.75
Flux Spike (Step)	4.1 to 5.1
Flux Spike (Cosine)	2.27, 5.75, 7.00

The experimental program was run on the flow loop available in the Heat Transfer Laboratory of the Mechanical Engineering Department. Therefore the operating pressure was limited to approximately 200 psia but the analytic results obtained from this data were successfully applied qualitatively to the higher pressure regions of practical interest. The ranges of other operating and test section conditions are listed below.

TEST SECTION

Material - Aluminum Tubes

Inside Diameter - .214 Inches (.544 cm)

Heated Length - 30 and 48 Inches (76.2 and 122 cm)

Inlet Calming Length - 3.7 Inches (9.4 cm)

OPERATING CONDITIONS

Pressure - 60 to 200 psia (4.2 to 14 kg/cm^2 abs)

Mass Flow Rate - .5, 1.5 and 2.0×10^6 $\frac{lbm}{hr\ ft^2}$ (680, 2040, and 2720 $kg/m^2 sec$)

Inlet Temperature - 60 to 290°F

Power - Direct Current Resistance Heating

Burnout Detection - Tubes Tested to Failure

It should be noted that several definitions of the critical condition are used throughout the literature. Generally the definition selected by an experimenter is related to the burnout detection mechanism used. In this work since each tube was tested to failure, the critical condition is taken as the physical destruction of the aluminum test section. Correspondingly the critical location is defined as the location of the test section failure.

1.3 Literature Survey

Review of the literature on the subject of axial heat flux distribution reflects the developing interest in this area manifested by expanding experimental programs and more sophisticated analytic procedures. However, as this literature is reviewed it should be noted that for all efforts except that of Becker[16] and Tong[17], which are the most recent, workers have attempted to characterise the results by intuitive judgments based on uniform flux results. Since uniform flux data indicates that the critical condition occurs at the exit where enthalpy is a maximum but heat flux is equivalent to that all along the tube, it is not possible to distinguish whether the critical heat flux is governed by local or integrated conditions. Hence, in the case of nonuniform flux distributions, we find some test results are interpreted to suggest that the critical heat flux is a function of local conditions along the nonuniformly heated test section, while other results

are interpreted to suggest that the total integrated heat transfer or exit enthalpy determines the critical condition which is therefore independent of the local conditions at the critical location.

The seemingly perplexing part of this disagreement is that reliable data supporting each interpretation has been presented. In anticipation of the conclusions of this work it can be stated that both the above interpretations can be shown to be correct, if each is viewed within the framework of a broader interpretation of the critical phenomenon. That is, the critical condition is a phenomenon which, when represented by the analytic model developed in this work, is dependent on both local and integral conditions, the relative importance of each, depending upon the existing thermal and hydrodynamic conditions.

Among the earliest results were those of the Bettis Plant reported in the summary report by DeBertoli et al[1]* which includes results of DeBortoli, Roarty and Weiss[2] and Weiss[3]. These results consisted of the two basic kinds of nonuniform heat flux experiments (1) gradual variation of axial heat flux in cosine or other shape distributions where (d(q/A)/dx is small) and (2) axial step changes in heat flux commonly called hot-patch or spike tests.

The cosine tests reported by DeBertoli were for a rectangular test section (0.055 in. x 2.116 in. x 27 in. or 0.14 cm x 5.36 cm x 68.5 cm) with 2000 psia (136 atm) water

*Numbers in parentheses refer to references listed in the Bibliography.

for a center-peak-to-minimum heat flux of 4.0 and maximum-to-average of 1.38. The critical condition always occurred between the peak flux location and the channel exit. A plot of local heat flux vs. local enthalpy at the critical condition resulted in a downward sloping curve which was approximately 70% of the critical heat flux calculated for a uniform flux distribution at the same mass flow velocity and exit enthalpy by the Bell[4] correlation. A surprising result was the observation that with the central peak in the cosine distribution, the magnitude of <u>average</u> heat flux vs <u>exit</u> enthalpy when a critical condition exists somewhere along the tube length would lie close (+15% to -25%) to a plot of critical heat flux vs exit enthalpy for the uniform flux distribution data.

The hot-patch tests performed at Bettis utilized a rectangular channel (0.097 in. x 1.0 in. x 27 in. or 0.25 cm x 68.5 cm) with water at 2000 psia (136 atm). The first 26 5/8 in. (67.5 cm) of the channel were at a uniform heat flux ϕ_1 and the last 3/8 in. (0.95 cm) was operated at heat flux ϕ_2 where ϕ_2/ϕ_1 was maintained at 1.98 throughout the tests. The results are shown in Fig. 1 where the upper curve is ϕ_2 at the critical condition and the lower curve is the corresponding magnitude of $\phi_1=\phi_2/1.98$. Superimposed on this plot is the curve for ϕ_3, the critical heat flux obtained for the same exit enthalpy and flow rate when the channel is uniformly heated along the entire 27 in. (68.5 cm) length. At around 60 ^{o}F (33 ^{o}C) exit subcooling, $\phi_2=\phi_3$, and at exit quality of around 50%, $\phi_3=\phi_1$. It is seen that the ratio

$$E_p = \left(\frac{\phi_3-\phi_1}{\phi_2-\phi_1}\right)$$

decreases from around unity well in the subcooled region to near zero as quality increases. These results show that for the subcooled exit region, where E_p=1, the equivalent hot-patch heat flux must be achieved in the uniformly heated case to obtain burnout, hence suggesting the importance of local conditions in the burnout phenomena. On the other hand, in the 50% quality region, where E_p=0, burnout is achieved at the same exit enthalpy even though the hot-patch heat flux is greater than the uniformly heated tube flux. This suggests that the integrated conditions are of prime importance in this region.

These initial results illustrated the existence of non-uniform flux effects and indicated the need to allow for these effects in design, particularly since these distributions could lower the critical heat flux from that expected by extrapolation of uniform flux distributions data. The next investigation in this area was an extensive program performed by Swenson et al[5], with 2000 psia (136 atm) water for cosine distributions with central peak, central peak with spike, peak near inlet and peak near outlet in 0.411 to .446" dia. (1.04 to 1.17 cm) and 72 in. (183 cm) long tubes. The flux spike tests were very limited but did indicate a decrease in effectiveness, E_p, as the exit quality increased in agreement with the Bettis results. However, in this case the quality range was limited to approximately 30% to 24%. For the central-peak flux distribution, the data at the critical location was about one-half of the magnitude of $(q/A)_{crit}$ at the same enthalpy in a tube with uniform flux distribution.

The data for both skewed cosine distributions were still lower. The average heat flux vs exit quality (critical condition existing between the location of the peak flux and the exit) agreed reasonably well with $(q/A)_{crit}$ vs. exit enthalpy for uniform flux distribution for the central peak and the peak-near-outlet data but the data for peak-near-inlet fell much below this. These results indicate that when additional flux distributions are considered, the apparent success obtained with cosine and central peak distributions in comparing the average critical heat flux to the critical heat flux for uniform distributions cannot be generalized. This fact should be borne in mind in the following discussion of other programs which have achieved success in applying such techniques or their variations to cosine shape distributions only. From a practical point of view, these techniques of simple comparison with, or extrapolation of, uniform heat flux data give reasonable answers when applied to cosine distributions and can be used in these cases. However, for the important cases of peaked inlet and outlet distributions, these techniques fail dramatically and thus indicate that these methods are not based on a correct fundamental interpretation of the critical phenomena.

Reported programs in this group which deal exclusively with the cosine flux distribution include that of Janssen and Kervinen[6], Casterline and Matzner[7], Shaefer and Jack[8], Lee and Obertelli[9] and Lee[10]. Janssen and Kervinen carried out experiments for cosine, and truncated-cosine heat flux distributions for an annulus (0.54 in. x 0.875 in. x 100 in. or 1.37 cm x 2.22 cm x 254 cm) with only

the inner rod heating 1000 psia (68 atm) water. The ratios of maximum flux to minimum flux, M, were 1.86, 3.25 and 3.5. In all cases the inlet was subcooled and the operation was reported to be stable without noticeable flow oscillations. The data from these experiments was analysed by plotting local heat flux versus local quality for all points on the cosine test section at the critical power on the same curve with similar data for uniform flux distributions as represented by a General Electric correlation for such data (see Fig. 2). Assuming that the critical condition depends only on local conditions, the point of tangency between these curves will allow prediction of (1) the burnout location and (2) the power level at burnout. Based on this type of analysis, the cosine data was about 9 to 20% lower than predicted. Considering that (1) the actual burnout location was uncertain to at least ± 1 inches due to placement of thermocouples whose temperature rise was monitered and (2) that the uniform rod data upon which the correlation was based had a deviation of the same order as above (9 to 20%), the method predicts the cosine distribution behavior well. However, it should be noted that using the same uniform correlation and the integrated burnout concept, the cosine average heat is also within 20% of the uniform critical heat flux. Thus for cosine data of reasonable steepness, predictions of comparable accuracy can be obtained with the two basically divergent views of the burnout phenomenon.

Similar results were obtained in the high mass flow range ($G \geq 3.0 \times 10^6$ lbm/hr ft^2) by Casterline and Matzner[7] who carried out cosine distribution experiments in a 192 in. long (487 cm)

.400 inch diameter (1.02 cm) tube with water at 1000 psia (70.2 $\frac{kg}{cm^2}$). However for lower mass flow rates, the cosine tube supported higher heat fluxes for the same local conditions than the uniform tubes. Thus for lower mass flow rates, analyses based on both local and average conditions fail for this distribution with the rather extreme ratio of MAXIMUM FLUX/ MINIMUM FLUX = 34.8. However this discrepancy may be due to the presence of reported severe pressure oscillations which were probably due to the inherent compressibility existing in the void fraction in the long tube since the inlet conditions were in all cases subcooled.

Limited but interesting data applicable to nozzle cooling applications was obtained by Schaefer and Jack[8] for central peak shapes at very high heat fluxes. These experiments were performed with tubes having heated lengths of 1.5 and 5.5 in. (3.81 and 14.0 cm), .120 in. (.304 cm) diameters in 200 psia (14.0 $\frac{kg}{cm^2}$) water. The flux gradient was large since the heated length was short and M large (5.88). The experiments were run at high mass velocity ($G = 4.0 \times 10^7 \frac{lbm}{hr\ ft^2}$) and yielded high local critical heat fluxes ($q/A = 4.0 \times 10^7 \frac{BTU}{hr\ ft^2}$). Hence this data which is outside the normal range of variables is available for comparison with new methods of analysis.

Extensive additional tests with cosine flux distributions have been reported by Lee and Obertelli[9] and Lee[10]. These experiments were performed with 60 to 144 in. (152 to 366 cm) tubes of diameters .373 or .383 in. (.95 or .975 cm) in water at pressures of 550 to 1600 psia (38.6 to 112 $\frac{kg}{cm^2}$). The first report surveys the entire range of variables listed, while the

second report contains data from the 144 in. long tubes at 1000 psia only. These reports show that the average heat flux condition for estimating burnout is satisfactory. This condition can be expressed as the equivalence of the average cosine heat flux with the critical uniform heat flux under the same thermal and hydrodynamic test conditions or simply as equivalence of total input power to the test sections in each case. The reports also introduce another prediction method based on the integrated condition concept. In this case prediction of burnout power and location is obtained as the point of intersection between cosine and uniform data on a local heat flux versus length plot. However, the length used on this plot for the uniform case is an equivalent length which is defined as

$$L_E \times \phi(Z) = \int_0^Z \phi_{MAX} \cos\left(\frac{\pi Z}{L_T}\right) dz$$

where $\phi(Z)$ = heat flux on the cosine tube at a point distant (Z) from the inlet. In this manner, for each location on the cosine tube, an equivalent length of a uniform tube is defined such that the local heat fluxes and integrated power inputs are the same at that point (Z) for uniform and cosine heat flux distributions (see Fig. 3). Using this refined method good results for the critical power and location are achieved for the range of cosine shapes tested (M=5.0).

Only three additional investigations have been completed utilizing flux distributions other than the cosine shape. Bertoletti et al[11] tested rods 25.4 in. long (64.5 cm) of .318 in. diameter (.807 cm) in water at 1020 psia (71.5 kg/cm^2). These sections represented linear increasing and linear decreas-

ing flux distributions in addition to cosine and uniform distributions. In all nonuniform distribution cases the maximum flux to minimum flux ratio, M, was about 2.3. The data was presented to show the equivalence of total power input for test sections of all flux distributions for the same thermal and hydrodynamic test conditions. Review of the data confirms this equivalence for the cases of inlet quality above saturation. However for subcooled inlet conditions, which are of direct interest to many practical applications, divergence of total power input of up to 10 to 20% between the various flux distributions is apparent, with the exit peaked distribution exhibiting the lowest allowable total power. Additional CISE data reported by Silvestri[12] further indicates that the total power input is not independent of flux shape for subcooled inlet conditions. In these experiments, heat was added uniformly over only the first and last quarter of the tube with the middle half being unheated. The data showed that for subcooled inlet conditions, the total power for the nonuniform flux distribution was also up to 10 to 15% below that for the uniform flux. Such deviations, which were also previously pointed out for exit peaked shapes in Swenson's data of reference (5), are of direct consequence to reactor design for the control-rods-withdraw configuration. In addition this deviation illustrates that the total power input equivalence concept is not valid over the complete range of nonuniform flux distributions of interest.

The experiments of Styrikovich et al[13] were performed in 6.3 in. (16.0 cm) long tubes of diameter .236 in. (.6 cm) in water at 1470 and 2000 psia (103 and 140 $\frac{kg}{cm^2}$). The outside

diameter of the test sections varied linearly (increasing and decreasing) with length, hence the flux distribution varied as the square of the external diameter. Results with subcooled inlet conditions, which did not exhibit flow pulsations, indicated that the local critical heat flux for both increasing and decreasing flux shape was greater than the uniform critical heat flux at the same inlet conditions. In addition for the linearly decreasing flux, the onset of the critical condition occurred near the inlet as contrasted to the CISE tests where it was detected by wall thermocouples to set at the tube exit in all cases. To explain these results, the proposal is advanced by Styrikovich that the deviation of the upstream heat flux distribution from uniform causes an attendent deviation in vapor content in the boundary layer. Postulating that the vapor content in the boundary layer is effective in aiding or retarding the vapor film formation which causes the critical condition, higher upstream heat flux is predicted to promote achieving the critical condition while the reverse holds for lower upstream heat flux levels. This qualitative explanation has been modified and adopted in part in the analysis of the data of the present investigation.

Duke[14] performed a series of critical heat flux and film heat transfer coefficient measurements with an exponential decreasing flux distribution (M=27.0) in 36 in. (91.5 cm) long tubes of .187 in. (.476 cm) diameter in water at 535 to 1915 psia (37.5 to 134.5 $\frac{kg}{cm^2}$). The range of mass flow rates investigated was limited to the rather low values of .01 to .24x10^6 lb/hr ft^2 (13.6 to 325.0 $\frac{kg}{m^2 sec}$). The results for both critical

heat flux and heat transfer coefficient were correlated by statistical techniques and hence application of these correlations outside the limited range of variables investigated is very questionable.

Additional investigations with varied nonuniform flux distributions are presently being carried out in the USA and Sweden. The U.S. work is being performed at Babcock and Wilcox Co. on 72 in. (183 cm) long tubes of .446 in. (1.13 cm) diameter in water at pressures of 1000, 1500, and 2000 psia (70.2, 105 and 140.4 $\frac{kg}{cm^2}$). The flux distributions include those of the previous Babcock and Wilcox work[5] as well as several of the same distributions tested in annular configurations. The most recent progress report[15] indicated that the data agreed well with that of their previous program. Preliminary Babcock and Wilcox review of this latest data indicated that analysis based on local condition hypothesis was not valid whereas analysis based on the integrated average critical heat flux or the input power to the critical location looked promising. Such an analysis is a variation of the total input power equivalence but realistically considers only the power input to the critical location.

The Swedish work[16] is being performed for linear increasing and decreasing flux distributions in .236 in. and .394 in. (.6 cm and 1.0 cm) long tubes. The local burnout heat flux data is apparently predicted by the correlation of Becker[17] when the nonuniform heat flux is accounted for in the related heat balance equation. The basic correlation is a

simplification of the results of Isbin[18] which assumes the critical condition to occur at the axial position where the annular liquid film disappears. Becker achieves simplification of Isbin's model by assuming based on his own data for uniform tubes that the critical condition is a function of local conditions only. The success of this local condition hypothesis in predicting the critical heat flux for linearly increasing flux distributions is not surprising, since in this case the local flux and local enthalpy are both a maximum at the critical location. However, this is not the case for linearly decreasing flux where upstream burnout may occur and here the accurate predictions obtained may be significant. However a significant drawback of the entire procedure is that the critical location is not predicted and in fact the calculation of critical heat flux requires knowledge, presumably to be supplied from experimental data, of the critical location. However since the completed report is not yet available, comprehensive critical review of this method of analysis is not yet possible.

The most recently published work is that of Tong et al[19] in which the hypothesis is forwarded that the critical condition occurs when the enthalpy of a superheated liquid layer adjacent to the heated surface reaches a limiting value. The superheated layer is presumably formed and maintained by a bubble layer which isolates it from the core. The limiting enthalpy value of nonuniform flux cases was taken equal to that for a uniform flux. Using this approach a correction factor, F, was defined to enable prediction of nonuniform behavior from existing uniform data.

$$F = \frac{q''_{DNB,\ \text{equivalent to uniform flux}}}{q''_{DNB,\ \text{local in nonuniform flux}}}$$

The analytic expression for F is a function of (1) local critical heat flux, (2) a constant C which was determined to be a function of local conditions and (3) an integral of local heat flux weighted by the factor $e^{-C(l_{DNB}-z)}$. Thus we see F combines local (1 and 2) and integrated (3) effects in a manner determined by the model chosen. This method is applied to experimental data of many varied flux distributions yielding predicted F values within $\pm$ 25% of experimentally determined values. While this agreement does not significantly improve the accuracies available from other schemes, the method does yield the following significant result. In the subcooled and low quality region, the factor C is large and thus the product $C\ (l_{DNB}-z)$ is small. This reduces the weighting factor and results in local conditions primarily determining the critical condition. Conversely for high qualities, C is small and integrated conditions primarily determine the critical condition. Using a basically different model for the critical condition, this same dependence of the critical condition on local versus integrated conditions is obtained in the present work.

From the foregoing review of the literature, we see that most attempts to deal with nonuniform flux effects have been based a priori on a concept that the critical condition is a phenomenon related to either local or integrated conditions. Significantly these attempts have satisfactorily predicted behavior over only narrow parameter ranges. In addition their apparent

successful interpretations of similar data from diametrically opposite viewpoints has lead to much confusion. The efforts of Becker[16] and Tong[19], while not yet pointing the way to a general satisfactory solution of the problem, have been based on postulated models of the heat transfer and critical phenomenon. In the case of Tong in particular, the application of the model itself to the various nonuniform flux distributions determines the relative importance of local versus integrated conditions. Such an approach seems to be the most reasonable method of analysis and it is along these lines that the subject investigation has been directed. However, to fully comprehend the formulation of the model which has been applied, it is necessary to review what is known regarding the flow of water and steam in heated tubes. In the next chapter, therefore, the subject of two phase flow in tubes with heat addition will be discussed as it relates to the subject experiment.

CHAPTER II

TWO PHASE FLOW WITH HEAT ADDITION

To provide a sound basis for the developments presented in Chapter IV, the present understanding of two phase flow in tubes with heat addition will be reviewed.

2.1 Flow Regimes

Consider a cylindrical tube with vertical upflow of water under forced convection being electrically resistance heated. Adapting the discussion of Milioti[20] let us review with reference to Fig. 4 the dominant flow regimes and associated heat transfer mechanisms which will ideally exist along the tube.

Coolant water entering the bottom of the tube is below the saturation temperature corresponding to its pressure. In Section 1, where subcooled water exists forced-convection governs the heating process.

As the water temperature approaches the saturation value, the surface temperature reaches the saturation temperature. As soon as the surface temperature exceeds the saturation temperature by a few degrees, the liquid immediately adjacent to the heated surface becomes superheated. In this condition, if the degree of superheat is sufficient, bubbles can form along the surface at suitable nucleation sites. Under certain conditions bubbles have been found to slide along the wall surface in the direction of flow. As the bubbles grow larger, they detach from the wall and enter the fluid stream where they collapse because of the cooler bulk stream temperature. This Section, 2, is the subcooled nucleate boiling region.

When the bulk stream temperature reaches saturation, the bubbles can now be sustained in the turbulent flow of water. This Section, 3, is the saturated nucleate boiling region characterized by very high heat transfer rates. It is in this region that the quality of the two-phase flow begins to increase. The bubbles cause a very high turbulence in the superheated liquid, as they grow and detach themselves from the wall. This intense turbulence of the liquid upon the surface accounts for the high heat transfer rates in this bubble flow region. As more and more bubbles form at the wall and join the bulk stream, they start to coalesce and form larger bubbles. This tendency is expected, because a large bubble has less surface area than the equivalent volume of small bubbles and thus there is a tendency for bubbles to agglomerate. The flow is now unstable under all conditions, and eventually slugs of intermittent water and steam give the hydrodynamic pattern called slug flow as shown in Section 4.

Downstream from Section 4, the steam slugs begin to predominate and the steam increases in proportion to the water to the point where it can now be considered the continuous phase. A thin film of slow moving superheated liquid forms on the wall, while the steam flows in the central core. The liquid film thickness is of the order of thousandths of an inch and has a wave-like surface. The steam moves with a much higher velocity than the liquid film, resulting in high heat transfer coefficients and an annular slip-type flow shown in Section 5. There is usually also a spray of small droplets in the steam core, hence, the name spray-annular flow region. Through Section 5,

the liquid film flow rate on the wall decreases due to net entrainment of liquid from the film and evaporation of the film. Depending on the local heat flux and quality, nucleation can also occur within the thin liquid film. Heat transfer can be though of primarily as conduction through the liquid film with evaporation at the liquid-vapor surface.

When Section 6 is reached, the liquid film has disappeared, the wall is dry, and one finds tiny droplets of water in the steam. As soon as the liquid film is destroyed and the wall dry, the evaporative cooling of the wall breaks down, causing a very large decrease in the heat transfer coefficient with a correspondignly large increase in wall temperature. In Section 7, single-phase dry saturated or superheated steam is present. Because only single-phase steam is present in this region, it can be considered a film boiling region. However, the heat fluxes which can be carried under this condition are considerably lower than those which can be carried with non-film boiling.

From this discussion, it is seen that the critical condition can be caused by at least two different mechanisms, (1) in the subcooled or low quality region by a vapor blanketing of the tube wall, or (2) in the high quality region by dryout of the liquid film. In fact, the occurrence of the critical condition can also be postulated to be caused by a nucleation induced disruption of the liquid film or by the instability characteristics of the slug region. Hence it is desirable

to quantitatively identify the existence of the various flow regimes possible and the transitions between these flow regimes. Flow maps exist for predicting this information for adiabatic systems but since the effects of heating tend to distort the regime boundaries, such maps are not an accurate representation of conditions with heat addition. Generally speaking, heating may be expected to promote the transitions between the regimes shown in Fig. 4 so that for given pressure and mass flow rates these transitions occur at lower qualities than in the adiabatic case. In particular the bubbly flow region may be suppressed and the flow may go directly from single phase to slug flow. Similarly the slug-annular transition may occur at lower quality. From limited results reported at high pressures by Suo[21] and at low pressures by Lopina[22], such expectations seem to be borne out.

With regard to the low pressure conditions of the subject tests, the corrections to an adiabatic flow map due to heating are small since the flow regime transitions occur at relatively low qualities. Considering the test conditions and the dimensions of the test sections, the relevant flow regime map for these experiments is presented in Fig. 5. The transitions pictured are limited to the transitions to annular from both bubble and slug.

At high mass velocities the annular transition is taken from the correlation of Baker.[24] For these conditions, the slug regime is suppressed and the transition occurs directly from bubbly to annular flow over the quality range of approxi-

maetly 6 to 10%. It should be recognized that at a given mass flow rate this transition to annular flow is gradual and intermediate flow regimes are probably encountered before true annular flow is achieved. As Fig. 5 shows, this transition describes conditions in the region of the test conditions investigated. Due to non-adiabatic conditions, additional uncertainties in the actual location of the flow regime transition are introduced. Hence a mean value of 8% was chosen to characterise the annular transition for all three flow rates of the subject data.

For completeness, the annular transition at lower flow rates is also illustrated on Fig. 5. At these low flow rates, the transition is from slug to annular flow and was calculated from the correlation of Haberstroh and Griffith.[23]

2.2 Critical Heat Flux

Prediction of the critical heat flux for uniform flux distribution is necessary in this study for two reasons:
(a) a uniform flux distribution correlation is required to evaluate published correlation methods for nonuniform flux distributions such as that of Janssen et al[6] and Lee[10].

(b) test runs with uniform distribution should be checked against available correlations to insure that operating procedures and the experimental rig are performing satisfactorily.

Unfortunately there is no existing low pressure (14.7 to 200 psia) quality range correlation which is applicable over a wide range of test conditions and geometries. In fact data in this region is limited to that of Lowdermilk and Weiland[25], Jens and Lottes[26], Lowdermilk, Lanzo and Siegel[27], Becker[28], Becker and Persson[17] and Lopina[22]. From this data, four correlations are available which use certain of this data as indicated below:

CORRELATION	DATA SOURCE
Lowdermilk, Lanzo and Siegel[27]	Lowdermilk, Lanzo and Siegel[27]
Von Glahn[29]	Lowdermilk, Lanzo and Siegel[27]
MacBeth[30]	Lowdermilk and Weiland[25], Jens and Lottes[26], Becker[28] — 15 psia; 250 psia
Becker and Persson[17]	Becker[28], Becker and Persson[17]

The correlation of Lowdermilk, Lanzo and Siegel[27] is based on their data obtained at inlet temperature of 75°F, atmospheric exit pressure, and diameters from 0.051 inches to .188 in. The correlation establishes two burnout regimes: a high velocity, low-exit quality regime for $G/(L/D)^2 < 150$ correlated by $(q/A)_{CR} D^{0.2} (L/D)^{0.15} = 1400\ G^{0.5}$

and a low velocity, high exit quality regime for $G/(L/D)^2 > 150$ correlated by

$$(q/A)_{CR} D^{0.2} (L/D)^{0.85} = 270 G^{0.85}$$

The correlation of Von Glahn[29] is intended to cover cryogenic fluids as well as water over the pressure range 14.7 to 2000 psia. The correlation is based on a relationship developed between X_c, a critical vaporization parameter, and a function consisting of several dimensionless groups. Specifically

$$X_c = f\left[\underbrace{\frac{GD}{(\frac{L}{D})^{1.3}}}_{\text{Flow Parameter}} \quad \underbrace{\frac{Pr_v^{0.4}}{\mu_v}\left(\frac{\rho_e-\rho_v}{\rho_v}\right)^{0.4}\left(\frac{\mu_v}{\mu_L}\right)^{1.7} N_B}_{\text{Fluid Property Parameter}}\right]$$

where $X_c = \dfrac{Q_c}{w\Delta H}$

$$N_B = \frac{\sqrt{g}\,\mu_v^2\sqrt{\rho_e-\rho_v}}{\rho_v(g_c\sigma_e)^{1.5}}$$

the functional relation f being graphically described in the NASA report.

The MacBeth correlation[30] also represents data as either a high-velocity or a low velocity regime with the boundary between regimes defined graphically. For a system pressure $p < 200$ psia, and a $L/D < 200$, the maximum mass velocity for existence of a low velocity regime is $.25 \times 10^6$ lb/hr ft^2. Thus the data for this report lies within the high velocity regime which is given as

$$q/Ax10^{-6} = \frac{A + \frac{1}{4}CD(Gx10^{-6})\Delta H_1}{1+CL}$$

where $A = y_o D^{y_1}(Gx10^{-6})^{y_2}$

$C = y_3 D^{y_4}(Gx10^{-6})^{y_5}$

$D \equiv$ inches

The "y" coefficients obtained by MacBeth by computer optimization of data at various pressures are

	15 psia	250 psia
y_o	1.12	1.77
y_1	-0.211	-0.553
y_2	0.324	-0.260
y_3	0.001	0.0166
y_4	-1.4	-1.4
y_5	-1.05	-0.937

Finally the correlation of Becker[17] as discussed in Chapter I covers the pressure range 142.5 to 195.0 psia. The correlation, which is based on extension of the flow model of Isbin[18] is presented as curves of

$$\frac{1}{q/A(\frac{\dot{m}}{F})^{1/2}} \text{ versus } X_{CRIT}$$

where $X_{CRIT} \equiv$ the steam quality at the critical location

$q/A \equiv$ surface heat flux, $\frac{kJ}{m^2 S}$

$\frac{\dot{m}}{F} \equiv$ mass velocity, $\frac{kg}{m^2 S}$

Each of these correlations together with the uniform flux distribution data of this report are plotted in Figs. 6, 7, and 8. The wide variation in predicted critical heat flux values

is obvious. In addition the dependence of critical heat flux on pressure for the MacBeth correlation is opposite to that for the Becker and Von Glahn correlations. In appraising these figures the following conclusions can be drawn (the deviation between stable and unstable points will be discussed in Chapter III).

(1) The MacBeth correlation contains only the early and limited data of Lowdermilk and Weiland[25], which is suspect to flow instabilities as described in the later report by Lowdermilk[27], and the data of Jens and Lottes[26] which was taken at low flow rates (.01 to $.04 \times 10^{-6}$ lb/hr ft^2) in large diameter (.94 in) tubes. Hence this correlation would not be expected to yield reasonable results for the subject test conditions.

(2) The Von Glahn and Lowdermilk correlations are based on Lowdermilk[27] data which had limited diameters (up to .188 inches) and a single subcooling. Thus as discussed by Lopina,[22] for the test diameters of the subject test data, these correlations are not applicable.

(3) The Becker correlation yields good agreement with results at low flow rates ($G = 0.5 \times 10^6$ lb/hr ft^2). As flow rate increases, the agreement becomes poorer.

(4) The 250 psia prediction of MacBeth's correlation agrees well with the data. However the data is at generally lower pressures than the pressure for which the correlating line was established.

These results indicate that the available low pressure correlations do not appear to be based on the correct fundamental variables. Hence although each is satisfactory over the range of data from

which it was derived, none can be safely extrapolated to the desired region of the subject test conditions. Therefore, the best empirical procedure for representing the present data appears to be use of a simple equation of the form, $(q/A)_{CR} = C_1 + C_2 \Delta H_{INLET}$ where the constants can be determined from the data of Figures 6, 7 and 8.

CHAPTER III

EXPERIMENTAL PROGRAM

3.1 Description of Apparatus

The following section contains a description of the experimental facility and test sections which was used in this investigation. This was divided into four categories: the hydraulic system, the power supply, the associated instrumentation and the test sections. Although detailed descriptions of the apparatus are available in other reports,[31] they are repeated here for the convenience of the reader. The basic apparatus had been designed and constructed in a previous study by Bergles.[32]

3.1.1 Hydraulic System

A schematic of the flow loop is shown in Fig. 9. The pipings and fittings, all of brass and stainless steel for corrosion resistance, are erected around a test bench constructed of Dexion slotted angles and plywood. Rayon reinforced rubber hose was used where flexible connections were required. Flow circulation is provided by a Fairbanks Morse two-stage regenerative pump (260 psi at 3.6 gal/min) driven through a flexible coupling by a 3 HP Allis Chalmers induction motor. To avoid contamination of the system water, the pump was fitted with special seals of teflon-impregnated asbestos. A relief valve set for 300 psi protected the pump casing from overpressure.

The main flow loop contains a Jamesbury ball valve to control the overall pressure drop. The test section line, installed in parallel with the main loop can be isolated by means of two more Jamesbury ball valves. To limit coolant

loss upon test section failure, upstream and downstream check valves were built into the test section connector pieces. The upstream valve contains a spring sized to hold the valve open during normal operation with system pressure on either side of the valve but closed at test section failure with system pressure upstream and ambient pressure downstream. The downstream valve is simply held open by system pressure during normal operation but closed at test section failure by the pressure difference between the back system pressure and the ambient test section pressure. The test section flow rate is controlled by means of Jenkins needle valves set just upstream and downstream of the test section itself. The valve downstream is particularly useful in adjusting test section pressure. The test section line also contains two basic Fischer-Porter flowmeters with the appropriate isolating valves. Four Chromalox heaters of approximately 6 kw. each are also provided to control the test section inlet temperature. Three of these are controlled simply with "off-on" switches while the fourth can provide a continuous range from 0 to 6 kw. by means of a bank of two variacs mounted on the test bench. Pressure fluctuations at the outlet of the pump are damped out by means of a 2.5 gallon Greer accumulator charged with nitrogen to an initial pressure of 40 psi. This accumulator contains a flexible bladder-type separator which prevents the nitrogen from being absorbed by the system water. A Jamesbury ball valve isolates the accumulator from the loop at shut-down.

Since the system is closed loop, the heat added to the system water is rejected to a shell-and-tube heat exchanger

connected to a city water line. Due to seasonal temperature variations, the minimum operating temperature varies from approximately 50°F in the winter to 75°F for summer operation. Continuous deionization and deoxygenation is provided in a parallel loop containing four resin beds, two of which provide deionization and the other two, deoxygenation. The conductivity of the loop water may be maintained at 1.5×10^6 ohm-cm as read on a Barnstead meter. In order to insure a minimum of dissolved air in the system, a 5 gallon degassing tank was provided with five electrical heaters (3-220 VAC and 2-110 VAC). This tank was also used to provide makeup water to the system. A storage tank for filling the system and degassing tank was mounted above the degassing tank and could be filled with distilled water from standard 5 gallon bottles with a small Hypro pump. Both the storage tank and the degassing tank were equipped with glass sight gages so that the proper levels could be maintained.

3.1.2 Power Supply

Power was supplied to the test section by means of two 36 kw. Chandrysson externally excited generators, each capable of delivering 3000 amperes at 12 volts. The generators are driven by 440 volt-3 phase-600 rpm synchronous motors.

The power could be regulated from zero to maximum power as desired through a portable control console. The generator outputs were connected in series and the output from one was added to or subtracted from the output of the other. Water-cooled shunts, installed in parallel with the test section, eliminated the shock of a sudden open circuit caused by a test section

burnout.

An existing buss-bar system was used, with the addition of air cooled copper braided cables just at the test section. The use of these flexible cables permitted flexibility in the size of the test section which could be accomodated. At the upstream end of the test section, the cable assembly is clamped to an aluminum plate to which a rigid aluminum test section holder is attached. At the downstream side, the connection to the test section holder is accomplished by a flexible braided conductor. This entire connection to the test section was put in tension by a spring arrangement to assure adequate allowance for thermal expansion of the test section. The test section holders were made of aluminum plate in two segments which, when bolted together, clamped to a bushing surrounding the test section. The downstream end of the test section was connected to the piping with rubber hose to provide electrical insulation and increased flexibility.

3.1.3 Instrumentation

Instrumentation was provided to monitor the steady-state and transient conditions throughout the system. Pressure gages on the main loop, as indicated in Fig. 9, aid in adjusting the pressure level in the test section and in determining system stability. A thermocouple was installed in the degassing tank to monitor the water temperature during degassing operations. Another at the discharge of the pump insured that the water temperatures in the deionizing beds never exceeded 140°F. A variety of metering tubes and floats which could be installed interchangeably in the basic Fischer-Porter flowmeter housing

provided measurement of the test section flows from 1.5 to 4000 lbm/hr. The results were calibrated at installation and checked periodically against the initial calibration.

The test section itself was instrumented with thermocouples to record inlet and outlet water temperatures. In both cases, the thermocouples were located at positions where the flow was well-mixed. At the downstream end, the thermocouple was located far enough from the exit of the heated section so that it could be safely assumed that the vapor fraction is completely condensed.

Thermocouples were constructed from Leeds and Northrup 24-gage duplex copper-constantan wire. Calibrations were performed and deviations from N.B.S. standard tables were found to be slight so that no corrections were necessary. All of the thermocouples were connected to a common ice junction through a twelve position Leeds and Northrup thermocouple switch. The output could be read on either a potentiometer or a recorded. The recorder is a pen-type, single channel instrument manufactured by Minneapolis-Honeywell Brown. There are five manually selected ranges for 0-6, 5-11, 10-16, 15-21, and 20-26 millivolts. Occasional calibration against the potentiometer insured the accuracy of the recorder to within .01 millivolts.

Test section pressures, both upstream and downstream were monitored on 4 1/2 inch U.S. gage supergages with 0-200 psi range. Each gage was checked on a dead weight tester and calibrated to an accuracy of approximately .5 psi over the entire range. They were checked against one another periodically at various static pressure levels under zero flow conditions.

Porous-plug snubbers were provided to protect the gages from severe pressure fluctuations.

The heat input to the test section was computed from measurements of the voltage drop across the heated length and the current to the section. The voltage drop was read on a Weston, multirange d.c. voltmeter with a specified accuracy of ±1/2% of full scale. The current was inferred from the voltage drop across an air-cooled N.B.S. shunt with a calibrated conductance of 60.17 amps/m.v.

3.1.4 Test Section

The required flux shapes were obtained by machining the tube outside diameter to obtain the desired variation in wall cross-sectional area since electrical power generation is directly proportional to resistance. The design was made within the limits imposed by (a) available power and hydraulic supply (b) test conditions and geometries desired for investigation and (c) materials having adequate resistivity and machinability. A discussion of the interplay between these variables and the final test section designs is presented in Appendix C. Confirmation of the shape of the experimental flux distribution was obtained on a sampling basis by room temperature incremental resistance measurements and by 100% inspection of resultant outside diameter dimensions. Details of the results of these procedures and discussion of other factors affecting the shape of the experimental flux distribution are included in Appendix A. See Figure 10 for schematic presentation of the various test sections used in the investigation.

3.2 Experimental Procedures and Experience

3.2.1 General Loop Operation

Many aspects of the experimental procedure, particularly the installation of test sections and final preparation of the loop for operation, were common to all types of runs. Distilled water was pumped into the storage tank from the standard five gallon bottles. The system and degassing tank were filled by gravity. Vents on the flowmeter, preheaters, test section, exit plenum, and the deionization tank were opened to allow the displaced air to escape. The degassing tank vent was open at all times. The other vents were closed when no further bubbles were seen. The pump was then turned on and all valves opened and closed several times to dislodge any remaining air pockets. The vents were then opened and closed again in turn until air-free water was obtained at each vent. Visual observation of the flow through the glass flowmeter tube aided in determining when the system was free of air.

At this point, all the degassing tank heaters were turned on, and water was circulated through the system. The temperature of the degassing tank water was monitored on the recorder, and all but one of the heaters turned off as the boiling point was approached. If this was not done, the degassing tank was found to boil too vigorously with the result that considerable overpressure built up in the tank and a large amount of water was forced out through the vent. When boiling occurred, water from the loop was bypassed into the degassing tank. The amount of flow was regulated so that a small but continuous

flow of steam issued from the vent hose. The system water was effectively degassed by being dumped into the boiling water at the top of the degassing tank. This was continued until the temperature in the loop rose to approximately 180°F. Care was taken to shut off flow to the deionization tank before the loop temperature exceeded 140°F. The entire procedure took about 30 minutes. A standard Winkler analysis, described in Reference (32), indicated that this method of degassing reduced the air content to less than .1 cc air/liter. Upon completion of the process, the remaining tank heaters were shut off, and the heat exchanger turned on. The flow of system water to the degassing tank was turned off as soon as steam stopped coming out the vent. The system was then ready for operation. This process was repeated at the beginning of each day of operation, where the degassing take was refilled, or when air bubbles were visible in the flowmeter. The daily degassing was necessary since the degassing tank is vented to the atmosphere, and the water in the tank would eventually become saturated with air (18 cc/liter).

The system was then operated for at least 15 minutes at zero power before taking measurements. At the end of this time the system water was completely cool and had been thoroughly circulated through the deionizers. This time was also used to allow the generators to warm up. If the generators were used immediately after starting, fluctuations in the power level were much larger and harder to control. If a particularly low resistance test section was in place, it was necessary to disconnet one of the power leads until the generators had come up to speed. If this was not done, high

voltage drops could result from the fact that the two generators did not speed up in unison and on occasion could lead to unwanted burnouts.

At shutdown, it was necessary to isolate the accumulator from the loop. Otherwise, the water would be forced out of the accumulator, into the loop, and eventually out through the degassing tank vent. The pump and generator were connected together electrically so that the generators would be shut off if the pump should be turned off accidentally or due to a power failure. However, the generators could be shut off independently by means of a switch on the control console. Turning off the generators or the pump also interrupted the power to the preheaters. This was a safety precaution to prevent burning out the heater elements should they be left on with no flow.

3.2.2 Loop Operation for Critical Heat Flux Data

At the beginning of each test run, the bypass flow was reduced to maximize the pressure drop taken across the needle valve upstream of test section. A large upstream restriction pressure drop was desired to minimize the occurence of flow oscillations. These oscillations did occur early in the test program and steps taken to analyse and eliminate them will be discussed in Section 3.2.4. For low mass flow rates ($G=0.5 \times 10^6$) a 3/8" exit line was used and desired exit pressure maintained throughout the entire test run by adjusting the needle valve in the line. For higher mass flow rates ($G=1.0$ and 2.0×10^6) a 1" exit line was used but in this case since valve manipulation

did not allow adequate adjustment of exit pressure, the exit pressure was not directly set but allowed to vary within the desired range with the power level and inlet subcooling.

With the mass flow rate and test pressures established, the generators were turned on and power applied to the test section. After a heat balance was taken, power level was gradually increased simultaneously with adjustment of inlet temperature by operation of the loop preheaters. This adjustment was complete before the test section power achieved approximately 50% of the anticipated burnout power. In the final approach to burnout, mass flow rate and inlet temperature were maintained constant as power was increased in small steps. Test section inlet and exit pressures were maintained approximately constant at low flow rates but increased at high flow rates as power increased. At each step in power level, values of all these variables were recorded manually. Since only inlet temperature was automatically recorded, only values of inlet temperature and test section voltage (meter was continually viewed) were noted at burnout. The values of all other parameters at burnout were obtained by extrapolating data recorded at previous power steps.

When burnout did occur, the generators, preheaters and pump were turned off and the test section line isolated from the main loop. When a new test section was inserted, a small volume of undegassed water was necessarily allowed into the system from the fill tank because the test section line was above the level of the degassing tank. Care was taken to bleed the system under such circumstances to minimize the

amount of air entrapped in the system. When the pump was restarted, the flow meter was observed to ensure that air bubbles were not present. This departure from the initial thoroughly degassed conditions for certain test runs was considered acceptable since critical test results should not be effected by slight differences in the degassed condition of the loop water.

3.2.3 Two Phase Heat Transfer Coefficient Measurements

In addition to burnout measurements, an attempt was made to measure two phase heat transfer coefficients. As discussed in Chapter IV, such data is necessary for the critical heat flux model presented. For these measurements, a test section with two independent power supplies attached was used. The inlet portion was heated with the generators described in Section 3.1.2, while a 1.5 inch portion at the exit was heated by a motor generator set capable of delivering about 17 volts at 700 amperes. The power to the inlet section was adjusted to yield a desired quality condition in the exit portion. The exit section or nucleation section was designed to minimize the heat input to the fluid (and hence the quality change) but maximize the available heat flux which could be achieved. By measuring temperature differences, $T_{WALL}-T_{SATURATION}$, at pre-established values of pressure, mass flow and quality, determination of heat transfer coefficients for these conditions was attempted.

The experimental difficulties encountered for the test conditions explored i.e. steam-water mixtures at X=.10 to .60, P=100 psia, G=0.5 to 2.0 x 10^6 lbm/hr ft^2 and D=.214 inches, were

a) The mechanical strength of the nucleation portion of the test section was poor due to the thin wall

required to achieve high heat fluxes by resistance heating with the available power supply. The wall thickness could be increased by decreasing D, or by heating the test section indirectly by conduction from a resistance coil wound around the test section.

b) The exit pressure could not be maintained constant for flows in the quality region thus causing $T_{SATURATION}$ to vary. This may be able to be corrected by installation of a pressure regulating valve, although it appears that the configuration and hydraulic characteristics of the existing loop prevent adequate correction of this problem.

c) Accurate measurement of low temperature differences, .5 to 3°F, was not possible due to (b) above as well as inherent difficulties in accurately measuring the wall temperature, even with a guard heater arrangement.

Although some data was obtained it was generally not internally consistent, particularly in the low temperature difference regions of interest. Hence, the heat transfer coefficients obtained were not considered accurate and therefore not used further in this work.

3.2.4 Correction of Oscillatory Instabilities

Certain of the data obtained during the loop checkout with uniform heat flux distribution exhibited critical heat flux values (see Figs. 8 and 9) significantly lower than the bulk of other data. In addition during certain of these experimental runs, the flow rate was observed to oscillate as the

critical condition was approached.

Although no compressibility was deliberately inserted in the system between the control valve and the heated section, it was felt that enough compressibility was present upstream of the control valve in the form of preheaters and accumulators to initiate an instability if other conditions were also present. These conditions reduce per the theory of Maulbetsch[31] to the requirement that the slope of the overall pressure drop vs flow rate curve goes to zero. Overall pressure drop here includes both the control valve and the heated section. Check of the suspect points by this method confirmed that the instabilities resulted from this cause. A sample graphical comparison is given on Fig. 11 of the heated section versus control valve pressure drop which shows that the overall slope does go to zero at the flow rate where oscillation and the critical condition occurred. Similar calculations along with some experimental measurements were made on the points which were believed to be valid and the overall slope was established as positive.

To eliminate this oscillatory instability based on this theory, an increase in the slope of the control valve characteristic or a decrease in the slope of the test section characteristic is necessary. Since the test section characteristic is determined by the desired test conditions, only modification of the control valve characteristic is possible. For the loop available, the pump delivery pressure and the heat exchanger condensing pressure (15 psia) limit the overall pressure drop available which is distributed between the control valve, test section, and other line losses. Hence, to increase the control

valve pressure drop, extraneous line losses were reduced by increasing the exit line diameter from 3/8" to 1". With this modification, stable data at the higher flow rates was obtained. However for conditions of low inlet subcooling, instabilities were encountered for certain test sections exhibiting rapid axial variation in heat flux and data under these conditions could not be obtained. Apparently, in these cases the test section pressure drop vs flow rate characteristic became equal to the control valve characteristic thus causing the slope of the overall pressure drop characteristic to go to zero. It should be noted that this problem could probably have been corrected and data for these cases obtained by installation of a higher head pump which would permit increased pressure drop to be taken across the control valve.

3.2.5 Critical Flow Considerations

Since the sonic velocity can be quite low in a two phase flow, it is desirable to check whether or not a choked flow condition existed. Such a condition could lead to erroneous results regarding critical heat flux levels for various operating conditions. Using the slip equilibrium model of Fauske[33], from Fauske's Fig. 4, we see that the minimum critical velocity is achieved at minimum pressure and maximum quality. Calculating this minimum critical velocity for composite worst case test conditions, we obtain the results shown below. Basing the calculation on a hypothetical composite case which would yield a higher predicted critical velocity than any real case assures that the results obtained are conservative estimates. Since the actual

Actual Mass Velocity	Composite Worst Case: Tube Num.	Minimum Observed Pressure	Tube Num.	Maximum Observed Quality	Predicted Critical Velocity	Actual is % of Predicted Critical Velocity
556 $\frac{lb}{sec\ ft^2}$	2554	72	1256	.35	620 $\frac{lb}{sec\ ft^2}$	90%
278	1502	57	508	.52	320	87%
139	514	85	1552	.80	300	45%

velocities are in all cases less than the predicted critical velocities, it is reasonable to conclude that the critical velocities were not achieved during the experimental program. Direct confirmation of this conclusion by varying the test section exit pressure to achieve a critical velocity was not possible due to the operating limitations of the test loop.

CHAPTER IV

PRESENTATION AND DISCUSSION OF RESULTS

4.1 Experimental Results

The complete range of variables investigated was presented in Chapter I. Basically for each axial flux distribution, critical heat flux tests were conducted at three mass velocities, $G = 0.5$, 1.0 and 2.0×10^6 lbm/hr ft^2 and a range of inlet subcooling conditions. The total number of tests, each carried to physical failure of the test section was approximately 144. A complete listing of the experimental data is presented in Appendix I

The basic experimental results are presented as:

1) the total power applied to a channel to attain a critical condition (defined in this investigation as physical destruction of the aluminum test section). This parameter is of particular interest since maximization of Q_{crit} is a prime objective in engineering design.

2) the physical location of the critical condition (defined in this investigation as the failure location in the aluminum test section).

The test results for each of the three mass velocities are presented in terms of Q_{crit} and critical location in Figures 12 through 22. It should be noted that in all cases the inlet condition was subcooled and the total critical power, Q_{crit}, in these figures is presented as a function of the independent variable, inlet subcooling ΔH_{in}.

4.1.1 Total Critical Power

Considering the uniform flux results as a basis for reference, the following observations of Q_{crit} are apparent from

Figures 12, 15, and 17 which present cosine flux distribution behavior and Figures 21 and 22 which summarize behavior of the remaining flux shapes.

Q_{crit} - Cosine and Other Flux Distributions with Maximum Flux Near or at the Test Section Inlet

The value of Q_{crit} for these distributions is general 10% larger than Q_{crit} for uniform flux data. However, for the inlet flux peak distribution, the value of Q_{crit} did drop to 10% less than Q_{crit} for uniform flux data as the mass flow velocity increased to $G = 2.0 \times 10^6$ lbm/hr ft^2. As the inlet condition approaches saturation, Q_{crit} for these nonuniform flux distributions decreases in the same manner as the uniform flux data. There is no apparent dependence of Q_{crit} between distributions of the same shape with different M values (ratio of maximum to minimum flux). For cosine flux distributions in particular, no apparent stratification exists between the results for M = 2.27, 4.0 and 5.75. These results indicate that the total critical power, Q_{crit} cannot be significantly increased by tailoring of the flux distribution to an optimum shape.

Q_{crit} - Flux Distributions with Maximum Flux Near or at the Test Section Exit

The value of Q_{crit} for these distributions can be significantly less than Q_{crit} for uniform flux distributions at the same operating conditions. The deviation depends on the degree of inlet subcooling, ΔH_{in}, the mass velocity, G, the flux shape, and its associated M ratio. For the maximum inlet subcooling investigated, about -300 btu/lbm, Table IV-A below summarizes the maximum decreases observed in total critical power.

Flux Distribution	MASS VELOCITY, G, LBM/HR-FT^2		
	0.5×10^6	1.0×10^6	2.0×10^6
Linear increasing (M=2.27)	-20%	-5%	-5%
Linear increasing (M=5.75)	-35%	-15%	-30%
Peak exit (M=5.75)	-15%	-15%	-30%

Table IV-A

MAXIMUM DECREASE IN Q_{CRIT} COMPARED TO UNIFORM FLUX DISTRIBUTION RESULTS

As the inlet condition approaches saturation, the deviations of Table IV-A decrease, resulting in approximately equal values of Q_{crit} for uniform and nonuniform flux distributions at low inlet subcooling levels.

The increased deviations with increased M for a given flux shape are clearly apparent in the table above. This dependence is observed for results in the annular regime and several results which were obtained in the subcooled region. In fact the test data show (Fig. 21 and 22) that if the flux distribution is severely peaked, the flux level can be high enough to cause a critical condition at a location where subcooled conditions prevail. Thus the actual flux distribution can cause both (1) decreased Q_{crit} compared to uniform flux data when both data are in the annular regime and (2) severely decreased Q_{crit} due to a subcooled critical condition which occurs at a high flux location of the nonuniform distribution.

Similar results have also been obtained by other experimenters at higher pressures. Portions of the data of Bertoletti (11), Swenson (5) and the most recent Babcock and Wilcox inves-

tigation (15), are presented in Figures 23, 24 and 25 which confirm the principal observations of this study, namely

1) For cosine and other distributions with the maximum flux near or at the test section inlet, Q_{crit} is within $\pm 10\%$ of uniform flux data and decreases as ΔH_{in} approaches the saturated inlet condition.

2) For distributions with the maximum flux near or at the test section exit, Q_{crit} can be up to 30% less than the uniform flux data at large inlet subcoolings. This deviation approaches zero as ΔH_{in} approaches the saturated inlet condition.

4.1.2 Critical Location

The location of the critical phenomenon for each test section was also determined experimentally and is presented in Figures 14, 17, and 20. The tabulation of Appendix F in some cases indicated two critical locations. In these cases, before effective corrective action was taken, the test sections were somewhat bowed during testing and upon attaining the critical condition, both a thermal failure and mechanical failure occurred. The thermal failure was characterized by melting of approximately an 1/8" wide by 1 " long (axial) rectangular portion of the test section. In Appendix F, the actual critical location is reported as the midpoint of the thermal failure with its axial extent listed as the $\pm$ value. The mechanical failure was a complete circumferential shearing of the test section characterized by a jagged unfused cleavage. In certain cases, which are noted, a double thermal failure did occur. In all other cases, the first

listed location, is the thermal failure location and this is used in subsequent analysis. These results can be summarized as follows.

CRITICAL LOCATION - UNIFORM FLUX

The critical location occurred within 1% of the test section exit, the slight deviation probably being attributable to axial conduction effects.

CRITICAL LOCATION - MONOTONICALLY INCREASING FLUX (i.e. LINEAR INCREASING)

The critical location occurred within 1% of the test section outlet except for one case. In this case, test section 1204 which was tested at $G = 1.0 \times 10^6$ and $\Delta H_{in} = -160$ BTU/LBM, the critical location was slightly upstream from the exit ($.7 \pm .5$ inches from exit of the 30 inch test section).

CRITICAL LOCATION - FLUX PEAK ALONG TEST SECTION AT ANY LOCATION EXCLUDING EXIT (i.e. COSINE, PEAK NEAR INLET, PEAK NEAR EXIT, LINEAR DECREASING)

The critical location for these flux distributions always occurred between the flux peak and the test section exit or at the test section exit. The critical location is dependent on inlet subcooling, ΔH_{in}, and moves upstream from the tube exit with increased subcooling. In addition, for a given flux shape, the critical location appears also dependent on M. For example for cosine distributions the critical location is further upstream for M values of 2.27 and 5.75 versus 4.03. For linear decreasing flux shape, increased M value (5.75 versus 2.27) results in upstream movement of the critical location.

The data of other investigators generally confirm these results particularly the upstream movement of the critical location for the peak inlet flux distribution with increased inlet subcooling. However precise determination of the critical location was not generally obtained due to the burnout detection systems used. The CISE investigators (11) on the other hand, indicated that in all cases the onset of the critical condition occurred at the test section exit.

The possibility that the onset of the critical condition occurred at the exit but moved, causing a physical failure upstream, was considered and investigated in this work. Differential thermocouples were used with the point of interest and an unheated exit portion of the test section as the two opposing inputs. A series of thermocouples were simultaneously used to monitor several locations between the tube exit and the expected burnout location. The output from these thermocouples was recorded on a multichannel recording oscillograph by galvanometers with natural frequencies ranging from 50 to 300 cycles per second. However, these traces did not show movement of a wall temperature excursion from the tube exit to the critical location. Thus it appeared that the critical condition occurred initially and only at the location of tube failure.

4.1.3 Reproducibility of the Data

Several runs were made at almost identical inlet and mass velocity conditions to establish the reproducibility of the data. These results, tabulated below in Table IV-B, indicate that differences exist in total critical power, Q_{crit}, up to $\pm$ 10% and in critical location up to 4.0 inches. Note that

Test Section	Date	Flux Shape	M	G $\frac{LBM}{HR\ FT^2}$	ΔH_{inlet} $\frac{BTU}{LBM}$	Q_{crit} $x10^{-5}\frac{BTU}{hr}$	% Diff.	Critical Location Inches (From Inlet)	Inches Diff.
142	10/21	UNIFORM	1.0	$2.0x10^6$	-271.2	2.029	10%	29.8±0	
135	9/25			$1.99x10^6$	-270.8	2.232		29.6±0	.2
310	9/3	COSINE	4.03	$1.0x10^6$	-246.5	1.435	7.2%	24.0±0	3.2 to 4.0
333	9/23				-246.9	1.538		27.6±.4	
511	10/14	COSINE	5.75	$0.5x10^6$	-159.2	7.404	8.3%	24.3±.2	1.3 to 2.1
512	10/14				-154.4	6.837		22.6±.2	
1271	11/12	LINEAR DECREASING	2.27	$1.0x10^6$	-249.9	7.572	5.5%	26.4±1.4	0 to 3.3
1252	11/19				-247.5	7.988		25.5±1.0	

TABLE IV-B REPRODUCIBILITY OF RESULTS

the error analysis of reference A indicates a probable variation of $\pm 3.4\%$ in total critical power. Thus Q_{crit} has been determined in this work to at least within $\pm$ 10%. The observed variation in the critical location is quite large. However, from the analysis to be presented, such variations are shown to be probable and still consistent with the more accurate determination of Q_{crit}.

4.2 Formulation of the Method of Analysis

With the experimental results presented, a method of analysis is desired which predicts the salient features of these results and permits interpolation and some extrapolation of these data to other conditions of interest. The most convenient approach initially appeared to be extension of the models of Becker (16) and Isbin (18) to the nonuniform distribution case. This model, applicable to the annular regime, identifies processes which increase and deplete the film flow rate and establishes dryout of the annular film as the mechanism causing the critical condition. Dryout in this model and throughout this discussion refers to the decrease of the annular film flow rate to a low value sufficient to cause the annular film to break up and expose dry patches of the heating surface. However, since the annular film flow rate calculated in this manner is generally always a minimum at the tube exit, such a model apparently cannot predict the observed occurrence of the critical condition upstream of the test section exit for certain nonuniform flux distributions. Consequently, while the decrease of film flow rate to some low value has been demonstrated by Harwell researchers (34) to be responsible for the critical phenomenon

in some cases, an additional mechanism probably is responsible for the occurrence of upstream critical conditions. This mechanism must cause a severe local decrease in the heat transfer coefficient sufficient to initiate the critical phenomenon at an axial location where the nominal film flow rate may not necessarily go to zero. Mechanisms for promoting local disruption of an annular film have been proposed by other investigators. In particular, the occurrence of bubble nucleation on the tube wall within the annular film has often been cited as a possible mechanism. Since the initiation of nucleation is principally dependent on local heat flux, the occurrence of nucleation is particularly dependent on the flux shape and its M (ratio of maximum to minimum flux) value. Hence results from a variety of axial heat flux distributions offer a particularly appropriate means to evaluate the nucleation effect as a second mechanism responsible for the occurrence of the critical phenomenon in addition to the dryout effect.

The definitions used in formulation of a model which includes this nucleation-induced disruption of the annular film are presented in Figure 26. At every point along the test section, in the quality region, the ratio of flux required to initiate nucleation to the actual flux can be obtained as indicated in Figures 26a, b, c, and d. If this ratio is at or above one, nucleation is presumed to occur, the intensity of nucleation being directly proportional to the value of the ratio. Approximation of the local film flow rate is also required since intuition leads one to conclude that the magnitude of film flow rate affects the intensity of nucleation required

to locally disrupt the annular film sufficiently to cause the critical condition.

The principal factors governing the magnitude of the film flow rate are (a) evaporation from the film surface (b) entrainment from the film and (c) re-entrainment of water droplets from the vapor core into the film. Two major simplifying assumptions were made (1) for each test section the annular film is formed at the slug-annular transition with the same initial film flow rate, and (2) the effect of (b) and (c) was assumed approximately equal for all tubes. Since the test sections investigated were all 30 inches long (except for three test sections of 48 inches length) and the quality change per unit length did not vary greatly with flux distribution, the decrease film flow rate was assumed proportional to the evaporation effect only. Consequently the local film flow rate was taken inversely proportional to the enthalpy addition from the slug-annular transition point to the point of interest, ΔH_{ann-x}.

In this manner the necessary parameters are established to confirm the hypothesis that the critical condition is caused by either

(a) a nucleation-induced disruption of the annular film or if (a) does not occur, then ultimately by

(b) dryout resulting from decrease of the nominal film flow rate to zero.

The parameters are evaluated at the critical location and displayed as illustrated on Figure 26e as $(q/A)_c/(q/A)_i$ versus ΔH_{ann-c}. Figure 26e also indicates the expected behavior of the experimental data. For critical conditions occurring

where the flux ratio is above one, nucleation is occurring and mechanism (a) should be operative. In this region, the nucleation intensity necessary to disrupt the annular film should decrease with decreasing film flow rate. Hence the locus of critical conditions should exhibit a negative slope as indicated.

Where the flux ratio is below one, nucleation is suppressed and hence mechanism (b) should be operative. Since the only mechanism for depletion of the initial film flow rate is assumed to be evaporation, the amount of evaporation required by mechanism (b) to produce dryout should be equal for all axial flux distributions. Hence below a flux ratio of one, the locus of critical conditions should be a vertical line representing constant ΔH_{ann-c}. Since all critical conditions in this region are presumably due to dryout, the critical location of the data falling in this region should be only at the test section exit.

Figure 26e according to this model, should be valid for all axial flux distributions operated at given mass velocity and pressure. While small variations in pressure are accounted for in the calculation of the basic parameters, large variations (>100 psia for example) result in variation in nucleation bubble size and thus may fundamentally affect the basic assumed mechanism. The success of this postulated model can in part be measured by the degree of scatter of test results about a mean critical condition locus. While some distribution about a mean locus is inevitable due to the simplifying assumptions made concerning the film flow rate and experimental scatter, a

reasonable coalescence of data from all nonuniform axial flux distributions on such a plot should be achieved if the postulated model is valid.

Before presenting the experimental results, the exact method of calculating parameters required by the assumed model will be presented.

4.3 Calculation Procedure for the Method of Analysis

The presentation of data on an ΔH_{ann-c} versus $(q/A)_c/(q/A)_i$ requires determination of the following parameters.

1) QUALITY AT SLUG-ANNULAR TRANSITION - For the low pressure data of this investigation, this quality is taken as 8% as discussed in Chapter II.

2) ΔH_{ann-c}, CHANGE IN ENTHALPY FROM THE SLUG-ANNULAR TRANSITION LOCATION TO THE CRITICAL LOCATION - Establishing the transition location at the location where quality equals 8% and the critical location from experimental results, ΔH_{ann-c} can be readily calculated by a heat balance as described in Appendix D.

3) $(q/A)_c$, CRITICAL HEAT FLUX - The critical heat flux can be obtained directly from experimental results as described in Appendix D.

4) $(q/A)_i$, HEAT FLUX REQUIRED FOR INCIPIENT BOILING - This heat flux must be calculated at the same conditions of pressure, quality, and mass velocity as $(q/A)_c$. The Bergles-Rohsenow result (35) is used to calculate the heat flux required for incipient boiling. Although this result was derived for single phase flow, it should also be applicable to nucleation in a liquid film in contact with the heated surface. The

implicit assumption is that the temperature distribution within the liquid film can be expressed by the Fourier conduction relation with the conductivity evaluated at the wall surface temperature. The details of the analysis are summarized in the insert on Figure 27. The result, presented below, yields $(q/A)_i$ as a function of pressure and temperature difference, $T_{WALL} - T_{SAT}$.

$$(q/A)_i = 15.60P^{1.156}(T_{WALL} - T_{SAT})^{2.30/P^{0.0234}}$$

From Figure 27 it is seen that this result requires that a minimum cavity size in the heated surface be present to serve as a nucleation site. Hence for applicability of this result, it is essential that the existence of cavities of the required minimum cavity size be confirmed. The dependence of $(q/A)_i$ with pressure and temperature difference and the minimum cavity size required are also shown in Figure 27. For comparison the limiting condition for incipient boiling, the approximate fully developed boiling curve, for 100 psia is also shown in Figure 27. This curve was obtained by modifying the results of Jens and Lottes (36) to reflect the results of Bernath and Begell (37) which indicate that slightly larger superheats are required for an aluminum surface compared to a nickel or stainless steel surface.

To use the Bergles-Rohsenow result for predicting performance of a test system, the two phase heat transfer coefficient at the critical location conditions must be established. For the range of pressures and qualities investigated, the Dengler-Addoms Correlation (38) is directly applicable

$$h_{TP} = h_L(1/x_{tt})^{0.5} \quad .$$

A more general correlation which is also applicable to steam water mixtures at higher pressures and other fluids has been proposed by Chen (39), and is fully presented in Appendix D. This result gives heat transfer coefficients about 15% lower than the Dengler-Addoms correlation for the conditions of interest. Since the Dengler-Addoms result is based on data at similar conditions to those of this investigation, it is used unless otherwise noted to calculate heat transfer coefficients. The dependence of $h_{Dengler\text{-}Addoms}$ with mass velocity and quality at a given pressure is shown in Figure 28. Combining the results of Bergles and Rohsenow

$$(q/A)_i = f(p)\ (T_{WALL} - T_{SAT})^{f(p)}$$

and Dengler-Addoms

$$q/A = h_{Dengler\text{-}Addoms}\ (T_{WALL} - T_{SAT})$$

at the critical conditions, (P_c, X_c, and G), the heat flux required for inception of nucleation is obtained as the intersection of the two equations as illustrated in Figure 29.

With the required parameters determined, the critical condition can be presented on a $\Delta H_{ann\text{-}c}$ versus $(q/A)_c/(q/A)_i$ plot. Similarly for every point along the test section at the total critical power condition, the pressure, quality and mass velocity can be calculated and $(q/A)_i$ established. Figure 30 illustrates the results for test section 1271. In general, as Figure 30 shows, at low qualities $(q/A)_i$ is low and hence the flux ratio $(q/A)_x/(q/A)_i$ is large.

In this manner conditions along the entire test section at the total critical power can be represented as shown on Figure 31. For total input power levels less than the critical level, operating conditions can be calculated for all points along the test section by the methods described above. Figure 31 also presents curves for power levels less than the critical level.

It should be noted that Figure 31 presents the behavior of only the linearly decreasing flux shape. Representation of other flux shapes on a plot of the same coordinates exhibit different shapes since values of ΔH_{ann-x}, $(q/A)_i$ and particularly $(q/A)_x$ are dependent on the axial flux distribution. The analysis of the experimental data using the methods just described will be presented next.

4.4 Application of the Method of Analysis to Experimental Data

The parameters ΔH_{ann-c} and $(q/A)_c/(q/A)_i$ were calculated for all experimental data. Figures 32, 33 and 34 present the experimental results at each of the three mass velocities investigated. In each case the data can be bracketed to define a critical condition region. This region should ideally reduce to a single line which represents the locus of critical conditions. However, in view of the assumptions made in representing the film flow rate, as well as experimental scatter of the results themselves, the width of the data band is to be expected.

The results of Figures 32, 33, and 34 depend on the existence in the aluminum surface of cavities of the size required by the Bergles-Rohsenow nucleation theory. For the experimental conditions of this investigation, the maximum radius size

required is about 8×10^{-5} ft. Confirmation of the existence of such cavity sizes was attempted by visual observation of the boiling surface at high magnification (1000x). However, the depth of field resolution was not sufficient to permit identification of any surface features of depth less than about 3×10^{-6} ft. Thus while no hemispherical cavities of the required dimension 8×10^{-5} ft could be observed, suitable elliptical or other irregular shaped nucleating cavities of minor radius less than 3×10^{-6} ft could not be detected by the Zeis microscope used. However, as discussed by Brown in reference (40), the surfaces were investigated by another method which confirmed the existence of nucleation sites by their active nucleation behavior in a superheated pool. This method indicated that cavities of about $2.0 \pm 2.0 \times 10^{-5}$ ft equivalent radius were present in the test surface. Since these cavity sizes were slightly less than those required by the theory, in principle a modification should be made to the theory as shown in the insert of Figure 35 to account for this deviation. The remainder of Figure 35 presents a dimensionless representation from Brown (40) of the Bergles-Rohsenow nucleation theory modified to account for surfaces having limited cavity sizes. However, as Figure 35 shows, for the experimental conditions of this test, only slightly higher heat fluxes are required because of the actual cavity sizes present. In view of the small correction involved and the uncertainty in actually assessing the cavity sizes present in the test aluminum surfaces, this small correction was not made in analysing the data in this investigation.

As anticipated, the critical limits of Figures 32, 33, and 34 are negatively sloping lines representing the decreased nucleation intensity necessary to disrupt the annular film as the film flow rate decreases. In addition, where the flux ratio decreases below one, i.e., where nucleation ceases, the critical limits become vertical suggesting that in this region, dryout is the mechanism for causing the critical condition. As previously mentioned, data falling in this dryout region should exhibit a critical condition at the test section exit only. Table IV-C below tabulates data in this dryout region from Figure 33 (nonuniform heat flux data was obtained in the dryout region for $G = 1.0 \times 10^6 \frac{LBM}{HR\ FT^2}$ only). In all but one case the critical location occurred within 3% of the tube exit. In this one case (No. 1555) and other cases having the critical location between 1 and 3% from the exit, the flux profile had a severe negative gradient with length near the exit. Thus axial conduction effects probably account for the slight deviations from predicted behavior of these test sections.

Clearer delineation of this dryout region was not possible since 48 inches was the maximum length of test sections that could be fabricated and installed in the apparatus. However, Figure 36 presents additional low pressure data taken at Harwell (41) on uniform tubes from 9 to 96 inches long. In Figure 36 the dryout region is clearly apparent. In addition, however, the dotted lines in this figure identify an additional stratification within the critical region with tube length. This stratification is probably due to entrainment and re-entrainment contributions to the film flow rate which must be

expected to vary significantly with varying test section length.

Test Section	Flux Shape	M	Critical Location	ΔH_{ann-c}	$(q/A)_c/(q/A)_i$
210	COSINE	2.27	29.6 ± 1 inches	331.2	1.2
211	COSINE	2.27	29.5 ± 0	326.5	1.09
332	COSINE	4.03	28.9 ± .2	313.7	1.01
336	COSINE	4.03	29.5 ± .3	312.2	.74
508	COSINE	5.75	29.0 ± .3	350.6	.69
1254	LINEAR DECREASING	2.27	29.8 ± 0	333.1	1.10
1255	LINEAR DECREASING	2.27	29.8 ± 0	343.3	1.13
1554	LINEAR DECREASING	5.75	29.2 ± .4	339.4	.74
1555	LINEAR DECREASING	5.75	28.2 ± .1	326.7	.86
1556	LINEAR DECREASING	5.75	28.6 ± .5	324.9	.69
2506	LINEAR PEAK INLET	5.75	29.3 ± .3	334.4	.71

TABLE IV-C CRITICAL LOCATIONS FOR TEST SECTIONS HAVING RATIO $(q/A)_c/(q/A)_i$ APPROXIMATELY EQUAL TO OR LESS THAN ONE. ($G=1.0 \times 10^6$ LBM/HR-FT^2)

4.4.1 Discussion of Results

From Figures 32, 33 and 34, it is seen that a critical region can be established which represents both postulated mechanisms for the critical condition. This critical region is shown below to provide a reasonable criteria for predicting both Q_{crit} and critical location for all axial flux distributions.

4.4.1.1 Total Critical Power

Figure 31 previously showed the variation in test section operating lines with total input power. Since the critical condition can occur whenever any portion of the test section operating line projects into the critical region, the power change necessary for any point of an operating line to pass through the critical region represents the maximum uncertainty in predicting total critical power. As Figures 37 and 38 which represent various flux distributions show, it requires about 20% variation in total power for any given test section location to pass through the width of the critical region. Taking the critical locus through the midpoint of the critical region, prediction of Q_{crit} within $\pm$ 10% can be made for any flux distribution investigated once the critical region for given mass velocity and pressure is experimentally established. This region can be established by a combination of tests of uniform and nonuniform flux distributions as in this study or with uniform data only as the Harwell data of Figure 36 indicates.

4.4.1.2 Critical Location

The critical location results presented in Figures 14, 17 and 20 exhibited some significant variations with flux distribution and inlet subcooling. These variations can be qualitatively explained in terms of the critical regions established for each mass velocity on the $(q/A)_c/(q/A)_i$ versus ΔH_{ann-c} plots. The basis of these qualitative arguments is that the critical condition will occur at that test section location of the operating line which first intersects the critical region.

EFFECT OF FLUX DISTRIBUTION

The most striking experimental result is that for uniform and linearly increasing flux distributions as opposed to the others tested, the critical condition always occurs at the tube exit. A clear explanation lies in the shape of the test section operating lines for these flux distributions. As shown in Figure 39, the operating lines are convex when viewed from the origin. Thus the tube exit always intersects the critical region first, causing the critical condition to occur at the tube exit.

On the other hand for the flux distributions with a flux peak along or at the exit of the test section, the operating lines are concave when viewed from the origin as illustrated in Figures 40, 41 and 42. This concave portion is always bounded by the location of maximum flux and the tube exit. Hence some location downstream of the maximum flux always will intersect the critical region before the maximum flux location. This characteristic appears to explain the observation that the critical condition always occurs between the maximum flux location and the tube exit for such flux distributions.

EFFECT OF M VALUE

The second experimental observation is that for test sections of the same flux shape at the same inlet subcooling, an increase in M will cause the critical location to move upstream from the tube exit. This is shown in Figure 40 for the linearly decreasing flux shape and for the cosine flux shape. The increased concavity resulting from increased M value causes upstream portions of the operating line to inter-

sect the critical region before the tube exit portions. However, for the cosine shape M = 2.27 this result does not follow as shown in Figure 40 because the M factor is so low that the operating line is a straight line almost parallel to the critical region. Hence in this case, failure at any point past the maximum flux location is generally equally probable.

EFFECT OF INLET SUBCOOLING

The significant effect on critical location due to inlet subcooling can also be qualitatively explained. First, it should be observed that the effect of decreased subcooling on the test section operating line is to extend it to larger values of ΔH_{ann-x}. This results from a net gain in total heat input over the annular region owing to a larger decrease in heat input from the inlet to the annular transition compared to the decrease in total critical power. The effect of this change in operating line length is to permit the exit portion of the operating line to approach the dryout portion of the critical region where the critical condition will occur if local conditions do not cause its prior occurrence upstream from the tube exit. For this reason, the critical location should move to the tube exit as the inlet subcooling is decreased. This effect is shown in Figure 41 for the inlet and the exit flux peak distributions, and Figure 42 for the linearly decreasing flux distribution. It should be recognized that due to the shapes of the operating lines and critical regions, in some cases several locations are equally probable as the critical location. Thus the locations of the critical conditions have a fairly large experimental spread (see Table IV-B) and consequently can be only qualitatively

confirmed by the model developed in this work.

The effect of experimental variables on the critical condition can be summarized as follows:

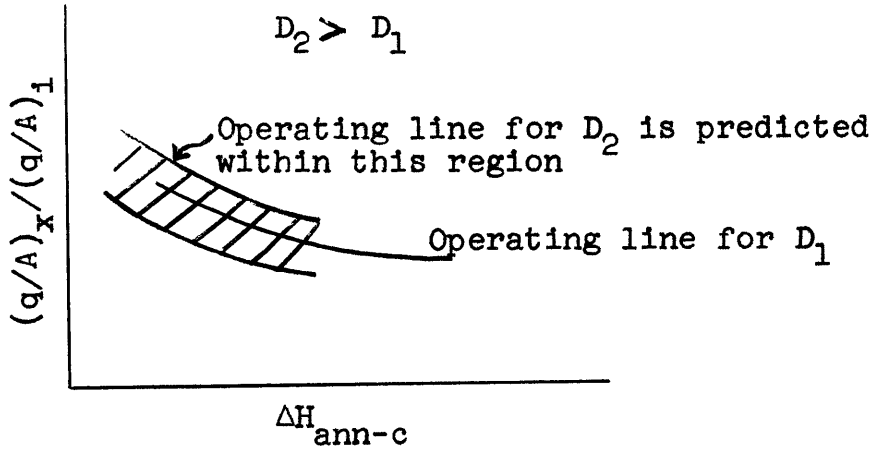
Mass velocity - The mass velocity has been the key variable in the presentation of Figures 32, 33 and 34. Figure 43 summarizes the results for the three mass velocity values selected. This data exhibits the behavior predicted by Bell (4) that for a given quality (ΔH_{ann-x} in this case) the critical heat flux is inversely proportional to the mass velocity.

Length - The test data of Figures 32, 33, 34 and Figure 36 which presents the Harwell (41) data, illustrates that the location of the critical condition approaches the dryout region as the test length increases. Figure 44 shows that for the longer tube lengths, the test section operating lines for uniform flux are S shaped instead of simply convex as are the shorter lengths. If a similar S shape can be shown to exist for long uniform tubes at high pressures, it is possible that an upstream portion of the test section operating line would first intersect the critical region. This could offer a plausible explanation for the upstream critical conditions which have been observed by Waters et al (42).

Inlet Subcooling - As previously discussed, decreased inlet subcooling tends to extend the test section operating line to larger exit quality regions (larger ΔH_{ann-x}). Thus inlet subcooling variations can cause the critical phenomenon mechanism to change from nucleation-induced film disruption to dryout. Figure 45 indicates the effect of the inlet subcooling on the

Harwell data. It should be noted that in Figure 45 for the 12" long section, the inlet subcooling does not cause the ΔH_{ann-c} to increase at low values. On the Harwell presentations this effect shows as an unexplained decrease in critical heat flux with low inlet subcoolings. Unfortunately, analysis of the Harwell data by the method proposed in this report does not explain this discrepancy.

Diameter - The effect of diameter has not been investigated in this study. Prediction of the effect is difficult since a diameter change results in conflicting increases and decrease of the relevant parameters. For example at fixed G, as the diameter increases, the local flux q/A tends to be decreased but since the local quality would also decrease, $(q/A)_1$ would also tend to decrease. The net result on the flux ratio cannot easily be predicted although ΔH_{ann-c} would be expected to be decreased. Thus as diameter increased, with G, P, ℓ and ΔH_{INLET} constant, the operating curve may be elevated or lowered on the flux ratio (vertical) axis, but would be displaced toward the origin of the ΔH_{ann-c} axis.



This prediction assumes that the basic mechanism is not fundamentally altered by a diameter change. This assumption may not be valid since a diameter change will affect the ratio of surface radius of curvature to bubble diameter, a parameter which could be of importance in defining the critical condition mechanism.

4.4.2 Discussion of Results - Flux Spikes

In addition to the experimental results already presented, eleven additional tests were performed with test sections having a localized flux peak, i.e. a flux spike. These flux spikes were superimposed on available test sections already having uniform and cosine flux distributions by additional local reduction in the tube outside diameters. The flux profiles investigated are illustrated in Fig. 10 and the test geometry and results are tabulated in Appendix F.

The investigation of flux spike shapes is important for the following two reasons which are discussed in detail below.

1) The flux peak offers a unique opportunity to investigate the validity of the model already developed to describe the occurrence of the critical condition.

2) The effect of such flux peaks on the critical condition and the resultant total critical power is pertinent since flux peaks are present in reactor systems.

APPLICATION OF MODEL TO FLUX PEAK DATA

Figures 46 and 47 present the test results on the appropriate coordinates for comparison with the predictions of the model which has been developed. Note that Fig. 46 represents cosine flux distributions with stepped spikes of length varying from .085 to 1.5 inches. Figure 47 represents uniform flux

distributions with cosine spikes of length varying from 1.0 to 9.0 inches. Axial conduction effects have been investigated and determined to be negligible since in the worst case (shortest spike length), the applicable L/D ratio is about 15. From the results of Figures 46 and 47, the following conclusions can be drawn:

1) For short spike lengths, a larger value of the flux ratio, $(q/A)_c(q/A)_i$, is necessary to cause a critical condition than predicted by the model. However, for spike lengths greater than about 1.5 inches, or as the flux peak distributions approaches the shape of the other flux distributions investigated, the critical condition can be predicted by the model. This observation indicates that conditions prior to the flux peak location play some additional role not included in the model in defining the occurrence of the critical condition. However, sufficient additional data for flux spikes was not obtained to generalize the model to accurately predict behavior of flux spikes of short length. Nevertheless, the model developed can still be applied in practice to flux peaks of short length since conservative predictions result.

2) The existance of two critical regions, one caused by nucleation induced film disruption and the other by film dryout is further confirmed. This confirmation is particularly apparent from Fig. 47 where the flux peak M values (maximum flux/minimum flux) were systematically altered. For the lowest M values, the nucleation-induced film disruption mechanism is operative since the flux peak reaches a critical condition before the test section exit reaches the dryout region.

TOTAL CRITICAL POWER

Table IV-D below presents the results of the total critical power for test sections with flux peaks. These results indicate that the total critical power for flux peak distributions up to an M value of 5.75 is slightly greater (0-15%) than that for uniform flux distributions at the same inlet conditions. The increase is inversely proportional to the M value, the test sections with lower M values exhibiting the largest increases in total critical power. For flux spikes of M = 7.0, the total critical power becomes slightly less (0 to -4%) than that for uniform flux distributions at the same inlet conditions. As mentioned above, these results can be confirmed for spike lengths 1.5 inches or greater by application of the model developed. However, for flux peaks of shorter lengths, the model yields conservative predictions and hence total critical power values less than those for uniform flux distributions would probably be predicted for these cases.

TABLE IV-D

TOTAL CRITICAL POWER RESULTS FOR TEST SECTIONS WITH FLUX PEAKS

Test Section	Spike Length inches	Ratio of Maximum to Minimum Flux	Inlet Subcooling BTU/lbm	Critical Power BTU/hr	% increase in total critical power above that for uniform flux distribution
0326	.085	4.17	-67.4	1.09×10^5	+5.0%
0345	.50	4.17	-119.3	1.255×10^5	+9.2%
0343	.50	4.52	-116.6	1.205×10^5	+5.8%
0344	1.5	5.14 to 4.54	-113.8	1.198×10^5	+5.7%
7210	1.0	2.27	-114.1	1.247×10^5	+9.4%
7510	1.0	5.75	-115.3	1.138×10^5	+0.7%
7710	1.0	7.0	-110.1	1.125×10^5	+0.5%
7250	5.0	2.27	-116.5	1.300×10^5	+14.6%
7550	5.0	5.75	-105.6	1.109×10^5	+0.0%
7750	5.0	7.0	-103.0	1.061×10^5	-4.0
7290	9.0	2.27	-116.8	1.263×10^5	+10.2%

4.5 Application to Higher Pressures

The success of the model in explaining behavior of low pressure results suggests its application to higher pressure data. In applying the model to existing high pressure data, two difficulties are encountered.

1) Measurements or a correlation of the heat transfer coefficient for annular flow at pressures above 550 psia are not available. Consequently the Chen correlation (39) was extrapolated from 550 psia to 2000 psia to yield required two phase heat transfer coefficients.

2) The critical condition locations for available non-uniform results at high pressures have a large uncertainty. This results from the burnout detection systems used to detect the location of the critical condition.

However, estimating heat transfer coefficients from the Chen correlation and carrying the uncertainty in critical location, the model has been applied to a limited amount of high pressure data with the results illustrated in Figs. 48 and 50. In these cases, the quality at the annular transition location has been approximated as 6% and 14% respectively from the preliminary results of Suo (21).

The shape of the critical locus in these figures is similar to that for low pressure data in that the flux ratio required to produce the critical condition decreases as the film flow decreases. However, the magnitude of the flux ratio required to produce the critical condition is an order of magnitude higher than for low pressure conditions. This could result from the uncertainty in the two phase heat transfer

coefficient value. A dryout region is not indicated in these figures. Additional data at the test conditions represented in these figures is necessary to fill in the regions of higher ΔH_{ann-c} to establish the existence of a dryout region. Even if the heat transfer coefficient is an error, such a region should still be indicated although it may occur at a flux ratio higher than 1.

Figure 48 represents Babcock and Wilcox data at 1000 psia from reference 15. The limit bands indicated reflect the large uncertainty in critical condition location which result in very broad limits for the critical region. As illustrated in Fig. 49, the width of the critical region including the maximum uncertainty limits is about $\pm$ 40%. However even considering the most probably critical locations, the width of the critical region is still $\pm$ 20%.

Figure 50 presents earlier Babcock and Wilcox data from reference (5) taken at 2000 psia. The width of the critical limits can be considerably reduced if the diameter difference between test sections in this experiment is recognized. As illustrated in Fig. 51, the minimum critical region in this case is approximately $\pm$ 15%. This latter Babcock and Wilcox data also contains four results for test sections with flux spikes superimposed on cosine flux distributions. These data indicates a distinct movement of the critical condition from the flux spike to the test section exit as the inlet subcooling decreased.

In terms of the model, this effect can be qualitatively explained. Recall that the effect of decreased inlet subcooling

as discussed in Section 4.4.1.2 is to extend the test section operating line to larger exit quality regions (larger ΔH_{ann-c}). Thus decreased inlet subcooling should cause the critical phenomenon to shift from a nucleation-induced film disruption at the flux peak location to film dryout at the test section exit. The critical location will thus shift with decreased inlet subcooling from the flux peak to the tube exit.

Figure 52 illustrates the operating lines of the flux spike test sections. The critical location is seen to shift to the test section exit which extends to larger values of ΔH_{ann-x} with decreased subcooling. If a dryout region is assumed to exist at high values of ΔH_{ann-x} as was shown for the lower pressure results, these Babcock and Wilcox as well as the Bettis flux spike results of reference (1) can be explained. In particular the behavior of the spike effectiveness value, E_p, as introduced by Bettis (reference 1) and illustrated in Fig. 1 is readily predictable. When the critical condition is caused by nucleation-induced film disruption, ϕ_3 will equal ϕ_2 (see Chapter 1 for definitions) and E_p will equal 1. For a dryout caused critical condition, ϕ_3 will equal ϕ_1 and E_p will equal 0. Hence the model predicts the observed Bettis result that with decreased inlet subcooling E_p goes from 1 to 0 and the critical condition moves from the flux peak location to the tube exit.

However, due to the uncertainties in heat transfer coefficient and critical location determination and limited data at fixed conditions of flow, pressure and diameter, application of the model to high pressure data as yet does not indicate the existence of the dryout region and results in a broad predicted

critical region due to the film disruption mechanism. Nevertheless the model does yield the correct shape of the critical locus in the nucleation-induced film disruption region as well as a reasonable possible explanation for flux spike results. These qualitative predictions indicate that successful extrapolation of the model to the high pressure region may be accomplished when the heat transfer coefficient and critical location are determined more accurately for test runs in this region.

CHAPTER V

SUMMARY AND CONCLUSIONS

5.1 Summary

An experimental and analytic investigation of the effect of axial heat flux distribution on the critical flux has been performed. Experimental determination of the total critical power and critical location was accomplished for a wide variety of flux distributions. An analytic model describing the occurrence of the critical condition was developed which explains the behavior of the low pressure experimental results.

This model assumes that the critical condition is caused by either

(a) a nucleation-induced disruption of the annular film or if (a) does not occur, then ultimately by

(b) dryout resulting from decrease of the nominal film flow rate to zero.

The basic assumptions in analytically formulating this model are

(1) an annular film is established at the annular transition location predicted by Baker (24)

(2) the effects of entrainment and re-entrainment on the local annular film flowrate are approximately equal for tubes of similar length. Hence the local film flow rate decrease with test section length was assumed proportional to the evaporation effect only

(3) the heat flux required to initiate nucleation can be predicted from the Bergles-Rohsenow correlation (35) using heat transfer coefficients calculated from the Dengler-Addoms correlation (38).

The resulting procedure does not allow prediction of critical conditions from simply the specification of the relevant independent variables but does provide a method by which limited experimental data can be used to establish a locus of critical conditions which is applicable to test sections with nonuniform axial flux distributions. Specifically uniform test data taken at fixed pressure, mass flow rate, and diameter can be used to predict critical conditions for various flux distributions at the same pressure, mass flow rate and diameter but with varying inlet subcooling and test section length.

5.2 Conclusions

The conclusions of this investigation can be summarized as follows.

1) Total input power to achieve a critical condition:

(a) For the cosine and other flux distributions with the maximum flux near or at the test section inlet, the total critical power is within -10% (peak inlet) to +10% (others) of that for uniform flux distribution.

(b) For flux distributions with the maximum flux near or at the test section exit, the total critical power can be up to 30% less than that for uniform flux distributions. This deviation, however, approaches zero as the inlet condition approaches the saturated condition.

(c) For flux spikes of various lengths with the ratio of maximum to minimum flux up to about six, the total critical power is about 0 to 10% greater than that for uniform flux distributions. For more severe flux spikes, the total critical power becomes less than that for uniform flux distributions.

2) The Critical Location:

(a) For uniform and monotonically increasing flux distributions, the critical location occurs very near to or at the test section exit.

(b) For flux distributions with the flux peak at any location except the test section exit, the critical condition can occur upstream depending on the inlet subcooling and the M walue (ratio of maximum to minimum flux). The critical condition tends to move upstream as either the subcooling and M value increases.

3) The analytical model proposed to describe the occurrence of the critical condition successfully explains the test data for all axial flux distributions except flux spikes of short ($\leq$ 1.5 inch) extent. For these short flux spikes, the model predicts lower local critical heat flux and total power values than were determined by experiment.

4) Application of the model to high pressure data gives qualitative agreement with test results. More precise experimental determination of the critical location and data yielding two phase heat transfer coefficients are needed at these higher pressures to effectively test the validity of the model under higher pressure conditions.

5.3 Design Procedure (50-200 psia)

Based on the conclusions of this investigation, the following design procedure can be used to establish safe operating limits for vertical up flow in tubes with nonuniform axial flux distributions.

1) Establish locus of critical conditions - For the mass velocity, pressure and tube diameter of interest, use existing

critical data to plot the critical conditions on coordinates of $(q/A)_c/(q/A)_i$ versus ΔH_{ann-c}. Section 4.3 explains in detail the method of calculating these parameters from experimental data. This data may include uniform flux data or a combination of uniform and nonuniform flux data from tubes of all lengths.

2) Establish design conditions - Pick the axial flux distribution and values of inlet subcooling and test section length of interest. These values along with the previously established values of mass velocity, pressure, and diameter fully establish the design conditions.

3) Calculate the test section operating line for an arbitrary value of total input power, Q_{TOT} - Select a value of Q_{TOT} and calculate the test section operating line as described in Section 4.3 Plot this operating line with the locus of critical conditions determined per (2) above.

4) Establish Q_{crit} - For varying values of Q_{TOT}, plot operating lines until the locus of critical conditions is intercepted. The value of Q_{TOT} for this intersection is Q_{crit} and the test section axial location at the intersection is the location of the critical condition.

5) Optimize - Vary inlet subcooling, test section length and axial flux distribution as allowed by design requirements to maximize the parameters of design interest; generally the total critical power (Q_{crit}).

APPENDIX A

ERROR ANALYSIS

It is important to estimate the probable errors in the two basic parameters of interest, the critical heat input to the test section and the local heat flux.

The heat input is computed from measurements of the voltage drop across the heated length and the current to the section. Since the critical condition was generally reached while the input power was being increased to a slightly higher level, the error in the total critical power includes both an uncertainty from this operational procedure and a measuring instrument uncertainty.

For the voltage drop, this operational variation was about .15 volts over the range 12 to 27 volts and the voltmeter accuracy was $\pm$ 1/2% of full scale. Hence in the worst case (lowest power level) the uncertainty in the voltage at the critical condition was

$$r = 12 \pm .3 \text{ volts or } \pm 2.5\%$$

The current was inferred from the voltage drop across an air-cooled N.B.S. shunt with a calibrated conductance of 60.17 amps/mo. The uncertainty from the operational procedure was .3 mv over the range 23 to 52 mv, and the voltmeter accuracy was $\pm$ 1/2% of full scale. Hence in the worst case (lowest power level) the uncertainty in the current at the critical condition was

$$I = 60.17(23 \pm .6) \text{ amps or } \pm 2.6\%$$

Hence the most probably error in power for the lowest power cases was

$$\sqrt{(2.5)^2 + (2.6)^2} \cong 3.4\%$$

Note that the experimental reproducibility of total critical power results as summarized in Table IV-B was 5 to 10%.

The local flux for electrically heated test sections is obtained as

$$\phi(z) = \frac{dA_s}{dQ} = \frac{dA_s}{I^2 dR} = \frac{dA_s}{I^2 \frac{\rho(T) d\ell}{A_x(\ell)}}$$

From these equations we see that perturbations in the local flux are principally caused by variations in $A_x(\ell)$, $\rho(T)$, and dQ (axial conduction effects). The variations in these parameters will be separately estimated to arrive at the overall experimental error in the local flux.

A_x-Wall Cross-Section Area

Variations in A_x are due to (1) variations in test section internal diameter and (2) variations in the outside diameter due to machining. The machining errors were controlled by 100% inspection of test section outside diameters for conformance with allowed tolerances. The net actual variation in A_x was established by measuring wall thicknesses on 32 sections taken from seven tubes selected randomly to represent all the basic designs. From these measurements the average variation from design of wall thicknesses (4 at each section) was 3.5% with a maximum variation of 7.5%.

$\rho(T)$ - Electrical Resistivity

Variations in resistivity result from wall temperature differences due to axial changes in heat transfer coefficient. The changes in heat transfer coefficient result from the axial quality changes which can exist in a test section.

The variation in wall temperature along a test section can be bounded as follows. The minimum (T_W-T_{SAT}) can be taken from the fully developed boiling curve at a heat flux of 3×10^5 since heat fluxes of interest in this work were all above 3×10^5 BTU/hr ft^2. From Fig. 29, $(T_W-T_{SAT})_{MIN}$ is 40°F. The maximum (T_W-T_{SAT}) can be also taken from the fully developed boiling curve at the maximum heat flux achieved in test i.e. 3×10^6 BTU/hr ft^2. From Fig. 29 $(T_W-T_{SAT})_{MAX}$ equals 70°F. Hence, the maximum wall temperature difference for the composite worst case is 30°F.

Now for the 2024-T3 alubminum used, the resistivity as a function of temperature is

$$\rho(T) \text{ ohm-ft} = .1765\times10^{-6}\left[1+1.152\times10^{-3}T^{\circ}F\right]$$

in the range 200-500°F. Based on the nominal experimental pressure of 100 psia, (327.8°F) the maximum variation in resistivity along a test section would be 2.2%

dQ - Axial Conduction

Axial conduction effects can also be bounded by a worst case analysis. The maximum axial heat transfer is given by

$$dQ_{axial} = kA_x\frac{\partial T}{\partial z}$$

where

$k_{2024T3\ aluminum} = 80\ \frac{BTU}{hr\ ft^{\circ}F}$

$A_{x\ maximum} = 248\times10^{-6}$ ft^2 (.3020.0 inch, .214 inch I.D.)

$\left(\frac{\partial T}{\partial x}\right)_{maximum} = \frac{30^{\circ}F}{7.5/12\ ft} = 48^{\circ}F/ft$ (the maximum axial temperature difference of 30°F can occur over a minimum distance of 7.5 in. in the peak inlet and exit designs)

Hence $dQ_{AXIAL\ MAXIMUM} \lesssim 1$ BTU/hr. The minimum radial heat transfer, assuming the minimum heat flux is 1×10^5 BTU/hr ft^2, is about 500 BTU/hr.

Hence in the worst composite case the axial heat flow is less than .5% of the radial heat flux. This is primarily due to the thin wall test section geometry which yields large L(length)/D(wall thickness) ratios thus inhibiting axial conduction. In the immediate regions of the test section inlet and exit, the temperature gradients are probably more severe and the local flux profiles in these extreme locations may be somewhat effected by axial conduction effects.

Overall Variation

Combining the effects discussed above, and the estimate of the most probable error in local heat flux is obtained as

$$\sqrt{(3.5)^2 + (2.2)^2 + (.5)^2} \cong 4.2\%$$

48" Long Test Sections

These test sections were fabricated by coupling two shorter length together with a 1 1/2" threaded thin walled sleeve (TEST SECTION 114136) or a 1" soldered thin walled sleeve (OTHERS). Hence, at the midsection of these test sections over the sleeve length, the heat flux is slightly lower than over the remainder of the test section.

APPENDIX B

TEST SECTION ANALYSIS

The analysis of the experimental data first requires calculation of various parameters from the test section data. These parameters, which are dependent on the flux profile shape are **derived on the following pages.**

The governing heat balance expression relating heat flux and electrical heat imput, applicable to a length dx of tubing is

$$\phi(x)\pi D_i dx = I^2 dR = I^2 \frac{\rho\, dx}{A_x(x)} \qquad \text{(B-1)}$$

The assumptions inherent in this expression are

1. One dimensional (radial) heat flow
2. Adiabatic outside diameter tube wall
3. Constant radial temperature profile so that ρ (T) is a constant
4. No asmuithal variation in tube wall thickness so that the power is generated uniforml; throughout the tube wall at any axial location.

This expression can be assumed to be applicable over the entire tube length with the additional assumption of

1. Constant tube temperature so that ρ which

is temperature dependent is a constant over the entire tube length.

These assumptions are shown, in Appendix A, to be met for the data presented and analyzed in this work and hence equation (1) serves as a valid point of reference for the following derivations. In the following derivations consistency of units is assumed; hence for use in actual computations numerical factors should be inserted where appropriate to assure this consistency of units. Also for the uniform and linear flux shapes, x is used as the axial position variable, while for the cosine and peaked flux shapes, z is used as the axial position variable.

UNIFORM FLUX PROFILE

The flux shape in this case, figure 10, is simply

$$\phi(x) = \phi \tag{B-2}$$

From equation (1) we obtain

$$A_x(x) = A_x = \frac{I^2 \rho}{\phi \pi D_i}$$

and by the governing assumptions we find that $A_x(x) = A_x$ and hence D_o is also constant. However it is desirable to obtain all relevant parameters in terms of experimentally determined quantities as is accomplished below

a. $\phi(x) = \phi$

$$Q(x) = \int_o^x \phi \, \pi D_i \, dx$$

$$Q_{TOT} = \phi \, \pi D_i \ell$$

$$\phi = \frac{Q_{TOT}}{\pi D_i \ell} \tag{B-3}$$

b. $D_o(x) = D_o$

From equation (1) we obtained A_x as a constant, hence

$$D_o = \sqrt{\frac{4}{\pi} A_x + D_i^2} \tag{B-4}$$

Now A_x is a function of the overall tube resistance R which is established to make maximum use of the available D.C. power supply. The maximum power supply available is 72 kilowatts at 24 volts and 300 amperes hence establishing the optimum tube resistance as 8.0×10^{-3} ohms.

Again from equation (1)

$$dR = \frac{\rho\, dx}{A_x(x)}$$

$$R = \frac{\rho \ell}{A_x}$$

and substituting this into equation (4) we obtain

$$D_o = \sqrt{\frac{(4)}{\pi}\frac{\rho \ell}{R} + D_i^2} \qquad \text{(B-5)}$$

c. $Q(x)$

Now $Q(x) = \int_o^x \phi(x)\pi D_i\, dx$ in general. For $\phi(x) = \phi$

per equation (3) we obtain simply.

$$Q(x) = Q_{TOT}\ \frac{x}{\ell} \qquad \text{(B-6)}$$

COSINE FLUX PROFILE

The flux shape in this case as shown in figure 10 is

$$\phi(z) = \phi_{MAX} \cos \frac{\pi z}{L} \quad \text{for } -\frac{\ell}{2} \leq z \leq +\frac{\ell}{2} \qquad \text{(B-7)}$$

Note that as defined in figure 10, L represents one half wavelength of a cosine wave which is truncated at $z = \pm \ell/2$ to form a test section of physical length ℓ. Using this flux shape, equation (7) and equation (1), we derive the relevant parameters in terms of experimental quantities as follows:

a. $\phi(z)$

$$Q(z) = \int_{-\ell/2}^{z} \phi(z)\, \pi\, D_i\, dz$$

$$Q_{TOT} = \int_{-\ell/2}^{+\ell/2} \phi_{MAX} \cos \frac{\pi z}{L}\, \pi\, D_i\, dz$$

Yields

$$\phi_{MAX} = \frac{Q_{TOT}}{2D_i L \sin \frac{\pi}{2} \frac{\ell}{L}}$$

and

$$\phi(z) = \frac{Q_{TOT}}{2D_i L \sin \frac{\pi}{2} \frac{\ell}{L}} \cos \frac{\pi z}{L} \qquad \text{(B-8)}$$

This expression however contains the quantity, L, which can be expressed in terms of the physical length, ℓ, and the quantity M which is defined below as the ratio of

the maximum flux to minimum flux.

$$M = \frac{\phi_{MAX}}{\phi_{MIN}} \tag{B-9}$$

and thus is a crutial variable in selection of the flux profile for experimentation.

Now from (1) we see that for D_i, I^2, and ρ constant, $\phi(z)$ is inversely proportional to $A_x(z)$. Hence at $z = 0$ where $\phi(z)$ is maximum, $A_x(z)$ is minimum and conversely at $z = \pm \ell/2$ where $\phi(z)$ is minimum, $A_x(z)$ is maximum. This leads to the relations.

$$\phi(z) = \phi_{MAX} \cos \frac{\pi z}{L} \quad ; \quad A_x(z) = \frac{A_{MIN}}{\cos \frac{\pi z}{L}} \tag{B-10a}$$

$$\text{at } z = +\ell/2 \quad \phi_{MIN} = \phi_{MAX} \cos \frac{\pi \ell}{2L} \text{ and } A_{MAX} = \frac{A_{MIN}}{\cos \frac{\pi \ell}{2L}} \tag{B-10b}$$

$$\text{Hence} \quad \cos \frac{\pi}{2} \frac{\ell}{L} = \frac{\phi_{MIN}}{\phi_{MAX}} = \frac{A_{MIN}}{A_{MAX}} = \frac{1}{M} \tag{B-10c}$$

Thus we obtain

$$L = \frac{\pi \ell/2}{\cos^{-1} 1/M} \tag{B-11}$$

and using the identity, $\sin \alpha = \sqrt{1 - \cos^2 \alpha}$, we obtain

$$\sin \frac{\pi}{2} \frac{\ell}{L} = \sqrt{1 - \cos^2 \frac{\pi \ell}{2L}} = \sqrt{\frac{M^2 - 1}{M^2}} \tag{B-12}$$

Substituting these values into equation (8) we obtain the desired result

$$\phi(z) = \frac{Q_{TOT}}{2D_i L \sqrt{\frac{M^2 - 1}{M^2}}} \cos \frac{\pi z}{L} \tag{B-13}$$

where L is retained for convenience and defined in equation (11).

b. $D_o(z)$

$$\text{Now} \quad D_o(z) = \sqrt{\frac{(4)}{\pi} A_x(z) + D_i^2} \tag{B-14}$$

Again from equation (1) obtain

$$R = \int_{-\ell/2}^{+\ell/2} dR = \int_{-\ell/2}^{+\ell/2} \frac{\rho\, dz}{A_x(z)}$$

Now substituting from equation (10) where $A_x(z)$ is defined, obtain

$$R = \int_{-\ell/2}^{+\ell/2} \frac{\rho}{A_{MIN}} \cos \frac{\pi z}{L} \, dz$$

$$R = \frac{2\rho}{A_{MIN}} \frac{L}{\pi} \sin \frac{\pi}{2} \frac{\ell}{L}$$

$$\text{or} \quad A_x(z) = \frac{A_{MIN}}{\cos \frac{\pi z}{L}} = \frac{2\rho L}{\pi R} \frac{\sin \frac{\pi}{2} \frac{\ell}{L}}{\cos \frac{\pi z}{L}} \tag{B-15}$$

Substituting (15) into (14) we obtain the desired result

$$D_o(z) = \sqrt{\frac{(8)\rho L \sin \frac{\pi}{2} \frac{\ell}{L}}{\pi^2 R \cos \frac{\pi z}{L}} + D_i^2} = \sqrt{\frac{(4) A_{MIN}}{\pi \cos \frac{\pi z}{L}} + D_i^2}$$

(B-16)

c. $Q(z)$

Now $$Q(z) = \int_{-\ell/2}^{z} \pi D_i \, \phi(z) \, dz$$

$$Q(z) = \int_{-\ell/2}^{-z} \pi D_i \, \phi_{MAX} \cos \frac{\pi z}{L} \, dz \quad \text{for } -\ell/2 \leq z \leq 0$$

$$= \int_{-\ell/2}^{+z} \pi D_i \phi_{MAX} \cos \frac{\pi z}{L} \, dz \quad \text{for } 0 \leq z \leq +\ell/2$$

Carrying out the indicated operations and substituting for

$$\phi_{MAX} = \frac{Q_{TOT}}{2D_i L \sin \frac{\pi}{2} \frac{\ell}{L}} \qquad \text{per equation B-8}$$

and

$$\sin \frac{\pi}{2} \frac{\ell}{L} = \sqrt{\frac{M^2 - 1}{M^2}} \qquad \text{per equation B-12}$$

obtain

$$Q(z) = \frac{Q_{TOT}}{2} \left[1 - \frac{\sin \frac{\pi z}{L}}{\sqrt{\frac{M^2 - 1}{M^2}}} \right] \text{for } -\frac{\ell}{2} \leq z \leq 0 \qquad \text{(B-17)}$$

and

$$Q(z) = \frac{Q_{TOT}}{2} \left[1 + \frac{\sin \frac{\pi z}{L}}{\sqrt{\frac{M^2 - 1}{M^2}}} \right] \text{for } 0 \leq z \leq +\ell/2 \qquad \text{(B-18)}$$

where L is defined as equal to $\frac{\pi \ell/2}{\cos^{-1} 1/M}$ per equation (11).

LINEARLY INCREASING FLUX PROFILE

The flux shape in this case as shown in figure 10 is

$$\phi(x) = \phi_{IN} + (\phi_{OUT} - \phi_{IN}) \frac{x}{\ell} \quad \text{for} \quad 0 \leq x \leq \ell \qquad \text{(B-19)}$$

Using this flux shape equation and equation (1) we obtain

a. $\phi(x)$

$$Q_{TOT} = \int_0^{\ell} \left[\phi_{IN} + (\phi_{OUT} - \phi_{IN}) \frac{x}{\ell}\right] \pi D_{IN} dx$$

$$Q_{TOT} = \frac{\pi D_i \ell}{2} \left[\phi_{IN} + \phi_{OUT}\right] \qquad \text{(B-20)}$$

Now $M = \dfrac{\phi_{OUT}}{\phi_{IN}}$ for a linearly increasing flux

and hence

$$Q_{TOT} = \frac{\pi D_i \ell}{2(144)} \phi_{OUT} \left[\frac{1+M}{M}\right] = \frac{\pi D_i \ell}{2} \phi_{IN} \left[1+M\right]$$

$$\phi_{OUT} = \left(\frac{2Q_{TOT}}{\pi D_i \ell}\right) \left[\frac{M}{1+M}\right] \qquad \text{(B-21)}$$

$$\phi_{IN} = \left(\frac{2Q_{TOT}}{\pi D_i \ell}\right) \left[\frac{1}{1+M}\right] \qquad \text{(B-22)}$$

Substituting these expressions for ϕ_{IN} and ϕ_{OUT} into equation (19), we obtain the desired result

$$\phi(x) = \frac{2Q_{TOT}}{A_s} \left(\frac{1}{1+M}\right) \left[1 + (M-1) \frac{x}{\ell}\right] \qquad \text{(B-23)}$$

b. $D_o(x)$

Now in general $$D_o(x) = \sqrt{\frac{4}{\pi} A_x(x) + D_i^2} \qquad \text{(B-24)}$$

Proceeding as in the cosine tube case we obtain from equation (1) the general expression for overall tube resistance, R,

$$R = \int_o^{\ell} dR = \int_o^{\ell} \frac{\rho\, dx}{A_x(x)} \qquad \text{(B-25)}$$

Now from equation (1) we also obtain an expression for $A_x(x)$ as follows:

$$\phi(x) = \frac{I^2 \rho}{\pi D_i} \frac{1}{A_x(x)} \qquad \text{(B-26)}$$

$$\text{At } x = 0 \quad \phi_{IN} = \frac{I^2 \rho}{\pi D_i} \frac{1}{A_{IN}} \qquad \text{(B-26a)}$$

$$\text{At } x = \ell \quad \phi_{OUT} = \frac{I^2 \rho}{\pi D_i} \frac{1}{A_{OUT}} \qquad \text{(B-26b)}$$

$$\text{Hence} \quad \frac{\phi_{IN}}{\phi_{OUT}} = \frac{A_{OUT}}{A_{IN}} = \frac{1}{M} \qquad \text{(B-26c)}$$

Substituting the above equations, 26a and b, into equation (1) we obtain

$$\phi(x) = \frac{I^2 \rho}{\pi D_i} \left[\frac{1}{A_{IN}} + \left(\frac{1}{A_{OUT}} - \frac{1}{A_{IN}} \right) \frac{x}{\ell} \right] \qquad \text{(B-27)}$$

Now equating the expressions for $\phi(x)$ from equations(26) and (27) obtain

$$A_x(x) = \frac{1}{\frac{1}{A_{IN}} + \left(\frac{1}{A_{OUT}} - \frac{1}{A_{IN}} \right) \frac{x}{\ell}} \qquad \text{(B-28)}$$

or utilizing equation (26c)

$$A_x(x) = \frac{A_{IN}}{1 + (M-1)\frac{x}{\ell}} \qquad \text{(B-29)}$$

Now substituting the expression for $A_x(x)$, equation (29), into equation (25), we obtain

$$R = \int_0^{\ell} \frac{\rho\left(1+(M-1)\frac{x}{\ell}\right)}{A_{IN}}\, dx = \frac{\rho \ell}{2A_{IN}}(M+1) \qquad \text{(B-30)}$$

Hence

$$A_{IN} = \frac{\rho \ell}{2R}(M+1)$$

and from equation (29)

$$A_x(x) = \frac{\rho \ell\ (M+1)}{2R\left[1+(M-1)\frac{x}{\ell}\right]} \qquad \text{(B-31)}$$

Substituting equations (29) and (31) into the general expression for $D_o(x)$, equation (24), we obtain the desired results.

$$D_o(x) = \sqrt{\frac{2\rho \ell\,(M+1)}{\pi R\left[1+(M-1)\frac{x}{\ell}\right]} + D_i^2} = \sqrt{\frac{(4)A_{IN}}{\pi\left[1+(M-1)\frac{x}{\ell}\right]} + D_i^2} \qquad \text{(B-32)}$$

c. $Q(x)$

Now $Q(x) = \int_0^x \pi D_i\, \phi(x)dx$

Performing the indicated integration yields

$$\phi(x) = \frac{2Q_{TOT}}{1+M}\left(\frac{1}{\ell}\right)\left[\frac{x}{\ell} + \left(\frac{M-1}{2}\right)\frac{x^2}{\ell^2}\right] \qquad \textbf{(B-33)}$$

LINEARLY DECREASING FLUX PROFILE

The flux shape in this case is the mirror image of the linearly decreasing profile and is shown in figure 10. In this case the maximum flux occurs at the test section inlet and hence is written as

$$\phi(x) = \phi_{IN} - (\phi_{IN} - \phi_{OUT}) \frac{x}{\ell} \quad \text{for} \quad 0 \leq x \leq \ell \qquad \text{(B-34)}$$

and M in this case is defined as the inverse of the linearly increasing flux case and is written as

$$M = \frac{\phi_{IN}}{\phi_{OUT}} \qquad \text{(B-35)}$$

These basic expressions are different from corresponding quantities of the linearly increasing flux profile and hence yield different expressions for the desired parameters as shown below.

a. $\phi(x)$

$$Q_{TOT} = \int_0^{\ell} \left[\phi_{IN} - (\phi_{IN} - \phi_{OUT}) \frac{x}{\ell}\right] \pi D_i \, dx$$

$$Q_{TOT} = \frac{\pi D_i \ell}{2} \left[\phi_{IN} + \phi_{OUT}\right] \qquad \text{(B-36)}$$

However since $M = \frac{\phi_{IN}}{\phi_{OUT}}$, we obtain

$$Q_{TOT} = \frac{\pi D_i \ell}{2} \phi_{IN} \left[\frac{1+M}{M}\right] = \frac{\pi D_i \ell}{2} \phi_{IN} \left[1+M\right] \qquad \text{(B-37)}$$

and $$\phi_{IN} = \frac{2Q_{TOT}}{\pi D_i \ell}\left(\frac{M}{1+M}\right) \tag{B-38}$$

$$\phi_{OUT} = \frac{2Q_{TOT}}{\pi D_i \ell}\left(\frac{1}{1+M}\right) \tag{B-39}$$

Substituting these expressions for ϕ_{IN} and ϕ_{OUT} into equation (34), we obtain the desired result

$$\phi(x) = \frac{2Q_{TOT}}{A_s}\left(\frac{M}{1+M}\right)\left(1 - \left(\frac{M-1}{M}\right)\frac{x}{\ell}\right) \tag{B-40}$$

b. $D_o(x)$

Now in general $$D_o(x) = \sqrt{\frac{4}{\pi} A_x(x) + D_i^2} \tag{B-41}$$

From equation (1) obtain

$$R = \int_o^{\ell} dR = \int_o^{\ell} \frac{\rho\, dx}{A_x(x)} \tag{B-42}$$

Now from equation (1), we also obtain an expression for $A_x(x)$ as follows

$$\phi(x) = \frac{I^2 \rho}{\pi D_i}\ \frac{1}{A_x(x)} \tag{B-43}$$

At $x = 0$ $$\phi_{IN} = \frac{I^2 \rho}{\pi D_i}\ \frac{1}{A_{IN}} \tag{B-43a}$$

At $x = \ell$ $$\phi_{OUT} = \frac{I^2 \rho}{\pi D_i}\ \frac{1}{A_{OUT}} \tag{B-43b}$$

Hence

$$\frac{\phi_{IN}}{\phi_{OUT}} = \frac{A_{OUT}}{A_{IN}} = M \tag{B-43c}$$

Substituting the above equations, (43a) and (43b), into equation (1) we obtain

$$\phi(x) = \frac{I^2 \rho}{\pi D_i} \left[\frac{1}{A_{IN}} + \left(\frac{1}{A_{OUT}} - \frac{1}{A_{IN}} \right) \frac{x}{\ell} \right] \tag{B-44}$$

Now equating the expressions for $\phi(x)$ from equations (43) and (44) obtain

$$A_x(x) = \frac{1}{\frac{1}{A_{IN}} + \left(\frac{1}{A_{OUT}} - \frac{1}{A_{IN}} \right) \frac{x}{\ell}} \tag{B-45}$$

or utilizing equation (43c)

$$A_x(x) = \frac{A_{IN}}{1 + \frac{1-M}{M} \frac{x}{\ell}} \tag{B-46}$$

Now substituting equation (46) into equation (42)

$$R = \int_0^{\ell} \frac{\rho \left(1 + \left(\frac{1-M}{M}\right) \frac{x}{\ell}\right)}{A_{IN}} dx = \frac{\rho \ell}{2A_{IN}} \left(\frac{M+1}{M}\right) \tag{B-47}$$

Hence

$$A_{IN} = \frac{\rho \ell}{2R} \left(\frac{M+1}{M}\right) \tag{B-48}$$

and from equation (46)

$$A_x(x) = \frac{\rho \ell \left(\frac{M+1}{M}\right)}{2R \left[1 + \left(\frac{1-M}{M}\right) \frac{x}{\ell}\right]} \tag{B-49}$$

Substituting equations (46) and (49) into the general expression for $D_o(x)$, equation (41), we obtain the desired results

$$D_o(x) = \sqrt{\frac{2\rho\ell\left(\frac{M+1}{M}\right)}{\pi R\left[1+\left(\frac{1-M}{M}\right)\frac{x}{\ell}\right]} + D_i^2} = \sqrt{\frac{4A_{IN}}{\pi\left[1+\left(\frac{1-M}{M}\right)\frac{x}{\ell}\right]} + D_i^2} \qquad \text{(B-50)}$$

c. $Q(x)$

Now $Q(x) = \int_o^x \pi D_i \, \phi(x) \, dx$

where per equation (40)

$$\phi(x) = \frac{2Q_{TOT}}{A_s}\left(\frac{M}{1+M}\right)\left(1 - \left(\frac{M-1}{M}\right)\frac{x}{\ell}\right)$$

Performing the indicated integration yields

$$Q(x) = 2Q_{TOT}\left(\frac{M}{M+1}\right)\left(\frac{x}{\ell} - \left(\frac{M-1}{2M}\right)\frac{x^2}{\ell^2}\right) \qquad \text{(B-51)}$$

PEAKED COSINE PROFILE

To simulate an inlet or outlet flux peaking, a flux profile consisting of cosine shaped portion and an exponential portion was chosen as shown in figure 10. For the inlet flux peaked tubes, the cosine portion was established by fixing the maximum position 7.5 inches from the inlet. The exponential portion was blended into the cosine profile at 12 inches from the inlet by a suitable choice (1.33) of the constant ξ which occurs in the exponential expression for the flux. The outlet flux peaked tubes are mirror images of the inlet peaked tubes. Hence the expressions for the flux profile in the inlet peaked geometry are:

$$\phi(z) = \phi_{MAX} \cos \frac{\pi z}{L'} \quad \text{for } -\frac{\ell'}{2} \leq z \leq 0 \qquad \text{(B-51a)}$$

$$\phi(z) = \phi_{MAX} \cos \frac{\pi z}{L'} \quad \text{for } 0 \leq z \leq (\ell - \lambda - .5\ell') \qquad \text{(B-51b)}$$

$$\phi(u) = \phi_{u=o} \exp\left(-\frac{\xi u}{\lambda}\right)$$

$$= \phi_{MAX} \cos \frac{\pi(\ell - \lambda - .5\ell')}{L'} \exp\left(\frac{\xi u}{-\lambda}\right) \text{ for } 0 \leq u \leq \lambda \qquad \text{(B-51c)}$$

For this specific design, the break point between the cosine and exponential portions of the flux profile was

taken at 12 inches from the tube inlet and hence for the tubes under consideration:

$$M = 5.75$$

$$\ell = 30 \text{ inches}$$

$$\mathcal{L} = \ell - 12 = 18 \text{ inches}$$

$$\ell' = 15 \text{ inches}$$

$$L' = \frac{\pi \ell'}{2\cos^{-1}\frac{1}{M}} = 16.88 \text{ inches}$$

$$\xi = 1.33 \text{ (dimensionless)}$$

However, the derivations of relevant parameters will be carried out without the insertion of these specific numerical values to obtain more general defining equations.

a. $\phi(z \text{ and } u)$

Now $$Q(z) = \int_{-\ell/2}^{z} \phi(z)\, \pi D_i \, dz$$

$$Q_{TOT} = \pi D_i \left[\int_{-\ell/2}^{o} \phi_{MAX} \cos \frac{\pi z}{L'} \, dz + \int_{o}^{\ell - \mathcal{L} - .5\ell'} \phi_{MAX} \cos \frac{\pi z}{L'} \, dz + \int_{o}^{\ell} \phi_{MAX} \cos \frac{\pi(\ell - \mathcal{L} - .5\ell')}{L'} \exp -\left(\frac{\xi u}{\mathcal{L}}\right) du \right]$$

$$Q_{TOT} = \pi D_i \phi_{MAX} \left[\frac{L'}{\pi} \sin \frac{\pi z}{L'} \Big|_{-\ell/2}^{\ell - \mathcal{L} - .5\ell'} + \cos \frac{\pi(\ell - \mathcal{L} - .5\ell')}{L'} \left(-\frac{\mathcal{L}}{\xi}\right) \exp\left(-\frac{\xi u}{\mathcal{L}}\right) \Big|_{o}^{\mathcal{L}} \right] \qquad \text{(B-52)}$$

Hence $\phi_{MAX} = \frac{Q_{TOT}}{\pi D_i C_1}$ (B-53)

where $C_1 = \left[\frac{L'}{\pi}\left(\sin\frac{\pi}{L'}(\ell - \ell - .5\ell') + \sin\frac{\pi\ell'}{L'2}\right) + \cos\frac{\pi(\ell - \ell - .5\ell')}{L'}\left(1-\exp(-\xi)\right)\frac{\ell}{\xi}\right]$

$= \left[\frac{L'}{\pi}\left(\sin\frac{\pi}{L'}(\ell - \ell - .5\ell') + \sqrt{\frac{M^2-1}{M^2}}\right) + \cos\frac{\pi(\ell - \ell - .5\ell')}{L'}\left(1-\exp(-\xi)\right)\frac{\ell}{\xi}\right]$ (B-54)

Substituting the expressions for ϕ_{MAX} back into equations (51 a,b, and c) we obtain the desired result:

$$\phi(z) = \phi_{MAX}\cos\frac{\pi z}{L'} = \frac{Q_{TOT}}{\pi D_i C_1}\cos\frac{\pi z}{L'} \quad \text{for } -\frac{\ell'}{2} \le z \le 0 \qquad \text{(B-55a)}$$

$$\phi(z) = \phi_{MAX}\cos\frac{\pi z}{L'} = \frac{Q_{TOT}}{\pi D_i C_1}\cos\frac{\pi z}{L'} \quad \text{for } 0 \le z \le \ell - \ell - .5\ell' \qquad \text{(B-55b)}$$

$$\phi(u) = \phi_{MAX}\cos\frac{\pi(\ell - \ell - .5\ell')}{L'}\exp\left(-\frac{\xi u}{\ell}\right)$$

$$\phi(u) = \frac{Q_{TOT}}{\pi D_i C_1}\cos\frac{\pi(\ell - \ell - .5\ell')}{L'}\exp\left(-\frac{\xi u}{\ell}\right) \quad \text{for } 0 \le u \le \ell \qquad \text{(B-55c)}$$

In the above expressions the quantities L', ℓ', and M are derived and defined in the same manner as in the cosine flux case. Hence we obtain

$$\cos\frac{\pi}{2}\frac{\ell'}{L'} = \frac{Q_{MIN}}{Q_{MAX}} = \frac{A_{MIN}}{A_{MAX}} = \frac{1}{M} \qquad \text{(B-57)}$$

and

$$L = \frac{\pi\,\ell'/2}{\arccos(1/M)} \qquad \text{(B-58)}$$

where MIN and MAX refer to values on the cosine portion of the profile.

b. D_o(z and u)

Now in general $D_o(z \text{ or } u) = \sqrt{\frac{4}{\pi} A_x(z \text{ or } u) + D_i^2}$ (B-59)

From equation (1) we obtain

$$R = \int_{-\ell'/2}^{\ell} dR = \int_{-\ell'/2}^{\ell} \frac{\rho \, d(z \text{ or } u)}{A_x(z \text{ or } u)} \qquad \text{(B-60)}$$

Now over the region $-\ell'/2 \leq z \leq \ell - \ell - .5\ell'$, $A_x(z)$ can be expressed as

$$A_x(z) = \frac{A_{MIN}}{\cos \frac{\pi z}{L'}} \qquad \text{(B-61)}$$

whereas over the region $0 \leq u \leq \ell$, $A_x(u)$ can be expressed as

$$A_x(u) = \frac{A_{MIN} / \cos \frac{\pi}{L'} (\ell - \ell - .5\ell')}{\exp\left(-\frac{\xi u}{\ell}\right)} \qquad \text{(B-62)}$$

Hence

$$R = \int_{-\ell'/2}^{\ell - \ell - .5\ell'} \frac{\rho}{A_{MIN}} \cos \frac{\pi z}{L'} \, dz + \int_0^{\ell} \frac{\rho \cos \frac{\pi}{L'}(\ell - \ell - .5\ell')}{A_{MIN}} \exp\left(-\frac{\xi u}{\ell}\right) du \qquad \text{(B-63)}$$

Integrating we obtain R in terms of A_{MIN} as

$$R = \frac{\rho}{A_{MIN}} \left(\frac{L'}{\pi} \left(\sin \frac{\pi \ell'}{2L'} + \sin \frac{\pi}{L'}(\ell - \ell - .5\ell') \right) + \frac{\cos \frac{\pi}{L'}(\ell - \ell - .5\ell')}{\xi / \ell} \left(1 - \exp(-\xi)\right) \right) \qquad \text{(B-64)}$$

or $R = \dfrac{\rho C_1}{A_{MIN}}$ where C_1 is defined by equation (54)

Thus $A_{MIN} = \dfrac{\rho C_1}{R}$ (B-65)

Hence in the range $-\ell'/2 \leq z \leq \ell - \ell - .5\,\ell'$

$$A_x(z) = \frac{A_{MIN}}{\cos\frac{\pi z}{L'}} \quad \text{where } A_{MIN} \text{ is defined by equation (65)} \tag{B-66}$$

and in the range $0 \leq u \leq \ell$

$$A_x(u) = \frac{A_{MIN}}{\cos\frac{\pi}{L'}(\ell - \ell - .5\,\ell')\exp\left(-\frac{\xi u}{\rho}\right)} \tag{B-67}$$

where A_{MIN} is defined by equation (65).

Hence the desired result for $D_o(z)$ can be obtained by substituting equation (61) into equation (59) obtaining

$$D_o(z) = \sqrt{\frac{4}{\pi}\frac{A_{MIN}}{\cos\frac{\pi z}{L'}} + D_i^2} \tag{B-68}$$

where A_{MIN} is expressible as a function of tube parameters only (i.e. R, ℓ, ℓ', ℓ and ξ) per equation (65).

The desired result for $D_o(u)$ can be obtained by substituting equation (62) into equation (59), obtaining

$$D_o(u) = \sqrt{\frac{4}{\pi}\frac{A_{MIN}}{\left(\cos\frac{\pi}{L'}(\ell - \ell - .5\,\ell')\exp\left(-\frac{\xi u}{\rho}\right)\right)} + D_i^2} \tag{B-69}$$

where A_{MIN} is also expressed per equation (65).

c. Q (z and u)

Now $Q(x) = \int_{INLET}^{x} \phi(x)\, \pi\, D_i\, dx$ where $\phi(x)$ as a function of position and total power was previously derived in equation (55). Substituting this expression for ϕ and performing the indicated integrations, we obtain the desired results in the range $-\ell'/2 \leq z \leq 0$.

$$Q(z) = \int_{-\ell'/2}^{z} \frac{Q_{TOT}}{\pi D_i C_1}\, \pi\, D_i \cos \frac{\pi z}{L'}\, dz$$

$$= \frac{Q_{TOT} L'}{C_1 \pi} \left[\sin \frac{\pi}{2} \frac{\ell'}{L'} + \sin \frac{\pi z}{L'} \right]$$

$$Q(z) = \frac{Q_{TOT} L'}{C_1 \pi} \left[\sqrt{\frac{M^2-1}{M^2}} - \sin \frac{\pi |z|}{L'} \right] \qquad \text{(B-70)}$$

In the range $0 \leq z \leq \ell - \ell' - .5\ell'$

$$Q(z) = \int_{-\ell'/2}^{z} \frac{Q_{TOT}}{\pi D_i C_1}\, \pi D_i \cos \frac{\pi z}{L'}\, dz$$

$$Q(z) = \frac{Q_{TOT} L'}{C_1 \pi} \left[\sqrt{\frac{M^2-1}{M^2}} + \sin \frac{\pi z}{L'} \right] \qquad \text{(B-71)}$$

In the range $0 \leq u \leq \ell$

$$Q(z) = \int_{-\ell'/2}^{\ell - \ell' - .5\ell'} \phi(z)\, \pi D_i\, dz + \int_{0}^{u} \phi(u)\, \pi D_i\, du$$

$$Q(z) = \frac{Q_{TOT} L'}{C_1 \pi} \left[\sin \frac{\pi(\ell - \ell' - .5\ell')}{L'} + \sin \frac{\pi}{2} \frac{\ell'}{L'} \right] + \qquad \text{(B-72)}$$

$$\frac{Q_{TOT}\, \ell}{C_1\, \xi} \left[\cos \frac{\pi(\ell - \ell' - .5\ell')}{L'} \left(1 - \exp\left(- \frac{\xi u}{\ell} \right) \right) \right]$$

OUTLET PEAK

This flux profile is shown in figure 10. The analytic expression for the flux profile is as follows:

$$\phi(u) = \phi_{MAX} \cos \frac{-\pi(+\ell - \mathcal{L} - .5\ell')}{L'} \exp\left(\xi\left(\frac{u-\mathcal{L}}{\mathcal{L}}\right)\right)$$

$$= \phi_{MAX} \cos \frac{\pi(\ell - \mathcal{L} - .5\ell')}{L'} \exp\left(\xi\left(\frac{u-\mathcal{L}}{\mathcal{L}}\right)\right) \text{ for } 0 \leq u \leq \mathcal{L} \qquad \text{(B-73a)}$$

$$\phi(z) = \phi_{MAX} \cos \frac{\pi z}{L'} \quad \text{for } -(\ell - \mathcal{L} - .5\ell') \leq z \leq 0 \qquad \text{(B-73b)}$$

$$\phi(z) = \phi_{MAX} \cos \frac{\pi z}{L'} \quad \text{for } 0 \leq z \leq +\ell'/2 \qquad \text{(B-73c)}$$

a. $\phi(z)$

Now Q_{TOT} is expressable by equation (52) for the inlet peak case since the flux profile are mirror images. Hence

$$\phi_{MAX} = \frac{Q_{TOT}}{\pi D_i C_1} \quad \text{were } C_1 \text{ is also given by equation (54).} \qquad \text{(B-74)}$$

Substituting equation (74) into equations (73 a, b, and c) we obtain

$$\phi(u) = \frac{Q_{TOT}}{\pi D_i C_1} \cos \frac{\pi(\ell - \mathcal{L} - .5\ell')}{L'} \exp\left(\xi\left(\frac{u-\mathcal{L}}{\mathcal{L}}\right)\right) \text{ for } 0 \leq u \leq \mathcal{L} \qquad \text{(B-75)}$$

$$\phi(z) = \frac{Q_{TOT}}{\pi D_i C_1} \cos \frac{\pi z}{L'} \quad \text{for } -(\ell - \mathcal{L} - .5\ell') \leq z \leq 0 \qquad \text{(B-75b)}$$

$$\phi(z) = \frac{Q_{TOT}}{\pi D_i C_1} \cos \frac{\pi z}{L'} \quad \text{for } 0 \leq z \leq +\ell'/2 \qquad \text{(B-75c)}$$

b. D_o(z and u)

The desired relations for tube outside diameter, D_o(z and u), are obtained in the same manner as the inlet peak case. Since the two cases are mirror images of each other

$$R = \frac{f C_1}{A_{MIN}} \quad \text{where } C_1 \text{ is defined by equation (54)} \tag{B-76}$$

and $$A_{MIN} = \frac{f C_1}{R} \tag{B-77}$$

This result may easily be **seen by direct integration. Now** in this case, the wall cross sectional areas are given by

$$A_x(u) = \frac{A_{MIN}}{\cos \frac{\pi}{L'}(\ell - f - .5\ell') \exp\left(\xi\left(\frac{u-f}{f}\right)\right)} \quad \text{for } 0 \le u \le f \tag{B-78}$$

$$A_x(z) = \frac{A_{MIN}}{\cos \frac{\pi z}{L'}} \quad \text{for } -(\ell - f - .5\ell') \le z \le +\ell'/2 \tag{B-79}$$

Hence the desired results are

$$D_o(z) = \sqrt{\frac{4}{\pi} \frac{A_{MIN}}{\cos \frac{\pi z}{L'}} + D_i^2} \tag{B-80}$$

where A_{MIN} is expressible as a function of tube parameters only (i.e. R, ℓ, ℓ', f, and ξ) by equations (74 and 54).

and $$D_o(u) = \sqrt{\frac{4}{\pi} \frac{A_{MIN}}{\cos \frac{\pi}{L'}(\ell - f - .5\ell') \exp\left(\xi\left(\frac{u-f}{f}\right)\right)} + D_i^2} \tag{B-81}$$

where A_{MIN} is also expressed by equations (77 and 54).

c. Q(z and u)

Now $Q(x) = \int_{\text{INLET}}^{x} \phi(x)\, \pi D_i\, dx$ where

$\phi(x)$ as a function of position and total power was previously derived in equation (75). Substituting this expression for ϕ and performing the indicated integrations we obtain the desired results.

In the range $0 \leq u \leq \ell'$

$$Q(u) = \frac{Q_{TOT}}{C_1} \cos \frac{\pi(\ell - \ell' - .5\ell')}{L'} \left(\frac{\ell'}{\xi}\right) \exp\left(\frac{\xi}{\ell'}(u-\ell') - \exp(-\xi)\right) \tag{B-82a}$$

In the range $-(\ell - \ell' - .5\ell') \leq z \leq 0$, where z is inherently negative

$$Q(z) = \frac{Q_{TOT}}{C_1}\left(\frac{\ell'}{\xi} \cos \frac{\pi(\ell - \ell' - .5\ell')}{L'} \left(1 - \exp(-\xi)\right) + \frac{L'}{\pi}\left(\sin \frac{\pi(\ell - \ell' - .5\ell')}{L'} - \sin \frac{\pi|z|}{L'}\right)\right) \tag{B-82b}$$

In the range $0 \leq z \leq +\ell'/2$, where z is positive

$$Q(z) = \frac{Q_{TOT}}{C_1}\left(\frac{\ell'}{\xi} \cos \frac{\pi(\ell - \ell' - .5\ell')}{L'} \left(1 - \exp(-\xi)\right) + \frac{L'}{\pi}\left(\sin \frac{\pi(\ell - \ell' - .5\ell')}{L'} + \sin \frac{\pi z}{L'}\right)\right) \tag{B-82c}$$

FLUX SPIKE (COSINE SHAPED)

This flux profile is shown in Fig. 10. The analytic expression for the flux profile is as follows:

$$\phi = \phi_{MIN} \text{ for } -(\ell - \mathcal{L} + \frac{\ell'}{2}) \leq z \leq -\ell'/2 \qquad \text{(B-83a)}$$

$$\phi = \phi_{MAX}\cos\frac{\pi z}{L'} \text{ for } -\frac{\ell'}{2} \leq z \leq +\ell'/2 \qquad \text{(B-83b)}$$

$$\phi = \phi_{MIN} \text{ for } +\ell'/2 \leq z \leq \mathcal{L} - \frac{\ell'}{2} \qquad \text{(B-83c)}$$

a. $\phi(z)$

$$\text{Now } Q(z) = \int_{-(\ell - \mathcal{L} + \ell'/2)}^{\mathcal{L} - \ell'/2} \phi(z)\pi D_i dz$$

$$\text{Hence } Q_{TOT} = \int_{-(\ell - \mathcal{L} + \frac{\ell'}{2})}^{-\ell'/2} \phi_{MIN}\pi D_i dz + \int_{-\frac{\ell'}{2}}^{+\ell'/2} \phi_{MAX}\cos\frac{\pi z}{L'}\pi D_i dz$$

$$+ \int_{+\ell'/2}^{+\mathcal{L} - \frac{\ell'}{2}} \phi_{MIN}\pi D_i dz$$

$$Q_{TOT} = \pi D_i \phi_{MIN}\left[\ell - \ell'\right] + \phi_{MAX} 2D_i L' \sin\frac{\pi}{2}\frac{\ell'}{L'}$$

$$\text{Since } M \equiv \frac{\phi_{MAX}}{\phi_{MIN}}$$

$$\text{We obtain } Q_{TOT} = \pi D_i \phi_{MAX}\left\{\frac{\ell - \ell'}{M} + \frac{2L'}{\pi}\sin\frac{\pi}{2}\frac{\ell'}{L'}\right\} \qquad \text{(B-84)}$$

$$\text{Let } C_7 \equiv \frac{\ell - \ell'}{M} + \frac{2L'}{\pi}\sin\frac{\pi}{2}\frac{\ell'}{L'}$$

$$\text{or } \frac{\ell - \ell'}{M} + \frac{2L'}{\pi}\sqrt{\frac{M^2-1}{M^2}} \text{ (per Eq. B-12)} \qquad \text{(B-85)}$$

Hence we obtain

$$\phi_{MAX} = \frac{Q_{TOT}}{\pi D_i C_7} \tag{B-86a}$$

$$\phi_{MIN} = \frac{Q_{TOT}}{M\pi D_i C_7} \tag{B-86b}$$

Substituting these expressions for ϕ_{MAX} and ϕ_{MIN} into Eq. (B-83) we obtain

$$\phi(z) = \frac{Q_{TOT}}{M\pi D_i C_7} \quad \text{for} \quad -(\ell - \ell + \frac{\ell'}{2}) \leq z \leq -\frac{\ell'}{2} \tag{B-87a}$$

$$\phi(z) = \frac{Q_{TOT}}{\pi D_i C_7} \cos\frac{\pi z}{L'} \quad \text{for} \quad -\frac{\ell'}{2} \leq z \leq \frac{\ell'}{2} \tag{B-87b}$$

$$\phi(z) = \frac{Q_{TOT}}{M\pi D_i C_7} \quad \text{for} \quad +\frac{\ell'}{2} \leq z \leq \ell - \frac{\ell'}{2} \tag{B-87c}$$

b. $D_o(z)$

The relation for the tube outside diameter, D_o, is obtained as follows. The wall cross sectional areas are given as

$$A_x(z) = \frac{A_{MIN}}{\cos\frac{\pi \ell'}{2L'}} = MA_{MIN} \quad \text{for} \quad -(\ell - \ell + \frac{\ell'}{2}) \leq z \leq -\ell'/2$$

$$+\frac{\ell'}{2} \leq z \leq \ell - \ell'/2 \tag{B-88a}$$

$$A_x(z) = \frac{A_{MIN}}{\cos\frac{\pi z}{L'}} \qquad -\frac{\ell'}{2} \leq z \leq +\frac{\ell'}{2} \tag{B-88b}$$

Now since $R = \int_{TOT} dR = \int_{TOT} \frac{\rho dz}{A_x(z)}$

Substituting for $A_x(z)$ from Eq. (B-88) we obtain

$$R = \int_{-(\ell - \mathcal{L} + \ell'/2)}^{-\ell'/2} \frac{\rho dz}{MA_{MIN}} + \int_{+\frac{\ell'}{2}}^{\mathcal{L}-\frac{\ell'}{2}} \frac{\rho dz}{MA_{MIN}} + \int_{-\frac{\ell'}{2}}^{+\frac{\ell'}{2}} \frac{\rho dz}{\left(\frac{A_{MIN}}{\cos\frac{\pi z}{L'}}\right)}$$

$$R = \frac{\rho}{A_{MIN}} \left[\frac{(\ell - \ell')}{M} + \frac{2L'}{\pi} \sqrt{\frac{M^2-1}{M^2}} \right] \qquad \text{(B-89)}$$

$$\text{Hence } A_{MIN} = \frac{\rho}{R} \left[\frac{\ell - \ell'}{M} + \frac{\ell'}{\cos^{-1}\frac{1}{M}} \sqrt{\frac{M^2-1}{M^2}} \right] \qquad \text{(B-90)}$$

$$\text{Hence } D_o(z) = \sqrt{\frac{4}{\pi} MA_{MIN} + D_i^2} \quad \text{for } -(\ell - \mathcal{L} + \frac{\ell'}{2}) \le z \le -\ell'/2 \qquad \text{(B-91a)}$$

$$+\ell'/2 \le z \le \mathcal{L} - \frac{\ell'}{2}$$

$$= \sqrt{\frac{4}{\pi} \frac{A_{MIN}}{\cos\frac{\pi z}{L'}} + D_i^2} \quad \text{for } -\frac{\ell'}{2} \le z \le +\frac{\ell'}{2} \qquad \text{(B-91b)}$$

where A_{MIN} is given by Eq. (B-90).

c. Q(z)

$$\text{Now } Q(z) = \int_{-(\ell - \mathcal{L} + \ell'/2)}^{z} \pi D_i \phi(z) dz \qquad \text{(B-92)}$$

where $\phi(z)$ as a function of position and total power was previously derived in Eq. (B-83).

In the range $-(\ell - \mathcal{L} + \frac{\ell'}{2}) \le z \le -\ell'/2$

$$Q(z) = \int_{-(\ell - \mathcal{L} + \ell'/2)}^{-z} \pi D_i \frac{Q_{TOT}}{M \pi D_i C_7} dz$$

$$Q(z) = \frac{Q_{TOT}}{MC_7} (-z + \ell - \mathcal{L} + \frac{\ell'}{2}) \qquad \text{(B-93a)}$$

In the range $-\frac{\ell'}{2} \leq z \leq 0$

$$Q(z) = \int_{-(\ell-\mathscr{L}+\ell'/2)}^{-\ell'/2} \pi D_i \frac{Q_{TOT}}{MC_7 \pi D_i} dz + \int_{-\ell'/2}^{-z} \pi D_i \frac{Q_{TOT}}{\pi D_i C_7} \cos\frac{\pi z}{L'} dz$$

$$= \frac{Q_{TOT}}{MC_7}(\ell-\mathscr{L}) + \frac{Q_{TOT}}{C_7}\frac{L'}{\pi}\left[\sqrt{\frac{M^2-1}{M^2}} - \sin\frac{\pi|z|}{L'}\right] \qquad \text{(B-93b)}$$

In the range $0 \leq z \leq +\frac{\ell'}{2}$

$$Q(z) = \frac{Q_{TOT}}{MC_7}(\ell-\mathscr{L}) + \int_{-\ell'/2}^{0} \pi D_i \frac{Q_{TOT}}{\pi D_i C_7} \cos\frac{\pi z}{L'} dz$$

$$+ \int_{0}^{z} \pi D_i \frac{Q_{TOT}}{\pi D_i C_7} \cos\frac{\pi z}{L'} dz$$

$$Q(z) = \frac{Q_{TOT}}{MC_7}(\ell-\mathscr{L}) + \frac{Q_{TOT}}{C_7}\frac{L'}{\pi}\left[\sqrt{\frac{M^2-1}{M^2}} + \sin\frac{\pi z}{L'}\right] \qquad \text{(B-93c)}$$

In the range $+\frac{\ell'}{2} \leq z \leq \mathscr{L} - \frac{\ell'}{2}$

$$Q(z) = \frac{Q_{TOT}}{MC_7}(\ell-\mathscr{L}) + \frac{Q_{TOT}L'2}{C7\pi}\sqrt{\frac{M^2-1}{M^2}} + \int_{+\ell'/2}^{z} \pi D_i \frac{Q_{TOT}}{M\pi D_i C_7} dz$$

$$= \frac{Q_{TOT}}{MC_7}(\ell-\mathscr{L}+z-\ell'/2) + \frac{Q_{TOT}}{C_7}\frac{L'2}{\pi}\sqrt{\frac{M^2-1}{M^2}} \qquad \text{(B-93d)}$$

APPENDIX C

TEST SECTION DESIGN

The initial factor to be considered in the design of the test sections is the characteristics of the available power supply. With the 24 volt, 3000 ampere supply available, Ohms Law indicates that an overall tube resistance of 8.0×10^{-3} ohms is necessary to achieve full power of 72 kw without exceeding either the generator voltage or current limitations.

Secondly the range of mass velocity (G) to be investigated is fixed. In this investigation values of $.5 \times 10^6$, 1.0×10^6 and 2.0×10^6 were chosen to cover the range reported by previous investigators and/or selected in reactor design application. Now the dimensions, D_i and ℓ, are established by consideration of the limiting operating condition requiring the maximum heat input (and flux) to achieve the critical condition. Thus we take the limiting case as that of $G_{MAX}(2.0 \times 10^6)$, and $X_{in\text{-}MIN}$(about -.28 for 80 psia) which utilizing the critical heat flux correlation of Macbeth (reference 30) defines a critical heat flux ϕ as

$$\phi_c \cdot 10^{-6} = \frac{A + \frac{1}{4} C D_i (G \cdot 10^{-6}) \Delta H_{SUB\text{-}IN}}{1 + C \ell} \qquad (C\text{-}1)$$

where A and C both represent expressions which are functions of D_i, G, and P.

A second equation defining the limits of tube geometry results from the identity $\phi_c = \frac{Q_{TOT}}{A_s}$. Substituting for A_s we obtain

$$\phi_c D_i = \frac{Q_{TOT}}{\pi \ell} \qquad (C\text{-}2)$$

However, additional factors also limit the selection of individual values of ℓ and D_i.

a) To simulate reactor conditions and also to avoid effects on critical heat flux resulting from very short test lengths, it is desirable that ℓ be as large as possible, at least 20 inches or greater.

b) It is desirable to work within the limits of existing uniform flux data to provide a reference point for the nonuniform flux data obtained. This existing data can then be used as a check of uniform data obtained during this study and to provide the basis for a uniform flux correlation useful to analytic work. Hence the following restrictions on ℓ/D ratio are in order

$$50 \leq \ell/D \leq 250$$

c) As reported by Bergles (reference 32) for the subcooled burnout case, small tube data deviates from the data obtained for large tubes. This probably is a consequence of the existence of considerable nonequilibrium vapor volume as the hydraulic diameter

becomes comparable to bubble dimensions. Although this study is concerned primarily with burnout in the quality region, nucleation can occur within the annular film. This nucleation and the present lack of definition of the mechanics of the burnout process in this case make it prudent to restrict the test section diameters to relatively large values, .150 inches or greater, to eliminate any extraneous diameter effect on the results.

d) Finally a limitation on maximum tube inside diameter is imposed by the desire to achieve maximum pump discharge pressure (270 psia) to assure adequate flow control of the loop. From the pump characteristic, the maximum flow rate allowed is about 1800 lb/hr which corresponds to a pump discharge of 260 psia. Since

$$G = \frac{W}{A_F} = \frac{W}{\frac{\pi}{4}\left(\frac{D_i}{144}\right)^2} \qquad (C\text{-}3)$$

For $G_{MAX}=2.0X10^{-6}$, the maximum inside diameter is .410 inches.

Summarizing now we have two equations (1 and 2) and three unknowns (ℓ, D_i and ϕ_c) with the following additional restrictions from physical grounds listed above

$$.150 \text{ inches} \leq D \leq .410 \text{ inches}$$

$$\ell \geq 20 \text{ inches}$$

$$50 \leq \ell/D \leq 250$$

From the range of values which satisfy these conditions, the following set of parameters was selected

$$D = .214 \text{ inches}$$

$$\ell = 30 \text{ inches}$$

and hence $\ell/D = 140$ and $\phi_c(\text{MAX G and } \Delta H_{SUB-IN}) = 1.8 \times 10^{-6}$ BTU/hr ft^2.

Next the degree of steepness of the test flux shapes was established. The M values (M = MAXIMUM FLUX/MINIMUM FLUX) of this study were chosen to duplicate and bracket those of other investigators.

With the conditions established above, the finished tube dimensions for the flux shapes chosen can be calculated and the test section material selected.

The tube outside diameter for aluminum and hence the required amount of wall material to be removed was less than that for A nickel and stainless steel, due to the lower value of resistivity for Aluminum 2024-T3. Since the machinability of Aluminum 2024-T3 is also good, it was selected as the working material.

The specification of the actual machined dimensions of the test sections, the outside diameter as a function of axial length, can be calculated from expressions in Appendix B. Equation (B-16) typically illustrates alternate expressions for $D_o(z)$ as a function of ρ, R and M or A_{MIN} and M. Either expression can be used for tube design.

Permissable dimensional tolerances were established by the requirement that the local flux at any point should be within 5% of the design. Since

$$dP = I^2 dR = I^2 \rho \frac{d}{A_x}$$

$$dP \alpha \frac{1}{A_x \text{local}}$$

Hence for locations of small wall cross section area the machining tolerance to hold $\pm 5\%$ power becomes tighter. The tolerances specified for the first batches of machined tubes reflected this fact and specified several tolerances, each one applicable over a different axial location range. However, as manufacturing techniques improved, the minimum tolerance, applicable only to the area of minimum wall thickness, was applied to the entire tube. Typically on wall thicknesses ranging from .009 inches to .044 inches, a tolerance of $\pm$ .001 inches was met. This resulted in flux shapes at any point within 2 - 5% of design.

APPENDIX D

DATA REDUCTION AND ANALYSIS

The reduction of the experimental data and the computation of parameters relevant to the analytic model developed are performed by the computer program described in Appendix E. The computational methods and equations upon which this program is based are presented in this appendix in the following order

a) INITIAL DATA

b) PARAMETERS DERIVED FROM FIRST LAW (BASIC DATA REDUCTION)

c) ANALYTIC MODEL

d) ANNULAR FILM CHARACTERISTICS

a) INITIAL DATA

For each fabricated test section, the following data is available:

D_i, $\mathscr{L}$, M

L, L' (applicable only to test sections with a cosine shaped portion)

$\mathscr{L}$, ξ , ℓ' (applicable only to peaked inlet, peaked outlet, or spike-cosine shaped test sections)

The following additional data is obtained from each experiment

T_{IN}	E	$P_{p\ OUT}$
W	I	P_{IN}
		P_{OUT}

From these data, $\Delta P = P_{IN} - P_{OUT}$ and H_{IN} are directly available.

b) PARAMETERS DERIVED FROM FIRST LAW

Using the above data, the desired parameters at the test section inlet and along the test section are calculated as follows

TUBE INLET $X_{IN} = \frac{H_{IN}-H_{f-IN}}{H_{fg-IN}} = \frac{\Delta H_{SUB-IN}}{H_{fg-IN}}$

AXIALLY ALONG TUBE

(q/A_x), $(q/A)_c$, Q_x, Q_c per equations in Appendix B

$H_x = H_{IN} + \frac{Q_x}{W}$

$X_x = \frac{H_x-H_{f-x}}{H_{fg-x}}$

In addition parameters associated with the saturation location and the bubbly-annular transition point are calculated as follows

SATURATION LOCATION

$Q_{X=0} = -\Delta H_{SUB-IN} W$

$L_{X=0}$ is length at which $Q_x = Q_{X=0}$. This parameter is obtained by solving the relevant Q_x equation in Appendix B for the position variable having first made the substitution $Q_{X=0} = Q_x$

$L_S = \mathcal{L} - L_{X=0}$

$Q_{SAT} = EI\ 3.41\ BTU/hr/watt - Q_{X=0} = Q_{TOT} - Q_{X=0}$

BUBBLY-ANNULAR TRANSITION LOCATION

The value of x at the transition location is established by repetition of calculations for increasing

distances beyond the zero quality length, $L_{X=O}$, until the preset value of quality at the transition point is attained. With x thus established at the transition location, the additional parameters below are calculated

$$Q_{ANN} = Q_{TOT} - Q_X$$

$$Q_{ANN-C} = Q_C - Q_X$$

CALCULATION OF P(X)

In all the above work, calculation of P_x is computed by the empirical formulation below. This formulation was established by calculating pressure drops using the Martinelli-Nelson model (43) for tubes representing the extreme ranges in pressure drop and mass flow experienced. These results of pressure over tube length were then fitted by two straight lines, the latter line which is applicable over the higher quality regions having the more negative slope to reflect the larger rate of pressure drop in the higher quality region. The empirical fitted results compared well with the calculated results. While this method gives pressure results which are only within $\pm$ 10%, these values are used only to obtain enthalpy, quality, and heat flux for incipient nucleation which are relatively insensitive to small changes in pressure. This procedure was adopted since the accuracy obtained was acceptable and a more complicated program for pressure calculation was therefore not needed.

For $x \leq L_{X=0}$, $P_x = P_{IN}$ (neglects single phase pressure drop)

For $L_{X=0} < x \leq 1.6\ L_{X=0}$

$$P_x = P_{IN} - .750\ \Delta P\ \left(\frac{x-L_{X=0}}{\ell-L_{X=0}}\right)$$

For $x > 1.6\ L_{X=0}$

$$P_x = P_{BK} - (P_{BK}-P_{OUT})\left(\frac{x-1.6L_{X=0}}{\ell-1.6L_{X=0}}\right)$$

where

$$P_{BK} = P_{IN} - .750\ \Delta P\ \left(\frac{0.60L_{X=0}}{\ell-L_{X=0}}\right)$$

c) ANALYTIC MODEL

The model discussed in Chapter IV requires computation of the heat flux to initiate nucleate boiling at given conditions of mass flow rate G, pressure P, quality X and tube geometry, D, ℓ. The correlations used in this computation are

TWO PHASE HEAT TRANSFER COEFFICIENT, h

1) DENGLER-ADDOMS CORRELATION (38)

$$h = 3.5\ h_L(1/X_{tt})^{+0.5} \quad \text{for } .25 < X_{tt} < 70$$

where

$$h_L = .023\left(\frac{k_L}{D/12.0}\right)(Re)^{0.8}(Pr_L)^{0.4}$$

and

$$1/X_{tt} = \left(\frac{X}{1-X}\right)^{0.9}\left(\frac{v_v}{v_L}\right)^{0.5}\left(\frac{\mu_v}{\mu_L}\right)^{0.1}$$

2) CHEN CORRELATION (39)

$$h = h_{MAC} + h_{MIC}$$

$$h_{MAC} = 0.23\left(\frac{k_L}{D/12.0}\right)(Re_L)^{0.8}(Pr_L)^{0.4}F$$

where

$$Re_L = \frac{G(1-X)D}{\mu_L 12.0}$$

F = function of $\frac{1}{X_{tt}}$ defined by Chen's Fig. 7.

and

$$h_{MIC} = 0.00122\,\frac{k_L^{0.79}C_{PL}^{0.45}v_v^{0.24}g_o^{0.25}}{\sigma^{0.5}\mu_L^{0.29}H_{fg}^{0.24}v_\ell^{0.49}}(\Delta T)^{0.24}(\Delta P)^{0.75}S$$

where

$\Delta T = T_{WALL} - T_{SAT}$

ΔP = difference in vapor pressure corresponding to ΔT, lb_f/ft^2

S = function of $Re_L F^{1.25}$ defined by Chen's Fig. 8.

<u>BERGLES-ROHSENOW INCIPIENT HEAT FLUX FOR NUCLEATION, $(q/A)_i$</u> (35)

$$(q/A)_i = 15.60p^{1.156}(T_{WALL} - T_{SAT})^{2.30/p^{0.0234}}$$

The associated maximum cavity size required is obtained as

$$r = \frac{+\alpha + 2T_{WALL} \pm \sqrt{\frac{2\alpha\beta T_{WALL}^2}{\gamma} + 4T_{WALL}\alpha + \alpha^2}}{2\gamma - \alpha\beta}$$

where

$$\gamma = q/A/k = {}^{o}F/ft \text{ or } {}^{o}R/ft$$

$$\alpha = \frac{h_{fg}\ 778}{R_g} = {}^{o}R \text{ where } R_g = 85.8\ \frac{lb_f\ ft}{lb_m\ {}^{o}R}$$

$$\beta = \frac{P}{\sigma\ 144.0} = \frac{1}{ft}$$

d) ANNULAR FILM CHARACTERISTICS (44)

The GEAP report presents curves of $\frac{b-a}{b}$ as a function of $F'(\frac{b-a}{b})$. The film thickness, b-a, is thus obtained from the quantities b (radius in ft) and $F'(\frac{b-a}{b})$ where

$$F'(\frac{b-a}{b}) = \sqrt{\frac{(-\frac{dP}{dz})_{TOT-TP} \frac{b}{2.0 g_o}}{\rho_L}} \left(\frac{3600\ \rho_G}{G_G}\right)\left(\frac{\rho_L}{\rho_G}\right)^{1/3} \left(\frac{g\rho_L}{g_o(-\frac{dP}{dz})_{TOT-TP}}\right)^{-n}$$

where

$$n = o \text{ if } (-\frac{dP}{dz})_{TOT-TP} \geq \frac{g}{g_o}\rho_L$$

$$n = -1/3 \text{ if } (-\frac{dP}{dz})_{TOT-TP} < \frac{g}{g_o}\rho_L$$

Computation of the film flow rate, G_f is accomplished by the following series of equations

$$\tau_{WALL} = \left[(-\frac{dP}{dz})_{TOT-TP} - \frac{g\rho_L}{g_o}(1 - \frac{a^2}{b^2})\right]\frac{b}{2}$$

$$y^+ = y\sqrt{\frac{\tau_{WALL}\ 4.17 \times 10^8}{\rho_L}}\ \frac{\rho_L}{\mu_L}$$

where

$$y \equiv b-a$$

$$G_{film} = \frac{2}{b}\mu_L F(y^+)$$

where

$$F(y^+) = 3y^+ + 2.5y^+ \ln y^+ - 64 \quad \text{for } y^+ > 30$$

$$= 12.5 - 8.05y^+ + 5y^+ \ln y^+ \quad \text{for } 5 < y^+ \leq 30$$

$$= 0.5y^{+2} \quad \text{for } y^+ \leq 5$$

The results of the GEAP report are applicable only to adiabatic conditions and hence are not strictly applicable to the conditions of the subject investigation. However, the test results were analysed based on the above equations to explore the possibility of calculating local film flow rates by this method. Since contradictory answers were obtained, the extrapolation of the equations to the test conditions was not considered reliable and hence analysis by this means was not pursued.

APPENDIX E

COMPUTER PROGRAM FOR DATA REDUCTION AND ANALYSIS

The experimental data obtained was reduced in accordance with the equations of Appendix D by a program written in FORTRAN and run on the MIT Computation Center IBM 7090 computer.

The program consists of a main program (AXIAL) which identifies from the input the flux shape of each tube (i.e. uniform, cosine, etc.) and transfers control to one of seven subroutines, one for each flux shape, where computations are initiated. These routines (UNIFRM, COSINE, LININC, LINDEC, PKIN, PKOUT, SPKCOS) together with the subroutines for calculating the saturated liquid and evaporation enthalpy (LIQEN and EVAPEN respectively) perform calculations of desired parameters at the critical location and over the entire length of the test section. In addition these subroutines call the subroutines (UNIANN, COSANN, LNIANN, LNDANN, PKIANN, PKOANN, SPKANN, CSPIKE) which calculate the desired parameters at the location of the bubbly-annular transition.

Calculation of the annular film thickness and the film flow rate past the bubbly-annular transition point is initiated by the subroutine FILMFR

which is also called by the seven basic subroutines (UNIFRM, COSINE, etc.). The subroutine FILMFR accomplishes this calculation by calling the subroutines listed below.

a) Local momentum pressure gradient based on the homogeneous flow assumption (HOMMGD).

b) Overall momentum pressure drop divided by the length yielding a linear momentum pressure gradient (GRDMOM).

c) Fluid properties - specific volume of saturated water (SPECVL), specific volume of saturated water vapor (SPECVG), saturation temperature (SATTMP), viscosity of saturated liquid (VISCOS), saturated liquid enthalpy (LIQEN) and evaporation liquid enthalpy (EVAPEN).

d) The Martinelli-Nelson friction pressure gradient multiplier (MNPGRD).

e) The ratio of film thickness to tube radius for given value of Levy's universal factor F' (UNIVER).

If it is desired to exclude calculation of the film thickness and flow rate, it is sufficient to substitute dummy subroutines in place of subroutines FILMFR and GRDMOM.

The program also computes the relevant variables for the model by which the test results are analysed. These variables are (1) the change in enthalpy from the bubbly-annular transition location to the local point of interest

and (2) the ratio of the local flux to the flux required to initiate nucleation in the liquid film based on both Chen's (39) and Dengler's (38) correlations. The calculation is initiated from the subroutine FILMFR by calling subroutines BONUCF and LONUCF which perform the desired calculations respectively at the burnout location and any local position of interest. The associated subroutines used in this calculation are

(1) Chen's two phase heat transfer coefficient (XHCHEN)

(2) Largest pit radius needed for nucleation per the Bergles-Rohsenow theory (XRAD)

(3) Fluid properties (in addition to those listed above under FILMFR) - thermal conductivity of saturated water (XTHCON), specific heat at constant pressure of saturated water (XCPLIQ), steam-water surface tension (XSURFT), pressure of saturated water (XSATP), saturated vapor viscosity (XVISCG)

(4) Derived property dependent quantities - difference in vapor pressure corresponding to given water temperature difference (XDELTV), Martinelli parameter (XXTT), Chen's F factor (XFCHEN) and Chen's factor (XSCHEN).

In addition provision is available thru subroutine NFLUX2 for a revised nucleation flux criteria in those cases where the maximum available surface pit radius is less than that required by the Bergles-Rohsenow criteria. However, NFLUX2 presently exists as a dummy subroutine.

A complete listing of the fortran statements for this program is included at the end of this appendix.

A listing of the variable names and the physical parameters which they represent is presented in Tables E-1, E-2, and E-3 where Table E-2 includes specifically the variables associated with the calculation of annular film thickness and flow rate (Subroutines FILMFR, GRDMOM and other called subroutines) and Table E-3 pertains to BONUCF and LONUCF and associated subroutines.

The procedure for inputing data to run this program is as follows. Following the star data card which follows the compiled program is the first data card on which the number of individual cases to be run is punched. This number is fixed point and should be punched, right oriented, in the field 1-5. This card controls the actual number of executions of the program which should correspond to the number of cases to be reduced.

The remaining data cards directly pertain to the data for individual tubes. For uniform, cosine and linear flux shapes, five cards are required for each case. For the peaked flux shapes a sixth card is required as described below. For the cosine spike shape a seventh card is required.

a) First card - A fixed point number, right oriented, should be punched in the field 1-5. This number identifies the flux shape according to the code; 1 - uniform, 2 - cosine, 3 - linear increasing, 4 - linear decreasing, 5 - peaked inlet,

6 - peaked exit and 7-spiked cosine.

b) Second Card - Seven floating point input variables should be punched in sequence in fields of ten each. The variables, in sequence, are TUBE, RATIOM, DIAINS, VOLTS, AMPS, ENTHIN, FLMASS. The physical parameters and units represented by these variables are listed in Table E-1. Since these variables are all floating point, they should be punched with a decimal point unless specific care is taken to right orient them in their field and provide sufficient digits to accomodate the format statements in the program. This comment applies equally to cards 3, 4, 5 and 6.

c) Third Card - Six floating point input variables should be punched in sequence in fields of ten each. The variables in sequence are PRESP, PRESIN, PRESOT, RESDP, TSDP, BOLOCA.

d) Fourth Card - Two floating point input variables should be punched in sequence in field of ten each. The variables in sequence are XLNGTH and SHUNTM.

e) Fifth Card - A fixed point variable JLOCAT is punched right oriented in columns 1-5, and a floating point variable QUALIA is punched in columns 6-15.

f) Sixth Card - Three floating point input variables should be punched in sequence in fields of ten each.

The variables in sequence are SCRPTL, ZETA and PLNGTH and are applicable only to the peaked inlet and exit flux shapes and with new definitions to the **spike cosine** shape.

g) Seventh Card - The fixed point variable J, should be punched in format I5. This card is applicable only to **spike cosine** flux shape.

The following characteristics of the program should be noted in particular.

1) PRESP and RESDP are input only to maintain a complete record of the data for each tube. Since they are not used in the subsequent calculation, they can if desired be set equal to zero for convenience.

2) AMPS represents the tube amperage in millivolts (shunt voltage drop) and is used in conjunction with SHUNTM to calculate the tube current. SHUNTM represents the number of amperes per millivolt for the particular calibration shunt installed in the heat transfer laboratory. Since the product AMPS and SHUNTM represents tube current in amperes, the arbitrary value 1.00 can be assigned to SHUNTM if an experiment yields current directly in amperes.

A group of punched input cards for the case of an inlet peaked and a cosine spike tube are shown for illustration with the program listing.

The basis for the formulations of the subroutines for fluid properties and the subroutines MNPGRD and UNIVER are discussed below. The polynomial fits of data for subroutines below were taken from the work of Trembley (45) unless otherwise noted.

a) Subroutine SPECVL - Specific Volume of Saturated Liquid vs. Pressure

The specific volume of saturated liquid as function of pressure was obtained by fitting the Keenan and Keyes' values (46) on a power series to obtain for $P < 400$ psia,

$$v_f(P) = \sum_{i=0}^{9} a_i P^i$$

where

$a_0 = 1.6401745\ (10^{-2})$ $\quad a_5 = 3.8991151\ (10^{-15})$

$a_1 = 2.3289060\ (10^{-5})$ $\quad a_6 = -4.3187213\ (10^{-18})$

$a_2 = -1.5364591\ (10^{-7})$ $\quad a_7 = 2.8681090\ (10^{-21})$

$a_3 = 7.4158910\ (10^{-10})$ $\quad a_8 = -1.0458372\ (10^{-24})$

$a_4 = -2.1694997\ (10^{-12})$ $\quad a_9 = 1.6082445\ (10^{-28})$

for $P \geq 400$ psia,

$$v_f(P) = \sum_{i=0}^{4} b_i P^i$$

where

$b_o = 1.7382154\ (10^{-2})$ $\quad b_3 = 6.6669956\ (10^{-13})$

$b_1 = 5.5320054\ (10^{-6})$ $\quad b_4 = -2.1537248\ (10^{-17})$

$b_2 = -1.9348749\ (10^{-9})$

b) Subroutine SPECVG - Specific Volume of Saturated Vapour vs. Pressure

The specific volume of saturated vapour as a function of pressure was obtained by a power series fit of the Keenan and Keyes' values.

For $P < 200$ psia, we have

$$v_g(P) = \sum_{i=0}^{10} a_i P^i$$

where

$a_0 = 7.0026614\ (10^1)$
$a_1 = -5.2270893\ (10^0)$
$a_2 = 2.2026868\ (10^{-1})$
$a_3 = -5.7651685\ (10^{-3})$
$a_4 = 9.8819624\ (10^{-5})$
$a_5 = -1.1389329\ (10^{-6})$
$a_6 = 8.8808151\ (10^{-9})$
$a_7 = -4.6173317\ (10^{-11})$
$a_8 = 1.5321887\ (10^{-13})$
$a_9 = -2.9334747\ (10^{-16})$
$a_{10} = 2.4643861\ (10^{-19})$

For $200 \leq P < 400$ psia,

$$v_g(P) = \sum_{i=0}^{5} b_i P^i$$

where

$b_0 = 9.1051359\ (10^0)$
$b_1 = -7.6398584\ (10^{-2})$
$b_2 = 3.4342061\ (10^{-4})$
$b_3 = -8.6394549\ (10^{-7})$
$b_4 = 1.1495386\ (10^{-9})$
$b_5 = -6.3157880\ (10^{-13})$

For $P \geq 400$ psia,

$$v_g(P) = \sum_{i=0}^{7} c_i P^i$$

where

$c_0 = 4.2909747\ (10^0)$ $\quad$ $c_4 = 3.6138355\ (10^{-11})$

$c_1 = -1.6646162\ (10^{-2})$ $\quad$ $c_5 = -1.7180116\ (10^{-14})$

$c_2 = 3.5532997\ (10^{-5})$ $\quad$ $c_6 = 4.4959690\ (10^{-18})$

$c_3 = -4.5689872\ (10^{-8})$ $\quad$ $c_7 = -4.9699884\ (10^{-22})$

c) Subroutine LIQEN - Enthalpy of Saturated Liquid vs. Pressure

The enthalpy of saturated liquid as function of pressure was obtained by a power series fit of the Keenan and Keyes' values.

For $P < 200$ psia,

$$h_f(P) = \sum_{i=0}^{9} a_i P^i$$

where

$a_0 = 1.1222734\ (10^2)$ $\quad$ $a_5 = 2.1239014\ (10^{-7})$

$a_1 = 6.3204790\ (10^0)$ $\quad$ $a_6 = -1.0067598\ (10^{-9})$

$a_2 = -1.4742752\ (10^{-1})$ $\quad$ $a_7 = 2.9480958\ (10^{-12})$

$a_3 = 2.5403593\ (10^{-3})$ $\quad$ $a_8 = -4.8430355\ (10^{-15})$

$a_4 = -2.8788220\ (10^{-5})$ $\quad$ $a_9 = 3.4075972\ (10^{-18})$

For $P \geq 200$ psia,

$$h_f\ (P) = \sum_{i=0}^{7} b_i P^i$$

where

$b_o = 2.4510585\ (10^2)$ $\quad$ $b_4 = -6.8660980\ (10^{-10})$

$b_1 = 7.1675962\ (10^{-1})$ $\quad$ $b_5 = 2.6573456\ (10^{-13})$

$b_2 = -9.9955201\ (10^{-4})$ $\quad$ $b_6 = -5.5654666\ (10^{-17})$

$b_3 = 1.0516702\ (10^{-6})$ $\qquad$ $b_7 = 4.8594220\ (10^{-21})$

d) Subroutine EVAPEN - Latent Heat vs. Pressure

By definition the latent heat is simply the enthalpy difference between that of the saturated vapour and that of the saturated liquid ($h_{fg} = h_g - h_f$). It was obtained by fitting the Keenan and Keyes' values on a power series.

For $P < 400$ psia,

$$h_{fg}(P) = \sum_{i=0}^{9} a_i P^i$$

where

$a_0 = 9.9704457\ (10^{2})$ $\qquad$ $a_5 = -1.2499843\ (10^{-9})$

$a_1 = -2.1762821\ (10^{0})$ $\qquad$ $a_6 = 1.9322768\ (10^{-12})$

$a_2 = 1.9558791\ (10^{-2})$ $\qquad$ $a_7 = -1.8023251\ (10^{-15})$

$a_3 = -1.2610018\ (10^{-4})$ $\qquad$ $a_8 = 9.2680092\ (10^{-19})$

$a_4 = 5.0308804\ (10^{-7})$ $\qquad$ $a_9 = -2.0148643\ (10^{-22})$

For $P > 400$ psia,

$$h_{fg}(P) = \sum_{i=0}^{4} b_i P^i$$

where

$b_0 = 8.9642372\ (10^{2})$ $\qquad$ $b_3 = -4.3416487\ (10^{-8})$

$b_1 = -3.3549732\ (10^{-1})$ $\qquad$ $b_4 = 4.8788247\ (10^{-12})$

$b_2 = 1.2678091\ (10^{-4})$

e) Subroutine SATTMP - Saturation Temperature vs. Pressure

The saturation temperature as function of pressure was obtained from Steltz and al. (47).

$$T = \sum_{i=0}^{8} a_i P_L^i$$

where

	$0.2 \leq P < 450$ psia	$450 \leq P < 3206$ psia
P_L	$\ln(10\ P)$	$\ln P = 0$
a_0	$3.5157890\ (10^1)$	$1.1545164\ (10^4)$
a_1	$2.4592588\ (10^1)$	$-8.3860182\ (10^3)$
a_2	$2.1182069\ (10^0)$	$2.4777661\ (10^3)$
a_3	$-3.4144740\ (10^{-1})$	$-3.6344271\ (10^2)$
a_4	$1.5741642\ (10^{-1})$	$2.6690978\ (10^1)$
a_5	$-3.1329585\ (10^{-2})$	$-7.8073813\ (10^{-1})$
a_6	$3.8658282\ (10^{-3})$	0
a_7	$-2.4901784\ (10^{-4})$	0
a_8	$6.8401559\ (10^{-6})$	0

f) Subroutine VISCOS - <u>Viscosity of Saturated Liquid and Vapour vs. Temperature</u>

The viscosity of saturated liquid as function of temperature to 600°F was obtained by a power series fit of Wellman and Sibbitt's data. **(48)**

$$\mu_f = \sum_{i=0}^{10} a_i T^i$$

where

$a_0 = 8.0144599\ (10^0)$ $\quad a_6 = 8.4382483\ (10^{-13})$

$a_1 = -1.6728317\ (10^{-1})$ $\quad a_7 = -1.4493830\ (10^{-15})$

$a_2 = 2.0423535\ (10^{-3})$ $\quad a_8 = 1.5963800\ (10^{-18})$

$a_3 = -1.6324668\ (10^{-5})$ $\quad a_9 = -1.0173273\ (10^{-21})$

$a_4 = 8.8555744\ (10^{-8})$ $\quad a_{10} = 2.8496174\ (10^{-25})$

$a_5 = -3.3015965\ (10^{-10})$

Above 600°F the viscosity was obtained by a series of straight line fits of the Wellman and Sibbitt data.

g) Subroutine MNPGRD - Martinelli-Nelson's Friction Pressure Gradient Ratio

Jones' polynomial fit (49) of Martinelli-Nelson values was used, i.e.,

$$\phi_{M-N} = \exp \sum_{i=1}^{4} \sum_{j=0}^{7} a_{ij} \cdot P^j \cdot X^i$$

where

$p = P/1000$

$X = \ln (100\ x + 1)$

j	a_{1j}	a_{2j}	a_{3j}
0	$2.5448316\ (10^{0})$	$-5.1756752\ (10^{-1})$	$1.0193956\ (10^{-1})$
1	$-7.8896201\ (10^{0})$	$1.9550200\ (10^{0})$	$-3.7233785\ (10^{-1})$
2	$1.5575870\ (10^{1})$	$-9.6886164\ (10^{-1})$	$-1.9025685\ (10^{-1})$
3	$-1.7340906\ (10^{1})$	$-4.6120079\ (10^{0})$	$-2.2654839\ (10^{0})$
4	$1.0409842\ (10^{1})$	$8.4910340\ (10^{0})$	$-3.4925414\ (10^{0})$
5	$-3.2044877\ (10^{0})$	$-5.9583098\ (10^{0})$	$2.3299085\ (10^{0})$
6	$4.2484805\ (10^{-1})$	$1.8989183\ (10^{0})$	$-7.2534973\ (10^{-1})$
7	$-1.0804871\ (10^{-2})$	$-2.2867680\ (10^{-1})$	$8.6169847\ (10^{-2})$

j	a_{4j}
0	$-8.0606798\ (10^{-3})$
1	$2.6160876\ (10^{-2})$
2	$6.0288725\ (10^{-2})$
3	$-3.2426871\ (10^{-1})$
4	$4.6553847\ (10^{-1})$
5	$-3.0333482\ (10^{-1})$
6	$9.3379834\ (10^{-2})$
7	$-1.1021915\ (10^{-2})$

Corrected Pressure Gradient Ratio

It was recognized that the Martinelli-Nelson values of $\emptyset$ correspond to a mass velocity of about 200 lbm/sec-ft^2 and that the pressure gradient ratio depends not only on quality and pressure but also on the mass velocity. Jones (49) has derived a mass velocity correction factor that is valid for $G \leq 10^3$ lbm/sec-ft^2. This factor is function of both pressure and mass velocity and is expressed in polynomial form as

$$\Omega' = \sum_{i=0}^{5} (a_i + b_i P) \cdot G_o^{\,i}$$

where

$$G_o = \ln (.0036\ G + 0.2)$$

i	a	b
0	$1.4012797\ (10^{0})$	$-3.8229399\ (10^{-5})$
1	$-6.8082318\ (10^{-2})$	$-4.5200014\ (10^{-4})$
2	$-8.3387593\ (10^{-2})$	$1.2278415\ (10^{-4})$
3	$3.5640886\ (10^{-2})$	$1.5165216\ (10^{-4})$
4	$2.1855741\ (10^{-2})$	$-3.4296260\ (10^{-5})$
5	$-6.3676796\ (10^{-3})$	$-3.2820747\ (10^{-5})$

But, at $G \simeq 200$ at any pressure Jones predicts of value of $\Omega' = 1.4$. Since the Martinelli-Nelson pressure gradient ratios correspond to that mass velocity, Jones' correction factor should therefore be unity. **Therefore, the suggested Jones factor was normalized as**

$$\Omega = \Omega' - 0.4$$

It was found by Trembley (45) that the transition across the $G = 10^3$ boundary yielded a serious discontinuity. Hence

$$\Omega = \Omega\Big|_{G = 10^3} \quad \text{for } G > 10^3 \text{ was assumed.}$$

The two-phase to liquid-phase pressure gradient ratio is therefore

$$\phi = \Omega \cdot \phi_{M\text{-}N}$$

h) Subroutine UNIVER - The relevant curves of GEAP 4615 relating the ratio film thickness/tube radius to the calculated factor F' were fit by an MIT Computational

Center Share program (50). The form of the fit is

$$\frac{b-a}{b} = \sum_{i=0}^{n} a_i \left(F'\left(\frac{b-a}{b}\right)\right)^{i-1}$$

i) Subroutine XTHCON - Thermal Conductivity of Saturated Liquid Water vs Temperature

The thermal conductivity of saturated liquid water was obtained by a series of straight line fits of the data of Wellman and Sibbitt (48).

j) Subroutine XCPLIQ - Constant Pressure Specific Heat of Saturated Liquid Water vs Temperature

The specific heat of saturated liquid water was obtained by a series of straight line fits of the data of Wellman and Sibbitt (48).

k) Subroutine XSURFT - Surface Tension of Saturated Water

The surface tension for saturated water as a function of pressure to 1000 psia was obtained by a power series fit on Volyak's data. (51)

$$\sigma = \sum_{i=0}^{10} a_i P^i$$

where

$a_0 = 6.3225462\ (10^{1})$ $\quad a_6 = 2.8461426\ (10^{-13})$

$a_1 = -3.2677020\ (10^{-1})$ $\quad a_7 = -3.0063514\ (10^{-16})$

$a_2 = 2.8126518\ (10^{-3})$ $\quad a_8 = 1.9734415\ (10^{-19})$

$a_3 = -1.7494856\ (10^{-5})$ $\quad a_9 = -7.3149007\ (10^{-23})$

$a_4 = 6.8880390\ (10^{-8})$ $\quad a_{10} = 1.1689972\ (10^{-26})$

$a_5 = -1.7378005\ (10^{-10})$

Above 1000 psia (544.69°F) the surface tension was obtained by a series of straight line fits to data presented in figure E.2 of Rohsenow and Choi (52).

1) Subroutine XSATP - Saturation Pressure vs. Temperature

The saturation pressure corresponding to the temperature was obtained from Steltz et al (47) as

$$P = P_c \cdot 10^{-X}$$

where

$$X = \frac{t}{T_K}\left(\frac{N_u}{D_N}\right)$$

$$N_u = A + Bt + Ct^3 + Et^4$$

$$D_N = 1 + Dt$$

$$P_c = 3206.182$$

$$t = T_c - T_K$$

$$T_c = 647.27$$

$$T_K = \frac{T - 32}{1.8} + 273.16$$

	$50 \leq T < 200$	$200 < T \leq 705$
A	3.2437814	3.3463130
B	$5.86826\ (10^{-3})$	$4.14113\ (10^{-2})$
C	$1.1702379\ (10^{-8})$	$7.515484\ (10^{-9})$
D	$2.1878462\ (10^{-3})$	$1.3794481\ (10^{-2})$
E	0	$6.56444\ (10^{-11})$

m) Subroutine XVISCG - Viscosity of Saturated Vapour

For $T \leq 500^{\circ}F$, the viscosity of saturated vapour was taken from Kestin's correlation **(53)**

$$\mu_g(P,T) = 2.419\ (10^{-4})\left[88.020 + 0.32827 \cdot T_c + 2.1350\ (10^{-4})T_c^{\,2} - 1.6018\ (10^{-2})(1858-5.90T_c)/v_g\right]$$

where

$T_c = (T-32)/1.8$

$v_g(P,T)$ = (use **subroutine SPECVG**)

For $T > 500^{\circ}F$, we used Keyes' correlation as given by Quan **(54)**

$$\mu_g(P,T) = 2.419\ (10^{-3})\left[420\ T^{1/2}(1+2600\ T^{-1} \cdot 10^{-30T^{-1}})^{-1} + 1.5\ (10^{0.0906/v_g-1})\right]$$

TABLE E-1

VARIABLE NAME	PHYSICAL PARAMETER OR DEFINING EQUATION	UNITS
Input Variables		
NTUBES	Number of tubes	-
MSHAPE	Index representing tube flux shape	-
TUBE	Tube identification no.	-
RATIOM	M	-
DIAINS	D_{in}	inches
VOLTS	V	volts
AMPS	a	millivolt
ENTHIN	h_{IN}	BTU/lb m
FLMASS		lb m/hr
JLOCAT	Index indicating length over which calculation of thermal and hydralic parameters should be made.	-
PRESP	Pump outlet pressure	psia
PRESIN	P_{IN}	psia
PRESOT	P_{OUT}	psia
QUALIA	Quality at bubbly-annular transition	wt % steam
RESDP	Pressure drop across needle value at test section inlet	psi
TSDP	ΔP	psi
BOLOCA	c	inches
XLNGTH	ℓ	inches
SHUNTM	S	amperes/millivolt
SCRPTL	$\mathcal{L}$	inches
ZETA	ξ	-
PLNGTH	ℓ'	inches

Intermediate Computed Variables

ARG	$\arcsin\left[\pm\left(\frac{2Q_{X=0}}{Q_{TOT}-1}\right)\left(\frac{M^2-1}{M^2}\right)\right]$	-
CONSTP	C_1	inches
COSABK	$\cos\frac{\pi}{L'}(\ell-\mathcal{L}-.5\ell')$	-
COSLEN	L or L'	inches
EXTRAA	SINABK + ONEMSQ	-
EXTRAB	(SCRPTL * COSABK)/ZETA	inches
EXTRAC	(POWERT * COSLEN)/(CONSTP * π)	BTU/hr
EXTRAD	C_2	-
EXTRAE	(POWERT * 144.0)/(CONSTP * DIAINS * π)	BTU/hr ft^2
EXTRAF	(POWERT * COSABK * SCRPTL)/(CONSTP * ZETA)	BTU/hr
EXTRAG	Unused floating point variable	
EXTRAH	DVLSPL(see FILMFR)	ft^3/lb m
EXTRAI	DVLSPG (see FILMFR)	ft^3/lb m
EXTRAJ	QUALOX (see FILMFR)	wt % steam
FACMIB	$1-\frac{\sin\frac{\pi}{L}\left\lvert\frac{c-\ell/2}{2}\right\rvert}{\left(\frac{M^2-1}{M^2}\right)^{1/2}}$	-
FACPLB	$1+\frac{\sin\frac{\pi}{L}\left(\frac{c-\ell/2}{2}\right)}{\left(\frac{M^2-1}{M^2}\right)^{1/2}}$	-
FACTMI	$1-\frac{\sin\frac{\pi}{L}\lvert z\rvert}{(M^2-1/M^2)^{1/2}}$	-
FACTPL	$1+\frac{\sin\frac{\pi}{L}\lvert z\rvert}{\left(\frac{M^2-1}{M^2}\right)^{1/2}}$	-

Intermediate Computed Variables (Cont.)

K	Position index	-
L	Position index	-
ONEOVM	$1/M$	-
ONEMSQ	$(\frac{M^2-1}{M^2})^{1/2}$	-
POWOQ	$Q_{X=0}$	BTU/hr
PBREAK	P_{BK}	psia
SINABK	$\sin \frac{\pi}{L'}(\ell - \ell - .5\ell')$	-
SIGNZ	$\pm (\frac{M^2-1}{M^2})^{1/2} (\frac{2Q_{X=0}}{Q_{TOT}} - 1)$	-
ULOCAT	$1 - \exp(-\xi)$	-

Output Variables

AREAFL	A_F	ft^2
AREAIS	A_s	ft^2
CFXAVG	ϕ_{AVG}	BTU/hr ft^2
CFXBO	ϕ_c	BTU/hr ft^2
CFXLOX	$\phi(x)$	BTU/hr ft^2
CFXLOY	$\phi(y)$	BTU/hr ft^2
DMEFB	H_{f-c}	BTU/lb m
DMEFGB	H_{fg-c}	BTU/lb m
DMEFX	H_{f-x}	BTU/lb m
DMEFGX	H_{fg-x}	BTU/lb m

Output Variables

DMEFY	H_{f-y}	BTU/lb m
DMEFGY	H_{fg-y}	BTU/lb m
ENFPX	H_f	BTU/lb m
ENFGPX	H_{fg}	BTU/lb m
ENLOB	H_c	BTU/lb m
ENLOX	H_x	BTU/lb m
ENLOY	H_y	BTU/lb m
ENSIN	ΔH_{SUB-IN}	BTU/lb m
ENSLOB	ΔH_{SUB-C}	BTU/lb m
ENSLOX	ΔH_{SUB-X}	BTU/lb m
ENSLOY	ΔH_{SUB-Y}	BTU/lb m
P	P	psia
PANBOL	Q_{ANN-c}	BTU/hr
POWERA	Q_{ANN}	BTU/hr
POWERB	Q_c	BTU/hr
POWERT	Q_{TOT}	BTU/hr
POWERX	Q(x)	BTU/hr
POWERY	Q(y)	BTU/hr
PSATL	Q_s	BTU/hr
PSLBOL	Q_{sc}	BTU/hr
QUALOL	$L_{X=0}$	inches
QUALO4	$16.0L_{X=0}$	inches
QUALIN	X_{IN}	wt % steam
QUALOB	X_c	wt % steam
QUALOX	X(x)	wt % steam
SATL	L_s	inches
U	u	inches
X	x	inches
Y	y	inches
Z	z	inches

TABLE E-2

FILMFR, GRDMOM and called subroutines

VARIABLE NAME	PHYSICAL PARAMETER OR DEFINING EQUATION	UNITS
Intermediate Computed Variables		
a	Distance from centerline to film-core interface	inches
b	Tube radius	inches
BMAOA	b-a/b	
COLM 1)		
COLM 2)	Intermediate variables	
COLM 3)	in the subroutine MNPGRD	
COLM 4)		
DENFO	$\mathbf{H}_{f\text{-OUT}}$	BTU/lb m
DENFGO	$\mathbf{H}_{fg\text{-OUT}}$	BTU/lb m
DP	P/1000	psia
DPMOM	$\Delta P_{TPF\text{-MOM}}$	lb_f/ft^2
DX	log (100 X +1.0)	-
DUMMY A	Linear momentum gradient	lb_f/ft^3
DUMMY B	I	-
DUMMY C	K + 1, L + 1	-
ENO	h_{OUT}	BTU/lb m
ENSO	$\Delta\mathbf{H}_{OUT}$	BTU/lb m
FFACTP	f/4.0	-
FILMTK	12.0(b-a)	ft
GRAVAC	g = 32.2	ft/sec^2
GRAVCS	g_O= 32.2	$\frac{lb_m}{lb_f}\ \frac{ft}{sec^2}$
GRAVCH	g_{OO}= 4.17 X 10^{+8}	$\frac{lb_m}{lb_f}\ \frac{ft\delta}{shr^2}$

Intermediate Computed Variables (Cont.)

GRDMT	$dP/dz_{TPF\text{-}MOM}$	lb_f/ft^3
GSUBZ	log(.0036 G/3600.0 + 0.2)	
GTOT	G	$lb_m/hr\ ft^2$
GTOTSC	G/3600.0	$\frac{lb_m}{sec\text{-}ft^2}$
I	3 or 2; spacing between calculations along the tube length.	inches
OMEGA	$\Omega = \Omega' - 0.4$	
OMEGAP	Ω	
PGMULT	ϕ	-
PHIMN	$\phi_{M\text{-}N}$	-
PSUBL	log (10.0p)	-
QUALO	X_{OUT}	-
QUALO 4	16.0 $L_{X=0}$	inches
SUMCOL, SUMO, SUM 1, SUM 2, SUM 3, SUM 4, SUM 5	Intermediate variables in the subroutine MNPGRD.	
T	T	^oF
TERM 1	$(v_g/v_\ell)^{0.334}$	-
TERM 2	$3600.0/v_g G_G$	sec/ft
TERM 3	$\left(\frac{(-\frac{dP}{dz})_{TPF\text{-}TOT} 32.2b\ v_\ell}{2}\right)^{1/2}$	ft/sec
TERM 4	$\left(\frac{g}{g_O v_\ell (-\frac{dP}{dz})_{TPF\text{-}TOT}}\right)^n$	-
FISCL	μ	$lb_m/hr\ ft$
VOLSPL	v_ℓ	$ft^3/lb\ m$
VOLSPG	v_g	$ft^3/lb\ m$

Output Variables

DBMAOA	$\frac{b-a}{b}$	-
DPGMLT	ϕ_{M-N}	-
DT	T	^{o}F
DVLSPG	v_g	$ft^3/lb\ m$
DVLSPL	v_f	$ft^3/lb\ m$
DVISCL	μ	$lb_m/hr\ ft$
FACTUN	F	-
FFACT	f	-
FYPLUS	$F(y^+)$	-
GFILM	G_{FILM}	$lb_m/hr\ ft^2$
GGAS	G_G	$lb_m/hr\ ft^2$
GLIQ	G_L	$lb_m/hr\ ft^2$
GLQENT	G_{L-ENT}	$lb_m/hr\ ft^2$
GRDFS	$\frac{dP}{dz})_{SP-FRICTION}$	lb_f/ft^3
GRDFT	$\frac{dP}{dz})_{TPF-FRICTION}$	lb_f/ft^3
GRDMT	$\frac{dP}{dz})_{TPF-MOM}$	lb_f/ft^3
GRDTOT	$\frac{dP}{dz})_{TPF-TOT}$	lb_f/ft^3
PCLIQ	% LIQ	$\frac{lb_m\ liquid}{lb_m\ total}$
PCLENT	%E	lb_m liquid entrained/ lb_m liquid
REYNUM	Re	-
TAUWAL	τ	lb_f/ft^2
TKINCH	b-a	inches
VALUEN	n	-
VELOC	V	ft/sec
YPLUS	y^+	-

TABLE E-3

BONUCF, LONUCF and called subroutines

VARIABLE NAME	PHYSICAL PARAMETER OR DEFINING EQUATION	UNITS
INPUT VARIABLE		
J	J/8 = spacing at which calculations are performed over spiked portion of test section ~~47~~ (CSPIKE)	-
INTERMEDIATE AND OUTPUT VARIABLES		
BERGHT	$(\frac{1.0}{15.6\ p^{1.156}})^{\frac{p^{.0234}}{2.30-p.0234}}$	-
BMAOA	$(q/A)x/(q/A)_{1-CHEN}$	-
CC	$(q/A)x/(q/A)_{1-DENGLER}$	-
CPLIQ	C_p	BTU/LBM-^{o}F
DD	$1.0/X_{tt}$	-
DELTEN	h_{ANN-c}	BTU/LBM
DELTT	T_W-T_{SAT}	^{o}F
DELTVP	ΔP corresponding to T_W-T_{SAT}	lbf/ft^2
DTCHEN	$(T_W-T_{SAT})_{CHEN}$	^{o}F
DTDENG	$(T_W-T_{SAT})_{DENGLER}$	^{o}F
EE	$F_{CHEN}^{1.25}\ Re_L$	-
FILMTK	$(1-\bar{X}/X)^{0.9}$	-
HCHEN	h_{CHEN}	BTU/HR FT^{o}F
HDB	$h_{DITTUS-BOELTER}$	BTU/HR-FT-^{o}F
HDENG	$h_{DENGLER}$	BTU/HR FT^{o}F
HMAC	h_{MAC}(from CHEN)	BTU/HR FT^{o}F

Intermediate and Output Variables (Cont.)

HMIC	h_{MIC}(from CHEN)	BTU/HR FT^{o}F
M	UNUSED FIXED POINT VARIABLE	-
N	FIXED POINT INDEX FROM CSPIKE	-
NFLUX	QUALO4	inches
QACHEN	$(q/A)_{1\text{-CHEN}}$	BTU/HR FT^2
QADENG	$(q/A)_{1\text{-DENGLER}}$	BTU/HR FT^2
QUALO4	$8(\ell - x + \ell')$	inches
PRNUMB	N_{PR}	-
RADIUS	R_{MIN}	ft.
RADMAX	Maximum pit radius available in test section	ft.
REYNLQ	Re_L	-
SATP	P_{SAT}	lb$_F$/in^2
SCHEN	S_{CHEN}	-
SMALLT	Intermediate variable in XSATP	-
SURFTL	σ	lb$_F$/ft^2
TAUWAL	$(\mu_L/\mu_G)^{.1}$	-
THCOND	k	BTU/HR FT^{o}F
VISCG	μ_G	LBM/HR FT
XTT	X_{tt}	-
YPLUS	$(v_L/v_G)^{.5}$	-

SAMPLE INPUT DATA

PEAK INLET FLUX DISTRIBUTION - #2503

```
    5
2503.     5.75     .213     13.9     30.9     204.2     123.75
281.      120.     99.      161.     21.      28.1
30.00     60.17
   31     0.080
18.0      1.33     15.0
```

UNIFORM FLUX DISTRIBUTION WITH COSINE SPIKE

#7210

```
    7
7210.     2.27     .213     16.7     36.4     203.4     250.0
280.      128.     35.      152.     93.      29.8
30.00     60.17
   31     0.080
6.0       0.0      1.0
    1
```

PROGRAM LISTING

```
C     DATA REDUCTION FOR NONUNIFORM AXIAL HEAT FLUX INPUT                    00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,      00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,                00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,          00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,             00050
     4PRPEAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,           00060
     5 COSLEN,ONEMSO,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,                    00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                      00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,                  00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                            00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ           00110
      COMMON QUALIA,GLIQ,TKINCH,                                             00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,     00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,      00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,     00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,        00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,     00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,      00180
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC           00190
      COMMON N,M,THCOND,ECHEN,SCHEN,VISCG,CPLIQ,SURFTL,                      00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,             00210
     2 PDNUMB,REDGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,                   00220
     3 DTCHEN,PADMAX,DELTEN,RADIUS,CC,DD,EE                                  00230
C     MSHAPE VALUE INDICATES THE TUBE FLUX SHAPE,MSHAPE=1 IS UNIFRM          00240
C    1MSHAPE=2 IS COSINE, MSHAPE=3 IS LINEAR INCREASING, AND MSHAPE=4 IS     00250
C    2DECREASING FLUX,MSHAPE 5=PEAKED INLET, AND MSHAPE 6= PEAKED EXIT       00260
      READ 505,NTUBES                                                        00270
      PRINT 505,NTUBES                                                       00280
  505 FORMAT (I5)                                                            00290
  510 FORMAT (I5)                                                            00300
  512 FORMAT (1H1,I5)                                                        00310
      DO 2000 I=1,NTUBES                                                     00320
      READ 510,MSHAPE                                                        00330
      PRINT 512,MSHAPE                                                       00340
      IF (ABSF(MSHAPE-1)  )  5, 100, 5                                       00350
    5 IF (ABSF(MSHAPE-2)  )  10, 200, 10                                     00360
   10 IF(ABSF(MSHAPE-3)) 15,600,15                                           00370
   15 IF(ABSF(MSHAPE-4)) 20,800,20                                           00380
   20 IF(ABSF(MSHAPE-5))  30,1100,30                                         00390
   30 IF(ABSF(MSHAPE-6)) 1600,1400,1600                                      00400
C     STATMENTSBEGINNING WITH 100 ARE FOR UNIFORM FLUX, 200 COSINE           00410
C    1 600 LINEAR INCREASING,800 LINEAR DECREASING,1100 PEAKED               00420
C    2 INLET, AND 1400 PEAKED EXIT                                           00430
  100 CALL UNIFRM                                                            00440
      GO TO 2000                                                             00450
  200 CALL COSINE                                                            00460
      GO TO 2000                                                             00470
  600 CALL LININC                                                            00480
      GO TO 2000                                                             00490
  800 CALL LINDEC                                                            00500
      GO TO 2000                                                             00510
 1100 CALL PKIN                                                              00520
      GO TO 2000                                                             00530
 1400 CALL PKOUT                                                             00540
      GO TO 2000                                                             00550
 1600 CALL SPKCOS                                                            00560
      GO TO 2000                                                             00570
 2000 CONTINUE                                                               00580
      CALL EXIT                                                              00590
      END                                                                    00600
```

```
      SUBROUTINE UNIFRM                                                      00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,      00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,                00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,          00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,             00050
     4PRPEAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,           00060
     5 COSLEN,ONEMSO,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,                    00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                      00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,                  00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                            00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ           00110
      COMMON QUALIA,GLIQ,TKINCH,                                             00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,     00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,      00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,     00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,        00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,     00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,      00180
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC           00190
  515 FORMAT (F10.0,F10.2,F10.4,4F10.1)                                      00200
  520 FORMAT (5F10.0,1F10.2)                                                 00210
  525 FORMAT (2F10.2)                                                        00220
  530 FORMAT (I5,F10.3)                                                      00230
  540  FORMAT(24H INLET LIQUID ENTHALPY = F8.2,                              00240
     1 25H    INLET EVAP ENTHALPY =F8.2, 22H    INLET SUBCOOLING =F8.2)     00250
  543 FORMAT(16H INLET QUALITY = F6.3)                                       00260
  545 FORMAT(12H FLOW AREA =3PE15.2,25H    INSIDE SURFACE AREA =0PE15.4)     00270
  550 FORMAT(35H LENGTH WHERE QUALITY EQUALS ZERO =F15.2,                    00280
     1 42H    LENGTH OVER WHICH QUALITY ABOVE ZERO =F15.2)                   00290
  555 FORMAT(24H POWER OVER SAT LENGTH =1PE10.3,17H    POWER TO BO =         00300
     1 1PE10.3,26H    POWER FROM SAT TO BO = 1PE10.3)                        00310
  560 FORMAT(20H AVG CRITICAL FLUX =1PF10.3,                                 00320
     1 25H    CRITICAL FLUX AT BO = 1PF10.3)                                00330
  565 FORMAT(F10.2)                                                          00340
  570 FORMAT(F10.1)                                                          00350
  575 FORMAT(2F20.2)                                                         00360
      READ 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS                  00370
      READ 520,PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA                         00380
      READ  525,XLNGTH,SHUNTM                                                00390
      READ 530,JLOCAT,QUALIA                                                 00400
      PRINT 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS                  00410
      PRINT 520,PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA                        00420
      RETURN                                                                 00430
      END                                                                    00440
```

```
      PRINT 525,XLNGTH,SHUNTM                                          00430
      PRINT530, JLOCAT,QUALIA                                          00440
  100 P=PRESIN                                                         00450
      CALL LIQEN                                                       00460
      DMEFX=ENEPX                                                      00470
      CALL EVAPEN                                                      00480
      DMEFGX=ENEGPX                                                    00490
      ENSIN=ENTHIN-DMEFX                                               00500
      QUALIN=ENSIN/DMEFGX                                              00510
      POWERT=VOLTS*AMPS*3.41*SHUNTM                                    00520
      AREAFL=(3.1416*DIAINS*DIAINS)/576.0                              00530
      AREAIS=(3.1416*XLNGTH*DIAINS)/144.0                              00540
      QUALOL=(-XLNGTH*ENSIN*FLMASS)/POWERT                             00550
      SATL=XLNGTH-QUALOL                                               00560
      PSATL=POWERT*(SATL/XLNGTH)                                       00570
      POWERB=POWERT*(BOLOCA/XLNGTH)                                    00580
      IF (BOLOCA-QUALOL) 750,750,755                                   00590
  755 IF (BOLOCA-(1.6*QUALOL)) 760,760,765                             00600
  750 P=PRESIN                                                         00610
      GO TO 770                                                        00620
  760 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))           00630
      GO TO 770                                                        00640
  765 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))         00650
      P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-        00660
     1 (1.60*QUALOL)))                                                 00670
  770 CALL LIQEN                                                       00680
      DMEFB=ENEPX                                                      00690
      CALL EVAPEN                                                      00700
      DMEFGB=ENEGPX                                                    00710
      ENLOB=ENTHIN+POWERB/FLMASS                                       00720
      ENSLOB=ENLOB-DMEFB                                               00730
      QUALOB=ENSLOB/DMEFGB                                             00740
  145 PSLBOL =PSATL -  (POWERT -POWERB )                               00750
  150 CFXAVG =POWERT/AREAIS                                            00760
      CFXBO=POWERT/AREAIS                                              00770
      PRINT 540,DMEFX,DMEFGX,ENSIN                                     00780
      PRINT 543, QUALIN                                                00790
      PRINT545,AREAFL,AREAIS                                           00800
      PRINT 550,QUALOL,SATL                                            00810
      PRINT 555 , PSATL, POWERB, PSLBOL                                00820
      PRINT 560,CFXAVG,CFXBO                                           00830
      PRINT 775,P,DMEFB,DMEFGB                                         00840
      PRINT 780,ENLOB,ENSLOB                                           00850
      PRINT 785,QUALOB                                                 00860
  775 FORMAT(17H PRESSURE AT BO =F6.1,25H     SAT LIQ ENTH AT BO =F8.2,  00870
     1 22H     EVAP ENTH AT BO =F8.2)                                    00880
  780 FORMAT(13H ENTH AT BO =F8.2, 27H     SUBCOOLED ENTH AT BO =F8.2)   00890
  785 FORMAT(16H QUALITY AT BO =F6.3)                                  00900
      CALL GRDMOM                                                      00910
      CALL UNIANN                                                      00920
      DO 460 K=1,JLOCAT,3                                              00930
  156 X=K-1                                                            00940
      IF(X-QUALOL)160 ,160 ,157                                        00950
  157 IF(X-(1.60*QUALOL) ) 162,162,165                                 00960
  160 P=PRESIN                                                         00970
      GO TO 167                                                        00980
  162 P=PRESIN-(0.750*TSDP*(X-QUALOL)/(XLNGTH-QUALOL))                 00990
      GO TO 167                                                        01000
  165 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL) /(XLNGTH-QUALOL))        01010
  166 P=PBREAK-((PBREAK-PRESOT)*(X-(1.60*QUALOL))/                     01020
     1 (XLNGTH-(1.60*QUALOL)))                                         01030
  167 CALL LIQEN                                                       01040
      DMEFX=ENEPX                                                      01050
      CALL EVAPEN                                                      01060
      DMEFGX=ENEGPX                                                    01070
      PRINT 565 ,X                                                     01080
      PRINT 570 ,P                                                     01090
      PRINT 575,DMEFX,DMEFGX                                           01100
  170 CFXLOX=POWERT/AREAIS                                             01110
  175 POWERX=POWERT*(X/XLNGTH)                                         01120
  180 ENLOX=ENTHIN + POWERX/FLMASS                                     01130
  185 ENSLOX=ENLOX-DMEFX                                               01140
  190 QUALOX=ENSLOX/DMEFGX                                             01150
      PRINT 700,POWERT,POWERX,CFXLOX                                   01160
      PRINT 710,ENLOX                                                  01170
      PRINT 720,ENSLOX,QUALOX                                          01180
  700 FORMAT(14H POWER TOTAL = E9.4/,                                  
     1 28H POWER INPUT TO POSITION X = E9.4/,                          
     2 18H LOCAL HEAT FLUX = E11.5)                                    01210
  710 FORMAT(31H LOCAL ENTHALPY AT POSITION X = F8.2)                  01220
  720 FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,       01230
     130H LOCAL QUALITY AT POSITION X = F6.3)                          01240
      CALL FILMER                                                      01250
  460 CONTINUE                                                         01260
      RETURN                                                           01270
      END                                                              01280
```

```
      SUBROUTINE COSINE                                                00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,          00030
     2DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,APEAFL,APEAIS,      00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOQ,ONEOVM,      00060
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9 DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ     00110
      COMMON QUALIA,GLIQ,TKINCH,                                       00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,  00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,  00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00160
     5DVISCL,REYNUM,FFACTP,FFACT,VFLOC,GPDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,  00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DRMAOA,A,FILMTK,YPLUS,  00180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       00190
  515 FORMAT (F10.0,F10.2,F10.4,4F10.1)                                00200
  520 FORMAT  (5F10.0, 1F10.2)                                         00210
  525  FORMAT (2F10.2)                                                 00220
  530 FORMAT(I5,F10.3)                                                 00230
  540  FORMAT(24H INLET LIQUID ENTHALPY = F8.2,                        00240
     1 25H    INLET EVAP ENTHALPY =F8.2, 22H    INLET SUBCOOLING =F8.2)  00250
  543 FORMAT(16H INLET QUALITY = F6.3)                                 00260
  545 FORMAT(12H FLOW AREA =3PE15.2,25H    INSIDE SURFACE AREA =0PE15.4)  00270
  550 FORMAT(35H LENGTH WHERE QUALITY EQUALS ZERO =F15.2,              00280
     1 42H    LENGTH OVER WHICH QUALITY ABOVE ZERO =F15.2)             00290
  555 FORMAT(24H POWER OVER SAT LENGTH =1PE10.3,17H    POWER TO BO =   00300
     1 1PE10.3,26H    POWER FROM SAT TO BO = 1PE10.3)                  00310
  560  FORMAT(20H AVG CRITICAL FLUX =1PF10.3,                          00320
     1 25H    CRITICAL FLUX AT BO = 1PE10.3)                          00330
  565  FORMAT(F10.2)                                                   00340
  570  FORMAT(F10.1)                                                   00350
  575  FORMAT(2F20.2)                                                  00360
      READ 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS             00370
      READ 520,PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA                   00380
```

```
      READ 525,XLNGTH,SHUNTM                                                    00390
      READ 530,JLOCAT,QUALIA                                                    00400
      PRINT 515,TUBE,PATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS                     00410
      PRINT 520,PRESP,PRESIN,PRESOT,PESDP,TSDP,BOLOCA                           00420
      PRINT 525,XLNGTH,SHUNTM                                                   00430
      PRINT 530,JLOCAT,QUALIA                                                   00440
      P=PRESIN                                                                  00450
      CALL LIQEN                                                                00460
      DMEFY=ENEPX                                                               00470
      CALL EVAPEN                                                               00480
      DMEFGY=ENEGPX                                                             00490
      ENSIN=ENTHIN-DMEFY                                                        00500
      QUALIN=ENSIN/DMEFGY                                                       00510
      POWERT=VOLTS*AMPS*3.41*SHUNTM                                             00520
      AREAFL=(3.1416*DIAINS*DIAINS)/(576.0)                                     00530
      AREAIS=(3.1416*XLNGTH*DIAINS)/144.0                                       00540
  225 POWOO= -ENSIN*FLMASS                                                      00550
  230 ONEOVM =1.0/PATIOM                                                        00560
  235 COSLEN=(1.5708*XLNGTH)/ACOSF(ONEOVM)                                      00570
  240 ONEMSQ= SQRTF(  (PATIOM**2 -1.0) / PATIOM**2 )                            00580
      IF (1.0-(2.0*POWOO/POWERT)  ) 255, 255, 245                               00590
  245 SIGNZ =ONEMSQ* (1.0-(2.0*POWOO/POWERT)  )                                 00600
      GO TO 275                                                                 00610
  255 SIGNZ= ONEMSQ*(  (2.0*POWOO/POWERT)  - 1.0 )                              00620
  260 ARG=ASINF(SIGNZ)                                                          00630
  265 Z =COSLEN*ARG /3.1416                                                     00640
  270 QUALOL=(XLNGTH/2.00)+Z                                                    00650
      GO TO 280                                                                 00660
  275 ARG=ASINF(SIGNZ)                                                          00670
  280 Z=COSLEN*ARG/3.1416                                                       00680
  285 QUALOL=(XLNGTH/2.00)-Z                                                    00690
  290 SATL=XLNGTH-QUALOL                                                        00700
  295 PSATL= POWERT -POWOO                                                      00710
      IF (BOLOCA-(XLNGTH/2.00)) 325,325,343                                     00720
  325 FACMIR=(1.0-(SINF( (3.1416*((XLNGTH/2.00)-BOLOCA) )/COSLEN)/              00730
     1ONEMSQ))                                                                00740
  335 POWERB = (POWERT*FACMIR) /2.0                                             00750
      IF (BOLOCA-QUALOL) 750,750,755                                            00760
  755 IF (BOLOCA-(1.6*QUALOL)) 760,760,765                                      00770
  760 P=PRESIN                                                                  00780
      GO TO 770                                                                 00790
  765 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))                    00800
      GO TO 770                                                                 00810
  750 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))                  00820
      P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-                 00830
     1 (1.60*QUALOL)))                                                        00840
  770 CALL LIQEN                                                                00850
      DMEFR=ENEPX                                                               00860
      CALL EVAPEN                                                               00870
      DMEFGR=ENEGPX                                                             00880
      ENLOR=ENTHIN+POWERB/FLMASS                                                00890
      ENSLOR=ENLOR-DMEFR                                                        00900
      QUALOR=ENSLOR/DMEFGR                                                      00910
  338 CFXRO=144.0*(POWERT/(2.0*DIAINS*COSLEN*ONEMSQ))*                          00920
     1COSF(3.1416*(  (XLNGTH/2.0)-BOLOCA) /COSLEN)                            00930
  340 PSLROL =POWERB -POWOO                                                     00940
      GO TO 353                                                                 00950
  343 FACPLR=(1.0+(SINF( (3.1416*(BOLOCA-(XLNGTH/2.0) ) )/COSLEN)               00960
     1/ONEMSQ ))                                                              00970
  345 POWERB =(POWERT*FACPLR) /2.0                                              00980
      IF (BOLOCA-QUALOL) 850,850,855                                            00990
  855 IF (BOLOCA-(1.6*QUALOL)) 860,860,865                                      01000
  850 P=PRESIN                                                                  01010
      GO TO 870                                                                 01020
  860 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))                    01030
      GO TO 870                                                                 01040
  865 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))                  01050
      P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-                 01060
     1 (1.60*QUALOL)))                                                        01070
  870 CALL LIQEN                                                                01080
      DMEFR=ENEPX                                                               01090
      CALL EVAPEN                                                               01100
      DMEFGB=ENEGPX                                                             01110
      ENLOB=ENTHIN+POWERB/FLMASS                                                01120
      ENSLOB=ENLOB-DMEFB                                                        01130
      QUALOB=ENSLOB/DMEFGB                                                      01140
  348 CFXBO=144.0*(POWERT/(2.0*DIAINS*COSLEN*ONEMSQ))*                          01150
     1COSF(3.1416*(BOLOCA-(XLNGTH/2.0) )/COSLEN )                             01160
  350 PSLBOL =POWERB -POWOO                                                     01170
  353 CFXAVG = POWERT / AREAIS                                                  01180
      PRINT 540,DMEFY,DMEFGY,ENSIN                                              01190
      PRINT 543, QUALIN                                                         01200
      PRINT 545, AREAFL ,AREAIS                                                 01210
      PRINT 550 ,QUALOL, SATL                                                   01220
      PRINT 555 ,PSATL, POWERB, PSLBOL                                          01230
      PRINT  560,CFXAVG,CFXBO                                                   01240
      PRINT 775,P,DMEFB,DMEFGB                                                  01250
      PRINT 780,ENLOB,ENSLOB                                                    01260
      PRINT 785,QUALOB                                                          01270
  775 FORMAT(17H PRESSURE AT BO =F6.1,25H      SAT LIQ ENTH AT BO =F8.2,        01280
     1 22H      EVAP ENTH AT BO =F8.2)                                         01290
  780 FORMAT(13H ENTH AT BO =F8.2, 27H      SUBCOOLED ENTH AT BO =F8.2)         01300
  785 FORMAT(16H QUALITY AT BO =F6.3)                                           01310
      CALL GRDMOM                                                               01320
      CALL COSANN                                                               01330
      DO 460 L=1,JLOCAT,3                                                       01340
  360 Y=L-1                                                                     01350
      IF (Y - QUALOL) 370, 370, 365                                             01360
  365 IF (Y -(1.6*QUALOL)  ) 375, 375, 380                                      01370
  370 P = PRESIN                                                                01380
      GO TO 390                                                                 01390
  375 P=PRESIN-(0.750*TSDP*(Y-QUALOL)/(XLNGTH-QUALOL) )                         01400
      GO TO 390                                                                 01410
  380 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL) )                 01420
  385 P=PBREAK-((PBREAK-PRESOT)*(Y-(1.60*QUALOL))/                              01430
     1 (XLNGTH-(1.60*QUALOL)))                                                01440
  390 CALL LIQEN                                                                01450
      DMEFY=ENEPX                                                               01460
      CALL EVAPEN                                                               01470
      DMEFGY=ENEGPX                                                             01480
      PRINT 565,Y                                                               01490
      PRINT 570, P                                                              01500
      PRINT 575,DMEFY,DMEFGY                                                    01510
      IF (Y-(XLNGTH/2.0) )400,400,428                                           01520
  400 FACTMI=(1.0-(SINF( (3.1416*( (XLNGTH/2.0)-Y) )                            01530
     1/COSLEN)) /ONEMSQ)                                                      01540
  410 POWERY =(POWERT*FACTMI) / 2.0                                             01550
  412 CFXLOY=144.0*(POWERT/(2.0*DIAINS*COSLEN*ONEMSQ))*                         01560
     1COSF(3.1416*( (XLNGTH/2.0)-Y)/COSLEN)                                   01570
  415 ENLOY = ENTHIN + (POWERT*FACTMI) / (2.0 *FLMASS)                          01580
  420 ENSLOY=ENLOY-DMEFY                                                        01590
  425 QUALOX=ENSLOY/DMEFGY                                                      01600
      GO TO 455                                                                 01610
  428 FACTPL=(1.0+(SINF( (3.1416*(Y-(XLNGTH/2.0) ) )                            01620
     1/COSLEN) )/ONEMSQ)                                                      01630
  430 POWERY = (POWERT*FACTPL) / 2.0                                            01640
  433 CFXLOY=144.0*(POWEPT/(2.0*DIAINS*COSLEN*ONEMSQ))*                         01650
     1COSF(3.1416*(Y-(XLNGTH/2.0) )/COSLEN)                                   01660
  435 ENLOY = ENTHIN + ( POWERT* FACTPL) / ( 2.0 * FLMASS)                      01670
  440 ENSLOY=ENLOY-DMEFY                                                        01680
```

```
 450 QUALOX=ENSLOY/DMEFGY                                                01690
 455 CONTINUE                                                            01700
     PRINT 700,POWERT,POWERY,CFXLOY                                      01710
     PRINT 710,ENLOY                                                     01720
     PRINT 720,ENSLOY,QUALOX                                             01730
 700 FORMAT(14H POWER TOTAL = E9.4/,
    1 28H POWER INPUT TO POSITION X = E9.4/,
    2 18H LOCAL HEAT FLUX = E11.5)                                       01760
 710 FORMAT(31H LOCAL ENTHALPY AT POSITION7X = F8.2)                     01770
 720 FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,          01780
    130H LOCAL QUALITY AT POSITION X = F6.3)                             01790
     CALL FILMER                                                         01800
 460 CONTINUE                                                            01810
     RETURN                                                              01820
     END                                                                 01830
```

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     SUBROUTINE LININC                                                   01290
     COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,   01300
    1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,             01310
    2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,       01320
    3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,          01330
    4PBREAK,POWEPX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,        01340
    5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,                 01350
    6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                   01360
    7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,               01370
    8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                         01380
    9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ        01390
     COMMON QUALIA,GLIQ,TKINCH,                                          01400
    1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,  01410
    2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,   01420
    3VOLSPG,QUALO4,POWEPA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,  01430
    4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,     01440
    5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,  01450
    6R,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,   01460
    7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC        01470
 515 FORMAT (F10.0,F10.2,F10.4,4F10.1)                                   01480
 520 FORMAT (5F10.0,1F10.2)                                              01490
 525 FORMAT (2F10.2)                                                     01500
 530 FORMAT(I5,F10.3)                                                    01510
 540 FORMAT(24H INLET LIQUID ENTHALPY = F8.2,                            01520
    1 25H    INLET EVAP ENTHALPY =F8.2, 22H    INLET SUBCOOLING =F8.2)  01530
 543 FORMAT(16H INLET QUALITY = F6.3)                                    01540
 545 FORMAT(12H FLOW AREA =3PE15.2,25H    INSIDE SURFACE AREA =0PE15.4)  01550
 550 FORMAT(35H LENGTH WHERE QUALITY EQUALS ZERO =F15.2,                 01560
    1 42H    LENGTH OVER WHICH QUALITY ABOVE ZERO =F15.2)                01570
 555 FORMAT(24H POWER OVER SAT LENGTH =1PE10.3,17H    POWER TO BO =      01580
    1 1PE10.3,26H    POWER FROM SAT TO BO = 1PE10.3)                     01590
 560 FORMAT(20H AVG CRITICAL FLUX =1PE10.3,                              01600
    1 25H    CRITICAL FLUX AT BO = 1PE10.3)                              01610
 565 FORMAT(F10.2)                                                       01620
 570 FORMAT(F10.1)                                                       01630
 575 FORMAT(2F20.2)                                                      01640
     READ 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS                01650
     READ 520,PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA                      01660
     READ 525,XLNGTH,SHUNTM                                              01670
     READ 530,JLOCAT,QUALIA                                              01680
     PRINT 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS               01690
     PRINT 520,PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA                     01700
     PRINT 525,XLNGTH,SHUNTM                                             01710
     PRINT 530,JLOCAT,QUALIA                                             01720
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```
 100 P=PRESIN                                                            01730
     CALL LIQEN                                                          01740
     DMEFX=ENEPX                                                         01750
     CALL EVAPEN                                                         01760
     DMEFGX=ENEGPX                                                       01770
     ENSIN=ENTHIN-DMEFX                                                  01780
     QUALIN=ENSIN/DMEFGX                                                 01790
     POWERT=VOLTS*AMPS*3.41*SHUNTM                                       01800
     AREAFL=(3.1416*DIAINS*DIAINS)/576.0                                 01810
     AREAIS=(3.1416*XLNGTH*DIAINS)/144.0                                 01820
     POWOO=-(ENSIN*FLMASS)                                               01830
     QUADA=(RATIOM-1.00)/(2.00*XLNGTH)                                   01840
     QUADC=-(XLNGTH*(RATIOM+1.00)*POWOO)/(2.00*POWERT)                   01850
     QUALOL=(-1.00+(ABSF(SQRTF(1.00-4.00*QUADA*QUADC))))/(2.00*QUADA)    01860
     SATL=XLNGTH-QUALOL                                                  01870
     PSATL=POWERT-POWOO                                                  01880
     POWERB=((POWERT*2.00)/(RATIOM+1.00))*((BOLOCA/XLNGTH)               01890
    1 +(BOLOCA*BOLOCA*(RATIOM-1.00))/(XLNGTH*XLNGTH*2.00))               01900
     IF (BOLOCA-QUALOL) 750,750,755                                      01910
 755 IF (BOLOCA-(1.6*QUALOL)) 760,760,765                                01920
 750 P=PRESIN                                                            01930
     GO TO 770                                                           01940
 760 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))              01950
     GO TO 770                                                           01960
 765 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))            01970
     P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-           01980
    1 (1.60*QUALOL)))                                                    01990
 770 CALL LIQEN                                                          02000
     DMEFB=ENEPX                                                         02010
     CALL EVAPEN                                                         02020
     DMEFGB=ENEGPX                                                       02030
     ENLOB=ENTHIN+POWERB/FLMASS                                          02040
     ENSLOB=ENLOB-DMEFB                                                  02050
     QUALOB=ENSLOB/DMEFGB                                                02060
     CFXBO=((2.0*POWERT)/(AREAIS*(1.00+RATIOM)))                         02070
    1 *(1.00+(BOLOCA*(RATIOM-1.00))/XLNGTH)                              02080
     PSLBOL=POWERB-POWOO                                                 02090
     CFXAVG=POWERT/AREAIS                                                02100
     PRINT 540,DMEFX,DMEFGX,ENSIN                                        02110
     PRINT 543, QUALIN                                                   02120
     PRINT545,AREAFL,AREAIS                                              02130
     PRINT 550,QUALOL,SATL                                               02140
     PRINT 555 , PSATL, POWERB, PSLBOL                                   02150
     PRINT 560,CFXAVG,CFXBO                                              02160
     PRINT 775,P,DMEFB,DMEFGB                                            02170
     PRINT 780,ENLOB,ENSLOB                                              02180
     PRINT 785,QUALOB                                                    02190
 775 FORMAT(17H PRESSURE AT BO =F6.1,25H     SAT LIQ ENTH AT BO =F8.2,   02200
    1 22H     EVAP ENTH AT BO =F8.2)                                     02210
 780 FORMAT(13H ENTH AT BO =F8.2, 27H     SUBCOOLED ENTH AT BO =F8.2)     02220
 785 FORMAT(16H QUALITY AT BO =F6.3)                                     02230
     CALL GRDMOM                                                         02240
     CALL  LNIANN                                                        02250
     DO 460 K=1,JLOCAT,3                                                 02260
 156 X=K-1                                                               02270
     IF(X-QUALOL)160 ,160 ,157                                           02280
 157 IF(X-(1.60*QUALOL) ) 162,162,165                                    02290
 160 P=PRESIN                                                            02300
     GO TO 167                                                           02310
 162 P=PRESIN-(0.750*TSDP*(X-QUALOL)/(XLNGTH-QUALOL))                    02320
     GOTO 167                                                            02330
 165 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL) /(XLNGTH-QUALOL))           02340
 166 P=PBREAK-((PBREAK-PRESOT)*(X-(1.60*QUALOL))/                        02350
    1 (XLNGTH-(1.60*QUALOL)))                                            02360
 167 CALL LIQEN                                                          02370
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      DMEFX=ENEPX                                                       02380
      CALL EVAPEN                                                       02390
      DMEFGX=ENEGPX                                                     02400
      PRINT 565 ,X                                                      02410
      PRINT 570 ,P                                                      02420
      PRINT 575,DMEFX,DMEFGX                                            02430
      CFXLOX=((2.0*POWERT)/(AREAIS*(RATIOM+1.00)))                      02440
     1 *(1.00+((X*(RATIOM-1.00))/XLNGTH))                               02450
      POWERX=((POWERT*2.00)/(RATIOM+1.00))*(X/XLNGTH+((X*X*(RATIOM-1.00)02460
     1 )/(XLNGTH*XLNGTH*2.00)))                                         02470
  180 ENLOX=ENTHIN + POWERX/FLMASS                                      02480
  185 ENSLOX=ENLOX-DMEFX                                                02490
  190 QUALOX=ENSLOX/DMEFGX                                              02500
      PRINT 700,POWERT,POWERX,CFXLOX                                    02510
      PRINT 710,ENLOX                                                   02520
      PRINT 720,ENSLOX,QUALOX                                           02530
  700 FORMAT(14H POWER TOTAL = E9.4/,                                   02540
     1 28H POWER INPUT TO POSITION X = E9.4/,                           02550
     2 18H LOCAL HEAT FLUX = E11.5)                                     02560
  710 FORMAT(31H LOCAL ENTHALPY AT POSITION7X = F8.2)                   02570
  720 FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,        02580
     130H LOCAL QUALITY AT POSITION X = F6.3)                           02590
      CALL FILMER                                                       02600
  460 CONTINUE                                                          02610
      RETURN                                                            02620
      END                                                               02630
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      SUBROUTINE LINDEC                                                 02640
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS, 02650
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           02660
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     02670
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        02680
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      02690
     5 COSLEN,ONEMSO,SIGMZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               02700
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 02710
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             02720
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       02730
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      02740
      COMMON QUALIA,GLIQ,TKINCH,                                        02750
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSURZ,SUM0,SUM1,02760
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO, 02770
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,02780
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   02790
     5DVISCL,REYNUM,FEACTP,FEACT,VELOC,GRDES,DPGMLT,GRDFT,DGRDMT,GRDTOT,02800
     6R,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS, 02810
     7TAUWAL,EYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC      02820
  515 FORMAT (F10.0,F10.2,F10.4,4F10.1)                                 02830
  520 FORMAT (6F10.2,1F10.2)                                            02840
  525 FORMAT (2F10.2)                                                   02850
  530 FORMAT(I5,F10.3)                                                  02860
  540 FORMAT(24H INLET LIQUID ENTHALPY = F8.2,                          02870
     1 25H    INLET EVAP ENTHALPY =F8.2, 22H    INLET SUBCOOLING =F8.2) 02880
  543 FORMAT(16H INLET QUALITY = F6.3)                                  02890
  545 FORMAT(12H FLOW AREA =3PE15.2,25H    INSIDE SURFACE AREA =0PE15.4) 02900
  550 FORMAT(35H LENGTH WHERE QUALITY EQUALS ZERO =F15.2,               02910
     1 42H    LENGTH OVER WHICH QUALITY ABOVE ZERO =F15.2)             02920
  555 FORMAT(24H POWER OVER SAT LENGTH =1PE10.3,17H    POWER TO BO =    02930
     1 1PE10.3,26H    POWER FROM SAT TO BO = 1PE10.3)                   02940
  560 FORMAT(20H AVG CRITICAL FLUX =1PE10.3,                            02950
     1 25H    CRITICAL FLUX AT BO = 1PE10.3)                           02960
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  565 FORMAT(F10.2)                                                     02970
  570 FORMAT(F10.1)                                                     02980
  575 FORMAT(2F20.2)                                                    02990
      READ 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS             03000
      READ 520,PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA                    03010
      READ  525,XLNGTH,SHUNTM                                           03020
      READ 530,JLOCAT,QUALIA                                            03030
      PRINT 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS             03040
      PRINT 520,PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA                   03050
      PRINT 525,XLNGTH,SHUNTM                                           03060
      PRINT 530,JLOCAT,QUALIA                                           03070
  100 P=PRESIN                                                          03080
      CALL LIQEN                                                        03090
      DMEFX=ENEPX                                                       03100
      CALL EVAPEN                                                       03110
      DMEFGX=ENEGPX                                                     03120
      ENSIN=ENTHIN-DMEFX                                                03130
      QUALIN=ENSIN/DMEFGX                                               03140
      POWERT=VOLTS*AMPS*3.41*SHUNTM                                     03150
      AREAFL=(3.1416*DIAINS*DIAINS)/576.0                               03160
      AREAIS=(3.1416*XLNGTH*DIAINS)/144.0                               03170
      POWOO=-(ENSIN*FLMASS)                                             03180
      QUADA=(RATIOM-1.00)/(2.00*XLNGTH*RATIOM)                          03190
      QUADC=(XLNGTH*(RATIOM+1.00)*POWOO)/(2.00*POWERT*RATIOM)           03200
      QUALOL=(1.00-(ABSF(SQRTF(1.00-4.00*QUADA*QUADC))))                03210
     1 /(2.00*QUADA)                                                    03220
      SATL=XLNGTH-QUALOL                                                03230
      PSATL=POWERT-POWOO                                                03240
      POWERB=((POWERT*2.00*RATIOM)/(RATIOM+1.00))*                      03250
     1((BOLOCA/XLNGTH)-(BOLOCA*BOLOCA*(RATIOM-1.00))/(XLNGTH            03260
     2*XLNGTH*2.00*RATIOM))                                             03270
      IF (BOLOCA-QUALOL) 750,750,755                                    03280
  755 IF (BOLOCA-(1.6*QUALOL)) 760,760,765                              03290
  750 P=PRESIN                                                          03300
      GO TO 770                                                         03310
  760 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))            03320
      GO TO 770                                                         03330
  765 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))          03340
      P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-         03350
     1 (1.60*QUALOL)))                                                  03360
  770 CALL LIQEN                                                        03370
      DMEFB=ENEPX                                                       03380
      CALL EVAPEN                                                       03390
      DMEFGB=ENEGPX                                                     03400
      ENLOB=ENTHIN+POWERB/FLMASS                                        03410
      ENSLOB=ENLOB-DMEFB                                                03420
      QUALOB=ENSLOB/DMEFGB                                              03430
      CFXBO=((2.0*POWERT*RATIOM)/(AREAIS*(1.00+RATIOM)))*               03440
     1 (1.00-(BOLOCA*(RATIOM-1.00))/(XLNGTH*RATIOM))                    03450
      PSLBOL=POWERB-POWOO                                               03460
      CFXAVG=POWERT/AREAIS                                              03470
      PRINT 540,DMEFX,DMEFGX,ENSIN                                      03480
      PRINT 543, QUALIN                                                 03490
      PRINT545,AREAFL,AREAIS                                            03500
      PRINT 550,QUALOL,SATL                                             03510
      PRINT 555 , PSATL, POWERB, PSLBOL                                 03520
      PRINT 560,CFXAVG,CFXBO                                            03530
      PRINT 775,P,DMEFB,DMEFGB                                          03540
      PRINT 780,ENLOB,ENSLOB                                            03550
      PRINT 785,QUALOB                                                  03560
  775 FORMAT(17H PRESSURE AT BO =F6.1,25H     SAT LIQ ENTH AT BO =F8.2, 03570
     1 22H     EVAP ENTH AT BO =F8.2)                                   03580
  780 FORMAT(13H ENTH AT BO =F8.2, 27H     SUBCOOLED ENTH AT BO =F8.2)  03590
  785 FORMAT(16H QUALITY AT BO =F6.3)                                   03600
      CALL GRDMOM                                                       03610
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      CALL LNDANN                                                       03620
      DO 460 K=1,JLOCAT,3                                               03630
  156 X=K-1                                                             03640
      IF(X-QUALOL)160 ,160 ,157                                         03650
  157 IF(X-(1.60*QUALOL) ) 162,162,165                                  03660
  160 P=PRESIN                                                          03670
      GO TO 167                                                         03680
  162 P=PRESIN-(0.750*TSDP*(X-QUALOL)/(XLNGTH-QUALOL))                  03690
      GOTO 167                                                          03700
  165 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL) /(XLNGTH-QUALOL))         03710
  166 P=PBREAK-((PBREAK-PRESAT)*(X-(1.60*QUALOL))/                      03720
     1 (XLNGTH-(1.60*QUALOL)))                                          03730
  167 CALL LIQEN                                                        03740
      DMEFX=ENEPX                                                       03750
      CALL EVAPEN                                                       03760
      DMEFGX=ENEGPX                                                     03770
      PRINT 565 ,X                                                      03780
      PRINT 570 ,P                                                      03790
      PRINT 575,DMEFX,DMEFGX                                            03800
      CFXLOX=((2.0*POWERT*RATIOM)/(AREAIS*(1.00+RATIOM)))*              03810
     1(1.00-(X*(RATIOM-1.00))/(XLNGTH*RATIOM))                          03820
      POWEPX=((POWERT*2.00*RATIOM)/(RATIOM+1.00))*((X/XLNGTH)           03830
     1-(X*X*(RATIOM-1.00))/(XLNGTH*XLNGTH*2.00*RATIOM))                 03840
  180 ENLOX=ENTHIN + POWEPX/FLMASS                                      03850
  185 ENSLOX=ENLOX-DMEFX                                                03860
  190 QUALOX=ENSLOX/DMEFGX                                              03870
      PRINT 700,POWERT,POWEPX,CFXLOX                                    03880
      PRINT 710,ENLOX                                                   03890
      PRINT 720,ENSLOX,QUALOX                                           03900
  700 FORMAT(14H POWER TOTAL = E9.4/,                                   03910
     1 28H POWER INPUT TO POSITION X = F9.4/,                           03920
     2 18H LOCAL HEAT FLUX = E11.5)                                     03930
  710 FORMAT(31H LOCAL ENTHALPY AT POSITION7X = F8.2)                   03940
  720 FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,        03950
     130H LOCAL QUALITY AT POSITION X = F6.3)                           03960
      CALL FILMER                                                       03970
  460 CONTINUE                                                          03980
      RETURN                                                            03990
      END                                                               04000
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      SUBROUTINE PKIN                                                   00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESAT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLROL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PBREAK,POWEPX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOQ,ONEOVM,      00060
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,EXTRAG,                00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIQ,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWEPA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00170
     6R,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,RMAOA,DBMAOA,A,FILMTK,YPLUS,  00180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       00190
  515 FORMAT (F10.0,F10.2,F10.4,4F10.1)                                 00210
  520 FORMAT  (5F10.0, 1F10.2)                                          00220
  525 FORMAT (2F10.2)                                                   00230
  530 FORMAT(I5,F10.3)                                                  00240
  540 FORMAT(24H INLET LIQUID ENTHALPY = F8.2,                          00250
     1 25H    INLET EVAP ENTHALPY =F8.2, 22H    INLET SUBCOOLING =F8.2)  00260
  543 FORMAT(16H INLET QUALITY = F6.3)                                  00270
  545 FORMAT(12H FLOW AREA =3PE15.2,25H    INSIDE SURFACE AREA =0PE15.4) 00280
  550 FORMAT(35H LENGTH WHERE QUALITY EQUALS ZERO =F15.2,                00290
     1 42H    LENGTH OVER WHICH QUALITY ABOVE ZERO =F15.2)              00300
  555 FORMAT(24H POWER OVER SAT LENGTH =1PE10.3,17H    POWER TO BO =     00310
     1 1PE10.3,26H    POWER FROM SAT TO BO = 1PE10.3)                   00320
  560 FORMAT(20H AVG CRITICAL FLUX =1PE10.3,                            00330
     1 25H    CRITICAL FLUX AT BO = 1PE10.3)                            00340
  565 FORMAT(F10.2)                                                     00350
  570 FORMAT(F10.1)                                                     00360
  575 FORMAT(2F20.2)                                                    00370
  580 FORMAT (3F10.2)                                                   00380
      READ 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS             00390
      READ 520,PRESP,PRESIN,PRESAT,RESDP,TSDP,BOLOCA                    00400
      READ 525,XLNGTH,SHUNTM                                            00410
      READ 530,JLOCAT,QUALIA                                            00420
      READ 580,SCRPTL,ZETA,PLNGTH                                       00430
      PRINT 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS             00440
      PRINT 520,PRESP,PRESIN,PRESAT,RESDP,TSDP,BOLOCA                   00450
      PRINT 525,XLNGTH,SHUNTM                                           00460
      PRINT 530,JLOCAT,QUALIA                                           00470
      PRINT 580,SCRPTL,ZETA,PLNGTH                                      00480
      P=PRESIN                                                          00490
      CALL LIQEN                                                        00500
      DMEFY=ENEPX                                                       00510
      CALL EVAPEN                                                       00520
      DMEFGY=ENEGPX                                                     00530
      ENSIN=ENTHIN-DMEFY                                                00540
      QUALIN=ENSIN/DMEFGY                                               00550
      POWERT=VOLTS*AMPS*3.41*SHUNTM                                     00560
      AREAFL=(3.1416*DIAINS*DIAINS)/(576.0)                             00570
      AREAIS=(3.1416*XLNGTH*DIAINS)/144.0                               00580
  225 POWOQ= -ENSIN*FLMASS                                              00590
  230 ONEOVM =1.0/RATIOM                                                00600
      COSLEN= (1.5708*PLNGTH) /ACOSF(ONEOVM)                            00610
  240 ONEMSQ= SQRTF(  (RATIOM**2 -1.0) / RATIOM**2 )                    00620
      SINABK=SINF(3.1416*(XLNGTH-SCRPTL-(.500*PLNGTH))/COSLEN)          00630
      COSABK=COSF(3.1416*(XLNGTH-SCRPTL-(.500*PLNGTH))/COSLEN)          00640
      EXTRAA=SINABK+ONEMSQ                                              00650
      EXTRAB=(SCRPTL*COSABK)/ZETA                                       00660
      CONSTP=((COSLEN*EXTRAA)/3.1416)+(EXTRAB*(1.00-EXPF(-ZETA) ) )     00670
      EXTRAC=(POWERT*COSLEN)/(3.1416*CONSTP)                            00680
      EXTRAD=1.0+(((COSLEN*EXTRAA/3.1416)-(CONSTP*POWOQ/POWERT))/EXTRAB) 00690
      EXTRAE=(144.0*POWERT)/(CONSTP*DIAINS*3.1416)                      00700
      IF (POWOQ-(EXTRAC*ONEMSQ)) 245,245,255                            00710
  245 SINZ=ONEMSQ-(POWOQ/EXTRAC)                                        00720
      ARG=ASINF(SINZ)                                                   00730
      Z=COSLEN*ARG/3.1416                                               00740
      QUALOL=(PLNGTH/2.00)-Z                                            00750
      GO TO 270                                                         00760
  255 IF (POWOQ-(EXTRAC*(ONEMSQ+SINABK))) 260,260,265                   00770
  260 SINZ= -(ONEMSQ-(POWOQ/EXTRAC))                                    00780
      ARG=ASINF(SINZ)                                                   00790
      Z=COSLEN*ARG/3.1416                                               00800
      QUALOL=(PLNGTH/2.00)+Z                                            00810
      GO TO 270                                                         00820
  265 U=(-SCRPTL/ZETA)*LOGF(EXTRAD)                                     00830
      QUALOL=XLNGTH-SCRPTL+U                                            00840
  270 SATL=XLNGTH-QUALOL                                                00850
      PSATL=POWERT-POWOQ                                                00860
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      IF (BOLOCA-(PLNGTH/2.00)) 275,275,280                              00870
  275 POWERB=EXTRAC*(ONEMSQ-SINF(3.1416*((PLNGTH/2.00)-                  00880
     1BOLOCA)/COSLEN))                                                   00890
      IF (BOLOCA-QUALOL) 750,750,755                                     00900
  755 IF (BOLOCA-(1.6*QUALOL)) 760,760,765                               00910
  750 P=PRESIN                                                           00920
      GO TO 770                                                          00930
  760 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))             00940
      GO TO 770                                                          00950
  765 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))           00960
      P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-          00970
     1 (1.60*QUALOL)))                                                   00980
  770 CALL LIQEN                                                         00990
      DMEFB=ENEPX                                                        01000
      CALL EVAPEN                                                        01010
      DMEFGB=ENEGPX                                                      01020
      ENLOB=ENTHIN+POWERB/FLMASS                                         01030
      ENSLOB=ENLOB-DMEFB                                                 01040
      QUALOB=ENSLOB/DMEFGB                                               01050
      CFXBO =EXTRAE*COSF(3.1416*((PLNGTH/2.00)-                          01060
     1BOLOCA)/COSLEN)                                                    01070
      GO TO 350                                                          01080
  280 IF (BOLOCA-(XLNGTH-SCRPTL)) 285,285,290                            01090
  285 POWERB=EXTRAC*(ONEMSQ+SINF(3.1416*(                                01100
     1BOLOCA-(PLNGTH/2.00))/COSLEN)   )                                  01110
      IF (BOLOCA-QUALOL) 850,850,855                                     01120
  855 IF (BOLOCA-(1.6*QUALOL)) 860,860,865                               01130
  850 P=PRESIN                                                           01140
      GO TO 870                                                          01150
  860 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))             01160
      GO TO 870                                                          01170
  865 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))           01180
      P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-          01190
     1 (1.60*QUALOL)))                                                   01200
  870 CALL LIQEN                                                         01210
      DMEFB=ENEPX                                                        01220
      CALL EVAPEN                                                        01230
      DMEFGB=ENEGPX                                                      01240
      ENLOB=ENTHIN+POWERB/FLMASS                                         01250
      ENSLOB=ENLOB-DMEFB                                                 01260
      QUALOB=ENSLOB/DMEFGB                                               01270
      CFXBO =EXTRAE*COSF(3.1416*(                                        01280
     1BOLOCA-(PLNGTH/2.00))/COSLEN)                                      01290
      GO TO 350                                                          01300
  290 POWERB=(POWERT/CONSTP)*((COSLEN*EXTRAA/3.1416)+EXTRAB*(1.00-       01310
     1EXPF( (-ZETA)*(BOLOCA-(XLNGTH-SCRPTL))/SCRPTL)))                   01320
      IF (BOLOCA-QUALOL) 950,950,955                                     01330
  955 IF (BOLOCA-(1.6*QUALOL)) 960,960,965                               01340
  950 P=PRESIN                                                           01350
      GO TO 970                                                          01360
  960 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))             01370
      GO TO 970                                                          01380
  965 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))           01390
      P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-          01400
     1 (1.60*QUALOL)))                                                   01410
  970 CALL LIQEN                                                         01420
      DMEFB=ENEPX                                                        01430
      CALL EVAPEN                                                        01440
      DMEFGB=ENEGPX                                                      01450
      ENLOB=ENTHIN+POWERB/FLMASS                                         01460
      ENSLOB=ENLOB-DMEFB                                                 01470
      QUALOB=ENSLOB/DMEFGB                                               01480
      CFXBO =EXTRAE*COSABK* EXPF( (-ZETA)*(                              01490
     1 BOLOCA-(XLNGTH-SCRPTL))/SCRPTL)                                   01500
  350 PSLBOL =POWERB -POWOO                                              01510
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      CFXAVG = POWERT / AREAIS                                           01520
      PRINT 540,DMEFY,DMEFGY,ENSIN                                       01530
      PRINT 543, QUALIN                                                  01540
      PRINT 545, AREAFL ,AREAIS                                          01550
      PRINT 550 ,QUALOL, SATL                                            01560
      PRINT 555 ,PSATL, POWERB, PSLBOL                                   01570
      PRINT  560,CFXAVG,CFXBO                                            01580
      PRINT 775,P,DMEFB,DMEFGB                                           01590
      PRINT 780,ENLOB,ENSLOB                                             01600
      PRINT 785,QUALOB                                                   01610
  775 FORMAT(17H PRESSURE AT BO =F6.1,25H     SAT LIQ ENTH AT BO =F8.2,  01620
     1 22H     EVAP ENTH AT BO =F8.2)                                    01630
  780 FORMAT(13H ENTH AT BO =F8.2, 27H     SUBCOOLED ENTH AT BO =F8.2)   01640
  785 FORMAT(16H QUALITY AT BO =F6.3)                                    01650
      CALL GRDMOM                                                        01660
      CALL PKIANN                                                        01670
      DO 460 L=1,JLOCAT,2                                                01680
  360 Y=L-1                                                              01690
      IF (Y - QUALOL) 370, 370, 365                                      01700
  365 IF (Y -(1.6*QUALOL)  ) 375, 375, 380                               01710
  370 P = PRESIN                                                         01720
      GO TO 390                                                          01730
  375 P=PRESIN-(0.750*TSDP*(Y-QUALOL)/(XLNGTH-QUALOL) )                  01740
      GO TO 390                                                          01750
  380 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL) )          01760
  385 P=PBREAK-((PBREAK-PRESOT)*(Y-(1.60*QUALOL))/                       01770
     1 (XLNGTH-(1.60*QUALOL)))                                           01780
  390 CALL LIQEN                                                         01790
      DMEFY=ENEPX                                                        01800
      CALL EVAPEN                                                        01810
      DMEFGY=ENEGPX                                                      01820
      PRINT 565,Y                                                        01830
      PRINT 570, P                                                       01840
      PRINT 575,DMEFY,DMEFGY                                             01850
      IF (Y-(PLNGTH/2.0)) 400,400,410                                    01860
  400 POWERY=EXTRAC*(ONEMSQ-SINF(3.1416*((PLNGTH/2.00)-                  01870
     1Y      )/COSLEN)  )                                                01880
      CFXLOY=EXTRAE*COSF(3.1416*((PLNGTH/2.00)-                          01890
     1Y      )/COSLEN)                                                   01900
      GO TO 435                                                          01910
  410 IF (Y-(XLNGTH-SCRPTL)) 415,415,425                                 01920
  415 POWERY=EXTRAC*(ONEMSQ+SINF(3.1416*(                                01930
     1Y      -(PLNGTH/2.00))/COSLEN)   )                                 01940
      CFXLOY=EXTRAE*COSF(3.1416*(                                        01950
     1Y      -(PLNGTH/2.00))/COSLEN)                                     01960
      GO TO 435                                                          01970
  425 POWERY=(POWERT/CONSTP)*((COSLEN*EXTRAA/3.1416)+EXTRAB*(1.00-       01980
     1EXPF( (-ZETA)*(Y      -(XLNGTH-SCRPTL))/SCRPTL)))                 01990
      CFXLOY=EXTRAE*COSABK* EXPF( (-ZETA)*(                              02000
     1Y      -(XLNGTH-SCRPTL))/SCRPTL)                                   02010
  435 ENLOY=ENTHIN+(POWERY/FLMASS)                                       02020
  440 ENSLOY=ENLOY-DMEFY                                                 02030
  450 QUALOX=ENSLOY/DMEFGY                                               02040
  455 CONTINUE                                                           02050
      PRINT 700,POWERT,POWERY,CFXLOY                                     02060
      PRINT 710,ENLOY                                                    02070
      PRINT 720,ENSLOY,QUALOX                                            02080
  700 FORMAT(14H POWER TOTAL = E9.4/,                                    02090
     1 28H POWER INPUT TO POSITION X = E9.4/,                            02100
     2 18H LOCAL HEAT FLUX = E11.5)                                      02110
  710 FORMAT(31H LOCAL ENTHALPY AT POSITION X = F8.2)                    02120
  720 FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,         02130
     130H LOCAL QUALITY AT POSITION X = F6.3)                            02140
      CALL FILMFR                                                        02150
  460 CONTINUE                                                           02160
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      RETURN                                                            02170
      END                                                               02180
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      SUBROUTINE PKOUT                                                  00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESD,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,APEAIS,     00040
     3 QUALOL,SATL,PSATL,POWERR,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
     5 COSLEN,ONEMSO,SIGNZ,ARG,Z,FACMIR,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIQ,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUMO,SUM1,00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO, 00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,00170
     6R,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS, 00180
     7TAUVAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC      00190
  515 FORMAT (F10.3,F10.2,F10.4,4F10.1)                                 00210
  520 FORMAT  (5F10.0, 1F10.2)                                          00220
  525 FORMAT (2F10.2)                                                   00230
  530 FORMAT(I5,F10.3)                                                  00240
  540 FORMAT(24H INLET LIQUID ENTHALPY = F8.2,                          00250
     1 25H    INLET EVAP ENTHALPY =F8.2, 22H     INLET SUBCOOLING =F8.2)  00260
  543 FORMAT(16H INLET QUALITY = F6.3)                                  00270
  545 FORMAT(12H FLOW AREA =3PE15.2,25H     INSIDE SURFACE AREA =0PE15.4)  00280
  550 FORMAT(35H LENGTH WHERE QUALITY EQUALS ZERO =F15.2,               00290
     1 43H    LENGTH OVER WHICH QUALITY ABOVE ZERO =F15.2)              00300
  555 FORMAT(24H POWER OVER SAT LENGTH =1PE10.3,17H     POWER TO BO =   00310
     1 1PE10.3,26H     POWER FROM SAT TO BO = 1PE10.3)                  00320
  560 FORMAT(20H AVG CRITICAL FLUX =1PF10.3,                            00330
     1 25H    CRITICAL FLUX AT BO = 1PF10.3)                           00340
  565 FORMAT(F10.2)                                                     00350
  570 FORMAT(F10.1)                                                     00360
  575 FORMAT(2F20.2)                                                    00370
  580 FORMAT (3F10.2)                                                   00380
      READ 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS             00390
      READ 520,PRESD,PRESIN,PRESOT,RESDP,TSDP,BOLOCA                    00400
      READ 525,XLNGTH,SHUNTM                                            00410
      READ 530,JLOCAT,QUALIA                                            00420
      READ 580,SCRPTL,ZETA,PLNGTH                                       00430
      PRINT 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS             00440
      PRINT 520,PRESD,PRESIN,PRESOT,RESDP,TSDP,BOLOCA                   00450
      PRINT 525,XLNGTH,SHUNTM                                           00460
      PRINT 530,JLOCAT,QUALIA                                           00470
      PRINT 580,SCRPTL,ZETA,PLNGTH                                      00480
      P=PRESIN                                                          00490
      CALL LIQEN                                                        00500
      DMEFY=ENEPX                                                       00510
      CALL EVAPEN                                                       00520
      DMEFGY=ENEGPX                                                     00530
      ENSIN=ENTHIN-DMEFY                                                00540
      QUALIN=ENSIN/DMEFGY                                               00550
      POWERT=VOLTS*AMPS*3.41*SHUNTM                                     00560
      AREAFL=(3.1416*DIAINS*DIAINS)/(576.0)                             00570
      APEAIS=(3.1416*XLNGTH*DIAINS)/144.0                               00580
  225 POWOO= -ENSIN*FLMASS                                              00590
  230 ONEOVM =1.0/RATIOM                                                00600
      COSLEN= (1.5708*PLNGTH) /ACOSF(ONEOVM)                            00610
  240 ONEMSO= SQRTF(  (RATIOM**2 -1.0) / RATIOM**2 )                    00620
      SINABK=SINF(3.1416*(XLNGTH-SCRPTL-(.500*PLNGTH))/COSLEN)          00630
      COSABK=COSF(3.1416*(XLNGTH-SCRPTL-(.500*PLNGTH))/COSLEN)          00640
      EXTRAA=SINABK+ONEMSO                                              00650
      EXTRAB=(SCRPTL*COSABK)/ZETA                                       00660
      CONSTP=((COSLEN*EXTRAA)/3.1416)+(EXTRAB*(1.00-EXPF(-ZETA) ) )     00670
      EXTRAF=(144.0*POWERT)/(CONSTP*DIAINS*3.1416)                      00680
      ULOCAT=1.00-EXPF(-ZETA)                                           00690
      EXTRAF=(POWERT*COSABK*SCRPTL)/(CONSTP*ZETA)                       00700
      IF (POWOO-(EXTRAF*ULOCAT)) 245,245,255                            00710
  245 U=SCRPTL+(SCRPTL/ZETA)*LOGF((POWOO/EXTRAF)+EXPF(-ZETA))           00720
      QUALOL=U                                                          00730
      GO TO 270                                                         00740
  255 IF (POWOO-((POWERT/CONSTP)*((EXTRAB*ULOCAT)+(COSLEN*SINABK/       00750
     13.1416)))) 260,260,265                                            00760
  260 SINZ= SINABK +((3.1416/COSLEN)*((EXTRAB*ULOCAT) - (CONSTP*POWOO/  00770
     1POWERT))  )                                                       00780
      ARG=ASINF(SINZ)                                                   00790
      Z=COSLEN*ARG/3.1416                                               00800
      QUALOL=XLNGTH-(PLNGTH/2.00)-Z                                     00810
      GO TO 270                                                         00820
  265 SINZ=-SINABK -((3.1416/COSLEN)*((EXTRAB*ULOCAT) - (CONSTP*POWOO/  00830
     1POWERT))  )                                                       00840
      ARG=ASINF(SINZ)                                                   00850
      Z=COSLEN*ARG/3.1416                                               00860
      QUALOL=XLNGTH-(PLNGTH/2.00)+Z                                     00870
  270 SATL=XLNGTH-QUALOL                                                00880
      PSATL=POWERT-POWOO                                                00890
      IF (BOLOCA-SCRPTL) 275,275,280                                    00900
  275 POWERR=EXTRAF*(EXPF(ZETA*(                                        00910
     1BOLOCA-SCRPTL)/SCRPTL)-EXPF(-ZETA))                               00920
      IF (BOLOCA-QUALOL) 750,750,755                                    00930
  755 IF (BOLOCA-(1.6*QUALOL)) 760,760,765                              00940
  750 P=PRESIN                                                          00950
      GO TO 770                                                         00960
  760 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))            00970
      GO TO 770                                                         00980
  765 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))          00990
      P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-         01000
     1 (1.60*QUALOL)))                                                  01010
  770 CALL LIQEN                                                        01020
      DMEFB=ENEPX                                                       01030
      CALL EVAPEN                                                       01040
      DMEFGB=ENEGPX                                                     01050
      ENLOB=ENTHIN+POWERR/FLMASS                                        01060
      ENSLOB=ENLOB-DMEFB                                                01070
      QUALOB=ENSLOB/DMEFGB                                              01080
      CFXBO=EXTRAF*COSABK*(EXPF(ZETA*(                                  01090
     1BOLOCA-SCRPTL)/SCRPTL))                                           01100
      GO TO 350                                                         01110
  280 IF (BOLOCA-(XLNGTH-(PLNGTH/2.00))) 285,285,290                    01120
  285 POWERR= (POWERT/CONSTP)*((EXTRAB*ULOCAT) + ((COSLEN/3.1416)*(     01130
     1SINABK-SINF((3.1416/COSLEN)*(XLNGTH-(PLNGTH/2.00)-BOLOCA) ) ) ) ) 01140
      IF (BOLOCA-QUALOL) 850,850,855                                    01150
  855 IF (BOLOCA-(1.6*QUALOL)) 860,860,865                              01160
  850 P=PRESIN                                                          01170
      GO TO 870                                                         01180
  860 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))            01190
      GO TO 870                                                         01200
  865 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))          01210
      P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))                  01220
     1 /(XLNGTH-(1.60*QUALOL)))                                         01230
```

```
870 CALL LIQEN                                                          01240
    DMEFB=ENEPX                                                         01250
    CALL EVAPEN                                                         01260
    DMEFGB=ENEGPX                                                       01270
    ENLOB=ENTHIN+POWEPB/FLMASS                                          01280
    ENSLOB=ENLOB-DMEFB                                                  01290
    QUALOB=ENSLOB/DMEFGB                                                01300
    CEXBO =EXTRAE*COSF((3.1416/COSLEN)*(XLNGTH-(PLNGTH/2.00)-BOLOCA))   01310
    GO TO 350                                                           01320
290 POWEPB= (POWERT/CONSTP)*((EXTRAB*ULOCAT) + ((COSLEN/3.1416)*(       01330
   1SINABK+SINF((3.1416/COSLEN)*(BOLOCA-(XLNGTH-(PLNGTH/2.00) ) ) ))    01340
   2 ))                                                                 01350
    IF (BOLOCA-QUALOL) 950,950,955                                      01360
955 IF (BOLOCA-(1.6*QUALOL)) 960,960,965                                01370
950 P=PRESIN                                                            01380
    GO TO 970                                                           01390
960 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))              01400
    GO TO 970                                                           01410
965 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))            01420
    P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-           01430
   1 (1.60*QUALOL)))                                                    01440
970 CALL LIQEN                                                          01450
    DMEFB=ENEPX                                                         01460
    CALL EVAPEN                                                         01470
    DMEFGB=ENEGPX                                                       01480
    ENLOB=ENTHIN+POWEPB/FLMASS                                          01490
    ENSLOB=ENLOB-DMEFB                                                  01500
    QUALOB=ENSLOB/DMEFGB                                                01510
    CEXBO =EXTRAE*COSF((3.1416/COSLEN)*(BOLOCA-(XLNGTH-(PLNGTH/2.00) )  01520
   1 ) )                                                                01530
350 PSLBOL =POWEPB -POWOO                                               01540
353 CEXAVG = POWERT / AREAIS                                            01550
    PRINT 540,DMEFY,DMEFGY,ENSIN                                        01560
    PRINT 543, QUALIN                                                   01570
    PRINT 545, AREAFL ,AREAIS                                           01580
    PRINT 550 ,QUALOL, SATL                                             01590
    PRINT 555 ,PSATL, POWEPB, PSLBOL                                    01600
    PRINT  560,CEXAVG,CEXBO                                             01610
    PRINT 775,P,DMEFB,DMEFGB                                            01620
    PRINT 780,ENLOB,ENSLOB                                              01630
    PRINT 785,QUALOB                                                    01640
775 FORMAT(17H PRESSURE AT BO =F6.1,25H      SAT LIQ ENTH AT BO =F8.2,  01650
   1 22H     EVAP ENTH AT BO =F8.2)                                     01660
780 FORMAT(13H ENTH AT BO =F8.2, 27H      SUBCOOLED ENTH AT BO =F8.2)   01670
785 FORMAT(16H QUALITY AT BO =F6.3)                                     01680
    CALL GROMM                                                          01690
    CALL PKOANN                                                         01700
    DO 460 L=1,JLOCAT,2                                                 01710
360 Y=L-1                                                               01720
    IF (Y - QUALOL) 370, 370, 365                                       01730
365 IF (Y -(1.60*QUALOL)  ) 375, 375, 380                               01740
370 P = PRESIN                                                          01750
    GO TO 390                                                           01760
375 P=PRESIN-(0.750*TSDP*(Y-QUALOL)/(XLNGTH-QUALOL) )                   01770
    GO TO 390                                                           01780
380 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL) )           01790
385 P=PBREAK-((PBREAK-PRESOT)*(Y-(1.60*QUALOL))/                        01800
   1 (XLNGTH-(1.60*QUALOL)))                                            01810
390 CALL LIQEN                                                          01820
    DMEFY=ENEPX                                                         01830
    CALL EVAPEN                                                         01840
    DMEFGY=ENEGPX                                                       01850
    PRINT 565,Y                                                         01860
    PRINT 570, P                                                        01870
    PRINT 575,DMEFY,DMEFGY                                              01880
    IF (Y-SCRPTL) 400,400,410                                           01890
400 POWERY=EXTRAF*(EXPF(ZETA*(                                          01900
   1Y      -SCRPTL)/SCRPTL)-EXPF(-ZETA))                                01910
    CEXLOY=EXTRAF*COSARK*(EXPF(ZETA*(                                   01920
   1Y      -SCRPTL)/SCRPTL))                                            01930
    GO TO 435                                                           01940
410 IF (Y-(XLNGTH-(PLNGTH/2.00))) 415,415,425                           01950
415 POWERY= (POWERT/CONSTP)*((EXTRAB*ULOCAT) + ((COSLEN/3.1416)*(       01960
   1SINABK-SINF((3.1416/COSLEN)*(XLNGTH-(PLNGTH/2.00)-Y      ) ) ) ) )  01970
    CEXLOY=EXTRAF*COSF((3.1416/COSLEN)*(XLNGTH-(PLNGTH/2.00)-Y      ))  01980
    GO TO 435                                                           01990
425 POWERY= (POWERT/CONSTP)*((EXTRAB*ULOCAT) + ((COSLEN/3.1416)*(       02000
   1SINABK+SINF((3.1416/COSLEN)*(Y      -(XLNGTH-(PLNGTH/2.00) ) ) ))   02010
   2 ))                                                                 02020
    CEXLOY=EXTRAF*COSF((3.1416/COSLEN)*(Y      -(XLNGTH-(PLNGTH/2.00) ) 02030
   1 ) )                                                                02040
435 ENLOY=ENTHIN+(POWERY/FLMASS)                                        02050
440 ENSLOY=ENLOY-DMEFY                                                  02060
450 QUALOX=ENSLOY/DMEFGY                                                02070
455 CONTINUE                                                            02080
    PRINT 700,POWERT,POWERY,CEXLOY                                      02090
    PRINT 710,ENLOY                                                     02100
    PRINT 720,ENSLOY,QUALOX                                             02110
700 FORMAT(14H POWER TOTAL = F9.4/,                                     
   1 28H POWER INPUT TO POSITION X = E9.4/,                             
   2 18H LOCAL HEAT FLUX = E11.5)                                       02140
710 FORMAT(31H LOCAL ENTHALPY AT POSITION7X = F8.2)                     02150
720 FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,          02160
   130H LOCAL QUALITY AT POSITION X = F6.3)                             02170
    CALL FILMER                                                         02180
460 CONTINUE                                                            02190
    RETURN                                                              02200
    END                                                                 02210
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      SUBROUTINE   SPKCOS
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,            00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,      00040
     3 QUALOL,SATL,PSATL,POWEPB,PSLBOL,CEXAVG,CEXLOX,JLOCAT,K,X,         00050
     4PBREAK,POWEPX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,DNEQVM,      00060
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CEXBO,L,Y,               00070
     6 FACTMT,POWERY,CEXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIQ,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,FNO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DFNFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       00190
      COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                 00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,        00210
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,             00220
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                             00230
 515 FORMAT (F10.0,F10.2,F10.4,4F10.1)                                  00240
 520 FORMAT  (5F10.0, 1F10.2)                                           00250
 525 FORMAT (2F10.2)                                                    00260
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530 FORMAT(I5,F10.3)                                                    00270
535 FORMAT(I5)                                                          00280
540  FORMAT(24H INLET LIQUID ENTHALPY = F8.2,                           00290
   1 25H    INLET EVAP ENTHALPY =F8.2, 22H    INLET SUBCOOLING =F8.2)  00300
543 FORMAT(16H INLET QUALITY = F6.3)                                    00310
545 FORMAT(12H FLOW AREA =3PE15.2,25H    INSIDE SURFACE AREA =0PE15.4)  00320
550 FORMAT(35H LENGTH WHERE QUALITY EQUALS ZERO =F15.2,                 00330
   1 42H    LENGTH OVER WHICH QUALITY ABOVE ZERO =F15.2)                00340
555 FORMAT(24H POWER OVER SAT LENGTH =1PE10.3,17H    POWER TO BO =      00350
   1 1PE10.3,26H    POWER FROM SAT TO BO = 1PE10.3)                     00360
560  FORMAT(20H AVG CRITICAL FLUX =1PE10.3,                             00370
   1 25H    CRITICAL FLUX AT BO = 1PE10.3)                             00380
565  FORMAT(E10.2)                                                      00390
570  FORMAT(E10.1)                                                      00400
575  FORMAT(2E20.2)                                                     00410
580  FORMAT (3E10.2)                                                    00420
     READ 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS              00430
     READ 520,PRESP,PRESIN,PRESOT,PESDP,TSDP,BOLOCA                     00440
     READ 525,XLNGTH,SHUNTM                                             00450
     READ 530,ULOCAT,QUALIA                                             00460
     READ 580,SCRPTL,ZETA,PLNGTH                                        00470
     READ 535,J                                                         00480
     PRINT 515,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS              00490
     PRINT 520,PRESP,PRESIN,PRESOT,PESDP,TSDP,BOLOCA                    00500
     PRINT 525,XLNGTH,SHUNTM                                            00510
     PRINT 530, ULOCAT,QUALIA                                           00520
     PRINT 580,SCRPTL,ZETA,PLNGTH                                       00530
     PRINT 535,J                                                        00540
     P=PRESIN                                                           00550
     CALL LIQEN                                                         00560
     DMEFF=ENFPX                                                        00570
     CALL EVAPEN                                                        00580
     DMEFGY=ENFGPX                                                      00590
     ENSIN=ENTHIN-DMEFF                                                 00600
     QUALIN=ENSIN/DMEFGY                                                00610
     POWERT=VOLTS*AMPS*3.41*SHUNTM                                      00620
     AREAFL=(3.1416*DIAINS*DIAINS)/(576.0)                              00630
     AREAIS=(3.1416*XLNGTH*DIAINS)/144.0                                00640
225  POWOO= -ENSIN*FLMASS                                               00650
230  ONEOVM =1.0/RATIOM                                                 00660
     COSLEN= (1.570*PLNGTH) /ACOSF(ONEOVM)                              00670
240  ONEMSQ= SQRTF(  (RATIOM**2 -1.0) / RATIOM**2 )                     00680
     CONSTP=  ((XLNGTH-PLNGTH)/RATIOM)+(2.0*COSLEN*ONEMSQ/              00690
    1  3.1416)                                                         00700
     EXTRAA=POWERT/(RATIOM*CONSTP)                                      00710
     EXTRAB=POWERT*COSLEN/(CONSTP*3.1416)                               00720
     ULOCAT=XLNGTH-SCRPTL+(PLNGTH/2.0)                                  00730
     EXTRAE=(144.0*POWERT)/(CONSTP*DIAINS*3.1416)                       00740
      IF(POWOO-(EXTRAA*(XLNGTH-SCRPTL)))  245,245,255                   00750
245  Z=ULOCAT-(POWOO/EXTRAA)                                            00760
     QUALOL=ULOCAT-Z                                                    00770
     GO TO 270                                                          00780
255  IF(POWOO-((EXTRAA*(XLNGTH-SCRPTL))+(EXTRAB*ONEMSQ                 00790
    1  )))   260,260,265                                               00800
260  SINZ=-((POWOO-(EXTRAA*(XLNGTH-SCRPTL)))/EXTRAB)+ONEMSQ             00810
     ARG=ASINF(SINZ)                                                    00820
     Z=COSLEN*ARG/3.1416                                                00830
     QUALOL=ULOCAT-Z                                                    00840
     GO TO 270                                                          00850
265  IF(POWOO-((EXTRAA*(XLNGTH-SCRPTL))+(EXTRAB*ONEMSQ                 00860
    1  *2.0)))  266,266,268                                            00870
266  SINZ=+((POWOO-(EXTRAA*(XLNGTH-SCRPTL)))/EXTRAB)-ONEMSQ             00880
     ARG=ASINF(SINZ)                                                    00890
     Z=COSLEN*ARG/3.1416                                                00900
     QUALOL=ULOCAT+Z                                                    00910
     GO TO 270                                                          00920
268  Z=ULOCAT+((POWOO-(EXTRAB*2.0*ONEMSQ))/EXTRAA)                      00930
     QUALOL=ULOCAT+Z                                                    00940
270  SATL=XLNGTH-QUALOL                                                 00950
     PSATL=POWERT-POWOO                                                 00960
     IF (BOLOCA -(XLNGTH-SCRPTL))  275,275,280                          00970
275  POWERB=EXTRAA*BOLOCA                                               00980
     IF (BOLOCA-QUALOL) 750,750,755                                     00990
755  IF (BOLOCA-(1.6*QUALOL)) 760,760,765                               01000
750  P=PRESIN                                                           01010
     GO TO 770                                                          01020
760  P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))             01030
     GO TO 770                                                          01040
765  PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))           01050
     P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-          01060
    1 (1.60*QUALOL)))                                                   01070
770  CALL LIQEN                                                         01080
     DMEFB=ENFPX                                                        01090
     CALL EVAPEN                                                        01100
     DMEFGB=ENFGPX                                                      01110
     ENLOB=ENTHIN+POWERB/FLMASS                                         01120
     ENSLOB=ENLOB-DMEFB                                                 01130
     QUALOB=ENSLOB/DMEFGB                                               01140
     CEXBO=EXTRAE/RATIOM                                                01150
     GO TO 350                                                          01160
280  IF (BOLOCA-ULOCAT)  285,285,290                                    01170
285  POWERB= (EXTRAA*(XLNGTH-SCRPTL))+                                  01180
    1 (EXTRAB*(ONEMSQ-SINF(3.1416*(ULOCAT-BOLOCA)/COSLEN)))             01190
     IF (BOLOCA-QUALOL) 850,850,855                                     01200
855  IF (BOLOCA-(1.6*QUALOL)) 860,860,865                               01210
850  P=PRESIN                                                           01220
     GO TO 870                                                          01230
860  P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))             01240
     GO TO 870                                                          01250
865  PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))           01260
     P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL)))                  01270
    1 /(XLNGTH-(1.60*QUALOL)))                                          01280
870  CALL LIQEN                                                         01290
     DMEFB=ENFPX                                                        01300
     CALL EVAPEN                                                        01310
     DMEFGB=ENFGPX                                                      01320
     ENLOB=ENTHIN+POWERB/FLMASS                                         01330
     ENSLOB=ENLOB-DMEFB                                                 01340
     QUALOB=ENSLOB/DMEFGB                                               01350
     CEXBO =EXTRAE*COSF(3.1416*(ULOCAT-BOLOCA)/COSLEN)                  01360
     GO TO 350                                                          01370
290  IF(BOLOCA-(ULOCAT+(PLNGTH/2.0)))  295,295,300                      01380
295  POWERB= (EXTRAA*(XLNGTH-SCRPTL))+                                  01390
    1(EXTRAB*(ONEMSQ+SINF(3.1416*(BOLOCA-ULOCAT)/COSLEN)))              01400
     IF (BOLOCA-QUALOL) 950,950,955                                     01410
955  IF (BOLOCA-(1.6*QUALOL)) 960,960,965                               01420
950  P=PRESIN                                                           01430
     GO TO 970                                                          01440
960  P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))             01450
     GO TO 970                                                          01460
965  PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))           01470
     P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL)))/(XLNGTH-         01480
    1 (1.60*QUALOL)))                                                   01490
970  CALL LIQEN                                                         01500
     DMEFB=ENFPX                                                        01510
     CALL EVAPEN                                                        01520
     DMEFGB=ENFGPX                                                      01530
     ENLOB=ENTHIN+POWERB/FLMASS                                         01540
     ENSLOB=ENLOB-DMEFB                                                 01550
     QUALOB=ENSLOB/DMEFGB                                               01560
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      CFXBO =FXTRAF*COSF(3.1416*(BOLOCA-ULOCAT)/COSLEN)                 01570
      GO TO 350                                                         01580
  300 POWERB=EXTRAA*(BOLOCA-PLNGTH)+(EXTRAB*2.0*ONEMSQ)                 01590
      IF (BOLOCA-QUALOL)   305,305,310                                  01600
  310 IF (BOLOCA-(1.6*QUALOL)) 315,315,320                              01610
  305 P=PRESIN                                                          01620
      GO TO 325                                                         01630
  315 P=PRESIN- (0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))            01640
      GO TO 325                                                         01650
  320 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))          01660
      P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-         01670
     1 (1.60*QUALOL)))                                                  01680
  325  CALL LIQEN                                                       01690
      DMEFB=ENEPX                                                       01700
      CALL EVAPEN                                                       01710
      DMEFGB=ENEGPX                                                     01720
      ENLOB=ENTHIN+POWERB/FLMASS                                        01730
      ENSLOB=ENLOB-DMEFB                                                01740
      QUALOB=ENSLOB/DMEFGB                                              01750
      CFXBO=EXTRAF/RATIOM                                               01760
  350 PSLBOL =POWERB -POWOO                                             01770
  353 CFXAVG = POWERT / AREAIS                                          01780
      PRINT 540,DMEFY,DMEFGY,ENSIN                                      01790
      PRINT 543, QUALIN                                                 01800
      PRINT 545, AREAFL ,AREAIS                                         01810
      PRINT 550 ,QUALOL, SATL                                           01820
      PRINT 555 ,PSATL, POWERB, PSLBOL                                  01830
      PRINT  560,CFXAVG,CFXBO                                           01840
      PRINT 775,P,DMEFB,DMEFGB                                          01850
      PRINT 780,ENLOB,ENSLOB                                            01860
      PRINT 785,QUALOB                                                  01870
  775 FORMAT(17H PRESSURE AT BO =F6.1,25H     SAT LIQ ENTH AT BO =F8.2,  01880
     1 22H     EVAP ENTH AT BO =F8.2)                                   01890
  780 FORMAT(13H ENTH AT BO =F8.2, 27H     SUBCOOLED ENTH AT BO =F8.2)   01900
  785 FORMAT(16H QUALITY AT BO =F6.3)                                   01910
      CALL GRDMOM                                                       01920
          CALL SPKANN                                                   01930
      DO 460 L=1,JLOCAT,3                                               01940
  360 Y=L-1                                                             01950
  363 IF(Y-(XLNGTH-SCRPTL)) 362,359,359                                 01960
  359 IF(N) 364,364,361                                                 01965
  361 IF(Y-(XLNGTH-SCRPTL+PLNGTH)) 460,460,362                          01970
  364 CALL CSPIKE                                                       01980
      GO TO 460                                                         01985
  362 IF (Y-QUALOL) 370,370,365                                         01990
  365 IF (Y -(1.6*QUALOL)  ) 375, 375, 380                              02000
  370 P = PRESIN                                                        02010
      GO TO 390                                                         02020
  375 P=PRESIN-(0.750*TSDP*(Y-QUALOL)/(XLNGTH-QUALOL) )                 02030
      GO TO 390                                                         02040
  380 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL) )         02050
  385 P=PBREAK-((PBREAK-PRESOT)*(Y-(1.60*QUALOL))/                      02060
     1 (XLNGTH-(1.60*QUALOL)))                                          02070
  390 CALL LIQEN                                                        02080
      DMEFY=ENEPX                                                       02090
      CALL EVAPEN                                                       02100
      DMEFGY=ENEGPX                                                     02110
      PRINT 565,Y                                                       02120
      PRINT 570, P                                                      02130
      PRINT 575,DMEFY,DMEFGY                                            02140
      IF (Y      -(XLNGTH-SCRPTL))400,400,410                           02150
  400 POWERY=EXTRAA*Y                                                   02160
      CFXLOY=EXTRAF/RATIOM                                              02170
      GO TO 435                                                         02180
  410 IF (Y      -ULOCAT)  415,415,425                                  02190
  415 POWERY= (EXTRAA*(XLNGTH-SCRPTL))+                                 02200
     1 (EXTRAB*(ONEMSQ-SINF(3.1416*(ULOCAT-Y       )/COSLEN)))          02210
      CFXLOY=EXTRAF*COSF(3.1416*(ULOCAT-Y)/COSLEN)                      02220
      GO TO 435                                                         02230
  425 IF(Y      -(ULOCAT+(PLNGTH/2.0)))430,430,433                      02240
  430 POWERY= (EXTRAA*(XLNGTH-SCRPTL))+                                 02250
     1 (EXTRAB*(ONEMSQ+SINF(3.1416*(Y          -ULOCAT)/COSLEN)))      02260
      CFXLOY=EXTRAF*COSF(3.1416*(Y      -ULOCAT)/COSLEN)                02270
      GO TO 435                                                         02280
  433 POWERY=EXTRAA*(Y      -PLNGTH)+(EXTRAB*2.0*ONEMSQ)                02290
      CFXLOY=EXTRAF/RATIOM                                              02300
  435 ENLOY=ENTHIN+(POWERY/FLMASS)                                      02310
  440 ENSLOY=ENLOY-DMEFY                                                02320
  450 QUALOX=ENSLOY/DMEFGY                                              02330
  455 CONTINUE                                                          02340
      PRINT 700,POWERT,POWERY,CFXLOY                                    02350
      PRINT 710,ENLOY                                                   02360
      PRINT 720,ENSLOY,QUALOX                                           02370
  700 FORMAT(14H POWER TOTAL = E9.4/,                                   02380
     1 28H POWER INPUT TO POSITION X = E9.4/,                           02390
     2 18H LOCAL HEAT FLUX = E11.5)                                     02400
  710 FORMAT(31H LOCAL ENTHALPY AT POSITION7X = F8.2)                   02410
  720 FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,        02420
     130H LOCAL QUALITY AT POSITION X = F6.3)                           02430
      CALL FILMER                                                       02440
  460 CONTINUE                                                          02450
      N=0                                                               
      RETURN                                                            02460
      END                                                               02470
```



```
      SUBROUTINE CSPIKE                                                 00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOA,JLOCAT,K,X,        00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00085
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00090
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00100
      COMMON QUALIA,GLIQ,TKINCH,                                        00110
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUMO,SUM1,00120
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSURL,T,VISCL,VOLSPL,ENO,  00130
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00140
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00150
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00160
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00170
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       00180
      COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                 00190
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLO,NFLUX,        00200
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,             00210
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                             00220
  364 QUALO4=8.0*(XLNGTH -SCRPTL+PLNGTH)                                00230
      NFLUX=QUALO4                                                      00240
      K=8.0*(XLNGTH-SCRPTL)                                             00250
      DO 459 N=K,NFLUX,J                                                00260
      ZETA=N                                                            00270
      Y=ZETA/8.0                                                        00275
  362 IF (Y-QUALOL) 370,370,365                                         00280
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      IF (Y -(1.6*QUALOL)  ) 375, 375, 380                              00300
      P = PRESIN                                                        00310
      GO TO 390                                                         00320
  375 P=PRESIN-(0.750*TSDP*(Y-QUALOL)/(XLNGTH-QUALOL) )                 00330
      GO TO 390                                                         00340
  380 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL) )         00350
  385 P=PBREAK-((PBREAK-PRESOT)*(Y-(1.60*QUALOL))/                      00360
     1 (XLNGTH-(1.60*QUALOL)))                                          00370
  390 CALL LIQEN                                                        00380
      DMEFY=ENEPX                                                       00390
      CALL EVAPEN                                                       00400
      DMEFGY=ENEGPX                                                     00410
      PRINT 565,Y,P,DMEFY,DMEFGY                                        00420
  565 FORMAT(4E20.3)                                                    00430
      IF (Y       -(XLNGTH-SCRPTL))400,400,410                          00440
  400 POWERY=EXTRAA*Y                                                   00450
      CFXLOY=EXTRAF/RATIOM                                              00460
      GO TO 435                                                         00470
  410 IF (Y      -ULOCAT)  415,415,425                                  00480
  415 POWERY= (EXTRAA*(XLNGTH-SCRPTL))+                                 00490
     1 (EXTRAB*(ONEMSQ-SINF(3.1416*(ULOCAT-Y     )/COSLEN)))            00500
      CFXLOY=EXTRAF*COSF(3.1416*(ULOCAT-Y     )/COSLEN)                 00510
      GO TO 435                                                         00520
  425 IF(Y      -(ULOCAT+(PLNGTH/2.0)))430,430,433                      00530
  430 POWERY= (EXTRAA*(XLNGTH-SCRPTL))+                                 00540
     1 (EXTRAB*(ONEMSQ+SINF(3.1416*(Y-ULOCAT     )/COSLEN)))            00550
      CFXLOY=EXTRAF*COSF(3.1416*(Y      -ULOCAT)/COSLEN)                00560
      GO TO 435                                                         00570
  433 POWERY=EXTRAA*(Y      -PLNGTH)+(EXTRAB*2.0*ONEMSQ)                00580
      CFXLOY=EXTRAF/RATIOM                                              00590
  435 ENLOY=ENTHIN+(POWERY/FLMASS)                                      00600
  440 ENSLOY=ENLOY-DMEFY                                                00610
  450 QUALOX=ENSLOY/DMEFGY                                              00620
  455 CONTINUE                                                          00630
      PRINT 700,POWERT,POWERY,CFXLOY                                    00640
      PRINT 710,ENLOY                                                   00650
      PRINT 720,ENSLOY,QUALOX                                           00660
  700 FORMAT(14H POWER TOTAL = E9.4/,                                   00670
     1 28H POWER INPUT TO POSITION X = E9.4/,                           00680
     2 18H LOCAL HEAT FLUX = E11.5)                                     00690
  710 FORMAT(31H LOCAL ENTHALPY AT POSITION7X = F8.2)                   00700
  720 FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,        00710
     130H LOCAL QUALITY AT POSITION X = F6.3)                           00720
      CALL FILMFR                                                       00730
  459 CONTINUE                                                          00740
      RETURN                                                            00750
      END                                                               00760
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      SUBROUTINE UNIANN                                                 00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,ROLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIP,FACPLR,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIQ,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUMO,SUM1,  00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSURL,T,VISCL,VOLSPL,ENO,   00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,  00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,     00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,  00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,   00180
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC        00190
      QUALO4=16.0*QUALOL                                                00200
      I=QUALO4                                                          00210
      DO 451  K=I,10000,1                                               00220
      DUMMYC=K+1                                                        
      X=DUMMYC/16.0                                                     
      IF(X-QUALOL)160 ,160 ,157                                         00240
  157 IF(X-(1.60*QUALOL) ) 162,162,165                                  00250
  160 P=PRESIN                                                          00260
      GO TO 167                                                         00270
  162 P=PRESIN-(0.750*TSDP*(X-QUALOL)/(XLNGTH-QUALOL))                  00280
      GO TO 167                                                         00290
  165 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL) /(XLNGTH-QUALOL))         00300
  166 P=PBREAK-((PBREAK-PRESOT)*(X-(1.60*QUALOL))/                      00310
     1 (XLNGTH-(1.60*QUALOL)))                                          00320
  167 CALL LIQEN                                                        00330
      DMEFX=ENEPX                                                       00340
      CALL EVAPEN                                                       00350
      DMEFGX=ENEGPX                                                     00360
  170 CFXLOX=POWERT/AREAIS                                              00400
  175 POWERX=POWERT*(X/XLNGTH)                                          00410
  180 ENLOX=ENTHIN + POWERX/FLMASS                                      00420
  185 ENSLOX=ENLOX-DMEFX                                                00430
  190 QUALOX=ENSLOX/DMEFGX                                              00440
      IF(QUALOX-QUALIA) 451,453,453                                     00540
  451 CONTINUE                                                          00550
  453 POWERA=POWERT-POWERX                                              
      PANBOL=POWERB-POWERX                                              
      PRINT 721,X,P                                                     00580
      PRINT 722,DMEFX,DMEFGX                                            00590
      PRINT 723,POWERA,PANBOL                                           00600
      PRINT 700,POWERT,POWERX,CFXLOX                                    00610
      PRINT 710,ENLOX                                                   00620
      PRINT 720,ENSLOX,QUALOX                                           00630
  700 FORMAT(14H POWER TOTAL = E9.4/,                                   
     1 28H POWER INPUT TO POSITION X = E9.4/,                           
     2 18H LOCAL HEAT FLUX = E11.5)                                     00660
  710 FORMAT(31H LOCAL ENTHALPY AT POSITION7X = F8.2)                   00670
  720 FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,        00680
     130H LOCAL QUALITY AT POSITION X = F6.3)                           00690
  721 FORMAT(51H CONDITIONS AT SLUG ANNULAR TRANSITION   POSITION =F8.1,  00700
     1 14H    PRESSURE =F8.1)                                          00710
  722 FORMAT(18H LIQUID ENTHALPY =F8.2,19H    EVAP ENTHALPY =F8.2)      00720
  723 FORMAT(28H POWER OVER ANNULAR REGION =1PE10.3,                    00730
     1 45H   POWER FROM SLUG ANNULAR TRANSITION TO BO =1PE10.3)         00740
      RETURN                                                            00750
      END                                                               00760
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      SUBROUTINE COSANN                                                 00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,ROLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
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     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,                00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                  00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,              00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                        00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ       00110
      COMMON QUALIA,GLIQ,TKINCH,                                         00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,  00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,   00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,  00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,     00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,  00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,   00180
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC        00190
      QUALO4=16.0*QUALOL                                                 00200
      I=QUALO4                                                           00210
      DO 451 L=I,10000,1                                                 00220
      DUMMYC=L+1
      Y=DUMMYC/16.0
      IF (Y - QUALOL) 370, 370, 365
  365 IF (Y -(1.6*QUALOL)  ) 375, 375, 380                               00240
  370 P = PRESIN                                                         00250
      GO TO 390                                                          00260
  375 P=PRESIN-(0.750*TSDP*(Y-QUALOL)/(XLNGTH-QUALOL) )                  00270
      GO TO 390                                                          00280
  380 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL) )          00290
  385 P=PBREAK-((PBREAK-PRESOT)*(Y-(1.60*QUALOL))/                       00300
     1 (XLNGTH-(1.60*QUALOL)))                                           00310
  390 CALL LIQEN                                                         00320
      DMEFY=ENEPX                                                        00330
      CALL EVAPEN                                                        00340
      DMEFGY=ENEGPX                                                      00350
      IF (Y-(XLNGTH/2.0) )400,400,428                                    00360
  400 FACTMI=(1.0-(SINE( (3.1416*( (XLNGTH/2.0)-Y) )                     00370
     1/COSLEN)) /ONEMSQ)                                                 00380
  410 POWERY =(POWERT*FACTMI) / 2.0                                      00390
  412 CFXLOY=144.0*(POWERT/(2.0*DIAINS*COSLEN*ONEMSQ))*                  00400
     1COSF(3.1416*( (XLNGTH/2.0)-Y)/COSLEN)                              00410
  415 ENLOY = ENTHIN + (POWERT*FACTMI) / (2.0 *FLMASS)                   00420
  420 ENSLOY=ENLOY-DMEFY                                                 00430
  425 QUALOX=ENSLOY/DMEFGY                                               00440
      GO TO 455                                                          00450
  428 FACTPL=(1.0+(SINE( (3.1416*(Y-(XLNGTH/2.0) ) )                     00460
     1/COSLEN) )/ONEMSQ)                                                 00470
  430 POWERY = (POWERT*FACTPL) / 2.0                                     00480
  432 CFXLOY=144.0*(POWERT/(2.0*DIAINS*COSLEN*ONEMSQ))*                  00490
     1COSF(3.1416*(Y-(XLNGTH/2.0) )/COSLEN)                              00500
  435 ENLOY = ENTHIN + ( POWERT* FACTPL) / ( 2.0 * FLMASS)               00510
  440 ENSLOY=ENLOY-DMEFY                                                 00520
  450 QUALOX=ENSLOY/DMEFGY                                               00530
  455  IF(QUALOX-QUALIA) 451,453,453                                     00540
  451 CONTINUE                                                           00550
  453  POWERA=POWERT-POWERY                                              00560
      PANBOL=POWERB-POWERY                                               00570
      PRINT 721,Y,P                                                      00580
      PRINT 722,DMEFY,DMEFGY                                             00590
      PRINT 723,POWERA,PANBOL                                            00600
      PRINT 700,POWERT,POWERY,CFXLOY                                     00610
      PRINT 710,ENLOY                                                    00620
      PRINT 720,ENSLOY,QUALOX                                            00630
  700 FORMAT(14H POWER TOTAL = E9.4/,                                    00640
     1 28H POWER INPUT TO POSITION X = E9.4/,
     2 18H LOCAL HEAT FLUX = E11.5)                                      00670
  710 FORMAT(31H LOCAL ENTHALPY AT POSITION7X = F8.2)                    00680
  720 FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,         00690
     130H LOCAL QUALITY AT POSITION X = F6.3)                            00700

  721 FORMAT(51H CONDITIONS AT SLUG ANNULAR TRANSITION   POSITION =F8.1,  00710
     1 14H    PRESSURE =F8.1)                                            00720
  722 FORMAT(18H LIQUID ENTHALPY =F8.2,19H    EVAP ENTHALPY =F8.2)       00730
  723 FORMAT(28H POWER OVER ANNULAR REGION =1PE10.3,                     00740
     1 45H   POWER FROM SLUG ANNULAR TRANSITION TO BO =1PE10.3)          00750
      RETURN                                                             00760
      END                                                                00770

      SUBROUTINE LNIANN                                                  01440
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  01450
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,            01460
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,      01470
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,         01480
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,       01490
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,                01500
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                  01510
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,              01520
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                        01530
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ       01540
      COMMON QUALIA,GLIQ,TKINCH,                                         01550
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,  01560
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,   01570
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,  01580
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,     01590
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,  01600
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,   01610
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC        01620
      QUALO4=16.0*QUALOL                                                 01630
      I=QUALO4                                                           01640
      DO 451 K=I,10000,1                                                 01650
      DUMMYC=K+1
      X=DUMMYC/16.0
      IF(X-QUALOL)160 ,160 ,157                                          01670
  157 IF(X-(1.60*QUALOL) ) 162,162,165                                   01680
  160 P=PRESIN                                                           01690
      GO TO 167                                                          01700
  162 P=PRESIN-(0.750*TSDP*(X-QUALOL)/(XLNGTH-QUALOL))                   01710
      GOTO 167                                                           01720
  165 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL) /(XLNGTH-QUALOL))          01730
  166 P=PBREAK-((PBREAK-PRESOT)*(X-(1.60*QUALOL))/                       01740
     1 (XLNGTH-(1.60*QUALOL)))                                           01750
  167 CALL LIQEN                                                         01760
      DMEFX=ENEPX                                                        01770
      CALL EVAPEN                                                        01780
      DMEFGX=ENEGPX                                                      01790
      CFXLOX=((2.0*POWERT)/(AREAIS*(RATIOM+1.00)))                       01800
     1 *(1.00+((X*(RATIOM-1.00))/XLNGTH))                                01810
      POWERX=((POWERT*2.00)/(RATIOM+1.00))*(X/XLNGTH+((X*X*(RATIOM-1.00)  01820
     1 )/(XLNGTH*XLNGTH*2.00)))                                          01830
  180 ENLOX=ENTHIN + POWERX/FLMASS                                       01840
  185 ENSLOX=ENLOX-DMEFX                                                 01850
  190 QUALOX=ENSLOX/DMEFGX                                               01860
  455  IF(QUALOX-QUALIA) 451,453,453                                     01870
  451 CONTINUE                                                           01880
  453  POWERA=POWERT-POWERX                                              01890
      PANBOL=POWERB-POWERX                                               01900
      PRINT 721,X,P                                                      01910
      PRINT 722,DMEFX,DMEFGX                                             01920
      PRINT 723,POWERA,PANBOL                                            01930
      PRINT 700,POWERT,POWERX,CFXLOX                                     01940
      PRINT 710,ENLOX                                                    01950
      PRINT 720,ENSLOX,QUALOX                                            01960
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700  FORMAT(14H POWER TOTAL = E9.4/,
     1 28H POWER INPUT TO POSITION X = E9.4/,
     2 18H LOCAL HEAT FLUX = E11.5)                                    01990
710  FORMAT(31H LOCAL ENTHALPY AT POSITION X = F8.2)                   02000
720  FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,        02010
     130H LOCAL QUALITY AT POSITION X = F6.3)                          02020
 721 FORMAT(51H CONDITIONS AT SLUG ANNULAR TRANSITION   POSITION =F8.1,  02030
     1 14H    PRESSURE =F8.1)                                          02040
 722 FORMAT(18H LIQUID ENTHALPY =F8.2,19H    EVAP ENTHALPY =F8.2)      02050
 723 FORMAT(28H POWER OVER ANNULAR REGION =1PE10.3,                    02060
     1 45H   POWER FROM SLUG ANNULAR TRANSITION TO BO =1PE10.3)        02070
      RETURN                                                           02080
      END                                                              02090



      SUBROUTINE LNDANN                                                00780
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00790
     1 PRESP,PRESIN,PRESOT,PESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,          00800
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00810
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,       00820
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,     00830
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,              00840
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                00850
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,            00860
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                      00870
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ     00880
      COMMON QUALIA,GLIQ,TKINCH,                                       00890
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSURZ,SUM0,SUM1,  00900
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00910
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,  00920
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   00930
     5DVISCL,REYNUM,FFACTP,FFACT,VFLOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,  00940
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00950
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYR,DUMMYC      00960
      QUALO4=16.0*QUALOL                                               00970
      I=QUALO4                                                         00980
      DO 451 K=I,10000,1                                               00990
      DUMMYC=K+1
      X=DUMMYC/16.0
      IF(X-QUALOL)160 ,160 ,157                                        01010
 157  IF(X-(1.60*QUALOL) ) 162,162,165                                 01020
 160  P=PRESIN                                                         01030
      GO TO 167                                                        01040
 162  P=PRESIN-(0.750*TSDP*(X-QUALOL)/(XLNGTH-QUALOL))                 01050
      GOTO 167                                                         01060
 165  PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL) /(XLNGTH-QUALOL))        01070
 166  P=PBREAK-((PBREAK-PRESOT)*(X-(1.60*QUALOL))/                     01080
     1 (XLNGTH-(1.60*QUALOL)))                                         01090
 167  CALL LIQEN                                                       01100
      DMEFX=ENEPX                                                      01110
      CALL EVAPEN                                                      01120
      DMEFGX=ENEGPX                                                    01130
      CFXLOX=((2.0*POWERT*RATIOM)/(AREAIS*(1.00+RATIOM)))*             01140
     1(1.00-(X*(RATIOM-1.00))/(XLNGTH*RATIOM))                         01150
      POWERX=((POWERT*2.00*RATIOM)/(RATIOM+1.00))*('X/XLNGTH)          01160
     1-(X*X*(RATIOM-1.00))/(XLNGTH*XLNGTH*2.00*RATIOM))                01170
 180  ENLOX=ENTHIN + POWERX/FLMASS                                     01180
 185  ENSLOX=ENLOX-DMEFX                                               01190
 190  QUALOX=ENSLOX/DMEFGX                                             01200
 455   IF(QUALOX-QUALIA) 451,453,453                                   01210
 451  CONTINUE                                                         01220
 453   POWERA=POWERT-POWERX                                            01230
      PANBOL=POWERB-POWERX                                             01240
      PRINT 721,X,P                                                    01250
      PRINT 722,DMEFX,DMEFGX                                           01260
      PRINT 723,POWERA,PANBOL                                          01270
      PRINT 700,POWERT,POWERX,CFXLOX                                   01280
      PRINT 710,ENLOX                                                  01290
      PRINT 720,ENSLOX,QUALOX                                          01300
 700  FORMAT(14H POWER TOTAL = E9.4/,
     1 28H POWER INPUT TO POSITION X = E9.4/,
     2 18H LOCAL HEAT FLUX = E11.5)                                    01330
 710  FORMAT(31H LOCAL ENTHALPY AT POSITION X = F8.2)                   01340
 720  FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,        01350
     130H LOCAL QUALITY AT POSITION X = F6.3)                          01360
 721 FORMAT(51H CONDITIONS AT SLUG ANNULAR TRANSITION   POSITION =F8.1,  01370
     1 14H    PRESSURE =F8.1)                                          01380
 722 FORMAT(18H LIQUID ENTHALPY =F8.2,19H    EVAP ENTHALPY =F8.2)      01390
 723 FORMAT(28H POWER OVER ANNULAR REGION =1PE10.3,                    01400
     1 45H   POWER FROM SLUG ANNULAR TRANSITION TO BO =1PE10.3)        01410
      RETURN                                                           01420
      END                                                              01430



      SUBROUTINE PKIANN                                                02880
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  02890
     1 PRESP,PRESIN,PRESOT,PESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,          02900
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     02910
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,       02920
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,     02930
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,              02940
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                02950
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,            02960
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                      02970
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ     02980
      COMMON QUALIA,GLIQ,TKINCH,                                       02990
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSURZ,SUM0,SUM1,  03000
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  03010
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,  03020
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   03030
     5DVISCL,REYNUM,FFACTP,FFACT,VFLOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,  03040
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  03050
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYR,DUMMYC      03060
      QUALO4=16.0*QUALOL                                               03070
      I=QUALO4                                                         03080
      DO 451 L=I,10000,1                                               03090
      DUMMYC=L+1
      Y=DUMMYC/16.0
      IF (Y - QUALOL) 370, 370, 365                                    03110
 365  IF (Y -(1.6*QUALOL)  ) 375, 375, 380                             03120
 370  P = PRESIN                                                       03130
      GO TO 390                                                        03140
 375  P=PRESIN-(0.750*TSDP*(Y-QUALOL)/(XLNGTH-QUALOL) )                03150
      GO TO 390                                                        03160
 380  PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL) )        03170
 385  P=PBREAK-((PBREAK-PRESOT)*(Y-(1.60*QUALOL))/                     03180
     1 (XLNGTH-(1.60*QUALOL)))                                         03190
 390  CALL LIQEN                                                       03200
      DMEFY=ENEPX                                                      03210
      CALL EVAPEN                                                      03220
      DMEFGY=ENEGPX                                                    03230
      IF (Y-(PLNGTH/2.0)) 400,400,410                                  03240
 400  POWERY=EXTRAC*(ONEMSQ-SINF(3.1416*((PLNGTH/2.00)-                03250
     1Y      )/COSLEN)  )                                             03260
      CFXLOY=EXTRAF*COSF(3.1416*((PLNGTH/2.00)-                        03270
     1Y      )/COSLEN)                                                03280
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      GO TO 435                                                          03290
  410 IF (Y-(XLNGTH-SCRPTL)) 415,415,425                                 03300
  415 POWERY=EXTRAC*(ONEMSO+SINF(3.1416*(                                03310
     1Y      -(PLNGTH/2.00))/COSLEN)   )                                 03320
      CFXLOY=EXTRAE*COSF(3.1416*(                                        03330
     1Y      -(PLNGTH/2.00))/COSLEN)                                     03340
      GO TO 435                                                          03350
  425 POWERY=(POWERT/CONSTP)*((COSLEN*EXTRAA/3.1416)+EXTRAB*(1.00-       03360
     1EXPF( (-ZETA)*(Y      -(XLNGTH-SCRPTL))/SCRPTL)))                 03370
      CFXLOY=EXTRAE*COSABK* EXPF( (-ZETA)*(                              03380
     1Y      -(XLNGTH-SCRPTL))/SCRPTL)                                   03390
  435 ENLOY=ENTHIN+(POWERY/FLMASS)                                       03400
  440  ENSLOY=ENLOY-DMEFY                                                03410
  450 QUALOX=ENSLOY/DMEFGY                                               03420
  455  IF(QUALOX-QUALIA) 451,453,453                                     03430
  451 CONTINUE                                                           03440
  453  POWERA=POWERT-POWERY                                              03450
      PANBOL=POWERB-POWERY                                               03460
      PRINT 721,Y,P                                                      03470
      PRINT 722,DMEFY,DMEFGY                                             03480
      PRINT 723,POWERA,PANBOL                                            03490
      PRINT 700,POWERT,POWERY,CFXLOY                                     03500
      PRINT 710,ENLOY                                                    03510
      PRINT 720,ENSLOY,QUALOX                                            03520
  700  FORMAT(14H POWER TOTAL = E9.4/,
     1 28H POWER INPUT TO POSITION X = E9.4/,
     2 18H LOCAL HEAT FLUX = E11.5)                                      03550
  710  FORMAT(31H LOCAL ENTHALPY AT POSITION7X = F8.2)                   03560
  720  FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,        03570
     130H LOCAL QUALITY AT POSITION X = F6.3)                            03580
  721 FORMAT(51H CONDITIONS AT SLUG ANNULAR TRANSITION   POSITION =F8.1, 03590
     1 14H    PRESSURE =F8.1)                                           03600
  722 FORMAT(18H LIQUID ENTHALPY =F8.2,19H    EVAP ENTHALPY =F8.2)       03610
  723 FORMAT(28H POWER OVER ANNULAR REGION =1PE10.3,                     03620
     1 45H   POWER FROM SLUG ANNULAR TRANSITION TO BO =1PE10.3)          03630
      RETURN                                                             03640
       END
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      SUBROUTINE PKQANN                                                  02100
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  02110
     1 PRESP,PRESIN,PRESOT,PESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,            02120
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,      02130
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,         02140
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,       02150
     5 COSLEN,ONEMSO,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,                02160
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                  02170
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,              02180
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAF,EXTRAG,                        02190
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ       02200
      COMMON QUALIA,GLIQ,TKINCH,                                         02210
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1, 02220
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  02230
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 02240
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    02250
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 02260
     6R,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  02270
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       02280
      QUALO4=16.0*QUALOL                                                 02290
      I=QUALO4                                                           02300
      DO 451 L=I,10000,1                                                 02310
      DUMMYC=L+1
      Y=DUMMYC/16.0
      IF (Y - QUALOL) 370, 370, 365                                      02330
  365 IF (Y -(1.6*QUALOL)  ) 375, 375, 380                               02340
  370 P = PRESIN                                                         02350
      GO TO 390                                                          02360
  375 P=PRESIN-(0.750*TSDP*(Y-QUALOL)/(XLNGTH-QUALOL) )                  02370
      GO TO 390                                                          02380
  380 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL) )          02390
  385 P=PBREAK-((PBREAK-PRESOT)*(Y-(1.60*QUALOL))/                       02400
     1 (XLNGTH-(1.60*QUALOL)))                                           02410
  390 CALL LIQEN                                                         02420
      DMEFY=ENEPX                                                        02430
      CALL EVAPEN                                                        02440
      DMEFGY=ENEGPX                                                      02450
      IF (Y-SCRPTL) 400,400,410                                          02460
  400 POWERY=EXTRAF*(FXPF(ZETA*(                                         02470
     1Y      -SCRPTL)/SCRPTL)-EXPF(-ZETA))                               02480
      CFXLOY=EXTRAE*COSABK*(EXPF(ZETA*(                                  02490
     1Y      -SCRPTL)/SCRPTL))                                           02500
      GO TO 435                                                          02510
  410 IF (Y-(XLNGTH-(PLNGTH/2.00))) 415,415,425                          02520
  415 POWERY= (POWERT/CONSTP)*((EXTRAB*ULOCAT) + ((COSLEN/3.1416)*(      02530
     1SINABK-SINF((3.1416/COSLEN)*(XLNGTH-(PLNGTH/2.00)-Y      ) ) ) ) )  02540
      CFXLOY=EXTRAE*COSF((3.1416/COSLEN)*(XLNGTH-(PLNGTH/2.00)-Y      ))  02550
      GO TO 435                                                          02560
  425 POWERY= (POWERT/CONSTP)*((EXTRAB*ULOCAT) + ((COSLEN/3.1416)*(      02570
     1SINABK+SINF((3.1416/COSLEN)*(Y      -(XLNGTH-(PLNGTH/2.00) ) ) ))  02580
     2 ))                                                                02590
      CFXLOY=EXTRAE*COSF((3.1416/COSLEN)*(Y      -(XLNGTH-(PLNGTH/2.00) )  02600
     1 ) )                                                               02610
  435 ENLOY=ENTHIN+(POWERY/FLMASS)                                       02620
  440  ENSLOY=ENLOY-DMEFY                                                02630
  450 QUALOX=ENSLOY/DMEFGY                                               02640
  455  IF(QUALOX-QUALIA) 451,453,453                                     02650
  451 CONTINUE                                                           02660
  453  POWERA=POWERT-POWERY                                              02670
      PANBOL=POWERB-POWERY                                               02680
      PRINT 721,Y,P                                                      02690
      PRINT 722,DMEFY,DMEFGY                                             02700
      PRINT 723,POWERA,PANBOL                                            02710
      PRINT 700,POWERT,POWERY,CFXLOY                                     02720
      PRINT 710,ENLOY                                                    02730
      PRINT 720,ENSLOY,QUALOX                                            02740
  700  FORMAT(14H POWER TOTAL = E9.4/,
     1 28H POWER INPUT TO POSITION X = E9.4/,
     2 18H LOCAL HEAT FLUX = E11.5)                                      02770
  710  FORMAT(31H LOCAL ENTHALPY AT POSITION7X = F8.2)                   02780
  720  FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,        02790
     130H LOCAL QUALITY AT POSITION X = F6.3)                            02800
  721 FORMAT(51H CONDITIONS AT SLUG ANNULAR TRANSITION   POSITION =F8.1, 02810
     1 14H    PRESSURE =F8.1)                                           02820
  722 FORMAT(18H LIQUID ENTHALPY =F8.2,19H    EVAP ENTHALPY =F8.2)       02830
  723 FORMAT(28H POWER OVER ANNULAR REGION =1PE10.3,                     02840
     1 45H   POWER FROM SLUG ANNULAR TRANSITION TO BO =1PE10.3)          02850
      RETURN                                                             02860
      END                                                                02870
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      SUBROUTINE  SPKANN                                                 00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,PESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,            00030
     2 DMEFX,ENFPX,DMEFGX,ENFGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,      00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,         00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,       00060
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     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,                00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                  00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,              00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                        00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ       00110
      COMMON QUALIA,GLIO,TKINCH,                                         00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1, 00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       00190
      COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                  00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHFN,HMAC,HMIC,REYNLO,NFLUX,         00210
     2  PRNUMB,BERGHT,HDB,HDFNG,QADFNG,DTDFNG,DELTT,QACHEN,             00220
     3 DTCHEN,RADMAX,DELTFN,RADIUS,CC,DD,EE                             00230
      QUALO4=16.0*QUALOL                                                 00240
      I=QUALO4                                                           00250
      DO 451 L=I,10000,1                                                 00260
      DUMMYC=L+1                                                         00270
      Y=DUMMYC/16.0                                                      00280
      IF (Y - QUALOL) 370, 370, 365                                      00290
  365 IF (Y -(1.6*QUALOL)  ) 375, 375, 380                               00300
  370 P = PRESIN                                                         00310
      GO TO 390                                                          00320
  375 P=PRESIN-(0.750*TSDP*(Y-QUALOL)/(XLNGTH-QUALOL) )                  00330
      GO TO 390                                                          00340
  380 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL) )          00350
  385 P=PBREAK-((PBREAK-PRESOT)*(Y-(1.60*QUALOL))/                       00360
     1 (XLNGTH-(1.60*QUALOL)))                                           00370
  390 CALL LIQEN                                                         00380
      DMEFY=ENEPX                                                        00390
      CALL EVAPEN                                                        00400
      DMEFGY=ENEGPX                                                      00410
      IF (Y       -(XLNGTH-SCRPTL))400,400,410                           00420
  400 POWERY=EXTRAA*Y                                                    00430
      CFXLOY=EXTRAF/PATIOM                                               00440
      GO TO 435                                                          00450
  410 IF (Y      -ULOCAT)  415,415,425                                   00460
  415 POWERY= (EXTRAA*(XLNGTH-SCRPTL))+                                  00470
     1 (EXTRAB*(ONEMSQ-SINF(3.1416*(ULOCAT-Y     )/COSLEN)))             00480
      CFXLOY=EXTRAF*COSF(3.1416*(ULOCAT-Y    )/COSLEN)                   00490
      GO TO 435                                                          00500
  425 IF(Y      -(ULOCAT+(PLNGTH/2.0)))430,430,433                       00510
  430 POWERY= (EXTRAA*(XLNGTH-SCRPTL))+                                  00520
     1 (EXTRAB*(ONEMSQ+SINF(3.1416*(Y-ULOCAT     )/COSLEN)))             00530
      CFXLOY=EXTRAE*COSF(3.1416*(Y      -ULOCAT)/COSLEN)                 00540
      GO TO 435                                                          00550
  433 POWERY=EXTRAA*(Y      -PLNGTH)+(EXTRAB*2.0*ONEMSQ)                 00560
      CFXLOY=EXTRAE/PATIOM                                               00570
  435 ENLOY=ENTHIN+(POWERY/FLMASS)                                       00580
  440 ENSLOY=ENLOY-DMEFY                                                 00590
  450 QUALOX=ENSLOY/DMEFGY                                               00600
  455  IF(QUALOX-QUALIA) 451,453,453                                     00610
  451 CONTINUE                                                           00620
  453  POWERA=POWERT-POWERY                                              00630
      PANBOL=POWERB-POWERY                                               00640
      PRINT 721,Y,P                                                      00650
      PRINT 722,DMEFY,DMEFGY                                             00660
      PRINT 723,POWERA,PANBOL                                            00670
      PRINT 700,POWERT,POWERY,CFXLOY                                     00680
      PRINT 710,ENLOY                                                    00690
      PRINT 720,ENSLOY,QUALOX                                            00700
  700 FORMAT(14H POWER TOTAL = F9.4/,                                    00710
     1 28H POWER INPUT TO POSITION X = E9.4/,                            00720
     2 18H LOCAL HEAT FLUX = E11.5)                                      00730
  710  FORMAT(31H LOCAL ENTHALPY AT POSITION7X = F8.2)                   00740
  720  FORMAT(41H LOCAL SUBCOOLED ENTHALPY AT POSITION X = F8.2/,        00750
     130H LOCAL QUALITY AT POSITION X = F6.3)                            00760
  721 FORMAT(51H CONDITIONS AT SLUG ANNULAR TRANSITION   POSITION =F8.1, 00770
     1 14H    PRESSURE =F8.1)                                           00780
  722 FORMAT(18H LIQUID ENTHALPY =F8.2,19H    EVAP ENTHALPY =F8.2)       00790
  723 FORMAT(28H POWER OVER ANNULAR REGION =1PE10.3,                     00800
     1 45H   POWER FROM SLUG ANNULAR TRANSITION TO BO =1PE10.3)          00810
      RETURN                                                             00820
      END                                                                00830
      SUBROUTINE BONUCF                                                  00010
      COMMON NTUBES,MSHAPE,TUBE,PATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,PFSDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,            00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,APEAFL,APEAIS,      00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,         00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,       00060
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,                00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                  00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,              00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                        00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ       00110
      COMMON QUALIA,GLIO,TKINCH,                                         00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1, 00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       00190
      COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                  00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHFN,HMAC,HMIC,REYNLO,NFLUX,         00210
     2  PRNUMB,BERGHT,HDB,HDFNG,QADFNG,DTDFNG,DELTT,QACHEN,             00220
     3 DTCHEN,RADMAX,DELTFN,RADIUS,CC,DD,EE                             00230
      IF(BOLOCA-QUALOL)  750,750,755                                     00240
  755 IF(BOLOCA-(1.6*QUALOL))  760,760,765                               00250
  750 P=PRESIN                                                           00260
      GO TO 770                                                          00270
  760 P=PRESIN-(0.750*TSDP*(BOLOCA-QUALOL)/(XLNGTH-QUALOL))              00280
      GO TO 770                                                          00290
  765 PBREAK=PRESIN-(0.750*TSDP*(0.60*QUALOL)/(XLNGTH-QUALOL))           00300
      P=PBREAK-((PBREAK-PRESOT)*(BOLOCA-(1.60*QUALOL))/(XLNGTH-          00310
     1 (1.60*QUALOL)))                                                   00320
  770 QUALOX=QUALOR                                                      00330
      IF(QUALOX)   780,780,775                                           00340
  775 CALL XXTT                                                          00350
      CALL SATTMP                                                        00360
      CALL VISCOS                                                        00370
      CALL XTHCON                                                        00380
      CALL XCPLIQ                                                        00390
      CALL XSURFT                                                        00400
      CALL EVAPEN                                                        00410
      CALL SPECVG                                                        00420
      CALL SPECVL                                                        00430
      PRNUMB= CPLIQ*VISCL/THCOND                                         00440
      A =(P**.0234)                                                      00450
      SUM1=A/(2.30-A)                                                    00460
      BERGHT=((1.0/(15.6*(P**1.156)))**SUM1)                             00470
      REYNUM=(GTOT*DIAINS)/(12.0*VISCL)                                  00480
      HDB=0.023*THCOND*(12.0/DIAINS)*(REYNUM**0.8)*(PRNUMB**0.4)         00490
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      HDENG=3.5*HDB/(XTT**0.5)                                          00490
      B=(2.30/(2.30-A))                                                 00500
      QADENG=(BERGHT*(HDENG** B))                                       00510
      DTDENG=QADENG/HDENG                                               00520
      PRINT 100,HDENG,QADENG,DTDENG                                     00530
  100 FORMAT(9H H DENG =E15.5,25H NUCL FLUX DENG-BERGLES =F15.5,        00540
     1  24H TWALL MINUS TSAT DENG =F15.5)                              00550
      DELTT=DTDENG                                                      00560
      CALL XHCHEN                                                       00570
      GO TO 10                                                          00580
    5 CALL XHCHEN                                                       00590
   10 QACHEN=(BERGHT*(HCHEN** B))                                       00600
      DTCHEN=QACHEN/HCHEN                                               00610
      PRINT 200,DTCHEN,DELTT,HCHEN,QACHEN                               00620
  200 FORMAT(10H DT CHEN =E10.5,14H DT PREVIOUS =E10.5,                 00630
     1 9H H CHEN =E10.5, 23H NUC FLUX CHEN-BERGLES=E10.5)               00640
      IF(ABSF(DTCHEN-DELTT)-0.05)  40,40,20                             00650
   20 DELTT=DTCHEN                                                      00660
      GO TO 5                                                           00670
   40 RADMAX=.0000575                                                   00680
      CALL XRAD                                                         00690
      IF (RADIUS-RADMAX)  50,50,60                                      00700
   60 CALL NFLUX2                                                       00710
   50 CONTINUE                                                          00720
      BMAOA=CFXBO/QACHEN                                                00730
      CC=CFXBO/QADENG                                                   00740
      DELTEN=(POWERB-(POWERT-POWERA))/FLMASS                            00750
 1000 PRINT 3000,DELTEN,BMAOA,CC                                        00760
 3000 FORMAT(40H DELTA ENTHALPY ANNULAR TRANS TO LOCAL =F9.2,           00770
     1 37H LOCAL FLUX OVER FLUX FOR NUCLEATION=F8.2,                    00780
     2  13H RATIO DENG =F8.2)                                          00790
  780 CONTINUE                                                          00800
      RETURN                                                            00810
      END                                                               00820
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      SUBROUTINE LONUCF                                                 00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOQ,ONEOVM,      00060
     5 COSLEN,ONEMSQ,SIGNZ,APG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTD,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIQ,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,  00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,  00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,  00170
     6R,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00180
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       00190
      COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                 00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,        00210
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,             00220
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                             00230
      CALL XXTT                                                         00240
      CALL SATTMP                                                       00250
      CALL VISCOS                                                       00260
      CALL XTHCON                                                       00270
      CALL XCPLIQ                                                       00280
      CALL XSURFT                                                       00290
      CALL FVAPEN                                                       00300
      CALL SPECVG                                                       00310
      CALL SPECVL                                                       00320
      PRNUMR= CPLIQ*VISCL/THCOND                                        00330
      A =(P**.0234)                                                     00340
      SUM1=A/(2.30-A)                                                   00350
      BERGHT=((1.0/(15.6*(P**1.156)))**SUM1)                            00360
      REYNUM=(GTOT*DIAINS)/(12.0*VISCL)                                 00370
      HDB=0.023*THCOND*(12.0/DIAINS)*(REYNUM**0.8)*(PRNUMB**0.4)        00380
      HDENG=3.5*HDB/(XTT**0.5)                                          00390
      B=(2.30/(2.30-A))                                                 00400
      QADENG=(BERGHT*(HDENG** B))                                       00410
      DTDENG=QADENG/HDENG                                               00420
      PRINT 100,HDENG,QADENG,DTDENG                                     00430
  100 FORMAT(9H H DENG =E15.5,25H NUCL FLUX DENG-BERGLES =F15.5,        00440
     1  24H TWALL MINUS TSAT DENG =E15.5)                              00450
      DELTT=DTDENG                                                      00460
      CALL XHCHEN                                                       00470
      GO TO 10                                                          00480
    5 CALL XHCHEN                                                       00490
   10 QACHEN=(BERGHT*(HCHEN** B))                                       00500
      DTCHEN=QACHEN/HCHEN                                               00510
      PRINT 200,DTCHEN,DELTT,HCHEN,QACHEN                               00520
  200 FORMAT(10H DT CHEN =E10.5,14H DT PREVIOUS =E10.5,                 00530
     1 9H H CHEN =E10.5, 23H NUC FLUX CHEN-BERGLES=E10.5)               00540
      IF(ABSF(DTCHEN-DELTT)-0.05)  40,40,20                             00550
   20 DELTT=DTCHEN                                                      00560
      GO TO 5                                                           00570
   40 RADMAX=.0000575                                                   00580
      CALL XRAD                                                         00590
      IF (RADIUS-RADMAX)  50,50,60                                      00600
   60 CALL NFLUX2                                                       00610
   50 CONTINUE                                                          00620
      IF(ABSF(MSHAPE-1))     900,905,900                                00630
  900 IF(ABSF(MSHAPE-2))    910,915,910                                 00640
  910 IF(ABSF(MSHAPE-3))    920,905,920                                 00650
  920 IF(ABSF(MSHAPE-4))     925,905,925                                00660
  925 IF(ABSF(MSHAPE-5))   930,915,930                                  00670
  930 IF(ABSF(MSHAPE-6))  940,915,940                                   00680
  940 IF(ABSF(MSHAPE-7))  915,915,915                                   00690
  905 BMAOA=CFXLOX/QACHEN                                               00700
      CC=CFXLOX/QADENG                                                  00710
      DELTEN=(POWERX-(POWERT-POWERA))/FLMASS                            00720
      GO TO 1000                                                        00730
  915 BMAOA=CFXLOY/QACHEN                                               00740
      CC=CFXLOY/QADENG                                                  00750
      DELTEN=(POWERY-(POWERT-POWERA))/FLMASS                            00760
 1000 PRINT 3000,DELTEN,BMAOA,CC                                        00770
 3000 FORMAT(40H DELTA ENTHALPY ANNULAR TRANS TO LOCAL =F9.2,           00780
     1 37H LOCAL FLUX OVER FLUX FOR NUCLEATION=F8.2,                    00790
     2  13H RATIO DENG =F8.2)                                          00800
      RETURN                                                            00810
      END                                                               00820
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      SUBROUTINE XRAD                                                   00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOQ,ONEOVM,      00060
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     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,                00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                  00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,              00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                        00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ       00110
      COMMON QUALIA,GLIQ,TKINCH,                                         00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1, 00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00180
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       00190
      COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                  00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,         00210
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,              00220
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                             00230
      A=ENFGPX*77R.0/85.5                                                00330
      B=(P*144.0)/SURFTL                                                 00340
      DX=QADENG/THCOND
      TWALL=DTDENG+T+460.0
      COLM1=2.0*A*B*TWALL*TWALL/DX
      COLM2=4.0*TWALL*A
      COLM3=A*A
      SUM1=A+(2.0*TWALL)
      SUM2=COLM1+COLM2+COLM3
      SUM3=(2.0*DX)-(A*B)
      RADIUS=(SUM1-SQRTF(SUM2))/SUM3
      PRINT  20,RADIUS
   20 FORMAT(48H LARGEST RADIUS(FT) NEEDED FOR NUCLEATION$$DENG=E10.4)
      DX=QACHEN/THCOND)                                                  00350
      TWALL=DELTT+T+460.0                                                00360
      COLM1=2.0*A*B*TWALL*TWALL/DX                                       00370
      COLM2=4.0*TWALL*A                                                  00380
      COLM3=A*A                                                          00390
      SUM1=A+(2.0*TWALL)                                                 00400
      SUM2=COLM1+COLM2+COLM3                                             00410
      SUM3=(2.0*DX)-(A*B)                                                00420
      RADIUS=(SUM1-SQRTF(SUM2))/SUM3                                     00430
      PRINT 10,RADIUS                                                    00440
   10 FORMAT(48H LARGEST RADIUS(FT) NEEDED FOR NUCLEATION$$CHEN=E10.4)
      RETURN                                                             00460
      END                                                                00470



      SUBROUTINE XHCHEN
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00010
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,            00020
     2 DMEFX,ENFPX,DMEFGX,ENFGPX,ENSIN,QUALIN,POWERT,AREAFL,APEAIS,      00030
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,         00040
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,       00050
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,                00060
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                  00070
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,              00080
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                        00090
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ       00100
      COMMON QUALIA,GLIQ,TKINCH,                                         00110
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1, 00120
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00130
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00140
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00150
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00160
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00170
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       00180
      COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                  00190
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,         00200
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,              00210
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                             00220
      CALL XDELTV                                                        00230
      CALL XFCHEN                                                        00240
      REYNLQ=(GTOT*DIAINS*(1.0-QUALOX))/(12.0* VISCL)                    00250
      CALL XSCHEN                                                        00270
      HMAC=0.023*(REYNLQ**0.8)*(PRNUMB**0.4)*THCOND* FCHEN               00275
     1  *(12.0/DIAINS)                                                   00280
      TERM1 =(THCOND**0.79)*( CPLIQ**0.45)*(VOLSPG**0.24)*               00290
     1 (4.17E+8**0.25)                                                   00300
      TERM2 =(SURFTL**0.5)*( VISCL**0.29)*(ENFGPX**0.24)*                00310
     1  (VOLSPL**0.49)                                                   00320
      TERM3=SCHEN*0.00122*(TERM1/TERM2)                                  00330
      HMIC=TERM3*(DELTT**0.24)*(ABSF(DELTVP)**0.75)                      00340
      HCHEN=HMAC+HMIC                                                    00360
      PRINT 100,T,VISCL,THCOND,CPLIQ,SURFTL,VISCG                        00370
      PRINT 150,P,ENFGPX,VOLSPG,VOLSPL                                   00380
      PRINT 200,SATP,DELTVP,PRNUMB,XTT,FCHEN,SCHEN,REYNLQ                00390
      PRINT 300,HMAC,HMIC,HCHEN                                          00400
  100 FORMAT(8H SATTMP=E10.4,  7H VISCL=E10.4,  8H THCOND=E10.4,         00410
     1  7H CPLIQ=E10.4,  8H SURFTL=E10.4, 7H VISCG=E10.4)                00420
  150 FORMAT(4H P =E10.4,9H ENFGPX =E10.4,9H VOLSPG =E10.4,              00430
     1 9H VOLSPL =E10.4)                                                 00431
  200 FORMAT(6H SATP=E10.4,8H DELTVP=E10.4,8H PRNUMB=E10.4,              00440
     1 5H XTT=E10.4,7H FCHEN=E10.4,  7H SCHEN=E10.4,8H REYNLQ=E10.4)     00450
  300 FORMAT(6H HMAC=E10.4,6H HMIC=E10.4,7H HCHEN=E10.4  )               00460
      RETURN                                                             00470
      END                                                                00480



      SUBROUTINE XTHCON                                                  00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,            00030
     2 DMEFX,ENFPX,DMEFGX,ENFGPX,ENSIN,QUALIN,POWERT,AREAFL,APEAIS,      00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,         00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,       00060
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,                00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                  00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,              00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                        00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ       00110
      COMMON QUALIA,GLIQ,TKINCH,                                         00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1, 00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00150
     4GTOT,DPMOM,7RDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00180
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       00190
      COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                  00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,         00210
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,              00220
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                             00230
      CALL SATTMP                                                        00240
      IF(T-80.0)  10,20,20                                               00250
   20 IF(T-130.0)  30,40,40                                              00260
   40 IF(T-180.0)  50,60,60                                              00270
   60 IF(T-230.0)  70,80,80                                              00280
   80 IF(T-280.0)  90,100,100                                            00290
  100 IF(T-380.0)  110,120,120                                           00300
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120  IF(T-500.0) 130,140,140                                          00310
140  IF(T-550.0)  150,160,160                                         00320
160  IF(T-600.0)  170,180,180                                         00330
180  IF(T-650.0)  190,200,200                                         00340
200  IF(T-690.0)  210,210,220                                         00350
10   THCOND=(.700E-3*T)+.302                                          00360
     RETURN                                                           00370
30   THCOND=(.486E-3*T)+.315                                          00380
     RETURN                                                           00390
50   THCOND=(.266E-3*T)+.3426                                         00400
     RETURN                                                           00410
70   THCOND=(.0834E-3*T)+.376                                         00420
     RETURN                                                           00430
90   THCOND=.3960                                                     00440
     RETURN                                                           00450
110  THCOND=(-.1595E-3*T)+.447                                        00460
     RETURN                                                           00470
130  THCOND=(-.318E-3*T)+.504                                         00480
     RETURN                                                           00490
150  THCOND=(-.496E-3*T)+.5974                                        00500
     RETURN                                                           00510
170  THCOND=(-.655E-3*T)+.6849                                        00520
     RETURN                                                           00530
190  THCOND=(-.931E-3*T)+.8504                                        00540
     RETURN                                                           00550
210  THCOND=(-1.5E-3*T)+1.22                                          00560
     RETURN                                                           00570
220  THCOND=.1854                                                     00580
     RETURN                                                           00590
     END                                                              00600
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     SUBROUTINE XCPLIQ                                                00010
C    LIMITS ON THIS SUBROUTINE ARE 32 DEG F (CPLIQ =1.000)            00020
C    AND 650 DEG F (CPLIQ =2.09)  DATA FROM WELLMAN THESIS            00030
     COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,00040
    1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,          00050
    2 DMEFX,ENFPX,DMEFGX,ENFGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,    00060
    3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,       00070
    4PRREAK,POWEPX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,     00080
    5 COSLEN,ONEMSQ,SIGMZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,              00090
    6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                00100
    7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,            00110
    8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                      00120
    9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ     00130
     COMMON QUALIA,GLIQ,TKINCH,                                       00140
    1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUMO,SUM1,00150
    2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,00160
    3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,00170
    4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,  00180
    5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,00190
    6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,00200
    7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC     00210
     COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                00220
    1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,FFYNLQ,NFLUX,       00230
    2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,            00240
    3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                           00250
     CALL SATTMP                                                      00260
     IF(T-160.0)  10,20,20                                            00270
20   IF(T-240.0)  30,40,40                                            00280
40   IF(T-320.0)  50,60,60                                            00290
60   IF(T-450.0)  70,80,80                                            00300
80   IF(T-500.0)  90,100,100                                          00310
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100  IF(T-550.0)  110,120,120                                         00320
120  IF(T-600.0)  130,140,140                                         00330
140  IF(T-630.0)  150,160,160                                         00340
160  IF(T-650.0)  170,170,180                                         00350
10   CPLIQ =1.000                                                     00360
     RETURN                                                           00370
30   CPLIQ =(1.5E-4*T)+.976                                           00380
     RETURN                                                           00390
50   CPLIQ =(2.88E-4*T)+.943                                          00400
     RETURN                                                           00410
70   CPLIQ =(6.61E-4*T)+.823                                          00420
     RETURN                                                           00430
90   CPLIQ =(13.0E-4*T)+.536                                          00440
     RETURN                                                           00450
110  CPLIQ =(24.8E-4*T)-.056                                          00460
     RETURN                                                           00470
130  CPLIQ =(40.0E-4*T)-.890                                          00480
     RETURN                                                           00490
150  CPLIQ =(66.67E-4*T)-2.50                                         00500
     RETURN                                                           00510
170  CPLIQ =(190.0E-4*T)-10.24                                        00520
     RETURN                                                           00530
180  CPLIQ =2.09                                                      00540
     RETURN                                                           00550
     END                                                              00560
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     SUBROUTINE XSURFT                                                00010
     COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,00020
    1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,          00030
    2 DMEFX,ENFPX,DMEFGX,ENFGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,    00040
    3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,       00050
    4PRREAK,POWEPX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,     00060
    5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,              00070
    6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                00080
    7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,            00090
    8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                      00100
    9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ     00110
     COMMON QUALIA,GLIQ,TKINCH,                                       00120
    1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUMO,SUM1,00130
    2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,00140
    3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,00150
    4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,  00160
    5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,00170
    6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,00180
    7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC     00190
     COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                00200
    1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,FFYNLQ,NFLUX,       00210
    2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,            00220
    3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                           00230
     IF(P-1000.0)  5,5,10                                             00240
5    CONTINUE                                                         00250
     SUM1=+6.3225462E+1-3.2677020E-1*P+2.8126518E-3*(P*P)             00260
    1 -1.7494856E-5*(P*P*P) +6.8880390E-8*(P*P*P*P)                   00270
    2 -1.7378005E-10*(P**5) +2.8461426E-13*(P**6)                     00280
    3 -3.0063514E-16*(P**7) +1.9734415E-19*(P**8)                     00290
    4 -7.3149007E-23*(P**9) +1.1689972E-26*(P**10)                    00300
     SURFTL=SUM1*2.24E-6*2.54*12.0                                    00310
     RETURN                                                           00320
10   CALL SATTMP                                                      00330
     IF(T-610.0)  15,15,20                                            00340
15   SUM1=33.8-(6.45*LOGF(T)  )                                       00350
     SURFTL=EXPF(SUM1)                                                00360
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      RETURN                                                            00370
   20 SUM1=63.6 -(11.1*LOGE(T)  )                                       00380
      SURFTL=EXPE(SUM1)                                                 00390
      RETURN                                                            00400
      END                                                               00410



      SUBROUTINE XSATP                                                  00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENFPX,DMEFGX,ENFGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PRREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
     5 COSLEN,ONEMSO,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIO,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSURL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   00160
     5DVISCL,REYNUM,EFACTP,EFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS, 00180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC      00190
      COMMON N,M,THCOND,ECHEN,SCHEN,VISCG,CPLIQ,SURFTL,                 00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,        00210
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,             00220
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                             00230
      COLM1=647.27                                                      00240
      COLM2=((T-32.0)/1.8) +273.16                                      00250
      SMALLT=COLM1-COLM2                                                00260
      SUM4 =3206.182                                                    00270
      IF (T-200.0)  5,5,10                                              00280
    5 SUM1 =1.0+(SMALLT*2.1878462E-3      )                           00290
      SUM2 =3.2437814+ (SMALLT*5.86*26E-3) +(SMALLT*SMALLT*             00300
     1 SMALLT*1.1702276E-5)                                             00310
      GO TO 15                                                          00320
   10 SUM1 =1.0+(SMALLT*1.3794481E-2)                                   00330
      SUM2 =3.2463130 +(SMALLT*4.14113E-2)                              00340
     1 +((SMALLT**3)*7.515484E-9) +((SMALLT**4)*6.56444E-11)            00350
   15 SUM3=(SMALLT*SUM2)/(COLM2*SUM1)                                   00360
      SATP=SUM4/(10.00**SUM3)                                           00370
      RETURN                                                            00380
      END                                                               00390



      SUBROUTINE XVISCG                                                 00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENFPX,DMEFGX,ENFGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PRREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
     5 COSLEN,ONEMSO,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIO,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSURL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   00160
     5DVISCL,REYNUM,EFACTP,EFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS, 00180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC      00190
      COMMON N,M,THCOND,ECHEN,SCHEN,VISCG,CPLIQ,SURFTL,                 00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,        00210
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,             00220
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                             00230
      COLM1=647.27                                                      00240
      COLM2=((T-32.0)/1.8) +273.16                                      00250
      SMALLT=COLM1-COLM2                                                00260
      SUM4 =3206.182                                                    00270
      IF (T-500.0)  5,5,10                                              00280
    5 COLM1 =2.1350E-4*(GSUBZ*GSUBZ)                                    00290
      COLM2 =(1858.0-(5.90*GSUBZ))/VOLSPG                               00300
      COLM3 =88.020+(.02827*GSUBZ)                                      00310
      VISCG=2.419E-4*(COLM3 +COLM1  -(1.6018E-2*COLI'2))                00320
      RETURN                                                            00330
   10 SUM1= 4.20*SQRTF(T)                                               00335
      TERM1=-30.0/T                                                     00340
      SUM3  =10.0**TERM1                                                00350
      SUM2  =1.0+ (2600.0/T)*SUM3                                       00355
      TERM2=.0906/VOLSPG                                                00360
      SUM5=((10.00**TERM2)  -1.0)                                       00370
      SUM4  =1.5*SUM5                                                   00380
      VISCG=2.419E-3*(( SUM1/SUM2)+SUM4)                                00395
      RETURN                                                            00400
      END
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      SUBROUTINE XDELTV                                                 00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENFPX,DMEFGX,ENFGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PRREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
     5 COSLEN,ONEMSO,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIO,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSURL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   00160
     5DVISCL,REYNUM,EFACTP,EFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS, 00180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC      00190
      COMMON N,M,THCOND,ECHEN,SCHEN,VISCG,CPLIQ,SURFTL,                 00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,        00210
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,             00220
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                             00230
      CALL SATTMP                                                       00240
      TWALL=DELTT+T                                                     00250
      T=TWALL                                                           00260
      CALL XSATP                                                        00270
      CALL SATTMP                                                       00280
      DELTVP=(SATP-P)*144.0                                             00290
      RETURN                                                            00300
      END                                                               00310
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      SUBROUTINE XXTT                                                   00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIQ,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO, 00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS, 00180
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC      00190
      COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                 00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLO,NFLUX,        00210
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,             00220
     3 DTCHEN,RADMAX,DELTFN,RADIUS,CC,DD,FF                             00230
      FILMTK=(((1.000-QUALOX)/QUALOX)**.9)                              00240
      CALL SPECVG                                                       00250
      CALL SPECVL                                                       00260
      YPLUS=((VOLSPL/VOLSPG)**.5)                                       00270
      CALL VISCOS                                                       00280
      CALL XVISCG                                                       00290
      TAUWAL=((VISCL/VISCG)**.1)                                        00300
      PRINT 10,QUALOX,FILMTK,YPLUS,TAUWAL                               00310
    1 FORMAT(9H QUALOX =F10.4,19H QUAL RATIO **.9  =F10.4,              00320
     119H SPVOL RATIO **.5 =F10.4,20H VISCOS RATIO **.1 =F10.4)         00330
      XTT=FILMTK*YPLUS*TAUWAL                                           00340
      RETURN                                                            00350
      END                                                               00360


      SUBROUTINE XFCHEN                                                 00010
C     LIMITS ON THIS SUBROUTINE ARE 1/XTT GREATER THAN .1(FGREATER THAN 00020
C     1.0)  AND (1.0/XTT) LESS THAN  100(F LESS THAN 70)                00030
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00040
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00050
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00060
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00070
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00080
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00090
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00100
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00110
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00120
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00130
      COMMON QUALIA,GLIQ,TKINCH,                                        00140
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00150
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO, 00160
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00170
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   00180
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00190
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS, 00200

     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC       00210
      COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                 00220
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLO,NFLUX,        00230
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,             00240
     3 DTCHEN,RADMAX,DELTFN,RADIUS,CC,DD,FF                             00250
      CALL XXTT                                                         00260
      DD=1.0/XTT                                                        00270
      IF(DD-.10)  10,20,20                                              00280
   20 IF(DD-.33)  30,40,40                                              00290
   40 IF(DD-1.5)  50,60,60                                              00300
   60 IF(DD-1000.0)   70,70,80
   10 FCHEN=1.0                                                         00320
      RETURN                                                            00330
   30 FCHEN=2.17*(DD**.336)                                             00340
      RETURN                                                            00350
   50 FCHEN=2.785*(DD**.561)                                            00360
      RETURN                                                            00370
   70 FCHEN=2.511*(DD**.716)                                            00380
      RETURN                                                            00390
   80 FHCHEN=344.0
      PRINT 90,FCHEN
   90 FORMAT(48H QUALOX(1/XTT)TOO LARGE EXCEEDS ALLOWED LIMITS =E10.4)
      RETURN                                                            00410
      END                                                               00420


      SUBROUTINE XSCHEN                                                 00010
C     LIMITS ON THIS SUBROUTINE ARE EE GREATER THAN 2E+4 (S=.80)        00020
C     AND EE LESS THAN 1E+6 (S=.1)                                      00030
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00040
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00050
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00060
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00070
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00080
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00090
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00100
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00110
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00120
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00130
      COMMON QUALIA,GLIQ,TKINCH,                                        00140
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00150
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO, 00160
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00170
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   00180
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00190
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS, 00200
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC      00210
      COMMON N,M,THCOND,FCHEN,SCHEN,VISCG,CPLIQ,SURFTL,                 00220
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLO,NFLUX,        00230
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,             00240
     3 DTCHEN,RADMAX,DELTFN,RADIUS,CC,DD,FF                             00250
      EE=(FCHEN**1.25)*REYNLO                                           00260
      IF(FF-20000.0)  10,20,20                                          00270
   20 IF(FF-70000.0)  30,40,40                                          00280
   40 IF(FF-450000.0)  50,60,60                                         00290
   10 SCHEN=.80                                                         00300
      RETURN                                                            00310
   30 SCHEN=6.15/(EE**.204)                                             00320
      RETURN                                                            00330
   50 SCHEN=4800.0/(EE**.825)                                           00340
      RETURN                                                            00350
   60 SCHEN=.10                                                         00360
      RETURN                                                            00370
      END                                                               00380
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```
      SUBROUTINE NFLUX2
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,
     1 PRESD,PRESIN,PRESOT,PESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,
     2 DMEFX,ENERX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,
     4PRBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,
     8 EXTRAA,EXTRAP,EXTRAC,EXTRAD,EXTRAE,EXTRAF,
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ
      COMMON QUALIA,GLIQ,TKINCH,
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC
      COMMON N,M,THCOND,ECHEN,SCHEN,VISCG,CPLIQ,SURFTL,
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE
      RETURN
      END
      SUBROUTINE FILMER
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,
     1 PRESD,PRESIN,PRESOT,PESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,
     2 DMEFX,ENERX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,
     4PRBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,
     8 EXTRAA,EXTRAP,EXTRAC,EXTRAD,EXTRAE,EXTRAF,
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ
      COMMON QUALIA,GLIQ,TKINCH,
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC
      COMMON N,M,THCOND,ECHEN,SCHEN,VISCG,CPLIQ,SURFTL,
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE
      IF(ABSF(MSHAPE-1))     900,905,900
  910 IF(ABSF(MSHAPE-2))     910,915,910
  920 IF(ABSF(MSHAPE-3))     920,905,920
  925 IF(ABSF(MSHAPE-4))     925,905,925
  930 IF(ABSF(MSHAPE-5))   930,915,930
  940 IF(ABSF(MSHAPE-6))   940,915,940
  945 IF(ABSF(MSHAPE-7))   915,915,915
  915 IF(POWERY-10.0)    1,1,2
  905 IF(POWERX-10.0)    1,1,2
    1 CALL BONUCF
      GO TO 180
    2 IF(QUALOX-QUALIA)  180,3,3
    3 CALL LONUCF
    4 CALL SPECVL
      DVLSPL=VOLSPL
      CALL SPECVG
      DVLSPG=VOLSPG
      TERM1=((DVLSPG/DVLSPL)**.333)
      GGAS=QUALOX*GTOT
      GLIQ=(1.00-QUALOX)*GTOT
      TERM2=3600.0/(DVLSPG*GGAS)
      CALL SATTMP
      CALL VISCOS
      DVISCL=VISCL
      DT=T
      REYNUM=(GTOT*DIAINS)/(DVISCL*12.0)
      IF(REYNUM-2500.0)5,5,10
    5 FFACTP=16.0/REYNUM
      GO TO 15
   10 FFACTP=0.046/(REYNUM**0.2)
   15 FFACT=4.0*FFACTP
      VELOC=(GTOT*DVLSPL)/3600.0
      GRDFS=(-FFACT*VELOC*VELOC)/(2.0*32.2*(DIAINS/12.0)*DVLSPL)
      CALL MNPGRD
      DPGMLT=ABSF(PGMULT)
      GRDFT=GRDFS*DPGMLT
        IF(EXTRAJ-0.0) 23,21,23
   21  DGRDMT=-ABSF(DUMMYA)
       GO TO 28
   23  CALL  HOMMGD
        DGRDMT=-ABSF(GRDMT)
   28   IF(DGRDMT+99000.0)  26,26,27
   26   DGRDMT=0.0
   27   CONTINUE
   24  GRDTOT=GRDFT+DGRDMT
      B=(DIAINS/12.0)/2.0
      GRAVAC=32.2
      GRAVCS=32.2
      PRINT 100,DPGMLT,DGRDMT,GRDFT,GRDTOT
      PRINT 110,GGAS,GLIQ
      PRINT 120,DVLSPL,DVLSPG,DT,DVISCL
      PRINT 130,REYNUM,FFACT,VELOC,GRDFS,FFACTP
      TERM3=SQRTF(ABSF((GRDTOT*B*32.2*DVLSPL)/2.0))
      IF(-GRDTOT-(GRAVAC/(GRAVCS*DVLSPL))) 25,20,20
   20 VALUEN=0.0
      GO TO 30
   25 VALUEN=-0.333
   30 TERM4=((GRAVAC/(GRAVCS*DVLSPL*(-GRDTOT)))**VALUEN)
      FACTUN=TERM1*TERM2*TERM3*TERM4
      PRINT 135,TERM1,TERM2,TERM3,TERM4
       CALL UNIVER
      BMAOA=BMAOA
      A=B*(1.00-ABSF(DBMAOA)  )
      FILMTK=BMAOA*B
      TKINCH=12.0*FILMTK
      TAUWAL=(B/2.0)*(-GRDTOT-(1.00-((A*A)/(B*B)))*(GRAVAC/(GRAVCS*DVL
     1SPL)))
      YPLUS=((B-A)/(DVLSPL*DVISCL))*(SQRTF(TAUWAL*DVLSPL*4.17E+8))
      IF(YPLUS-5.0)40,40,35
   35 IF(YPLUS-30.0)45,45,50
   40 FYPLUS=0.50*YPLUS*YPLUS
      GO TO 55
   45 FYPLUS=12.5-(8.05*YPLUS)+(5.0*YPLUS*LOGF(YPLUS))
      GO TO 55
   50 FYPLUS=(3.0*YPLUS)+(2.5*YPLUS*LOGF(YPLUS))-64.0
   55 GFILM=(2.0*DVISCL*FYPLUS)/B
      GLQENT=GLIQ-GFILM
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      PCLIQ=GLIQ/GTOT                                                   01000
      PCLENT=GLQENT/GLIQ                                                01010
   60 EXTRAJ=QUALOX                                                     01020
   70  EXTRAI=DVLSPG                                                   01030
      EXTRAH=DVLSPL                                                     01040
      PRINT 140,VALUEN,FACTUN,DBMAOA                                    01050
      PRINT 150,TAUWAL,YPLUS,FYPLUS                                     01060
      PRINT 160,TKINCH,GFILM,GLQENT                                     01070
      PRINT 170,PCLIQ,PCLENT                                            01080
  100 FORMAT(10H DPGMLT  =F8.1,10H  DGRDMT =F8.1,10H   GRDFT =F8.1,     01090
     111H   GRDTOT =F8.1)                                              01100
  110 FORMAT(7H GGAS =1PE10.3,8H  GLIQ =1PE10.3)                        01110
  120 FORMAT(9H DVLSPL =F8.4,11H   DVLSPG =F8.4,7H   DT =F8.2,          01120
     1 11H   DVISCL =F8.3)                                              01130
  130 FORMAT(9H REYNUM =1PE8.2,10H   FFACT =0PF8.5,10H   VELOC =F8.2,   01140
     110H   GRDFS =F8.2,11H   FFACTP =F8.5)                            01150
  135 FORMAT(8H TERM1 =F10.4,9H  TERM2 =F10.6,9H  TERM3 =F10.3,         01160
     1 9H  TERM4 =F10.4)                                                01170
  140 FORMAT(9H VALUEN =F8.3,11H   FACTUN =F8.4,11H   DBMAOA =F8.4)     01180
  150 FORMAT(9H TAUWAL =F10.2,9H  YPLUS =1PE10.3,11H   FYPLUS =1PE10.3) 01190
  160 FORMAT(9H TKINCH =F10.6,9H  GFILM =1PE10.2,10H  GLQENT =1PE10.2)  01200
  170 FORMAT(26H PERCENT LIQUID OF TOTAL =F10.2,                        01210
     1 46H   PERCENT OF LIQUID FLOW WHICH IS ENTRAINED =F10.2)          01220
  180 CONTINUE                                                          01230
      RETURN                                                            01240
      END                                                               01250
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      SUBROUTINE HOMMGD                                                 00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS, 00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
     5 COSLEN,ONEMSO,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIQ,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1, 00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO, 00140
     3VOLSPG,QUAL04,POWERA,PANBOL,DENEO,DENEGO,ENSO,QUALO,DVSPLO,DVSPGO, 00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS, 00180
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC      00190
      COMMON N,Y,THCOND,ECHEN,SCHEN,VISCG,CPLIQ,SUBFTL,                 00200
     1XTT,SATP,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLO,NFLUX,        00210
     2  DONUMB,REDGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,             00220
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                             00230
      GTOT=FLMASS/AREAFL                                                00240
      DPMOM=-((GTOT*GTOT)/4.17E+8)*                                     00250
     1 ((DVLSPL*(1.00-QUALOX+QUALOX*(DVLSPG/DVLSPL)))                   00260
     2 -(EXTRAH*(1.00-EXTRAJ+EXTRAJ*(EXTRAI/EXTRAH) ) ) )               00270
      IF(MSHAPE-4)   5,5,10                                             00280
    5  I=3                                                             00290
      DUMMYB=I                                                          00300
      GO TO 15                                                          00310
   10 IF (MSHAPE-7)  11,12,12                                           00320
   12 IF(Y-(XLNGTH-SCRPTL))  5,5,13                                     00330
   13  IF(Y-(XLNGTH-SCRPTL+PLNGTH))  14,14,16                           00340
   14 ZETA=J                                                            00350
      DUMMYB=ZETA/8.0                                                   00355
      GO TO 15                                                          00360
   16 DUMMYB=Y-(XLNGTH-SCRPTL+PLNGTH)                                   00370
      GO TO 15                                                          00380
   11 I=2                                                               00390
      DUMMYB=I                                                          00400
   15 GRDMT=DPMOM/(DUMMYB/12.0)                                         00410
      PRINT 20,DUMMYB,EXTRAJ,EXTRAI,EXTRAH                              00420
   20 FORMAT(9H DUMMYB =F6.2,27H QUALOX CONTROL VOL INLET =F8.2,        00430
     1 27H DVLSPG CONTROL VOL INLET =F8.4,                              00440
     227H DVLSPL CONTROL VOL INLET =F8.4)                               00450
      RETURN                                                            00460
      END                                                               00470
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      SUBROUTINE GRDMOM                                                 00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS, 00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
     5 COSLEN,ONEMSO,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIQ,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1, 00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO, 00140
     3VOLSPG,QUAL04,POWERA,PANBOL,DENEO,DENEGO,ENSO,QUALO,DVSPLO,DVSPGO, 00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   00160
     5DVISCL,REYNUM,FFACTP,FFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS, 00180
     7TAUWAL,FYPLUS,GFILM,GLQENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC      00190
      END=ENTHIN+(POWERT/FLMASS)                                        00200
      P=PRESOT                                                          00210
      CALL LIQEN                                                        00220
      DENEO=ENEPX                                                       00230
      CALL EVAPEN                                                       00240
      DENEGO=ENEGPX                                                     00250
      ENSO=ENO-DENEO                                                    00260
      QUALO=ENSO/DENEGO                                                 00270
      CALL SPECVL                                                       00280
      DVSPLO=VOLSPL                                                     00290
      CALL SPECVG                                                       00300
      DVSPGO=VOLSPG                                                     00310
      GTOT=FLMASS/AREAFL                                                00320
      DPMOM=((GTOT*GTOT*DVSPLO)/4.17E+8)*((1.00-QUALO)+(QUALO*(DVSPGO/DV 00330
     1SPLO))-1.00)                                                      00340
      DUMMYA=(-DPMOM)/(XLNGTH/12.0)                                     00350
        PRINT 175,DUMMYA                                                00360
  175  FORMAT(38H  DGRMT BASED ON LINEAR MOM GRADIENT =F12.1)
      RETURN                                                            00360
      END                                                               00370
```

```
      SUBROUTINE MNPGRD                                                 00010
C     LIMITS ON THE APPLICATION OF THIS SUBROUTINE ARE 70PERCENT QUALITY 00020
C     1 AND 2500 PSIA PRESSURE                                          00030
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS, 00040
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00050
```

```
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,      00060
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,        00070
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00080
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00090
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00100
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00110
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00120
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00130
      COMMON QUALIA,GLIO,TKINCH,                                        00140
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00150
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00160
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00170
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00180
     5DVISCL,REYNUM,FFACTP,FFACT,VFLOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00190
     6R,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00200
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLFNT,DUMMYA,DUMMYB,DUMMYC       00210
      DP=P/1000.0                                                       00220
      DX=LOGE(100.0*QUALOX +1.0)                                        00230
        COLM1=(DX)*(2.5448316 -7.8896201*DP +1.5575870E+1*(DP*DP)       00240
     1 -1.7340906E+1*(DP*DP*DP) +1.0409842E+1*(DP*DP*DP*DP)             00250
     2 -3.2044877*(DP*DP*DP*DP*DP) +6.2484805E-1*(DP*DP*DP*DP*DP*DP)    00260
     3 -1.0804971E-2*(DP*DP*DP*DP*DP*DP*DP)    )                       00270
      COLM2 =(DX*DX)*(-5.1756752E-1 +1.9550200*DP -9.6886164E-1*(DP*DP) 00280
     1 -4.6120079*(DP*DP*DP) +8.491034*(DP*DP*DP*DP)                    00290
     2 -5.958309?*(DP*DP*DP*DP*DP) +1.8989183*(DP*DP*DP*DP*DP*DP)       00300
     3 -2.2867680E-1*(DP*DP*DP*DP*DP*DP*DP)    )                       00310
      COLM3 =(DX*DX*DX)*(1.0193956E-1 -3.7233785E-1*DP                  00320
     1 -1.9025685E-1*(DP*DP) +2.2654839*(DP*DP*DP)                      00330
     2 -3.4025414*(DP*DP*DP*DP) +2.3299085*(DP*DP*DP*DP*DP)             00340
     3 -7.2534973E-1*(DP*DP*DP*DP*DP*DP) +8.6169847E-2*(DP*DP*DP*DP*DP  00350
     4 *DP*DP)    )                                                     00360
      COLM4=(DX*DX*DX*DX)*(-8.0606798E-3 +(2.6160876E-2 *DP)            00370
     1 +6.0288725E-2*(DP*DP) -3.2426871E-1*(DP*DP*DP)                   00380
     2 +4.6553847E-1*(DP*DP*DP*DP) -3.0333482E-1*(DP*DP*DP*DP*DP)       00390
     3+0.3379834E-2*(DP*DP*DP*DP*DP*DP) -1.1021915E-2*(DP*DP*DP*DP*DP   00400
     4 *DP*DP)    )                                                     00410
      SUMCOL=COLM1+COLM2+COLM3+COLM4                                    00420
      PHIMN=EXPE(SUMCOL)                                                00430
      GTOTSC=GTOT/3600.0                                                00440
       IF(GTOTSC-1000.0)          5,5,10                                00450
   5  GSUBZ=LOGE(0.0036*GTOTSC+0.2)                                     00460
       GO TO 15                                                         00470
  10   GSUBZ=LOGE(0.0036*1000.0+0.2)                                    00480
  15  SUM0=1.4012797-3.8229399E-5*P                                     00490
      SUM1= (-6.8082218E-2 -4.5200014E-4*P)*(GSUBZ)                     00500
      SUM2=(-8.3387593E-2 +1.2278415E-4*P)*(GSUBZ*GSUBZ)                00510
      SUM3=(3.5640886E-2 +1.5165216E-4*P)*(GSUBZ*GSUBZ*GSUBZ)           00520
      SUM4=(2.1855741E-2 -3.4296260E-5*P)*(GSUBZ*GSUBZ*GSUBZ*GSUBZ)     00530
      SUM5=(-6.7676795E-3-3.2820747E-5*P)                               00540
     1*(GSUBZ*GSUBZ*GSUBZ*GSUBZ*GSUBZ)                                  00550
       OMEGAP=SUM0+SUM1+SUM2+SUM3+SUM4+SUM5                             00560
      OMEGA=OMEGAP-0.4                                                  00570
      PGMULT=OMEGA*PHIMN                                                00580
       RETURN                                                           00590
      END                                                               00600
```

```
      SUBROUTINE  UNIVER
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,ROLOCA,XLNGTH,SHUNTM,P,            00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,      00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,         00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIO,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00160
     5DVISCL,REYNUM,FFACTP,FFACT,VFLOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00170
     6R,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLFNT,DUMMYA,DUMMYB,DUMMYC       00190
C       FOR N=0  REFER TO FIGURE 6 GEAP4615                             00200
C       FOR N=-0.333  REFER TO FIGURE 7  GEAP 4615                      00210
        IF(FACTUN-.250)  2,30,30                                        00220
   2    IF (VALUEN - 0.0)  7,9,7                                        00230
   7    IF (FACTUN-.046) 25,10,10                                       00240
   9    IF(FACTUN-.030)  20,5,5                                         00250
   5    BMAOA=+.94236102E-1-.73440465E+1*FACTUN+.18204540E+3*(FACTUN**2)00260
     1 -.13413306E+4*(FACTUN**3) -.55976792E+3*(FACTUN**4)              00270
     2 +.49524361E+5*(FACTUN**5) -.18569237E+6*(FACTUN**6)              00280
     3 -.56878640E+5*(FACTUN**7) +.23045481E+7*(FACTUN**8)              00290
     4 -.10236661E+8*(FACTUN**9) +.36205300E+8*(FACTUN**10)             00300
     5 -.13312636E+9*(FACTUN**11) -.44616646E+9*(FACTUN**12)            00310
     6 +.68296456E+10*(FACTUN**13) -.19259604E+11*(FACTUN**14)          00320
     7 +.12745609E+11*(FACTUN**15)                                      00330
       GO TO 35                                                         00340
  10  BMAOA=.97900332E-1 -.11388222E2*FACTUN +.38794992E3*(FACTUN**2)   00350
     1 -.48776956E4*(FACTUN**3) +.19313986E5*(FACTUN**4)                00360
     2 +.66295985E5*(FACTUN**5) -.12967245E6*(FACTUN**6)                00370
     3 -.53197482E7*(FACTUN**7) +.20432943E8*(FACTUN**8)                00380
       GO TO 35                                                         00390
  20   BMAOA=.0022                                                      00400
       GO TO 35                                                         00410
  25   BMAOA=.0159                                                      00420
       GO TO 35                                                         00430
  30   BMAOA=.250                                                       00440
  35   RETURN                                                           00450
       END                                                              00460
```

```
      SUBROUTINE SPECVL
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESP,PRESIN,PRESOT,RESDP,TSDP,ROLOCA,XLNGTH,SHUNTM,P,            00030
     2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,      00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CFXAVG,CFXLOX,JLOCAT,K,X,         00050
     4PBREAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,      00060
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CFXBO,L,Y,               00070
     6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIO,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,  00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO, 00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,    00160
     5DVISCL,REYNUM,FFACTP,FFACT,VFLOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT, 00170
     6R,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,  00180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLFNT,DUMMYA,DUMMYB,DUMMYC       00190
       IF (P-400.0)  5, 10,10                                           00200
   5   VOLSPL=1.6401745E-2 +2.3289060E-5*P -1.5364591E-7*(P*P)          00210
```

```
     1 +7.4158801E-10*(P*P*P) -2.1604007E-12*(P*P*P*P)
     2 +3.8901151E-15*(P*P*P*P*P) -4.3197213E-18*(P*P*P*P*P*P)
     3 +2.8681090E-21*(P*P*P*P*P*P*P) -1.0458372E-24*(P*P*P*P*P*P*P*P)
     4 +1.6082244E-28*(P*P*P*P*P*P*P*P*P)
       RETURN
  10 VOLSPL=1.7282154E-2 +5.5320054E-6*P -1.9348746E-9*(P*P)
     1 +5.6669056E-13*(P*P*P) -2.1537248E-17*(P*P*P*P)
       RETURN
       END



       SUBROUTINE SPECVC
       COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,     00020
      1 PRESP,PRESIN,PRESOT,PESDP,TSDP,ROLOCA,XLNGTH,SHUNTM,P,               00030
      2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,         00040
      3 QUALOL,SATL,PSATL,POWERR,PSLROL,CFXAVG,CFXLOX,JLOCAT,K,X,            00050
      4PROFAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,          00060
      5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIP,FACPLB,CFXBO,L,Y,                   00070
      6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                     00080
      7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,                 00090
      8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,
      9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ
       COMMON QUALIA,GLIQ,TKINCH,
      1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,
      2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,
      3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,
      4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,
      5DVISCL,REYNUM,FFACTP,FFACT,VFLOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,
      6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,
      7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC
       IF (P-200.0) 5,10,10
   5  VOLSPG=7.0026614E+1 -5.2270893*P +2.7026868E-1*(P*P)
      1 -5.7651685E-3*(P*P*P) +9.8819624E-5*(P*P*P*P)
      2 -1.1383329E-6*(P*P*P*P*P) +8.8808151E-9*(P*P*P*P*P*P)
      3 -4.6173317E-11*(P*P*P*P*P*P*P) +1.5321887E-13*(P*P*P*P*P*P*P*P)
      4 -2.9334747E-16*(P*P*P*P*P*P*P*P*P) +2.4643861E-19*(P*P*P*P*P*P*
      5  P*P*P)
       RETURN
  10 IF (P-400.0) 15, 20,20
  15 VOLSPG=9.1061359 -7.6308584E-2*P +3.4342061E-4*(P*P)
      1 -8.6304540E-7*(P*P*P) +1.1495386E-9*(P*P*P*P)
      2 -6.3157880E-13*(P*P*P*P*P)
       RETURN
  20  VOLSPG=4.2020747 -1.5646162E-2*P +3.5532997E-5*(P*P)
      1 -4.5698872E-8*(P*P*P) +3.6139355E-11*(P*P*P*P)
      2 -1.7192114E-14*(P*P*P*P*P) +4.4050A00E-18*(P*P*P*P*P*P)
      3 -4.9609894E-22*(P*P*P*P*P*P*P)
       RETURN
       END



       SUBROUTINE SATTMP
C      LIMITS ON THE APPLICATION OF THIS SUBROUTINE ARE ABOVE .2PSIA
C     1 AND BELOW 3206.0 PSIA
       COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,     00020
      1 PRESP,PRESIN,PRESOT,PESDP,TSDP,ROLOCA,XLNGTH,SHUNTM,P,               00030
      2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,         00040
      3 QUALOL,SATL,PSATL,POWERR,PSLROL,CFXAVG,CFXLOX,JLOCAT,K,X,            00050
      4PROFAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,          00060
      5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIP,FACPLB,CFXBO,L,Y,                   00070
      6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                     00080
      7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,                 00090
      8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,
      9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ
       COMMON QUALIA,GLIQ,TKINCH,
      1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,
      2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,
      3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,
      4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,
      5DVISCL,REYNUM,FFACTP,FFACT,VFLOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,
      6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,
      7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC
       CALL SATTMP
       IF(T-600.0)  5,5,10
   5   CONTINUE
       VISCL=8.0144599 -1.6728317E-1*T +2.0423535E-3*(T*T)
      1 -1.6324668E-5*(T*T*T) +8.8555744E-8*(T*T*T*T)
      2 -3.3015965E-10*(T*T*T*T*T) +8.4382483E-13*(T*T*T*T*T*T)
      3 -1.4493830E-15*(T*T*T*T*T*T*T) +1.5963800E-18*(T*T*T*T*T*T*T*T)
      4  -1.0173273E-21*(T*T*T*T*T*T*T*T*T)
      5  +2.8496174E-25*(T*T*T*T*T*T*T*T*T*T)
       RETURN
  10   IF(T-642.5)  15,20,20
  20   IF(T-675.0)  25,30,30
  30   IF(T-690.0)  35,35,40
  15   VISCL=.5100-.00050*T
       RETURN
  25   VISCL=.6310-.00069*T
       RETURN
  35   VISCL=.9985-.00123*T
```

```
       SUBROUTINE VISCOS                                                     00010
       COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,     00020
      1 PRESP,PRESIN,PRESOT,PESDP,TSDP,ROLOCA,XLNGTH,SHUNTM,P,               00030
      2 DMEFX,ENEPX,DMEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,         00040
      3 QUALOL,SATL,PSATL,POWERR,PSLROL,CFXAVG,CFXLOX,JLOCAT,K,X,            00050
      4PROFAK,POWERX,ENLOX,ENSLOX,QUALOX,DMEFY,DMEFGY,POWOO,ONEOVM,          00060
      5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIP,FACPLB,CFXBO,L,Y,                   00070
      6 FACTMI,POWERY,CFXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                     00080
      7CONSTP,SCRPTL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,                 00090
      8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                          00100
      9DMEFB,DMEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ         00110
       COMMON QUALIA,GLIQ,TKINCH,                                           00120
      1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,   00130
      2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO,    00140
      3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,   00150
      4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,      00160
      5DVISCL,REYNUM,FFACTP,FFACT,VFLOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,   00170
      6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMAOA,DBMAOA,A,FILMTK,YPLUS,    00180
      7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC         00190
       IF(T-600.0)  5,5,10                                                  00200
   5   CONTINUE                                                             00205
       VISCL=8.0144599 -1.6728317E-1*T +2.0423535E-3*(T*T)                  00207
      1 -1.6324668E-5*(T*T*T) +8.8555744E-8*(T*T*T*T)                       00210
      2 -3.3015965E-10*(T*T*T*T*T) +8.4382483E-13*(T*T*T*T*T*T)             00220
      3 -1.4493830E-15*(T*T*T*T*T*T*T) +1.5963800E-18*(T*T*T*T*T*T*T*T)     00230
      4  -1.0173273E-21*(T*T*T*T*T*T*T*T*T)                                00240
      5  +2.8496174E-25*(T*T*T*T*T*T*T*T*T*T)                              00250
       RETURN                                                               00260
  10   IF(T-642.5)  15,20,20                                                00270
  20   IF(T-675.0)  25,30,30                                                00280
  30   IF(T-690.0)  35,35,40                                                00290
  15   VISCL=.5100-.00050*T                                                 00300
       RETURN                                                               00310
  25   VISCL=.6310-.00069*T                                                 00320
       RETURN                                                               00330
  35   VISCL=.9985-.00123*T                                                 00340
                                                                            00350
```

```
      RETURN                                                            00360
   40 VISCL=.1480                                                       00370
      RETURN                                                            00380
      END                                                               00390
```

```
      SUBROUTINE EVADEN                                                 00010
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,  00020
     1 PRESD,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,           00030
     2 DWEFX,ENEPX,DWEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,     00040
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CEXAVG,CEXLOX,JLOCAT,K,X,        00050
     4BREAK,POWERX,ENLOX,ENSLOX,QUALOX,DWEFY,DWEFGY,POWOO,ONEOVM,       00060
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CEXBO,L,Y,               00070
     6 FACTMI,POWERY,CEXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                 00080
     7CONSTD,SCRATL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,             00090
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       00100
     9DWEFB,DWEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      00110
      COMMON QUALIA,GLIQ,TKINCH,                                        00120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,00130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO, 00140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,00150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   00160
     5DVISCL,REYNUM,EFACTB,EFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,00170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMADA,DBMADA,A,FILMTK,YPLUS, 00180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC      00190
      COMMON NSM,THCOND,ECHEN,SCHEN,VISCG,CPLIQ,SURFTL,                 00200
     1XTT,SATB,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,        00210
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,             00220
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE                             00230
      IF(P-200.0)   5,5,10                                              00240
    5 ENEGPX=9.970446752 -2.1762821*P +1.9558701E-2*(P**2)              00200
     1 -1.2610018E-4*(P**3) +5.0388804E-7*(P**4) -1.2499843E-9*(P**5)   00210
     2 +1.9322758E-12*(P**6) -1.8023251E-15*(P**7)                      00220
     3 +9.2680092E-19*(P**8) -2.0148643E-22*(P**9)                      00230
      RETURN                                                            00240
   10 ENEGPX=8.9642372E2-3.3545732E-1*P+1.2678091E-4*(P*P)              00200
     1 -4.3616497E-8*(P*P*P)+4.8788247E-12*(P**4)                       00210
      RETURN                                                            00220
      END                                                               00230
```

```
      SUBROUTINE LIQEN                                                    10
      COMMON NTUBES,MSHAPE,TUBE,RATIOM,DIAINS,VOLTS,AMPS,ENTHIN,FLMASS,   20
     1 PRESD,PRESIN,PRESOT,RESDP,TSDP,BOLOCA,XLNGTH,SHUNTM,P,            30
     2 DWEFX,ENEPX,DWEFGX,ENEGPX,ENSIN,QUALIN,POWERT,AREAFL,AREAIS,      40
     3 QUALOL,SATL,PSATL,POWERB,PSLBOL,CEXAVG,CEXLOX,JLOCAT,K,X,         50
     4BREAK,POWERX,ENLOX,ENSLOX,QUALOX,DWEFY,DWEFGY,POWOO,ONEOVM,        60
     5 COSLEN,ONEMSQ,SIGNZ,ARG,Z,FACMIB,FACPLB,CEXBO,L,Y,                70
     6 FACTMI,POWERY,CEXLOY,ENLOY,ENSLOY,QUALOY,FACTPL,                  80
     7CONSTD,SCRATL,ZETA,PLNGTH,J,U,ULOCAT,COSABK,SINABK,I,              90
     8 EXTRAA,EXTRAB,EXTRAC,EXTRAD,EXTRAE,EXTRAF,                       100
     9DWEFB,DWEFGB,ENLOB,ENSLOB,QUALOB,EXTRAG,EXTRAH,EXTRAI,EXTRAJ      110
      COMMON QUALIA,GLIQ,TKINCH,                                        120
     1DP,DX,COLM1,COLM2,COLM3,COLM4,SUMCOL,PHIMN,GTOTSC,GSUBZ,SUM0,SUM1,130
     2SUM2,SUM3,SUM4,SUM5,OMEGAP,OMEGA,PGMULT,PSUBL,T,VISCL,VOLSPL,ENO, 140
     3VOLSPG,QUALO4,POWERA,PANBOL,DENFO,DENFGO,ENSO,QUALO,DVSPLO,DVSPGO,150
     4GTOT,DPMOM,GRDMT,DVLSPL,DVLSPG,TERM1,TERM2,TERM3,TERM4,GGAS,DT,   160
     5DVISCL,REYNUM,EFACTB,EFACT,VELOC,GRDFS,DPGMLT,GRDFT,DGRDMT,GRDTOT,170
     6B,GRAVAC,GRAVCS,GRAVCH,VALUEN,FACTUN,BMADA,DBMADA,A,FILMTK,YPLUS, 180
     7TAUWAL,FYPLUS,GFILM,GLOENT,PCLIQ,PCLENT,DUMMYA,DUMMYB,DUMMYC      190
      COMMON NSM,THCOND,ECHEN,SCHEN,VISCG,CPLIQ,SURFTL,
     1XTT,SATB,SMALLT,DELTVP,TWALL,HCHEN,HMAC,HMIC,REYNLQ,NFLUX,
     2  PRNUMB,BERGHT,HDB,HDENG,QADENG,DTDENG,DELTT,QACHEN,
     3 DTCHEN,RADMAX,DELTEN,RADIUS,CC,DD,EE
      IF (P-200.0) 5, 5, 10                                             110
    5 ENEPX  = 1.1222734E2 + 6.3204790*P -1.4742752E-1*(P**2)           120
     1 +2.5403593E-3 *(P**3) -2.8788220E-5*(P**4) +2.1239014E-7*(P**5)  130
     2 -1.0067598E-9*(P**6) +2.9480958E-12*(P**7)                       140
     3 -4.8430356E-15*(P**8) +3.4075972E-18*(P**9)                      150
      RETURN                                                            160
   10 ENEPX  =2.4510585E2 +7.1675967E-1*P -9.9955201E-4*(P**2)          170
     1 +1.0516702E-6*(P**3) -6.8660980E-10*(P**4) +2.6573456E-13*(P**5) 180
     2 -5.5654666E-17*(P**6) +4.8594220E-21*(P**7)                      190
      RETURN                                                            200
      END                                                               210
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                                                        0034
                                TOTAL                   0034*
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APPENDIX F

TABULATION OF THE DATA

Flux Shape*	Test Section	M Value / Critical Location (In. from Inlet)	D_{IN} (Inches) / ± Variation in Critical Loc. (Inches)	$\mathcal{L}$ (Inches) / P_o (psia)	W (lb/hr) / X_o	P_{IN} (psia) / $(q/A)_o$ (BTU/hr ft^2)	P_{EXIT} (psia) / Q_{crit} (BTU/hr)	ΔP_{TS} (psi) / X_{exit}	H_{INLET} (BTU/LBM) / ΔH_{ANN-C} (BTU/LBM)	ΔH_{INLET} (BTU/LBM) / $(q/A)_o/(q/A)_1$ based on h_{tp} DENG	M at spike / $(q/A)_o/(q/A)_1$ based on h_{tp} CHEN	$\mathcal{L}'$ spike (In.) / Second Failure Loc. (In. from Inlet)	$(\mathcal{L}-\mathcal{L}')$ spike (In. from Inlet) / ± Variation or Third Failure Location (Inches)
1	109.0	1.00 29.5	.214 .1	30.0 105.6	121.0 .568	130.0 .616E 06	105.0 .8628E 05	25.0 .582	104.2 417.4	-214.5 5.4	11.7	C.	0.
1	137.0	1.00 29.5	.211 .2	30.0 110.5	121.5 .537	127.0 .645E 06	110.0 .8905E 05	17.0 .552	59.8 393.9	-257.1 6.2	13.0	C.	0.
1	136.0	1.00 29.6	.211 .1	30.0 100.4	122.0 .557	120.0 .576E 06	100.0 .7973E 05	20.0 .568	149.1 412.0	-163.3 4.8	9.8	C.	0.
1	116.0	1.00 29.5	.212 0.	30.0 117.4	125.0 .593	135.0 .600E 06	117.0 .8328E 05	18.0 .606	177.3 441.4	-144.5 5.0	11.9	C.	C.
1	138.0	1.00 29.9	.211 0.	30.0 88.1	122.0 .597	110.0 .547E 06	88.0 .7570E 05	22.0 .599	205.0 447.8	-100.7 3.2	7.3	C.	C.
1	115.0	1.00 29.5	.211 .2	30.0 107.4	124.0 .555	127.0 .522E 06	107.0 .7207E 05	20.0 .566	223.1 408.1	-93.8 4.4	9.5	C.	C.
1	117.0	1.00 29.7	.210 .1	30.0 112.3	120.0 .603	132.0 .518E 06	112.0 .7124E 05	20.0 .611	252.4 449.4	-67.6 4.1	9.8	C.	C.
2	205.0	2.27 19.6	.214 .6	30.0 112.1	125.0 .183	115.0 .608E 06	105.0 .7283E 05	10.0 .394	68.4 89.2	-240.7 25.4	40.4	C.	C.
2	206.0	2.27 23.5	.214 .3	30.0 110.0	125.0 .363	119.0 .514E 06	106.0 .7188E 05	19.0 .477	149.9 245.3	-161.9 9.3	15.3	C.	C.
2	208.0	2.27 26.9	.214 .6	30.0 87.5	125.0 .512	103.0 .410E 06	85.0 .7300E 05	18.0 .658	203.4 376.7	-97.3 3.3	6.2	C.	C.
2	207.0	2.27 29.5	.214 .1	30.0 98.4	125.6 .632	118.0 .327E 06	98.0 .7764E 05	20.0 .639	247.2 477.9	-63.9 2.0	4.9	C.	C.

2	337.0	4.03	.211	30.0	121.5	111.0	92.0	19.0	65.8	-240.6			
		29.4	.2	92.7	.602	.276E 06	.9355E 05	.609	453.1	1.7	3.9	0.	0.
2	313.0	4.03	.211	30.0	121.5	116.0	94.0	22.0	104.2	-205.6			
		29.5	.2	94.6	.614	.259E 06	.9019E 05	.620	462.5	1.6	3.7	28.5	0.
2	339.0	4.03	.213	30.0	124.4	111.0	89.0	22.0	153.8	-152.6			
		27.2	.2	92.2	.553	.387E 06	.8254E 05	.590	409.5	2.8	5.9	0.	0.
2	314.0	4.03	.210	30.0	120.0	112.0	92.0	20.0	176.9	-130.2			
		29.3	.2	92.7	.631	.254E 06	.8233E 05	.639	478.5	1.4	3.5	27.9	.4
2	340.0	4.03	.213	30.0	123.8	113.0	95.0	18.0	203.5	-104.3			
		28.9	0.	95.9	.624	.271E 06	.8138E 05	.636	473.8	1.6	4.0	0.	0.
2	324.0	4.03	.211	30.0	122.0	115.0	95.0	20.0	223.5	-85.6			
		28.9	.2	96.0	.618	.259E 06	.7709E 05	.629	466.3	1.6	3.8	27.4	.1
2	325.0	4.03	.211	30.0	121.5	114.0	93.0	21.0	254.0	-54.4			
		29.1	.3	93.8	.629	.236E 06	.7384E 05	.637	476.6	1.3	3.3	0.	0.
2	510.0	5.75	.214	30.0	125.6	104.0	86.0	18.0	74.3	-227.1			
		19.9	.2	97.2	.304	.715E 06	.8549E 05	.622	194.3	15.1	23.4	20.9	0.
2	511.0	5.75	.214	30.0	125.6	115.0	100.0	15.0	149.9	-159.2			
		24.3	.2	104.8	.417	.487E 06	.7404E 05	.496	292.6	6.8	11.7	0.	0.
2	512.0	5.75	.215	30.0	126.3	108.0	95.0	13.0	149.9	-154.4			
		22.6	.2	100.5	.337	.526E 06	.6837E 05	.445	223.8	9.3	14.9	0.	0.
2	513.0	5.75	.214	30.0	125.0	115.0	95.0	20.0	200.4	-108.7			
		20.1	1.1	104.2	.425	.557E 06	.8152E 05	.626	298.2	9.9	17.2	0.	0.
2	514.0	5.75	.214	30.0	125.6	105.0	85.0	20.0	202.3	-99.8			
		23.2	.4	91.4	.460	.542E 06	.7398E 05	.563	330.5	5.5	9.7	0.	0.
2	515.0	5.75	.214	30.0	125.6	115.0	95.0	20.0	254.6	-54.5			
		26.1	.2	98.2	.601	.401E 06	.7748E 05	.647	453.1	2.7	6.2	0.	0.
3	1202.0	2.27	.214	30.0	125.0	117.0	111.0	6.0	64.1	-246.3			
		29.7	.1	111.2	.336	.673E 06	.6829E 05	.345	221.7	13.7	22.2	0.	0.
3	1208.0	2.27	.214	30.0	125.0	107.0	97.0	10.0	149.5	-154.1			
		29.7	.1	97.2	.419	.650E 06	.6593E 05	.428	295.4	8.1	13.9	0.	0.
3	1209.0	2.27	.215	30.0	126.3	115.0	100.0	15.0	203.5	-105.6			
		29.9	0.	100.1	.523	.659E 06	.7095E 05	.526	383.7	6.3	12.6	0.	0.
3	1210.0	2.27	.214	30.0	125.0	113.0	95.0	18.0	254.7	-53.1			
		29.7	.2	95.2	.583	.659E 06	.7091E 05	.592	437.5	4.8	10.6	0.	0.
4	1260.0	2.27	.214	30.0	125.0	116.0	97.0	19.0	74.4	-235.4			
		29.6	.2	97.3	.615	.430E 06	.9693E 05	.622	463.9	2.7	6.5	0.	0.
4	1259.0	2.27	.214	30.0	125.0	118.0	97.0	21.0	149.1	-162.0			
		29.5	.2	97.5	.619	.395E 06	.8834E 05	.629	467.1	2.4	5.9	0.	0.
4	1258.0	2.27	.214	30.0	125.0	125.0	103.0	22.0	202.7	-112.9			
		29.7	0.	103.3	.671	.365E 06	.8714E 05	.676	510.1	2.1	6.0	0.	0.
4	1257.0	2.27	.214	30.0	125.0	120.0	98.0	22.0	257.6	-54.8			

		29.7	0.	98.2	.668	.353E C6	.7973E 05	.673	508.4	1.8	5.1	C.	C.
3	1501.0	5.75	.213	30.C	123.8	1C0.0	95.8	5.0	69.2	-229.3			
		29.6	.3	96.4	.27C	.714E C6	.5905E 05	.282	166.2	15.9	24.2	C.	C.
3	1503.0	5.75	.214	30.C	125.0	110.0	101.0	9.0	147.9	-157.8			
		29.8	0.	101.2	.398	.773E 06	.6386E 05	.405	277.5	11.0	18.5	C.	C.
3	1504.0	5.75	.214	30.0	125.C	1C9.0	93.0	16.0	206.5	-98.5			
		29.8	.1	93.2	.563	.9C1E 06	.7451E 05	.571	421.4	6.5	13.7	C.	C.
3	1505.0	5.75	.215	30.C	126.3	117.C	103.0	14.0	253.2	-57.3			
		29.5	.4	103.4	.490	.749E C6	.6284E 05	.508	356.4	7.9	15.0	C.	C.
4	1560.0	5.75	.215	30.C	126.3	116.0	96.0	20.0	72.3	-237.5			
		17.0	.5	107.3	.372	.617E 06	.9574E 05	.601	252.1	10.4	17.3	C.	C.
4	1550.0	5.75	.213	30.C	123.8	116.0	95.0	21.0	151.0	-158.8			
		28.3	.4	96.4	.629	.240E C6	.8893E 05	.645	476.1	1.4	3.5	C.	C.
4	1551.0	5.75	.214	30.C	125.C	124.0	102.0	22.0	206.1	-1C8.9			
		28.8	.5	103.C	.675	.221E 06	.8775E 05	.685	513.8	1.2	3.4	C.	C.
4	1552.0	5.75	.214	30.C	125.C	124.0	102.0	22.0	253.2	-81.8			
		28.3	.3	103.4	.675	.223E 06	.8245E 05	.691	515.5	1.2	3.4	C.	C.
5	2502.0	5.75	.215	30.C	126.3	110.0	91.0	19.0	73.9	-231.8			
		9.8	.2	108.5	.122	.110E C6	.9059E 05	.560	36.5	67.1	112.4	C.	C.
5	2503.0	5.75	.213	30.C	123.8	120.0	99.0	21.0	204.2	-1C8.2			
		28.1	.5	100.6	.677	.242E C6	.8813E 05	.696	517.8	1.3	3.8	C.	C.
6	2552.0	5.75	.214	30.0	125.0	109.0	98.0	11.0	67.6	-237.4			
		25.1	.3	103.9	.310	.916E 06	.7705E 05	.435	200.5	18.9	29.8	C.	C.
6	2553.0	5.75	.214	30.0	125.C	112.0	93.0	19.0	205.4	-101.7			
		28.0	.3	95.0	.602	.572E 06	.8179E 05	.635	454.8	3.7	8.5	C.	C.
1	132.0	1.00	.213	30.C	248.8	127.0	69.C	58.0	70.6	-246.3			
		29.8	.2	70.C	.4C8	.1C3E 07	.1435E 06	.414	260.8	3.1	4.9	29.528.500	
1	129.0	1.00	.213	30.C	247.5	123.0	67.0	56.C	112.0	-2C2.4			
		29.5	0.	68.8	.374	.9C1E C6	.1257E 06	.385	231.6	3.C	4.8	C.	C.
1	139.0	1.00	.210	30.0	241.5	129.0	64.0	65.0	150.7	-167.4			
		29.8	.1	64.9	.433	.9C4E C6	.1245E 06	.439	279.4	2.3	3.6	C.	C.
1	140.0	1.00	.210	30.C	241.5	128.0	63.0	65.0	205.7	-111.8			
		29.8	0.	63.6	.429	.797E C6	.1099E 06	.433	275.6	2.C	3.2	C.	C.
1	131.0	1.00	.210	30.C	241.5	132.0	67.0	65.0	260.6	-59.4			
		29.5	0.	68.3	.456	.758E C6	.1044E 06	.465	300.7	1.9	3.1	C.	C.
2	201.0	2.27	.213	30.C	247.5	123.0	63.C	60.0	68.4	-246.C			
		22.3	.3	98.1	.237	.1C6E 07	.1385E 06	.493	128.1	9.6	14.7	C.	C.
2	209.0	2.27	.214	30.0	250.C	132.0	77.0	55.0	150.7	-169.3			
		24.3	.2	97.6	.35C	.1C1E C7	.1392E 06	.474	221.0	5.6	9.C	C.	C.
2	210.0	2.27	.214	30.0	250.C	135.0	69.0	66.0	204.2	-117.6			
		29.6	.1	70.3	.492	.530E C6	.1297E 06	.497	331.2	1.2	2.1	C.	C.
2	211.0	2.27	.214	30.C	250.0	135.0	67.0	68.0	252.6	-69.2			
		29.5	0.	68.5	.487	.489E C6	.1162E 06	.493	326.5	1.1	1.9	C.	C.
2	310.0	4.03	.211	30.C	244.C	128.0	67.0	61.0	71.0	-246.5			
		24.0	0.	93.7	.322	.992E 06	.1435E 06	.428	196.0	5.8	9.1	C.	C.
2	331.0	4.03	.210	30.0	241.5	131.0	65.0	66.0	72.5	-246.9			
		27.6	.4	76.0	.45C	.684E C6	.1538E 06	.485	299.0	2.C	3.3	C.	C.

2	308.0	4.03	.211	30.0	243.0	133.0	67.0	66.0	101.3	-219.3			
		25.8	.2	85.3	.405	.837E 06	.1451E 06	.472	261.8	3.2	5.3	0.	0.
2	331.0	4.03	.211	30.0	243.0	137.0	66.0	71.0	151.8	-171.2			
		26.0	.2	82.3	.435	.769E 06	.1375E 06	.494	285.4	2.5	4.3	0.	0.
2	311.0	4.03	.210	30.0	240.0	137.0	69.0	68.0	176.5	-146.5			
		28.0	0.	76.4	.476	.540E 06	.1317E 06	.500	319.7	1.4	2.5	0.	0.
2	332.0	4.03	.213	30.0	247.5	136.0	67.0	69.0	205.5	-116.9			
		28.9	.2	70.9	.473	.415E 06	.1247E 06	.484	313.7	1.0	1.7	0.	0.
2	336.0	4.03	.213	30.0	248.8	135.0	67.0	68.0	255.4	-66.4			
		29.5	.3	68.5	.472	.315E 06	.1112E 06	.476	312.2	.7	1.3	0.	0.
2	309.0	4.03	.212	30.0	246.3	134.0	66.0	68.0	262.5	-58.7			
		28.0	.1	71.9	.450	.432E 06	.1065E 06	.469	296.1	1.2	1.9	27.5	.2
2	501.0	5.75	.212	30.0	246.0	125.0	64.0	61.0	73.9	-241.7			
		22.6	.6	97.0	.290	.110E 07	.1419E 06	.424	172.1	7.7	12.0	0.	0.
2	507.0	5.75	.214	30.0	251.3	132.0	65.0	66.0	150.7	-169.3			
		22.1	.7	96.4	.335	.109E 07	.1373E 06	.472	207.3	6.4	10.1	0.	0.
2	504.0	5.75	.214	30.0	251.3	135.0	70.0	65.0	204.6	-117.2			
		22.4	.2	95.3	.381	.102E 07	.1311E 06	.500	245.9	4.9	8.1	0.	0.
2	508.0	5.75	.214	30.0	250.0	138.0	68.0	70.0	255.1	-68.5			
		29.0	.3	71.1	.515	.328E 06	.1226E 06	.523	350.6	.7	1.3	0.	0.
3	1204.0	2.27	.213	30.0	248.8	120.0	62.0	58.0	153.0	-159.4			
		29.3	.5	64.9	.382	.117E 07	.1189E 06	.402	239.5	3.5	5.4	0.	0.
3	1205.0	2.27	.214	30.0	250.0	125.0	75.0	50.0	203.9	-111.7			
		29.8	.1	75.6	.410	.111E 07	.1122E 06	.415	267.6	3.6	5.8	0.	0.
3	1207.0	2.27	.214	30.0	250.0	132.0	65.0	67.0	253.9	-66.1			
		29.9	0.	65.3	.461	.108E 07	.1090E 06	.464	304.4	2.5	4.1	0.	0.
4	1271.0	2.27	.214	30.0	250.0	130.0	66.0	64.0	68.9	-249.8			
		26.4	1.4	78.6	.380	.757E 06	.1505E 06	.442	238.8	2.9	4.6	0.	0.
4	1252.0	2.27	.214	30.0	250.0	131.0	66.0	65.0	71.9	-247.5			
		25.5	1.0	81.7	.379	.799E 06	.1536E 06	.459	238.7	3.2	5.1	0.	0.
4	1253.0	2.27	.214	30.0	250.0	135.0	65.0	70.0	151.0	-170.8			
		29.9	0.	65.3	.447	.576E 06	.1313E 06	.449	287.9	1.4	2.3	0.	0.
4	1254.0	2.27	.214	30.0	250.0	138.0	63.0	75.0	203.5	-120.1			
		29.8	0.	63.8	.501	.576E 06	.1306E 06	.505	333.1	1.1	2.0	0.	0.
4	1255.0	2.27	.214	30.0	250.0	140.0	70.0	70.0	254.3	-70.5			
		29.8	0.	70.5	.508	.530E 06	.1203E 06	.510	343.3	1.1	2.1	0.	0.
3	1502.0	5.75	.213	30.0	248.8	102.0	57.0	45.0	71.8	-228.2			
		29.5	.3	70.0	.285	.141E 07	.1179E 06	.302	166.3	6.8	9.9	0.	0.
3	1507.0	5.75	.214	30.0	250.0	105.0	58.0	47.0	149.8	-152.3			
		29.8	.1	59.4	.326	.126E 07	.1040E 06	.334	193.5	4.2	6.1	0.	0.
3	1508.0	5.75	.214	30.0	250.0	123.0	64.0	59.0	206.5	-107.9			

		29.7	0.	65.2	.425	.139E 07	.1141E 06	.435	277.1	3.6	5.7	C.	C.
3	1509.0	5.75	.213	30.0	248.8	125.0	63.0	62.0	252.0	-63.6			
		29.7	.1	64.0	.420	.121E 07	.1005E 06	.428	270.4	3.2	5.0	C.	C.
4	1553.0	5.75	.214	30.0	250.0	129.0	64.0	65.0	71.9	-246.2			
		11.8	1.6	121.4	.096	.119E 07	.1450E 06	.423	12.4	36.2	61.5	C.	C.
4	1554.0	5.75	.214	30.0	250.0	140.0	67.0	73.0	150.3	-174.5			
		29.2	.4	69.5	.506	.349E 06	.1453E 06	.513	339.4	.7	1.3	C.	C.
4	1555.0	5.75	.213	30.0	248.8	140.0	68.0	72.0	202.4	-122.4			
		28.2	.1	73.3	.489	.359E 06	.1311E 06	.505	326.7	.9	1.5	C.	C.
4	1556.0	5.75	.213	30.0	248.8	140.0	67.0	73.0	255.1	-69.7			
		28.6	.5	70.8	.489	.302E 06	.1166E 06	.500	324.9	.7	1.2	C.	C.
5	2504.0	5.75	.215	30.0	252.5	120.0	62.0	58.0	69.3	-243.1			
		11.8	.5	115.6	.066	.124E 07	.1320E 06	.359	-12.4	50.1	84.0	C.	C.
5	2506.0	5.75	.213	30.0	247.5	140.0	68.0	72.0	208.7	-116.1			
		29.3	.3	70.2	.500	.325E 06	.1292E 06	.506	334.4	.7	1.3	C.	C.
6	2551.0	5.75	.215	30.0	252.5	153.0	131.0	22.0	81.7	-250.5			
		24.2	.3	146.3	.139	.152E 07	.1198E 06	.268	47.9	40.8	72.4	C.	C.
6	2556.0	5.75	.213	30.0	247.5	127.0	65.0	62.0	203.4	-113.5			
		24.4	.3	88.6	.342	.158E 01	.1241E 06	.480	214.8	8.0	12.6	C.	C.
1	142.0	1.00	.209	30.0	478.0	192.0	105.0	87.0	80.5	-271.2			
		29.8	0.	128.3	.210	.148E 07	.2029E 06	.215	92.9	7.3	11.9	C.	C.
1	135.0	1.00	.210	30.0	480.0	193.0	106.0	87.0	81.4	-270.8			
		29.6	0.	112.3	.264	.162E 07	.2232E 06	.275	128.5	5.2	8.3	C.	C.
1	130.0	1.00	.212	30.0	492.5	195.0	112.0	83.0	149.9	-203.2			
		29.5	.5	115.9	.268	.142E 07	.1981E 06	.278	132.4	4.7	7.5	C.	C.
1	141.0	1.00	.210	30.0	483.0	217.0	110.0	107.0	206.3	-156.6			
		29.8	0.	111.8	.316	.134E 07	.1848E 06	.321	164.2	3.4	5.6	C.	C.
1	133.0	1.00	.213	30.0	495.0	217.0	120.0	97.0	253.4	-109.5			
		29.4	.4	123.1	.320	.124E 07	.1724E 06	.329	172.2	3.5	5.8	276	515.0
2	213.0	2.27	.214	30.0	500.0	185.0	108.0	77.0	86.4	-262.1			
		21.6	.5	166.6	.087	.168E 07	.2150E 06	.240	4.5	28.6	50.1	C.	C.
2	212.0	2.27	.214	30.0	500.0	215.0	115.0	100.0	146.1	-216.0			
		26.9	.4	146.3	.233	.116E 07	.2065E 06	.284	108.5	6.0	10.1	C.	C.
2	202.0	2.27	.212	30.0	490.0	223.0	115.0	108.0	205.2	-160.1			
		27.9	.9	130.1	.320	.104E 07	.2017E 06	.349	171.6	3.2	5.3	C.	C.
2	203.0	2.27	.213	30.0	495.0	217.0	113.0	104.0	253.2	-109.7			
		23.1	.1	153.7	.242	.128E 07	.1751E 06	.339	117.9	6.8	11.5	C.	C.
2	329.0	4.03	.212	30.0	490.0	197.0	108.0	89.0	80.5	-273.5			
		25.9	.4	150.6	.221	.132E 07	.2344E 06	.288	105.7	7.5	12.8	C.	C.
2	330.0	4.03	.212	30.0	493.5	207.0	114.0	93.0	149.3	-209.5			
		22.0	.1	173.4	.181	.172E 07	.2154E 06	.315	77.4	14.7	26.0	25.8	.6

2	327.0	4.03	.213	30.0	495.0	215.0	115.0	100.0	202.8	-159.3			
		25.1	.4	148.6	.277	.124E 07	.2013E 06	.341	144.5	5.3	9.1	0.	0.
2	328.0	4.03	.212	30.0	490.0	225.0	115.0	110.0	255.5	-110.6			
		23.9	.3	153.8	.274	.124E 07	.1778E 06	.351	141.4	5.6	9.6	0.	0.
2	506.0	5.75	.215	30.0	505.0	155.0	95.0	60.0	62.5	-270.8			
		16.3	.1	155.0	-.059	.159E 07	.1984E 06	.170	0.	0.	0.	0.	0.
2	516.0	5.75	.214	30.0	502.5	178.0	105.0	73.0	80.9	-264.2			
		22.5	.4	156.1	.117	.166E 07	.2150E 06	.233	27.8	19.5	36.6	0.	0.
2	505.0	5.75	.214	30.0	500.0	207.0	113.0	94.0	151.6	-207.2			
		21.8	1.2	174.6	.172	.174E 07	.2123E 06	.305	69.7	15.8	28.3	0.	0.
2	502.0	5.75	.212	30.0	490.0	219.0	114.0	105.0	203.6	-160.1			
		23.3	0.	163.6	.242	.143E 07	.1956E 06	.335	119.3	8.2	14.2	0.	0.
2	503.0	5.75	.213	30.0	495.0	215.0	113.0	102.0	247.0	-115.1			
		22.0	.0	161.6	.239	.146E 07	.1811E 06	.346	118.0	8.4	14.4	21.8**	.0
3	1211.0	2.27	.214	30.0	500.0	158.0	103.0	55.0	60.7	-274.2			
		29.8	.1	117.8	.187	.206E 07	.2091E 06	.192	80.7	10.4	17.0	0.	0.
3	1212.0	2.27	.214	30.0	502.5	185.0	109.0	76.0	150.0	-198.5			
		29.8	.1	114.8	.252	.109E 07	.1932E 06	.260	123.4	6.7	10.6	0.	0.
3	1213.0	2.27	.214	30.0	500.0	200.0	101.0	99.0	206.2	-149.1			
		29.9	0.	102.0	.293	.176E 07	.1775E 06	.295	146.5	4.4	7.0	0.	0.
3	1200.0	2.27	.214	30.0	500.0	215.0	115.0	100.0	253.6	-108.5			
		29.8	.1	116.7	.316	.167E 07	.1694E 06	.322	168.5	4.5	7.4	0.	0.
4	1250.0	2.27	.214	30.0	500.0	200.0	112.0	88.0	75.1	-280.2			
		28.9	.8	120.6	.259	.109E 07	.2378E 06	.276	124.1	3.9	6.3	0.	0.
4	1251.0	2.27	.215	30.0	505.0	215.0	116.0	99.0	149.7	-212.4			
		29.7	.1	118.2	.311	.976E 00	.2214E 06	60.316	162.6	2.7	4.5	0.	0.
4	1256.0	2.27	.214	30.0	500.0	227.0	120.0	107.0	202.9	-164.0			
		29.5	.3	123.1	.342	.930E 00	.2081E 06	60.349	186.0	2.4	4.1	0.	0.
3	1500.0	5.75	.214	30.0	500.0	110.0	73.0	37.0	53.7	-252.0			
		29.9	0.	83.0	.086	.188E 07	.1552E 06	.089	3.7	13.4	23.5	0.	0.
3	1510.0	5.75	.214	30.0	500.0	170.0	104.0	66.0	148.4	-192.8			
		29.9	0.	120.8	.218	.217E 07	.1786E 06	.220	104.2	9.5	15.4	0.	0.
3	1511.0	5.75	.214	30.0	500.0	192.0	113.0	79.0	205.8	-145.9			
		29.8	.1	115.9	.281	.215E 07	.1775E 06	.287	145.4	6.7	10.7	0.	0.
3	1512.0	5.75	.213	30.0	495.0	203.0	113.0	90.0	252.2	-104.9			
		29.9	0.	113.8	.298	.193E 07	.1584E 06	.300	155.8	5.5	8.8	0.	0.
4	1557.0	5.75	.214	30.0	500.0	210.0	118.0	92.0	84.8	-275.3			
		22.4	.8	161.7	.216	.116E 07	.2489E 06	.309	100.5	7.5	12.8	0.	0.
5	2505.0	5.75	.213	30.0	495.0	225.0	121.0	104.0	205.2	-160.9			
		19.9	.4	173.4	.241	.103E 07	.2042E 06	.347	118.8	6.4	11.1	0.	0.

5	2501.0	5.75	.214	30.0	500.0	155.0	93.0	62.0	77.8	-255.4				
		10.9	.1	155.0	-.068	.2C1E 07	.1855E 06	.175	0.	0.	0.	C.	C.	
6	2555.0	5.75	.214	30.0	500.0	187.0	110.0	77.0	203.2	-146.2				
		27.0	.2	143.9	.221	.154E 07	.1716E 06	.273	107.3	8.3	14.C	C.	0.	
6	2554.0	5.75	.214	30.C	500.0	1C5.0	72.0	33.0	49.3	-252.8				
		22.3	.1	105.0	-.054	.210E 07	.1562E 06	.088	0.	0.	C.	C.	0.	
8	0326.0	4.03	.214	30.0	249.8	133.0	62.0	51.0	253.2	- 67.4	4.17	.085	20.0	
		28.4	.1	67.3	.450	.405E 06	.1090E 06	.465	297.7	1.0	1.7	0	0	
8	0345.0	4.03	.214	30.0	250.0	140.0	90.0	50.0	205.5	-119.3	4.17	.50	20.0	
		20.4	.0	112.2	.281	.430E 07	.1255E 06	.466	192.8	37.5	60.0			
8	0343.0	4.03	.215	30.0	252.5	137.0	70.0	60.0	204.0	-116.6	4.52	.50	27.0	
		27.2	.1	76.8	.408	.235E 07	.1205E 06	.450	276.1	7.9	12.7			
8	0344.0	4.03	.2117	30.0	244.0	135.0	60.0	75.0	202.5	-113.8	***	1.5	27.0	
		28.1	.1	61.0	.400	.156E 07	.1198E 06	.471	297.0	4.7	7.3			
7	7210.0	1.00	.2130	30.0	250.0	128.0	35.0	93.0	203.4	-114.1	2.27	1.0	24.0	
		29.8	.0	35.9	.500	.871E 06	.1247E 06	.505	318.7	.88	1.4			
7	7510.0	1.00	.214	30.0	250.0	122.0	36.0	86.0	198.4	-115.3	5.75	1.0	24.0	
		24.6	.2	59.1	.332	.408E 07	.1138E 06	.451	188.9	13.4	19.2			
7	7710.0	1.00	.213	30.0	250.0	120.0	36.0	85.0	202.3	-110.1	7.0	1.0	24.0	
		24.6	.2	58.4	.330	.481E 07	.1125E 06	.450	188.5	15.4	21.9			
7	7250.0	1.00	.2125	30.0	250.0	132.0	37.0	95.0	203.5	-116.5	2.27	5.0	22.0	
		29.7	.2	38.4	.518	.821E 06	.1300E 06	.525	336.5	.83	1.4			
7	7550.0	1.00	.212	30.0	250.0	115.0	36.0	79.0	203.5	-105.6	5.75	5.0	22.0	
		25.7	.2	55.9	.352	.239E 07	.1109E 06	.445	213.4	6.6	9.4			
7	7750.0	1.00	.211	30.0	250.0	115.0	37.0	78.0	206.1	-103.0	7.0	5.0	22.0	
		25.9	.0	57.7	.345	.228E 07	.1061E 06	.426	210.3	6.6	9.5			
7	7290.0	1.00	.211	30.0	250.0	135.0	38.0	97.0	205.0	-116.8	2.27	9.0	20.0	
		29.8	.0	39.0	.506	.733E 06	.1283E 06	.510	324.6	.77	1.2			
48" LONG TUBES														
1	114136	1.00	.212	48.0	250.0	140.0	38.0	102.0	254.2	- 70.6				
		47.6	.1	39.0	.484	.4915E 06	.1091E 06	.489	300.4	.56	.87			
1	139135	1.00	.210	48.0	240.0	138.0	38.0	100.0	206.1	-117.5				
		47.8	.1	38.7	.494	.5382E 06	.1184E 06	.498	310.1	.61	.95			
1	128110	1.00	.212	48.0	125.0	117.0	92.0	25.0	251.3	- 59.2				
		47.8	.2	92.1	.637	.3453E 06	.7667E 05	.641	481.6	1.8	4.5	47.5		
DATA TAKEN WITH OSCILLATORY INSTABILITY PRESENT														
1	107.0	1.00	.213	30.0	250.0	95.0	95.0	0	71.8	-222 7		17.0		
		27.0	0.0	95.0		.427E 06	.595E 05	.017						
1	108.0	1.00	.214	30.0	250.0	170.0	155.0	15.0	88.8	-252.3				
		28.3	.7			.834E 06	.1168E 06	.245						
1	120.0	1.00	.2115	30.0	244.0	209.0	181.0	28.0	90.8	-268.7				
		29.9	.1	181.2	.374	.1014E 07	.1404E 06	.376			25.0	12.8		
1	128.0	1.00	.211	30.0	243.0	193.0	170.0	23.0	124.3	-228.2				
		29.8	.0			.8620E 06	.1190E 06	.321						
1	111.0	1.00	.213	30.0	250.0	175.0	147.0	28.0	162.7	-180.9				
		29.6	.1			.725E 06	.1010E 06	.345						
1	119.0	1.00	.2135	30.0	249.0	225.0	195.0	30.0	175.8	-190.3				
		29.6	.1			.9900E 06	.1380E 06	.425						
1	118.0	1.00	.2135	30.0	249.0	218.0	190.0	29.0	238.7	-124.7				
		29.6	.2	190.5	.414	.8362E 06	.1168E 06	.422						
1	112.0	1.00	.2135	30.0	500.0	187.0	169.0	18.0	99.4	-250.0				
		28.1	1.6			.1110E 07	.1550E 06	.118						
1	122.0	1.00	.2105	30.0	483.0	211.0	187.0	24.0	104.8	-255.3				
		29.8	.0			.1125E 07	.1560E 06	.086			4.9			
1	113.0	1.00	.212	30.0	500.0	209.0	191.0	18.0	144.1	-215.6				
		25.8	3.7			.9760E 06	.1355E 06	.063						
1	128.0	1.00	.211	30.0	486.0	210.0	181.0	29.0	114.6	-245.2				
						.1262E 07	.1745E 06	.148						
FAST TRANSIENT TEST														
2	513.0	5.75	.214	30.0	125.0	115.0	95.0	20.0	200.4	-108.7				
		20.1	1.1	104.2	.425	.7339E 06	.8152E 05	.626	298.2	9.9	17.2			

*Axial Flux Distribution
1 - Uniform
2 - Cosine
3 - Linear Increasing
4 - Linear Decreasing
5 - Peak Inlet
6 - Peak Exit
7 - Uniform with Cosine Spike
8 - Cosine with Stepped Spike

**Second Thermal Failure
***5.14 to 4.54

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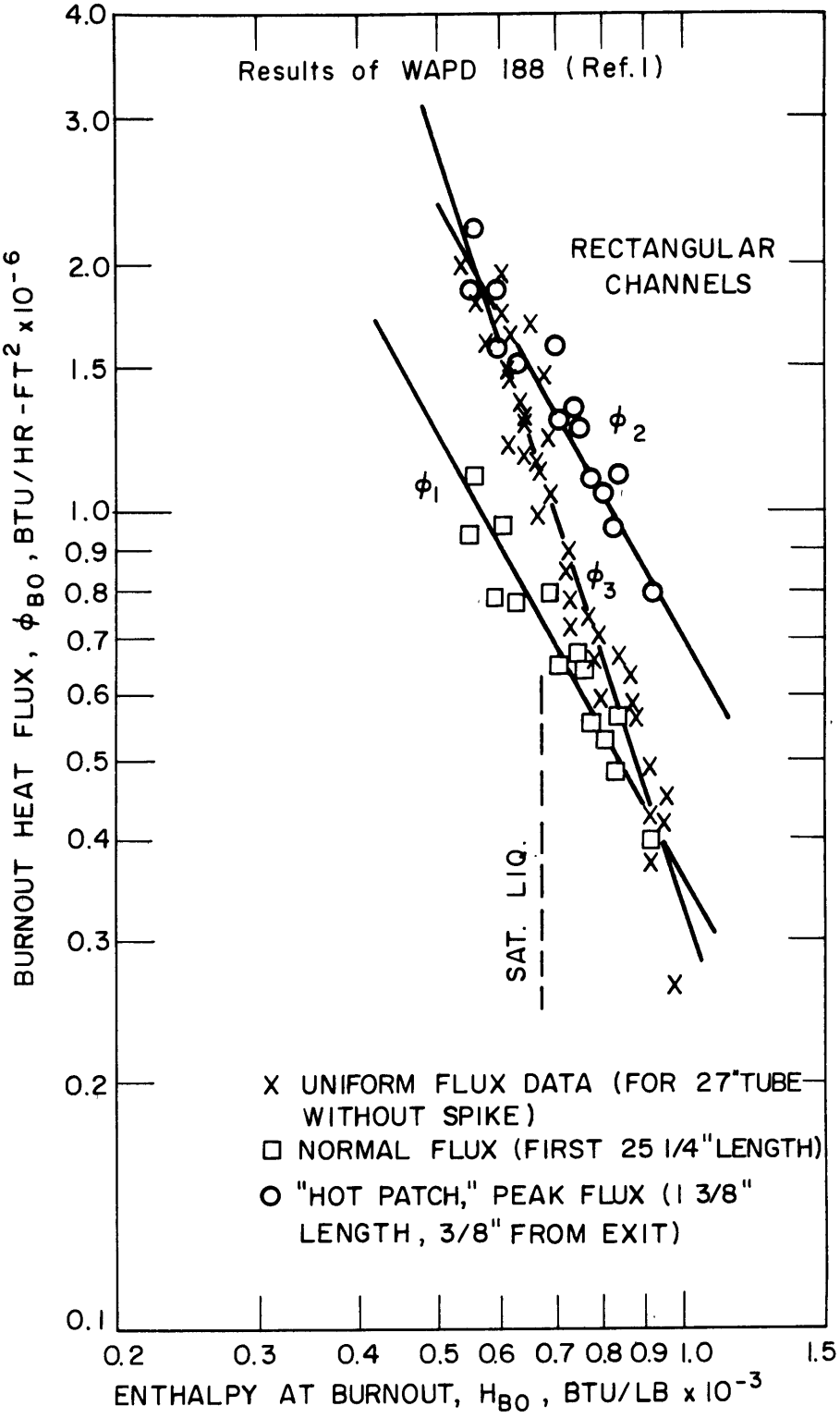

FIGURE 1. EFFECT OF LOCAL HEAT FLUX SPIKE ON BURNOUT

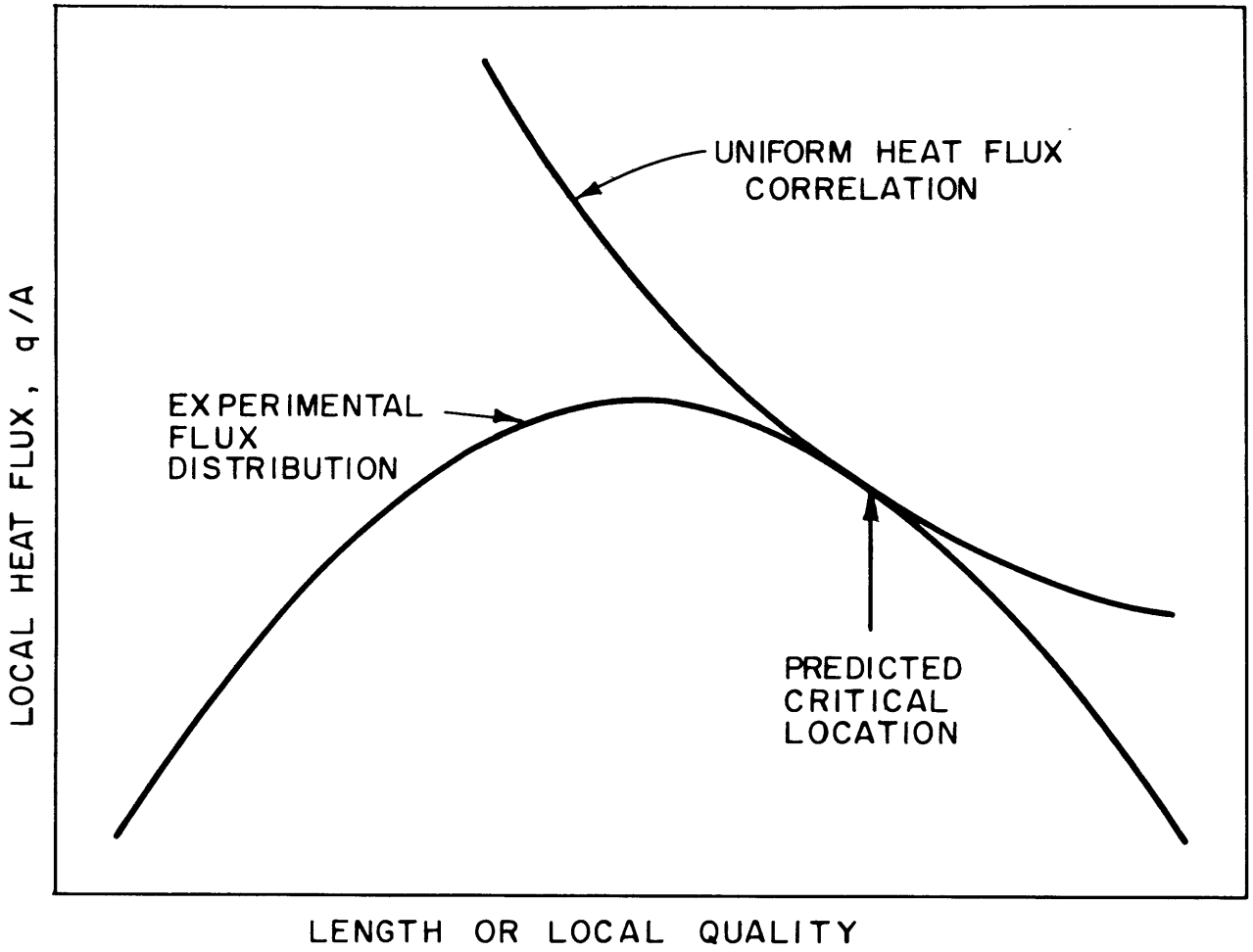

FIGURE 2. PREDICTION OF CRITICAL CONDITION BY LOCAL CONDITION METHOD OF JANSSEN AND KERVINEN (REF. 6)

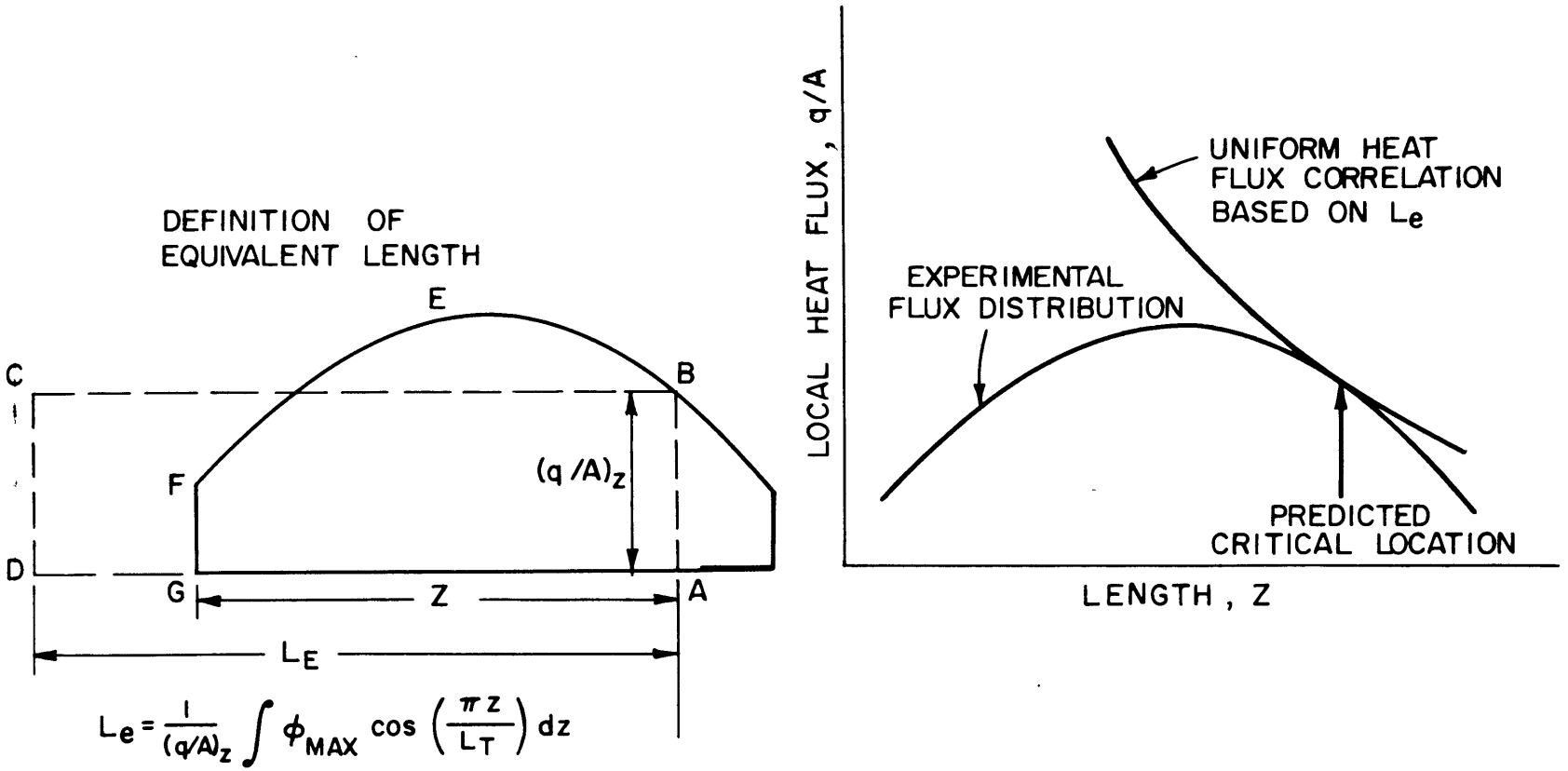

FIGURE 3. PREDICTION OF CRITICAL CONDITION BY EQUIVALENT LENGTH METHOD OF LEE AND OBERTELLI (REF 9)

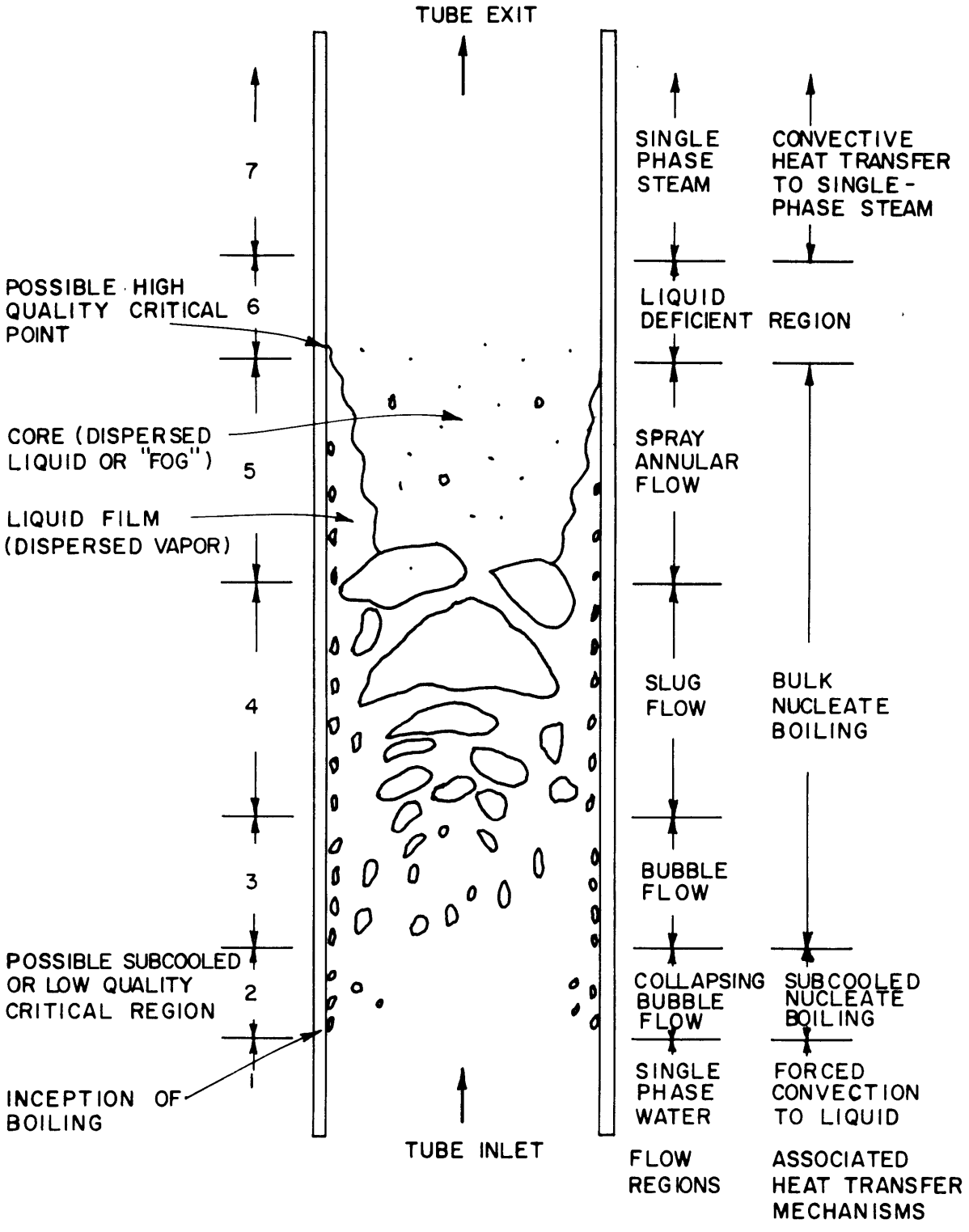

FIGURE 4. REGIMES OF TWO-PHASE FLOW

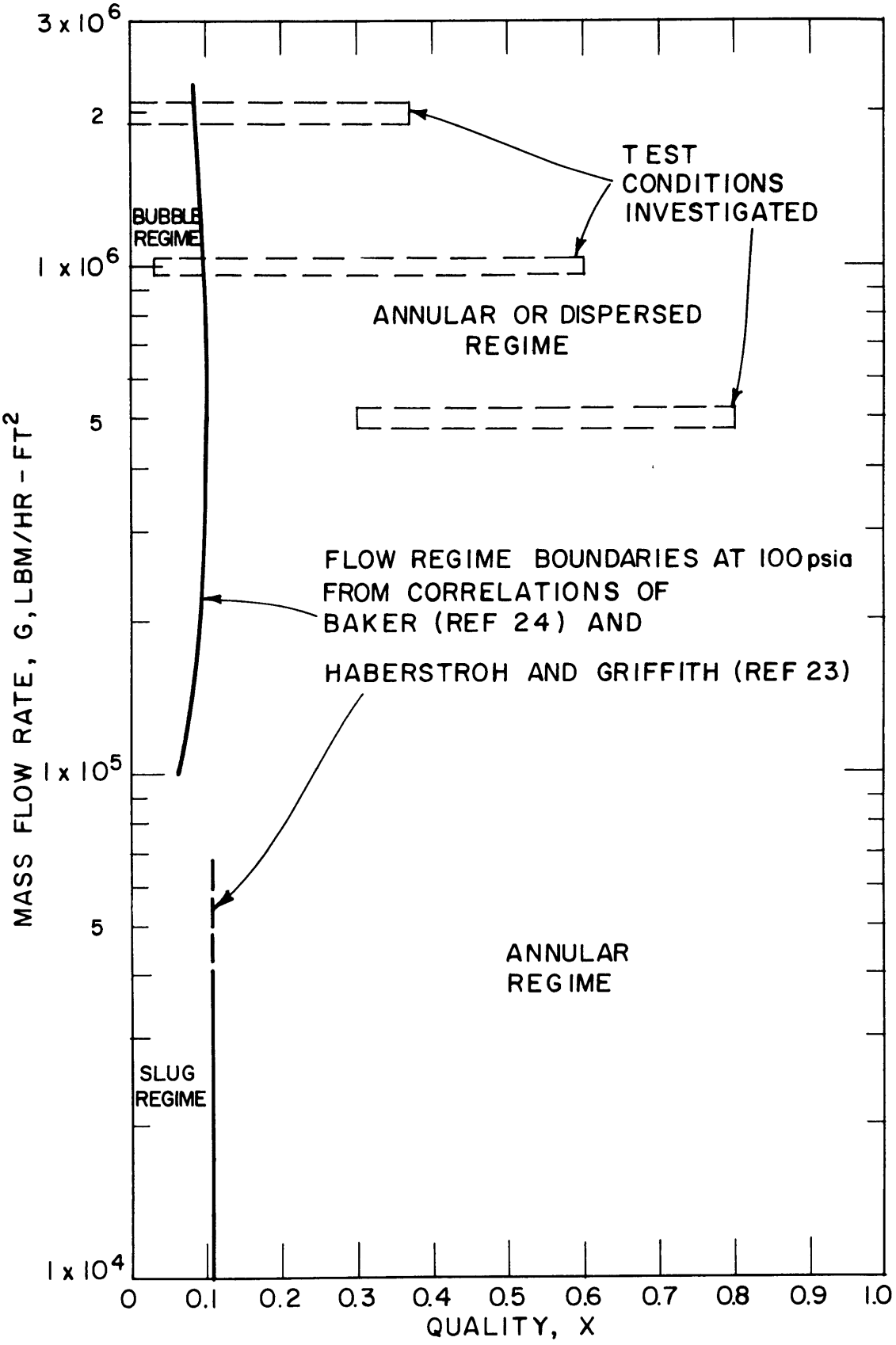

FIGURE 5. FLOW REGIME MAP FOR TEST CONDITIONS

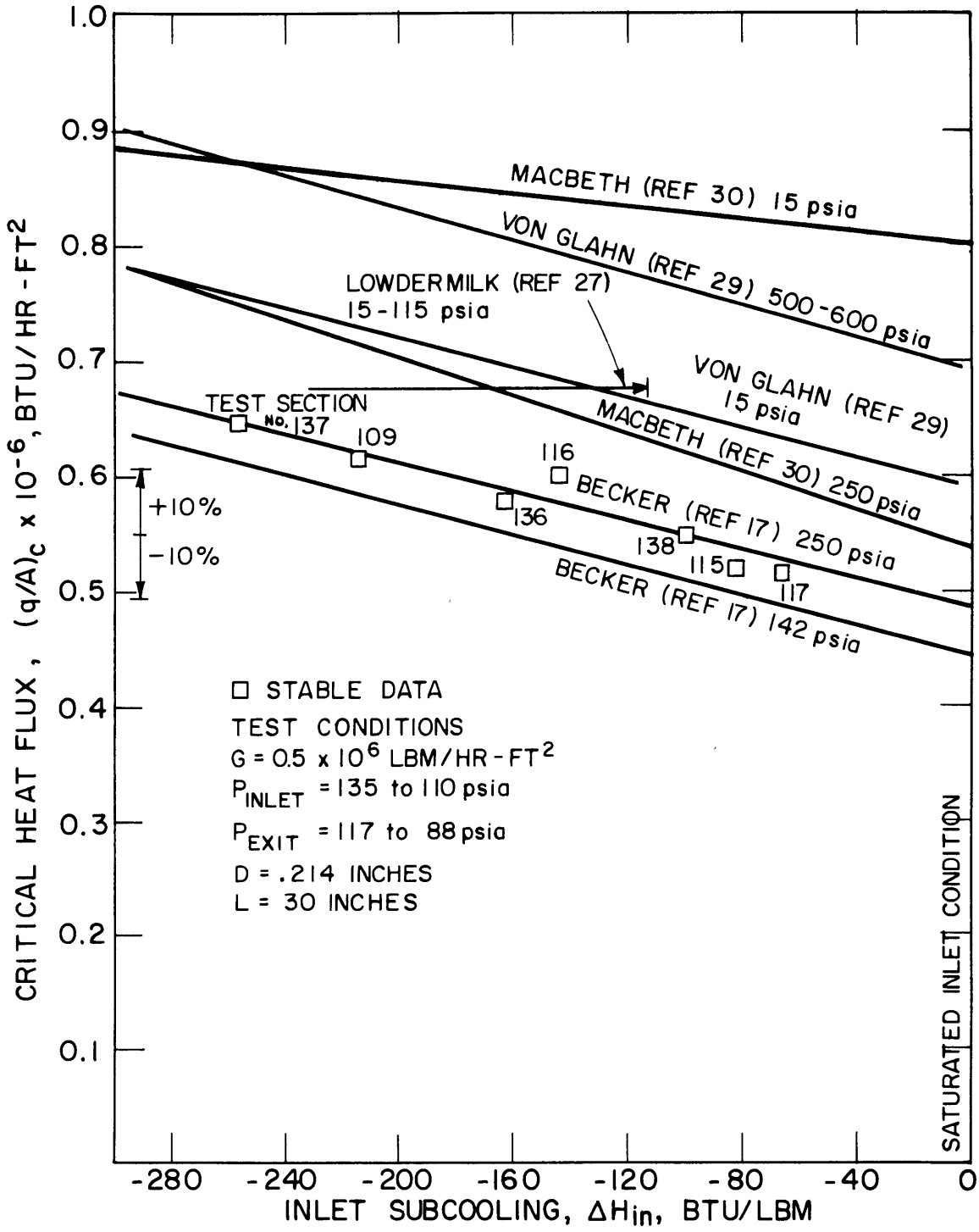

FIGURE 6. COMPARISON OF UNIFORM FLUX DATA WITH EXISTING CORRELATIONS, G = 0.5 x 10^6 LBM/HR-FT^2

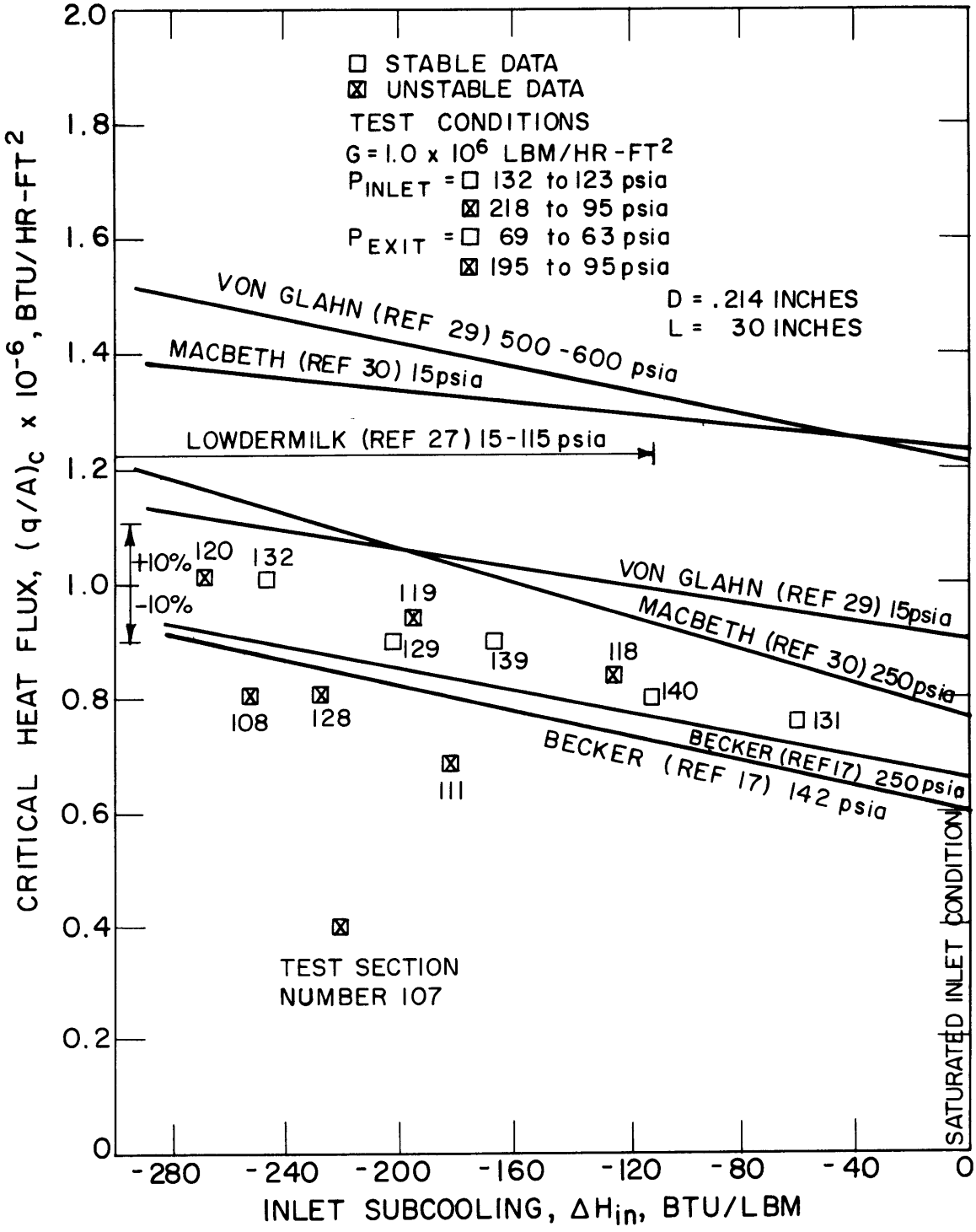

FIGURE 7. COMPARISON OF UNIFORM FLUX DATA WITH EXISTING CORRELATIONS, G = 1.0 x 10^6 LBM/HR-FT^2

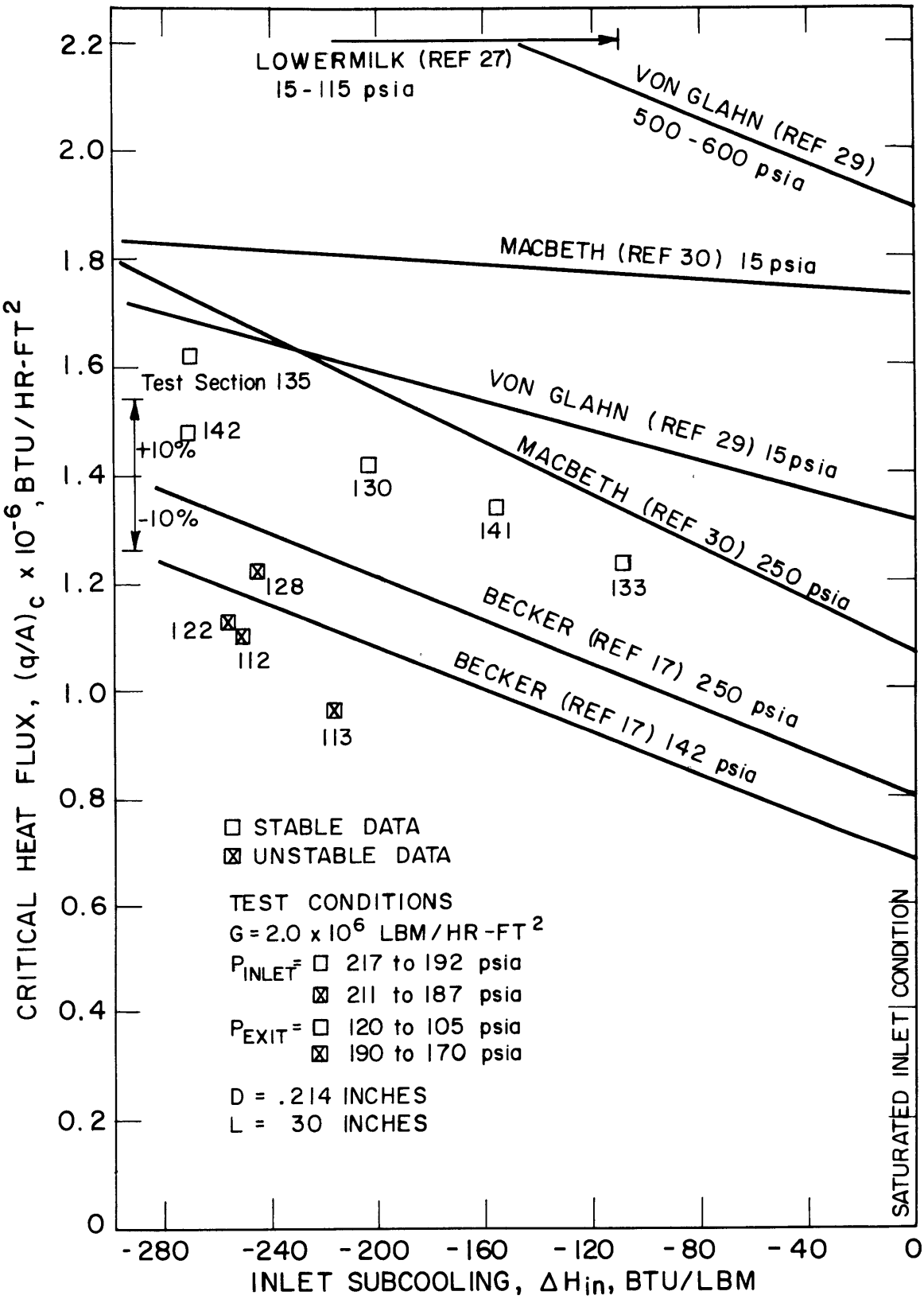

FIGURE 8. COMPARISON OF UNIFORM FLUX DATA WITH EXISTING CORRELATIONS, G = 2.0 x 10^6 LBM/HR-FT^2

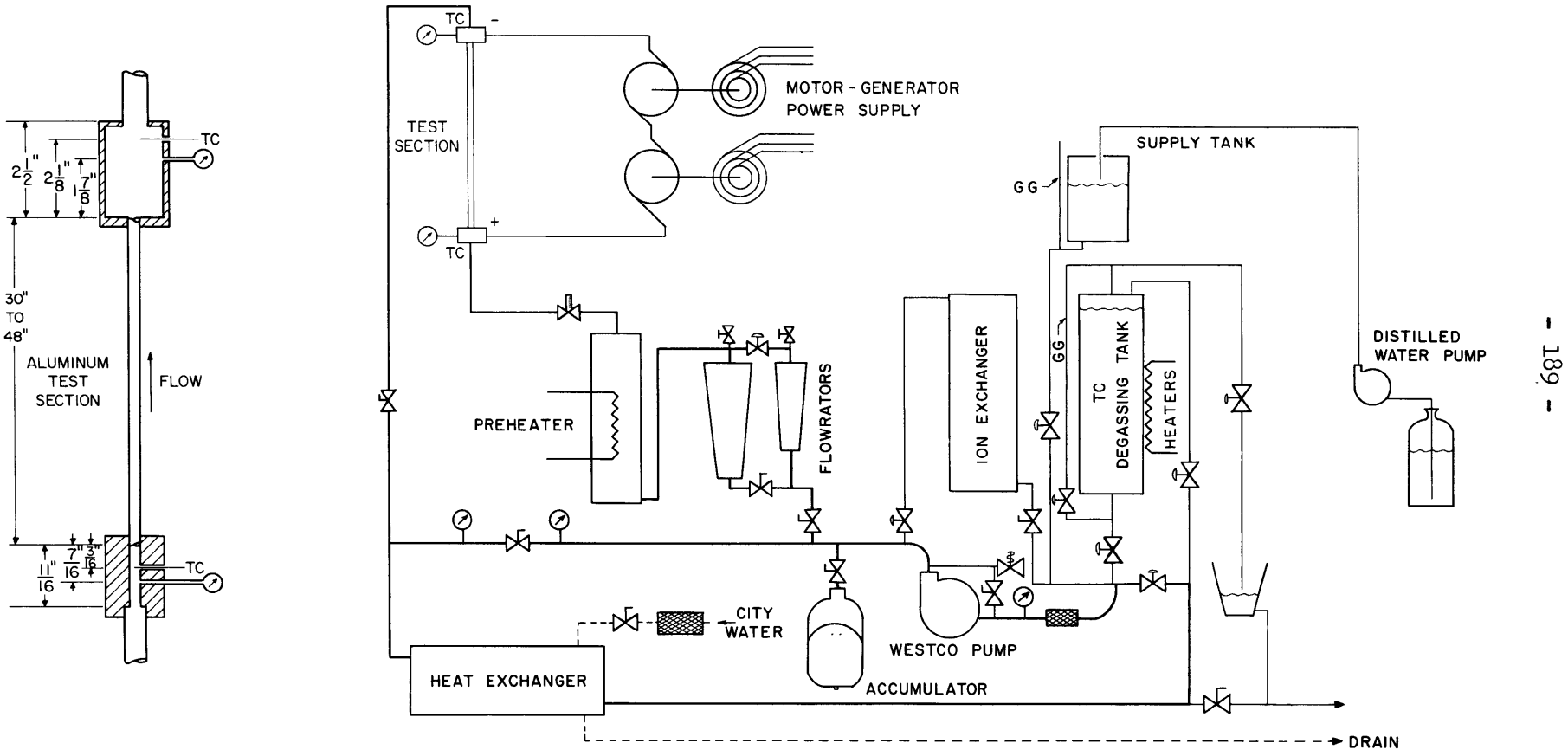

FIGURE 9. SCHEMATIC LAYOUT OF EXPERIMENTAL FACILITY AND TEST SECTION

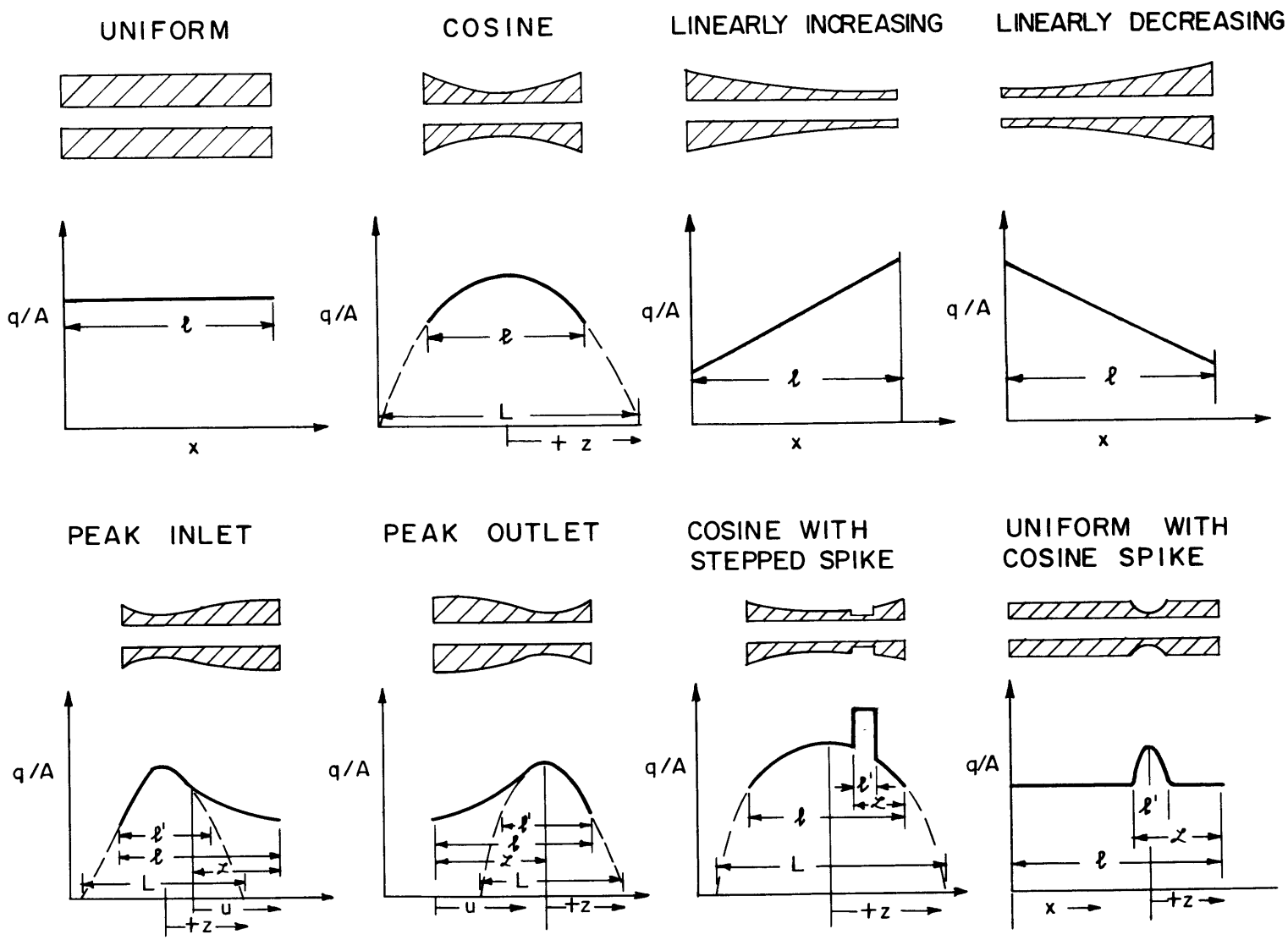

FIGURE 10. AXIAL FLUX DISTRIBUTIONS TESTED

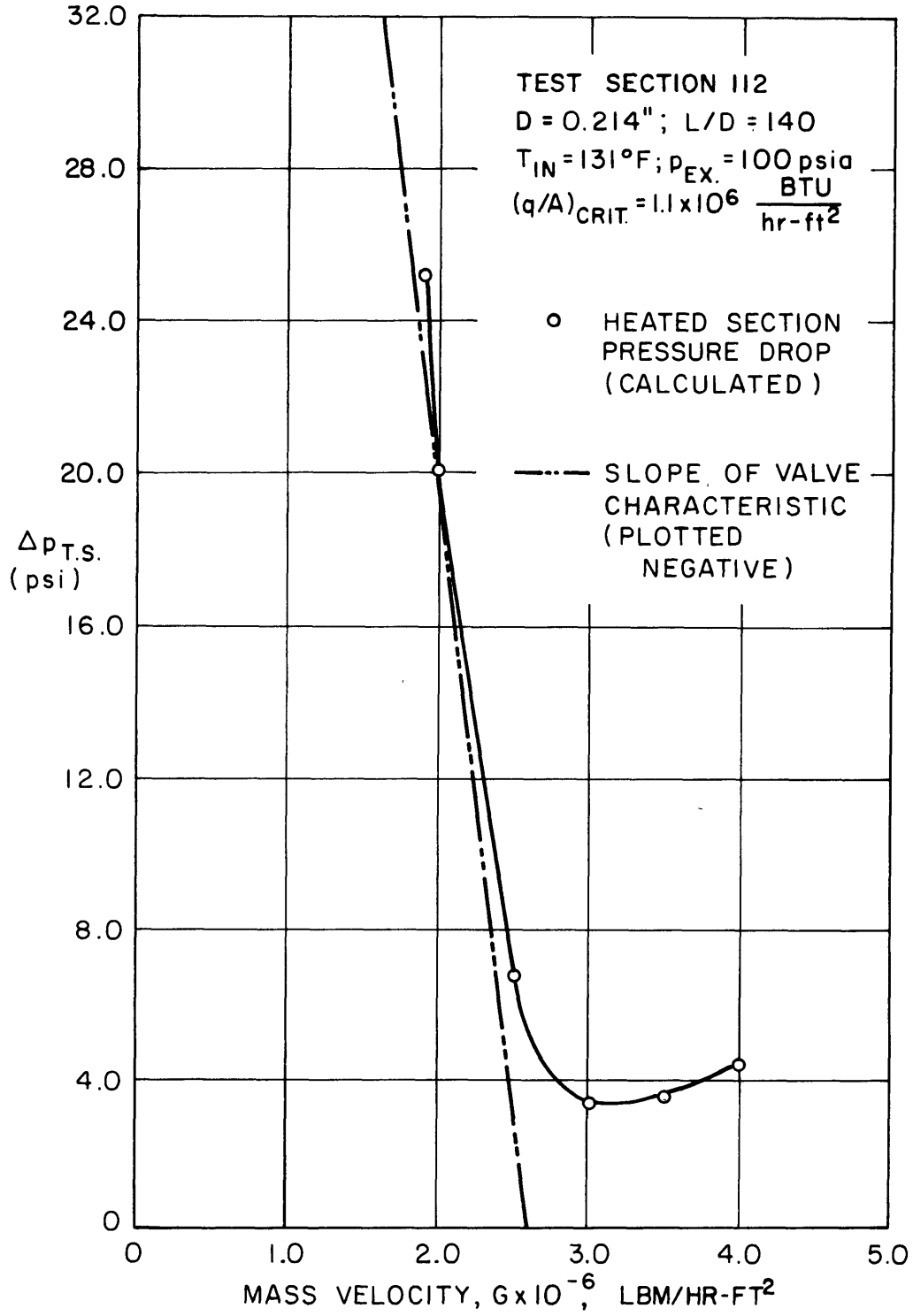

FIGURE 11: CONFIRMATION FOR TEST SECTION 112 THAT THE OVERALL SLOPE GOES TO ZERO AT THE FLOW RATE ($G=2.0 \times 10^6$ LBM/HR-FT^2) WHERE OSCILLATION OCCURED

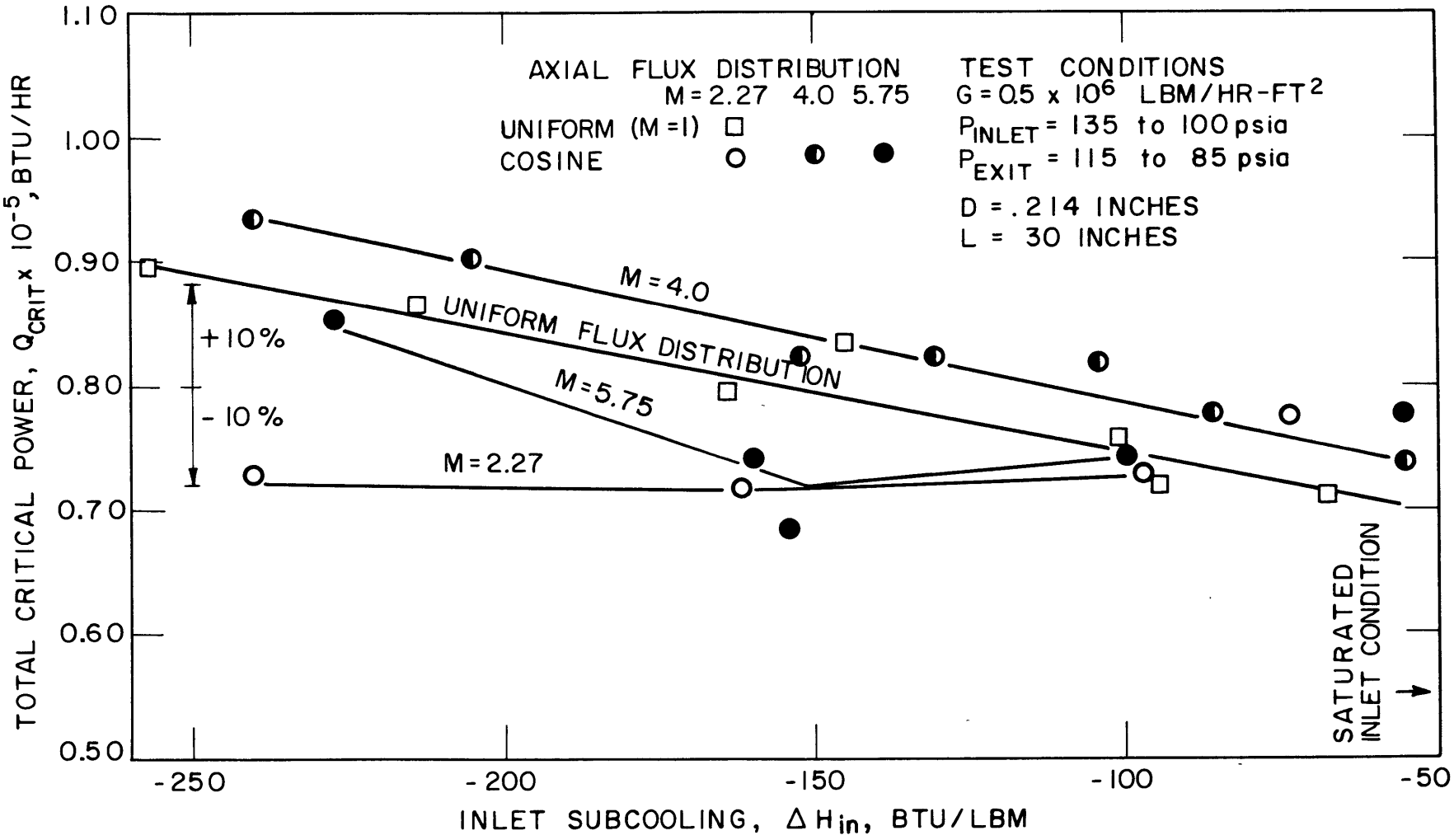

FIGURE 12. TOTAL CRITICAL POWER FOR UNIFORM AND COSINE FLUX DISTRIBUTIONS AT $G = 0.5 \times 10^6$ LBM/HR-FT^2

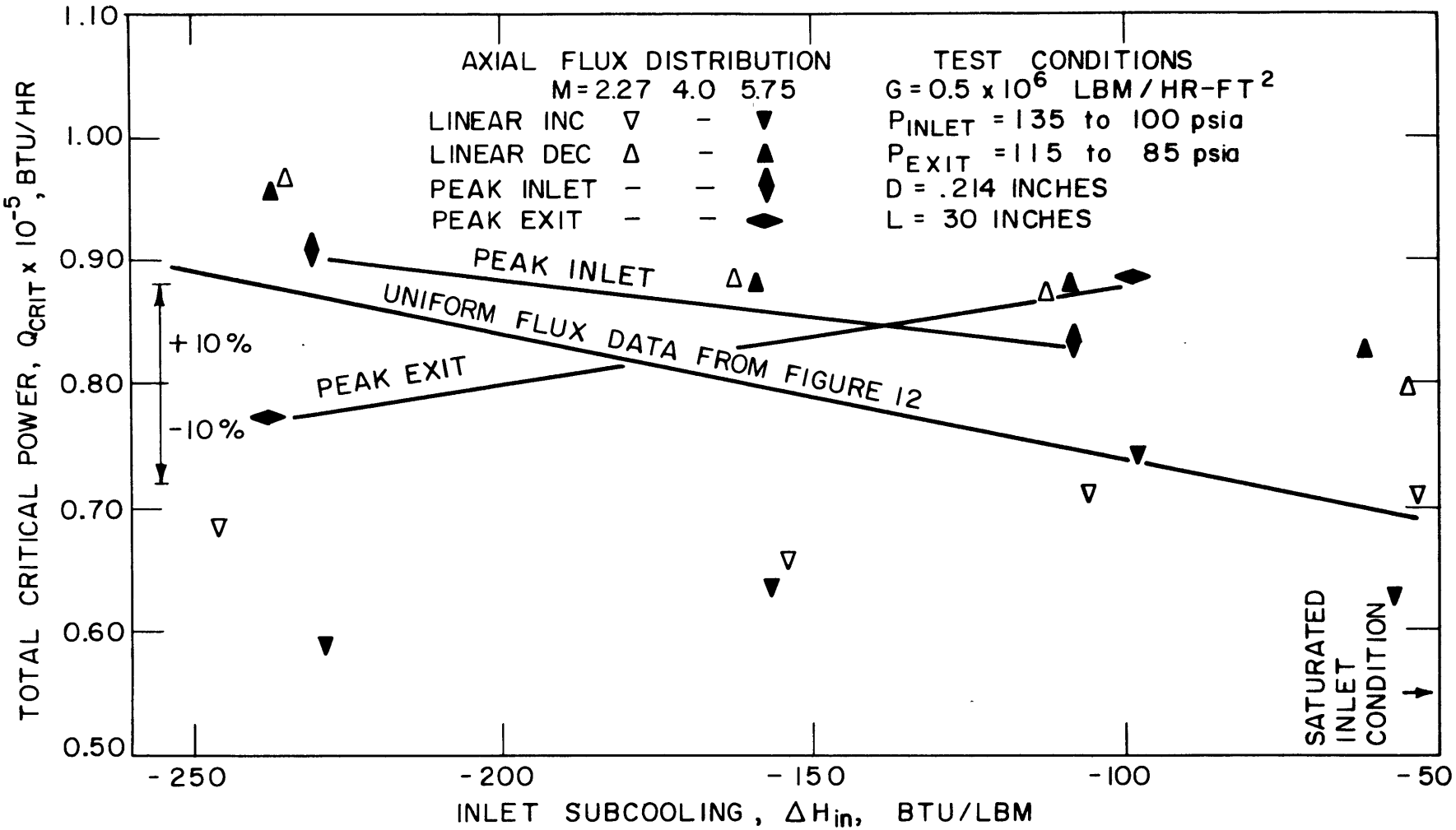

FIGURE 13. TOTAL CRITICAL POWER FOR LINEAR AND PEAKED FLUX DISTRIBUTIONS AT $G = 0.5 \times 10^6$ LBM/HR-FT^2

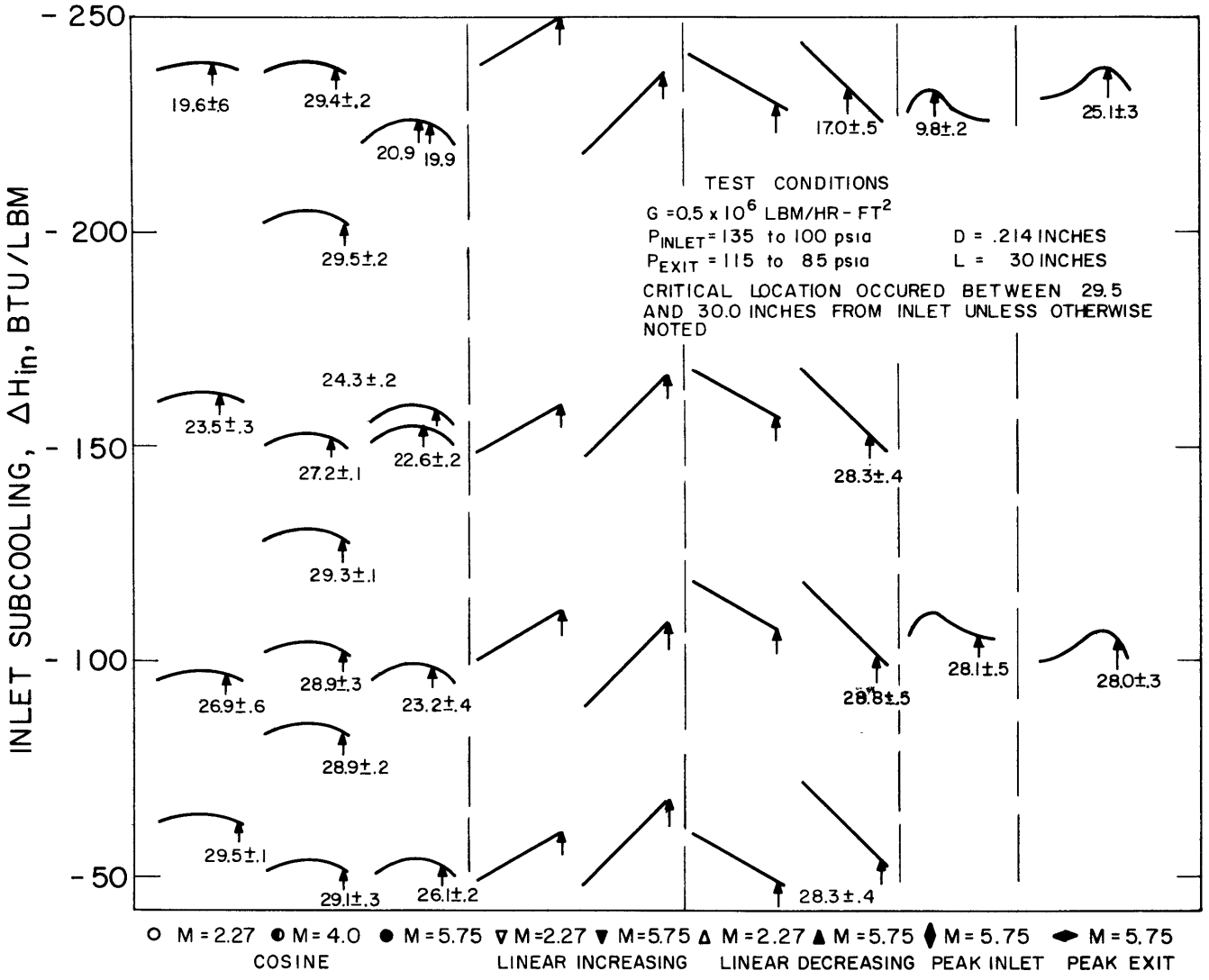

FIGURE 14. CRITICAL LOCATIONS (INCHES FROM INLET) FOR THE NONUNIFORM AXIAL FLUX DISTRIBUTIONS INVESTIGATED AT G = 0.5 x 10^6 LBM/HR-FT^2

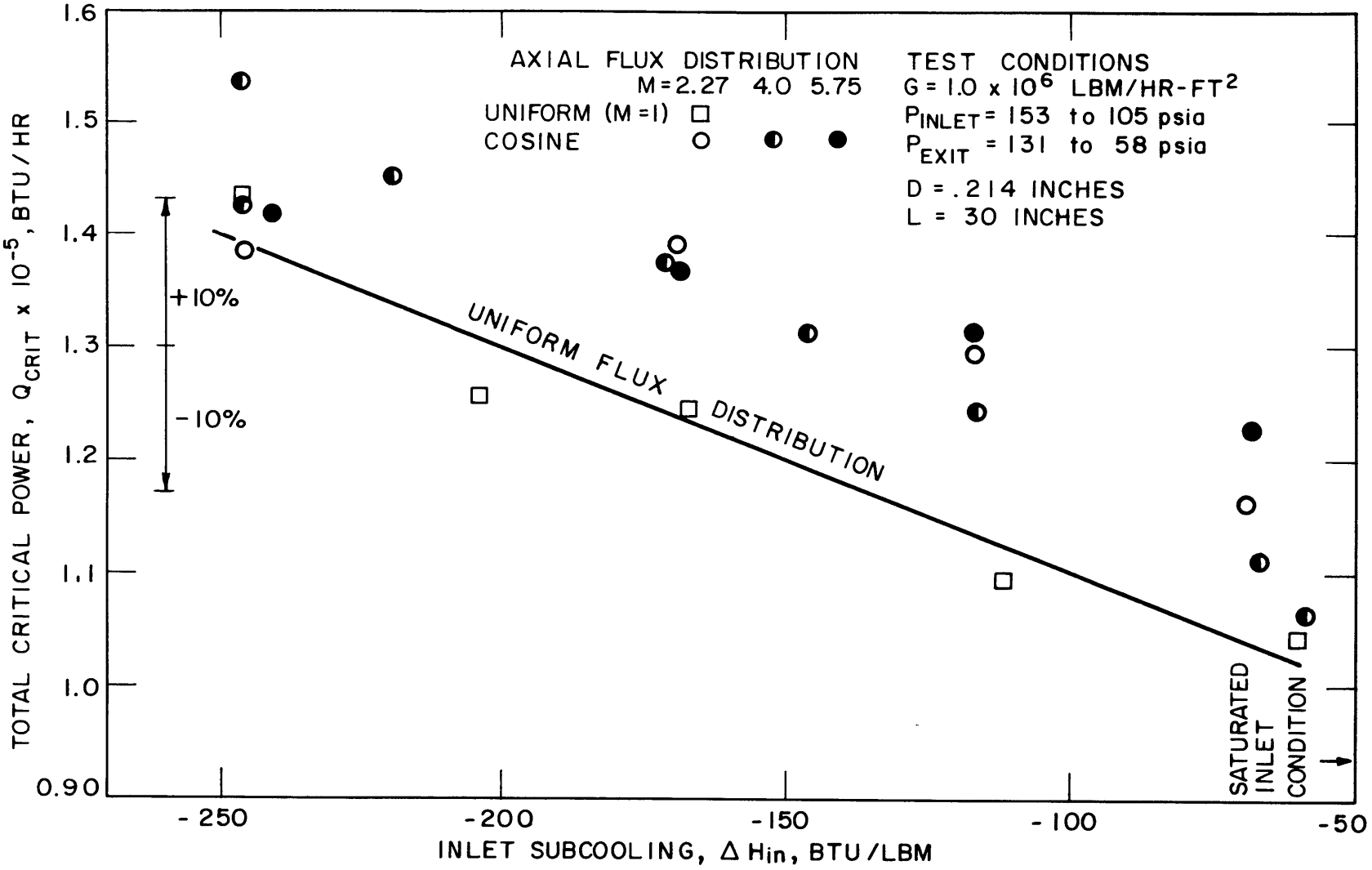

FIGURE 15. TOTAL CRITICAL POWER FOR UNIFORM AND COSINE FLUX DISTRIBUTIONS AT $G = 1.0 \times 10^6$ LBM/HR-FT^2

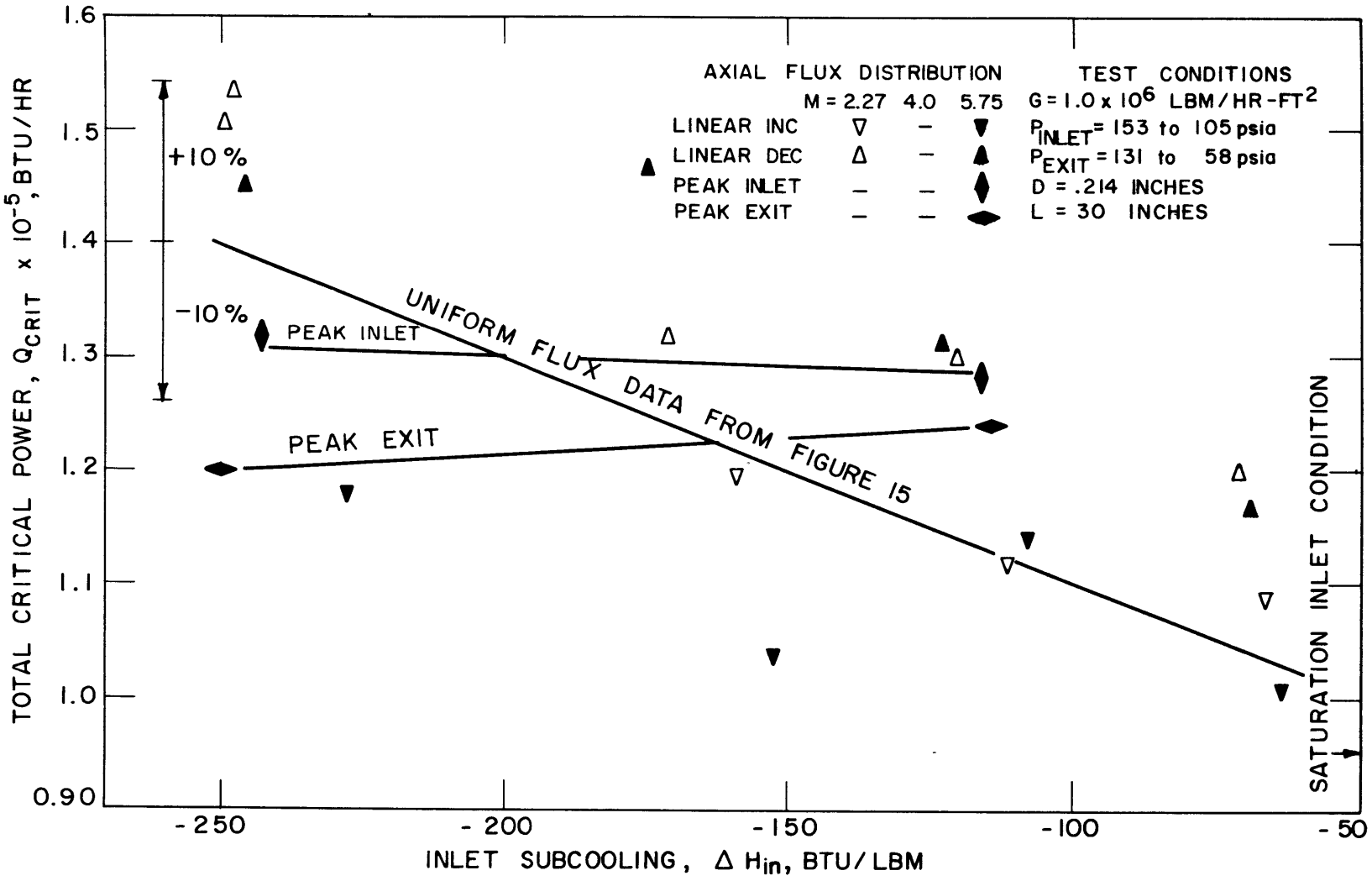

FIGURE 16. TOTAL CRITICAL POWER FOR LINEAR AND PEAKED FLUX DISTRIBUTIONS AT $G = 1.0 \times 10^6$ LBM/HR-FT^2

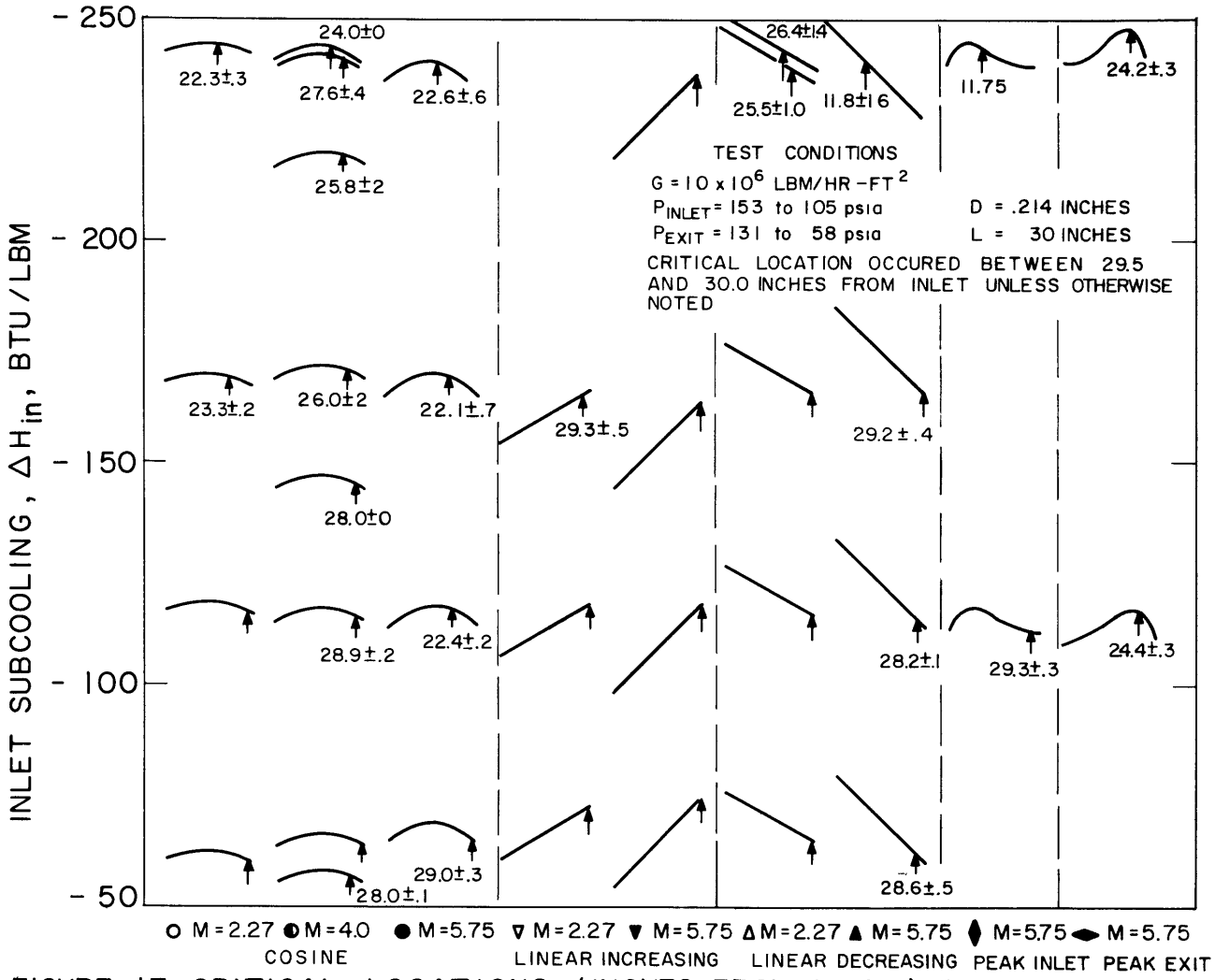

FIGURE 17. CRITICAL LOCATIONS (INCHES FROM INLET) FOR THE NONUNIFORM AXIAL FLUX DISTRIBUTIONS INVESTIGATED AT G = 1.0 x 10^6 LBM/HR-FT^2

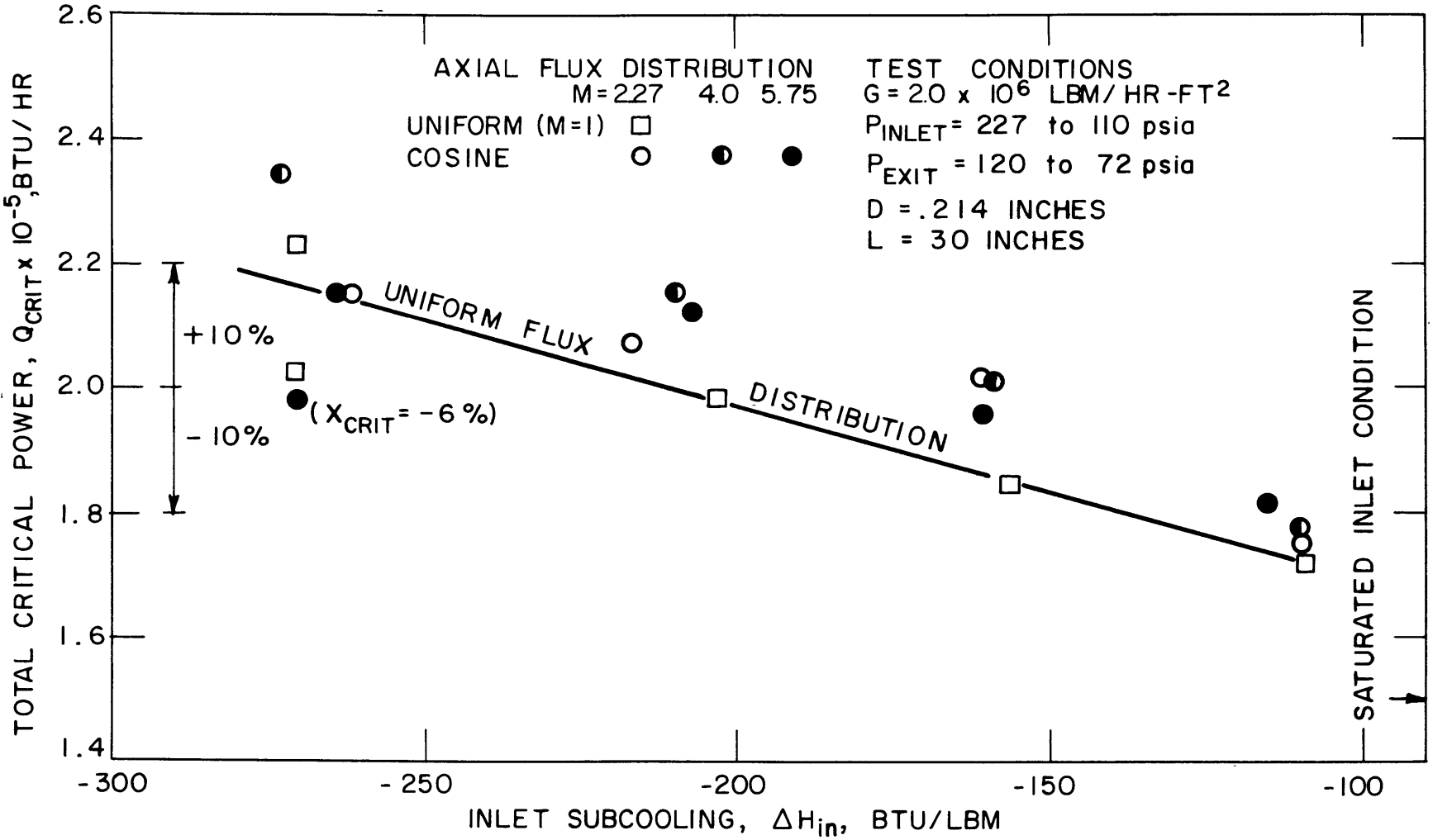

FIGURE 18. TOTAL CRITICAL POWER FOR UNIFORM AND COSINE FLUX DISTRIBUTIONS AT $G = 2.0 \times 10^6$ LBM/HR-FT^2

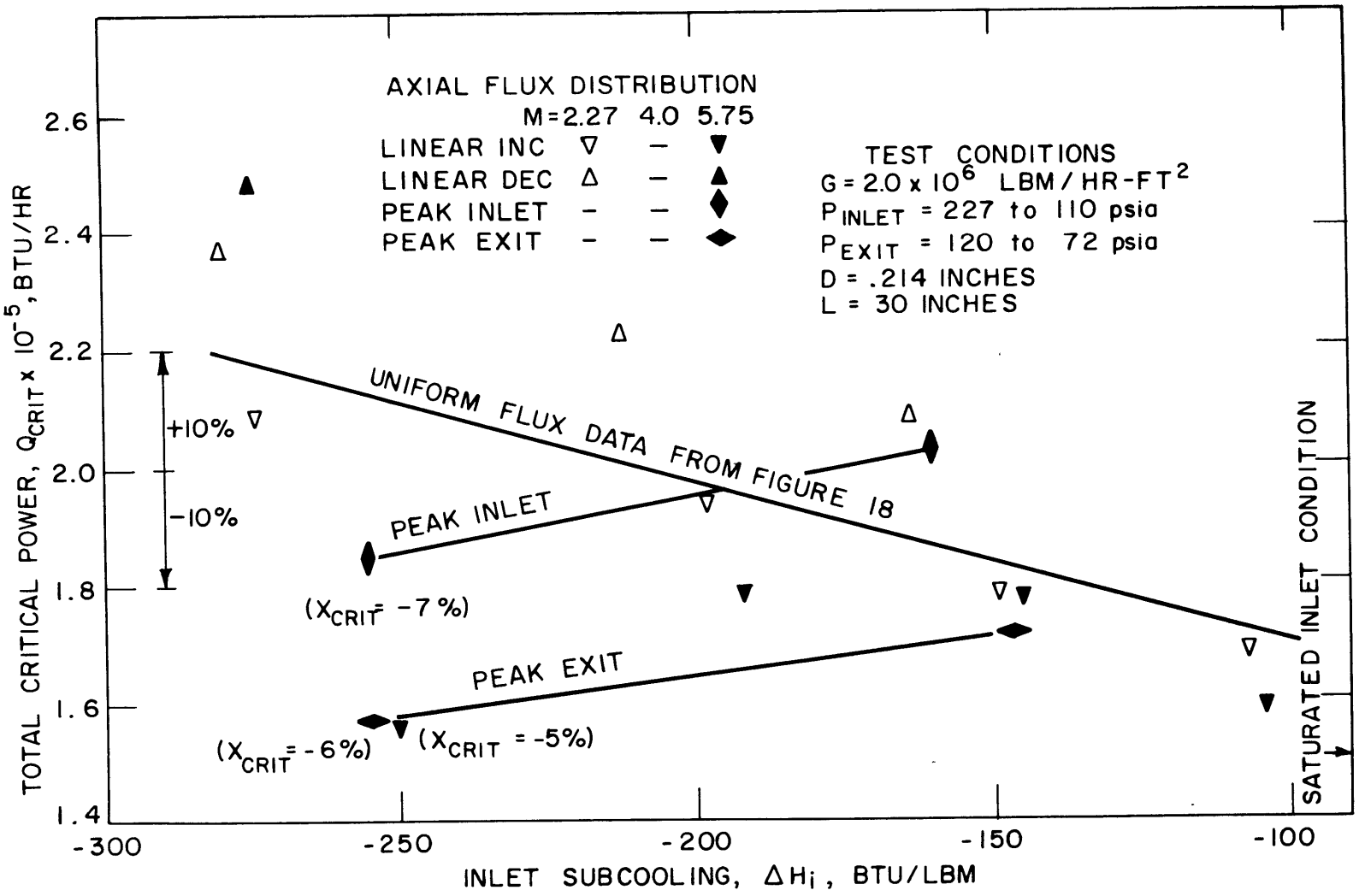

FIGURE 19. TOTAL CRITICAL POWER FOR LINEAR AND PEAKED FLUX DISTRIBUTIONS AT $G = 2.0 \times 10^6$ LBM/HR-FT^2

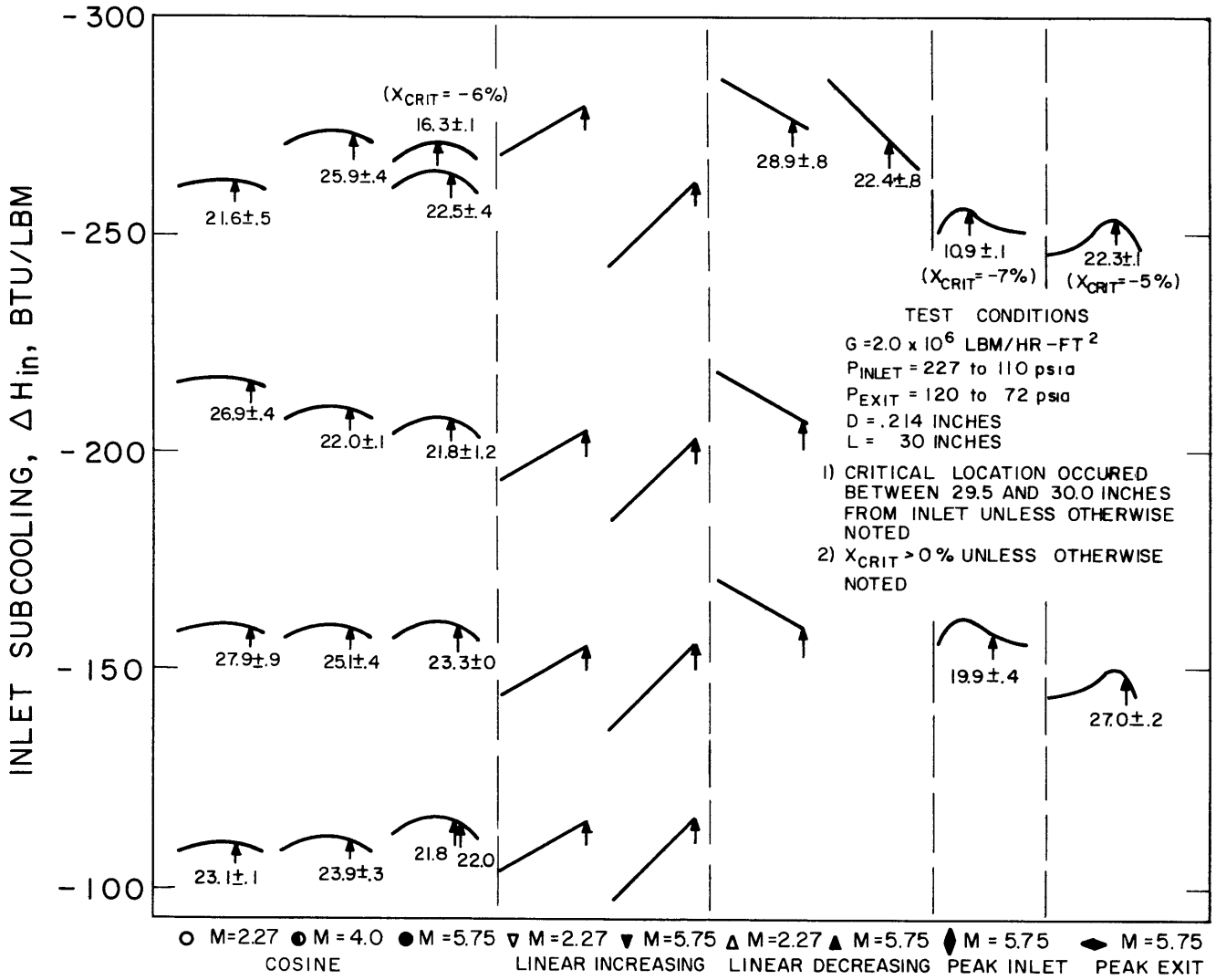

FIGURE 20. CRITICAL LOCATIONS (INCHES FROM INLET) FOR THE NONUNIFORM AXIAL FLUX DISTRIBUTIONS INVESTIGATED AT G = 2.0 x 10^6 LBM/HR-FT^2

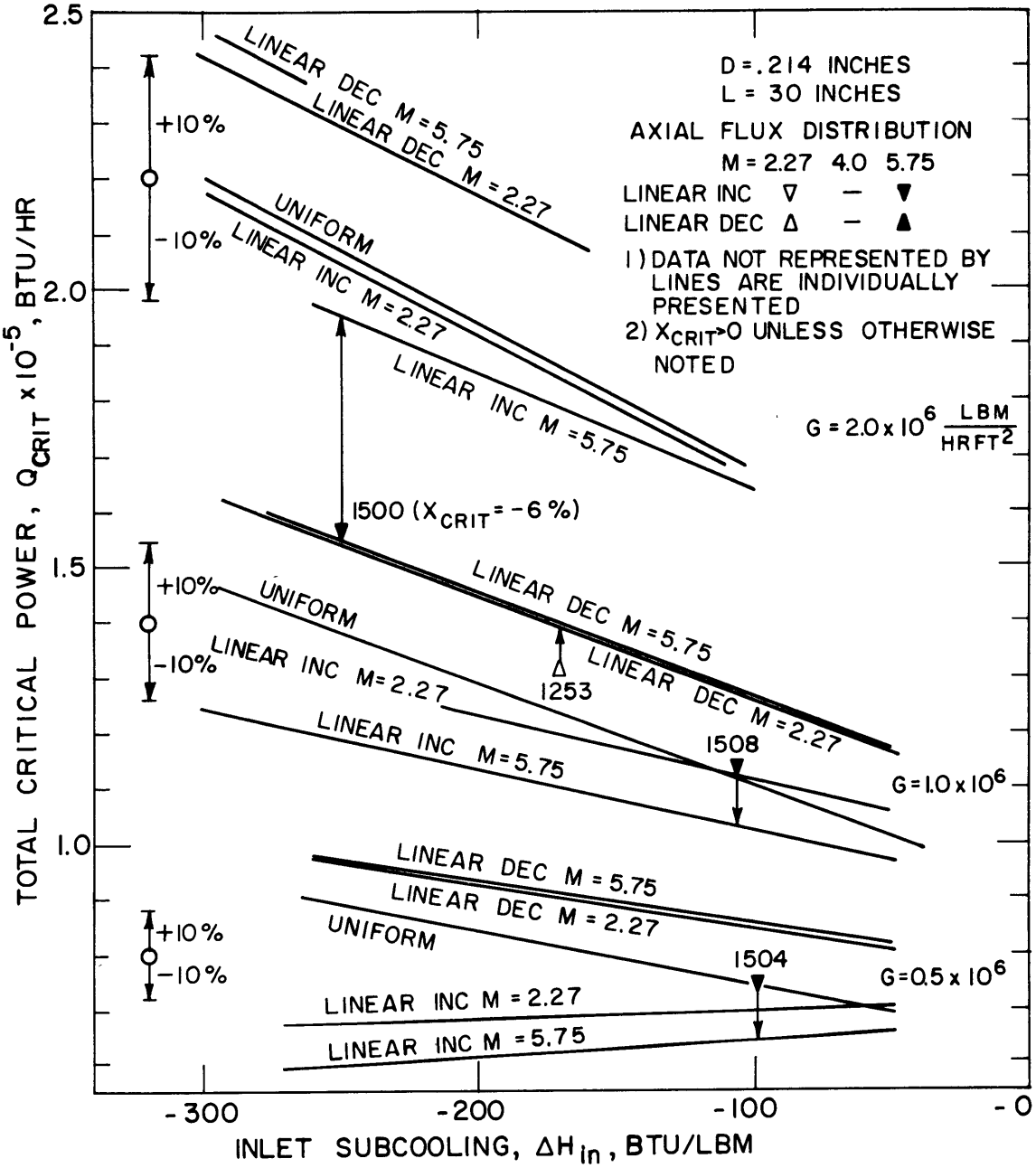

FIGURE 21. SUMMARY OF EFFECT OF LINEAR INCREASING AND DECREASING FLUX DISTRIBUTIONS ON TOTAL CRITICAL POWER

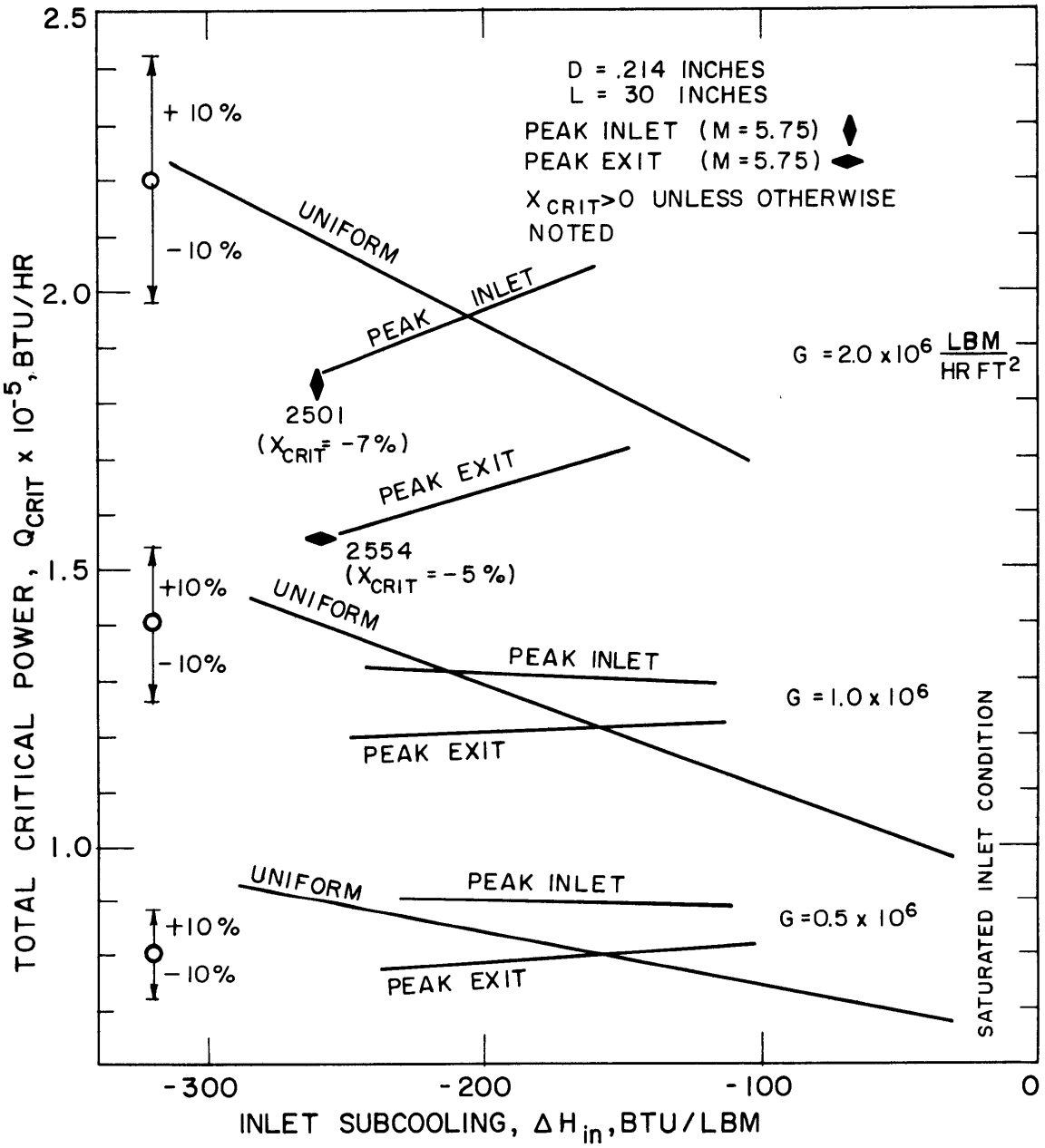

FIGURE 22. SUMMARY OF EFFECT OF PEAK INLET AND EXIT FLUX DISTRIBUTIONS ON TOTAL CRITICAL POWER

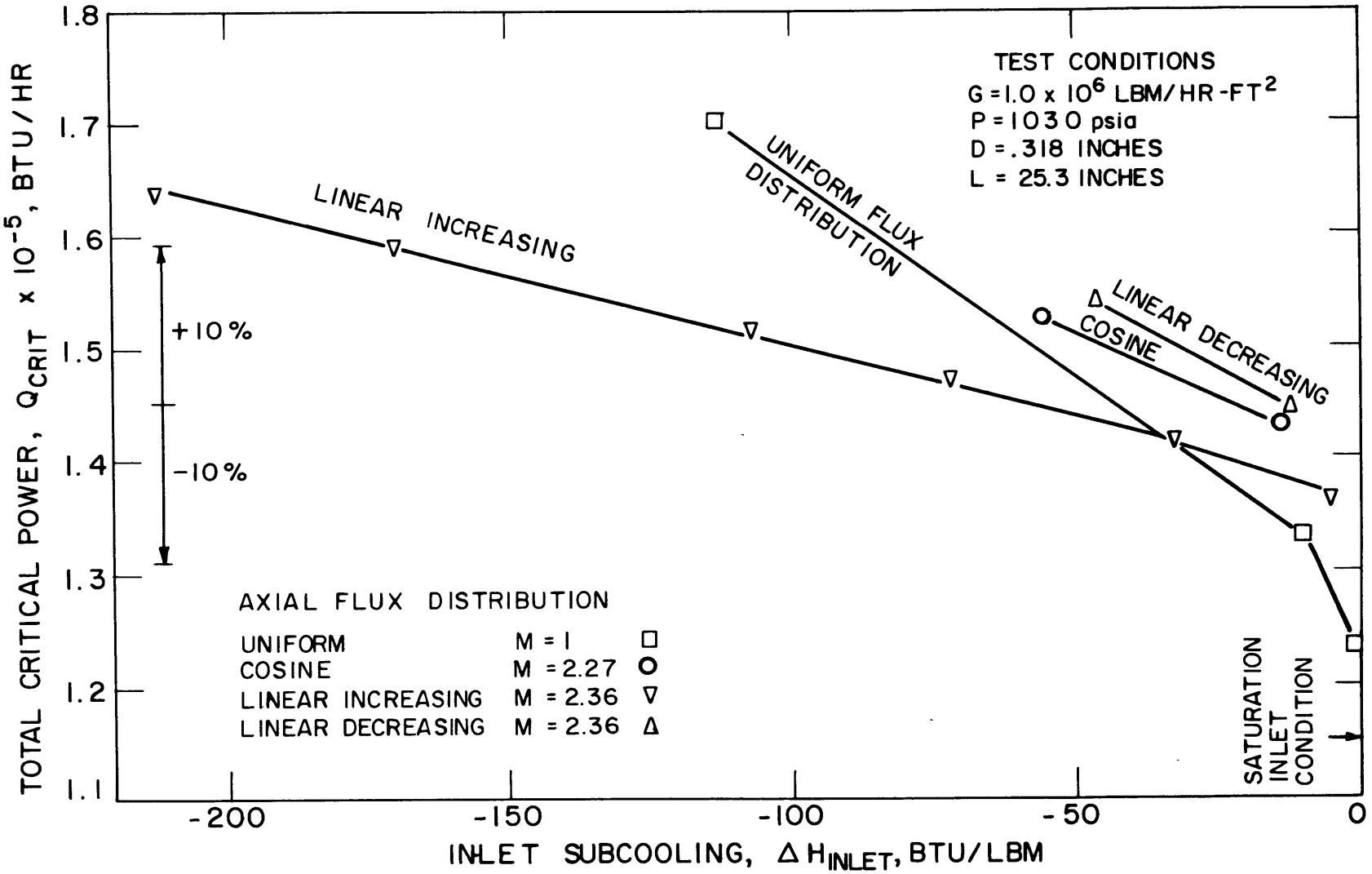

FIGURE 23. TOTAL CRITICAL POWER FOR DATA OF BERTOLETTI ET AL. (REF. 11)

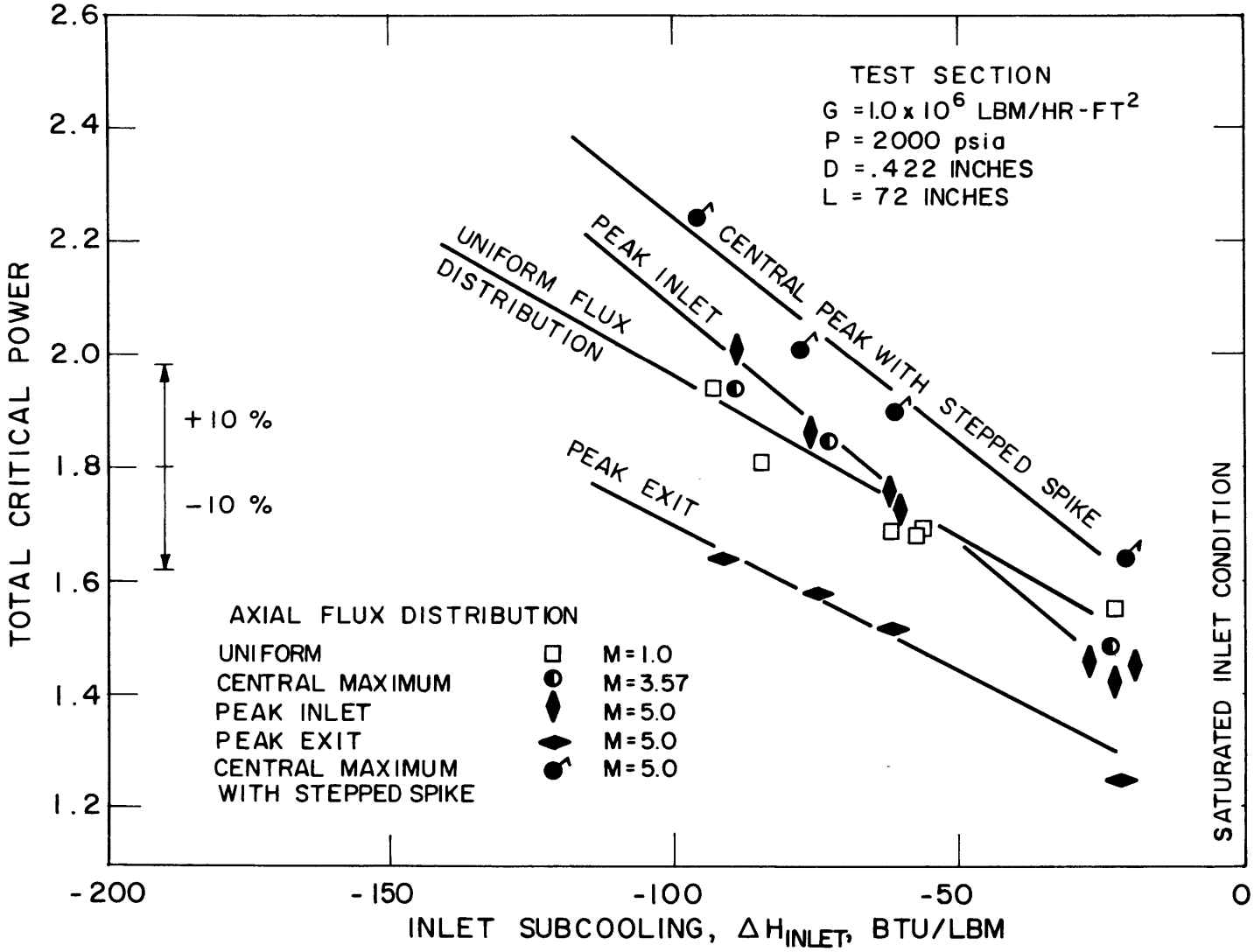

FIGURE 24. TOTAL CRITICAL POWER FOR DATA OF SWENSON (REF. 5)

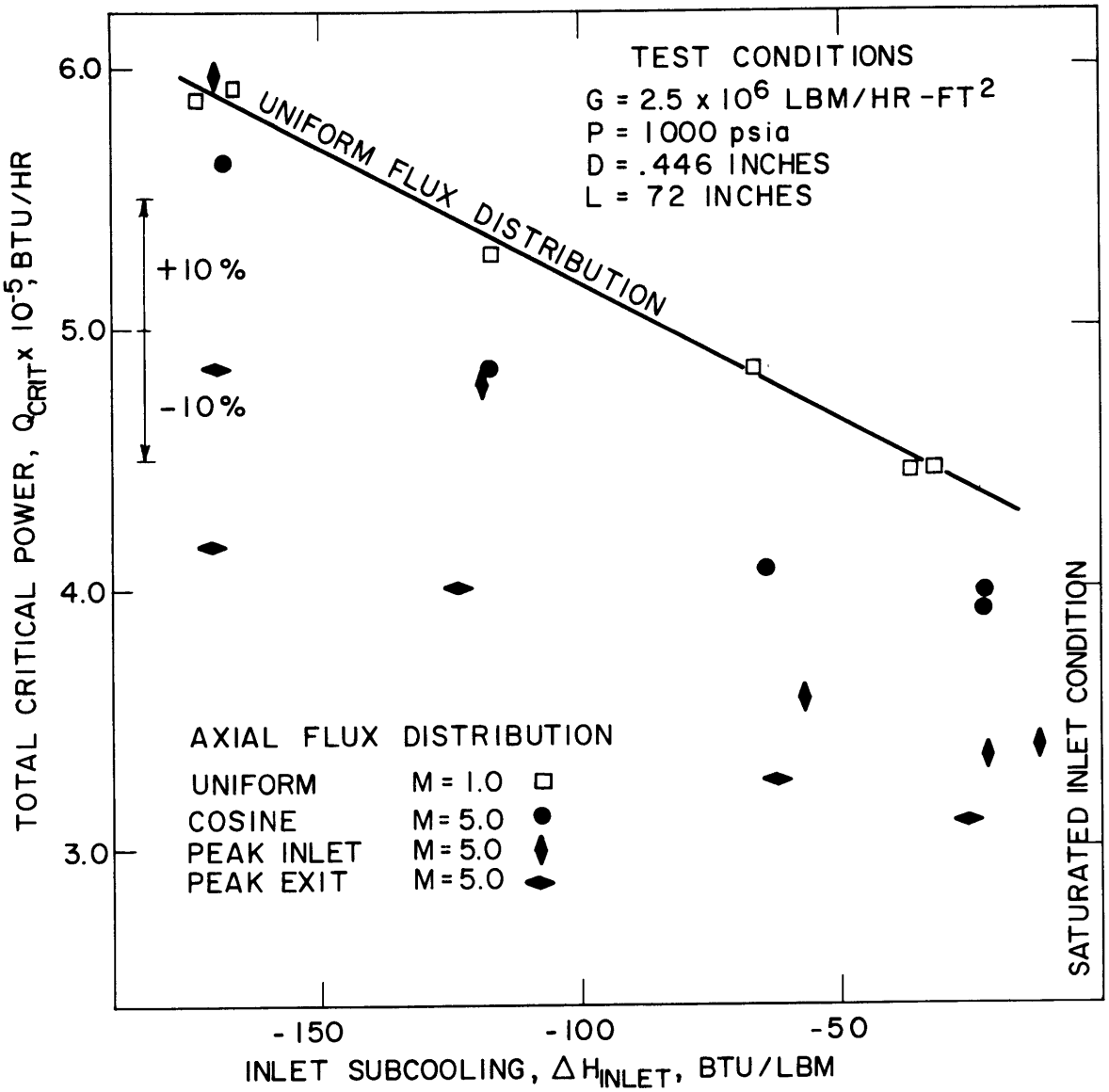

FIGURE 25 TOTAL CRITICAL POWER FOR DATA OF BABCOCK AND WILCOX (REF. 15)

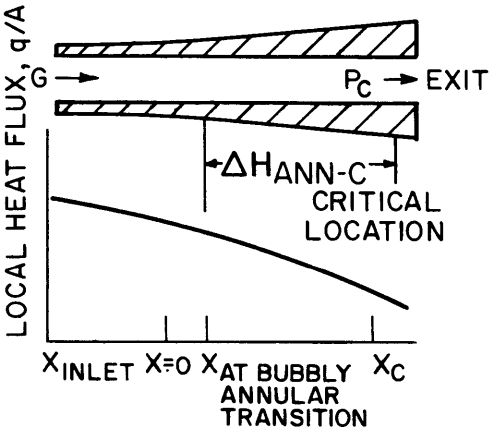

FIGURE 26a. LINEAR DECREASING HEAT FLUX

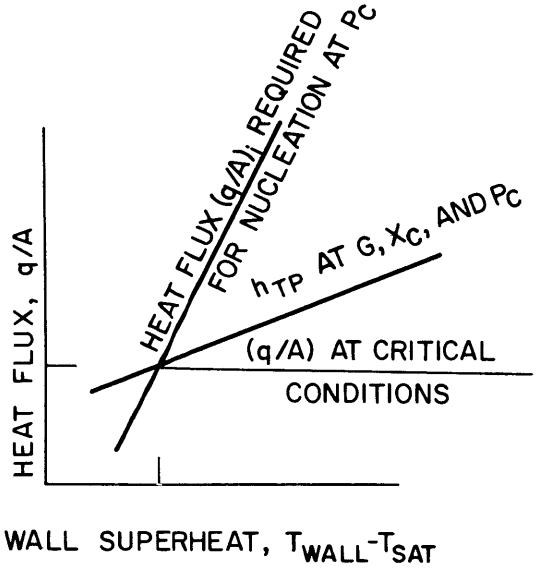

FIGURE 26b. $(q/A)_i$ AT CRITICAL CONDITIONS

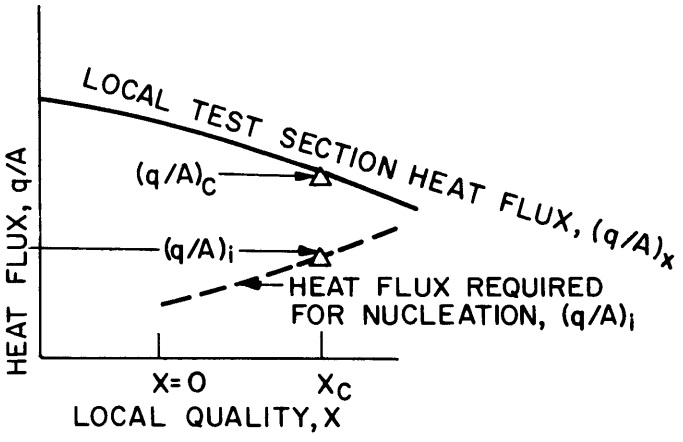

FIGURE 26c. HEAT FLUX CONDITIONS ALONG ENTIRE TEST SECTION

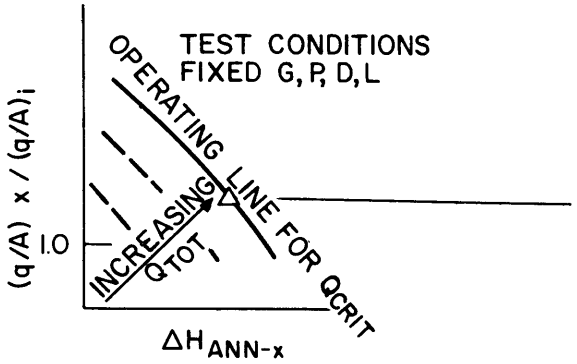

FIGURE 26d. OPERATING LINES FOR TEST SECTION FOR Q_{TOT} EQUAL AND LESS THAN Q_{CRIT}

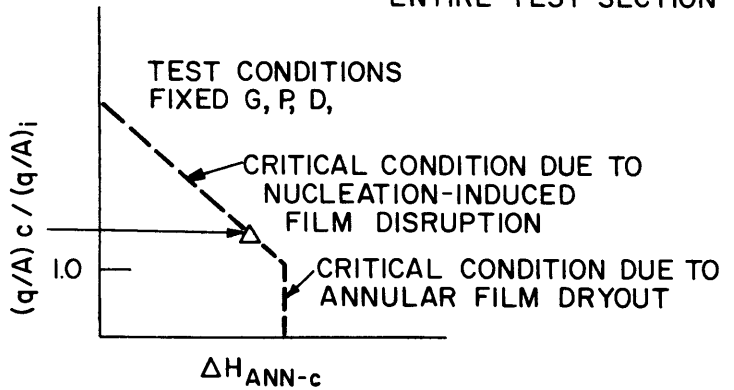

FIGURE 26e EXPECTED LOCUS OF CRITICAL CONDITIONS

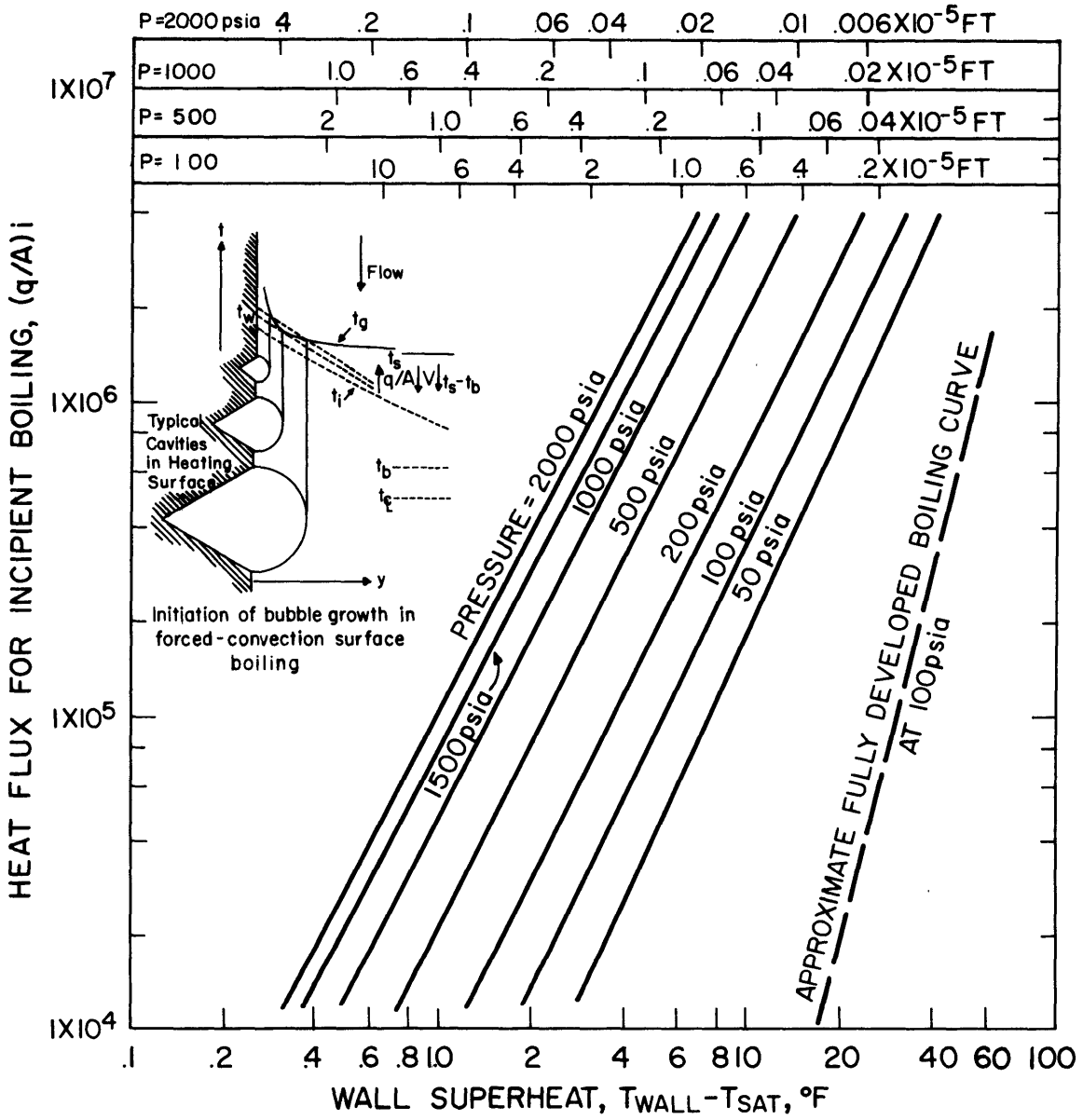

FIGURE 27. BERGLES-ROHSENOW CRITERIA (REF 35) FOR INCIPIENT BOILING $(q/A)i = 15.60\ P^{1.156}\ (T_{WALL}-T_{SAT})^{2.30}/P^{0.0234}$

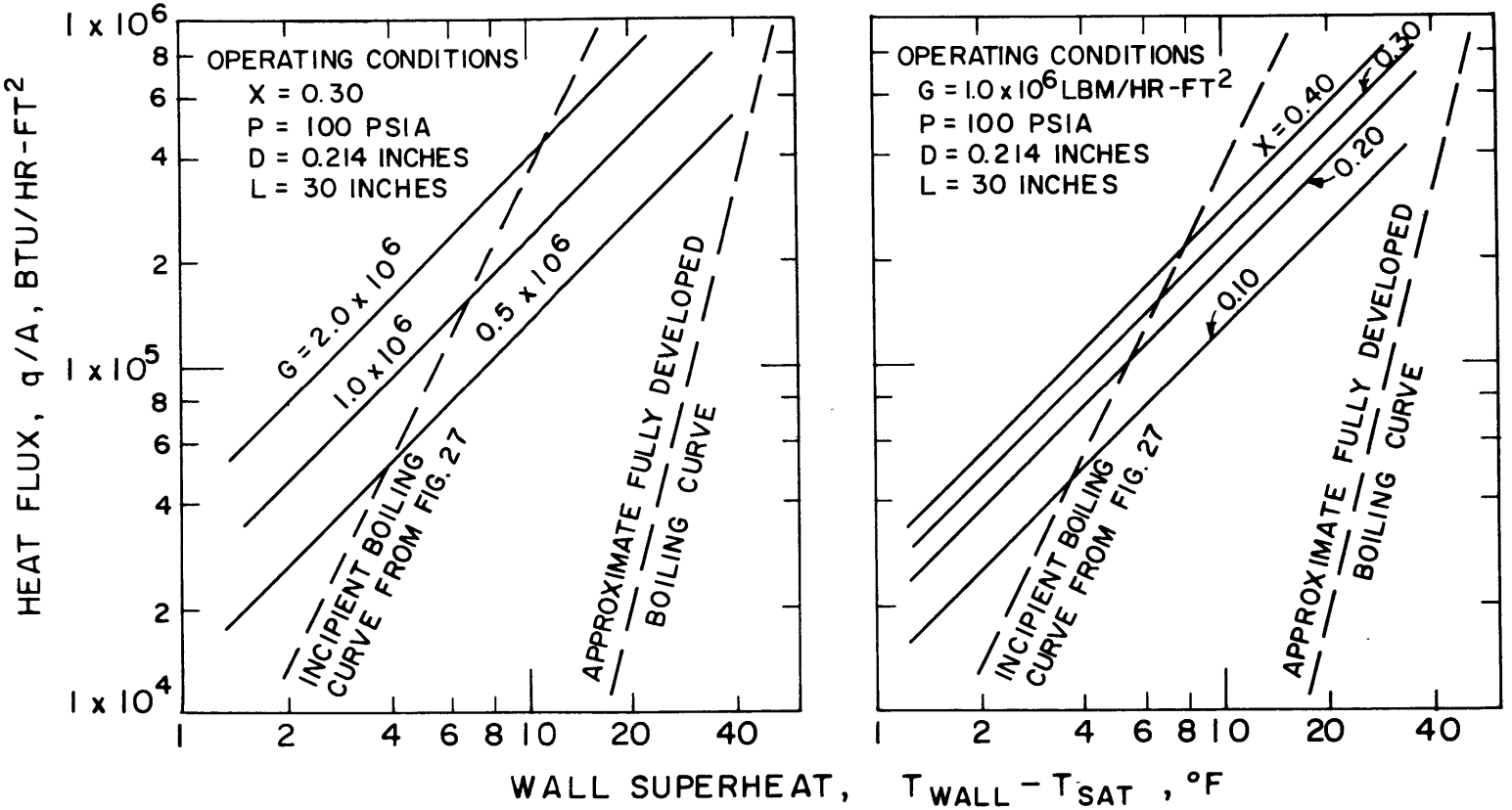

FIGURE 28. VARIATION OF TWO PHASE HEAT TRANSFER COEFFICIENT (h) WITH MASS FLOW RATE (G) AND QUALITY (X)

h_{TP} PER DENGLER-ADDOMS CORRELATION (REF 38)

$$h_{TP} = 3.5 h_L (1/X_{tt})^{0.5} \quad \text{where} \quad h_L = 0.023 \left(\frac{k_L}{D}\right)\left(\frac{GD}{\mu_L}\right)^{0.8}\left(Pr_L\right)^{0.4}$$

$$\frac{1}{X_{tt}} = \left(\frac{x}{1-x}\right)^{0.9}\left(\frac{V_v}{V_L}\right)^{0.5}\left(\frac{\mu_v}{\mu_L}\right)^{0.1}$$

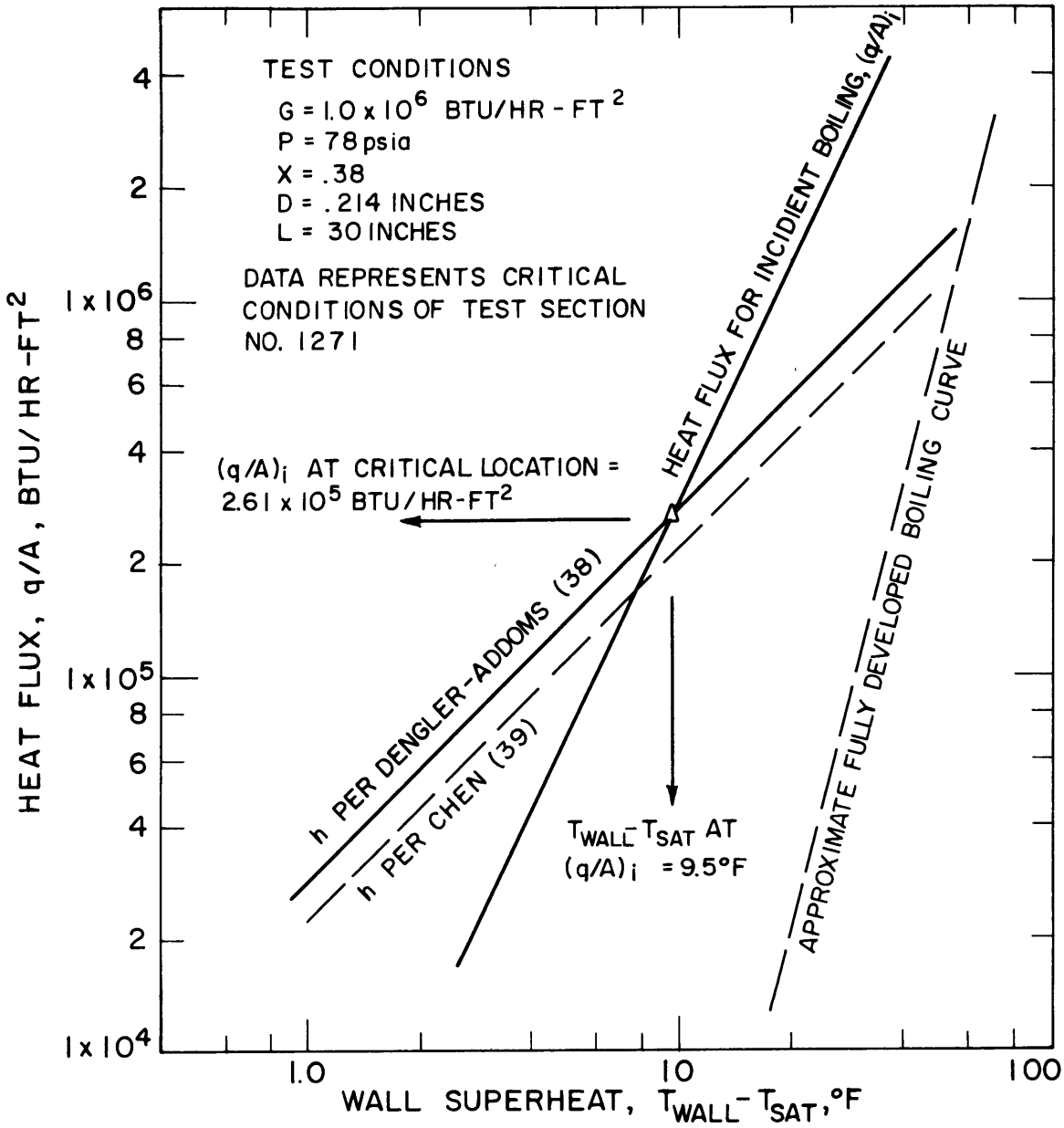

FIGURE 29. TYPICAL DETERMINATION OF HEAT FLUX REQUIRED FOR INCIPIENT BOILING, $(q/A)_i$, AT THE CRITICAL LOCATION

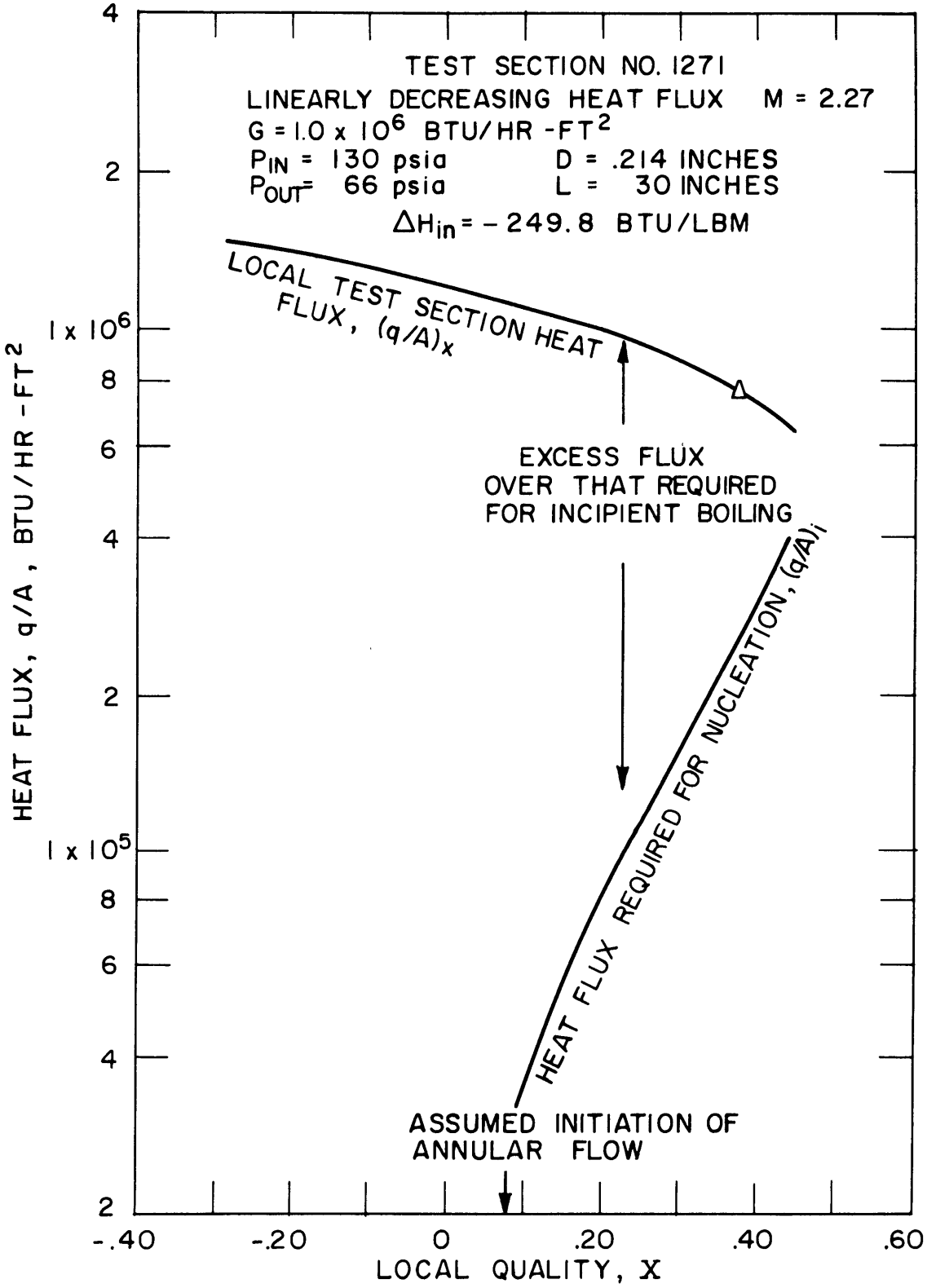

FIGURE 30. HEAT FLUX CONDITIONS ALONG TEST SECTION LENGTH

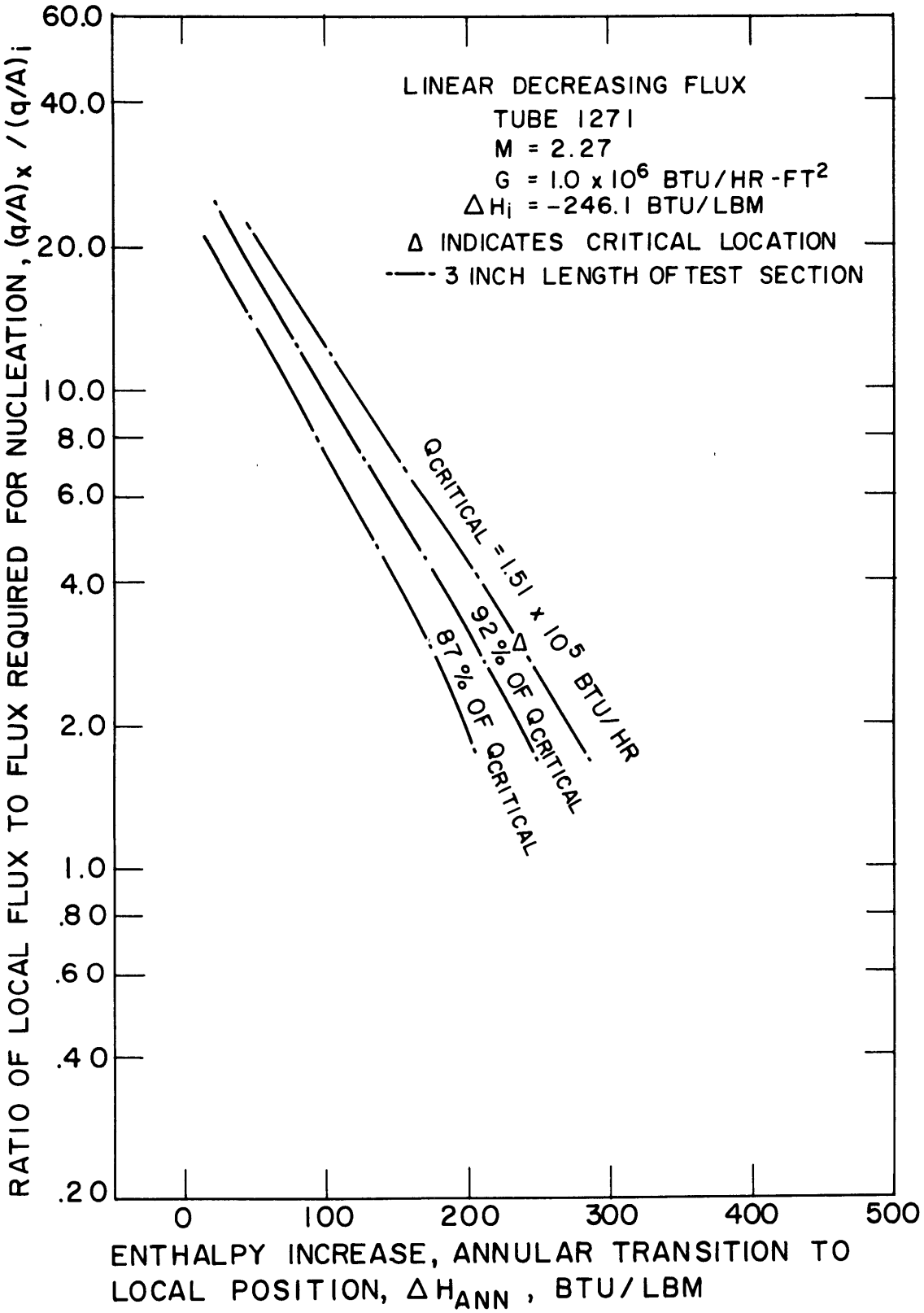

FIGURE 31. OPERATING LINES FOR TEST SECTION 1271 FOR Q_{TOT} EQUAL TO AND LESS THAN Q_{CRIT}

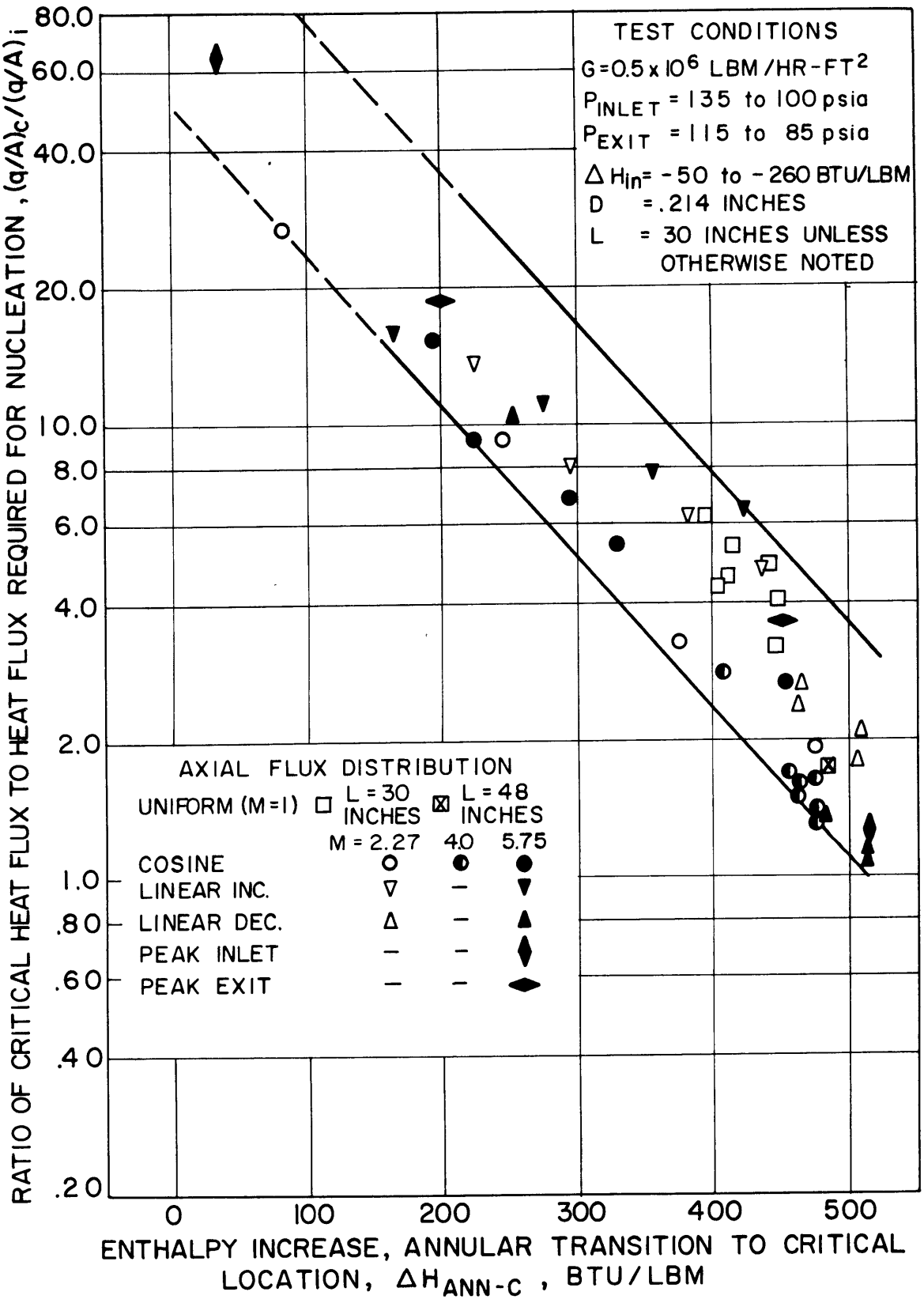

FIGURE 32. CRITICAL FLUX RESULTS AT G = 0.5 x 10^6 LBM/ HR - FT^2

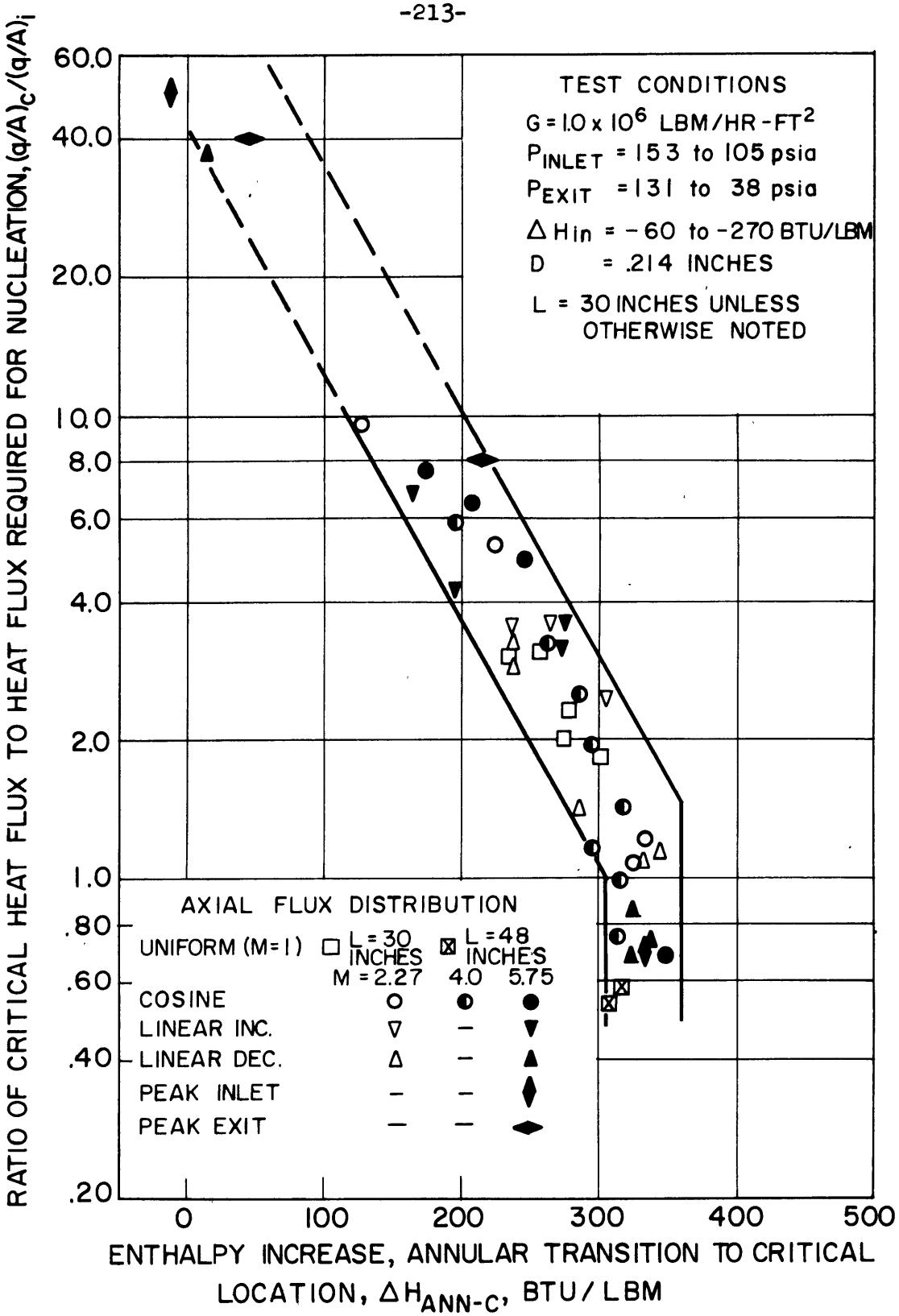

FIGURE 33. CRITICAL FLUX RESULTS AT G = 1.0 x 10^6 LBM/HR-FT^2

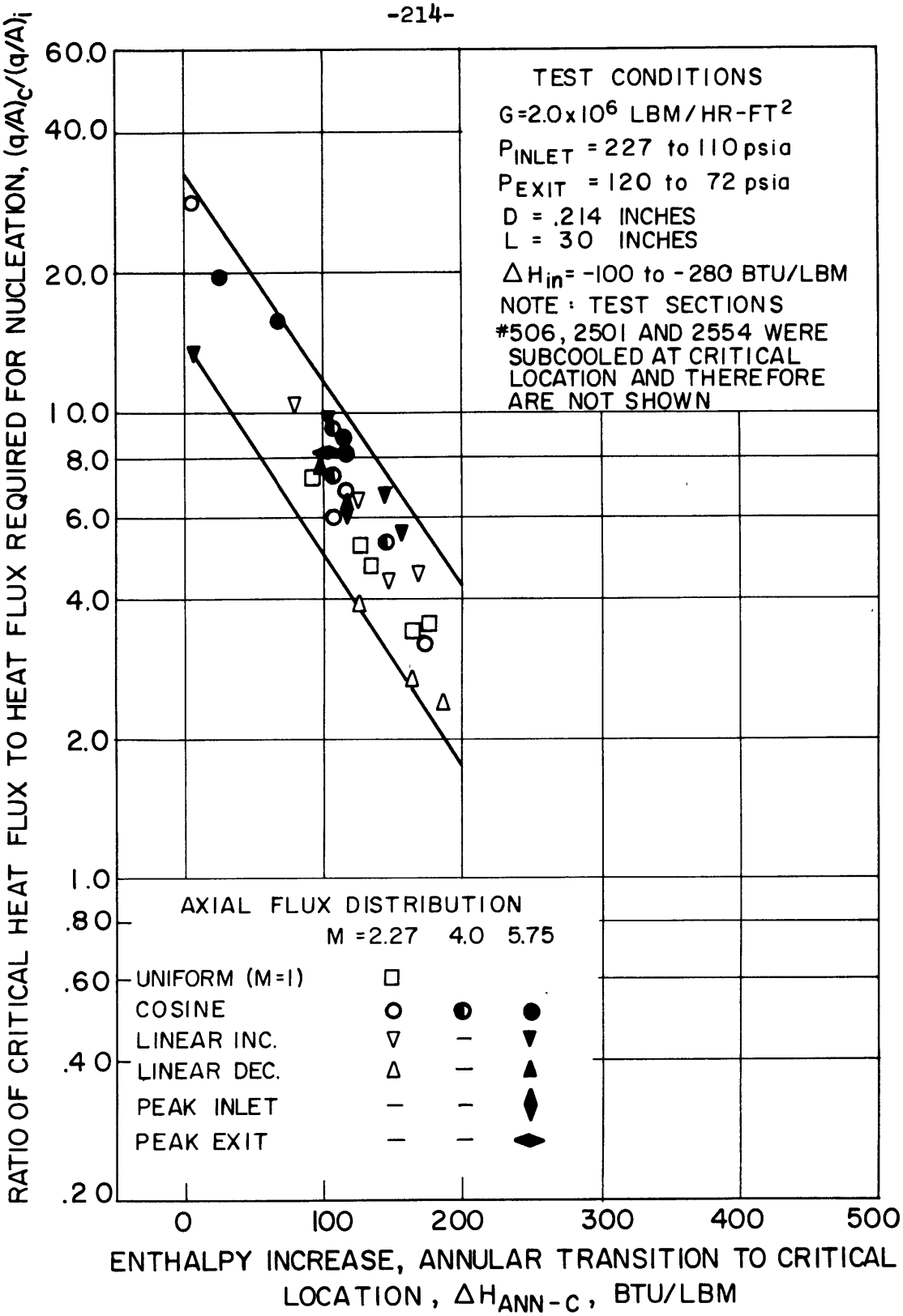

FIGURE 34. CRITICAL FLUX RESULTS AT G = 2.0 x 10^6 LBM/HR-FT^2

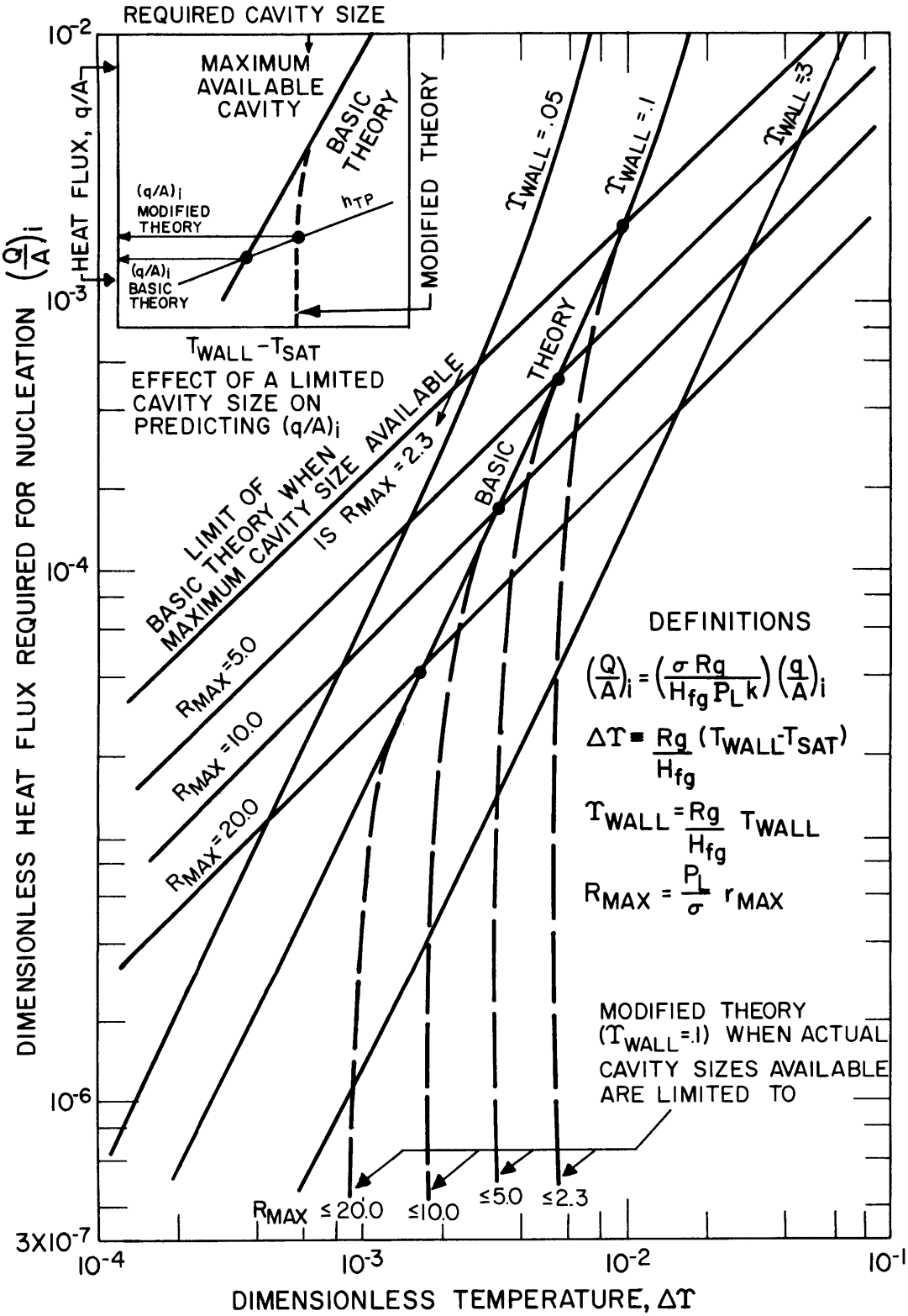

FIGURE 35. DIMENSIONLESS REPRESENTATION OF BERGLES-ROHSENOW NUCLEATION THEORY. THE EFFECT OF LIMITED MAXIMUM CAVITY SIZES IS SHOWN FOR P=100 psia ($T_W \sim .1$) ONLY

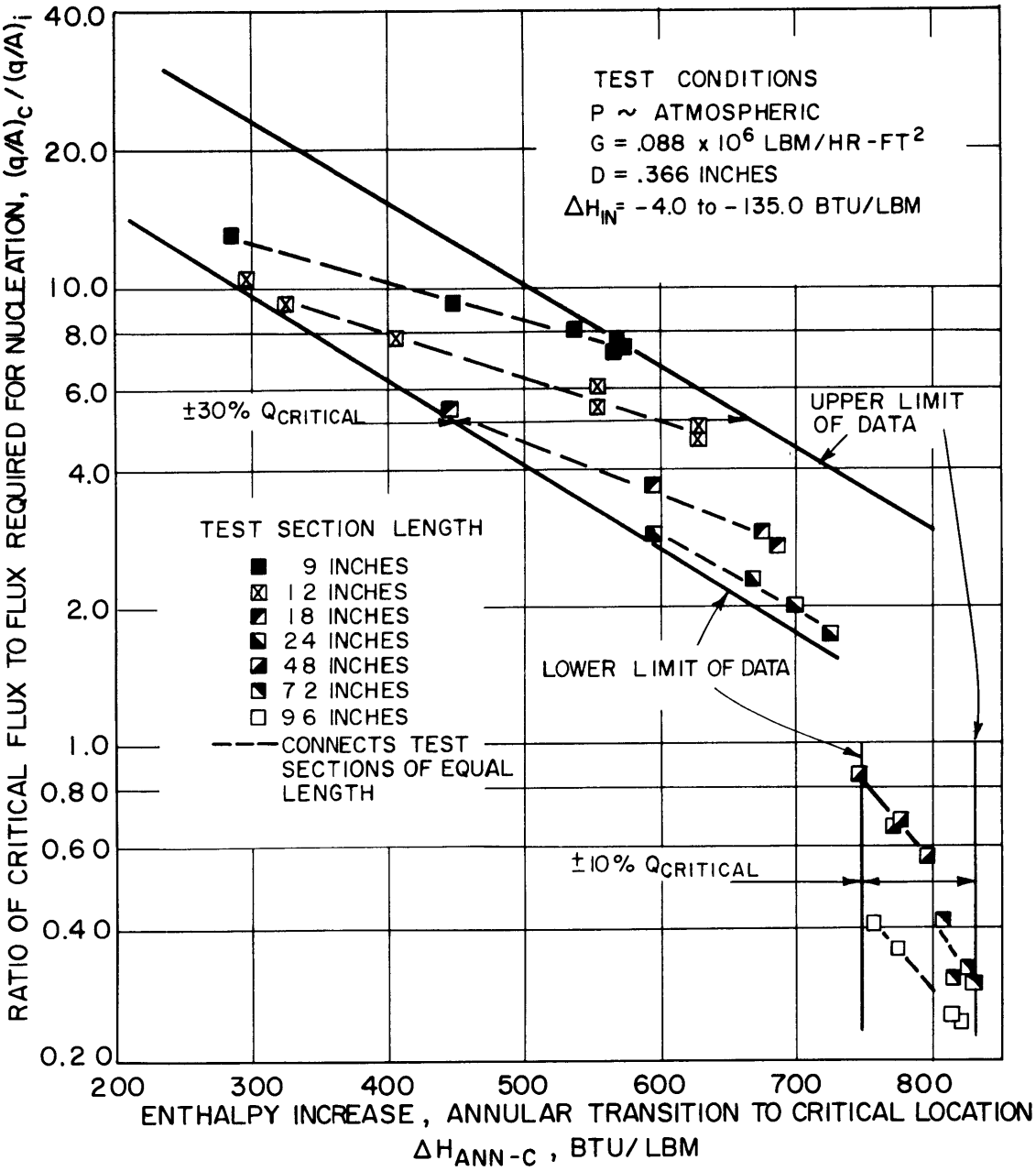

FIGURE 36. UNIFORM FLUX DISTRIBUTION DATA OF HEWITT ET AL. (REF.41)

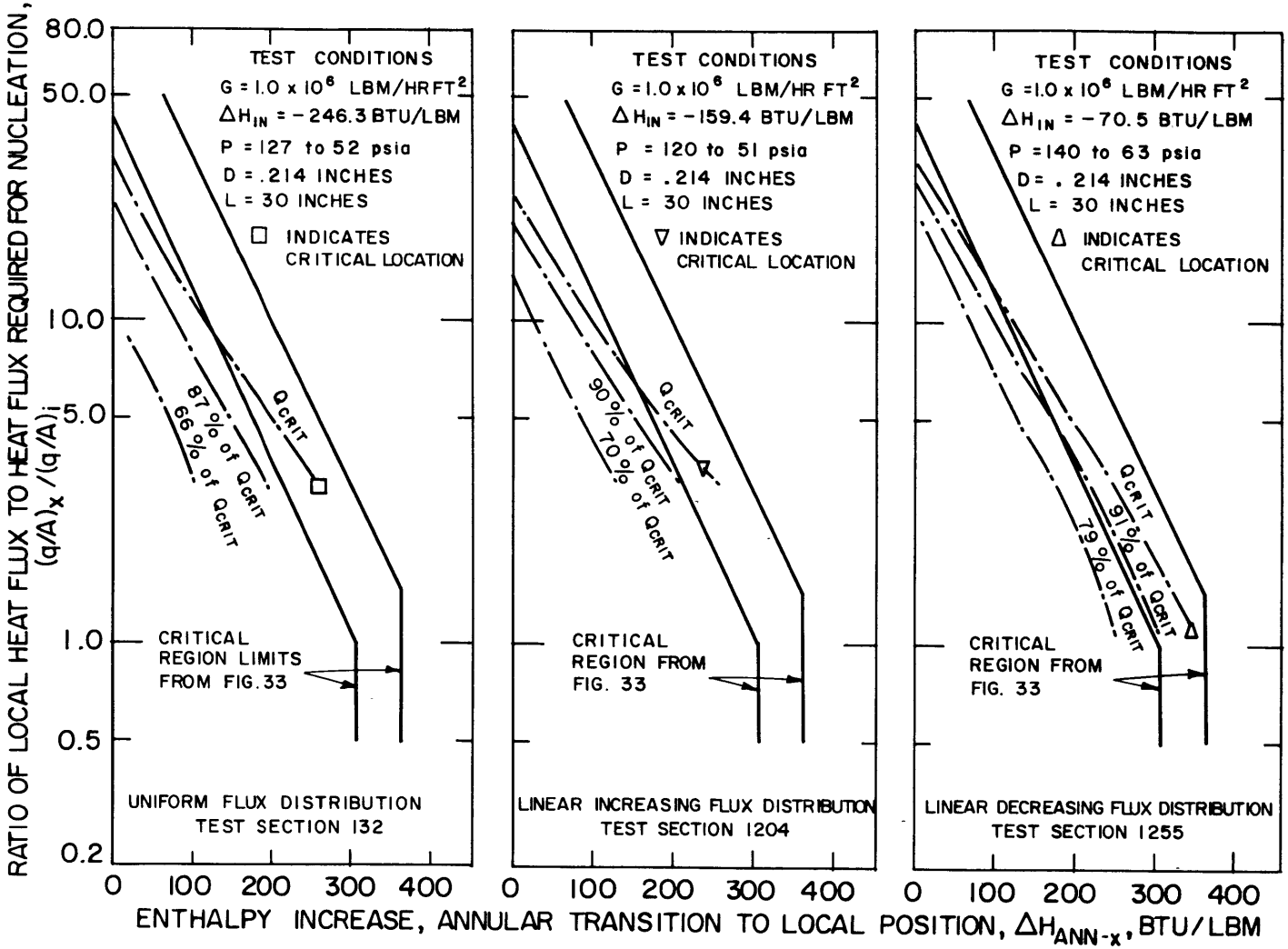

FIGURE 37. OPERATING HISTORIES FOR TOTAL INPUT POWER UP TO THE CRITICAL POWER (UNIFORM AND LINEAR FLUX DISTRIBUTIONS)

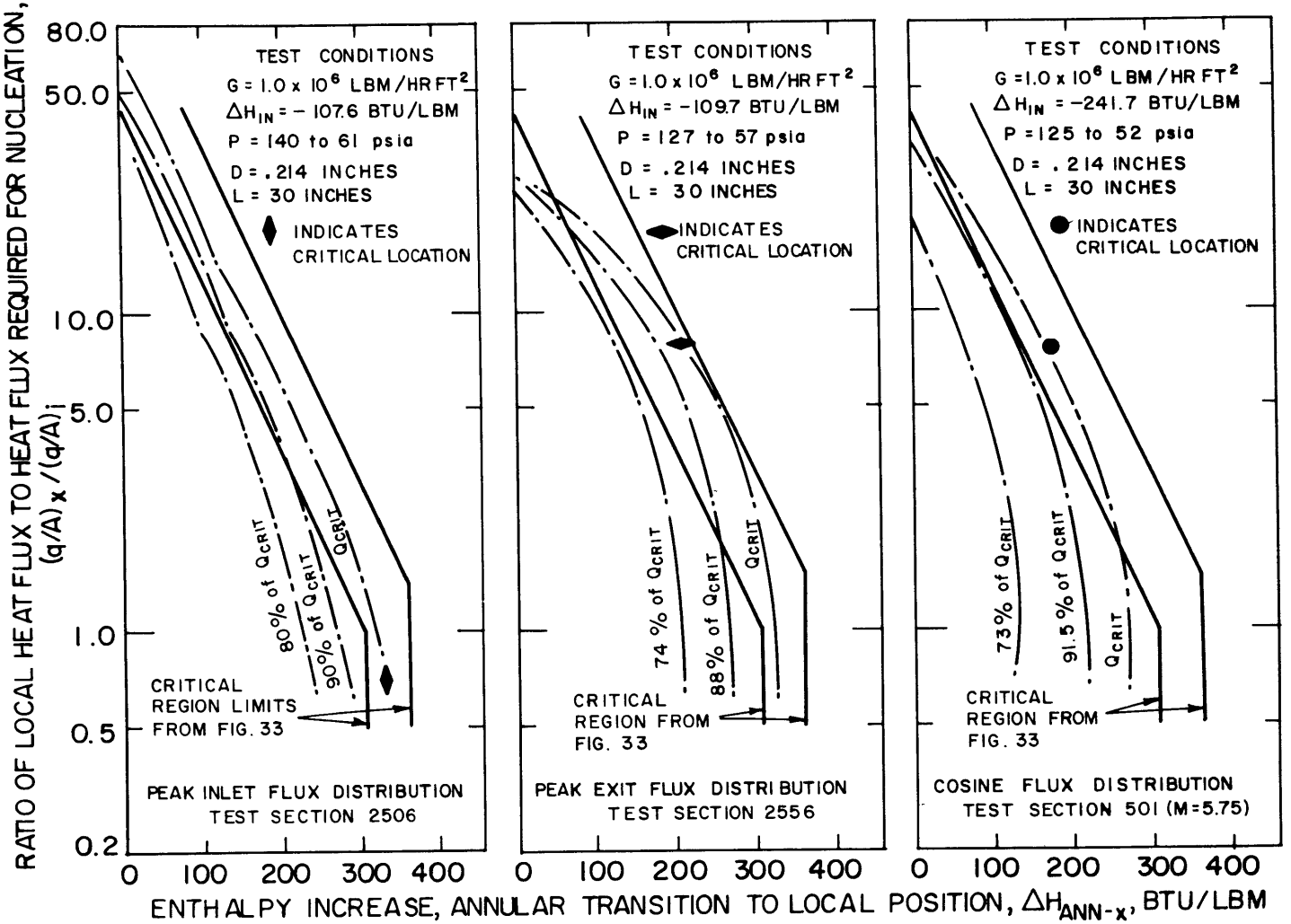

FIGURE 38. OPERATING HISTORIES FOR TOTAL INPUT POWER UP TO THE CRITICAL POWER (COSINE AND PEAKED FLUX DISTRIBUTIONS)

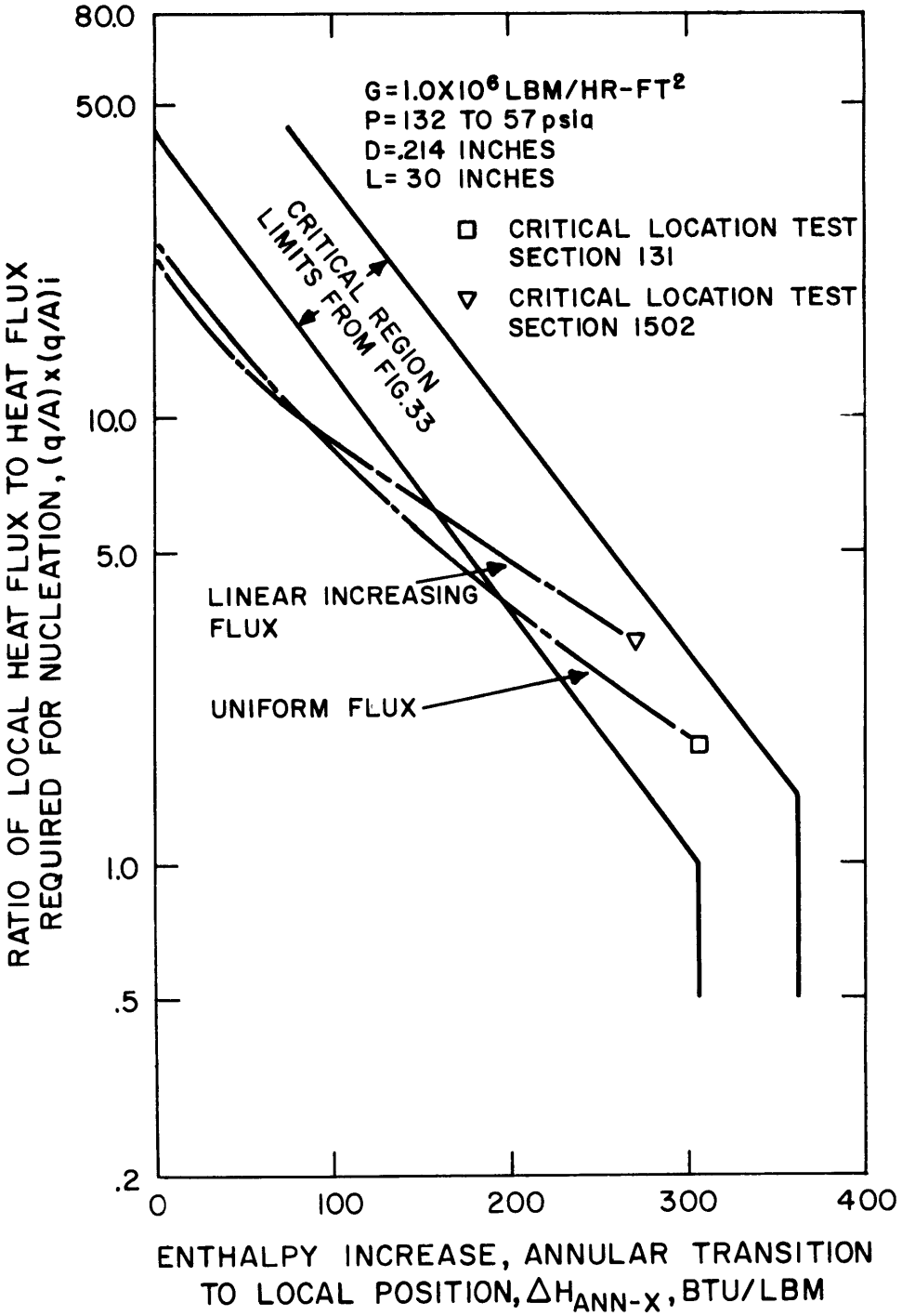

FIGURE 39. EFFECT OF AXIAL FLUX DISTRIBUTION ON THE CRITICAL LOCATION

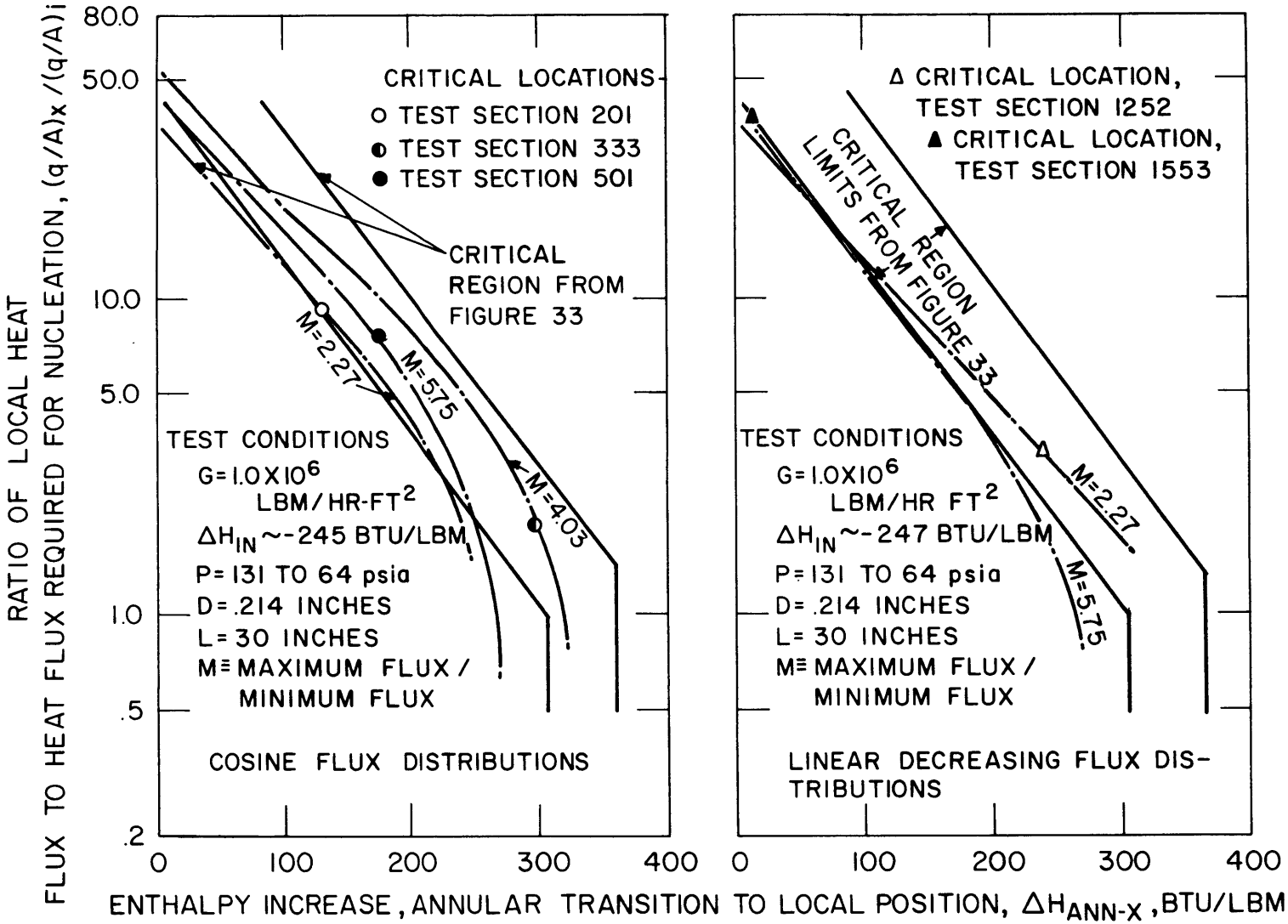

FIGURE 40. THE EFFECT OF M VALUE (RATIO OF MAXIMUM TO MINIMUM FLUX) ON THE CRITICAL LOCATION

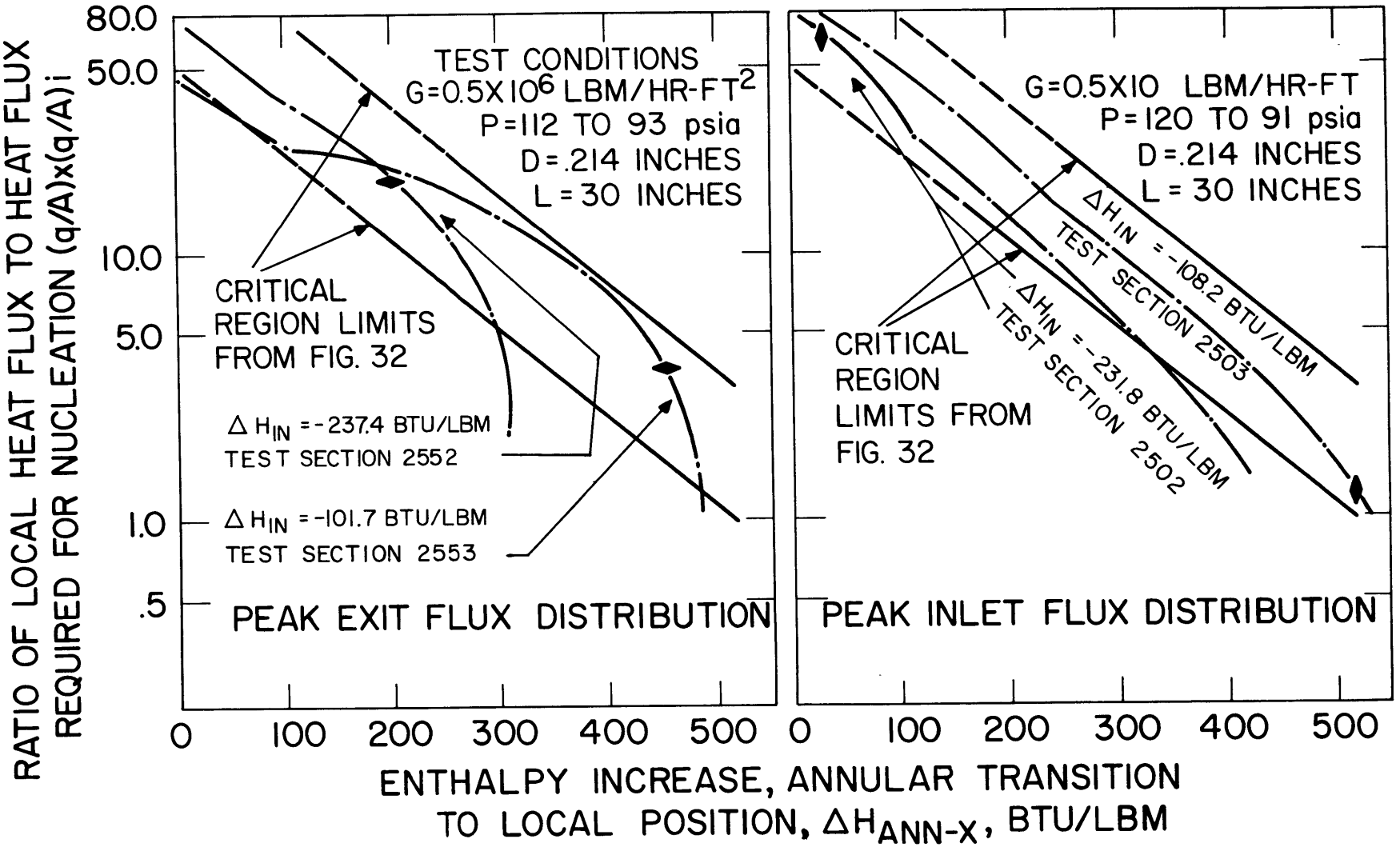

FIGURE 41. THE EFFECT OF INLET SUBCOOLING ON THE CRITICAL LOCATION (PEAK EXIT AND INLET FLUX DISTRIBUTIONS)

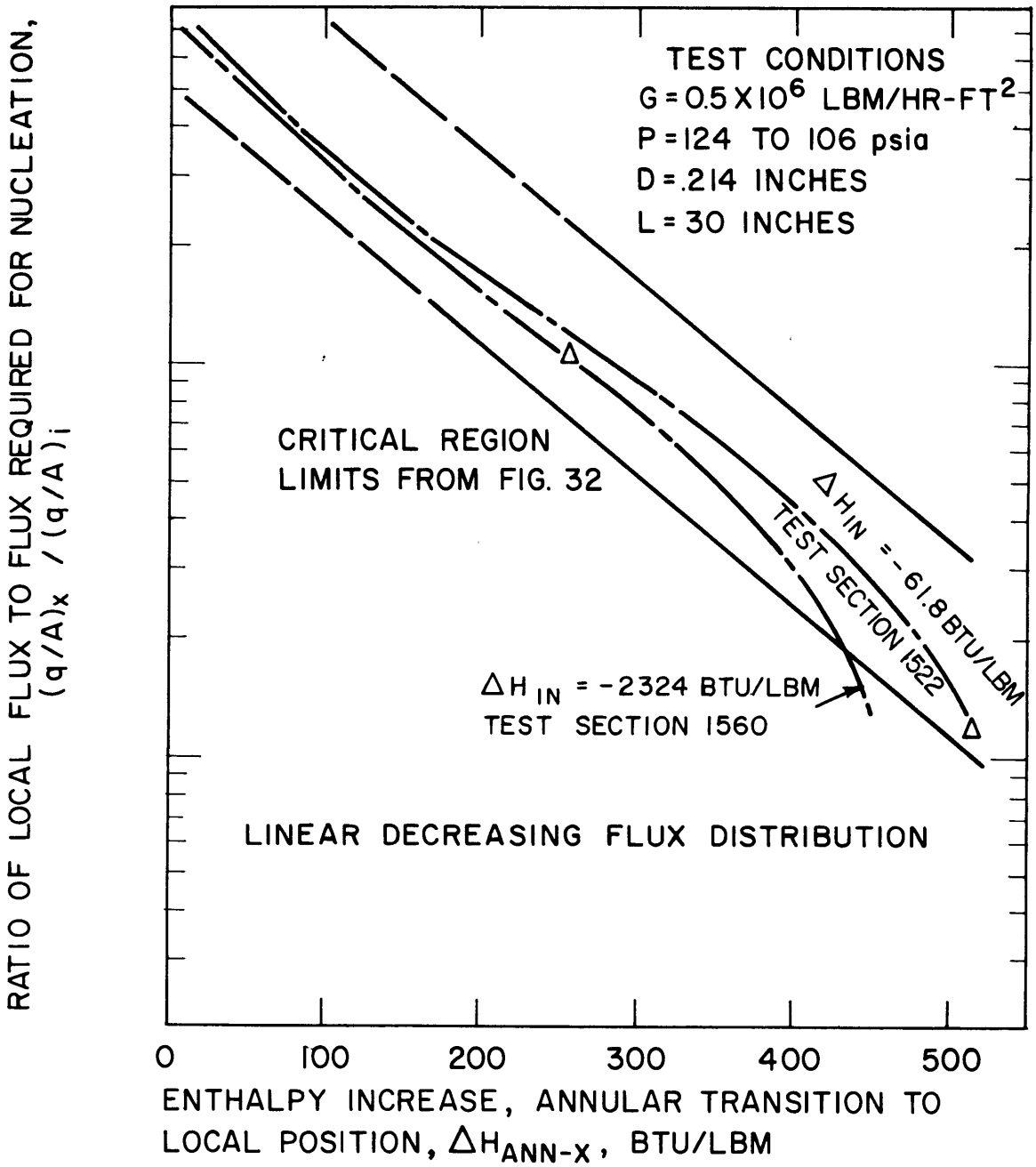

FIGURE 42. THE EFFECT OF INLET SUBCOOLING ON THE CRITICAL LOCATION (LINEAR DECREASING FLUX DISTRIBUTION)

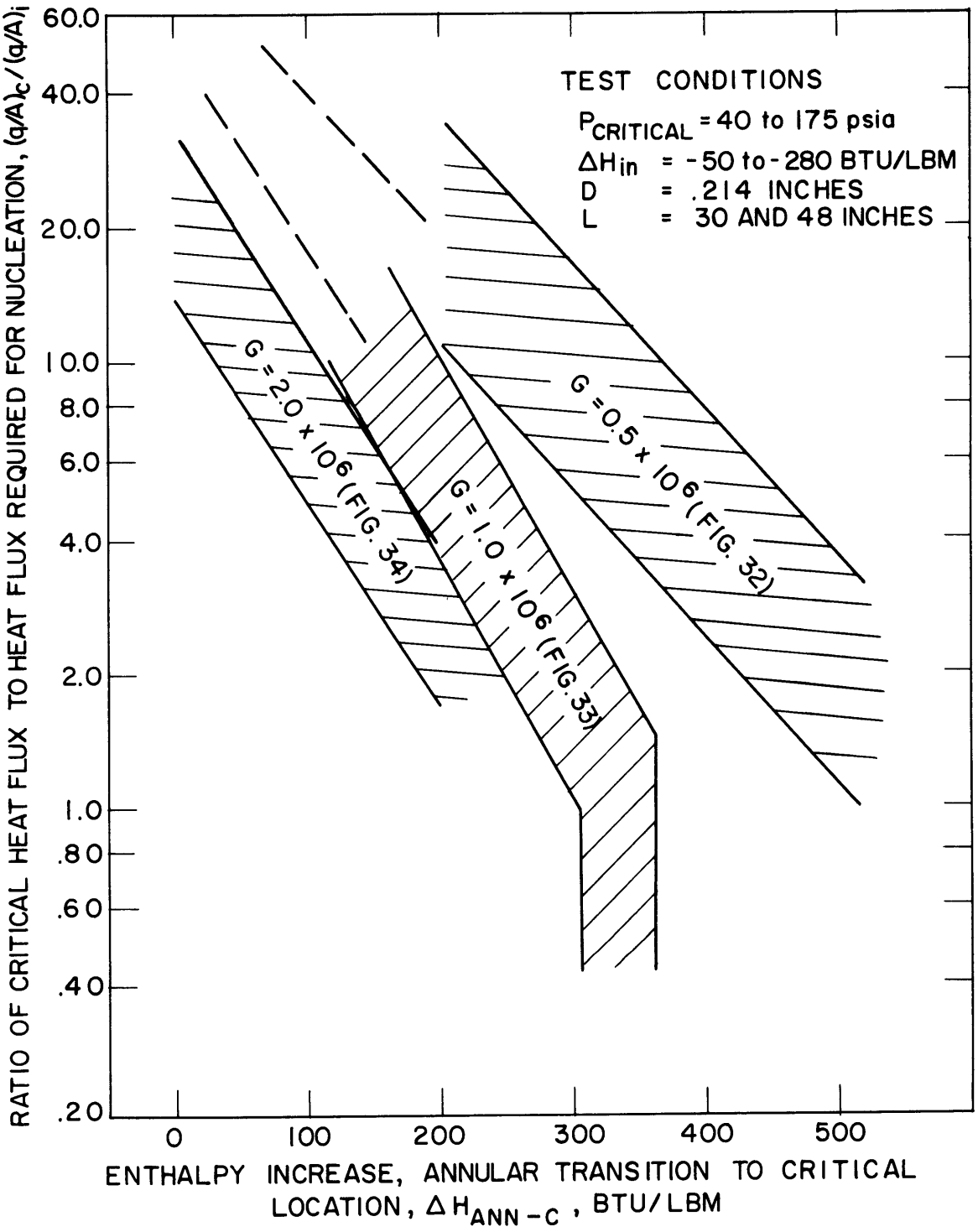

FIGURE 43. COMPARISON OF CRITICAL FLUX RESULTS FOR THE RANGE OF MASS VELOCITIES INVESTIGATED

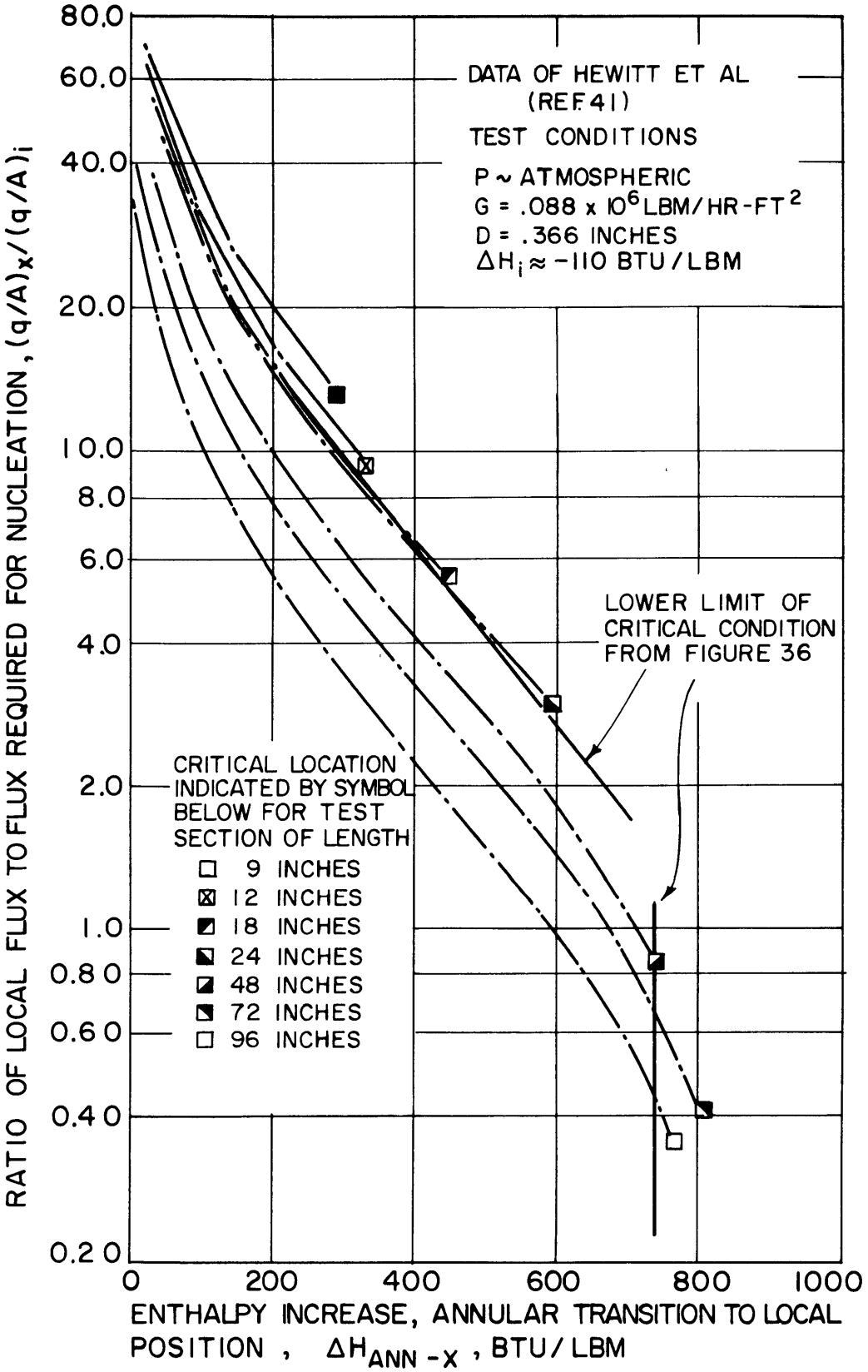

FIGURE 44. EFFECT OF LENGTH ON THE CRITICAL CONDITION

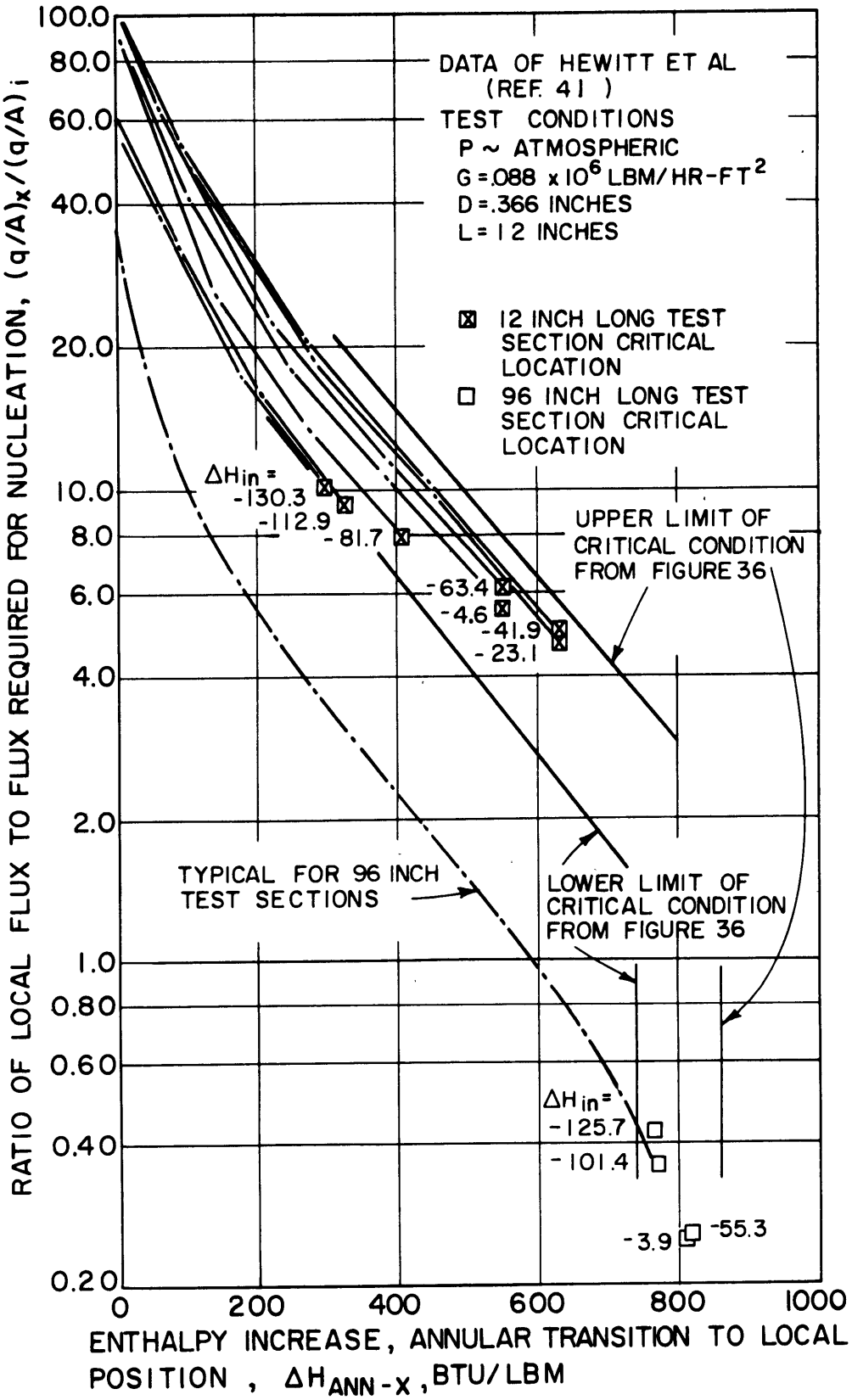

FIGURE 45. EFFECT OF INLET SUBCOOLING ON THE CRITICAL CONDITION

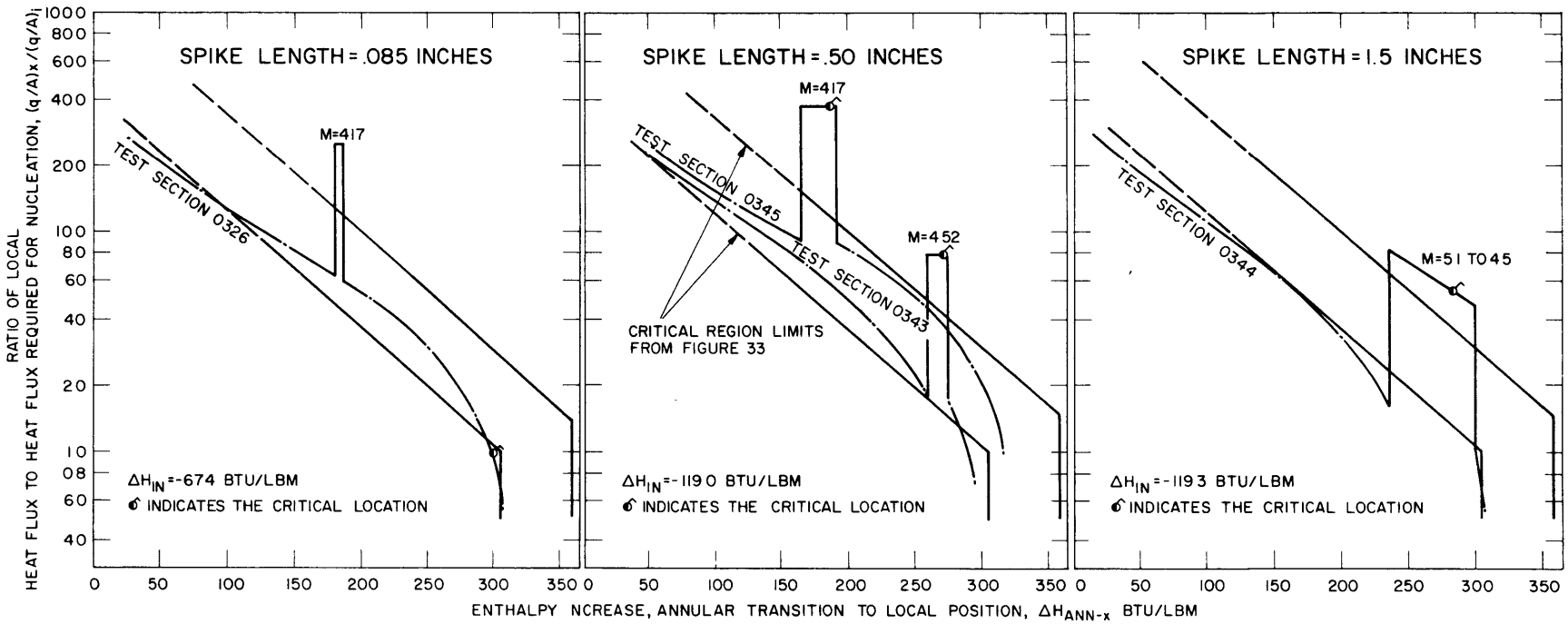

FIGURE 46 THE EFFECT OF FLUX SPIKE LENGTH ON THE CRITICAL CONDITION FOR G=10X10^6 LBM/HR-FT^2

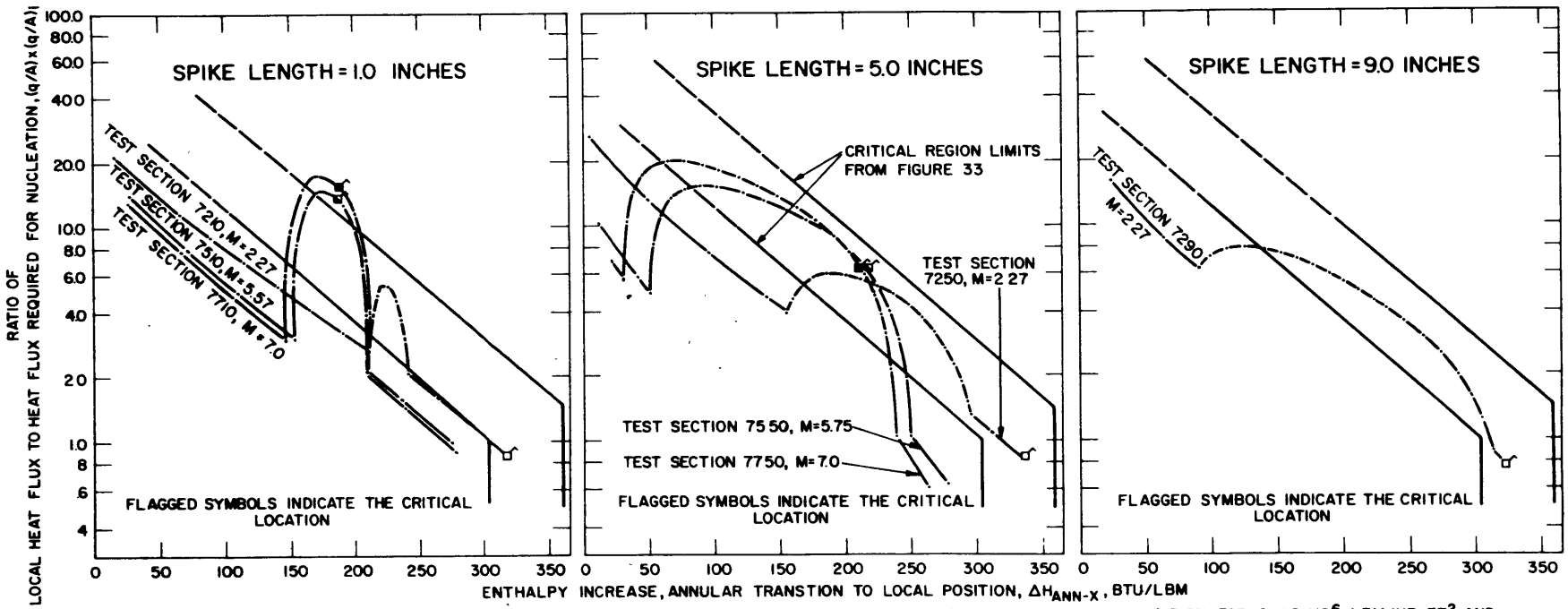

FIGURE 47. THE EFFECT OF FLUX SPIKE LENGTH AND M VALUE (RATIO OF MAXIMUM TO MINIMUM FLUX) ON THE CRITICAL CONDITION FOR G = 1.0 X 10^6 LBM/HR-FT^2 AND $\Delta H_{IN} \cong -110$ BTU/LBM

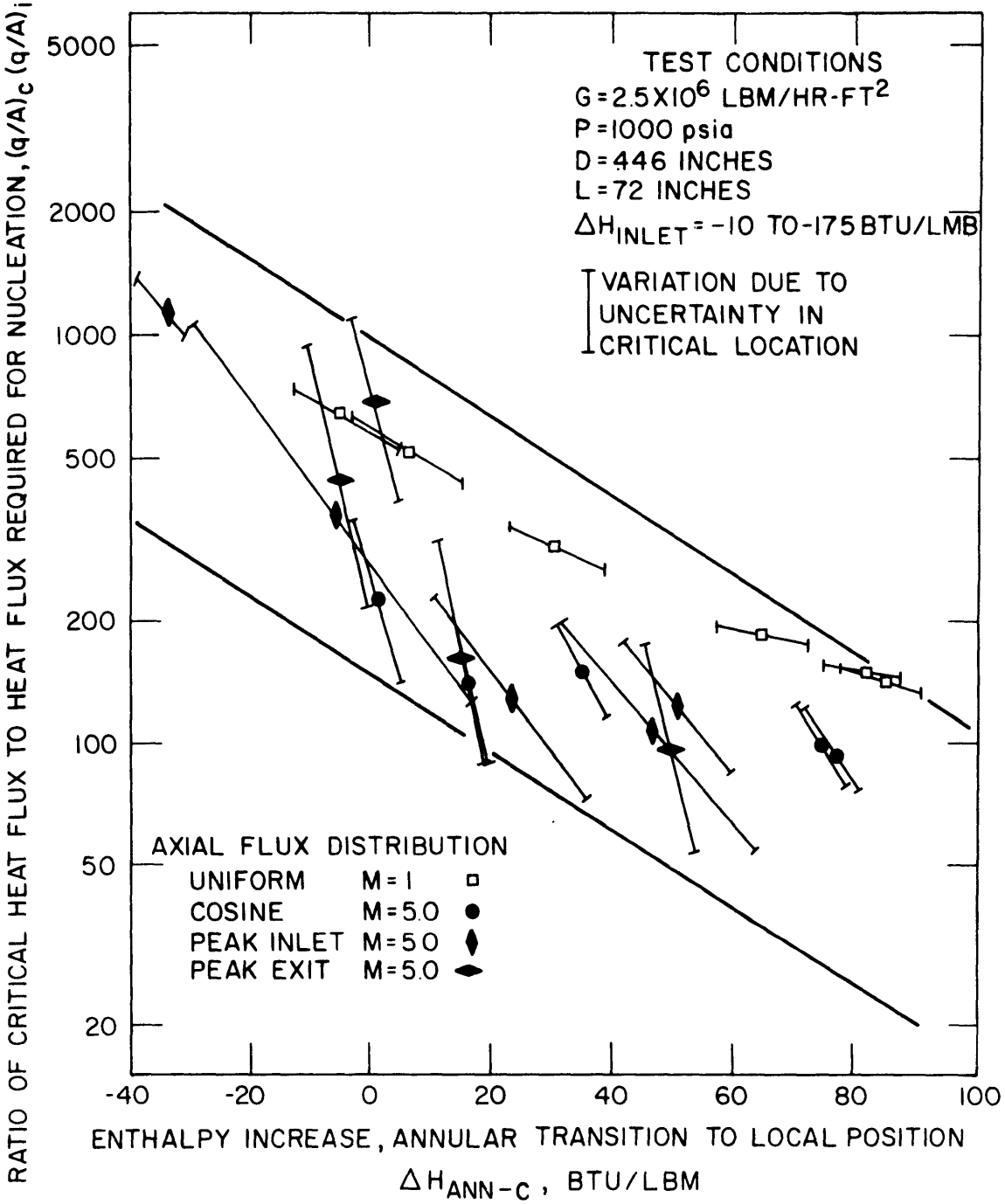

FIGURE 48. CRITICAL FLUX RESULTS AT 1000 PSIA FROM BABCOCK AND WILCOX DATA (REFERENCE 15)

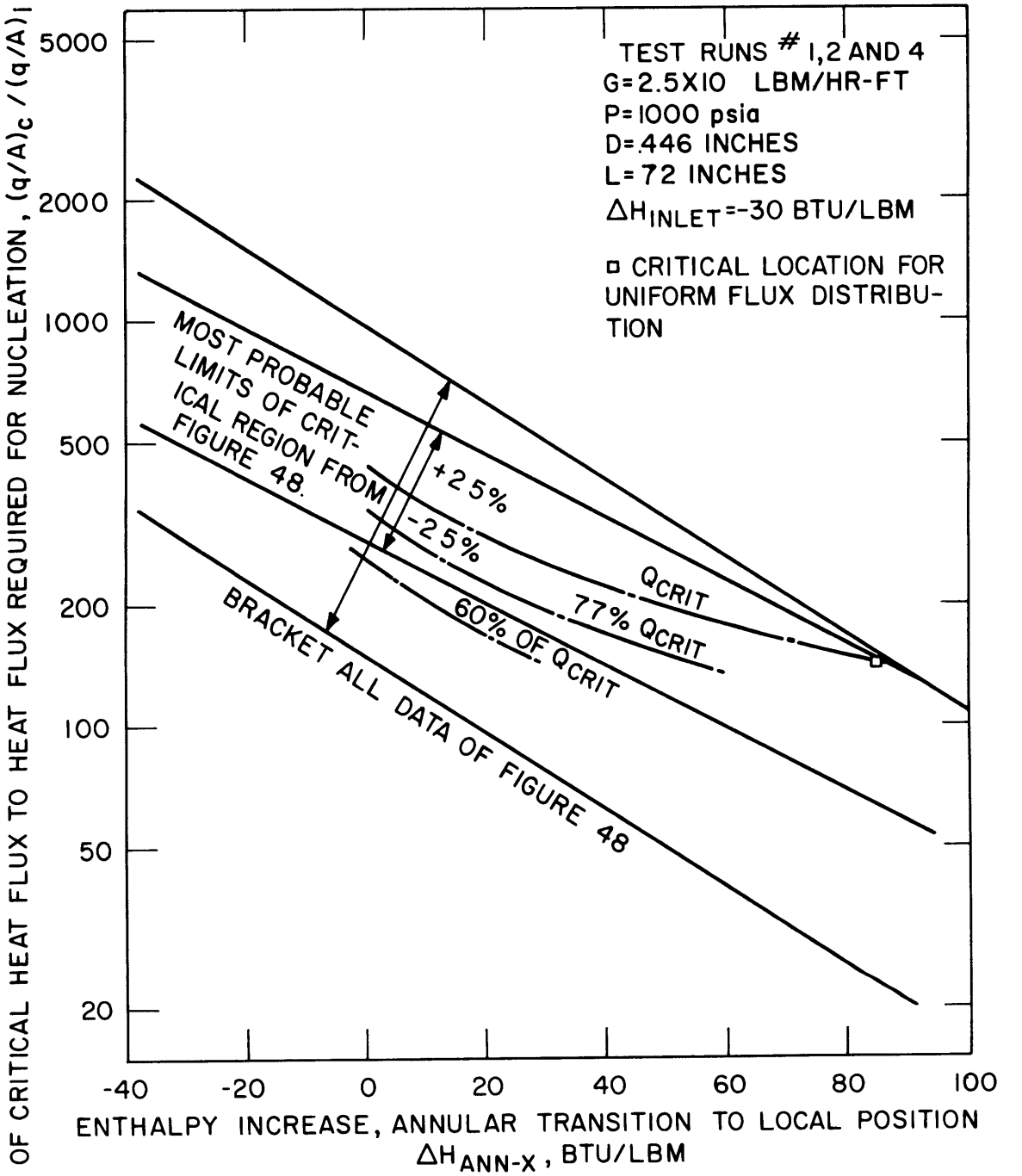

FIGURE 49. ESTIMATION OF THE CRITICAL REGION WIDTH (IN % TOTAL INPUT POWER) OF FIGURE 48 FOR 1000 psia DATA (REFERENCE 15)

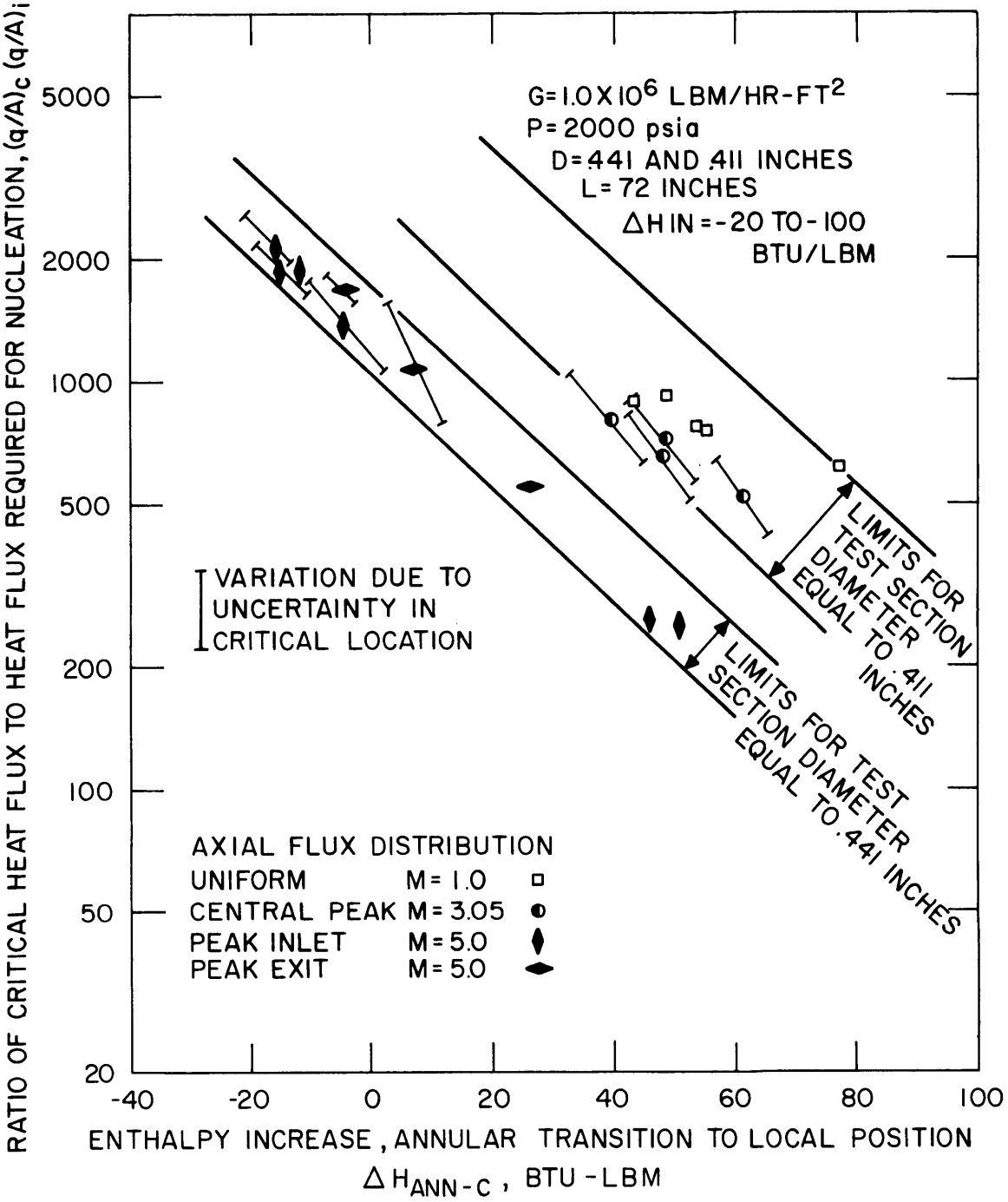

FIGURE 50. CRITICAL FLUX RESULTS AT 2000 PSIA FROM BABCOCK AND WILCOX DATA (REFERENCE 5)

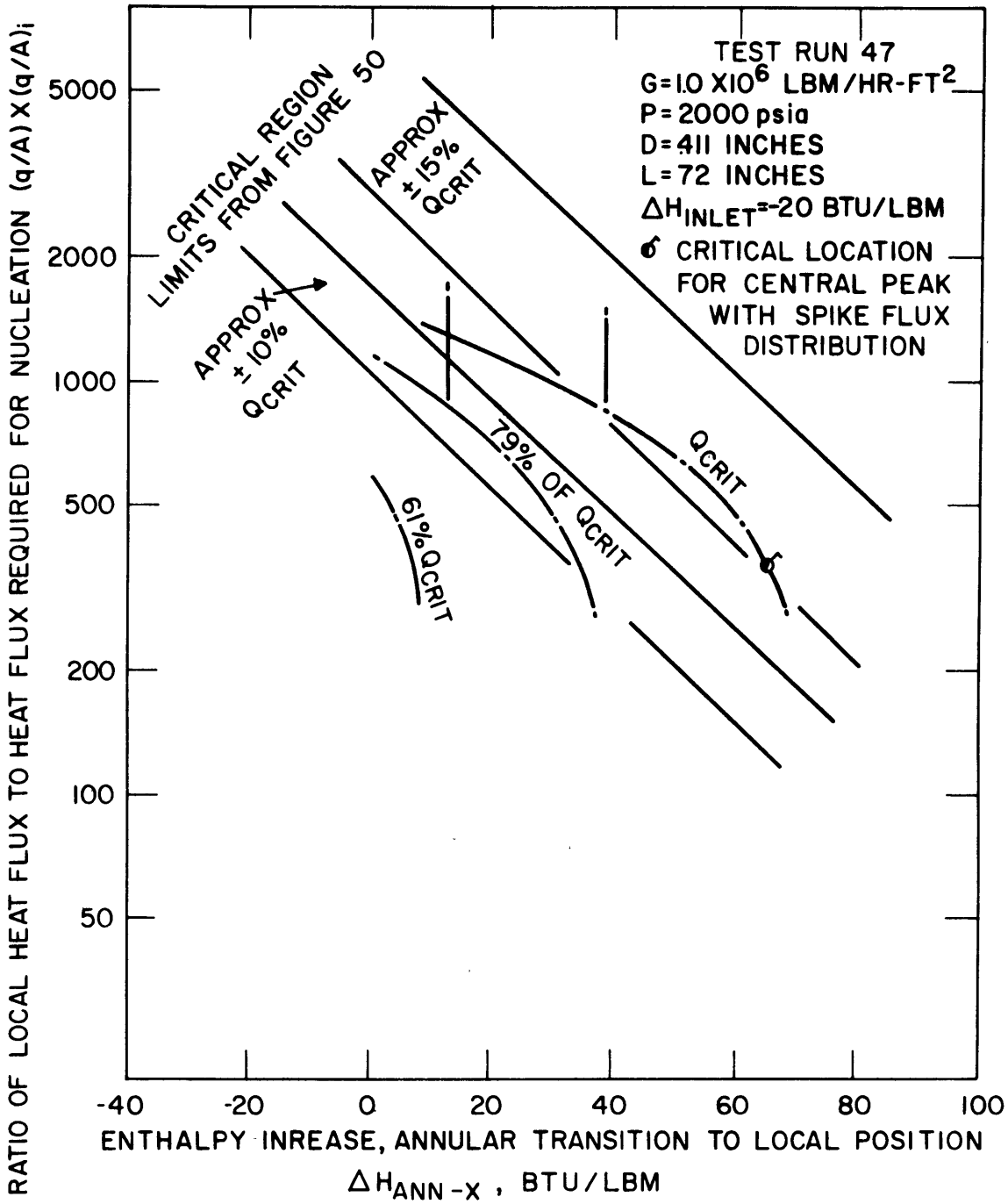

FIGURE 51. ESTIMATION OF THE CRITICAL REGION WIDTH (IN % TOTAL INPUT POWER) OF FIGURE 50 FOR 2000PSIA DATA REFERENCE 5)

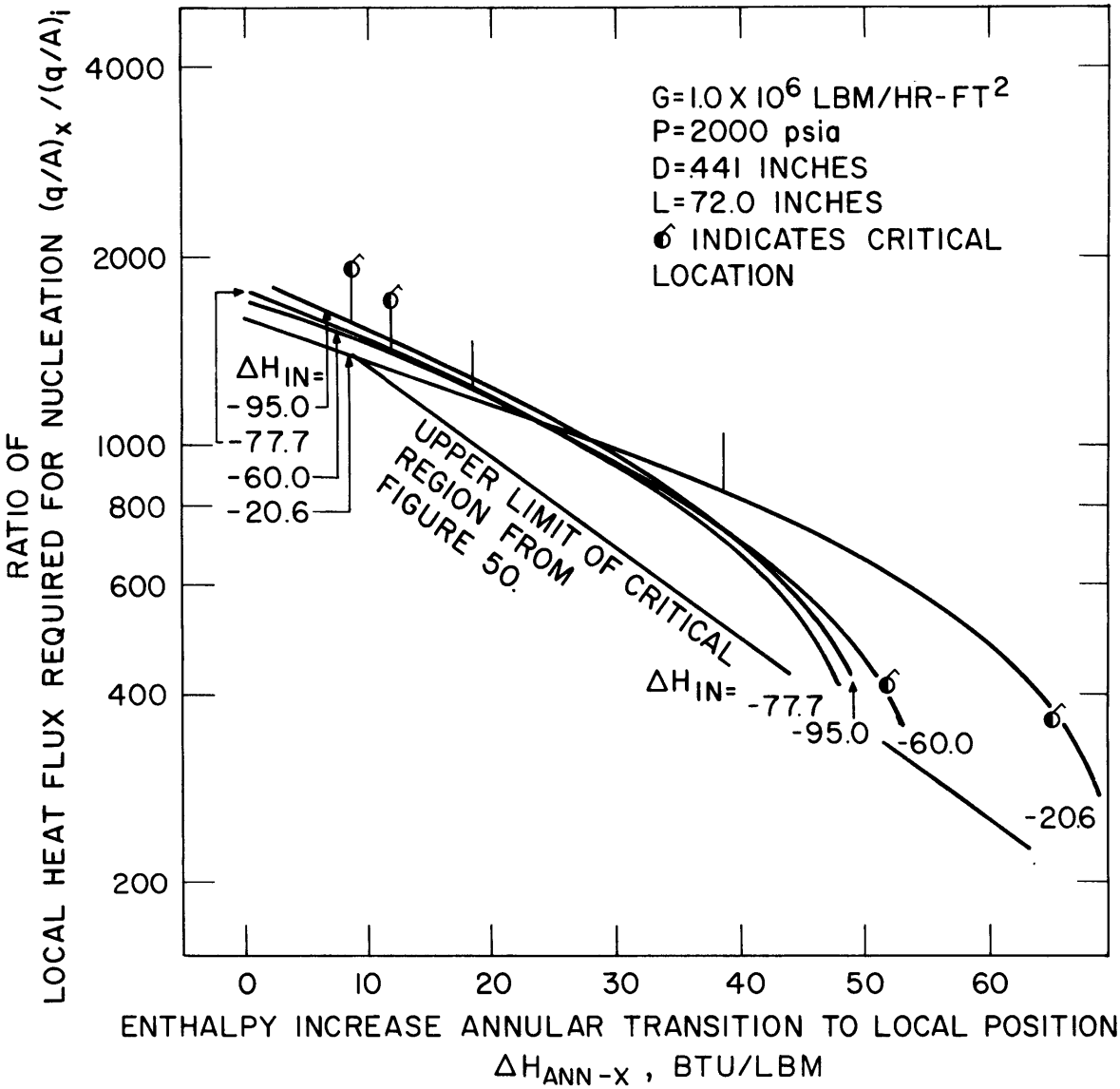

FIGURE 52. THE EFFECT OF INLET SUBCOOLING ON CRITICAL FLUX RESULTS FOR COSINE FLUX DISTRIBUTION WITH FLUX SPIKE (REFERENCE 5)