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# HEAT REMOVAL CHARACTERISTICS OF VOLUME HEATED BOILING POOLS WITH INCLINED BOUNDARIES

By


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MAY 1979


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# ABSTRACT

The state-of-the-art of heat transfer from boiling liquids having internal heat generation is reviewed. Considerable scatter is found in the existing data. Attempts to correlate these data have relied on both natural and forced convection concepts. This report describes a new series of experiments wherein the data scatter appears to have been improved by a factor of four to six from previous experiments when compared on the basis of standard deviation in correlation coefficients.

Local heat transfer data to both vertical and inclined surfaces (up to $30^{\circ}$ from vertical) are reported having maximum to minimum heat transfer ratios of up to 5:1. It is shown that with surface vapor fluxes up to twice the free bubble rise velocities given by Harmathy[22] there are two distinct flow regimes: bubbly and churn-turbulent.

In bubbly flows, the pool is generally quiescent and surface temperature fluctuations negligible. Two heat transfer regimes were identified: laminar-where $\overline{Nu} = 1.54\ Ra^{*}(L,\overline{\alpha},\theta)^{0.25}$ for $Ra^{*} \leq 1.865 \times 10^{11}$, and turbulent-where $\overline{Nu} = 0.0314\ Ra^{*}(L,\overline{\alpha},\theta)^{0.40}$ for $Ra^{*} > 1.865 \times 10^{11}$. Standard deviations in the correlation coefficients were 0.08 and 0.0016 respectively.

In churn-turbulent flows, the pool is generally chaotic and three dimensional. The surface temperatures showed large fluctuations up to the maximum pool-to-wall difference indicating intermittent destruction and renewal of boundary layer. Heat transfer coefficients were more uniform, and the maximum was observed to be in the range .25-.30 cal/cm$^2$ s $^{\circ}$C.




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The data reported herein are in general agreement with the data reported by Gabor, et al.[11], but with significantly less scatter. On the other hand, the more recent data of Gustavson, et al.[12] are lower than those reported herein by approximately a factor of two.

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## NOMENCLATURE

| | |
|---|---|
| $a$ | Test plate thickness |
| $C$ | Constant |
| $C_o$ | Distribution parameter |
| $g$ | Gravitational acceleration |
| Gr | Grashof number |
| $h$ | Heat transfer coefficient |
| $\overline{h}$ | Average heat transfer coefficient |
| $H$ | Height |
| $h_{fg}$ | Heat of vaporization |
| $j$ | Superficial velocity |
| $j_{g\infty}$ | Superficial vapor velocity at pool surface |
| $k$ | Thermal conductivity |
| $K_i$ | Correlation coefficient |
| $L$ | Length |
| $n$ | Defined in Eq. 10 |
| Nu | Nusselt number |
| $\overline{Nu}$ | Average Nusselt number ($\equiv \overline{h}L/k$) |
| $P$ | Pressure |
| Pr | Prandtl number ($\equiv \mu C_p/k$) |
| $\dot{Q}$ | Heat Flux |
| $\dot{Q}'''$ | Volumetric power density |
| Ra | Rayleigh number |
| Re | Reynolds number |
| $T$ | Temperature |
| $U_\infty$ | Terminal rise velocity of bubble |

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NOMENCLATURE (Cont'd)

| | |
|---|---|
| $V$ | Velocity |
| $V_{gj}$ | Drift velocity |
| $x$ | Coordinate (along wall) |
| $Y$ | Defined in Eq. 8 |
| $Z$ | Defined in Eq. 9 |
| $\alpha$ | Void fraction |
| $\overline{\alpha}$ | Average void fraction |
| $\beta$ | Coefficient of thermal expansion |
| $\epsilon$ | Fractional uncertainty |
| $\mu$ | Dynamic viscosity |
| $\nu$ | Kinematic viscosity |
| $\rho$ | Density |
| $\sigma$ | Standard deviation |
| $\theta$ | Wall angle from vertical |
| $\Gamma_v$ | Volumetric vapor source |
| $\xi$ | Normalized coordinate |

Subscripts

| | |
|---|---|
| ave | Average |
| B | Boiling |
| BN | Boron nitride |
| C | Forced convective |
| eff | Effective |
| f | Film |
| g | Gas |

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NOMENCLATURE (Cont'd)

| | |
|---|---|
| $\ell$ | Liquid |
| L | Laminar |
| N | Natural convective |
| o | Initial |
| T | Turbulent |
| TC | Thermal convective |
| v | Vapor |
| w | Wall |
| $\infty$ | Infinity |
| * | Modified |

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## 1. INTRODUCTION

The heat transfer characteristics of volume-heated boiling pools are of importance in the safety analysis of hypothetical core disruptive accidents (HCDA) in liquid metal fast breeder reactors (LMFBR). In general, these pools would be composed of molten fuel and steel and would generate heat as a result of fission product decay. The fluid dynamic characteristics, as well as the containability of such boiling systems, would depend intimately on the heat loads applied to the surrounding boundaries. In addition, the thermodynamic and hydrodynamic states of the boiling mixture might determine the initial or boundary conditions for separate but related phenomena, such as nuclear recriticality, structural integrity, flow and freezing of multiphase fluids, etc. Confidence in the conceptualization, as well as computation of such hypothetical events depends to a great deal upon the ability to predict the vapor generation rate, void fraction, and local boundary heat flux from such volume-boiling pools. It is the purpose of this report to present new experimental data for local boundary heat transfer coefficients and average void fraction in volume-boiling pools and compare these results to previous experimental data, as well as to existing empirical models.

## 2. HISTORICAL REVIEW

Numerous studies exist in the literature concerning heat transfer from liquid pools with an internal heat source. A brief review of this literature is indicated in Table 1.[1-7,13] However, investigations into the heat



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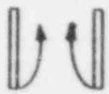
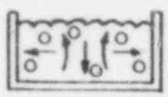
TABLE 1

REVIEW OF NATURAL CONVECTION HEAT TRANSFER

| GEOMETRY | | CORRELATION | REFERENCE |
|---|---|---|---|
|  | Vertical Cylinder Volume Heating Natural Convection | Numerical Finite Difference | (1) Essam<br>(2) Murgatroyd, Watson |
|  | Horizontal Plates Volume Heating Natural Convection | $Nu = KRa^n$ | (3) Kulacki, et al<br>(4) Nagle, et al<br>(5) Suo-Antilla, Catton |
|  | Vertical Plates Volume Heating Natural Convection | $T(t), q_w(t)$ | (6) Novotny, Eckert |
|  | Lenticular Pool Volume Heating Natural Convection | $Nu(\theta) = K[Gr \cdot Da \cdot Pr]^n$ | (7) Jahn, Reineke |
|  | Inclined Plate Natural Convection | $Nu(x) = KRa(x,\theta)^n$ | (13) Fujii, Imura |
|  | Volume Boiling Pool Mixed Convection | $\overline{Nu}$<br>$Nu(x)$ | (8-9) Hesson, Gunther, Stein<br>(10-11) Gabor, et al<br>(12) Gustafson, Kazimi, Chen |



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transfer and hydrodynamic behavior of volume-heated boiling pools have been few and none are known to exist prior to this decade.[8-12,15,18]

The earliest known attempt to consider the heat transfer from volume-heated boiling pools is the work performed at Argonne National Laboratory by Stein, et al.[9] In this work, a solution of NaCl and water was boiled in an open container by joule heating. The average downward and horizontal heat fluxes were measured by thermocouples soldered in small dead-end holes in the plates making up the electrodes and base, and in the coolant system.

A model was presented which separated the boundary heat transfer into a natural convection and forced convection regime. The natural convection regime was shown to agree with the correlation below,

$$\overline{Nu}_N = .677\ [Pr/(.952 + Pr)]^{1/4} Ra^{1/4} \tag{1}$$

where $\overline{Nu}_N = \dot{Q}_N L/(k\Delta T)$, $Ra = PrGr$, and $Gr = g\beta\Delta T L^3/\nu^2$. The forced convection regime was shown to be correlated by the relation,

$$\overline{Nu}_C = .644\ Pr^{1/3}\ Re^{1/2} \tag{2}$$

where $\overline{Nu}_C = \dot{Q}_C L/(k\Delta T)$ and $Re = V_B L/\nu$. Both relations were valid only for laminar flow conditions. For convenience, a thermal convection reference velocity, $V_{TC}$, was defined as

$$V_{TC} = (g\beta\Delta T L)^{1/2} = [g(\rho_w - \rho_\infty)L/\rho_f]^{1/2} \tag{3}$$

and an equivalent free stream velocity, $V_B$, was defined as below;

$$V_B = 40\ \dot{Q}_B^{0.72} \tag{4}$$

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it was reported that for $V_B/V_{TC} \leq 0.2$, forced convection heat transfer was negligible and Eq. 1 was applied. For $V_B/V_{TC} > 3.0$, thermal convection was negligible and Eq. 2 applied. For values of $V_B/V_{TC}$ intermediate to these values, mixed convection existed. The results of this investigation indicated that downward heat fluxes were found to be significantly larger than predictions from conduction theory would indicate; in addition, at the higher boiling heat fluxes, horizontal heat transfer was found to be significantly larger than values calculated by thermal convection alone, and could be correlated empirically by the laminar forced convection model.

The next attempt to experimentally characterize boundary heat transfer from volume-boiling pools was the work of Gabor, et al.[11] from Argonne National Laboratory. In their work, they used simulant solutions of $ZnSO_4$ in water. Base plates of two lengths (191 and 381 mm) and three electrode heights (64, 114, 230 mm) were used. The volumetric boiling power was supplied by joule heating as in the previous work. The electrodes and base plate were used as the heat transfer surfaces; thermocouples were buried halfway into the copper plates for temperature measurements, seven into the base plate, and two in each of the electrodes. Boundary heat losses were measured by calculating the enthalpy increase of the water coolant flowing in coils of copper tubing brazed to the backs of the electrodes. In these tests, the heat transfer rate to the vertical electrode was measured in two segments; for the 114 mm pool depth, the electrode was split into separately cooled segments of 25 mm at the top and 89 mm at the bottom. For the 230 mm pool depth, the electrode was split into a 25 mm upper segment and a 205 mm



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lower segment. The opposite electrode was unsegmented and of the same overall length.

The ratios of the boundary heat fluxes, $\dot{Q}_{upper}/\dot{Q}_{lower}$, were investigated as a function of the boiling heat flux, $\dot{Q}_B$. It was found that for low boiling heat flux ($\dot{Q}_B$ less than 3.5 cal/cm$^2$ s for the 230 mm pool; $\dot{Q}_B$ less than 6 cal/cm$^2$ s for the 114 mm pool), the ratio $\dot{Q}_{upper}/\dot{Q}_{lower}$ was in the range of 1.5 to 2, in agreement with the prediction from thermal convection theory. For high boiling heat flux ($\dot{Q}_B$ greater than 4.5 cal/cm$^2$ s for the 230 mm pool; $\dot{Q}_B$ greater than 9 cal/cm$^2$ s for the 114 mm pool), the heat flux ratio was more nearly equal unity and equal to the heat flux to the unsplit electrode. The data was correlated in terms of a Nusselt number and Reynolds number based on the superficial vapor velocity. The Prandtl number was assigned separate exponential weight of 0, 1/3, and 1/2 powers. As a result, a new model was presented for horizontal heat flux based on bubble-induced laminar forced convection of the form

$$\overline{Nu} = C\ Re^{1/2} \tag{5}$$

where the constant C included the effect of the Prandtl number and the superficial vapor velocity was defined as in Eq. 4.

While the studies reported so far have contributed to the understanding of some hydrodynamic and heat transfer processes occurring in internally heated boiling pools, they do not provide a mechanistic model for predicting local boundary heat transfer or void fraction in such pools. Recognizing this shortcoming, Gustavson, et al.[12] undertook an investigation into the local distribution of boundary heat transfer and void fraction in internally



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heated boiling pools. In their work, they also considered a rectangular pool of $ZnSO_4$ and water, joule heated by passing a-c current through the pool between two electrodes. Instead of using the electrode as the heat transfer surface, an instrumented test plate was installed, designed to allow measurement of local heat transfer to thermally isolated segments. Each segment was cooled by flowing water through separate cooling channels, and each flow rate was separately controlled to insure an isothermal pool-side surface temperature. The heat flux to each segment was measured by measuring the temperature rise and the flow rate of the coolant for each segment. The surface temperature of each segment was determined by extrapolating the interior thermocouple reading at the segment centerline to the test wall surface across 0.38 mm of aluminum and 0.76 mm Teflon sheet, which was cemented to the aluminum test wall surface for electrical insulation from the pool. A constant level weir was connected to an inlet at the pool bottom, which fed a steady flow of fluid to the pool to identically replace the losses due to vaporization. In this fashion, the net power for vaporization could be determined. The accuracy of the measured heat transfer coefficient in these tests was reported to be $\pm$ 40 percent.

The authors proposed that boundary heat transfer from volume-heated boiling pools was a mixed convection-type heat transfer phenomenon in which the effects were superimposable. They proposed, for laminar flow, that the thermal convective component be modeled as

$$Nu_N(x) = 0.42[Gr(x) \cdot Pr]^{0.25} \tag{6}^*$$

---

*In Ref. 12, the coefficient in Eq. 6 appeared as 0.41 instead of 0.42 suggested by Sparrow, et al.[23] for $Pr \simeq 1.86$, average Pr for all the present experiments.



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where Gr(x) was the local Grashof number based on the average pool film density difference, and $Nu_N(x)$ now represented the local natural heat transfer correlation where x was measured along the heat transfer surface downward from the free surface. The forced convective component was represented by

$$Nu_C(x) = 0.332\ Re(x)^{1/2} \cdot Pr^{1/3} \qquad (7)^{**}$$

where Re(x) was the local Reynolds number based on the superficial vapor velocity at the pool surface. The method of modeling the combined natural/forced convection from a volume-boiling pool consisted of correlating the ratio

$$Y = \frac{Nu}{Nu_N} \qquad (8)$$

to the group

$$Z = \frac{Nu_C}{Nu_N} \qquad (9)$$

where Nu was the effective Nusselt number, either local or average, for the combined heat transfer process. Following a general correlation procedure,[14] it was suggested that the functional form of the correlation should be

$$Y = [1 + Z^n]^{1/n} \qquad (10)$$

where n was determined by a best fit evaluation of the data (see Fig. 1). Alternate forms of Eqs. 6 and 7 were proposed for the case of turbulent heat

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** In Ref. 12, the exponent of the Prandtl number appeared as 1/2 instead of 1/3 as suggested by Kays[24]

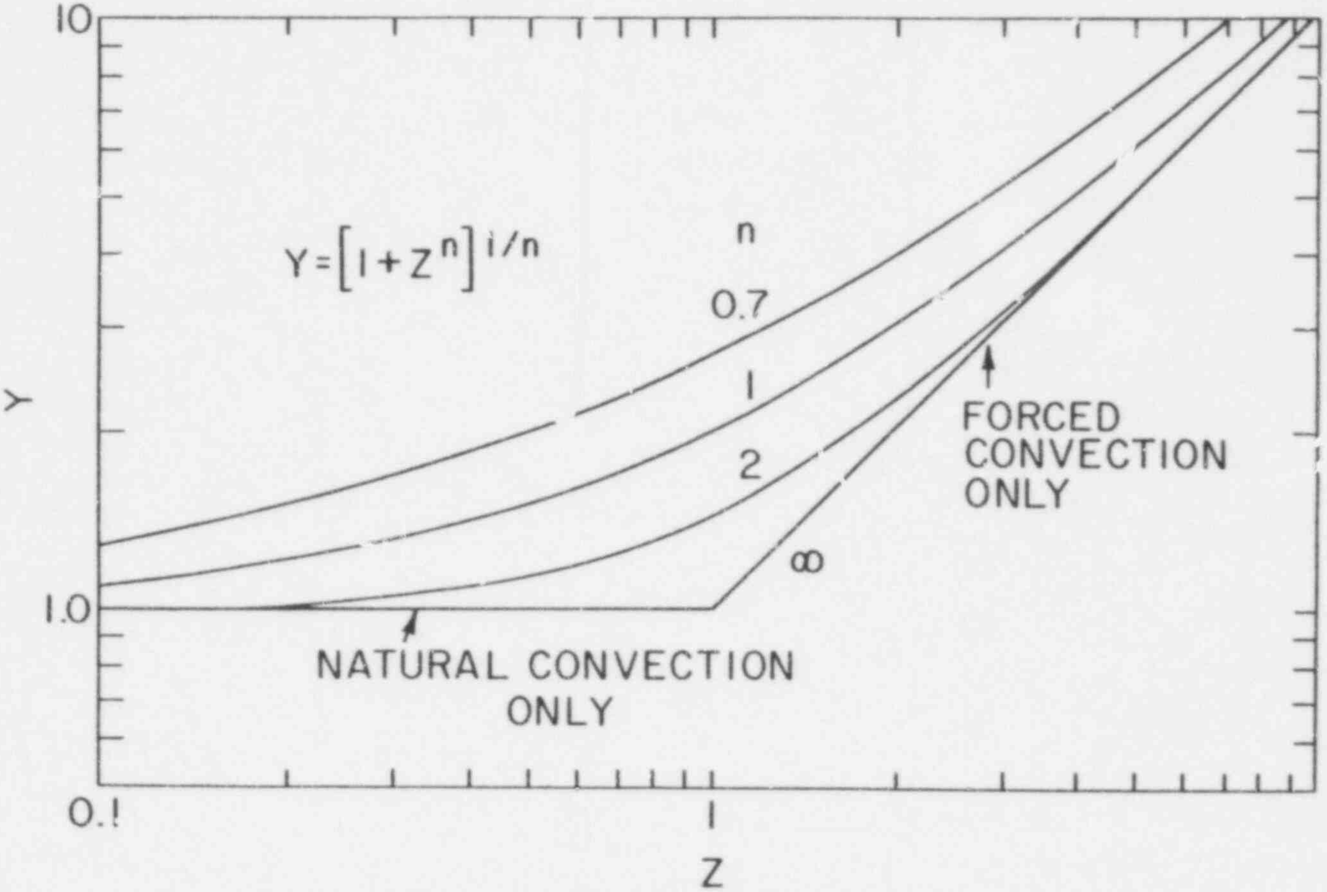


Figure 1 Proposed Correlation Scheme for Matching Forced and Free Convection Components of Boundary Heat Transfer Relation. (BNL Neg. No. 9-591-76).

transfer. The correlation was tested against the measured average heat transfer data from their tests. The best agreement was obtained using the laminar relations and a value of n = 1.[12]

## 3. ANALYTICAL MODELING

### 3.1 Heat Transfer

The data of Gustavson, et al. represent the first data available for local convective heat transfer coefficient from volume-heated boiling pools. The present authors conceived from the available data that the mode of heat transfer, instead of resembling mixed convection in which the effects were approximately superimposed, more closely approximated an enhanced mode of natural convection boundary layer flow and heat transfer. The phenomenon of boundary layer flow and heat transfer is depicted in Fig. 2. It is assumed that the vapor rising through the pool causes a net liquid drift upward, which encounters the free surface and is forced to return downward along the cold boundary. In this case, the net bouyancy effect is due to the liquid-to-two-phase density difference. The heat transfer distribution from the volumetrically boiling pool to the boundary exibits behavior not unlike a single-phase natural convection boundary layer, enhanced by the flow of net liquid recirculation due to upward vapor drag through the central liquid and downward along the walls. With this point of view in mind, single-phase natural convection boundary layer theory coupled with the bouyancy effect of the two-phase flow in the bulk liquid was used to attempt to correlate the Nusselt number to a modified Rayleigh number.



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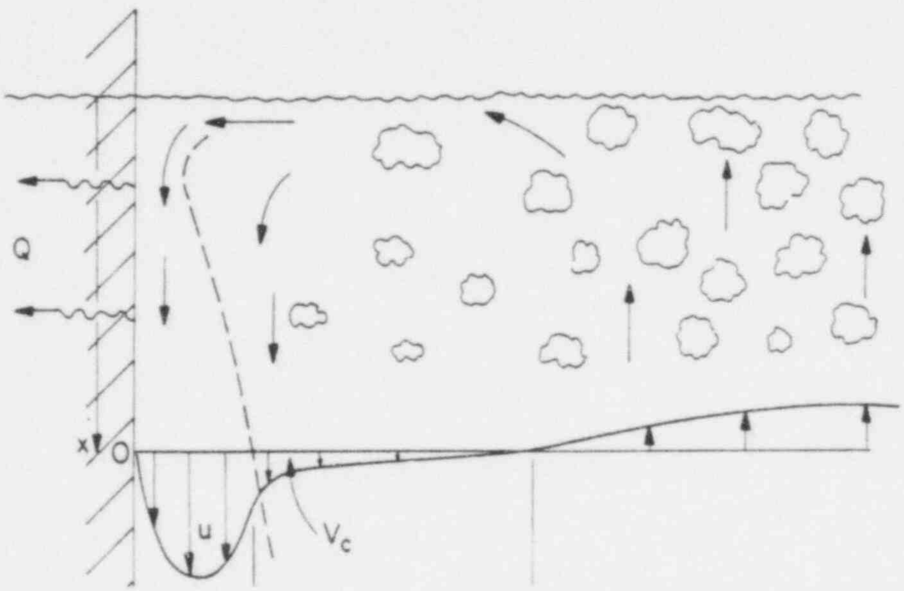


Figure 2 Schematic of Boundary Layer Flow and Heat Tra.sfer From Volume Boiling Pool. (BNL Neg. No. 9-369-76).

Assuming that $\alpha\rho_{v\infty} << (1 - \alpha)\rho_{\ell\infty}$, it has been shown that a modified Grashof number based on the void fraction may be defined as,[15]

$$Gr^*(x,\alpha) = g_{eff}[\rho_w - (1 - \alpha)\rho_{\ell\infty}]\rho_f x^3/\mu_f^2 \tag{11}$$

Furthermore, if the boundary is inclined from the vertical by an angle $\theta$ in such a manner that the boundary layer remains attached to the wall, the angle of inclination may be used to define the effective gravitational component in the direction of flow and Eq. 11 becomes

$$Gr^*(x,\alpha,\theta) = g\cos\theta[\rho_w - (1 - \alpha)\rho_{\ell\infty}]\rho_f x^3/\mu_f^2 \tag{12a}$$

If $\alpha\rho_{\ell\infty} >> \rho_w - \rho_{\ell\infty}$, this may be reduced to the simple form below

$$Gr^*(x,\alpha,\theta) \simeq \frac{g\cos\theta\alpha x^3}{\nu_f^2} \tag{12b}$$

The experimental data of Gustavson, et al. were correlated on the bases of modified single-phase natural convection theory of the forms below;

a: Using average pool void fraction,

$$Nu(x,\bar{\alpha}) = K_1[Gr^*(x,\bar{\alpha})\cdot Pr]^{0.25} \tag{13a}$$

and

b: Using locally measured void fraction,

$$Nu(x,\alpha) = K_2[Gr^*(x,\alpha)\cdot Pr]^{0.25} \tag{13b}$$

in which the properties used were the measured properties for the zinc sulfate solution at the appropriate film temperature. The value $K_i$ was determined from a log-log-linear least-squares fit to the data, and the



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forms of the correlations are

$$a - \quad Nu(x,\overline{\alpha}) = 0.78[Gr^*(x,\overline{\alpha}) \cdot Pr]^{0.25} \tag{14a}$$

with a standard deviation in the correlation coefficient of $\pm$ .35, and

$$b - \quad Nu(x,\alpha) = 0.76[Gr^*(x,\alpha) \cdot Pr]^{0.25} \tag{14b}$$

with a standard deviation in the correlation coefficient of $\pm$ .56. The data was visually interpreted to be in the laminar regime and for the most part, fell in the range $Ra(x) < 10^{11}$. The experimental data, as well as the log-log-linear least squares fit to the data for Eq. 14a are shown in Fig. 3. The scatter in the correlation is basically the experimental scatter, and no finer structure was observed. The form of the correlation was insensitive to whether the average or local void fraction was used probably because the effects of the 1/4 root of the void fraction over the measured range of $\alpha$ was lost in the scatter of the data. The use of the average void fraction is attractive since then the computation of local heat flux will not require knowledge of the local void distribution which is more difficult to measure and compute.

In order to use either correlation method to predict the effects of boundary heat transfer from volume-heated boiling pools, knowledge of the local or pool-average void fraction, as seen in Eqs. 13a,b is required.

## 3.2 Void Dynamics

The void distribution may be calculated based on a one-dimensional

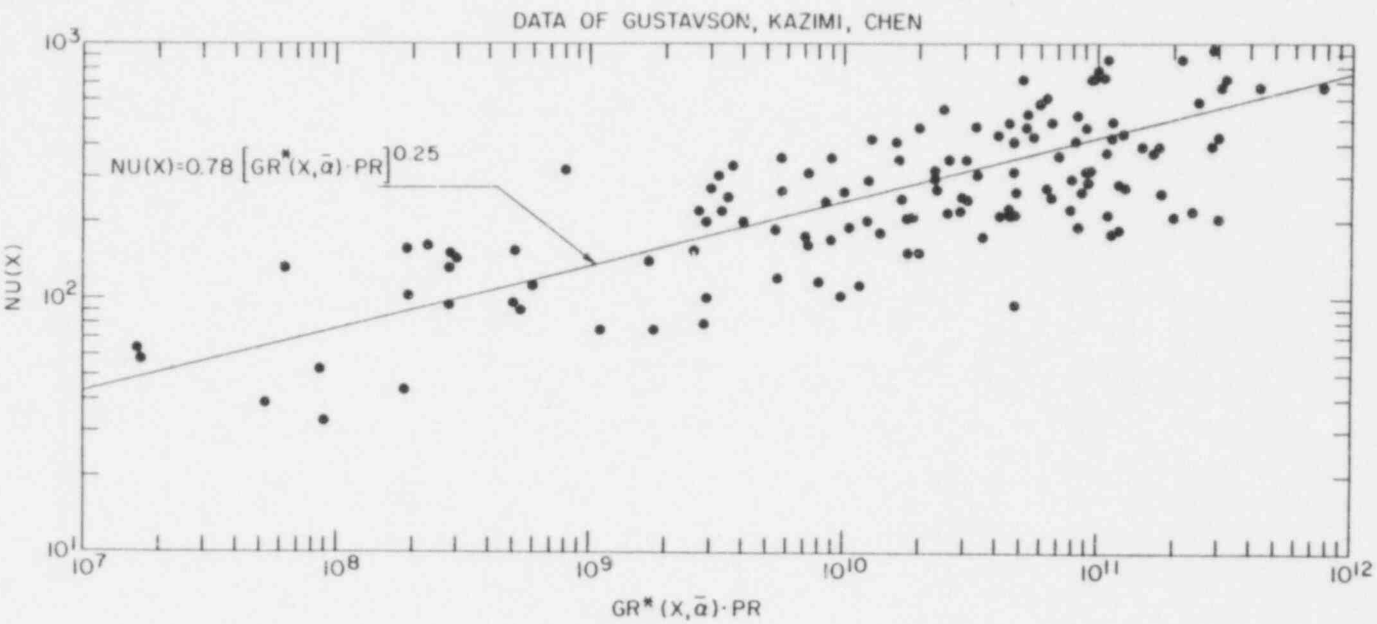


Figure 3   Modified Laminar Natural Convection Correlation of Boundary Heat Transfer from Volumetric-Boiling Pools (Based on Data from Ref. 12). (BNL Neg. No. 1-1295-79).

two-phase drift flux model.[15] Consider a volume-heated boiling pool in which the volumetric vapor source may be written as

$$\Gamma_v = \frac{\dot{Q}_B''''(1 - \alpha)}{h_{fg}} \tag{15}$$

where the term $(1 - \alpha)$ signifies that the local heat generation occurs only in the liquid and $\Gamma_v$ is the vapor source (gm/cm$^3$ s). For most low power boiling pools in which the evaporated liquid is "made-up," the liquid volume flux will be negligible in comparison to the vapor volume flux. The steady state vapor mass conservation equation may be written as

$$\frac{dj_g}{dx} = \frac{\dot{Q}_B''''(1 - \alpha)}{\rho_v h_{fg}} \tag{16}$$

The relation between the superficial vapor velocity, $j_g$, and the drift velocity, $V_{gj}$, may be written as,[16]

$$\frac{\langle j_g \rangle}{\langle \alpha \rangle} = C_o \langle j \rangle + V_{gj} \tag{17}$$

where the notation $\langle\ \rangle$ indicates a cross-sectional area average quantity. If we assume $\langle j \rangle \sim \langle j_g \rangle$ and the distribution parameter $C_o = 1.2$, this reduces to

$$\langle j_g \rangle = \frac{\langle \alpha \rangle V_{gj}}{1 - C_o \langle \alpha \rangle} \tag{18}$$

Assuming that the drift velocity, $V_{gj}$, can be represented as

$$V_{gj} = U_\infty (1 - \alpha)^n \tag{19}$$



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where n = 0 for churn-turbulent flow, and n = 2 for bubbly flow and dropping the bracket notation, Eq. 16 becomes

$$\frac{d}{d\xi}\left[\frac{\alpha(1-\alpha)^n}{1-C_o\,\alpha}\right] = K(1-\alpha) \tag{20}$$

subject to the initial condition

$$\alpha = 0 \quad \text{at} \quad \xi = 0 \tag{21}$$

where $\xi = x/H_o$ and $K = \frac{\dot{Q}_B''' H_o}{\rho_v h_{fg} U_\infty} = j_{g\infty}/U_\infty$. Equation 20 has been numerically integrated by two algorithms, an Euler predictor-corrector method and a fourth order Runge-Kutta method, with good agreement. The average void fraction, $\bar{\alpha}$, is defined as

$$\bar{\alpha} = \frac{\xi_{max} - 1}{\xi_{max}} \tag{22}$$

The results of the local void fraction calculation were compared to the local void fraction data of Gustavson, et al.,[12] for four selected experimental runs for a value of K = 1.75. Although agreement between calculation and experiment was poor on a local basis, the average void fraction for the four runs, $\bar{\alpha}_{meas} \sim .40$, agreed quite well with the calculated average void fraction, $\bar{\alpha}_{calc} \sim .41$.

The data of Gustavson, et al.[12] tend to support the concepts of boundary layer heat transfer and one-dimensional two-phase drift flux vapor distribution modeling for pools in the bubbly flow regime. However, the uncertainty in the measurements performed make it difficult to differentiate the degree of agreement with the various models proposed, as well as to



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identify the various flow regime transition criteria for hydrodynamic and heat transfer behavior. In particular, the conditions for transition from bubbly flow to churn-turbulent flow are not clear, nor are the changes in the associated hydrodynamic and heat transfer behavior. As a result, it is difficult to extrapolate these results to other heat transfer systems of interest, in particular the behavior of internally-heated boiling pools of nuclear fuel in an HCDA, which may exist at power levels beyond the range of the previous work. For these reasons, the experiment described herein was undertaken.

## 4. EXPERIMENTAL

### 4.1 Pool Description

A schematic view of the overall pool construction is seen in Fig. 4. The pool was rectangular in cross-section, 18 cm wide x 33.5 cm long. The electrodes were recessed into lexan walls and polished to eliminate surface nucleation. The electrodes, as well as the walls and base, could be supplied with cooling water flow to eliminate preferential surface nucleation if necessary. Evaporative and boiling vapor losses were recovered through a make-up water flow port connected to a constant level weir adjusted to $H_o$. The net make-up water flow rate was measured and converted to gross vaporization power. The make-up flow was introduced from the pool bottom into a baffled space to pre-heat the water to $T_{sat}$ and prevent inlet subcooling effects. No boiling occurred in this space. The entire pool was

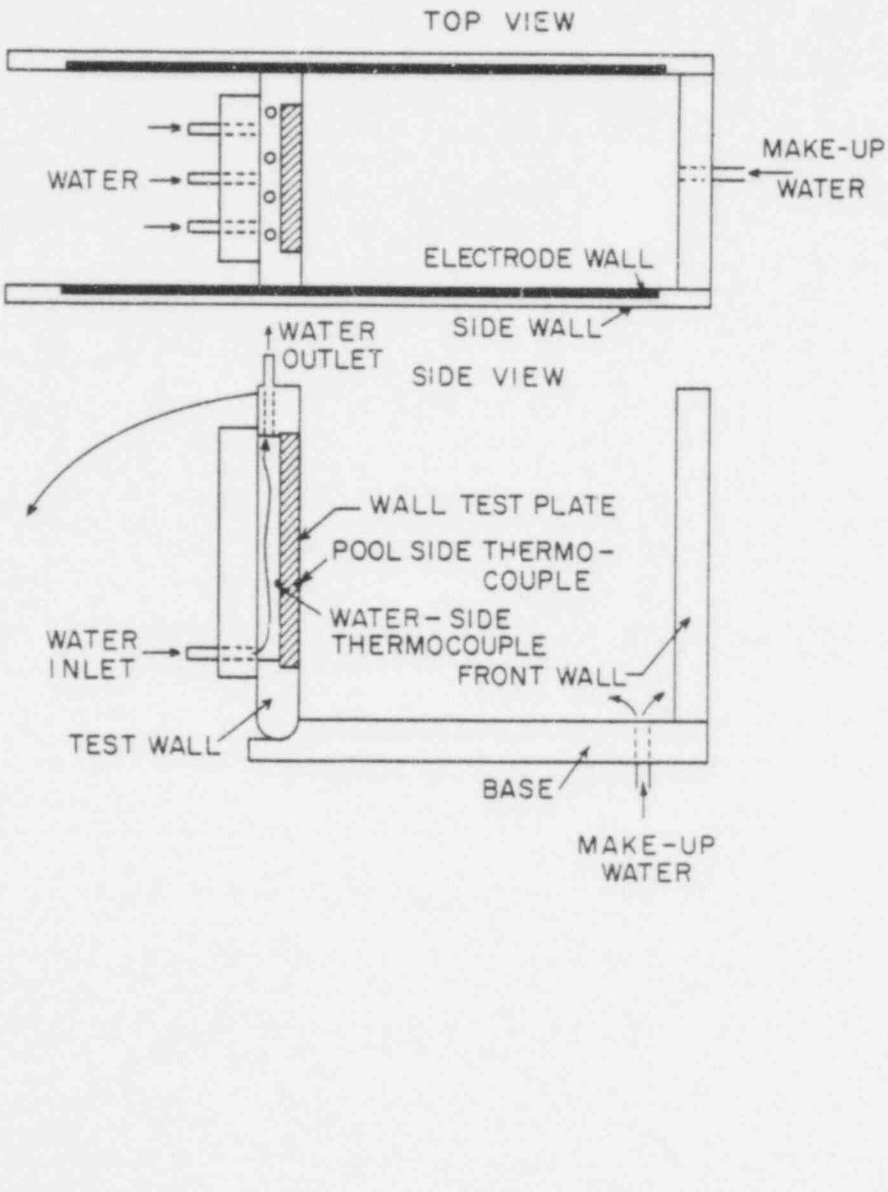


Figure 4 Schematic View of Inclined-Wall Volumetric Boiling Pool Apparatus. (BNL Neg. No. 1-1385-79).



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constructed of lexan with the exception of the copper electrodes and boron nitride test plate.

The boiling and nonboiling depths of the pool were measured with a voltage probe connected to a precision traversing mechanism. The conductor was lowered by the traversing mechanism until continuity was achieved and the voltmeter indicated the pool voltage. The pool was powered to the operating power and the probe was once again lowered until the operating voltage was again indicated. In this fashion, visual observations of pool depth were eliminated and more objective measurement of $H_o$ and $H_B$ was possible. The uncertainty in this measurement technique was essentially the fluctuations in pool height while boiling.

## 4.2 Test Plate

The test wall was constructed of lexan and was machined in such a fashion that the base of the test wall was continuously inclinable from the vertical position to any inclined position. A schematic of the test wall is shown in Fig. 5. The test surface was composed of boron nitride sheet (1.27 cm x 30.5 cm x 12.7 cm), machined and recessed into the lexan wall with the pool-side surface flush with the lexan and in direct contact with the boiling pool. The material has heat transfer characteristics of an excellent thermal conductor, but is electrically insulating at the same time. These properties, along with low water absorption and thermal expansion and ease of machining, made BN an ideal material for these tests. In addition, no electrically insulating covering was necessary, eliminating contact heat transfer resistance and temperature extrapolation. The back

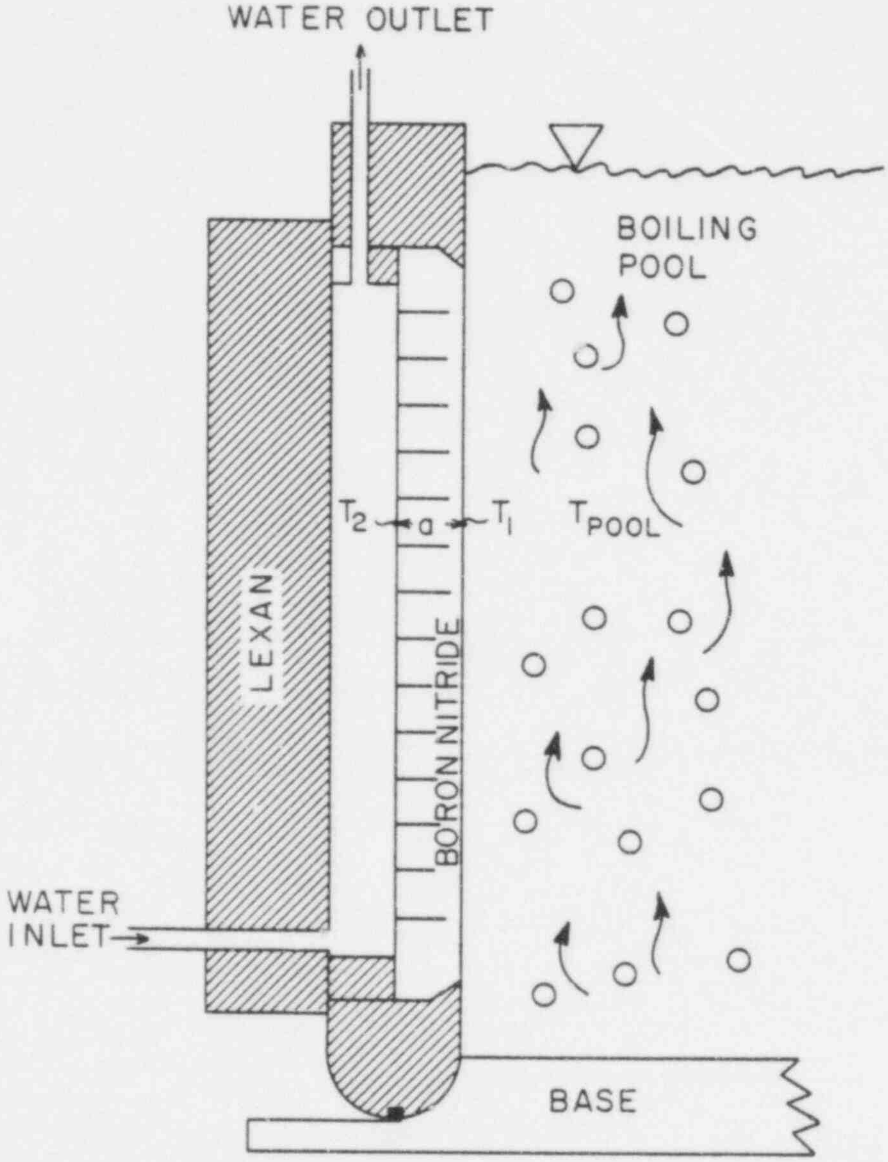


Figure 5 Schematic View of Inclined Wall Test Plate. (BNL Neg. No. 1-1384-79).

surface of the BN test plate was cooled by flowing water. A separate flow loop was designed to supply a continuous flow of water, 15-20 ℓpm, to remove the heat transfered to the wall. The flow rate was designed to be high enough that the convective resistance to heat transfer in the coolant loop was negligible. The entire back surface of the BN was exposed to the coolant flow. This eliminated channel coolant effects, as well as hot and cold spots from coil cooling techniques previously employed (see Fig. 5.). A picture of the assembled test pool may be seen in Fig. 6.

### 4.3 Test Plate Instrumentation

The BN was instrumented with chromel-alumel thermocouples for local heat transfer measurements. The thermocouples were 0.025 cm diameter stainless steel-clad microthermocouples, which were machined flat at the junction and electro-gold-plated with ∿ 0.003 cm of gold forming the hot junction across the isolated chromel and alumel leads. A schematic of the cross-sectionally polished and gold-plated microthermocouples is shown in Fig. 7. A photograph of the polished but unplated thermocouple tip may be seen in Fig. 8. The thermocouples were individually calibrated at the ice point and steam point taking local barometric pressure into account, and the average calibration data for each was compared to NBS type K data. It was found that all the gold-plated thermocouples calibrated to within ± .07 °C from the steam to the ice point. The gold-plated microthermocouples were then cemented into 26 locations in the BN wall, 19 on the front at 1.27 cm intervals, and 7 on the back at 3.81 cm intervals at locations listed in Table 2. They were installed in such a manner that the measuring junction

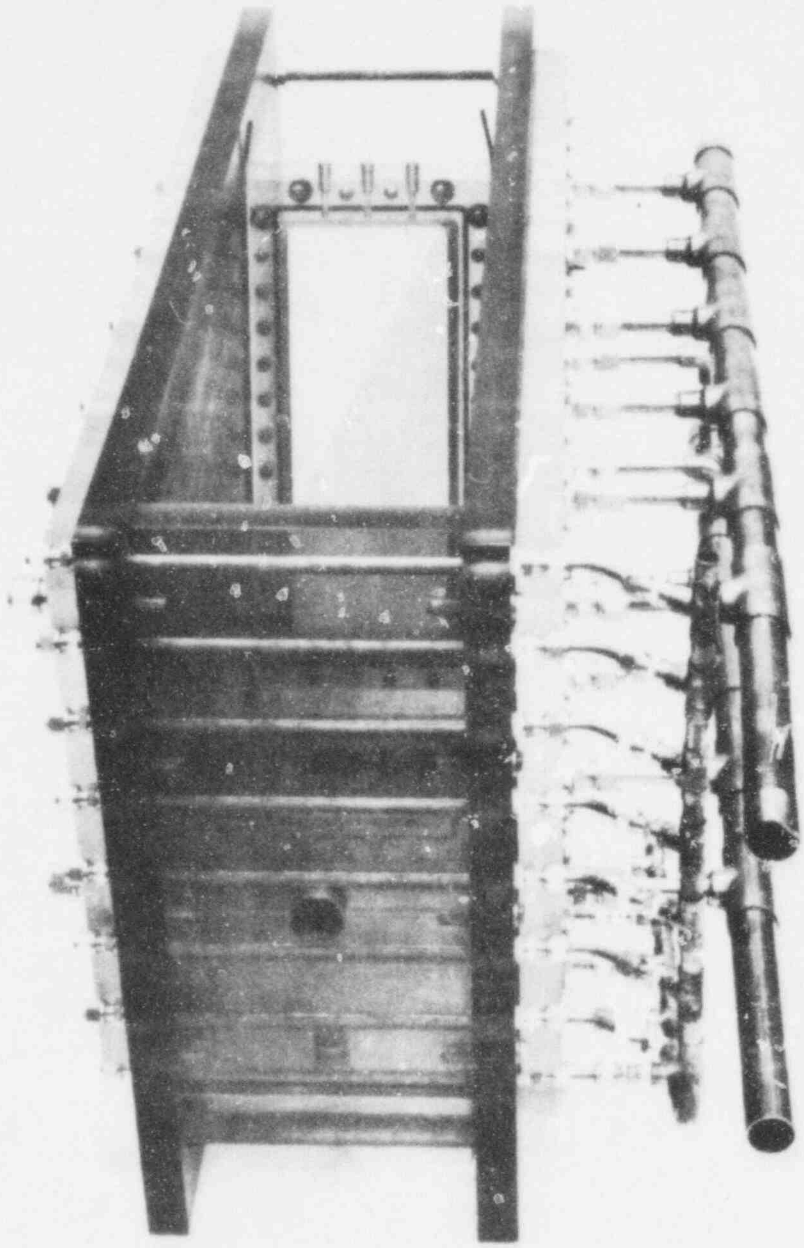

Figure 6 Photograph of Assembled Test Pool. (BNL Neg. No. 3-1418-77).



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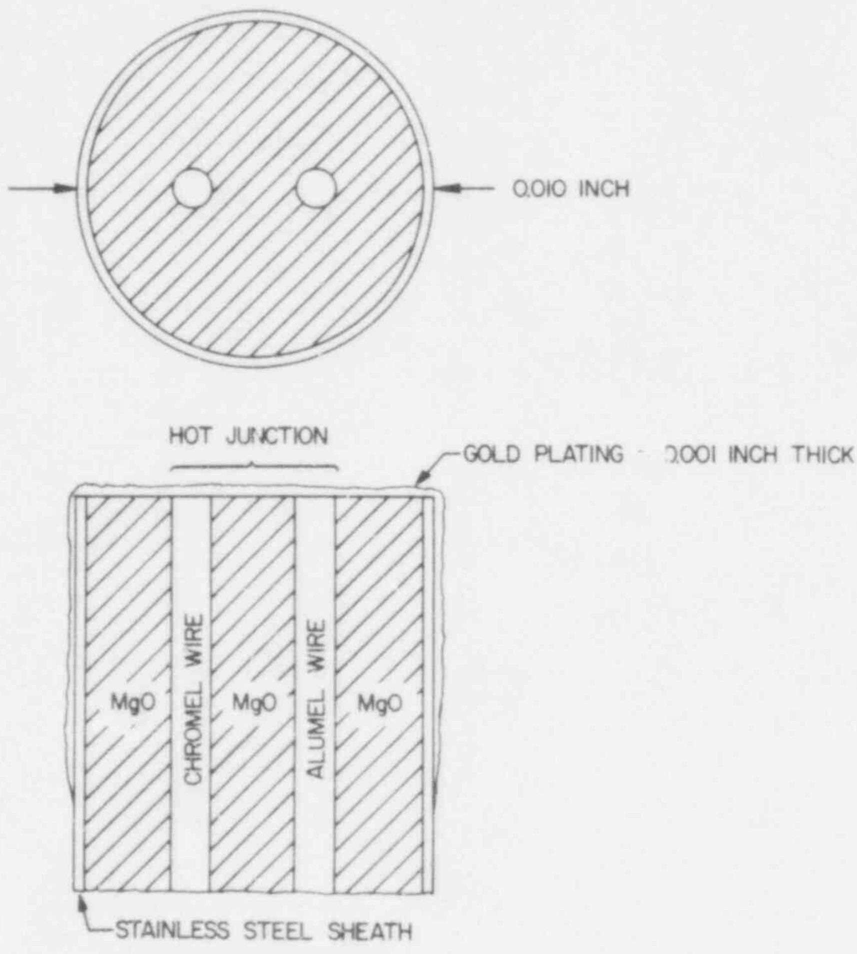


Figure 7 Schematic View of Gold Plated Microthermocouple. (BNL Neg. No. 2-376-77).



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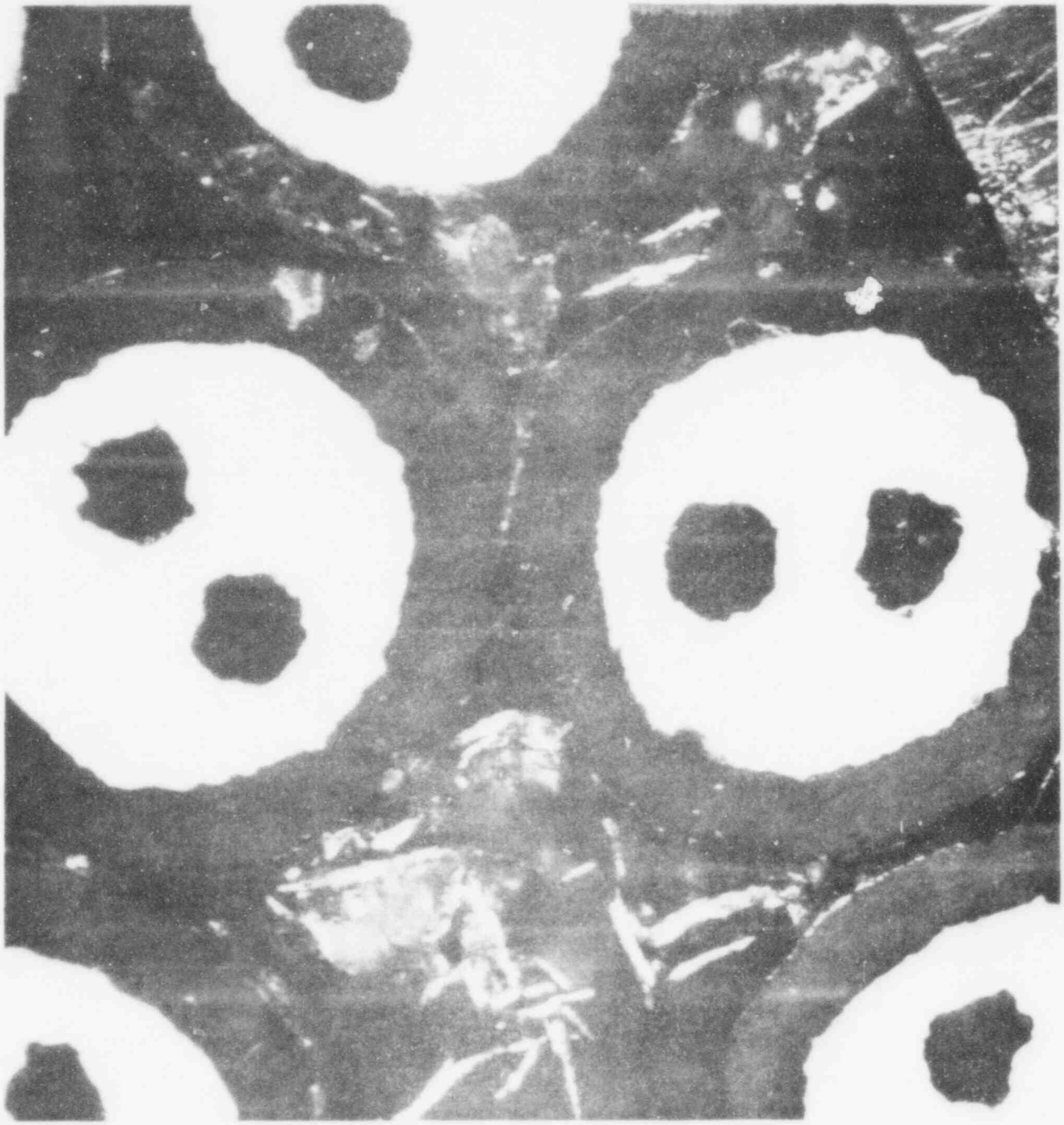

Figure 8 End View of Unplated Thermocouple Cross Section.
(BNL Neg. No. 3-1422-77).



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TABLE 2

THERMOCOUPLE LOCATIONS IN TEST PLATE

| Pool Side | | Coolant Side | |
|---|---|---|---|
| Thermocouple No. | Elevation Above Base(cm) | Thermocouple No. | Elevation Above Base(cm) |
| 1 | 31.40 | 20 | 8.54 |
| 2 | 30.13 | 21 | 12.35 |
| 3 | 28.86 | 22 | 16.16 |
| 4 | 27.59 | 23 | 19.97 |
| 5 | 26.32 | 24 | 23.78 |
| 6 | 25.05 | 25 | 27.59 |
| 7 | 23.78 | 26 | 31.40 |
| 8 | 22.51 | | |
| 9 | 21.24 | | |
| 10 | 19.97 | | |
| 11 | 18.70 | | |
| 12 | 17.43 | | |
| 13 | 16.16 | | |
| 14 | 14.89 | | |
| 15 | 13.62 | | |
| 16 | 12.35 | | |
| 17 | 11.08 | | |
| 18 | 9.81 | | |
| 19 | 8.54 | | |



494 070

was flush with the wall surface within an estimated ± .003 cm tolerance and cemented in place under a microscope. The gold-plated junction thus comprised part of the test wall surface. Heat losses along the thermocouple sheath were negligible since the leads were immersed in the plate at least 50 diameters.

## 4.4 Data Acquisition

The thermocouples were connected to a 150 $^{\circ}$F ± .2 $^{\circ}$F oven-type reference junction along with a thermocouple in the bulk pool, and the data was then routed to the automated data acquisition system. The centralized data acquisition and analysis system was constructed around an HP 9640 system, consisting of a 21 MX minicomputer with 112 kilowords of central memory, 7.5 megaword cartridge disk, and 9 track magnetic tape transport. Control of the system was accomplished by interactive software, which received transfer parameters from the experimenter and proceeded to scan the data channels upon command. The thermocouples were scanned by a 300 channel guarded crossbar scanner, which transferred data to an integrating digital voltmeter with microvolt resolution. Each thermocouple was sequentially sampled until the standard deviation of the output converged to a preset criterion or the maximum sample limit was exceeded. At this point, the scanner proceeded to the next thermocouple and repeated the same procedure until all 27 thermocouples had been integrated. The raw data was transferred to magnetic tape and preliminary engineering calculations were performed to convert the thermocouple output and system properties into local convective heat transfer coefficient and average pool void fraction.

A photograph of the entire inclined wall boiling pool test apparatus may be seen in Fig. 9.

All the measuring devices and their uncertainties are listed in Table 3.

## 5. EXPERIMENTAL RESULTS

### 5.1 Range of Experiments

The experiments described have been performed over a range of dimensionless vaporization power, $j_{g\infty}/U_\infty$, up to 1.8. Local heat fluxes along the inclined boundary were measured as indicated in Eq. 23.

$$h(x) = \frac{k_{BN}(T_{front}(x) - T_{back}(x))}{a \cdot (T_{pool} - T_{front}(x))} \tag{23}$$

Accuracy of these measurements was estimated to be within $\pm$ 5 percent. The tests reported herein do not have local void fraction measurements included, but rather have been correlated only on an overall average basis. The pool-average void fraction was measured as indicated in Eq. 24 with an estimated accuracy of $\pm$ 3 percent.

$$\overline{\alpha} = (H_B - H_o)/H_B \tag{24}$$

A complete error analysis is presented in Appendix A. Sample calculation of the heat transfer data is presented in Appendix B. For the boiling experiments presented here, the wall angles investigated were 90°, 75°, and 60° from horizontal with an accuracy of $\pm$ .5°. The flow regimes that were investigated are listed below and will be discussed in this order:



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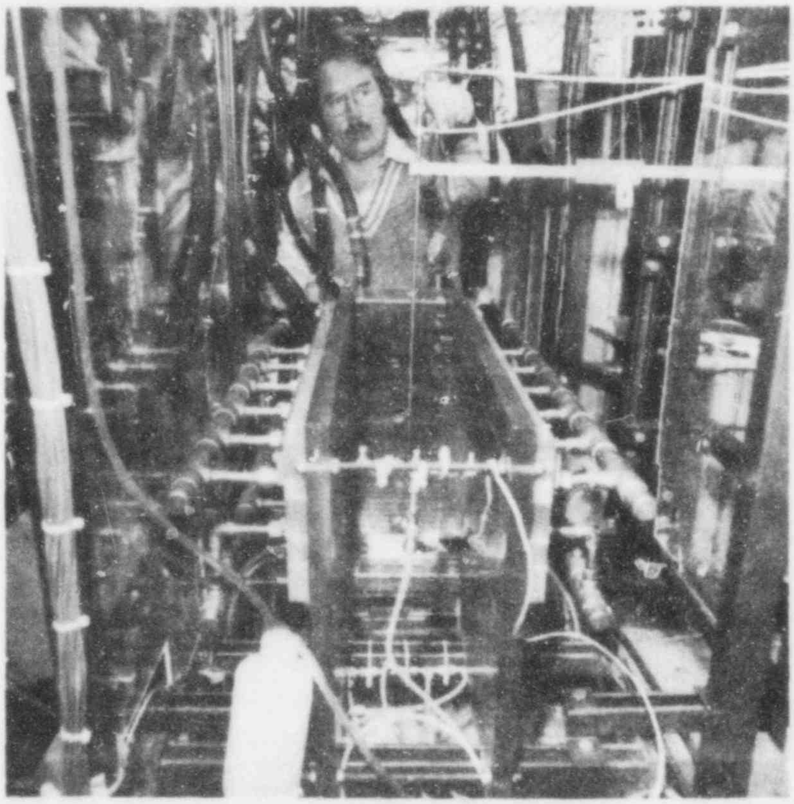

Figure 9 Photograph of Assembled Test Pool Facility. (BNL Neg. No. CN2-798-78).

TABLE 3

LIST OF MEASURING DEVICES USED
AND THEIR UNCERTAINTY

| INSTRUMENT | UNCERTAINTY |
|---|---|
| Thermocouple, Gold-Plated, Type K | $\pm$ .07 $^{o}$C |
| Digital Voltmeter, HP 3455A | $\pm$ 1 μv |
| Reference Junction, REF-CEL 200 | $\pm$ .10 $^{o}$C |
| Traversing Mechanism | $\pm$ .001 m |
| Make-Up Flow Meter System | $\pm$ .2 mℓ/s |
| Power Stats | $\pm$ 1 percent |
| Cross-Bar Scanner, HP 2911A,B, | |
| Hewlett-Packard Minicomputer, 21MX Series | |
| Printer-Plotter, Statos 42 | |

494 074

1. Nonboiling, single-phase

2. Boiling

   a. Incipient boiling

   b. Bubbly flow regime

   c. Transition

   d. Churn-turbulent flow regime

Tests were performed to determine if there were any measurable effects of the test wall coolant flow rate and make-up water temperature upon the boundary heat transfer distribution. The coolant flow rate was varied from 15-20 ℓpm with no measurable effect upon the magnitude of the measured heat transfer coefficients. The make-up water temperature was observed to have no effect as long as it entered the pool from the baffled preheating space at or close to $T_{sat}$.

## 5.2 Nonboiling Regime

Initial experiments were performed in nonboiling pools in order to perform operational checkout of the equipment and instrumentation. In addition, the nonboiling heat transfer to vertical and inclined boundaries was of interest in order to examine the nature of the boundary layer heat transfer. For these experiments, the total power applied to the pool was in the range of 1.0 to 2.5 kw. Boiling was not allowed to occur and heat transfer was single phase only. The profile of local boundary heat transfer behaved similar to single-phase laminar natural convection. The greatest magnitude of the local heat transfer coefficient was measured at or near the top of the test plate (i.e., the leading edge of boundary layer) and was in the range 0.015-0.020 cal/cm$^2$s $^o$C. Correlation of this data indicated that the behavior agreed very well with established single phase laminar natural convection as expected and verified the ability of the equipment to measure local boundary heat flux from volume-heated pools accurately. Alsc the use of the effective gravitational component,

$$g_{eff} = g \cos\theta \qquad (25)$$

was verified for natural convection, and the effect of the internal heat source on the boundary layer thickness was found to be negligible as calculated by the correction method of Randall and Sesonske.[17]

5.3 Incipient Boiling Regime

As the power that was applied to the pool was increased, the regime changed as volumetric bubble nucleation in the bulk liquid began to appear. The onset of nucleation was determined solely by visual observation of the pool. This regime was called the incipient boiling regime. The behavior was characterized by bubble formation and rise with little measurable increase in average pool height. The pool average void fraction was in the approximate range 0.00 to 0.03. The behavior of the boundary heat transfer was once again observed to resemble laminar natural convection as in the nonboiling tests. However, it was observed as in Fig. 10 that the maximum local heat transfer coefficient increased to approximately 0.08 cal/cm$^2$ s $^o$C. This was an increase over the nonboiling case of approximately a factor of 4-5. This indicated that although boundary layer-type heat transfer behavior was persisting, the superficial vapor velocity of the rising steam was causing a net recirculation of liquid which was rising through the

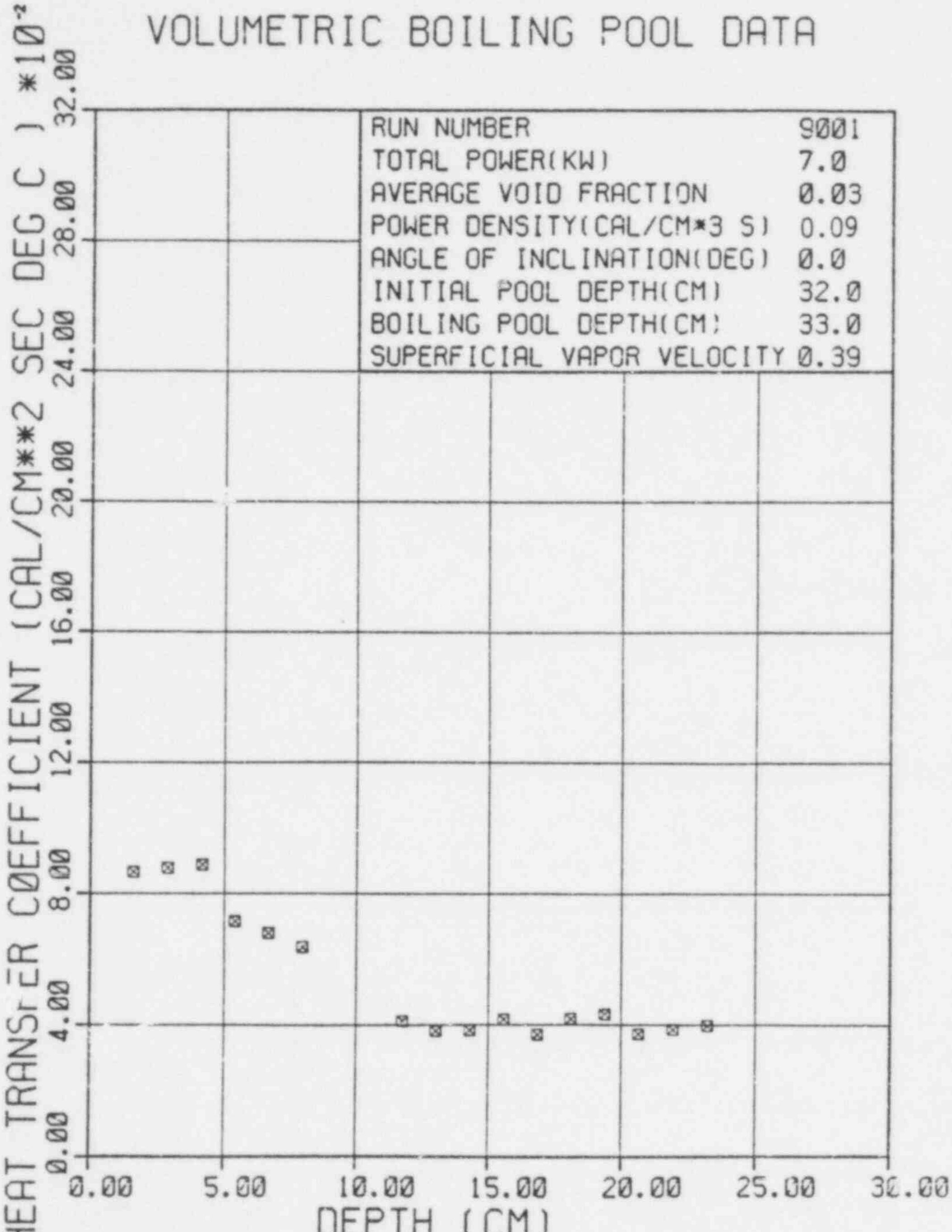


Figure 10 Profile of Local Boundary Heat Transfer Coefficient From Volume Boiling Pool - Run No. 9001 - Incipient Boiling. (BNL Neg. No. 4-844-79).

saturated pool. This liquid drift would encounter the free surface and turn towards the cold boundaries and flow downwards along the wall, enhancing the boundary layer heat transfer as evidenced in the magnitude of the convective coefficient. Boiling inception appeared to begin at a threshold value of $j_{g\infty}/U_\infty$ approximately equal to 0.2. Below this value, the pool was volume-heated single phase and above this value, two-phase effects and volumetric boiling became evident. This value of dimensionless superficial vapor velocity indicated the magnitude of the evaporative power losses from the pool. Reducing the total vaporization power, $j_{g\infty}/U_\infty$, by the evaporative losses, $(j_{g\infty}/U_\infty)_o$, yields the net boiling power presented in dimensionless form below:

$$(j_{g\infty}/U_\infty)^* = j_{g\infty}/U_\infty - (j_{g\infty}/U_\infty)_o \tag{26}$$

It is recognized that this evaporative loss term, $(j_{g\infty}/U_\infty)_o$, will be system dependent and will diminish as the pool free surface area to volume ratio decreases. Analysis of the void distribution was performed on the basis of $(j_{g\infty}/U_\infty)^*$ as will be seen.

## 5.4 Bubbly Flow Regime

A further increase in power applied to the pool resulted in net production of vapor and a finite void fraction. This flow regime was characterized by a stable array of densely packed bubbles which formed initially in the upper region of the pool above an essentially quiescent single-phase region below. As boiling power was increased further, the thickness of the bubbly boiling region increased, penetrating downward through the nonboiling region. The bubbly flow regime is a liquid-continuous flow regime in which

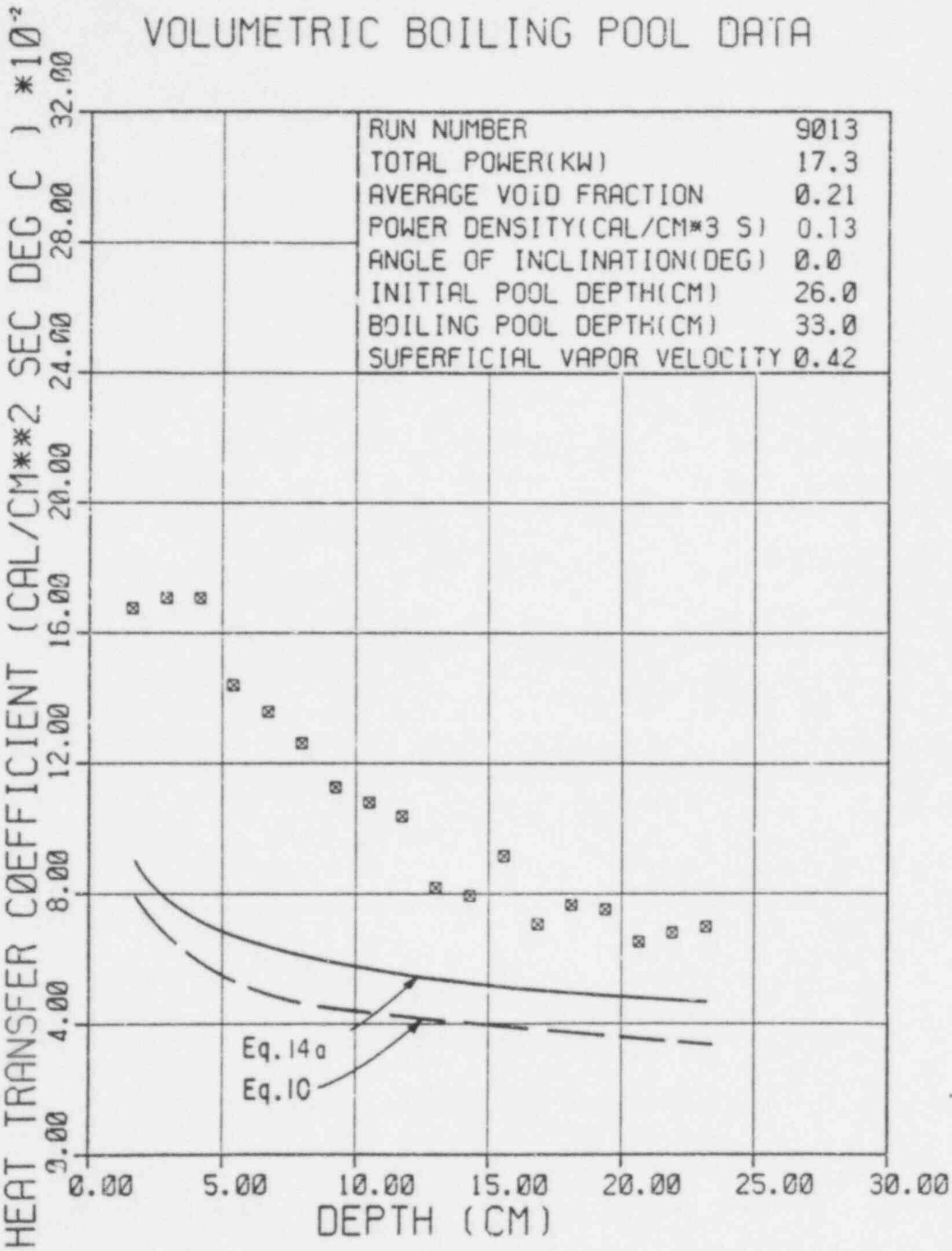


Figure 11 Profile of Local Boundary Heat Transfer Coefficient From Volume Boiling Pool - Run No. 9013 - Bubbly Flow. (BNL Neg. No. 3-1891-79).



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the dispersed phase is the vapor. As verification of this assumption, the time trace of power vs time was examined to determine the effect of bubbly motion upon electrical coupling of the liquid. Any decoupling of the liquid from the applied electric field would be recognized by a transient fluctuation of the power trace. None was evidenced, indicating that the pool power was evenly applied and distributed through the continuous liquid phase creating a constant volumetric power density. The pool average void fraction was observed to be very sensitive to the vaporization power in the bubbly flow regime. A small increase in $j_{g\infty}/U_\infty$ resulted in a rather large increase in $\overline{\alpha}$, as shown later in Fig. 14.

The maximum average void fraction achieved in these tests occurred for the bubbly flow regime just prior to flow regime transition and was approximately 0.55-0.60. While in the bubbly flow regime, the pool was observed to swell periodically. This is believed to be caused by local subcooling effects due to reentry into the pool of cold liquid from recirculating boundary layer flow which would cool the pool temporarily below the saturation temperature and induce partial void collapse.

The spatial profile of local boundary heat transfer coefficient maintained its boundary layer nature as before. An example of this is shown in Fig. 11. The maximum local heat transfer coefficient was observed, in all cases, to be at or near the pool surface, and its magnitude was measured at approximately 0.20 cal/cm$^2$ s $^o$C. The coefficient was observed to decrease as depth along the heat transfer surface increased and it was observed to vary in magnitude along the test plate surface by approximately a factor of 3-5. The average heat transfer coefficient for all the runs in the bubbly flow regime was calculated to be approximately 0.10; this was greater than the single-phase tests by about a factor of 5. The local heat transfer coefficient data was compared to the predictions of the models previously described in Eqs. 10[12] and 14a[15], and the comparison is shown graphically, for Run 9013, in Fig. 11; the comparison on a local basis is available for all the runs in Appendix C and will be presented later on an average basis in Table 6. It is clear in Fig. 11 that the local convective heat transfer coefficients for these experiments exceeded the calculations of both local heat transfer models available[12,15] (derived from the local boundary heat transfer data from volume boiling pools reported in Ref. 12) by as much as a factor of 2 or more. This will be supported by Table 6 which will present a comparison of the average convective coefficients for all the experiments reported to the models referenced[12,15] on an average basis.

## 5.5 Bubbly-Churn Turbulent Transition

As the pool power was increased further, a flow regime transition was observed to begin in the vicinity of $j_{g\infty}/U_\infty \sim 0.8$-$1.0$. This flow regime was characterized by an increasing instability in bubble array order and the onset of bubble agglomeration; densely packed bubbles in a liquid continuous flow began to break down into large regions of liquid and large regions of vapor. The onset of this transition region appeared for the most part to coincide with full penetration of the boiling region to the pool bottom. The runs that characterize this region are runs 6009-6011 and 6014-6015 (hydrodynamic only). These runs demonstrated a partial pool collapse due to the bubble agglomeration mechanism previously mentioned. Such behavior is observed in adiabatic bubble columns as previously shown.[19,20,21] The previously observed good agreement between measured and calculated average void fraction based on $(j_{g\infty}/U_\infty)^*$ for the bubbly flow regime was no longer observed; instead the measured void fraction fell between the calculated values based on both the bubbly and the churn turbulent drift flux This will be seen in Table 6 where the calculated average void fraction is that based on the bubbly flow drift flux model, and the number in parentheses is that for the churn-turbulent drift flux model. In addition, the previously observed periodic pool swelling behavior diminished.

The spatial profile of local boundary heat transfer coefficient continued to maintain a strong boundary layer behavior as before. However, as seen in Fig. 12, a great deal of scatter appeared, and the variation along the test wall became less. As has been noted previously[11], the magnitude of the heat flux became more nearly constant, and for this case, the ratio $\overline{h}_{upper}/\overline{h}_{lower}$ was approximately 4/3. The average boundary heat transfer coefficient was measured for transition runs 6009-6011 only, and was found to be approximately 0.125. This was greater by 25 percent over the average heat transfer coefficient in the bubbly flow regime and indicated that the hydrodynamic instability causing bubble agglomeration and flow regime transition was responsible for a corresponding increase in the boundary heat transfer coefficient. In spite of this apparent increase in the average boundary heat transfer, the measured heat transfer coefficients were in the range of those for the highest power bubbly flow regime runs. Correlation of the transition region data was close to the bubbly flow data, as we will

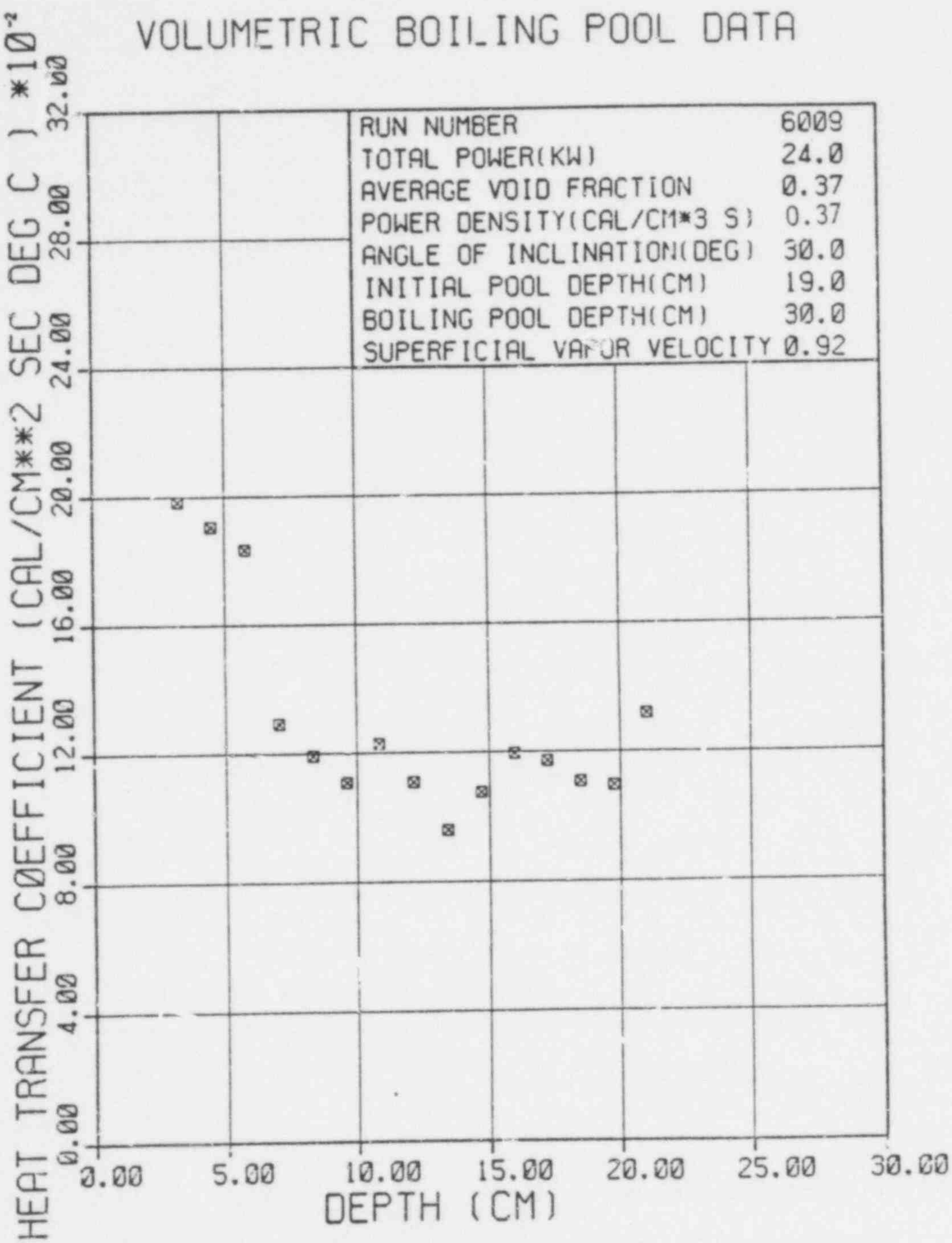


Figure 12 Profile of Local Boundary Heat Transfer Coefficient From Volume Boiling Pool - Run No. 6009 - Transition. (BNL Neg. No. 4-845-79).



494 083

see in the next section, however, the scatter in the measurements was greater, indicative of the instability in void dynamics observed.

### 5.6 Churn-Turbulent Flow Regime

The churn-turbulent flow regime appeared to dominate for $j_{g\infty}/U_\infty \geq 1.0$. This flow regime was characterized by a total breakdown in the well-ordered close packed bubble array observed for the bubbly flow regime. Instead, the hydrodynamic behavior appeared chaotic and highly "turbulent." Well-ordered flow patterns caused by upward vapor drift and downward boundary layer flow were no longer evident. In addition, the liquid-continuous flow hydrodynamics was destroyed by massive bubble agglomeration. This phenomenon appeared to be responsible for the creation of large regions locally which were entirely liquid or vapor. Large vapor flow paths appeared in the flow, allowing the escape of greater vapor mass flux than in the bubbly flow regime with considerably less liquid hold up. The result was a considerably lower average void fraction, as defined previously.

The flow regime transition from bubbl. .o churn turbulent flow occurred suddenly and completely at a value of $j_{g\infty}/U_\infty$ approximately equal to one. At this point, the average void fraction suddenly collapsed from a value of 0.55-0.60 to approximately 0.4[illegible]. Simultaneously, the apparently reasonable assumption (born out at this time by visual observations only) of one-dimensional flow for the bubbly flow regime and corresponding good agreement in average void fraction between experiments and one-dimensional drift flux void calculations appeared to no longer be valid for churn-turbulent flow. On the contrary, the flow appeared to become more three-dimensional in behavior, and the applicability of one-dimensional drift flux modeling under these conditions is questionable. Nevertheless, comparison between experimentally measured average void fraction data and calculated values based on the one-dimensional drift flux model for churn-turbulent flow was good. The average void fraction measured for the cases of transition and churn-turbulent flow was in the range of 0.40 and relatively insensitive to an increase in power for $j_{g\infty}/U_{\infty}$ up to 2.0.

During some of the bubbly flow runs, a thin but stable foaming layer was observed to form on the pool surface. The $ZnSO_4$ electrolyte solution was frequently replaced to avoid the addition of unwanted contaminants, but no surface active chemicals were added to destroy this thin foam. The reasons for its formation are not well known, although its presence has been observed before.[12,18] Regardless of its cause, the foam layer was invariably observed to completely and immediately disappear upon transition to the churn-turbulent flow regime, indicating that foams may not be an effective flow regime in such dynamic flow systems at dimensionless superficial vapor velocities in excess of unity, corresponding to vapor velocities greater than the bubble terminal rise velocity.

The heat transfer behavior also changed dramatically, and a sample of the local distribution of boundary heat transfer coefficient is demonstrated in Fig. 13. The apparent boundary layer nature of the heat transfer distribution seemed to disappear, replaced by a more uniform heat transfer coefficient along the boundary. The maximum local heat transfer coefficient was observed to be in the range 0.25-0.30 cal/cm$^2$ s $^o$C. The coefficient was observed to fluctuate temporally and spatially as well.

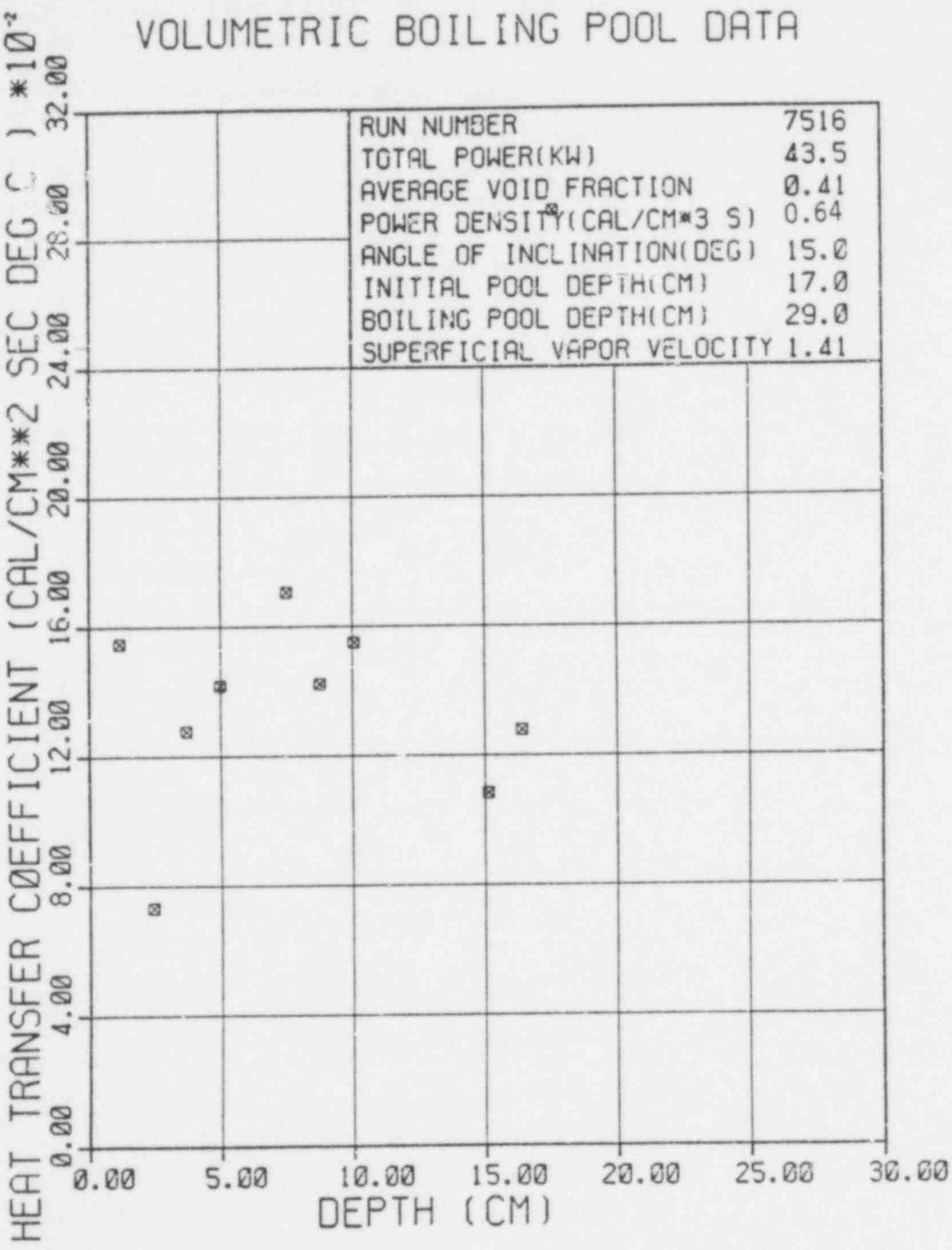


Figure 13 Profile of Local Boundary Heat Transfer Coefficient From Volume Boiling Pool - Run No. 7516 - Churn-Turbulent. (BNL Neg. No. 4-846-79).



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The temporal fluctuations are evident in the standard deviation data of the local boundary temperature history. Whereas for the bubbly flow regime, the standard deviation of the discretely sampled instantaneous wall temperature distribution was found to be in the range 0.2-0.6 $^{o}$C, and for the transition flow regime, the standard deviation of the wall temperature was found to be in the range of 1.0 $^{o}$C, a dramatic increase was observed for the churn-turbulent flow regime. The standard deviation of the local wall temperature averaging technique was found to be in the range 2.0-7.0 $^{o}$C, an order of magnitude greater than previously observed for the well-ordered bubbly flow regime. Interpretation of this data concerning the standard deviation of the local wall temperature in churn-turbulent flow indicated that the standard deviation was nearly equal in most cases to the difference between the saturated pool temperature and the average wall temperature, i.e.,

$$\sigma_w \doteq T_{pool} - \overline{T}_w \tag{27}$$

This was interpreted to mean that, intermittently, free stream conditions were present at the boundary of the pool. This indicated that the wall boundary layer was periodically being destroyed by the highly chaotic three-dimensional hydrodynamic behavior of the churn-turbulent flow and subsequently being reestablished. This type of intermittent renewal of the boundary layer may account for the enhanced heat transfer observed.

Investigation of the time trace of power applied to the pool was used to evaluate the effective overall electrical coupling of the liquid to the applied electric field as before. The power trace was observed to experience high frequency fluctuations in contrast to the steady nature of the bubbly flow regime. This was interpreted to mean that due to hydrodynamic fluctuations in the pool, the electrical resistance was fluctuating and perhaps portions of the liquid were becoming electrically isolated from the electric field; under such conditions the pool could no longer be characterized by liquid-continuous concepts. It is not clear at what dimensionless superficial vapor velocity (power) joule heating becomes ineffective in supplying uniform power density per unit liquid volume due to the observed electrical uncoupling mechanism in churn-turbulent flow. In the churn-turbulent flow regime for the heat transfer runs presented, the average boundary heat transfer coefficient was measured to be approximately 0.15 cal/cm$^2$ s $^o$C. This represented an increase of 50 percent over the average heat transfer coefficient measured for the bubbly flow regime.

## 6. DATA ANALYSIS AND DISCUSSIONS

### 6.1 Comparison of Calculated and Measured Pool Void Fraction

For the experiments presented so far, the average void fraction, $\bar{\alpha}$, was measured and compared to the dimensionless superficial vapor velocity based upon total vaporization power, $j_{g\infty}/U_\infty$. It was demonstrated that there existed a threshold velocity, $(j_{g\infty}/U_\infty)_o$, below which the pool would not boil. Subsequently, a net boiling superficial vapor velocity was defined, $(j_{g\infty}/U_\infty)^*$, as seen in Eq. 26. It has been determined that the quantity $(j_{g\infty}/U_\infty)_o$ was a system parameter and approximately equal to 0.2 for these tests.

A composite diagram of all the average void fraction data is plotted in

Fig. 14 as a function of the dimensionless superficial vapor velocity for the incipient boiling, bubbly flow, transition and churn-turbulent flow regimes.

The incipient boiling bubbly flow data and the churn-turbulent data were compared to the predictions of the one-dimensional drift flux model based upon net vaporization power and the appropriate drift flux model. In addition, the transition data were compared to both bubbly and churn-turbulent flow models. The comparisons are shown in graphical form in Fig. 15. The model was in fair agreement with the bubbly flow and incipient boiling data for small values of $j_{g\infty}/U_\infty$ and improved considerably as this value increased. This behavior was not unexpected in view of the strong sensitivity of the void fraction in the bubbly flow regime to small changes in boiling power as demonstrated in Fig. 14.

The transition data, due to the nature of the onset of flow instability, demonstrated poor agreement with both the bubbly and churn-turbulent flow models. As expected, however, the measured values did all fall intermediate to the two model predictions.

For the churn-turbulent flow data, good overall agreement between experiment and analysis was achieved. As pointed out previously, the sensitivity of the void fraction in the churn-turbulent flow regime to the vaporization power was considerably less than in the bubbly flow regime. This means that fluctuations in the power are not strongly reflected in the measured or calculated void fraction. This behavior is evident in Fig. 14 where the churn-turbulent data demonstrated a flat profile.

These data indicated the following behavior:

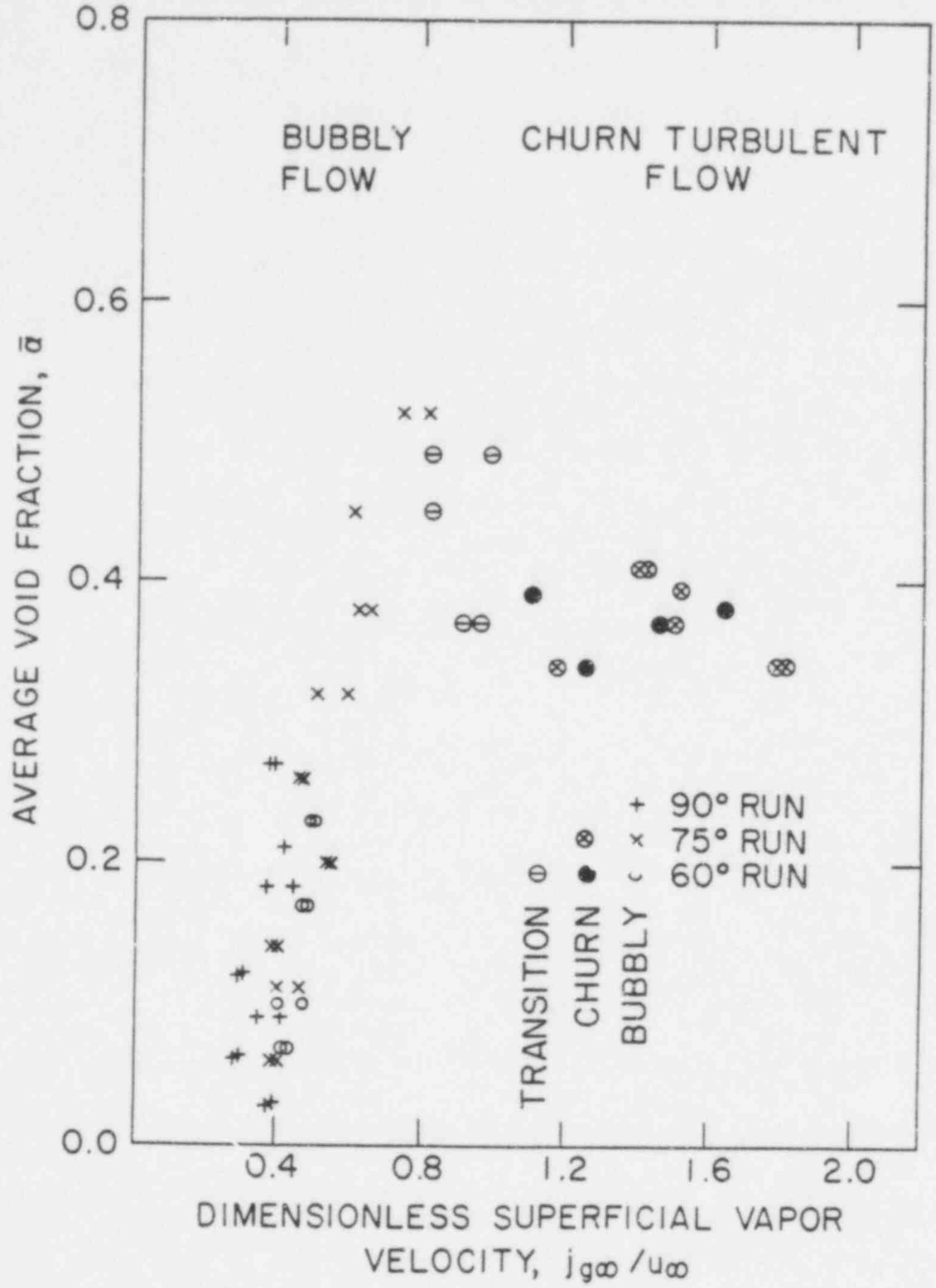


Figure 14 Pool Average Void Fraction, $\bar{\alpha}$, vs Dimensionless Superficial Vapor Velocity Based on Total Vaporization Power. (BNL Neg. No. 4-993-79).



494 090

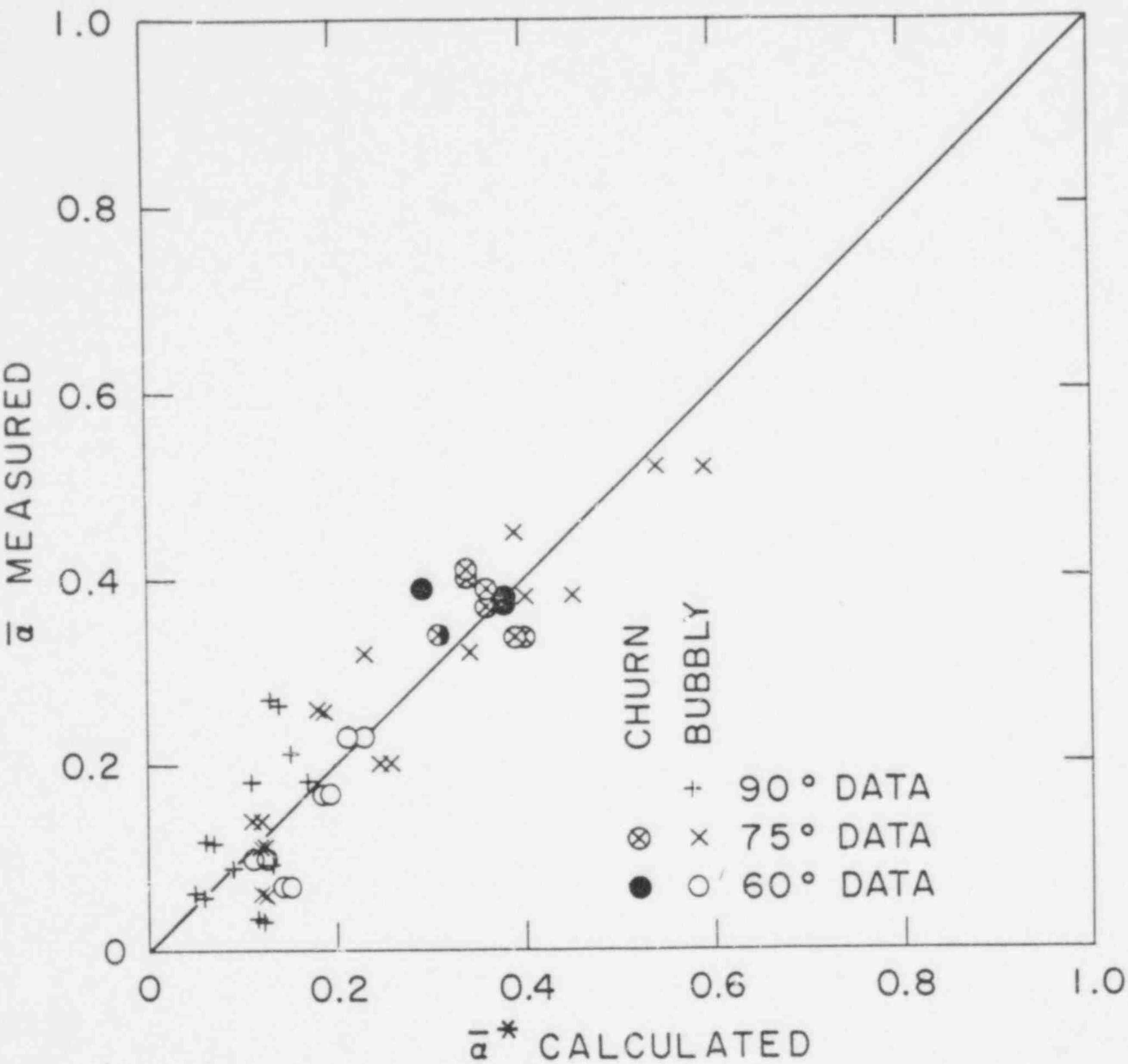


Figure 15 Comparison of Measured Average Void Fraction to Calculated Average Void Fraction Based on Net Boiling Power. (BNL Neg. No. 4-992-79).



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1. Evaporative losses were substantial in the bubbly flow regime for this pool with a large surface to volume ratio. For pools with smaller surface to volume ratio, this dependence is expected to diminish. In the churn-turbulent regime, the void fraction was less sensitive to the power and uncertainty in the boiling power and boundary heat losses contributed smaller uncertainty in the measured and calculated void fraction as demonstrated.
2. The nonboiling portion of the pool in the bubbly flow regime was not taken into account by the drift flux model. In addition, the effect of wall angle on the superficial vapor velocity is not presently incorporated into the analysis presented.
3. For the experiments reported to date, the pool-average void fraction never exceeded 0.60.
4. Transition from bubbly flow to churn-turbulent flow occurred for the total dimensionless superficial vapor velocity, $\bar{j}_{g\infty}/U_\infty$, in the range 0.8 to 1.0. This transition was accompanied by an immediate and sudden collapse in pool average void fraction from approximately 0.55-0.60 to 0.40.
5. The thin foaming layer which existed for some of the bubbly flow runs invariably was destroyed during transition to churn-turbulent flow. This was interpreted to mean that foaming flows were unstable for $j_{g\infty}/U_\infty$ greater than unity.

## 6.2 Natural Convection Analysis of Previous Data[12,11] For Heat Transfer From A Volume Boiling Pool to a Vertical Boundary

The correlation techniques described by Eqs. 13a,b were applied to local convective boundary heat transfer data of Gustavson, et al.[12] The assumption inherent in these equations is that the boundary layer is laminar, resulting in the assumed 1/4 exponent on the Rayleigh number. The local heat transfer correlations derived from the local heat transfer data and the (a) averaged void fraction data, (b) local void fraction data were found to be

$$a - \quad Nu(x,\bar{\alpha}) \simeq 0.78\ [Gr^{*}(x,\bar{\alpha}) \cdot Pr]^{0.25} \tag{14a}$$

and

$$b - \quad Nu(x,\alpha) \simeq 0.76\ [Gr^{*}(x,\alpha) \cdot Pr]^{0.25} \tag{14b}$$

The standard deviations were found to be $\pm$ 0.35 and $\pm$ 0.56 , respectively. It was observed that the convenience of utilizing the average void fraction, $\bar{\alpha}$, instead of the local void fraction, $\alpha$, resulted in little change in the correlation for heat transfer. The ratio of the correlation coefficients for the local heat transfer based on average vs. local void fraction was 1.03.

The same correlation technique was employed to test the existing data from 11 and 12 on an overall average basis. In this method, the average heat transfer coefficient and average void fraction were used. In conventional natural convection, it is assumed that the free stream density based on an equation of state is a constant since all properties outside the



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boundary layer are evaluated at free stream temperature and pressure. This would be the case of using the average void fraction in the heat transfer correlation. For this case, it can be shown for laminar flow that direct integration of the local heat transfer correlation yields the average heat transfer correlation with h replaced by $\overline{h}$ and x replaced by L. The coefficient for the average correlation, $K_T'$, is related to the coefficient for the local correlation from Eq. 13a as

$$K_L' = 1.33\ K_L \quad \text{for} \quad \alpha(x) = \overline{\alpha} \tag{28}$$

For the turbulent natural convection case, it can be shown similarly that the average turbulent correlation coefficient, $K_T'$, is related to the local correlation coefficient, $K_T$, by

$$K_L' = .83\ K_T \quad \text{for} \quad \alpha(x) = \overline{\alpha} \tag{29}$$

(See Appendix D for the derivation of Eqs. 28 and 29).

The average heat transfer data of Gustavson, et al.[12] were analyzed using the reported values for the superficial vapor velocity, average heat transfer coefficient, and average void fraction, as well as measured properties for $ZnSO_4$ electrolytic solution.

The average heat transfer coefficients for the data of Gabor, et al.[11] were not reported. They were calculated from the reported values of electrode heat flux, wall temperature, and pool temperature as

$$\overline{h} = \frac{\dot{q}'''_{electrode}}{(T_{pool} - \overline{T}_w)} \tag{30}$$



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The superficial vapor velocity, $j_{g\infty}$, was calculated from the reported value for the boiling heat flux as

$$j_{g\infty} \doteq \frac{\dot{q}'''_{BOIL}}{\rho_v h_{fg}} \tag{31}$$

The average void fraction data was reported. Only runs with an average void fraction greater than or equal to 0.05 were analyzed.

The results of the analysis of the data from Ref. 12 and Ref. 11 are presented in tabular form in Tables 4 and 5, and in graphical from in Figs. 16 and 17. It was found that the average natural convection correlation of the data of Gustavson, et al.[12] was

$$\overline{Nu} = \frac{\overline{h}L}{k} = 1.07 \left[\frac{g\overline{\alpha}L^3 Pr}{\nu_f^2}\right]^{0.25} \tag{32}$$

with a standard deviation of $\pm$ .30. The exponent was assigned from inspection of the data. The standard deviation of the correlation coefficient was found to be 0.30 or 28 percent, indicative of the scatter in the data. The majority of the data fell in the range of $Ra^* < 10^{12}$. As indicated in Fig. 16, there was no noticeably different trend observed for the foam or dense data. Examination of the magnitude of the average heat transfer coefficient and superficial vapor velocity indicated that most of the data fell in the bubbly flow region previously identified. The ratio of the correlation coefficients, $K'/K$, was 1.37, tending to reinforce the use of the average void fraction in correlating the local heat transfer data as well, as indicated in Fig. 3.

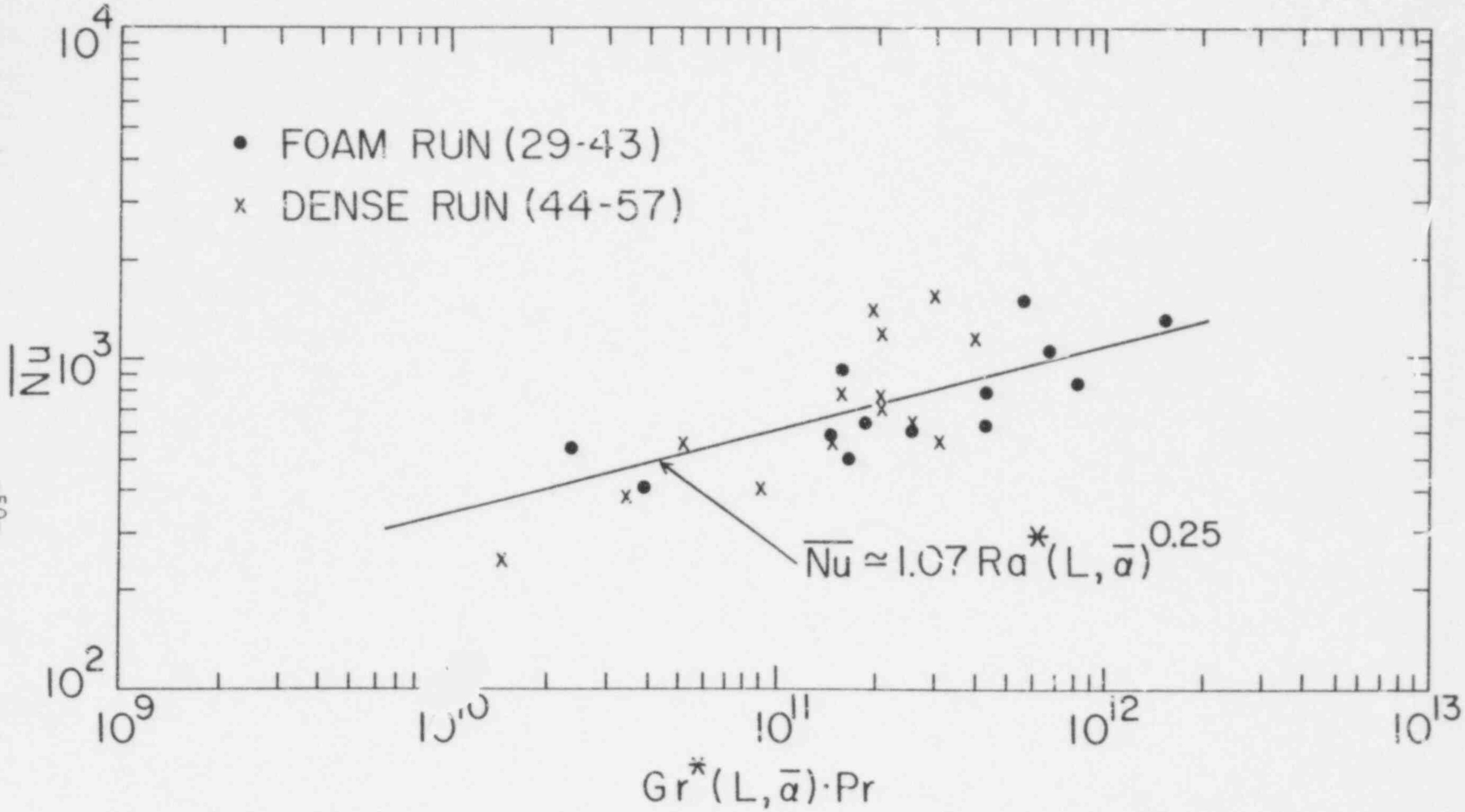


Figure 16 Natural Convection Correlation of Average Heat Transfer Data of Gustavson, et al.[12] (BNL Neg. No. 4-1304-79).

TABLE 4

AVERAGE HEAT TRANSFER AND VOID FRACTION DATA OF GUSTAVSON, ET AL.[12] AND COMPARISON TO EXISTING MODELS

| RUN | WALL TEMP DEG C | VOID FRACTION EXP | AVERAGE HEAT TRANS COEFF CAL/CM2 S DEG C EXP | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | SVV* | DEPTH CM | NUX | RAX | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | 86.8 | .44 | .075 | .079 | .057 | .071 | .19 | 17.10 | 788.6 | .4363E+12 | |
| 30 | 86.8 | .61 | .077 | .092 | .067 | .084 | .22 | 12.80 | 606.1 | .2530E+12 | |
| 31 | 89.0 | .67 | .095 | .082 | .063 | .079 | .43 | 2[illegible].50 | 1314. | .1529E+13 | |
| 32 | 90.8 | .41 | .132 | .076 | .054 | .067 | .17 | 18.90 | 1532. | .5609E+12 | |
| 34 | 90.2 | .62 | .098 | .086 | .060 | .074 | .17 | 17.60 | 1060. | .6782E+12 | |
| 35 | 88.6 | .62 | .073 | .084 | .078 | .100 | 1.[illegible]5 | 18.[illegible]9 | 843.6 | .8214E+12 | |
| 36 | 87.0 | .64 | .068 | .090 | .083 | .106 | 1.03 | 15.00 | 627.0 | .4301E+12 | |
| 37 | 89.2 | .40 | .078 | .085 | .068 | .087 | .35 | 12.20 | 584.6 | .1465E+12 | Foaming Runs |
| 38 | 88.3 | .24 | .072 | .080 | .069 | .088 | .35 | 9.30 | 411.4 | .3887E+11 | |
| 39 | 88.7 | .33 | .075 | .078 | .063 | .079 | .34 | 14.10 | 649.9 | .1854E+12 | |
| 40 | 83.0 | .05 | .066 | .049 | .039 | .049 | .11 | 13.40 | 544.2 | .2353E+11 | |
| 42 | 88.6 | .41 | .122 | .084 | .067 | .084 | .31 | 12.40 | 929.9 | .1559E+12 | |
| 43 | 89.2 | .63 | .074 | .097 | .073 | .092 | .27 | 11.00 | 590.4 | .1673E+12 | |
| 44 | 92.5 | .36 | .084 | .080 | .088 | .112 | 1.64 | 14.10 | 727.4 | .2050E+12 | |
| 45 | 87.7 | .37 | .088 | .080 | .087 | .112 | 1.62 | 14.10 | 762.9 | .2060E+12 | |
| 46 | 87 [illegible] | .43 | .113 | .079 | .078 | .101 | 1.24 | 16.70 | 1161. | .3959E+12 | |
| 47 | 87.0 | .36 | .074 | .081 | .085 | .109 | 1.28 | 12.80 | 582.6 | .1487E+12 | |
| 48 | 84.9 | .43 | .059 | .081 | .087 | .111 | 1.71 | 15.40 | 559.0 | .3079E+12 | |
| 49 | 90.2 | .46 | .072 | .084 | .073 | .094 | .62 | 14.10 | 623.8 | .2593E+12 | Dense Runs |
| 50 | 91.9 | .42 | .084 | .097 | .111 | .141 | 1.47 | 7.40 | 381.9 | .3426E+11 | |
| 51 | 87.0 | .31 | .064 | .093 | .097 | .124 | .78 | 6.20 | 244.1 | .1456E+11 | |
| 52 | 66.1 | .11 | .087 | .051 | .039 | .04[illegible] | .16 | 21.90 | 1179. | .2042E+12 | |
| 53 | 87.3 | .12 | .110 | .053 | .040 | .051 | [illegible]9 | 23.30 | 1577. | .2983E+12 | |
| 54 | 89.4 | .20 | .137 | .065 | .053 | .067 | .29 | 17.00 | 1432. | .1949E+12 | |
| 55 | 81.9 | .10 | .066 | .057 | .043 | .054 | .12 | 13.80 | 561.1 | .5032E+11 | |
| 56 | 86.2 | .23 | .084 | .069 | .062 | .080 | .55 | 15.20 | 785.7 | .1579E+12 | |
| 57 | 81.8 | .28 | .056 | .077 | .071 | .090 | .59 | 11.90 | 410.5 | .9056E+11 | |

* SVV indicates the dimensionless superficial vapor velocity.



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It was found that the average natural convection correlation of the data of Gabor, et al.[11] was

$$\overline{Nu} = \frac{\overline{h}L}{k} \approx 1.58 \left[\frac{g\overline{\alpha}L^3 Pr}{\nu_f^2}\right]^{0.25} \tag{33}$$

with a standard deviation of $\pm$ 0.33. There were no local void fraction or heat flux measurements available for this work to perform a similar comparison of the local and average heat transfer correlation coefficients as performed for the data in Ref. 12. Once again, the exponent was assigned after examining the data. The majority of the data fell in the range $Ra^* < 10^{12}$ as did Gustavson's data[12]. If the data were divided into two groups at $Ra^* = 10^{11}$, the correlation of the data on the basis of laminar and turbulent behavior would result in the set of correlations below,

$$\text{a -} \quad \overline{Nu} \simeq (1.42)Ra^{*.25} \qquad Ra^* < 10^{11} \tag{34a}$$

with a standard deviation of $\pm$ 0.25 for the laminar data and

$$\text{b -} \quad \overline{Nu} \simeq (.0309)Ra^{*.40} \qquad Ra^* > 10^{11} \tag{34b}$$

with a standard deviation of $\pm$ .0058 for the turbulent data. Although scatter in the data makes the determination of laminar vs. turbulent boundary layer behavior tenuous, both sets of correlations for Gabor's data are plotted in Fig. 17. This will be discussed in greater depth in the next section. Examination of the magnitudes of the average heat transfer coefficients and dimensionless superficial vapor velocities indicated that the majority of this data was also expected to fall in the bubbly flow regime.

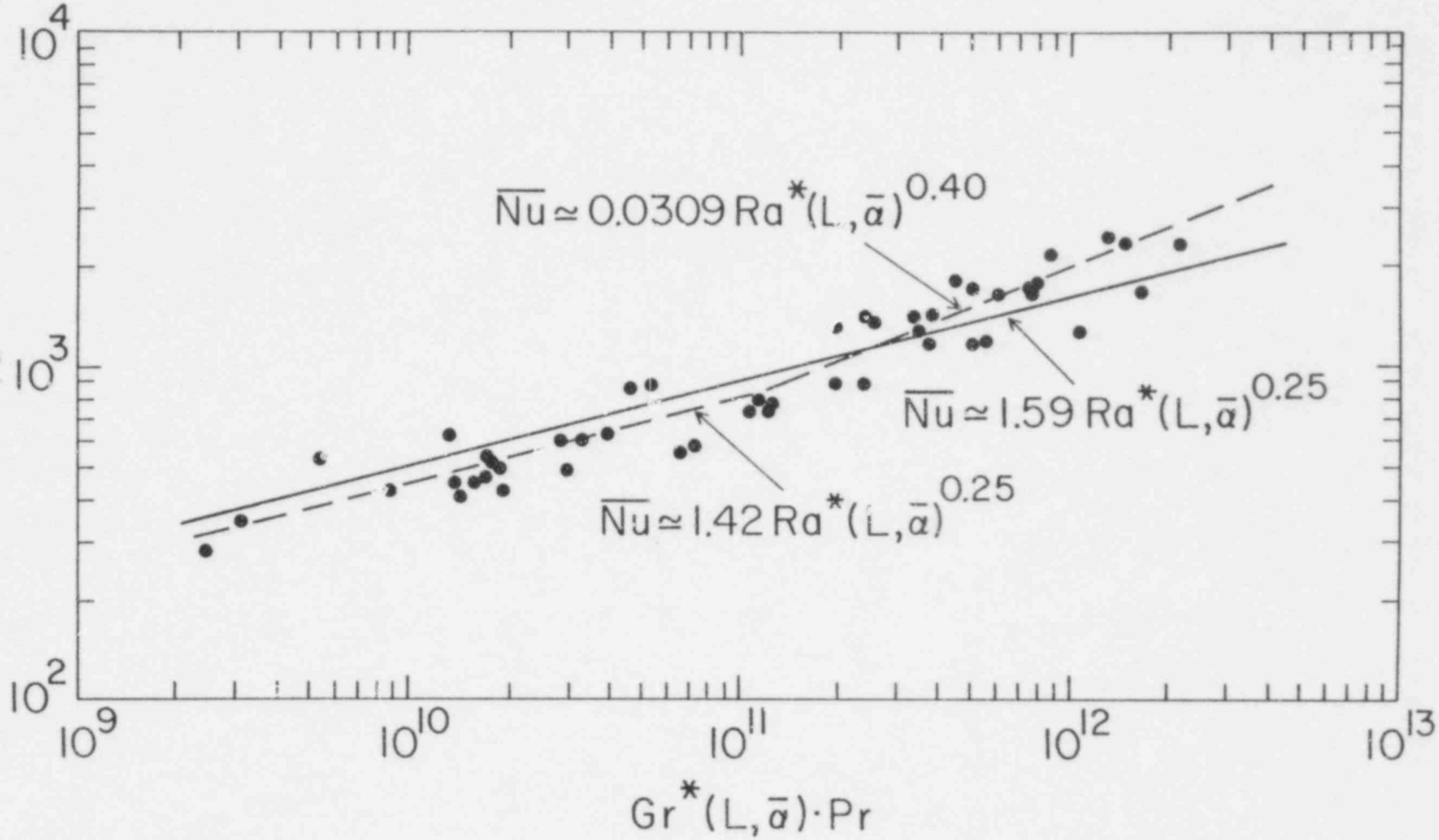


Figure 17 Natural Convection Correlation of Average Heat Transfer Data of Gabor, et al.[11] (BNL Neg. No. 4-1306-79).



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AVERAGE HEAT TRANSFER AND VOID FRACTION DATA OF GABOR, ET AL.[11] AND COMPARISON TO EXISTING MODELS

| RUN | WALL TEMP DEG C | VOID FRACTION EXP | AVERAGE HEAT TRANS COEFF CAL/CM2 S DEG C EXP | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | SVV* | DEPTH CM | NUX | RAX |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 59.7 | .41 | .098 | .072 | .073 | .093 | 1.34 | 19.30 | 1174. | .5034E+12 |
| 2 | 60.3 | .42 | .097 | .072 | .072 | .091 | 1.28 | 19.70 | 1186. | .5502E+12 |
| 3 | 55.6 | .31 | .085 | .069 | .065 | .082 | .74 | 16.50 | 872.0 | .2326E+12 |
| 4 | 55.9 | .51 | .088 | .072 | .061 | .077 | .67 | 23.30 | 1275. | .1079E+13 |
| 5 | 49.7 | .16 | .065 | .061 | .056 | .070 | .41 | 13.60 | 551.0 | .6502E+11 |
| 6 | 50.3 | .17 | .068 | .062 | .056 | .070 | .40 | 13.70 | 580.6 | .7086E+11 |
| 13 | 67.0 | .06 | .057 | .051 | .046 | .059 | .25 | 12.10 | 426.7 | .1887E+11 |
| 15 | 69.1 | .20 | .083 | .066 | .064 | .081 | .67 | 14.30 | 733.9 | .1050E+12 |
| 16 | 72.1 | .21 | .089 | .067 | .062 | .079 | .56 | 14.40 | 791.7 | .1143E+12 |
| 17 | 76.1 | .36 | .130 | .073 | .065 | .082 | .66 | 17.80 | 1428. | .3777E+12 |
| 18 | 74.7 | .35 | .116 | .073 | .070 | .089 | .96 | 17.50 | 1253. | .3465E+12 |
| 19 | 77.0 | .42 | .136 | .074 | .077 | .099 | 1.61 | 19.70 | 1653. | .6001E+12 |
| 20 | 77.4 | .58 | .137 | .074 | .069 | .089 | 1.35 | 27.10 | 2290. | .2162E+13 |
| 21 | 76.0 | .45 | .133 | .074 | .072 | .092 | 1.20 | 20.70 | 1699. | .7422E+12 |
| 23 | 70.2 | .05 | .061 | .049 | .044 | .056 | .22 | 12.00 | 452.5 | .1560E+11 |
| 24 | 76.9 | .27 | .092 | .070 | .063 | .081 | .58 | 15.60 | 885.3 | .1915E+12 |
| 25 | 81.3 | .45 | .130 | .075 | .067 | .086 | .85 | 20.70 | 1658. | .7619E+12 |
| 26 | 83.2 | .53 | .156 | .075 | .076 | .098 | 1.80 | 24.30 | 2334. | .1465E+13 |
| 27 | 82.8 | .05 | .064 | .050 | .042 | .053 | .15 | 12.00 | 473.0 | .1661E+11 |
| 28 | 83.1 | .10 | .080 | .058 | .052 | .066 | .31 | 12.70 | 625.7 | .3945E+11 |
| 29 | 88.0 | .45 | .137 | .076 | .061 | .077 | .46 | 20.70 | 1744. | .7868E+12 |
| 30 | 88.1 | .39 | .148 | .075 | .072 | .092 | 1.07 | 18.70 | 1702. | .5030E+12 |
| 37 | 53.0 | .06 | .070 | .049 | .050 | .063 | .38 | 12.10 | 527.2 | .1750E+11 |
| 38 | 52.3 | .09 | .063 | .054 | .051 | .065 | .36 | 12.50 | 490.3 | .2882E+11 |
| 39 | 58.3 | .23 | .084 | .066 | .064 | .081 | .69 | 14.80 | 772.1 | .1264E+12 |
| 40 | 57.1 | .23 | .081 | .066 | .064 | .081 | .68 | 14.80 | 744.8 | .1256E+12 |
| 46 | 50.4 | .09 | .077 | .054 | .061 | .076 | .74 | 12.50 | 599.8 | .2851E+11 |
| 52 | 44.5 | .05 | .060 | .047 | .049 | .061 | .40 | 12.00 | 450.0 | .1355E+11 |
| 55 | 50.8 | .10 | .076 | .055 | .062 | .078 | .77 | 12.70 | 601.4 | .3330E+11 |
| 56 | 58.1 | .56 | .103 | .072 | .067 | .084 | 1.14 | 25.90 | 1657. | .1647E+13 |
| 57 | 48.4 | .06 | .072 | .049 | .059 | .073 | .75 | 12.10 | 543.4 | .1705E+11 |
| 58 | 57.7 | .37 | .105 | .071 | .073 | .093 | 1.30 | 18.10 | 1181. | .3707E+12 |
| 92 | 58.7 | .09 | .123 | .063 | .069 | .087 | .50 | 7.00 | 534.6 | .5244E+10 |
| 95 | 59.2 | .17 | .130 | .073 | .073 | .092 | .51 | 7.70 | 621.4 | .1322E+11 |
| 96 | 61.2 | .32 | .146 | .081 | .083 | .105 | .86 | 9.40 | 851.4 | .4576E+11 |
| 97 | 60.4 | .34 | .146 | .082 | .083 | .105 | .87 | 9.70 | 878.8 | .5320E+11 |
| 102 | 65.3 | .11 | .087 | .049 | .043 | .055 | .43 | 25.80 | 1390. | .3325E+12 |
| 103 | 70.8 | .20 | .121 | .056 | .053 | .068 | .91 | 28.80 | 2154. | .8652E+12 |
| 105 | 64.9 | .09 | .085 | .047 | .042 | .054 | .44 | 25.30 | 1332. | .2560E+12 |
| 106 | 71.2 | .25 | .129 | .058 | .053 | .067 | .83 | 30.70 | 2447. | .1313E+13 |
| 109 | 63.8 | .14 | .106 | .055 | .049 | .063 | .45 | 19.90 | 1307. | .1926E+12 |
| 112 | 64.2 | .16 | .113 | .057 | .050 | .063 | .43 | 20.40 | 1429. | .2377E+12 |
| 113 | 66.3 | .23 | .132 | .061 | .060 | .076 | .96 | 22.20 | 1814. | .4452E+12 |
| 117 | 52.4 | .06 | .082 | .057 | .064 | .080 | .43 | 6.80 | 347.1 | .3095E+10 |
| 118 | 53.8 | .13 | .094 | .068 | .072 | .091 | .54 | 7.40 | 432.8 | .8710E+10 |
| 121 | 56.3 | .21 | .099 | .075 | .075 | .094 | .55 | 8.10 | 498.4 | .1871E+11 |
| 122 | 53.0 | .18 | .084 | .073 | .070 | .089 | .44 | 7.80 | 407.8 | .1406E+11 |
| 123 | 49.2 | .05 | .068 | .054 | .056 | .070 | .27 | 6.70 | 284.1 | .2423E+10 |

* SVV indicates the dimensionless superficial vapor velocity.

### 6.3 Correlation of Present Data

In a similar fashion to the natural convection correlation procedure employed to analyze the data from Refs. 11 and 12, the <u>average</u> heat transfer data for the present tests were likewise analyzed. The local distribution of boundary heat transfer coefficient, h(x), was integrated to determine the average heat transfer coefficient. The average void fraction was determined as described in Eq. 24. The superficial vapor velocity, $j_{g\infty}$, was determined by converting the flow rate of make-up water into an average vapor flux as

$$j_{g\infty} \simeq \frac{G\rho_{\ell}H_o}{\text{Vol.}\ \rho_v} \tag{35}$$

where G is the make-up flow rate ($cm^3$/sec), $H_o$ is the nonboiling pool depth (cm), and Vol. is the total pool volume ($cm^3$).

In a straight-forward fashion, the average heat transfer correlation was determined as indicated below for laminar bubbly flow,

$$\overline{Nu} = (1.54)\ Ra^*(L,\bar{\alpha},\theta)^{0.25} \qquad Ra^* \leq 1.865 \times 10^{11} \tag{36a}$$

with a standard deviation of $\pm$ 0.08, and for turbulent bubbly flow

$$\overline{Nu} = (0.0314)\ Ra^*(L,\bar{\alpha},\theta)^{0.40} \qquad Ra^* > 1.865 \times 10^{11} \tag{36b}$$

with a standard deviation of $\pm$ 0.0016. These data are available in Table 6, and the two correlations are plotted in Fig. 18. The scatter in the data is seen to be less by a factor of 4-6 than previously observed as can be seen in the standard deviation in the correlation coefficients and the transition from laminar to turbulent behavior is more evident. It was on

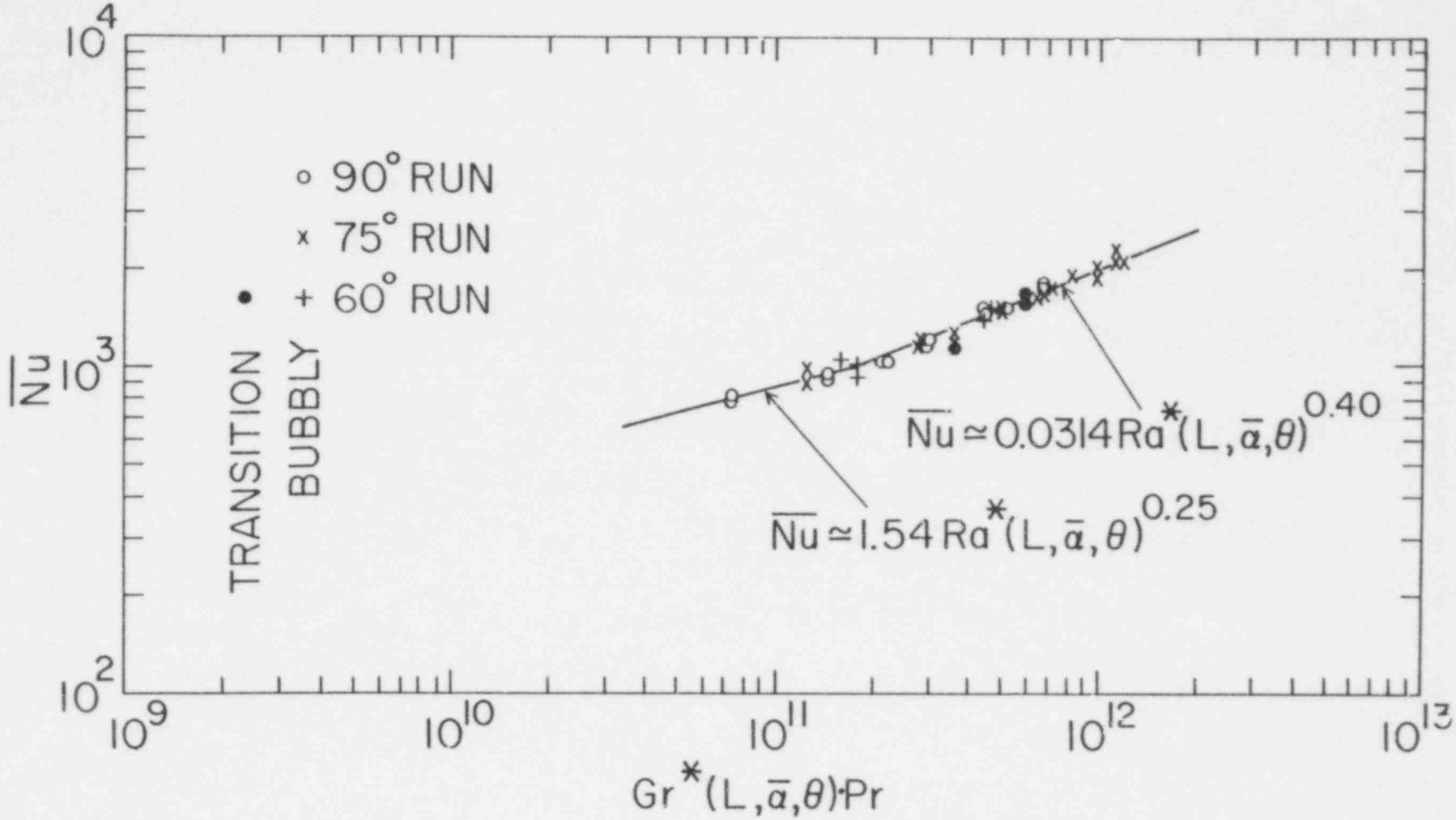


Figure 18 Natural Convection Correlation of Average Heat Transfer Data Based On Current Data. (BNL Neg. No. 4-1305-79).



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TABLE 6

COMPARISON OF MEASURED AND CALCULATED AVERAGE VOID FRACTION
AND HEAT TRANSFER COEFFICIENT FROM VOLUMETRIC BOILING POOL

| RUN | WALL TEMP DEG C | VOID FRACTION EXP | VOID FRACTION CALC | AVERAGE HEAT TRANS COEFF CAL/CM² S DEG C EXP | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | SVV* | DEPTH CM | NUX | RAX | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9001 | 82.3 | .03 | .12 | .054 | .037 | .037 | .047 | .39 | 23.2 | 771.5 | .7225E+11 | |
| 9002 | 83.1 | .03 | .12 | .056 | .037 | .037 | .047 | .39 | 23.2 | 779.9 | .7253E+11 | |
| 9003 | 83.5 | .06 | .05 | .063 | .044 | .038 | .049 | .28 | 23.2 | 899.7 | .1453E+12 | |
| 9004 | 83.8 | .06 | .05 | .064 | .044 | .038 | .049 | .28 | 23.2 | 914.0 | .1455E+12 | |
| 9005 | 84.3 | .09 | .13 | .072 | .049 | .044 | .056 | .41 | 23.2 | 1028. | .2190E+12 | |
| 9006 | 84.2 | .09 | .09 | .072 | .049 | .043 | .054 | .35 | 23.2 | 1028. | .2184E+12 | |
| 9007 | 85.9 | .12 | .06 | .081 | .053 | .044 | .055 | .30 | 23.2 | 1156. | .2940E+12 | |
| 9008 | 86.9 | .12 | .06 | .080 | .053 | .044 | .056 | .30 | 23.2 | 1142. | .2952E+12 | |
| 9009 | 88.3 | .18 | .11 | .104 | .059 | .048 | .062 | .37 | 23.2 | 1484. | .4453E+12 | |
| 9010 | 88.3 | .18 | .17 | .109 | .059 | .050 | .064 | .45 | 23.2 | 1555. | .4453E+12 | |
| 9011 | 89.8 | .27 | .13 | .121 | .065 | .052 | .066 | .38 | 23.2 | 1725. | .6728E+12 | |
| 9012 | 89.8 | .27 | .13 | .128 | .065 | .052 | .066 | .38 | 23.2 | 1825. | .6722E+12 | |
| 9013 | 89.1 | .21 | .15 | .105 | .061 | .051 | .065 | .42 | 23.2 | 1498. | .5212E+12 | |
| 7501 | 84.7 | .11 | .12 | .079 | .051 | .046 | .059 | .46 | 23.8 | 1157. | .2796E+12 | Bubbly |
| 7502 | 85.0 | .11 | .12 | .079 | .051 | .045 | .057 | .40 | 23.8 | 1157. | .2800E+12 | |
| 7503 | 85.7 | .14 | .12 | .086 | .055 | .046 | .059 | .39 | 23.8 | 1259. | .3574E+12 | |
| 7504 | 85.5 | .14 | .11 | .081 | .055 | .046 | .059 | .38 | 23.8 | 1186. | .3571E+12 | |
| 7505 | 88.5 | .20 | .25 | .106 | .060 | .052 | .066 | .54 | 23.8 | 1551. | .5167E+12 | |
| 7506 | 88.4 | .20 | .25 | .104 | .060 | .052 | .066 | .54 | 23.8 | 1522. | .5160E+12 | |
| 7507 | 89.8 | .26 | .18 | .115 | .064 | .053 | .067 | .46 | 23.8 | 1682. | .6760E+12 | |
| 7508 | 89.4 | .26 | .18 | .112 | .064 | .053 | .067 | .46 | 23.8 | 1639. | .6748E+12 | |
| 7509 | 90.8 | .32 | .34 | .121 | .068 | .057 | .073 | .59 | 23.8 | 1770. | .8357E+12 | |
| 7510 | 91.1 | .32 | .23 | .131 | .068 | .056 | .071 | .51 | 23.8 | 1916. | .8369E+12 | |
| 7511 | 91.7 | .38 | .40 | .136 | .071 | .059 | .076 | .62 | 23.8 | 1989. | .9965E+12 | |
| 7512 | 91.5 | .38 | .45 | .131 | .071 | .060 | .076 | .65 | 23.8 | 1916. | .9956E+12 | |
| 7513 | 92.3 | .45 | .39 | .148 | .074 | .061 | .077 | .61 | 23.8 | 2164. | .1183E+13 | |
| 7514 | 93.2 | .52 | .54 | .168 | .078 | .066 | .084 | .74 | 22.3 | 2301. | .1129E+13 | |
| 7515 | 92.7 | .52 | .59 | .159 | .078 | .067 | .085 | .81 | 22.3 | 2178. | .1127E+13 | |
| 7516 | 93.4 | .41 | .34 | .162 | .078 | .079 | .101 | 1.41 | 17.7 | 1761. | .4442E+12 | |
| 7517 | 93.1 | .41 | .34 | .141 | .078 | .079 | .101 | 1.43 | 17.7 | 1533. | .4436E+12 | |
| 7518 | 94.5 | .34 | .40 | .143 | .074 | .081 | .104 | 1.79 | 17.7 | 1554. | .3705E+12 | Churn-Turbulent |
| 7519 | 94.[illegible] | .34 | .40 | .136 | .074 | .082 | .105 | 1.82 | 17.7 | 1478. | .3699E+12 | |
| 7520 | 82.9 | .06 | .12 | .064 | .045 | .042 | .053 | .40 | 23.2 | 878.7 | .1243E+12 | Bubbly |
| 7521 | 82.3 | .06 | .12 | .072 | .045 | .042 | .053 | .40 | 23.2 | 988.7 | .1239E+12 | |
| 7522** | | .34 | .31 | | | | | 1.18 | | | | |
| 7523** | | .39 | .36 | | | | | 1.52 | | | | Churn-Turbulent |
| 7524** | | .37 | .36 | | | | | 1.50 | | | | |
| 6001 | 83.4 | .07 | .15 | .067 | .045 | .041 | .052 | .43 | 24.8 | 1023. | .1787E+12 | |
| 6002 | 88.4 | .17 | .19 | .103 | .057 | .048 | .061 | .48 | 24.8 | 1571. | .4445E+12 | |
| 6003 | 83.4 | .07 | .15 | .060 | .045 | .041 | .052 | .43 | 24.8 | 916.1 | .1788E+12 | |
| 6004 | 87.5 | .17 | .19 | .094 | .057 | .048 | .061 | .48 | 24.8 | 1434. | .4423E+12 | Bubbly |
| 6005 | 86.2 | .10 | .12 | .086 | .051 | .044 | .056 | .40 | 22.3 | 1180. | .1180E+12 | |
| 6006 | 87.0 | .10 | .11 | .083 | .052 | .045 | .058 | .40 | 21.0 | 1072. | .1577E+12 | |
| 6007 | 90.5 | .23 | .21 | .123 | .064 | .054 | .069 | .50 | 21.0 | 1588. | .3678E+12 | |
| 6008 | 90.7 | .23 | .23 | .130 | .064 | .054 | .069 | .51 | 21.0 | 1678. | .3681E+12 | |
| 6009 | 91.4 | .37 | .25(.65) | .130 | .072 | .065 | .084 | .92 | 21.0 | 1678. | .5946E+12 | |
| 6010 | 91.9 | .37 | .26(.66) | .122 | .072 | .066 | .084 | .96 | 21.0 | 1574. | .5944E+12 | Transition |
| 6011 | 90.7 | .45 | .22(.60) | .115 | .080 | .071 | .091 | .83 | 16.6 | 1173. | .3599E+12 | |
| 6012 | 92.2 | .38 | .38 | .153 | .079 | .084 | .108 | 1.64 | 15.1 | 1420. | .2278E+12 | |
| 6013** | | .37 | .38 | | | | | 1.46 | | | | Churn-Turbulent |
| 6014** | | .49 | .22(.59) | | | | | .82 | | | | |
| 6015** | | .49 | .26(.67) | | | | | .99 | | | | Transition |
| 6016** | | .39 | .29 | | | | | 1.11 | | | | |
| 6017** | | .34 | .31 | | | | | 1.26 | | | | Churn-Turbulent |

* SVV indicates the dimensionless superficial vapor velocity.

** No heat transfer data were recorded for these runs.



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the basis of these observations that the laminar-turbulent correlation of the data in Fig. 17 was analyzed. Although there have been no boundary layer measurements to substantiate the claim of turbulent boundary layer transition, the assignment of the laminar exponent (i.e., 0.25) and the turbulent exponent (i.e., 0.40) to the data correlation, similar to a single-phase natural convection, was done on the justification of observation of the marked change in the behavior of the data in the vicinity of $Ra^* \sim 1\text{-}2 \times 10^{11}$. This observation was made possible due to the elimination of the majority of the scatter in the data which was present in previous work. This is demonstrated by the relative scatter in the correlation coefficient which is 5 percent for both the laminar and turbulent cases. This is in sharp contrast to the 28 percent and 21 percent standard deviation in the correlations of the data of Gustavson[12] and Gabor[11] presented here, respectively.

The data in the transition region between bubbly and churn-turbulent flow exhibited more scatter than the bubbly flow data. However, correlation of this data behaved similar to the turbulent bubbly flow data as indicated in Fig. 18.

The churn-turbulent regime data, however, deviated sharply from the above observed behavior. For the same Rayleigh number, the churn-turbulent data was observed to lie significantly above the correlation for bubbly flow. There is insufficient data at this point to make any quantitative statements to correlate the data to particular model assumptions. However, the magnitude of the temporal fluctuations in the wall temperature, as well as the significantly higher boundary heat transfer coefficient were interpreted to indicate that the multi-dimensional hydrodynamic nature of the boiling pool was interfering with the formation of the wall boundary layer, if not destroying it.

The correlations derived from the data of Gustavson, et al.[12] and Gabor, et al.[11], as well as the present data, are summarized in Table 7. The local correlations of the data of Gustavson, et al.[12] indicated little sensitivity to the use of either the average or local void fraction. The ratio of the local and average correlation coefficients supported the use of the average void fraction in the correlation of the local heat transfer data. The correlations of the data of Gabor, et al.[11] and of the present work have been performed on an average basis only. Examination of the correlations derived revealed that the data agreed within the standard deviation of Gabor's data.[11] However, both exceeded the correlation of Gustavson's data[12] by a factor of approximately 1.5. This is in agreement with observations that the local heat transfer data exceeded the calculations of the previous existing models[12,15] derived from the data of Ref. 12 by a wide margin. The local heat transfer data of this work will be analyzed on a local basis in the future.

## 7. SUMMARY AND CONCLUSIONS

### 7.1 Bubbly Flow Regime

For volume-heated boiling pools characteristic of the kind investigated here and in the bubbly flow regime, the following conclusions can be made:

#### 7.1.1 Hydrodynamics

(1) The bubbly flow regime persisted for a value of $j_{g\infty}/U_\infty$

TABLE 7

SUMMARY OF LOCAL AND AVERAGE CORRELATIONS FOR HEAT TRANSFER FROM VOLUME BOILING POOLS

| AUTHOR | WALL ANGLE | LOCAL OR AVERAGE HEAT TRANSFER | LAMINAR OR TURBULENT | CORRELATION | STANDARD DEVIATION | RANGE OF RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| Gustavson, et al.[12] | Vertical | Local | Laminar | $Nu(x) = .78\ Ra^{*}(x,\bar{\alpha})^{0.25}$ | $\pm .35$ | $Ra^{*} < 10^{12}$ |
| | | Local | Laminar | $Nu(x) = .76\ Ra^{*}(x,\alpha)^{0.25}$ | $\pm .56$ | $Ra^{*} < 10^{12}$ |
| | | Average | Laminar | $\overline{Nu} = 1.07\ Ra^{*}(L,\bar{\alpha})^{0.25}$ | $\pm .30$ | $Ra^{*} < 2 \times 10^{12}$ |
| Gabor, et al.[11] | Vertical | Average | Laminar | $\overline{Nu} = 1.58\ Ra^{*}(L,\bar{\alpha})^{0.25}$ | $\pm .33$ | $Ra^{*} < 2 \times 10^{12}$ |
| | | Average | Laminar | $\overline{Nu} = 1.42\ Ra^{*}(L,\bar{\alpha})^{0.25}$ | $\pm .25$ | $Ra^{*} < 10^{11}$ |
| | | Average | Turbulent | $\overline{Nu} = .0309\ Ra^{*}(L,\bar{\alpha})^{0.}$[illegible] | $\pm .0058$ | $Ra^{*} > 10^{11}$ |
| Present Work | $90^{o}$, $75^{o}$ $60^{o}$ | Average | Laminar | $\overline{Nu} = 1.54\ Ra^{*}(L,\bar{\alpha},\theta)^{0.25}$ | $\pm .08$ | $Ra^{*} < 1.865 \times 10^{11}$ |
| | | Average | Turbulent | $\overline{Nu} = .0314\ Ra^{*}(L,\bar{\alpha},\theta)^{0.40}$ | $\pm .0016$ | $Ra^{*} > 1.865 \times 10^{11}$ |



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up to unity. In this flow regime, the pool underwent periodic swelling possibly due to subcooling from the returning cold boundary layer fluid into the pool bottom. The pool exhibited a stratified state with a boiling region over an essentially nonboiling single phase region below. The depth of the nonboiling region decreased as the volumetric vaporization source increased such that the nonboiling region was confined to the conditions where $j_{g\infty}/U_{\infty} < 0.2$.

(2) The maximum average void fraction observed in the bubbly flow regime was in the range 0.55 to 0.60 at $j_{g\infty}/U_{\infty}$ approximately unity. In this range of power, transition to a churn-turbulent flow regime was observed in which boiling penetrated to the pool bottom, and a sudden collapse in average pool void fraction was observed from approximately 0.55-0.60 to 0.40. While it might be coincidental, the upper limit in bubbly flow corresponds approximately with the packing density of spheres at $j_{g\infty}/U_{\infty} \sim 1$.

(3) In the bubbly flow regime, it was observed that surface evaporative losses were non-negligible for pool geometry utilized herein having a large surface-to-volume ratio, and that a significant fraction of the volumetric power density went into these losses. The net boiling power was defined as the total vaporization power minus the evaporative losses. It was found

that calculation of the pool-average void fraction by means of a one-dimensional drift flux model based on the net boiling power agreed well with the experimental data independent of the wall angle. Agreement between calculated and measured average void fraction improved for increasing power.

(4) The average void fraction in the bubbly flow regime was found to be very sensitive to the volumetric boiling power. Small changes in $j_{g\infty}/U_\infty$ were observed to cause large variations in the pool-average void fraction.

7.1.2 Heat Transfer

(1) Boundary heat transfer from volume-boiling pools in the bubbly flow regime behaved similar to natural convection-type boundary layer heat transfer. The spatial variation in the local heat transfer coefficient was as great as a factor of 3-5 along the wall, with the greatest heat transfer at or near the pool surface. The data reported here for local convective heat transfer coefficient exceeded those previously reported by Gustavson, et al.[12] by a factor of 2 or more but agreed with the earlier average pool data of Gabor, et al.[11] within the scatter in their data.

(2) For boundary layer-type heat transfer from volume-boiling pools in the bubbly flow regime, the effect of small angle



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of inclination of the boundary from vertical was modeled by defining an effective gravitational component along the wall as indicated below;

$$g_{eff} = g \cos\theta \quad (37)$$

where $\theta$ is the angle of inclination from the vertical. For the data described herein with inclinations up to $30^{o}$, this correlation proved adequate.

(3) Correlation of average heat transfer based on the average void fraction indicates laminar flow behavior up to Rayleigh number of $1.865 \times 10^{11}$. The correlation is of the approximate form

$$\overline{Nu} \doteq 1.54\ \overline{Ra}^{*}(L,\overline{\alpha},\theta)^{0.25} \text{ for } Ra^{*} < 1.865 \times 10^{11} \quad (38a)$$

For higher Rayleigh number, the data behaves similar to turbulent natural convection and the correlation for the range $Ra > 1.865 \times 10^{11}$ is

$$\overline{Nu} \doteq 0.0314\ \overline{Ra}^{*}(L,\overline{\alpha},\theta)^{0.40} \text{ for } Ra^{*} > 1.865 \times 10^{11} \quad (38b)$$

The consistency of the data presented herein represents a significant improvement over previously reported data of Gabor, et al.[11] and Gustavson, et al.[12]. The standard deviation in both cases was found to be 5 percent in marked contrast to the previous data having standard deviations of 21 to 28 percent.

## 7.2 Churn-Turbulent Flow Regime

For volume-heated boiling pools characteristic of the kind investigated here and in the churn-turbulent flow regime, the following conclusions can be made:

### 7.2.1 Hydrodynamics

(1) Flow regime transition from bubbly flow to churn-turbulent flow was observed to occur in the vicinity of $j_{g\infty}/U_{\infty}$ equal to one. Flow regime transition was accompanied by a marked collapse in the pool average void fraction from 0.55-0.60 to 0.40, similar to the bubble column observations in adiabatic flow as observed by Zuber and Hench and others.[19,21]

(2) The pool hydrodynamics appeared not to behave in a one-dimensional fashion any longer. Three-dimensional circulations appeared to dominate and caused large-scale bubble agglomeration, responsible for the lower void fraction even at higher vapor generation rates than in bubbly flow. Periodic swelling behavior of the pool ended.

(3) The liquid-continuous nature of the bubbly flow regime began to break down due to the three-dimensional nature of the flow and appearance of large vapor pockets in the flow. This behavior was indicated by fluctuations recorded in the power trace of the pool.

(4) Surface evaporative losses were found to be less significant for this regime than for bubbly flow. The void fraction appeared to be somewhat insensitive to increases in pool power in the range $1.0 < j_{g\infty}/U_\infty < 2.0$. The average void fraction in this range was measured to be approximately 0.40. The measured and calculated average void fraction data agreed well for the range of superficial velocity investigated.

7.2.2 Heat Transfer

(1) The average heat transfer coefficient was approximately 0.15 cal/cm$^2$s$^o$C. Large fluctuations were observed in the standard deviation of the local wall temperature fluctuations. In some instances, the fluctuations were of the same magnitude as the difference between the pool temperature and the time-averaged wall temperature, indicating partial or complete local destruction and renewal of the wall boundary layer. It is this mechanism that is believed responsible for the increased boundary heat transfer coefficient.

(2) The profile of local heat transfer coefficient was more uniformly distributed along the wall, exhibiting large fluctuations spatially. The maximum local heat transfer coefficient was observed to be in the range 0.25-0.30 cal/cm$^2$s$^o$C.

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## 9. REFERENCES


1. Essam, P., "Free Convection of Heat Generating Fluids in Cylindrical Tanks," Nuclear Engineering and Design, 11, 57-68 (1969).

2. Murgatroyd, W. and Watson, A., "An Experimental Investigation of Natural Convection of a Heat Generating Fluid Within a Closed Vertical Cylinder," J. Mech. Engr. Sci., 12 (5), 345-363 (1970).

3. Kulacki, F. A. and Goldstein, R. J., "Thermal Convection in a Horizontal Fluid Layer With Uniform Volumetric Energy Sources," J. Fluid Mechanics, 55, Part 2, 271-287 (1972).

4. Kulacki, F. A. and Nagle, M. E., "Natural Convection in a Horizontal Layer with Volumetric Energy Sources," J. Heat Transfer, 204-211 (May 1975).

5. Suo-Antilla, A. J. and Catton, I., "An Experimental Study of a Horizontal Layer of Fluid With Volumetric Heating and Unequal Surface Temperatures," Paper No. AIChE 6, 10th National Heat Transfer Conference, St. Louis (August 1976).

6. Novotny, J. L. and Eckert, E.R.G., "Experimental Study of Laminar Convection in the Channel Between Parallel Plates With Uniform Heat Sources in the Fluid," Int. J. Heat Mass Transfer, 7, 955-968 (1964).

7. Jahn, M. and Reineke, H. M., "Free Convection Heat Transfer With Internal Heat Source Calculations and Measurements," 5th International Heat Transfer Conference, Tokyo (1974).

8. Hesson, J. C. and Gunther, W. H., "Heat Transfer from Boiling Pools With Internal Heat Generation," Trans. Amer. Nucl. Soc., 15, 864-865 (1972).

9. Stein, R. P., Hesson, J. C., and Gunther, W. H., "Studies of Heat Removal From Heat Generating Boiling Pools," ANS Fast Reactor Safety Conference, CONF-740401, pp 865-880 (April 1974).

10. Gabor, J. D., et al., "Heat Removal from Heat Generating Pools," Trans. Amer. Nucl. Soc., 19, 257 (1974).

11. Gabor, J. D., Baker, L., Jr., Cassulo, J. C., and Mansoori, G. A., "Heat Transfer from Heat Generating Boiling Pools," ASME-AIChE National Heat Transfer Conference, St. Louis, MO, pp 78-80 (1976).

12. Gustavson, W. R., Chen, J. C., and Kazimi, M. S., "Heat Transfer and Fluid Dynamic Characteristics of Internally Heated Boiling Pools," BNL-NUREG-50759 (September 1977).

13. Fujii, T. and Imura, H., "Natural Convection Heat Transfer From a Plate With Arbitrary Inclination," Int. J. Heat Mass Transfer, 15, 755-767 (1972).

14. Churchill, S. W. and Usagi, R., "A General Expression for the Correlation of Rates of Transfer and Other Phenomena," AIChE, 18(6), pp. 1121-1128 (1972).

15. Greene, G. A., Jones, O. C., Jr., and Schwarz, C. E., "Thermo-Fluid Mechanics of Volume-Heated Boiling Pools," Third PAHR Information Exchange, Argonne National Laboratory, ANL-78-10, BNL-NUREG-50759, (November 1977).

16. Zuber, N. and Findlay, J. A., "Average Volumetric Concentration in Two-Phase Flow Systems," J. Heat Transfer, pp. 453-468 (November 1965).

17. Randall, I. E. and Sesonske, A., "Effect of a Volume-Heat Source on Free Convection Heat Transfer," AIChE, 5(2), pp. 150-154 (June 1959).

18. Ginsberg, T., Jones, O. C., Jr., Schwarz, C. E., and Chen, J. C., "Observations of Flow Characteristics of Volume Heated Boiling Pools," BNL-NUREG-24270 (December 1977).

19. Zuber, N. and Hench, J., "Steady-State and Transient Void Fraction of Bubbling Systems and Their Operating Limits," Part I: Steady-State Operation, General Electric Report 62GL100 (July 1962).

20. Wallis, G. B., <u>One-Dimensional Two-Phase Flow</u>, McGraw Hill Book Co., Inc., New York (1969).

21. Jones, O. C., Jr., "Statistical Considerations in Heterogeneous, Two-Phase Flowing Systems," Ph.D. Thesis, Rensselaer Polytechnic Institute, Troy, New York (1973).

22. Harmathy, T. Z., "Velocity of Large Drops and Bubbles in Media of Infinite or Restricted Extent," AIChE, 6, 281-288 (1960).

23. Sparrow, E. M. and Gregg, J. L., "Similar Solutions for Free Convection from a Nonisothermal Vertical Plate," Trans. ASME, 80, p. 379 (1958).

24. Kays, W. M., <u>Convective Heat and Mass Transfer</u>, McGraw-Hill Book Co., p. 207 (1966).

25. Rich, B. R., "An Investigation of Heat Transfer From an Inclined Flat Plate in Free Convection," Trans. ASME, 75, 489-499 (May 1953).

26. Eckert, E.R.G. and Jackson, T. W., "Analysis of Turbulent Free-Convection Boundary Layer on Flat Plate," Lewis Flight Propulsion Laboratory, Report 1015 (1950).

## APPENDIX A

Error Analysis:

1) Uncertainty in Heat Transfer Coefficient, h(x):

It was shown that the heat transfer coefficient is represented by the relation

$$h(x) = \frac{k_{BN}(T_{front}(x) - T_{back}(x))}{a \cdot (T_{pool} - T_{front}(x))} \quad (23)$$

The total uncertainty in h(x) may be computed by taking the total differential of Eq. 23 as follows:

$$dh = \frac{\partial h}{\partial k_{BN}} dk_{BN} + \frac{\partial h}{\partial \Delta T_{fb}} d\Delta T_{fb} + \frac{\partial h}{\partial a} da + \frac{\partial h}{\partial \Delta T_{pf}} d\Delta T_{pf} \quad \text{(A-1)}$$

where

$$\Delta T_{fb} \equiv T_{front}(x) - T_{back}(x) \quad \text{(A-2)}$$

and

$$\Delta T_{pf} \equiv T_{pool} - T_{front}(x) \quad \text{(A-3)}$$

The most probable mean square error, $\varepsilon_h^2$, is written as

$$\varepsilon_h^2 = \left(\frac{dh}{h}\right)^2 \quad \text{(A-4)}$$

and this reduces to

$$\varepsilon_h = \left[\varepsilon_{k_{BN}}^2 + \varepsilon_{\Delta T_{fb}}^2 + \varepsilon_a^2 + \varepsilon_{\Delta T_{pf}}^2\right]^{1/2} \quad \text{(A-5)}$$

The magnitude of each quantity in Eq. A-5 and its uncertainty are listed below:

| QUANTITY | MAGNITUDE | UNCERTAINTY |
|---|---|---|
| $k_{BN}$ | 0.041 cal/cm s $^{o}C$ | 0.001 |
| $T_{fb}$ | 20 $^{o}C$ * | 0.2 |
| $T_{pf}$ | 20 $^{o}C$ * | 0.2 |
| a | 1.27 cm | 0.002 |

*Nominal Value

The result is that the most probable uncertainty in h(x) is approximately $\pm$ 3 percent.

3) Uncertainty in Average Void Fraction, $\overline{\alpha}$:

The average void fraction may be written as

$$\overline{\alpha} = (H_B - H_o)/H_B \tag{24}$$

This mav be written in differential form as shown before to represent the mean square error in the average void fraction as

$$\varepsilon_{\overline{\alpha}} = \left[\left(\frac{H_o}{H_B(H_B - H_o)}\, dH_B\right)^2 + \left(\frac{1}{H_B - H_o}\, dH_o\right)^2\right]^{1/2} \tag{A-6}$$

where $dH_B \sim 0.5$ and $dH_o \sim 0.1$ cm. One can readily see that for small $\overline{\alpha}$ (i.e., $(H_B - H_o)$ small), the fractional error will be large and approaching $\infty$ as $(H_B - H_o) \rightarrow 0$.



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For $H_o$ = 20. cm and $H_B$ = 30. cm, the result is the most probable error in $\bar{\alpha}$ was approximately 3 percent. For $H_o$ = 25. cm and $H_B$ = 30. cm, the error was found to be approximately 8 percent. The value 3 percent is being used for the remaining calculations.

3) Uncertainty in Boundary Layer Coord·.ate, x

The coordinate from the free surface along the boundary layer, x, may be shown to be represented by

$$x_i = HBOIL/\cos\theta - HONE + (i - 1)EPSI \qquad \text{(A-7)}$$

in centimeters where HBOIL is the boiling depth measured from the pool bottom to the boiling free surface, HONE is the distance along the test wall from the base to the first thermocouple, and EPSI is the spacing along the test plate between thermocouples. The errors are independent and the incremental part, (i - 1) (EPSI), does not accumulate as may be expected. The reason for this is that each thermocouple location was sited with respect to the same reference point and not with respect to the previous thermocouple along the plate. In this fashion, the positional uncertainty was not accumulative.

In a similar fashion to A-2, the linearly independent uncertainties in x may be shown to be

$$\varepsilon_x = [\varepsilon_{HBOIL}^2 + \varepsilon_{HONE}^2 + \varepsilon_{EPSI}^2]^{1/2} \qquad \text{(A-8)}$$

The ..gnitude of each quantity in Eq. A-7 and its uncertainty are listed below:



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| QUANTITY | MAGNITUDE(cm) | UNCERTAINTY |
|---|---|---|
| HBOIL | 30.0 * | .5 |
| HONE | 31.4 | .2 |
| EPSI | 1.27 | .05 |

*Nominal Value

The result is that the most probable uncertainty in x is approximately 5 percent.

4) Uncertainty in Nu(x):

The Nusselt number is written as

$$Nu(x) = \frac{h(x)x}{k_f} \qquad \text{(A-9)}$$

where the uncertainty in $k_f$ is negligible. Similar to A-1 and A-2, it may be shown that the most probable error in Nu(x) is

$$\varepsilon_{Nu} = [\varepsilon_h^2 + \varepsilon_x^2]^{1/2} \qquad \text{(A-10)}$$

From the previous sections, it is clear that the most probable error in Nu(x) is 6 percent.

5) Uncertainty in $Ra^*(x)$:

The Rayleigh number may be shown to be represented as

$$Ra^*(x) = \frac{g\bar{\alpha}x^3 \cos\theta \, Pr}{\nu_f^2} \quad \text{(A-11)}$$

The uncertainty is $\bar{\alpha}$ has been shown previously to be approximately 3 percent. The uncertainties in g, cos θ, Pr, and $\nu_f$ are negligible. This then reduces to

$$\varepsilon_{Ra^*} = \left[\varepsilon_{\bar{\alpha}}^2 + 9\varepsilon_x^2\right]^{1/2} \quad \text{(A-12)}$$

From previously computed results, the most probable error in Ra(x) is shown to be 15 percent.

6) Uncertainty in Laminar Correlation Coefficient, K:

For laminar bubbly flow, the correlation coefficient may be shown to be

$$K = Nu/Ra^{*1/4} \quad \text{(A-13)}$$

It is readily shown that the most probable error in K is

$$\varepsilon_K = \left[\varepsilon_{Nu}^2 + \frac{1}{16}\,\varepsilon_{Ra^*}^2\right]^{1/2} \quad \text{(A-14)}$$

The result is that for laminar bubbly flow, the most probable error in the correlation coefficient is expected to be 7 percent. Recall that the standard deviation in the correlation coefficient was computed to be 5 percent, further substantiating this result.

7) Uncertainty in Turbulent Correlation Coefficient, K:

For turbulent bubbly flow, the correlation coefficient may be shown to be

$$K = Nu/Ra^{*0.4} \tag{A-15}$$

It may be readily shown that the most probable error in K is

$$\varepsilon_K = \left[\varepsilon_{Nu}^2 + (.4)^2\ \varepsilon_{Ra^*}^2\right]^{1/2} \tag{A-16}$$

The result is that for turbulent bubbly flow, the most probable error in the correlation coefficient is expected to be 8 percent. Recall that the standard deviation in the correlation coefficient was computed to be 5 percent, further substantiating this result.

All the quantities and their calculated probable errors are tabulated in Table A-1.



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TABLE A-1

SUMMARY OF EXPERIMENTAL UNCERTAINTIES

| QUANTITY | FRACTIONAL UNCERTAINTY |
|---|---|
| Heat Transfer Coefficient | 3 % |
| Boundary-Layer Coordinate | 5 % |
| Average Void Fraction | 3-8 % |
| Nusselt Number | 6 % |
| Rayleigh Number | 15 % |
| Laminar Correlation Coefficient | 7 % |
| Turbulent Correlation Coefficient | 8 % |



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APPENDIX B

Sample Calculation (Run 9001)

For each experimental run, 27 thermocouple readings are shown in Appendix A corresponding the the 27 local heat transfer measurements. The locations of all the test plate thermocouples are listed in Table 2. Let $TC_i$, $TF_i$, $TB_i$ and $T_{POOL}$ represent the actual thermocouple output, test plate front surface temperature, test plate coolant-side surface temperature, and pool temperature, respectively. Then the values $TC_i$ (i = 1-27) are mapped as follows:

$$TF_i = TC_i \qquad i = 1,19 \text{ on } 1.27 \text{ cm centers} \tag{B-1}$$

$$TB_i = TC_{i+19} \qquad i = 1,7 \text{ on } 3.81 \text{ cm centers} \tag{B-2}$$

$$T_{POOL} = TC_{27} \tag{B-3}$$

The test plate coolant-side has only seven thermocouples; the temperature distribution is filled out to 19 values by linearly interpolating two values between each pair of back-side thermocouples as follows.

An array TBFUL is defined and equivalent to TB by the assignment indicated below:

$$TBFUL_i = TB_j \tag{B-4}$$

for i = 1,4,˜,10,13,16,19  j = 7,6,5,4,3,2,1. Next, TBFUL (2,3,...17,18) are linearly in rpolated between the measured values TBFUL (1,4,7,10,13,16, 19). This fills out the front and coolant side temperature distributions to 19 points each. For i = 1, the data point is at the test plate top nearest to the free surface; for i = 19, the data point is at the test plate bottom furthest from the free surface.



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The following quantities are required for the actual calculation of the heat transfer data:

HBOIL is the boiling pool depth (cm) measured from the pool bottom.

$\theta$ is the wall angle inclination from vertical.

$k_{wall}$ is the boron nitride (BN) test plate thermal conductivity (= 0.041 cal/cm s $^{o}$C).

a is the BN thickness (= 1.27 cm).

$T_f$ is the average film temperature for calculating boundary layer properties $(=(\overline{T}_{front} + T_{pool})/2)$ where $\overline{T}_{front} = \frac{\sum_1^{19} TF_i}{19}$.

$\overline{\alpha}$ is the average void fraction (= $(H_B - H_o)/H_B$).

Pr is the Prandtl number evaluated at $T_f$ (= 1.94 for Run 9001).

$k_f$ is the film thermal conductivity evaluated at $T_f$ (= .00162 cal/cm s $^{o}$ C) for Run 9001.

$\nu_f$ is the film kinematic viscosity evaluated at $T_f$ (= .3124 cs for Run 9001).

$T_{film}$ = 91.7 $^{o}$C for Run 9001.

The local coordinate, $x_i$, local heat transfer coefficient, $h_i$, local Nusselt number, $Nu_i$, and the local Rayleigh number, $Ra_i$ are calculated according to the following formulae:

$$x_i = HBOIL/\cos\theta - 31.4 + (i - 1)\ 1.27 \qquad \text{(B-5)}$$

$$h_i = \frac{(TF_i - TBFUL_i)\ k_{wall}}{a \cdot (T_{pool} - TF_i)} \qquad \text{(B-6)}$$

$$Nu_i = h_i x_i / k_f \qquad \text{(B-7)}$$

$$Ra_i = g\bar{\alpha} x_i^3 \cos\theta \; Pr/\nu_f^2 \qquad \text{(B-8)}$$

for i = 1,19 where g is the gravitational acceleration coefficient.

The procedure is identical for all the runs; $\bar{\alpha}$, HBOIL, and $T_f$ may be different for each run.

EXAMPLE: RUN 9001, i = 1 (top most heat transfer channel, nearest pool surface).

$$HBOIL = 33.0 \text{ cm}$$

$$\cos\theta = 1.0$$

$$x_1 = 33.0 - 31.4 = 1.60 \text{ cm}$$

$$h_1 = \frac{(89.8 - 59.5).041}{1.27(101.1 - 89.8)} = .0866 \text{ cal/cm s}^{o}\text{C}$$

$$Nu_1 = (.0866)(1.60)/(.00162) = 85.4$$

$$Ra_1 = (980.)(.03)(1.60)^3(1.94)/(.003124)^2 = .2394 \times 10^8$$

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# APPENDIX C

In this appendix are listed the local heat transfer data for all the experiments performed. They are compiled in numerical order with the vertical wall ($90^\circ$) data first, the $75^\circ$ data second, and the $60^\circ$ data last. The flow regime for each run is listed in Table 6. The detailed thermocouple readings are indicated in the figures, and their locations on the test plate are tabulated in Table 2.

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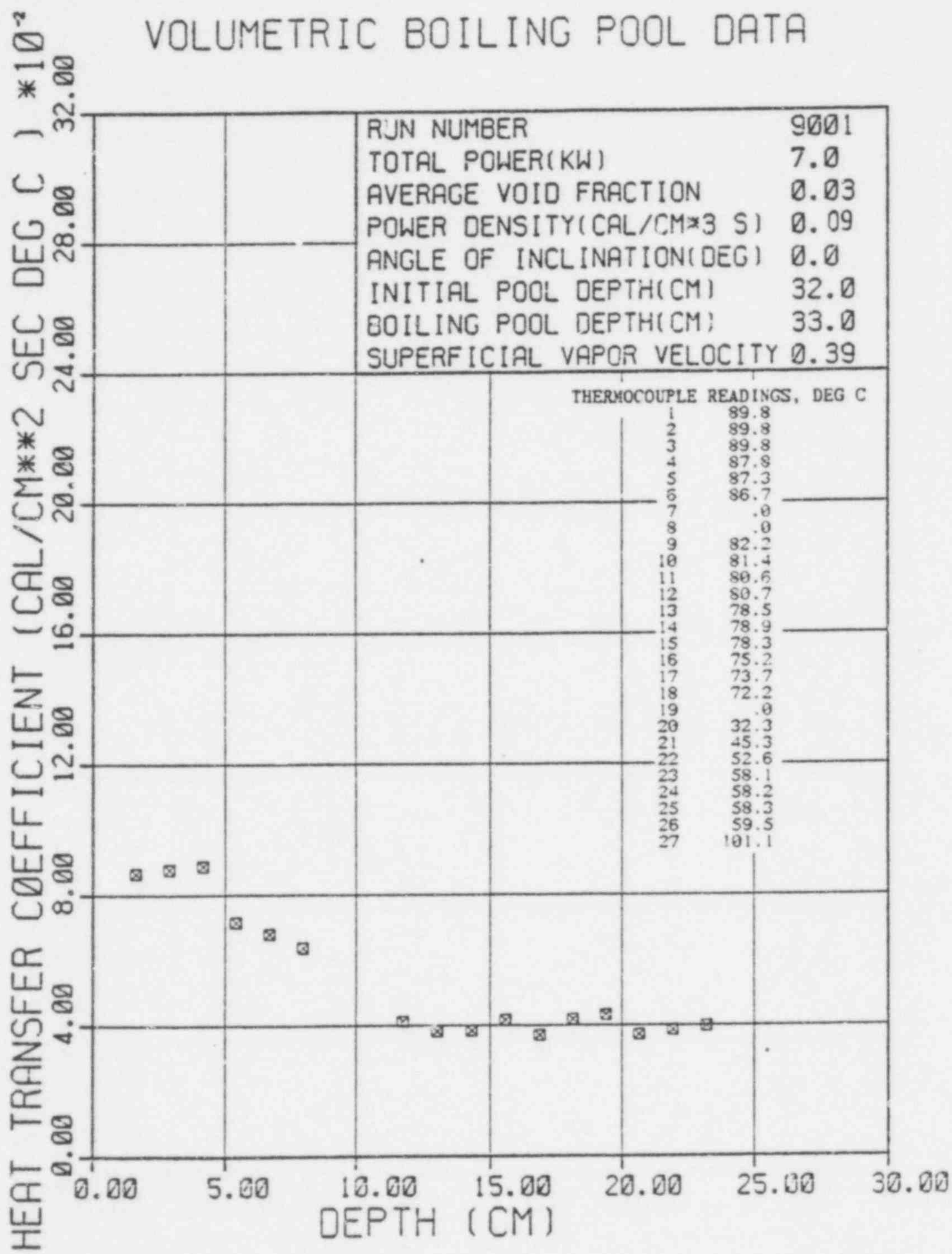
RUN NUMBER... 9001

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .03 |
| INITIAL POOL DEPTH(CM)........ | 32.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .09 |
| SUPERFICIAL VAPOR VELOCITY.... | .39 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)............ | 19238. |
| PRANDTL NUMBER................ | 1.94 |
| TOTAL POWER(KW)............... | 7.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 82.3 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.600 | .0866 | .0546 | .0584 | .0786 | 85.3 | .2394E+08 |
| 2.870 | .0877 | .0472 | .0471 | .0633 | 155.0 | .1382E+09 |
| 4.140 | .0889 | .0430 | .0413 | .0554 | 226.5 | .4147E+09 |
| 5.410 | .0716 | .0402 | .0375 | .0503 | 238.5 | .9254E+09 |
| 6.680 | .0679 | .0382 | .0348 | .0466 | 279.4 | .1742E+10 |
| 7.950 | .0638 | .0366 | .0328 | .0438 | 312.4 | .2936E+10 |
| 9.220 | | .0352 | .0311 | .0416 | | |
| 10.49 | | .0341 | .0298 | .0397 | | |
| 11.76 | .0411 | .0331 | .0286 | .0382 | 297.7 | .9505E+10 |
| 13.03 | .0382 | .0323 | .0277 | .0368 | 306.4 | .1293E+11 |
| 14.30 | .0383 | .0316 | .0268 | .0356 | 337.4 | .1709E+11 |
| 15.57 | .0416 | .0309 | .0260 | .0346 | 398.5 | .2206E+11 |
| 16.84 | .0370 | .0303 | .0254 | .0337 | 383.7 | .2791E+11 |
| 18.11 | .0418 | .0298 | .0247 | .0328 | 466.0 | .3471E+11 |
| 19.38 | .0433 | .0293 | .0242 | .0321 | 516.5 | .4254E+11 |
| 20.65 | .0373 | .0288 | .0237 | .0314 | 473.9 | .5146E+11 |
| 21.92 | .0386 | .0284 | .0232 | .0307 | 520.6 | .6155E+11 |
| 23.19 | .0397 | .0280 | .0228 | .0301 | 567.4 | .7288E+11 |
| 24.46 | | .0276 | .0224 | .0296 | | |



494 126


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 9001
TOTAL POWER(KW) 7.0
AVERAGE VOID FRACTION 0.03
POWER DENSITY(CAL/CM*3 S) 0.09
ANGLE OF INCLINATION(DEG) 0.0
INITIAL POOL DEPTH(CM) 32.0
BOILING POOL DEPTH(CM) 33.0
SUPERFICIAL VAPOR VELOCITY 0.39
THERMOCOUPLE READINGS, DEG C
1 89.8
2 89.8
3 89.8
4 87.8
5 87.3
6 86.7
7 .0
8 .0
9 82.2
10 81.4
11 80.6
12 80.7
13 78.5
14 78.9
15 78.3
16 75.2
17 73.7
18 72.2
19 .0
20 32.3
21 45.3
22 52.6
23 58.1
24 58.2
25 58.3
26 59.5
27 101.1
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00 5.00 10.00 15.00 20.00 25.00 30.00
DEPTH (CM)

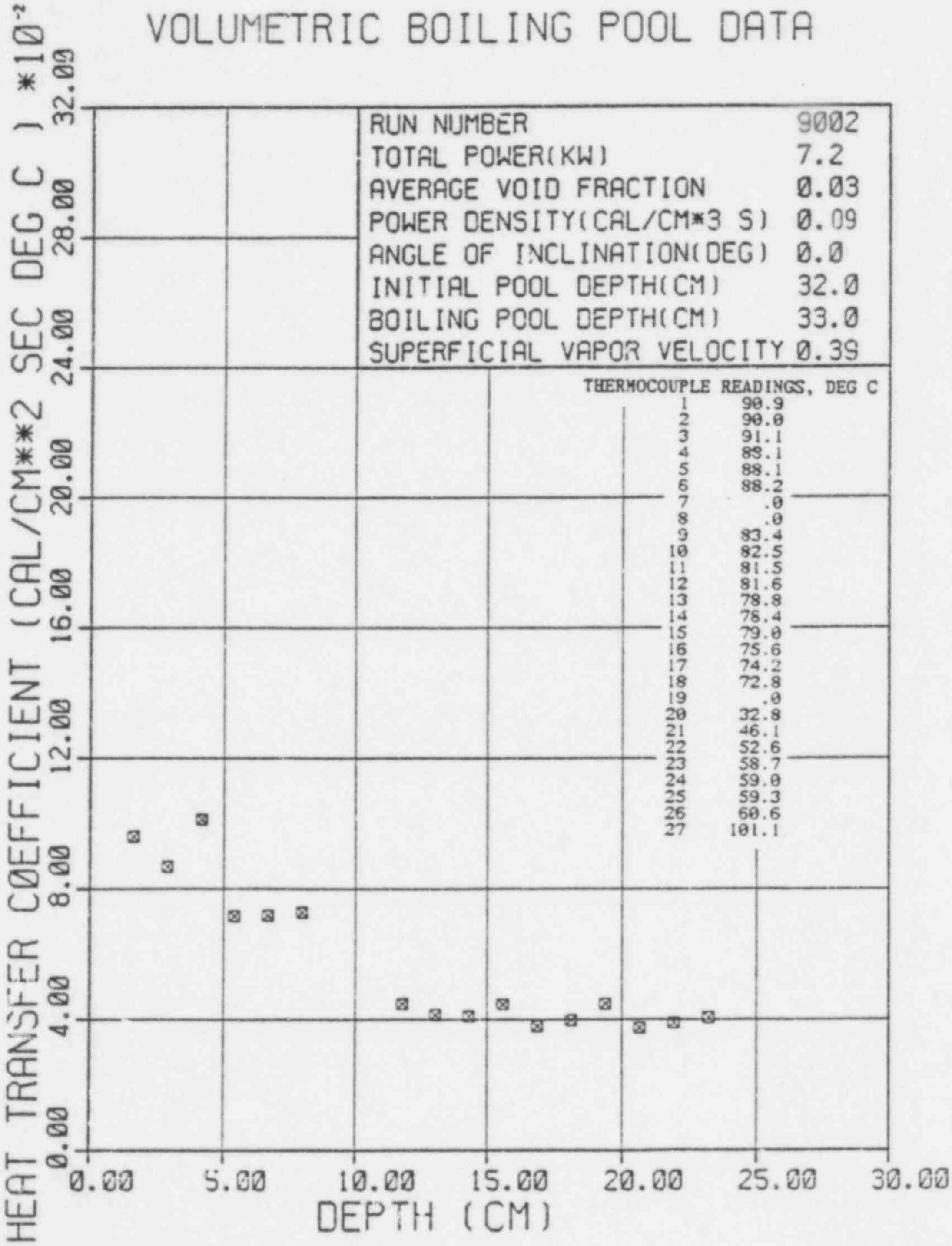
RUN NUMBER... 9002

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .03 |
| INITIAL POOL DEPTH(CM)........ | 32.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .09 |
| SUPERFICIAL VAPOR VELOCITY.... | .39 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)............ | 19238. |
| PRANDTL NUMBER................ | 1.93 |
| TOTAL POWER(KW)............... | 7.2 |
| AVERAGE SURFACE TEMP(DEG C)... | 83.1 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) | | | | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| | EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | | |
| 1.600 | .0959 | .0546 | .0584 | .0787 | 94.5 | .2403E+08 |
| 2.870 | .0868 | .0472 | .0471 | .0634 | 153.3 | .1387E+09 |
| 4.140 | .1013 | .0431 | .0413 | .0555 | 258.1 | .4163E+09 |
| 5.410 | .0715 | .0403 | .0375 | .0503 | 238.2 | .9290E+09 |
| 6.680 | .0718 | .0382 | .0349 | .0467 | 295.2 | .1749E+10 |
| 7.950 | .0728 | .0366 | .0328 | .0439 | 356.4 | .2948E+10 |
| 9.220 | | .0353 | .0312 | .0416 | | |
| 10.49 | | .0341 | .0298 | .0398 | | |
| 11.76 | .0449 | .0332 | .0287 | .0382 | 324.9 | .9542E+10 |
| 13.03 | .0413 | .0323 | .0277 | .0368 | 331.4 | .1298E+11 |
| 14.30 | .0409 | .0316 | .0268 | .0357 | 360.1 | .1716E+11 |
| 15.57 | .0446 | .0309 | .0261 | .0346 | 428.0 | .2214E+11 |
| 16.84 | .0379 | .0303 | .0254 | .0337 | 393.2 | .2802E+11 |
| 18.11 | .0398 | .0298 | .0248 | .0328 | 443.5 | .3485E+11 |
| 19.38 | .0449 | .0293 | .0242 | .0321 | 535.7 | .4270E+11 |
| 20.65 | .0373 | .0288 | .0237 | .0314 | 474.8 | .5166E+11 |
| 21.92 | .0390 | .0284 | .0232 | .0307 | 526.9 | .6179E+11 |
| 23.19 | .0406 | .0280 | .0228 | .0302 | 579.3 | .7317E+11 |
| 24.46 | | .0276 | .0224 | .0296 | | |



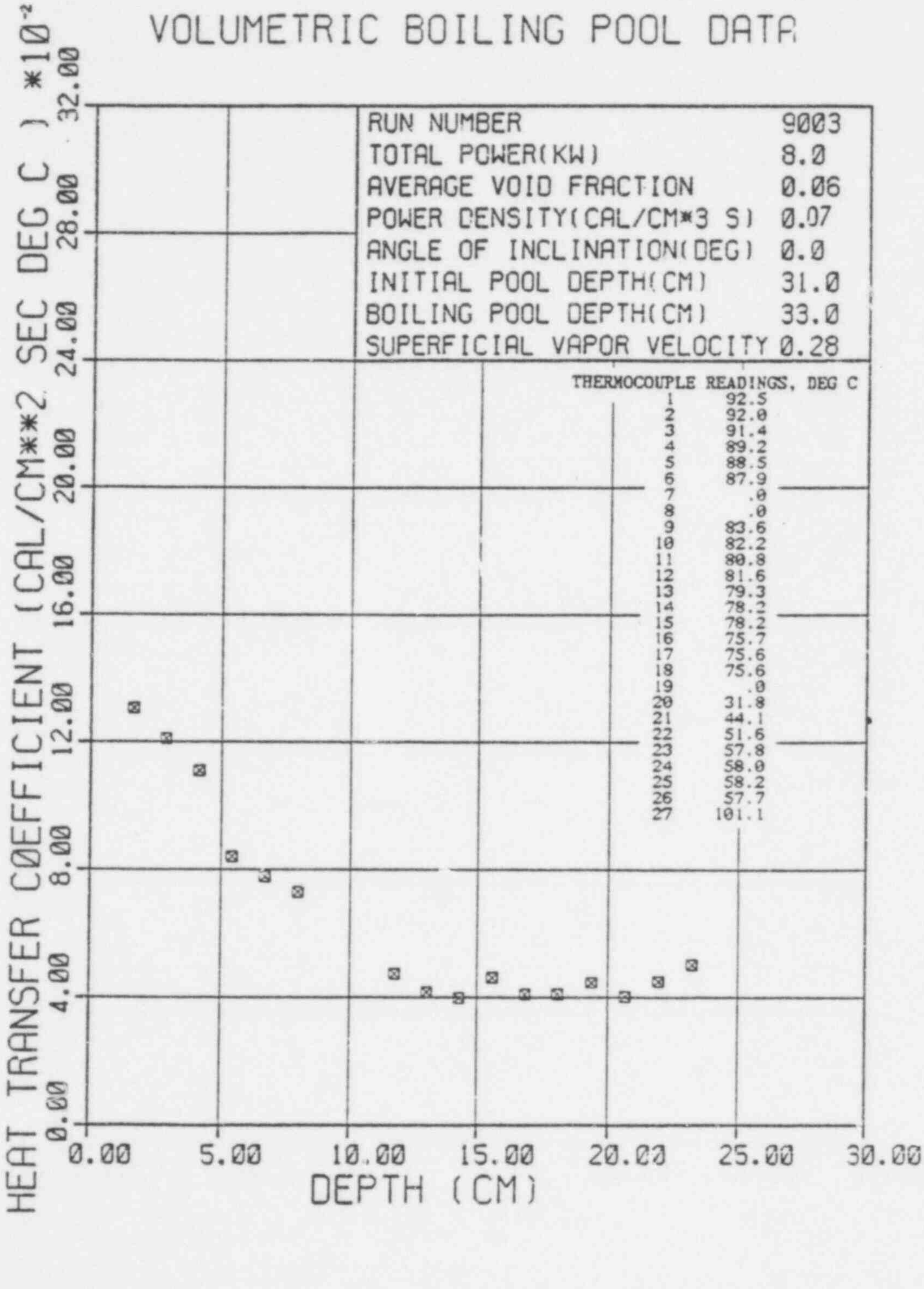
494 128


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 9002
TOTAL POWER(KW) 7.2
AVERAGE VOID FRACTION 0.03
POWER DENSITY(CAL/CM*3 S) 0.09
ANGLE OF INCLINATION(DEG) 0.0
INITIAL POOL DEPTH(CM) 32.0
BOILING POOL DEPTH(CM) 33.0
SUPERFICIAL VAPOR VELOCITY 0.39
THERMOCOUPLE READINGS, DEG C
1 90.9
2 90.0
3 91.1
4 88.1
5 88.1
6 88.2
7 .0
8 .0
9 83.4
10 82.5
11 81.5
12 81.6
13 78.8
14 78.4
15 79.0
16 75.6
17 74.2
18 72.8
19 .0
20 32.8
21 46.1
22 52.6
23 58.7
24 59.0
25 59.3
26 60.6
27 101.1
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C) *10^-2
DEPTH (CM)

RUN NUMBER... 9003

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .06 |
| INITIAL POOL DEPTH(CM)........ | 31.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .07 |
| SUPERFICIAL VAPOR VELOCITY.... | .28 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)............ | 18637. |
| PRANDTL NUMBER................ | 1.92 |
| TOTAL POWER(KW)............... | 8.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 83.5 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.600 | .1306 | .0650 | .0597 | .0800 | 128.7 | .4815E+08 |
| 2.870 | .1211 | .0562 | .0488 | .0650 | 213.9 | .2779E+09 |
| 4.140 | .1111 | .0513 | .0431 | .0572 | 283.0 | .8342E+09 |
| 5.410 | .0841 | .0479 | .0394 | .0521 | 280.1 | .1862E+10 |
| 6.680 | .0778 | .0455 | .0367 | .0485 | 319.9 | .3504E+10 |
| 7.950 | .0730 | .0435 | .0347 | .0457 | 357.1 | .5907E+10 |
| 9.220 | | .0420 | .0330 | .0434 | | |
| 10.49 | | .0406 | .0317 | .0416 | | |
| 11.76 | .0475 | .0395 | .0305 | .0400 | 343.7 | .1912E+11 |
| 13.03 | .0417 | .0385 | .0295 | .0386 | 334.3 | .2601E+11 |
| 14.30 | .0399 | .0376 | .0286 | .0374 | 350.9 | .3438E+11 |
| 15.57 | .0462 | .0368 | .0279 | .0364 | 443.2 | .4438E+11 |
| 16.84 | .0410 | .0361 | .0272 | .0354 | 425.2 | .5614E+11 |
| 18.11 | .0410 | .0354 | .0266 | .0346 | 457.3 | .6983E+11 |
| 19.38 | .0445 | .0349 | .0266 | .0338 | 531.5 | .8557E+11 |
| 20.65 | .0402 | .0343 | .0255 | .0331 | 510.6 | .1035E+12 |
| 21.92 | .0451 | .0338 | .0250 | .0325 | 608.2 | .1238E+12 |
| 23.19 | .0503 | .0333 | .0246 | .0319 | 717.5 | .1466E+12 |
| 24.46 | | .0329 | .0242 | .0313 | | |


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 9003
TOTAL POWER(KW) 8.0
AVERAGE VOID FRACTION 0.06
POWER DENSITY(CAL/CM*3 S) 0.07
ANGLE OF INCLINATION(DEG) 0.0
INITIAL POOL DEPTH(CM) 31.0
BOILING POOL DEPTH(CM) 33.0
SUPERFICIAL VAPOR VELOCITY 0.28
THERMOCOUPLE READINGS, DEG C
1 92.5
2 92.0
3 91.4
4 89.2
5 88.5
6 87.9
7 .0
8 .0
9 83.6
10 82.2
11 80.8
12 81.6
13 79.3
14 78.2
15 78.2
16 75.7
17 75.6
18 75.6
19 .0
20 31.8
21 44.1
22 51.6
23 57.8
24 58.0
25 58.2
26 57.7
27 101.1
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10⁻²
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

494 131

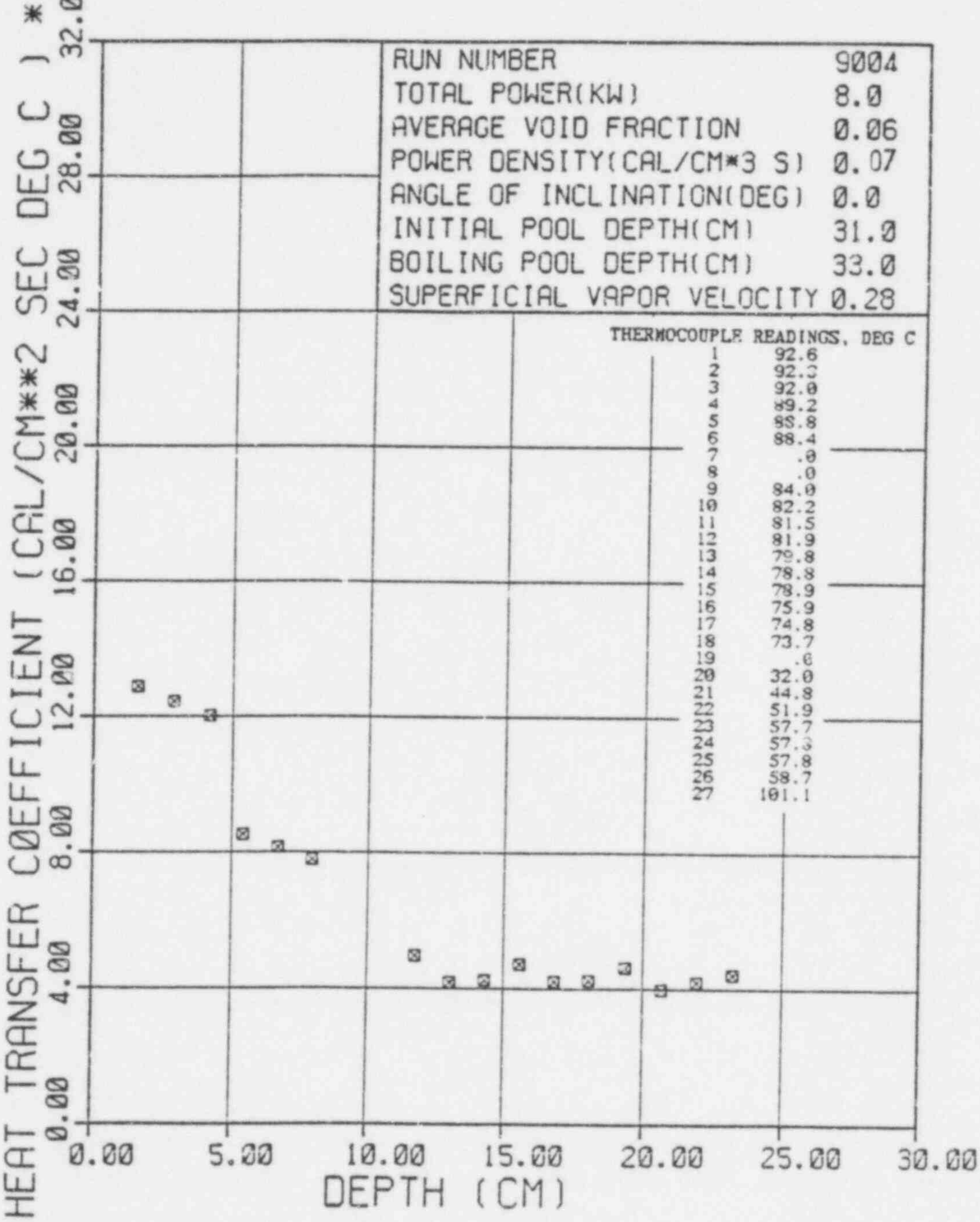
## RUN NUMBER... 9004

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .06 |
| INITIAL POOL DEPTH(CM)........ | 31.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .07 |
| SUPERFICIAL VAPOR VELOCITY.... | .28 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)............ | 18637. |
| PRANDTL NUMBER................ | 1.92 |
| TOTAL POWER(KW)............... | 8.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 83.8 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.600 | .1288 | .0650 | .0598 | .0801 | 126.8 | .4822E+08 |
| 2.870 | .1244 | .0562 | .048[illegible] | .0650 | 219.7 | .2783E+09 |
| 4.140 | .1203 | .0513 | .0431 | .0572 | 306.5 | .8354E+09 |
| 5.410 | .0852 | .0480 | .0394 | .0521 | 283.7 | .1864E+10 |
| 6.680 | .0814 | .0455 | .0367 | .0485 | 334.6 | .3509E+10 |
| 7.950 | .0778 | .0436 | .0347 | .0457 | 380.6 | .5916E+10 |
| 9.220 | | .0420 | .0330 | .0434 | | |
| 10.49 | | .0406 | .0317 | .0416 | | |
| 11.76 | .0496 | .0395 | .0305 | .0400 | 359.0 | .1915E+11 |
| 13.03 | .0418 | .0385 | .0295 | .0386 | 335.6 | .2605E+11 |
| 14.30 | .0424 | .0376 | .0287 | .0374 | 373.1 | .3443E+11 |
| 15.57 | .0472 | .0368 | .0279 | .0364 | 452.3 | .4444E+11 |
| 16.84 | .0423 | .0361 | .0272 | .0354 | 438.3 | .5623E+11 |
| 18.11 | .0424 | .0355 | .0266 | .0346 | 472.3 | .6993E+11 |
| 19.38 | .0461 | .0349 | .0260 | .0338 | 550.5 | .8570E+11 |
| 20.65 | .0398 | .0343 | .0255 | .0331 | 506.4 | .1037E+12 |
| 21.92 | .0421 | .0338 | .0250 | .0325 | 567.5 | .1240E+12 |
| 23.19 | .0441 | .0333 | .0246 | .0319 | 629.6 | .1468E+12 |
| 24.46 | | .0329 | .0242 | .0313 | | |

494 132

# VOLUMETRIC BOILING POOL DATA




494 133

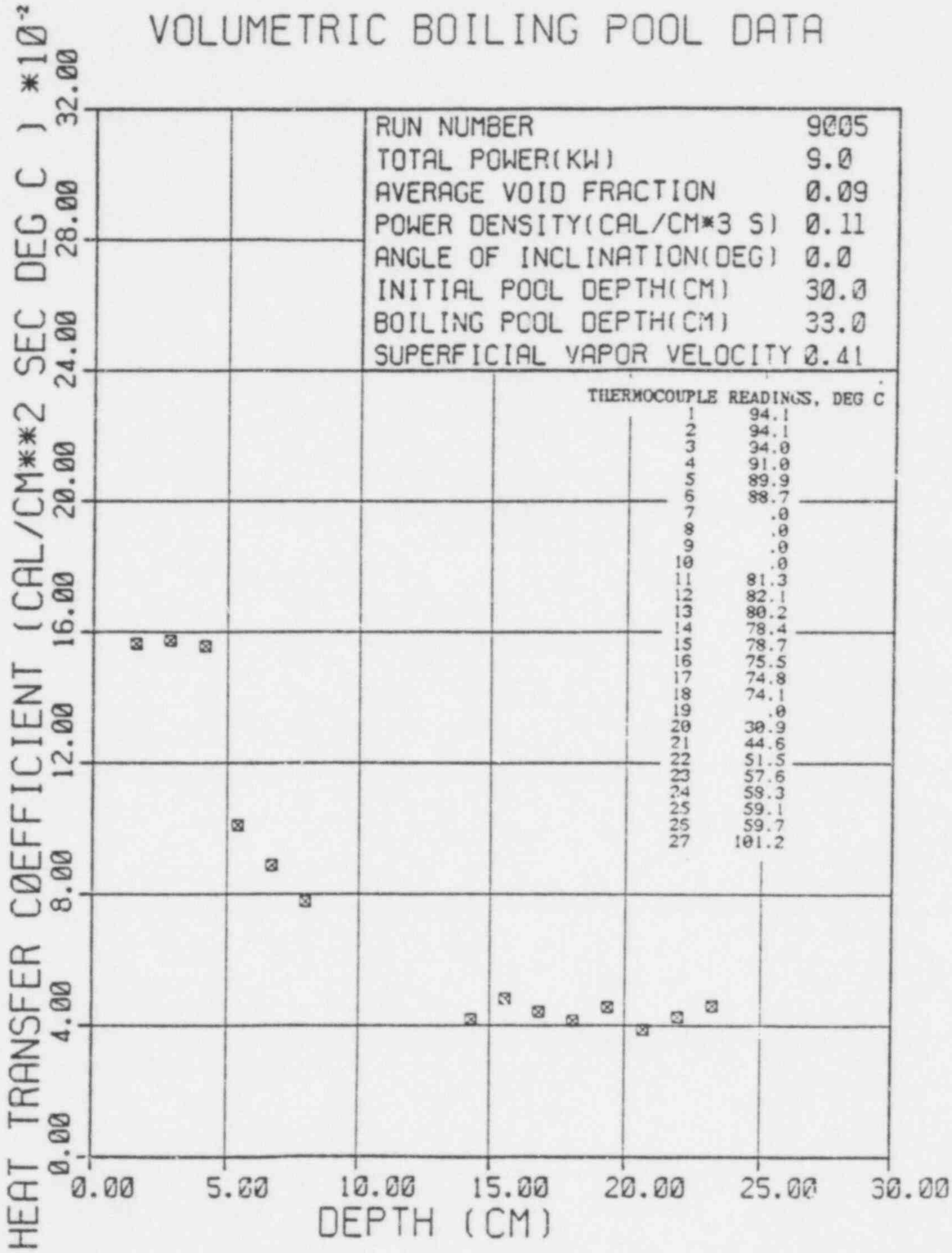
RUN NUMBER... 9005

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .09 |
| INITIAL POOL DEPTH(CM)........ | 30.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .11 |
| SUPERFICIAL VAPOR VELOCITY.... | .41 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)............ | 18036. |
| PRANDTL NUMBER................ | 1.91 |
| TOTAL POWER(KW)............... | 9.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 84.3 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.600 | .1564 | .0720 | .0687 | .0922 | 154.0 | .7255E+08 |
| 2.870 | .1573 | .0623 | .0559 | .0748 | 277.9 | .4187E+09 |
| 4.140 | .1556 | .0568 | .0493 | .0657 | 396.4 | .1257E+10 |
| 5.410 | .1010 | .0531 | .0450 | .0598 | 336.2 | .2804E+10 |
| 6.680 | .0688 | .0504 | .0419 | .0556 | 364.9 | .5279E+10 |
| 7.950 | .0778 | .0483 | .0395 | .0523 | 380.8 | .8899E+10 |
| 9.220 | | .0465 | .0376 | .0497 | | |
| 10.49 | | .0450 | .0361 | .0476 | | |
| 11.76 | | .0438 | .0347 | .0457 | | |
| 13.03 | | .0426 | .0336 | .0442 | | |
| 14.30 | .0417 | .0417 | .0326 | .0428 | 367.4 | .5179E+11 |
| 15.57 | .0483 | .0408 | .0317 | .0416 | 462.7 | .6685E+11 |
| 16.84 | .0441 | .0400 | .0309 | .0405 | 457.3 | .8458E+11 |
| 18.11 | .0413 | .0393 | .0302 | .0395 | 460.8 | .1052E+12 |
| 19.38 | .0456 | .0386 | .0295 | .0386 | 544.2 | .1289E+12 |
| 20.65 | .0388 | .0380 | .0289 | .0378 | 493.3 | .1560E+12 |
| 21.92 | .0425 | .0374 | .0284 | .0370 | 573.6 | .1865E+12 |
| 23.19 | .0460 | .0369 | .0279 | .0364 | 656.8 | .2209E+12 |
| 24.46 | | .0364 | .0274 | .0357 | | |



494 134


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 9005
TOTAL POWER(KW) 9.0
AVERAGE VOID FRACTION 0.09
POWER DENSITY(CAL/CM*3 S) 0.11
ANGLE OF INCLINATION(DEG) 0.0
INITIAL POOL DEPTH(CM) 30.0
BOILING POOL DEPTH(CM) 33.0
SUPERFICIAL VAPOR VELOCITY 0.41
THERMOCOUPLE READINGS, DEG C
1 94.1
2 94.1
3 34.0
4 91.0
5 89.9
6 88.7
7 .0
8 .0
9 .0
10 .0
11 81.3
12 82.1
13 80.2
14 78.4
15 78.7
16 75.5
17 74.8
18 74.1
19 .0
20 30.9
21 44.6
22 51.5
23 57.6
24 58.3
25 59.1
25 59.7
27 101.2
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C) *10⁻²
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

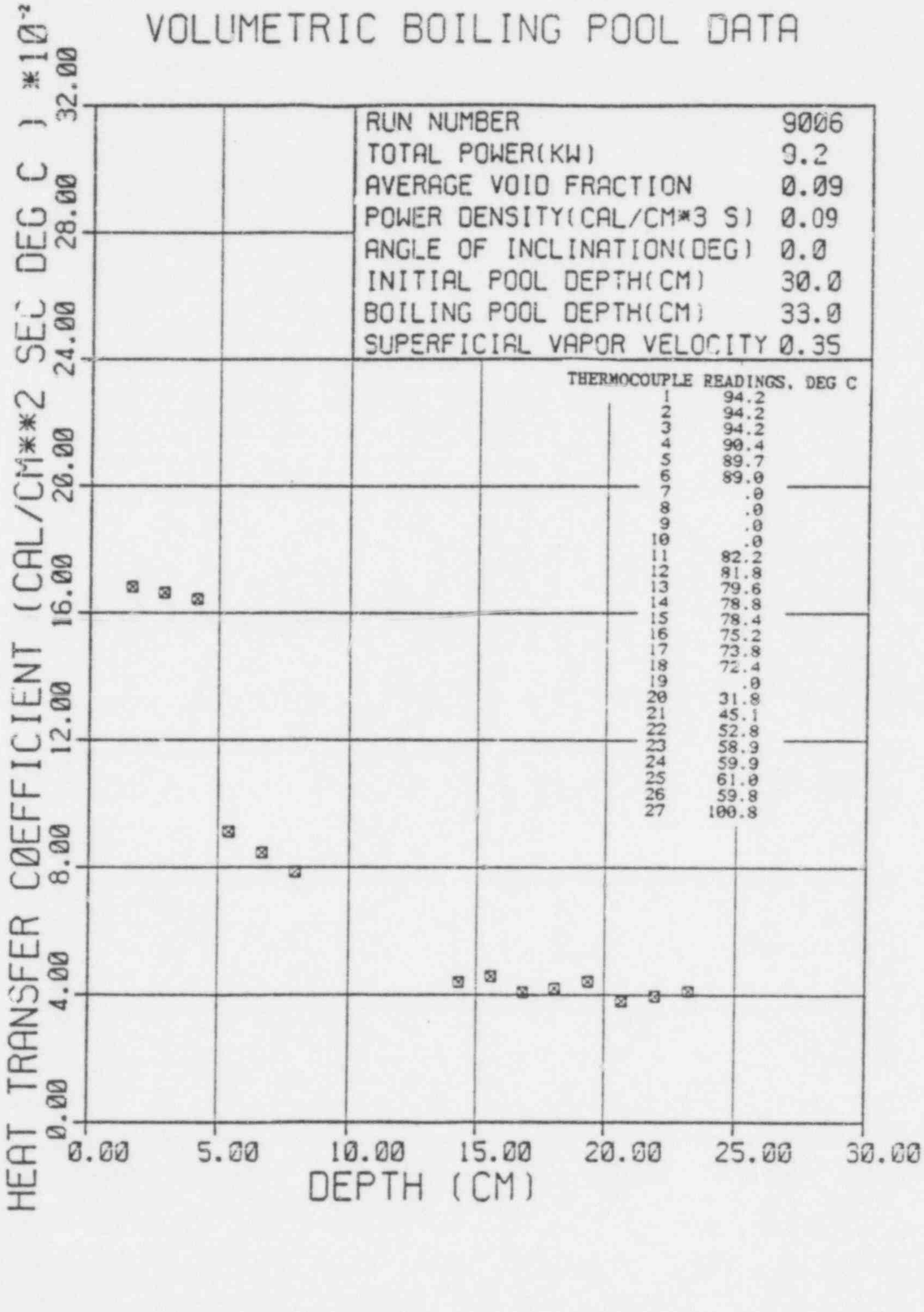
494 135

RUN NUMBER... 9006

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .09 |
| INITIAL POOL DEPTH(CM)........ | 30.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | ,09 |
| SUPERFICIAL VAPOR VELOCITY.... | .35 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)........... | 18036. |
| PRANDTL NUMBER................ | 1.92 |
| TOTAL POWER(KW)............... | 9.2 |
| AVERAGE SURFACE TEMP(DEG C)... | 84.2 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.600 | .1683 | .0720 | .0664 | .0890 | 165.7 | .7237E+08 |
| 2.870 | .1663 | .0622 | .0542 | .0723 | 293.8 | .4177E+09 |
| 4.140 | .1644 | .0568 | .0478 | .0636 | 418.8 | .1254E+10 |
| 5.410 | .0913 | .0531 | .0437 | .0579 | 303.9 | .2798E+10 |
| 6.680 | .0845 | .0504 | .0408 | .0539 | 347.6 | .5267E+10 |
| 7.950 | .0786 | .0482 | .0385 | .0508 | 384.7 | .8878E+10 |
| 9.220 | | .0465 | .0367 | .0482 | | |
| 10.49 | | .0450 | .0352 | .0462 | | |
| 11.76 | | .0437 | .0339 | .0444 | | |
| 13.03 | | .0426 | .0328 | .0429 | | |
| 14.30 | .0440 | .0416 | .0318 | .0416 | 387.0 | .5167E+11 |
| 15.57 | .0458 | .0408 | .0310 | .0404 | 439.1 | .6669E+11 |
| 16.84 | .0408 | .0400 | .0302 | .0394 | 423.0 | .8438E+11 |
| 18.11 | .0419 | .0393 | .0295 | .0384 | 467.3 | .1049E+12 |
| 19.38 | .0443 | .0386 | .0289 | .0376 | 528.4 | .1286E+12 |
| 20.65 | .0380 | .0380 | .0283 | .0368 | 482.5 | .1556E+12 |
| 21.92 | .0396 | .0374 | .0278 | .0361 | 534.5 | .1861E+12 |
| 23.19 | .0411 | .0369 | .0273 | .0354 | 586.8 | .2203E+12 |
| 24.46 | | .0364 | .0268 | .0348 | | |

494 136



VOLUMETRIC BOILING POOL DATA
RUN NUMBER 9006
TOTAL POWER(KW) 9.2
AVERAGE VOID FRACTION 0.09
POWER DENSITY(CAL/CM*3 S) 0.09
ANGLE OF INCLINATION(DEG) 0.0
INITIAL POOL DEPTH(CM) 30.0
BOILING POOL DEPTH(CM) 33.0
SUPERFICIAL VAPOR VELOCITY 0.35
THERMOCOUPLE READINGS, DEG C
1 94.2
2 94.2
3 94.2
4 90.4
5 89.7
6 89.0
7 .0
8 .0
9 .0
10 .0
11 82.2
12 81.8
13 79.6
14 78.8
15 78.4
16 75.2
17 73.8
18 72.4
19 .0
20 31.8
21 45.1
22 52.8
23 58.9
24 59.9
25 61.0
26 59.8
27 100.8
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10⁻²
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)




494 137

## RUN NUMBER... 9007

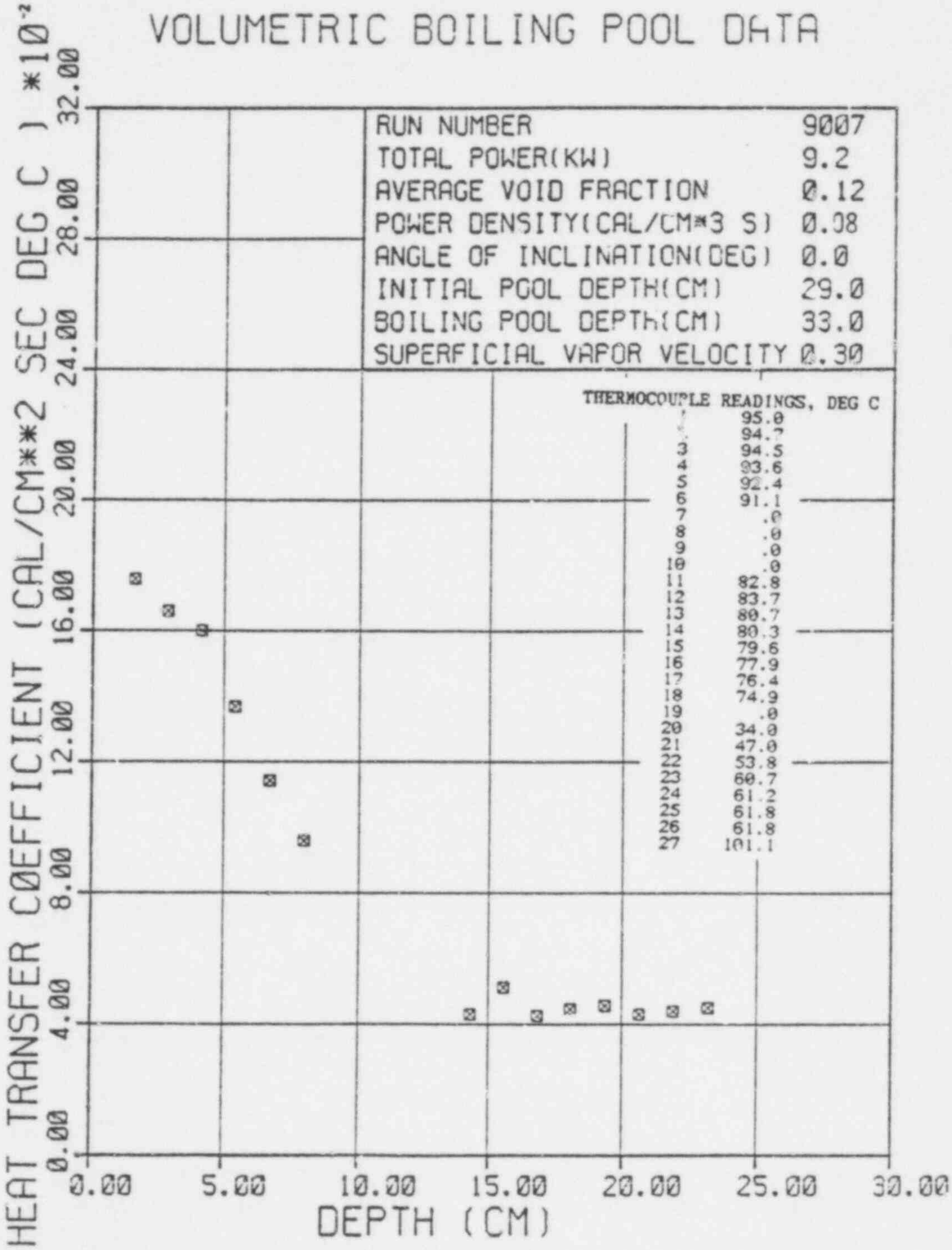
| | |
|---|---|
| AVERAGE VOID FRACTION......... | .12 |
| INITIAL POOL DEPTH(CM)........ | 29.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .08 |
| SUPERFICIAL VAPOR VELOCITY.... | .30 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)............ | 17435. |
| PRANDTL NUMBER................ | 1.90 |
| TOTAL POWER(KW)............... | 9.24 |
| AVERAGE SURFACE TEMP(DEG C)... | 85.9 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.600 | .1757 | .0776 | .0675 | .0900 | 173.0 | .9742E+08 |
| 2.870 | .1660 | .0670 | .0554 | .0734 | 293.0 | .5623E+09 |
| 4.140 | .1599 | .0612 | .0490 | .0647 | 407.4 | .1688E+10 |
| 5.410 | .1369 | .0572 | .0449 | .0591 | 455.6 | .3766E+10 |
| 6.680 | .1143 | .0543 | .0420 | .0550 | 469.7 | .7090E+10 |
| 7.950 | .0959 | .0520 | .0397 | .0519 | 469.0 | .1195E+11 |
| 9.220 | | .0501 | .0378 | .0493 | | |
| 10.49 | | .0485 | .0363 | .0473 | | |
| 11.76 | | .0471 | .0350 | .0455 | | |
| 13.03 | | .0459 | .0339 | .0440 | | |
| 14.30 | .0430 | .0449 | .0329 | .0426 | 378.7 | .6955E+11 |
| 15.57 | .0512 | .0439 | .0321 | .0415 | 490.5 | .8977E+11 |
| 16.84 | .0426 | .0431 | .0313 | .0404 | 441.0 | .1136E+12 |
| 18.11 | .0446 | .0423 | .0306 | .0395 | 497.5 | .1413E+12 |
| 19.38 | .0455 | .0416 | .0299 | .0386 | 543.1 | .1731E+12 |
| 20.65 | .0430 | .0409 | .0294 | .0378 | 546.3 | .2094E+12 |
| 21.92 | .0441 | .0403 | .0288 | .0371 | 594.6 | .2505E+12 |
| 23.19 | .0451 | .0398 | .0283 | .0364 | 642.8 | .2966E+12 |
| 24.46 | | .0392 | .0279 | .0358 | | |



494 138

# VOLUMETRIC BOILING POOL DATA




494 139

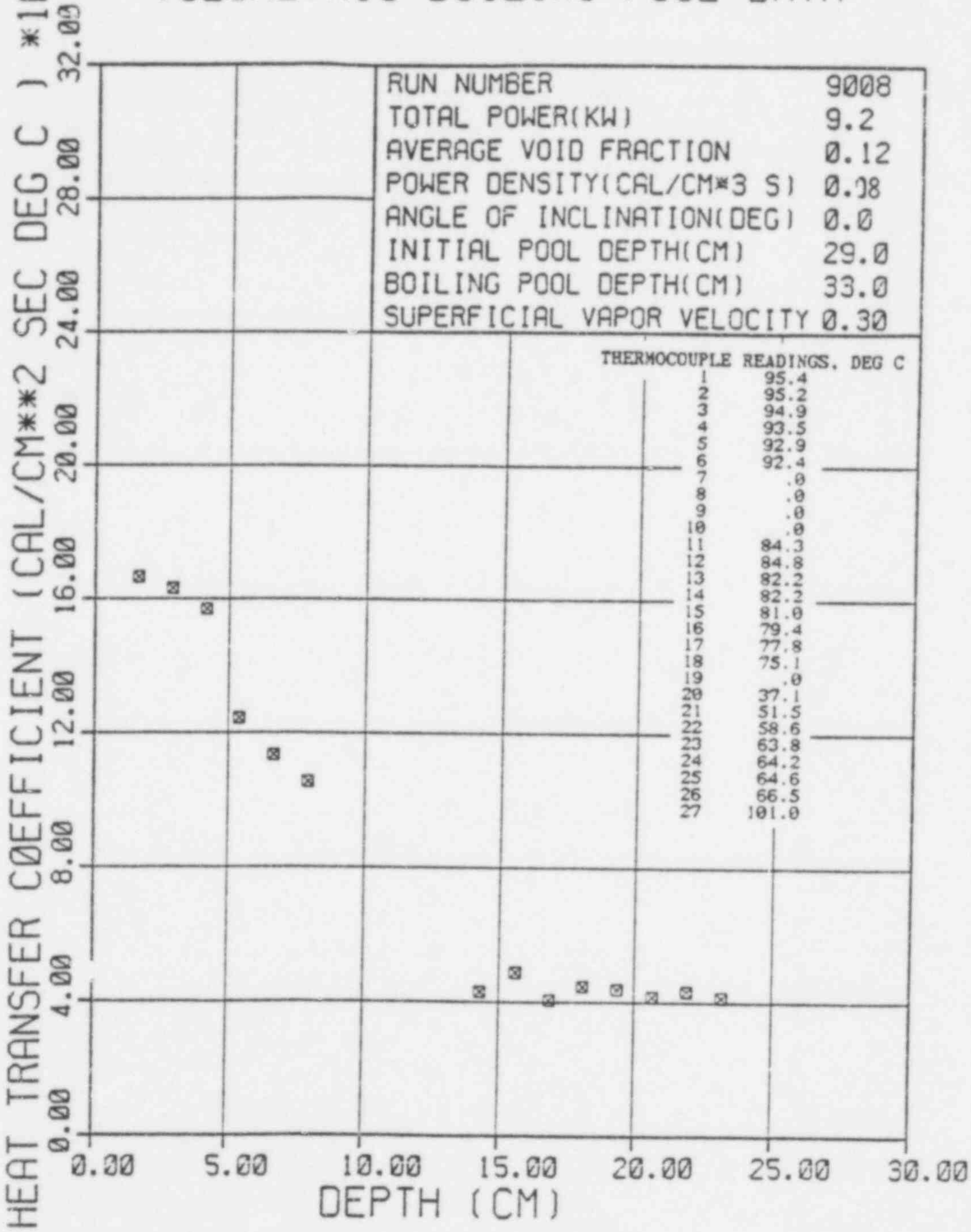
RUN NUMBER... 9008

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .12 |
| INITIAL POOL DEPTH(CM)........ | 29.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .08 |
| SUPERFICIAL VAPOR VELOCITY.... | .30 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)............ | 17435. |
| PRANDTL NUMBER................ | 1.89 |
| TOTAL POWER(KW)............... | 9.24 |
| AVERAGE SURFACE TEMP(DEG C)... | 86.9 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.600 | .1666 | .0777 | .0676 | .0901 | 164.0 | .9782E+08 |
| 2.870 | .1633 | .0671 | .0554 | .0735 | 288.2 | .5646E+09 |
| 4.140 | .1570 | .0613 | .0491 | .0648 | 399.8 | .1695E+10 |
| 5.410 | .1244 | .0573 | .0450 | .0591 | 413.9 | .3782E+10 |
| 6.680 | .1133 | .0543 | .0420 | .0550 | 465.6 | .7119E+10 |
| 7.950 | .1054 | .0520 | .0397 | .0519 | 515.2 | .1200E+11 |
| 9.220 | | .0501 | .0379 | .0494 | | |
| 10.49 | | .0485 | .0363 | .0473 | | |
| 11.76 | | .0472 | .0351 | .0455 | | |
| 13.03 | | .0460 | .0339 | .0440 | | |
| 14.30 | .0430 | .0449 | .0330 | .0427 | 378.0 | .6984E+11 |
| 15.57 | .0488 | .0440 | .0321 | .0415 | 466.9 | .9015E+11 |
| 16.84 | .0405 | .0431 | .0313 | .0404 | 419.8 | .1141E+12 |
| 18.11 | .0446 | .0424 | .0306 | .0395 | 496.7 | .1419E+12 |
| 19.38 | .0438 | .0416 | .0300 | .0386 | 522.1 | .1738E+12 |
| 20.65 | .0417 | .0410 | .0294 | .0378 | 529.6 | .2103E+12 |
| 21.92 | .0433 | .0404 | .0289 | .0371 | 583.5 | .2515E+12 |
| 23.19 | .0414 | .0398 | .0284 | .0364 | 590.3 | .2978E+12 |
| 24.46 | | .0393 | .0279 | .0358 | | |

494 140

# VOLUMETRIC BOILING POOL DATA






494 141

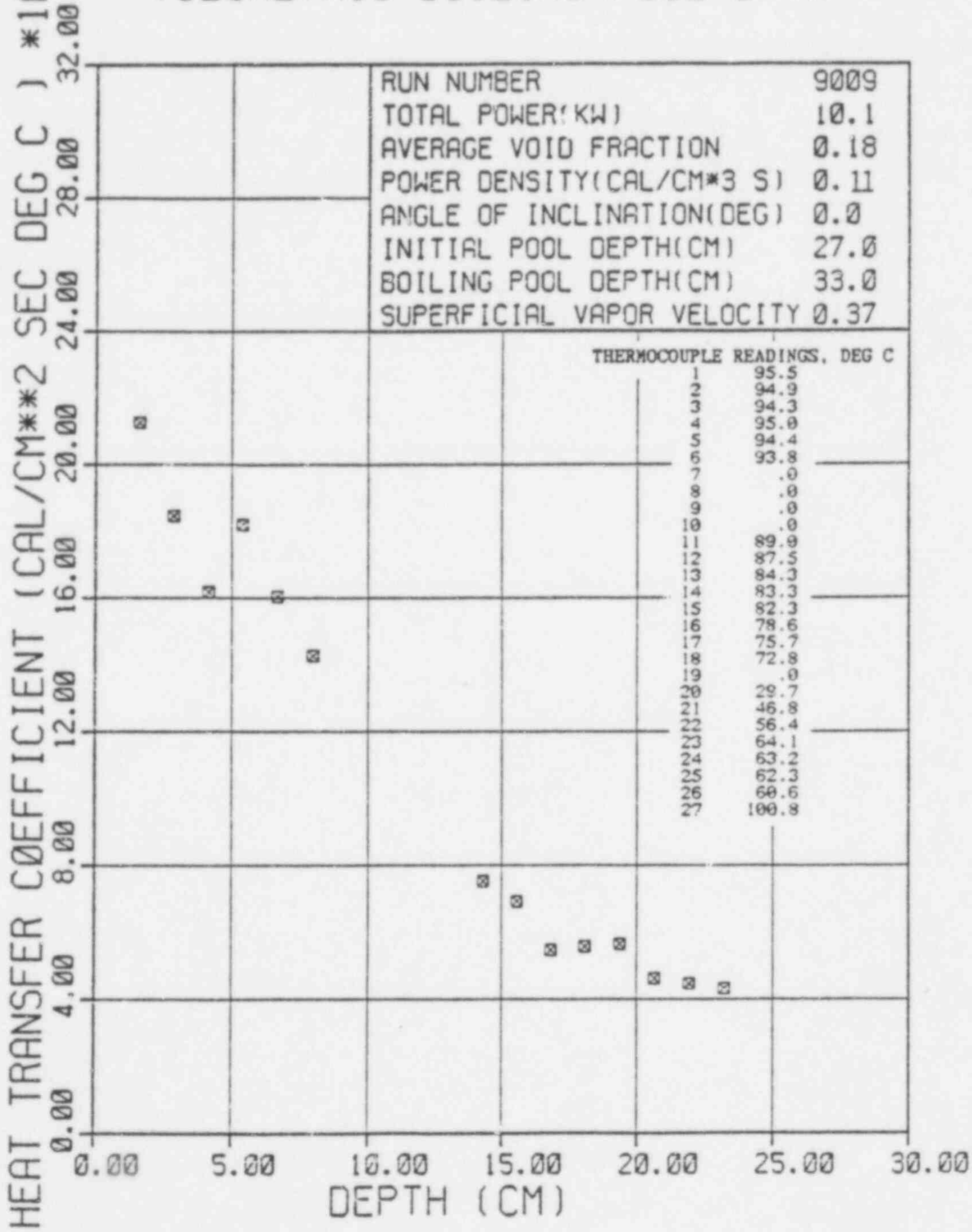
RUN NUMBER... 9009

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .18 |
| INITIAL POOL DEPTH(CM)........ | 27.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .11 |
| SUPERFICIAL VAPOR VELOCITY.... | .37 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)............ | 16232. |
| PRANDTL NUMBER................ | 1.88 |
| TOTAL POWER(KW)............... | 10.1 |
| AVERAGE SURFACE TEMP(DEG C)... | 88.3 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) | | | | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| | EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | | |
| 1.600 | .2126 | .0861 | .0750 | .1000 | 209.1 | .1475E+09 |
| 2.870 | .1846 | .0744 | .0615 | .0816 | 325.7 | .8515E+09 |
| 4.140 | .1617 | .0679 | .0545 | .0719 | 411.8 | .2556E+10 |
| 5.410 | .1820 | .0635 | .0499 | .0656 | 605.5 | .5704E+10 |
| 6.680 | .1604 | .0602 | .0466 | .0611 | 658.9 | .1074E+11 |
| 7.950 | .1425 | .0577 | .0441 | .0576 | 696.6 | .1810E+11 |
| 9.220 | | .0556 | .0420 | .0548 | | |
| 10.49 | | .0538 | .0403 | .0525 | | |
| 11.76 | | .0523 | .0389 | .0505 | | |
| 13.03 | | .0510 | .0376 | .0488 | | |
| 14.30 | .0751 | .0498 | .0366 | .0474 | 660.8 | .1053E+12 |
| 15.57 | .0693 | .0488 | .0356 | .0461 | 663.1 | .1360E+12 |
| 16.84 | .0546 | .0478 | .0347 | .0449 | 565.3 | .1720E+12 |
| 18.11 | .0555 | .0469 | .0340 | .0438 | 618.3 | .2140E+12 |
| 19.38 | .0564 | .0462 | .0333 | .0429 | 671.7 | .2622E+12 |
| 20.65 | .0462 | .0454 | .0326 | .0420 | 587.2 | .3172E+12 |
| 21.92 | .0445 | .0448 | .0320 | .0412 | 599.8 | .3794E+12 |
| 23.19 | .0431 | .0441 | .0315 | .0404 | 614.9 | .4492E+12 |
| 24.46 | | .0436 | .0309 | .0397 | | |

494 142

# VOLUMETRIC BOILING POOL DATA

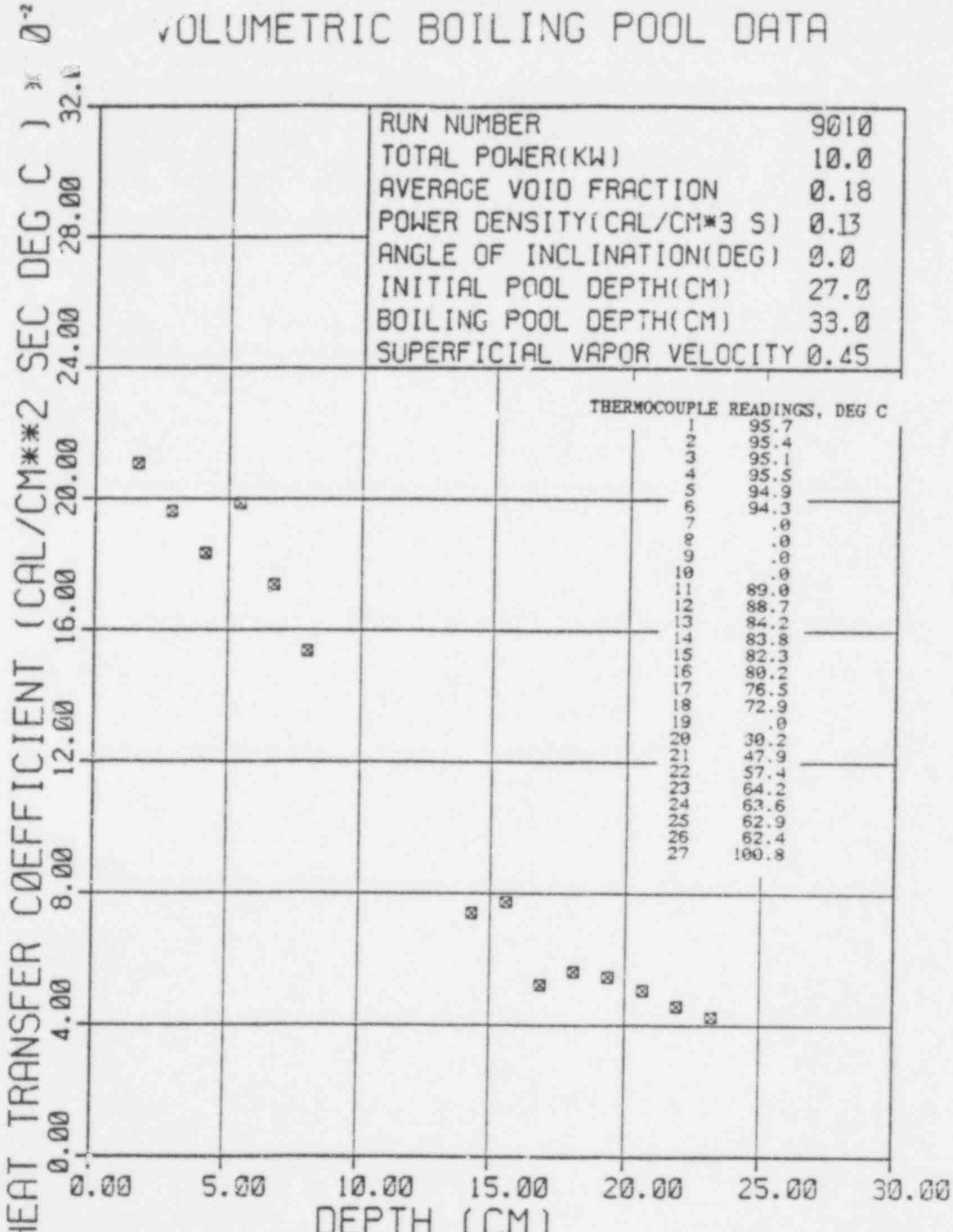



494 143

## RUN NUMBER... 9010

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .18 |
| INITIAL POOL DEPTH(CM)........ | 27.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .13 |
| SUPERFICIAL VAPOR VELOCITY.... | .45 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)............ | 16232. |
| PRANDTL NUMBER................ | 1.87 |
| TOTAL POWER(KW)............... | 10.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 88.8 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.600 | .2108 | .0862 | .0779 | .1043 | 207.4 | .1479E+09 |
| 2.870 | .1963 | .0745 | .0637 | .0848 | 346.4 | .8535E+09 |
| 4.140 | .1833 | .0679 | .0563 | .0746 | 466.6 | .2562E+10 |
| 5.410 | .1986 | .0635 | .0515 | .0681 | 660.5 | .5717E+10 |
| 6.680 | .1738 | .0603 | .0480 | .0633 | 713.9 | .1076E+11 |
| 7.950 | .1536 | .0577 | .0454 | .0597 | 751.0 | .1814E+11 |
| 9.220 | | .0556 | .0432 | .0567 | | |
| 10.49 | | .0539 | .0415 | .0543 | | |
| 11.76 | | .0523 | .0400 | .0523 | | |
| 13.03 | | .0510 | .0387 | .0505 | | |
| 14.30 | .0741 | .0498 | .0375 | .0489 | 651.1 | .1056E+12 |
| 15.57 | .0775 | .0488 | .0365 | .0476 | 741.5 | .1363E+12 |
| 16.84 | .0521 | .0478 | .0356 | .0464 | 539.6 | .1724E+12 |
| 18.11 | .0561 | .0470 | .0348 | .0452 | 625.2 | .2144E+12 |
| 19.38 | .0545 | .0462 | .0341 | .0442 | 649.4 | .2628E+12 |
| 20.65 | .0506 | .0455 | .0334 | .0433 | 642.7 | .3179E+12 |
| 21.92 | .0458 | .0448 | .0328 | .0425 | 617.7 | .3803E+12 |
| 23.19 | .0426 | .0442 | .0322 | .0417 | 607.1 | .4503E+12 |
| 24.46 | | .0436 | .0317 | .0410 | | |


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 9010
TOTAL POWER(KW) 10.0
AVERAGE VOID FRACTION 0.18
POWER DENSITY(CAL/CM*3 S) 0.13
ANGLE OF INCLINATION(DEG) 0.0
INITIAL POOL DEPTH(CM) 27.0
BOILING POOL DEPTH(CM) 33.0
SUPERFICIAL VAPOR VELOCITY 0.45
THERMOCOUPLE READINGS, DEG C
1 95.7
2 95.4
3 95.1
4 95.5
5 94.9
6 94.3
7 .0
8 .0
9 .0
10 .0
11 89.0
12 88.7
13 84.2
14 83.8
15 82.3
16 80.2
17 76.5
18 72.9
19 .0
20 30.2
21 47.9
22 57.4
23 64.2
24 63.6
25 62.9
26 62.4
27 100.8
HEAT TRANSFER CØEFFICIENT (CAL/CM**2 SEC DEG C ) * 10⁻²
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DEPTH (CM)
0.00
5.00
10.00
15.00
20.00
25.00
30.00

494 145

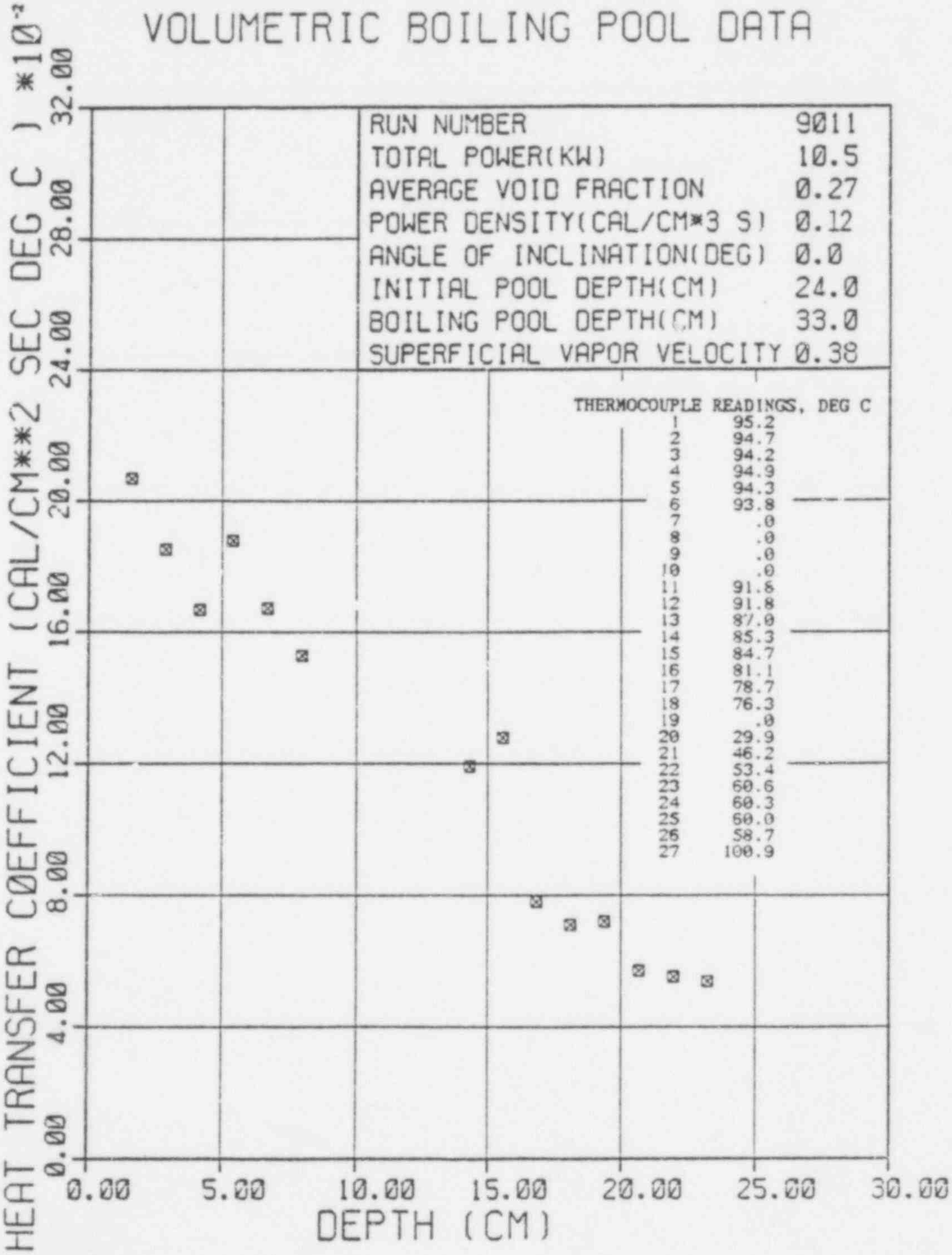
## RUN NUMBER... 9011

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .27 |
| INITIAL POOL DEPTH(CM)........ | 24.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .12 |
| SUPERFICIAL VAPOR VELOCITY.... | .38 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)............ | 14429. |
| PRANDTL NUMBER................ | 1.86 |
| TOTAL POWER(KW)............... | 10.5 |
| AVERAGE SURFACE TEMP(DEG C)... | 89.8 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.600 | .2067 | .0955 | .0806 | .1070 | 203.3 | .2229E+09 |
| 2.870 | .1852 | .0825 | .0663 | .0875 | 326.7 | .1287E+10 |
| 4.140 | .1669 | .0753 | .0588 | .0772 | 424.7 | .3862E+10 |
| 5.410 | .1878 | .0704 | .0539 | .0705 | 624.4 | .8618E+10 |
| 6.680 | .1673 | .0668 | .0504 | .0657 | 686.9 | .1622E+11 |
| 7.950 | .1528 | .0640 | .0477 | .0620 | 746.6 | .2735E+11 |
| 9.220 | | .0616 | .0455 | .0590 | | |
| 10.49 | | .0597 | .0437 | .0566 | | |
| 11.76 | | .0580 | .0422 | .0545 | | |
| 13.03 | | .0565 | .0408 | .0527 | | |
| 14.30 | .1192 | .0552 | .0397 | .0511 | 1047.7 | .1592E+12 |
| 15.57 | .1277 | .0541 | .0386 | .0497 | 1222.3 | .2054E+12 |
| 16.84 | .0780 | .0530 | .0377 | .0484 | 807.8 | .2599E+12 |
| 18.11 | .0710 | .0521 | .0369 | .0473 | 790.1 | .3233E+12 |
| 19.38 | .0719 | .0512 | .0361 | .0463 | 857.0 | .3962E+12 |
| 20.65 | .0569 | .0504 | .0354 | .0453 | 722.3 | .4793E+12 |
| 21.92 | .0552 | .0496 | .0348 | .0445 | 743.2 | .5732E+12 |
| 23.19 | .0538 | .0490 | .0342 | .0437 | 766.3 | .6788E+12 |
| 24.46 | | .0483 | .0336 | .0429 | | |



494 146



VOLUMETRIC BOILING POOL DATA
RUN NUMBER 9011
TOTAL POWER(KW) 10.5
AVERAGE VOID FRACTION 0.27
POWER DENSITY(CAL/CM*3 S) 0.12
ANGLE OF INCLINATION(DEG) 0.0
INITIAL POOL DEPTH(CM) 24.0
BOILING POOL DEPTH(CM) 33.0
SUPERFICIAL VAPOR VELOCITY 0.38
THERMOCOUPLE READINGS, DEG C
1 95.2
2 94.7
3 94.2
4 94.9
5 94.3
6 93.8
7 .0
8 .0
9 .0
10 .0
11 91.8
12 91.8
13 87.0
14 85.3
15 84.7
16 81.1
17 78.7
18 76.3
19 .0
20 29.9
21 46.2
22 53.4
23 60.6
24 60.3
25 60.0
26 58.7
27 100.9
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)


494 147

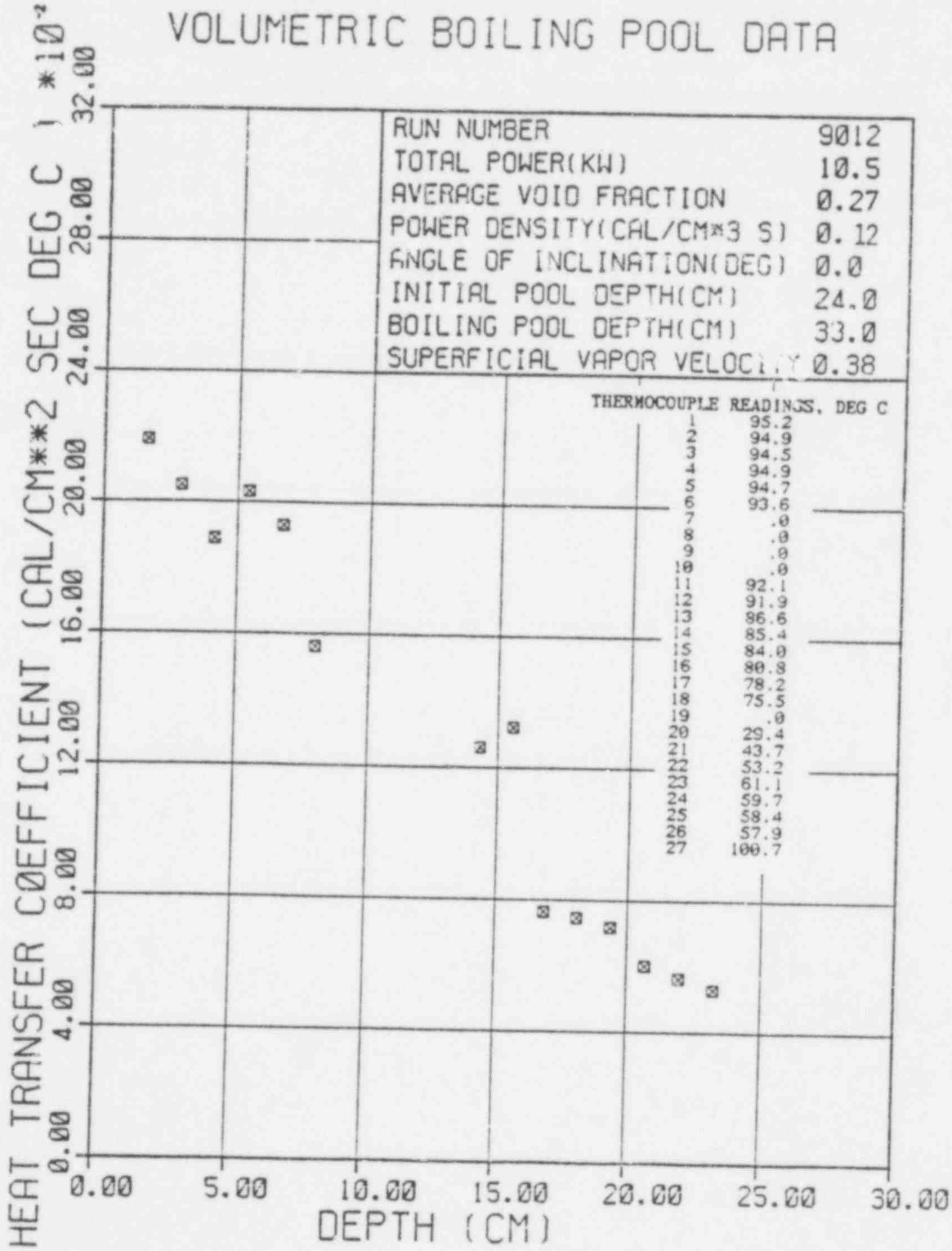
RUN NUMBER... 9012

| | |
|---|---|
| AVERAGE VOID FRACTION.......... | .27 |
| INITIAL POOL DEPTH(CM)........ | 24.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .12 |
| SUPERFICIAL VAPOR VELOCITY.... | .38 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)............ | 14429. |
| PRANDTL NUMBER................ | 1.86 |
| TOTAL POWER(KW)............... | 10.5 |
| AVERAGE SURFACE TEMP(DEG C)... | 89.8 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.600 | .2189 | .0955 | .0805 | .1070 | 215.3 | .2227E+09 |
| 2.870 | .2050 | .0825 | .0663 | .0874 | 361.7 | .1285E+10 |
| 4.140 | .1888 | .0753 | .0588 | .0772 | 480.6 | .3859E+10 |
| 5.410 | .2032 | .0704 | .0539 | .0705 | 675.6 | .8610E+10 |
| 6.680 | .1930 | .0668 | .0504 | .0657 | 732.4 | .1621E+11 |
| 7.950 | .1561 | .0640 | .0477 | .0620 | 762.9 | .2732E+11 |
| 9.220 | | .0616 | .0455 | .0590 | | |
| 10.49 | | .0597 | .0437 | .0565 | | |
| 11.76 | | .0580 | .0421 | .0545 | | |
| 13.03 | | .0565 | .0408 | .0527 | | |
| 14.30 | .1263 | .0552 | .0397 | .0511 | 1109.8 | .1590E+12 |
| 15.57 | .1323 | .0541 | .0386 | .0497 | 1266.3 | .2053E+12 |
| 16.84 | .0765 | .0530 | .0377 | .0484 | 791.6 | .2597E+12 |
| 18.11 | .0746 | .0521 | .0369 | .0473 | 830.7 | .3230E+12 |
| 19.38 | .0718 | .0512 | .0361 | .0463 | 855.1 | .3958E+12 |
| 20.65 | .0602 | .0504 | .0354 | .0453 | 764.0 | .4788E+12 |
| 21.92 | .0563 | .0496 | .0348 | .0445 | 759.1 | .5727E+12 |
| 23.19 | .0530 | .0489 | .0342 | .0437 | 754.8 | .6781E+12 |
| 24.46 | | .0483 | .0336 | .0429 | | |



494 148

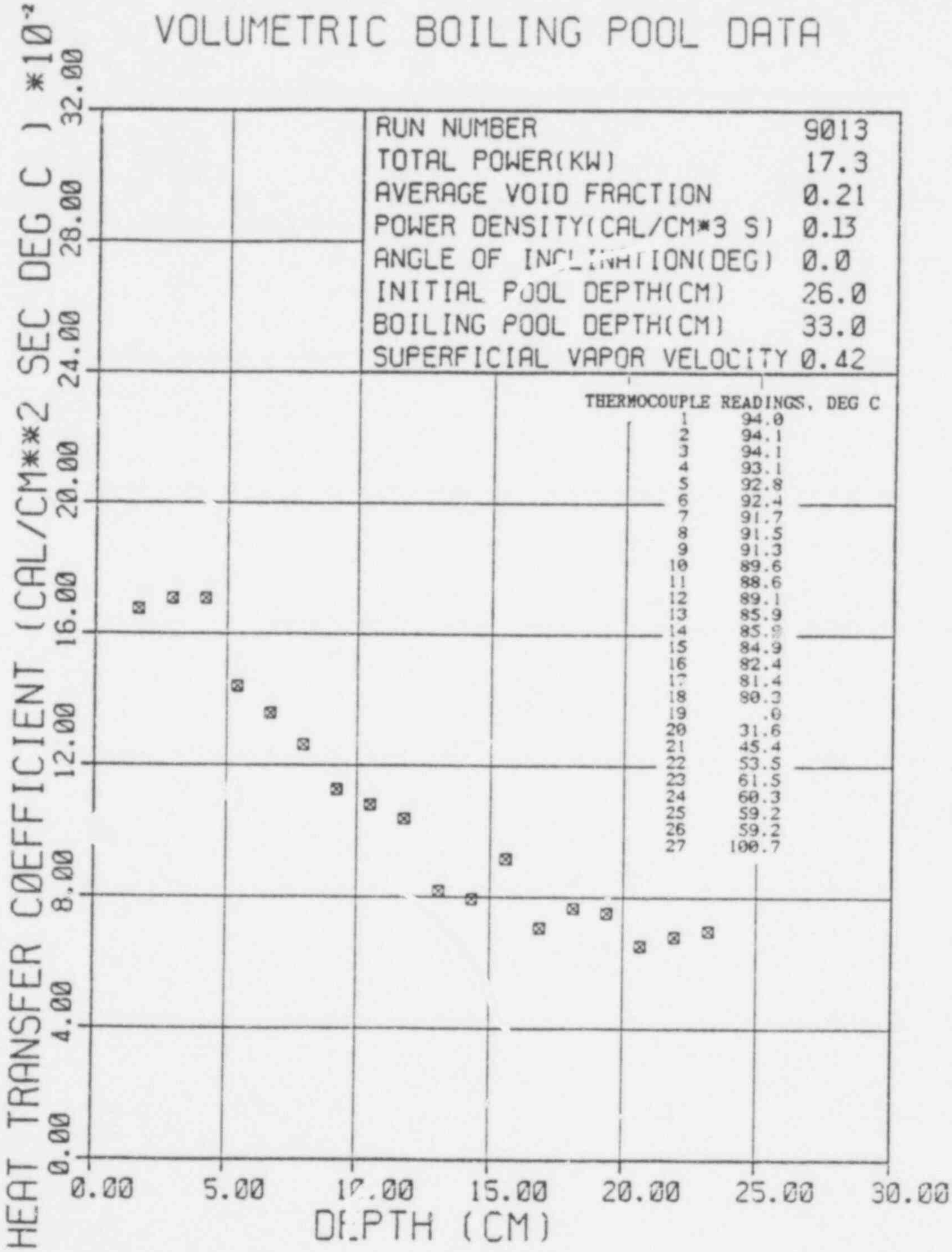

VOLUMETRIC BOILING POOL DATA
RUN NUMBER 9012
TOTAL POWER(KW) 10.5
AVERAGE VOID FRACTION 0.27
POWER DENSITY(CAL/CM*3 S) 0.12
ANGLE OF INCLINATION(DEG) 0.0
INITIAL POOL DEPTH(CM) 24.0
BOILING POOL DEPTH(CM) 33.0
SUPERFICIAL VAPOR VELOCITY 0.38
THERMOCOUPLE READINGS, DEG C
1 95.2
2 94.9
3 94.5
4 94.9
5 94.7
6 93.6
7 .0
8 .0
9 .0
10 .0
11 92.1
12 91.9
13 86.6
14 85.4
15 84.0
16 80.8
17 78.2
18 75.5
19 .0
20 29.4
21 43.7
22 53.2
23 61.1
24 59.7
25 58.4
26 57.9
27 100.7
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

494 149

RUN NUMBER... 9013

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .21 |
| INITIAL POOL DEPTH(CM)........ | 26.0 |
| BOILING POOL DEPTH(CM)........ | 33.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .13 |
| SUPERFICIAL VAPOR VELOCITY ... | .42 |
| ANGLE OF INCLINATION(DEGREES). | .00 |
| POOL VOLUME(CM**3)........... | 15631. |
| PRANDTL NUMBER................ | 1.87 |
| TOTAL POWER(KW)............... | 17.3 |
| AVERAGE SURFACE TEMP(DEG C)... | 89.1 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.600 | .1677 | .0896 | .0788 | .1051 | 164.9 | .1727E+09 |
| 2.870 | .1707 | .0774 | .0645 | .0856 | 301.2 | .9966E+09 |
| 4.140 | .1707 | .0706 | .0571 | .0755 | 434.5 | .2992E+10 |
| 5.410 | .1440 | .0661 | .0523 | .0689 | 479.0 | .6676E+10 |
| 6.680 | .1358 | .0627 | .0488 | .0641 | 557.7 | .1257E+11 |
| 7.950 | .1263 | .0600 | .0462 | .0604 | 617.2 | .2118E+11 |
| 9.220 | .1126 | .0578 | .0440 | .0575 | 638.5 | .3304E+11 |
| 10.49 | .1081 | .0560 | .0422 | .0551 | 697.0 | .4867E+11 |
| 11.76 | .1037 | .0544 | .0407 | .0530 | 749.9 | .6857E+11 |
| 13.03 | .0817 | .0530 | .0394 | .0512 | 654.7 | .9327E+11 |
| 14.30 | .0794 | .0518 | .0383 | .0497 | 698.2 | .1233E+12 |
| 15.57 | .0917 | .0507 | .0373 | .0483 | 877.4 | .1591E+12 |
| 16.84 | .0707 | .0497 | .0364 | .0471 | 731.7 | .2013E+12 |
| 18.11 | .0766 | .0488 | .0355 | .0459 | 852.5 | .2504E+12 |
| 19.38 | .0752 | .0480 | .0348 | .0449 | 895.9 | .3069E+12 |
| 20.65 | .0653 | .0473 | .0341 | .0440 | 828.7 | .3712E+12 |
| 21.92 | .0679 | .0466 | .0335 | .0432 | 915.2 | .4440E+12 |
| 23.19 | .0698 | .0459 | .0329 | .0424 | 995.0 | .5258E+12 |
| 24.46 | | .0453 | .0324 | .0416 | | |


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 9013
TOTAL POWER(KW) 17.3
AVERAGE VOID FRACTION 0.21
POWER DENSITY(CAL/CM*3 S) 0.13
ANGLE OF INCLINATION(DEG) 0.0
INITIAL POOL DEPTH(CM) 26.0
BOILING POOL DEPTH(CM) 33.0
SUPERFICIAL VAPOR VELOCITY 0.42
THERMOCOUPLE READINGS, DEG C
1 94.0
2 94.1
3 94.1
4 93.1
5 92.8
6 92.4
7 91.7
8 91.5
9 91.3
10 89.6
11 88.6
12 89.1
13 85.9
14 85.9
15 84.9
16 82.4
17 81.4
18 80.3
19 .0
20 31.6
21 45.4
22 53.5
23 61.5
24 60.3
25 59.2
26 59.2
27 100.7
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00 5.00 10.00 15.00 20.00 25.00 30.00
DEPTH (CM)

494 151

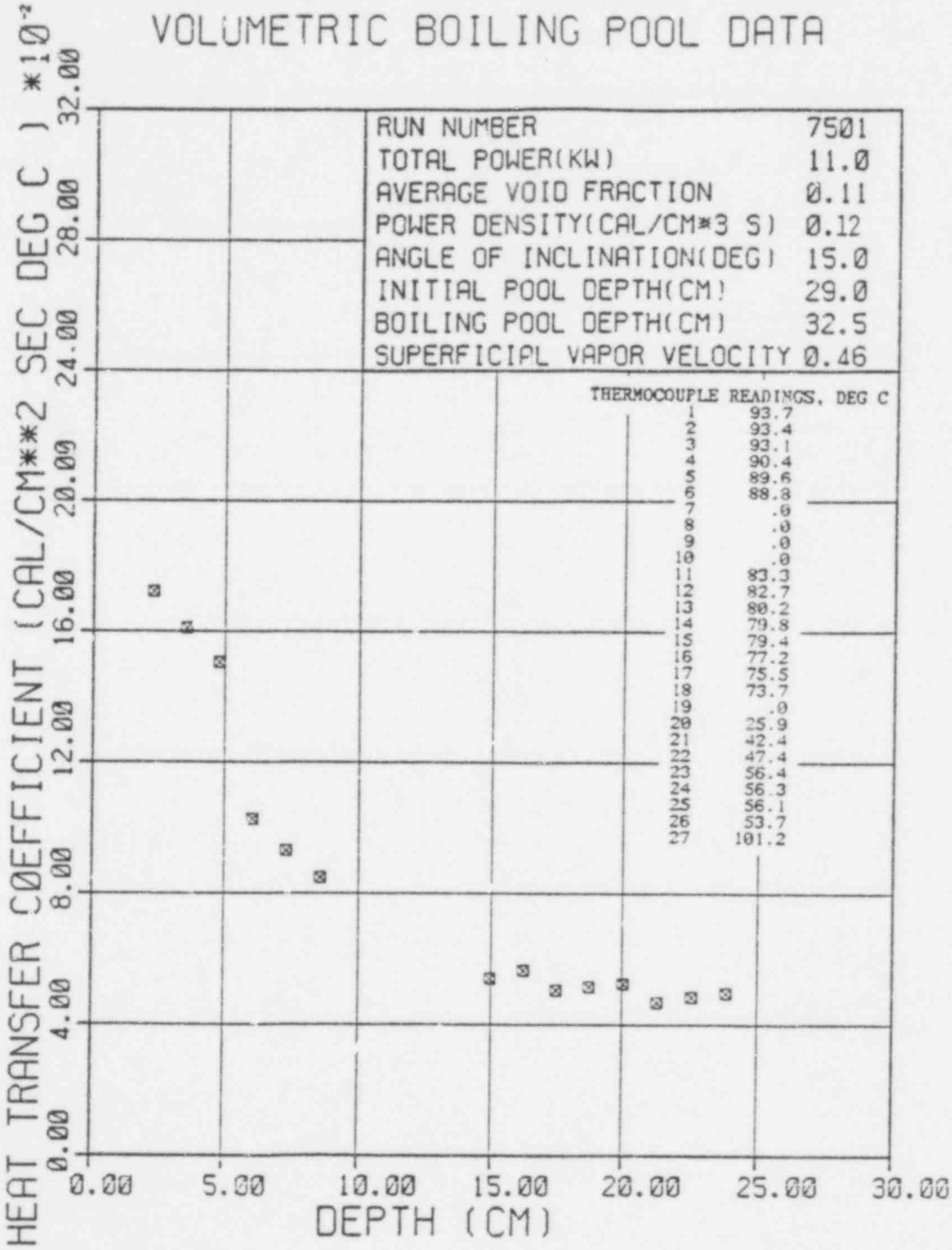
## RUN NUMBER... 7501

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .11 |
| INITIAL POOL DEPTH(CM)........ | 29.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .12 |
| SUPERFICIAL VAPOR VELOCITY.... | .46 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 19463. |
| PRANDTL NUMBER................ | 1.91 |
| TOTAL POWER(KW)............... | 11.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 84.7 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .1722 | .0691 | .0636 | .0853 | 238.0 | .2302E+09 |
| 3.516 | .1610 | .0618 | .0544 | .0727 | 348.4 | .8829E+09 |
| 4.786 | .1507 | .0572 | .0489 | .0652 | 443.8 | .2227E+10 |
| 6.056 | .1025 | .0539 | .0452 | .0600 | 382.1 | .4511E+10 |
| 7.326 | .0930 | .0514 | .0424 | .0562 | 419.5 | .7985E+10 |
| 8.596 | .0848 | .0494 | .0402 | .0532 | 448.5 | .1290E+11 |
| 9.866 | | .0477 | .0384 | .0507 | | |
| 11.14 | | .0463 | .0369 | .0486 | | |
| 12.41 | | .0451 | .0356 | .0469 | | |
| 13.68 | | .0440 | .0345 | .0453 | | |
| 14.95 | .0539 | .0430 | .0335 | .0440 | 496.0 | .6780E+11 |
| 16.22 | .0564 | .0421 | .0326 | .0428 | 562.5 | .8659E+11 |
| 17.49 | .0504 | .0414 | .0318 | .0417 | 542.6 | .1086E+12 |
| 18.76 | .0514 | .0406 | .0311 | .0407 | 593.2 | .[illegible]340E+12 |
| 20.03 | .0523 | .0400 | .0304 | .0398 | 644.9 | .1631E+12 |
| 21.30 | .0468 | .0394 | .0298 | .0390 | 613.5 | .1961E+12 |
| 22.57 | .0485 | .0388 | .0293 | .0383 | 673.4 | .2333E+12 |
| 23.84 | .0497 | .0383 | .0288 | .0376 | 728.4 | .2750E+12 |
| 25.11 | | .0378 | .0283 | .0369 | | |



494 152

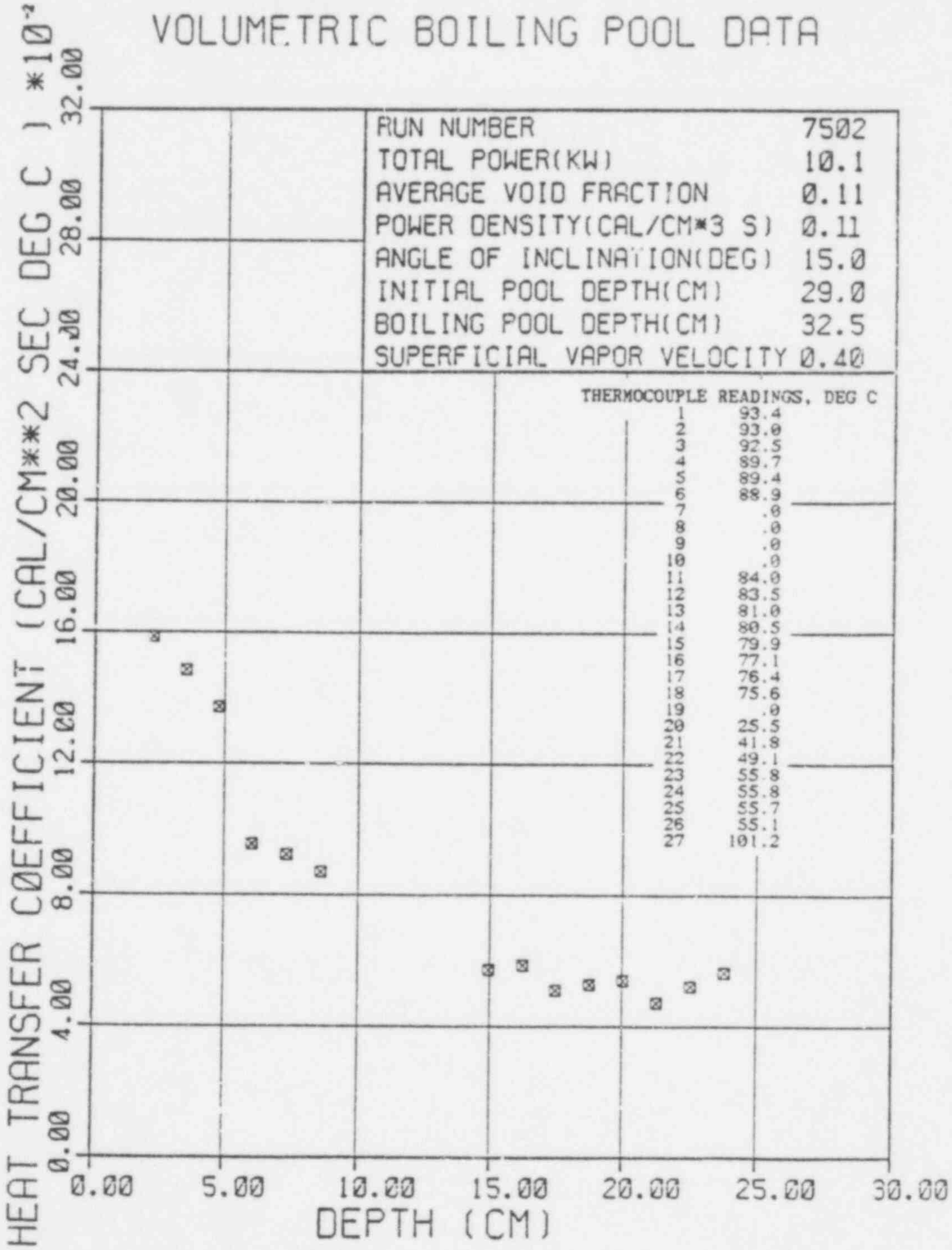

VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7501
TOTAL POWER(KW) 11.0
AVERAGE VOID FRACTION 0.11
POWER DENSITY(CAL/CM*3 S) 0.12
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 29.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.46
THERMOCOUPLE READINGS, DEG C
1 93.7
2 93.4
3 93.1
4 90.4
5 89.6
6 88.8
7 .0
8 .0
9 .0
10 .0
11 83.3
12 82.7
13 80.2
14 79.8
15 79.4
16 77.2
17 75.5
18 73.7
19 .0
20 25.9
21 42.4
22 47.4
23 56.4
24 56.3
25 56.1
26 53.7
27 101.2
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

RUN NUMBER... 7502

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .11 |
| INITIAL POOL DEPTH(CM)........ | 29.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .11 |
| SUPERFICIAL VAPOR VELOCITY.... | .40 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)........... | 19463. |
| PRANDTL NUMBER................ | 1.91 |
| TOTAL POWER(KW)............... | 10.1 |
| AVERAGE SURFACE TEMP(DEG C)... | 85.0 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .1585 | .0691 | .0619 | .0828 | 219.1 | .2305E+09 |
| 3.516 | .1484 | .0618 | .0530 | .0707 | 321.2 | .8842E+09 |
| 4.786 | .1373 | .0572 | .0477 | .0634 | 404.4 | .2230E+10 |
| 6.056 | .0954 | .0539 | .0441 | .0585 | 355.7 | .4517E+10 |
| 7.326 | .0921 | .0514 | .0414 | .0547 | 415.2 | .7997E+10 |
| 8.596 | .0870 | .0494 | .0393 | .0518 | 460.0 | .1292E+11 |
| 9.866 | | .0477 | .0375 | .0494 | | |
| 11.14 | | .0463 | .0361 | .0474 | | |
| 12.41 | | .0451 | .0348 | .0457 | | |
| 13.68 | | .0440 | .0337 | .0442 | | |
| 14.95 | .0571 | .0430 | .0328 | .0429 | 525.4 | .6790E+11 |
| 16.22 | .0587 | .0422 | .0319 | .0418 | 585.4 | .8672E+11 |
| 17.49 | .0510 | .0414 | .0312 | .0407 | 548.6 | .1087E+12 |
| 18.76 | .0528 | .0407 | .0305 | .0398 | 609.0 | .1342E+12 |
| 20.03 | .0541 | .0400 | .0299 | .0389 | 666.2 | .1633E+12 |
| 21.30 | .0473 | .0394 | .0293 | .0381 | 619.7 | .1964E+12 |
| 22.57 | .0521 | .0388 | .0287 | .0374 | 723.6 | .2337E+12 |
| 23.84 | .0563 | .0383 | .0283 | .0367 | 826.2 | .2754E+12 |
| 25.11 | | .0378 | .0278 | .0361 | | |

494 154


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7502
TOTAL POWER(KW) 10.1
AVERAGE VOID FRACTION 0.11
POWER DENSITY(CAL/CM*3 S) 0.11
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 29.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.40
THERMOCOUPLE READINGS, DEG C
1 93.4
2 93.0
3 92.5
4 89.7
5 89.4
6 88.9
7 .0
8 .0
9 .0
10 .0
11 84.0
12 83.5
13 81.0
14 80.5
15 79.9
16 77.1
17 76.4
18 75.6
19 .0
20 25.5
21 41.8
22 49.1
23 55.8
24 55.8
25 55.7
26 55.1
27 101.2
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10⁻²
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

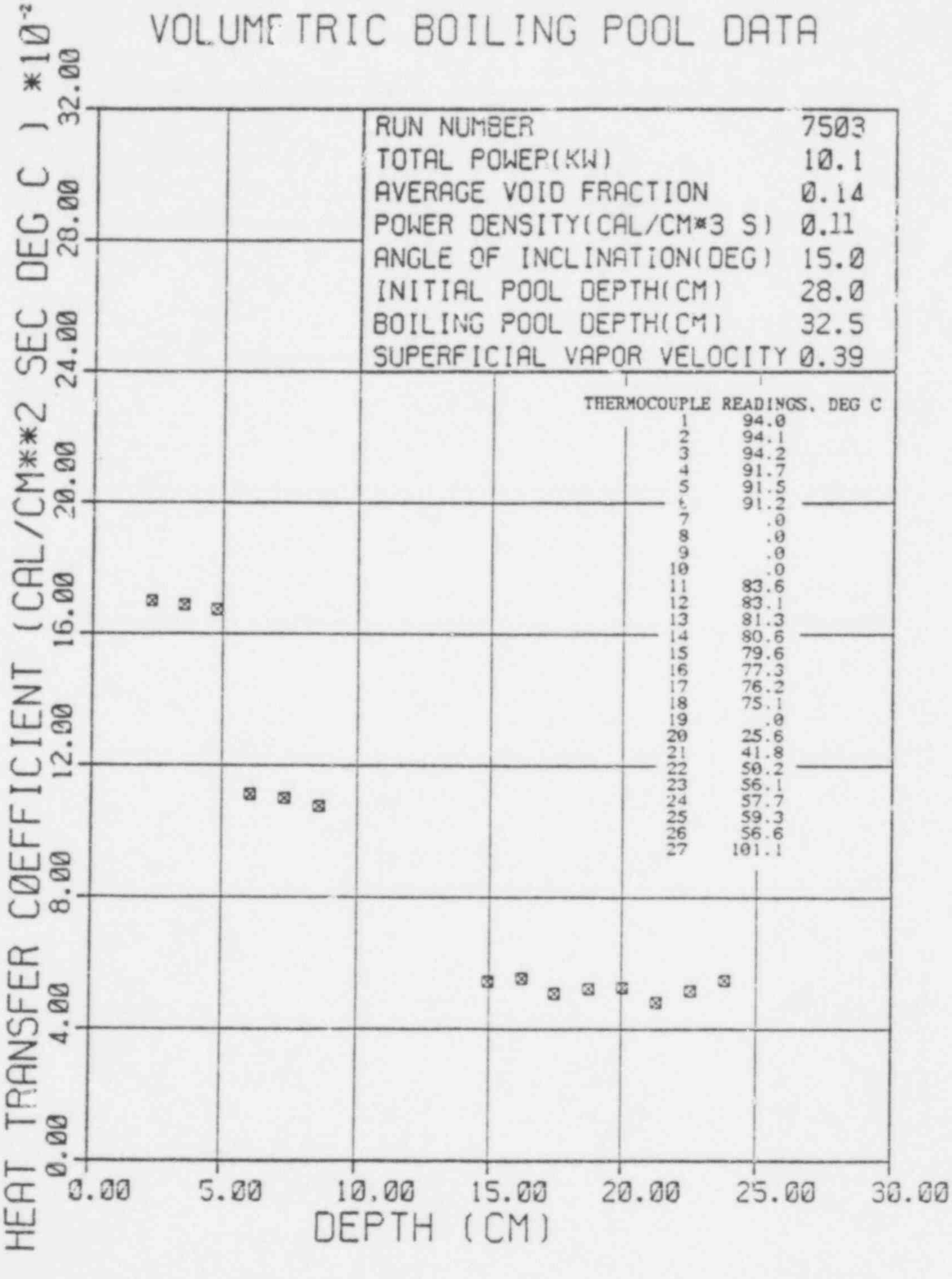
494 155

## RUN NUMBER... 7503

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .14 |
| INITIAL POOL DEPTH(CM)........ | 28.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .11 |
| SUPERFICIAL VAPOR VELOCITY.... | .39 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 18724. |
| PRANDTL NUMBER................ | 1.90 |
| TOTAL POWER(KW)............... | 10.1 |
| AVERAGE SURFACE TEMP(DEG C)... | 85.7 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .1701 | .0737 | .0641 | .0855 | 235.0 | .2972E+09 |
| 3.516 | .1688 | .0659 | .0550 | .0731 | 365.2 | .1140E+10 |
| 4.786 | .1675 | .0610 | .0496 | .0656 | 493.3 | .2875E+10 |
| 6.056 | .1113 | .0575 | .0459 | .0605 | 414.6 | .5825E+10 |
| 7.326 | .1101 | .0548 | .0431 | .0567 | 496.2 | .1031E+11 |
| 8.596 | .1075 | .0527 | .0409 | .0537 | 568.6 | .1666E+11 |
| 9.866 | | .0509 | .0391 | .0513 | | |
| 11.14 | | .0494 | .0376 | .0492 | | |
| 12.41 | | .0481 | .0363 | .0475 | | |
| 13.68 | | .0469 | .0352 | .0459 | | |
| 14.95 | .0544 | .0459 | .0342 | .0446 | 499.9 | .5754E+11 |
| 16.22 | .0555 | .0449 | .0333 | .0434 | 553.5 | .1118E+12 |
| 17.49 | .0507 | .0441 | .0326 | .0423 | 545.5 | .1402E+12 |
| 18.76 | .0523 | .0433 | .0318 | .0413 | 603.3 | .1730E+12 |
| 20.03 | .0526 | .0426 | .0312 | .0405 | 647.5 | .2106E+12 |
| 21.30 | .0482 | .0420 | .0306 | .0396 | 630.9 | .2532E+12 |
| 22.57 | .0516 | .0414 | .0300 | .0389 | 716.4 | .3013E+12 |
| 23.84 | .0548 | .0408 | .0295 | .0382 | 803.0 | .3551E+12 |
| 25.11 | | .0403 | .0291 | .0375 | | |

494 156


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7503
TOTAL POWER(KW) 10.1
AVERAGE VOID FRACTION 0.14
POWER DENSITY(CAL/CM*3 S) 0.11
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 28.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.39
THERMOCOUPLE READINGS, DEG C
1 94.0
2 94.1
3 94.2
4 91.7
5 91.5
6 91.2
7 .0
8 .0
9 .0
10 .0
11 83.6
12 83.1
13 81.3
14 80.6
15 79.6
16 77.3
17 76.2
18 75.1
19 .0
20 25.6
21 41.8
22 50.2
23 56.1
24 57.7
25 59.3
26 56.6
27 101.1
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00 5.00 10.00 15.00 20.00 25.00 30.00
DEPTH (CM)

494 157

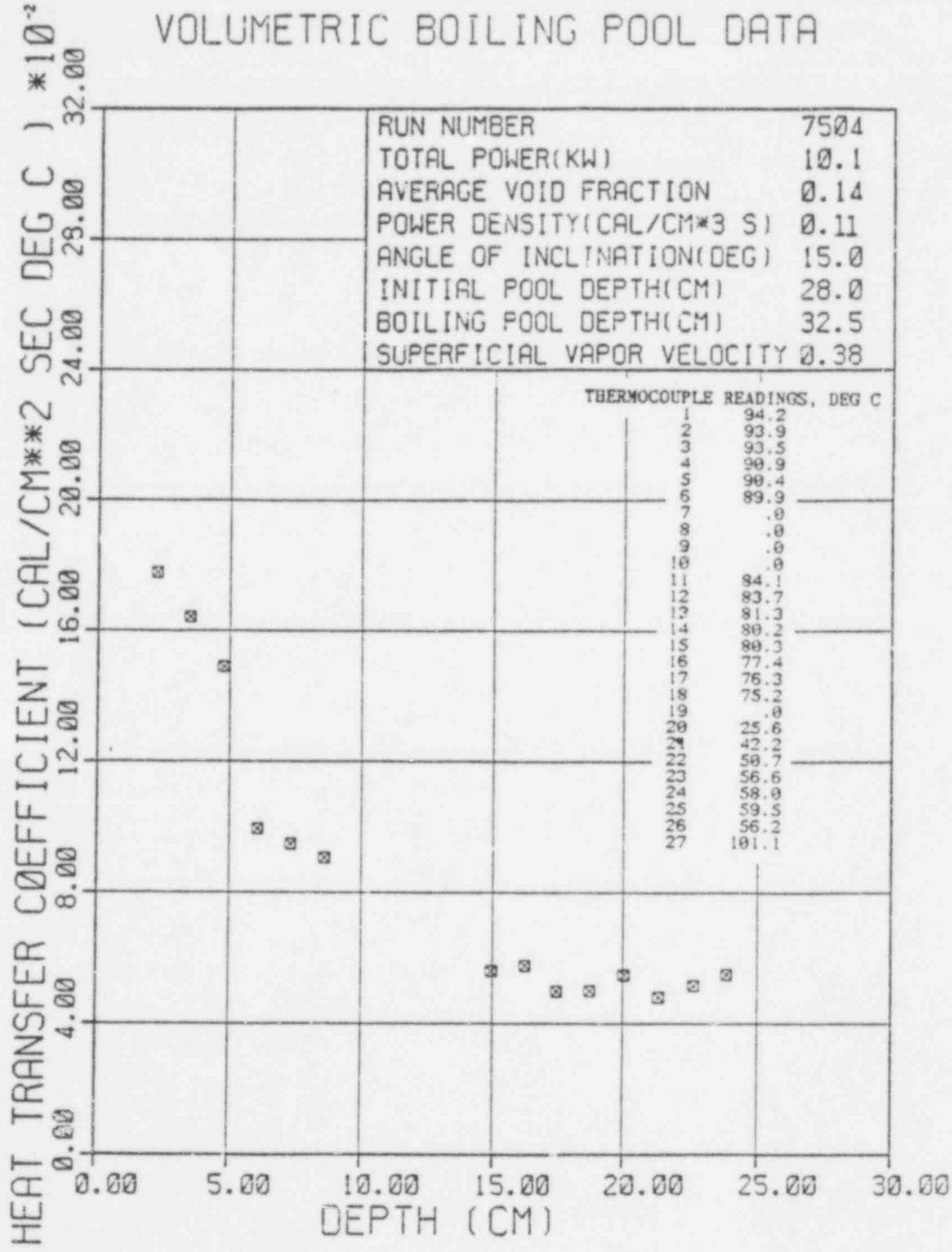
**RUN NUMBER... 7504**

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .14 |
| INITIAL POOL DEPTH(CM)........ | 23.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .11 |
| SUPERFICIAL VAPOR VELOCITY.... | .38 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 18724. |
| PRANDTL NUMBER................ | 1.90 |
| TOTAL POWER(KW)............... | 10.1 |
| AVERAGE SURFACE TEMP(DEG C)... | 85.5 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .1778 | .0736 | .0637 | .0850 | 245.7 | .2970E+09 |
| 3.516 | .1641 | .0658 | .0547 | .0727 | 355.1 | .1139E+10 |
| 4.786 | .1491 | .0610 | .0494 | .0653 | 439.1 | .2872E+10 |
| 6.056 | .0994 | .0575 | .0457 | .0602 | 370.3 | .5819E+10 |
| 7.326 | .0947 | .0548 | .0429 | .0564 | 427.1 | .1030E+11 |
| 8.596 | .0905 | .0527 | .0407 | .0535 | 478.7 | .1664E+11 |
| 9.866 | | .0509 | .0389 | .0510 | | |
| 11.14 | | .0494 | .0374 | .0490 | | |
| 12.41 | | .0480 | .0362 | .0472 | | |
| 13.68 | | .0469 | .0351 | .0457 | | |
| 14.95 | .0560 | .0459 | .0341 | .0444 | 514.6 | .8746E+11 |
| 16.22 | .0576 | .0449 | .0332 | .0432 | 574.5 | .1117E+12 |
| 17.49 | .0499 | .0441 | .0324 | .0421 | 536.8 | .1401E+12 |
| 18.76 | .0499 | .0433 | .0317 | .0412 | 576.4 | .1728E+12 |
| 20.03 | .0547 | .0426 | .0311 | .0403 | 674.5 | .2104E+12 |
| 21.30 | .0479 | .0420 | .0305 | .0395 | 628.3 | .2530E+12 |
| 22.57 | .0516 | .0414 | .0299 | .0387 | 716.3 | .3010E+12 |
| 23.84 | .0549 | .0408 | .0294 | .0380 | 805.6 | .3548E+12 |
| 25.11 | | .0403 | .0290 | .0374 | | |



494 158

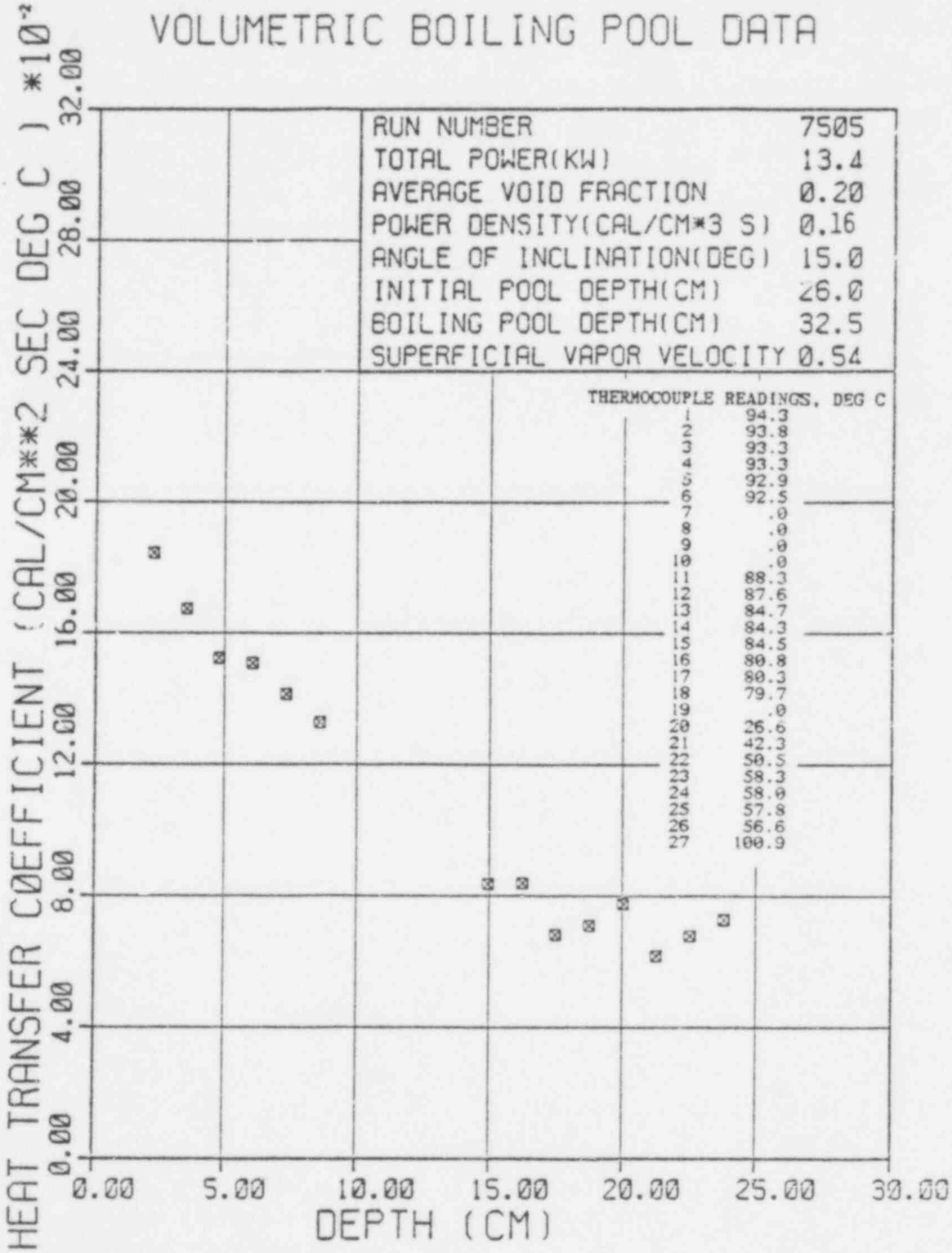

VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7504
TOTAL POWER(KW) 10.1
AVERAGE VOID FRACTION 0.14
POWER DENSITY(CAL/CM*3 S) 0.11
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 28.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.38
THERMOCOUPLE READINGS, DEG C
1 94.2
2 93.9
3 93.5
4 90.9
5 90.4
6 89.9
7 .0
8 .0
9 .0
10 .0
11 84.1
12 83.7
13 81.3
14 80.2
15 80.3
16 77.4
17 76.3
18 75.2
19 .0
20 25.6
21 42.2
22 50.7
23 56.6
24 58.0
25 59.5
26 56.2
27 101.1
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

RUN NUMBER... 7505

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .20 |
| INITIAL POOL DEPTH(CM)........ | 26.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .16 |
| SUPERFICIAL VAPOR VELOCITY.... | .54 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 17261. |
| PRANDTL NUMBER................ | 1.87 |
| TOTAL POWER(KW)............... | 13.44 |
| AVERAGE SURFACE TEMP(DEG C)... | 88.5 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .1844 | .0811 | .0724 | .0969 | 254.7 | .4345E+09 |
| 3.516 | .1673 | .0725 | .0620 | .0827 | 361.8 | .1667E+10 |
| 4.786 | .1525 | .0671 | .0559 | .0742 | 448.8 | .4203E+10 |
| 6.056 | .1508 | .0633 | .0516 | .0684 | 561.6 | .8514E+10 |
| 7.326 | .1414 | .0603 | .0485 | .0640 | 636.9 | .1507E+11 |
| 8.596 | .1328 | .0579 | .0460 | .0606 | 702.2 | .2435E+11 |
| 9.866 | | .0560 | .0439 | .0578 | | |
| 11.14 | | .0543 | .0422 | .0555 | | |
| 12.41 | | .0529 | .0408 | .0535 | | |
| 13.68 | | .0516 | .0395 | .0518 | | |
| 14.95 | .0835 | .0505 | .0384 | .0502 | 767.6 | .1280E+12 |
| 16.22 | .0837 | .0494 | .0374 | .0489 | 835.0 | .1634E+12 |
| 17.49 | .0682 | .0485 | .0365 | .0477 | 732.8 | .2049E+12 |
| 18.76 | .0710 | .0477 | .0357 | .0466 | 819.4 | .2529E+12 |
| 20.03 | .0777 | .0469 | .0350 | .0455 | 956.6 | .3078E+12 |
| 21.30 | .0618 | .0462 | .0343 | .0446 | 809.7 | .3702E+12 |
| 22.57 | .0678 | .0455 | .0337 | .0438 | 940.1 | .4404E+12 |
| 23.84 | .0729 | .0449 | .0331 | .0430 | 1068.3 | .5191E+12 |
| 25.11 | | .0443 | .0325 | .0422 | | |

494 160


VOLUMETRIC BOILING POOL DATA
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C) *10⁻²
32.00
28.00
24.00
20.00
16.00
12.00
8.00
4.00
0.00
RUN NUMBER 7505
TOTAL POWER(KW) 13.4
AVERAGE VOID FRACTION 0.20
POWER DENSITY(CAL/CM*3 S) 0.16
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 26.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.54
THERMOCOUPLE READINGS, DEG C
1 94.3
2 93.8
3 93.3
4 93.3
5 92.9
6 92.5
7 .0
8 .0
9 .0
10 .0
11 88.3
12 87.6
13 84.7
14 84.3
15 84.5
16 80.8
17 80.3
18 79.7
19 .0
20 26.6
21 42.3
22 50.5
23 58.3
24 58.0
25 57.8
26 56.6
27 100.9
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

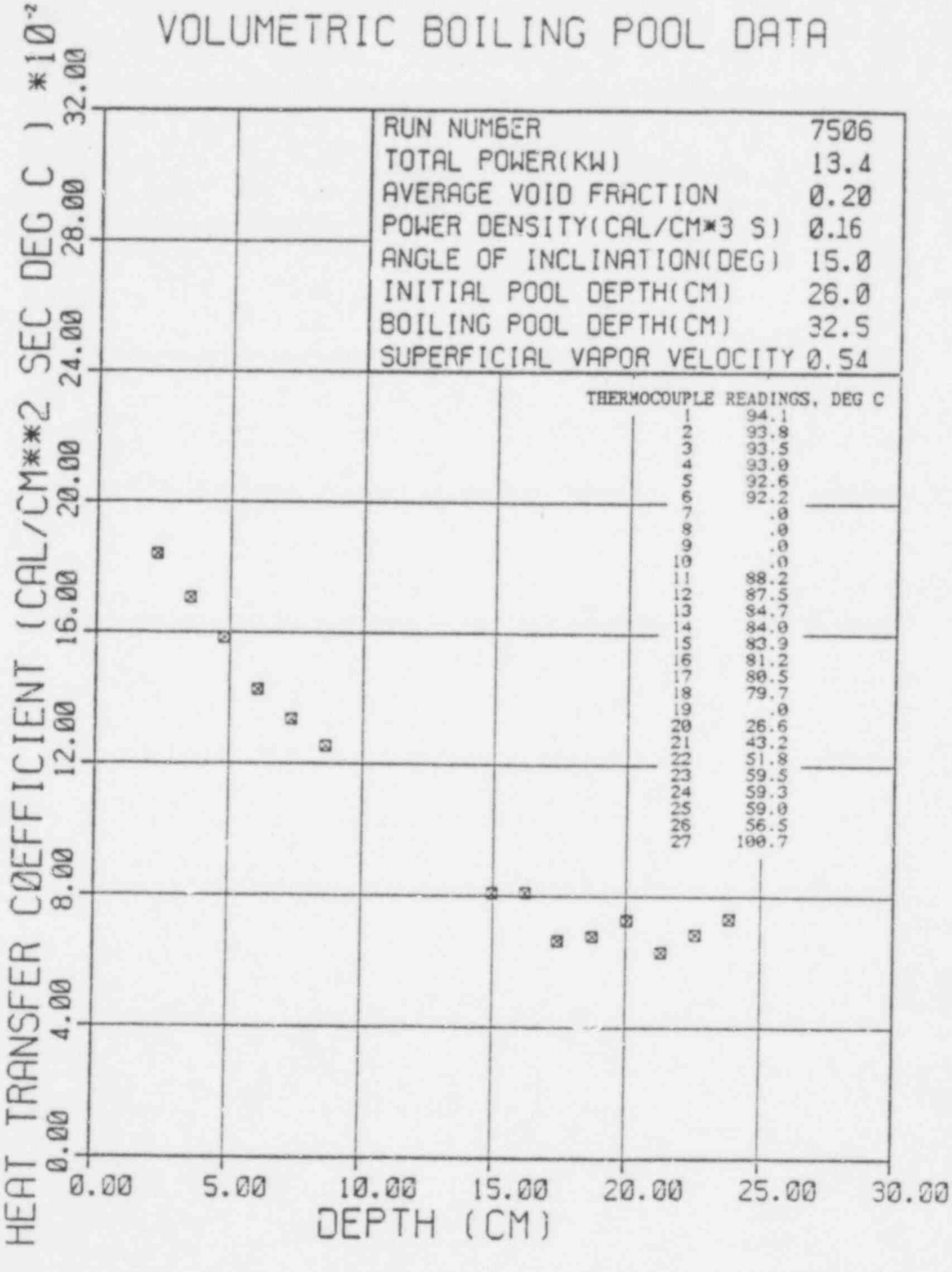
494 161

RUN NUMBER... 7506

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .20 |
| INITIAL POOL DEPTH(CM)........ | 26.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS.(CAL/CM3 SEC). | ,16 |
| SUPERFICIAL VAPOR VELOCITY.... | .54 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| OOL VOLUME(CM**3)............ | 17261. |
| PRANDTL NUMBER................ | 1.88 |
| TOTAL POWER(KW)............... | 13.44 |
| AVERAGE SURFACE TEMP(DEG C)... | 88.4 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .1839 | .0810 | .0724 | .0968 | 254.1 | .4339E+09 |
| 3.516 | .1706 | .0724 | .0629 | .0826 | 368.9 | .1664E+10 |
| 4.786 | .1584 | .0671 | .0558 | .0742 | 466.3 | .4197E+10 |
| 6.056 | .1426 | .0632 | .0516 | .0684 | 530.9 | .8503E+10 |
| 7.326 | .1335 | .0603 | .0484 | .0640 | 601.5 | .1505E+11 |
| 8.596 | .1253 | .0579 | .0459 | .0606 | 662.5 | .2431E+11 |
| 9.866 | | .0560 | .0439 | .0578 | | |
| 11.14 | | .0543 | .0422 | .0555 | | |
| 12.41 | | .0528 | .0408 | .0535 | | |
| 13.68 | | .0516 | .0395 | .0517 | | |
| 14.95 | .0808 | .0504 | .0384 | .0502 | 742.2 | .1278E+12 |
| 16.22 | .0810 | .0494 | .0374 | .0489 | 808.0 | .1632E+12 |
| 17.49 | .0664 | .0485 | .0365 | .0476 | 713.8 | .2046E+12 |
| 18.76 | .0678 | .0477 | .0357 | .0465 | 781.8 | .2526E+12 |
| 20.03 | .0727 | .0469 | .0349 | .0455 | 895.3 | .3074E+12 |
| 21.30 | .0629 | .0462 | .0343 | .0446 | 823.8 | .3697E+12 |
| 22.57 | .0685 | .0455 | .0336 | .0438 | 949.9 | .4398E+12 |
| 23.84 | .0731 | .0449 | .0331 | .0430 | 1071.8 | .5184E+12 |
| 25.11 | | .0443 | .0325 | .0422 | | |

494 162


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7506
TOTAL POWER(KW) 13.4
AVERAGE VOID FRACTION 0.20
POWER DENSITY(CAL/CM*3 S) 0.16
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 26.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.54
THERMOCOUPLE READINGS, DEG C
1 94.1
2 93.8
3 93.5
4 93.0
5 92.6
6 92.2
7 .0
8 .0
9 .0
10 .0
11 88.2
12 87.5
13 84.7
14 84.0
15 83.9
16 81.2
17 80.5
18 79.7
19 .0
20 26.6
21 43.2
22 51.8
23 59.5
24 59.3
25 59.0
26 56.5
27 100.7
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DEPTH (CM)
0.00
5.00
10.00
15.00
20.00
25.00
30.00

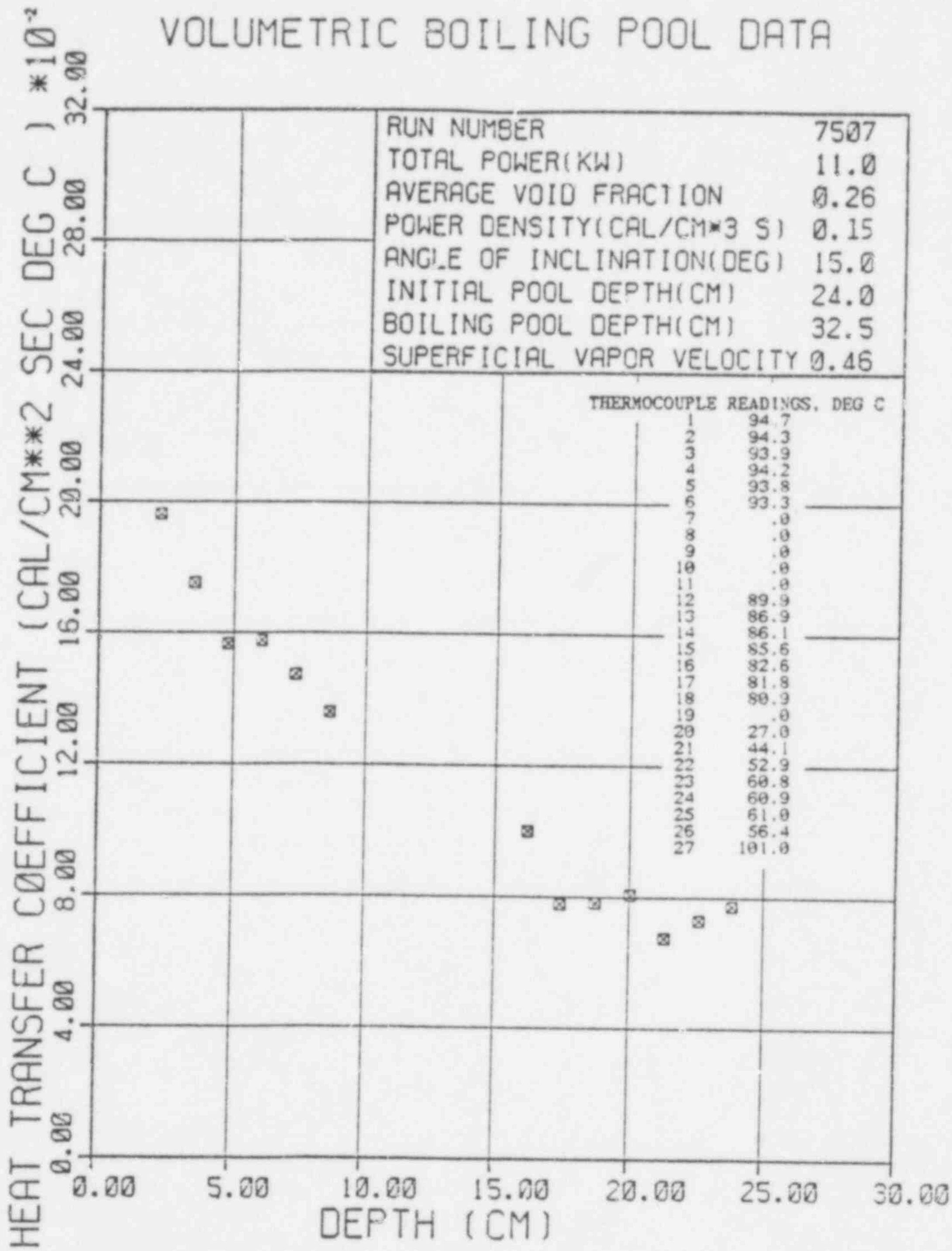
494 163

RUN NUMBER... 7507

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .26 |
| INITIAL POOL DEPTH(CM)........ | 24.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .15 |
| SUPERFICIAL VAPOR VELOCITY.... | .46 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 15818. |
| PRANDTL NUMBER................ | 1.86 |
| TOTAL POWER(KW)............... | 11.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 89.8 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .1963 | .0868 | .0734 | .0976 | 271.0 | .5718E+09 |
| 3.516 | .1752 | .0776 | .0631 | .0836 | 378.7 | .2193E+10 |
| 4.786 | .1566 | .0719 | .0570 | .0751 | 460.6 | .5531E+10 |
| 6.056 | .1576 | .0678 | .0528 | .0694 | 586.8 | .1121E+11 |
| 7.326 | .1472 | .0646 | .0496 | .0650 | 663.0 | .1984E+11 |
| 8.596 | .1357 | .0621 | .0471 | .0616 | 717.0 | .3204E+11 |
| 9.866 | | .0600 | .0451 | .0588 | | |
| 11.14 | | .0582 | .0434 | .0565 | | |
| 12.41 | | .0566 | .0419 | .0545 | | |
| 13.68 | | .0553 | .0406 | .0528 | | |
| 14.95 | | .0541 | .0395 | .0512 | | |
| 16.22 | .1000 | .0530 | .0385 | .0499 | 996.3 | |
| 17.49 | .0778 | .0520 | .0376 | .0486 | 836.7 | .2697E+12 |
| 18.76 | .0783 | .0511 | .0368 | .0475 | 902.6 | .3328E+12 |
| 20.03 | .0808 | .0503 | .0360 | .0465 | 995.2 | .4051E+12 |
| 21.30 | .0675 | .0495 | .0354 | .0456 | 884.2 | .4872E+12 |
| 22.57 | .0730 | .0488 | .0347 | .0447 | 1012.2 | .5796E+12 |
| 23.84 | .0774 | .0481 | .0342 | .0439 | 1134.2 | .6831E+12 |
| 25.11 | | .0475 | .0336 | .0432 | | |

494 164

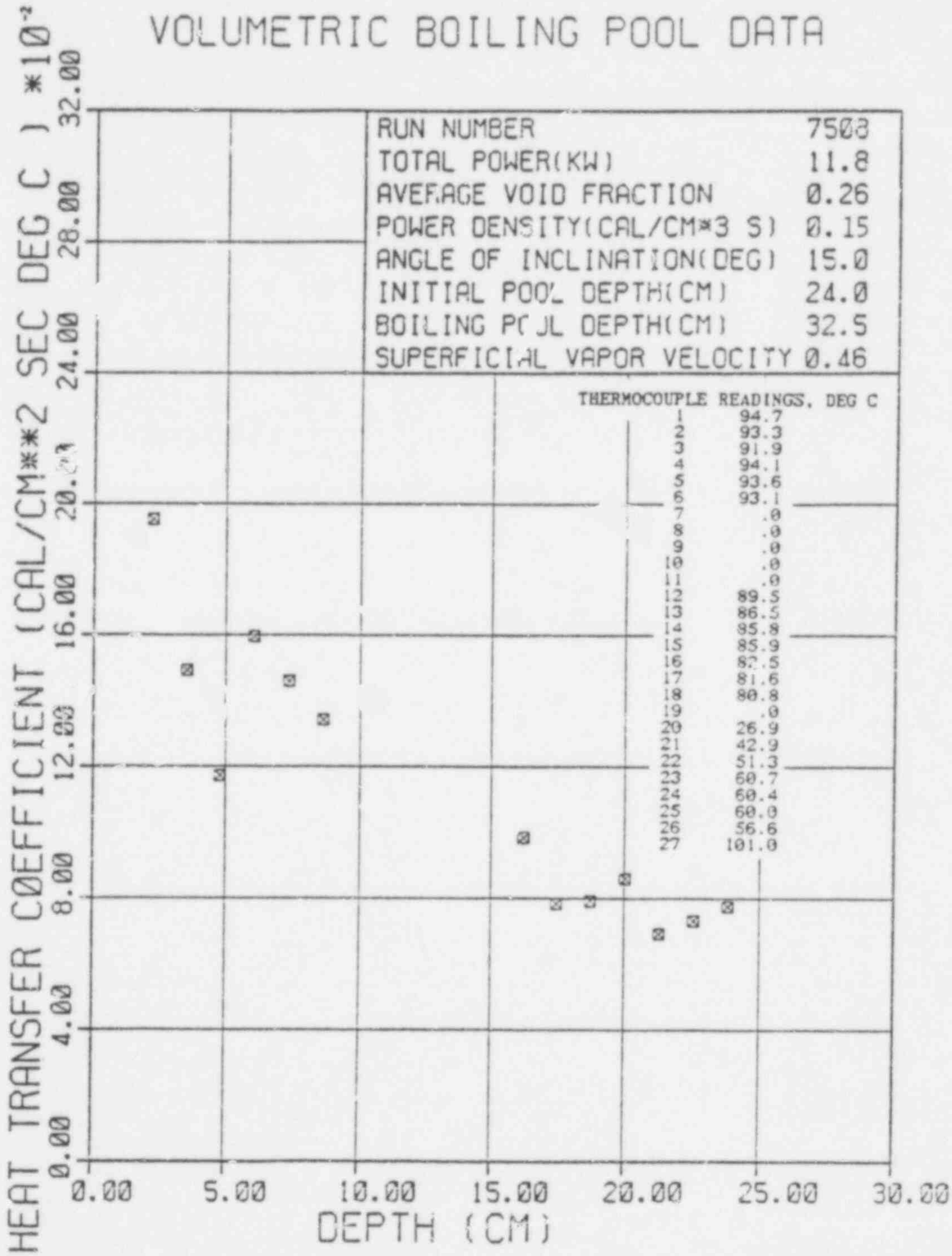

VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7507
TOTAL POWER(KW) 11.0
AVERAGE VOID FRACTION 0.26
POWER DENSITY(CAL/CM*3 S) 0.15
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 24.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.46
THERMOCOUPLE READINGS, DEG C
1 94.7
2 94.3
3 93.9
4 94.2
5 93.8
6 93.3
7 .0
8 .0
9 .0
10 .0
11 .0
12 89.9
13 86.9
14 86.1
15 85.6
16 82.6
17 81.8
18 80.9
19 .0
20 27.0
21 44.1
22 52.9
23 60.8
24 60.9
25 61.0
26 56.4
27 101.0
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

494 165

RUN NUMBER... 7508

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .26 |
| INITIAL POOL DEPTH(CM)........ | 24.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .15 |
| SUPERFICIAL VAPOR VELOCITY.... | .46 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 15818. |
| PRANDTL NUMBER................ | 1.87 |
| TOTAL POWER(KW)............... | [illegible].8 |
| AVERAGE SURFACE TEMP(DEG C)... | 89.4 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .1952 | .0868 | .0733 | .0976 | 269.6 | .5708E+09 |
| 3.516 | .1491 | .0776 | .0631 | .0835 | 322.3 | .2189E+10 |
| 4.786 | .1172 | .0718 | .0570 | .0751 | 344.8 | .5521E+10 |
| 6.056 | .1595 | .0677 | .0527 | .0693 | 594.0 | .1118E+11 |
| 7.326 | .1460 | .0646 | .0496 | .0650 | 657.5 | .1980E+11 |
| 8.596 | .1342 | .0621 | .0471 | .0616 | 709.0 | .3198E+11 |
| 9.866 | | .0600 | .0450 | .0588 | | |
| 11.14 | | .0582 | .0433 | .0565 | | |
| 12.41 | | .0566 | .0419 | .0545 | | |
| 13.68 | | .0553 | .0406 | .0527 | | |
| 14.95 | | .0540 | .0395 | .0512 | | |
| 16.22 | .0984 | .0530 | .0385 | .0498 | 981.3 | .2147E+12 |
| 17.49 | .0784 | .0520 | .0376 | .0486 | 842.4 | .2692E+12 |
| 18.76 | .0792 | .0511 | .0368 | .0475 | 913.4 | .3322E+12 |
| 20.03 | .0859 | .0502 | .0360 | .0465 | 1058.0 | .4044E+12 |
| 21.30 | .0691 | .0495 | .0353 | .0456 | 904.7 | .4863E+12 |
| 22.57 | .0733 | .0488 | .0347 | .0447 | 1016.5 | .5786E+12 |
| 23.84 | .0776 | .0481 | .0341 | .0439 | 1137.3 | .6819E+12 |
| 25.11 | | .0475 | .0336 | .0432 | | |


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7508
TOTAL POWER(KW) 11.8
AVERAGE VOID FRACTION 0.26
POWER DENSITY(CAL/CM*3 S) 0.15
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 24.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.46
THERMOCOUPLE READINGS, DEG C
1 94.7
2 93.3
3 91.9
4 94.1
5 93.6
6 93.1
7 .0
8 .0
9 .0
10 .0
11 .0
12 89.5
13 86.5
14 85.8
15 85.9
17 81.6
18 80.8
19 .0
20 26.9
21 42.9
22 51.3
23 60.7
24 60.4
25 60.0
26 56.6
27 101.0
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

## RUN NUMBER... 7509

AVERAGE VOID FRACTION......... .32

INITIAL POOL DEPTH(CM)........ 22.0

BOILING POOL DEPTH(CM)........ 32.5

VOL. POWER DENS.(CAL/CM3 SEC). .21

SUPERFICIAL VAPOR VELOCITY.... .59

ANGLE OF INCLINATION(DEGREES). 15.00

POOL VOLUME(CM**3)............ 14394.

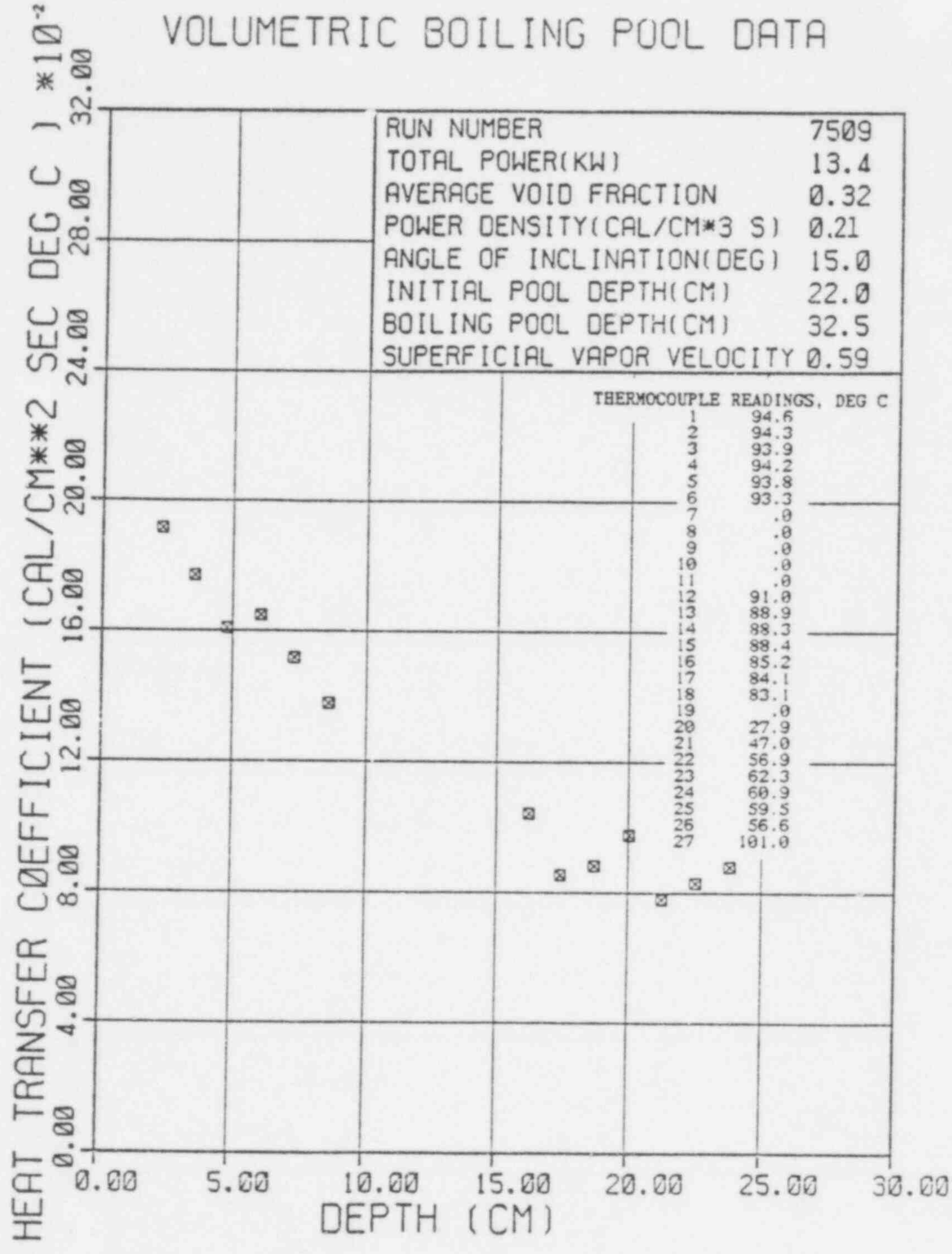
PRANDTL NUMBER................ 1.85

TOTAL POWER(KW)............... 13.44

AVERAGE SURFACE TEMP(DEG C)... 90.8

| [illegible] (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .1917 | .0917 | .0795 | .1061 | 264.6 | .7096E+09 |
| 3.516 | .1770 | .0820 | .0683 | .0907 | 382.5 | .2722E+10 |
| 4.756 | .1608 | .0759 | .0616 | .0815 | 473.0 | .6863E+10 |
| 6.056 | .1647 | .0715 | .0569 | .0751 | 613.1 | .1390E+11 |
| 7.326 | .1517 | .0682 | .0535 | .0704 | 683.0 | .2461E+11 |
| 8.596 | .1378 | .0655 | .0508 | .0667 | 727.9 | .3976E+11 |
| 9.866 | | .0633 | .0486 | .0636 | | |
| 11.14 | | .0614 | .0467 | .0611 | | |
| 12.41 | | .0598 | .0451 | .0589 | | |
| 13.68 | | .0584 | .0437 | .0570 | | |
| 14.95 | | .0571 | .0425 | .0554 | | |
| 16.22 | .1043 | .0559 | .0414 | .0539 | 1039.1 | .2669E+12 |
| 17.49 | .0854 | .0549 | .0404 | .0525 | 917.4 | .3347E+12 |
| 18.76 | .0882 | .0539 | .0395 | .0513 | 1016.7 | .4130E+12 |
| 20.03 | .0976 | .0531 | .0387 | .0502 | 1201.3 | .5027E+12 |
| 21.30 | .0781 | .0522 | .0380 | .0492 | 1021.5 | .6045E+12 |
| 22.57 | .0830 | .0515 | .0373 | .0483 | 1151.4 | .7193E+12 |
| 23.84 | .0881 | .0508 | .0367 | .0474 | 1290.1 | .8477E+12 |
| 25.11 | | .0501 | .0361 | .0466 | | |

VOLUMETRIC BOILING POOL DATA




494 169

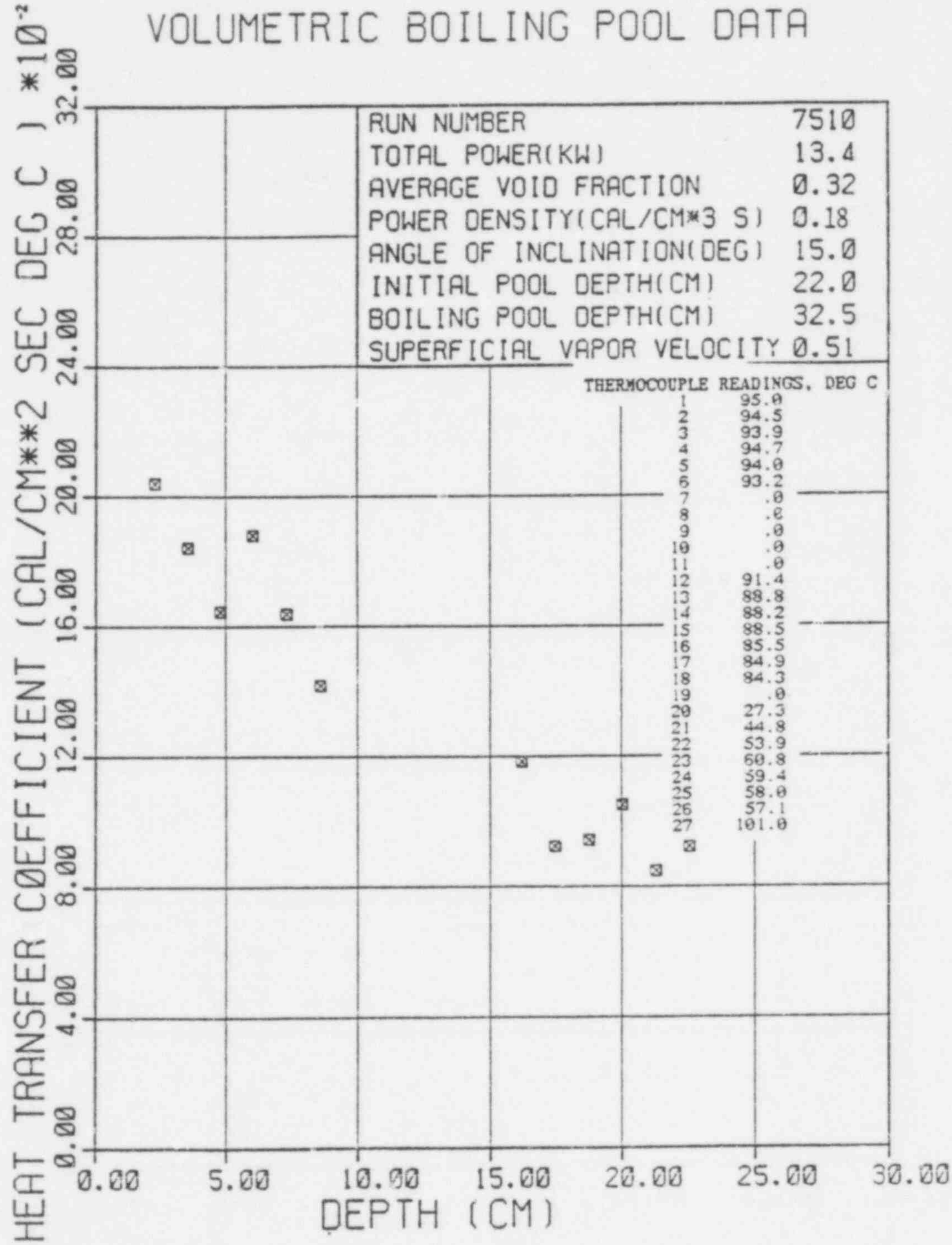
## RUN NUMBER... 7510

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .32 |
| INITIAL POOL DEPTH(CM)........ | 22.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .18 |
| SUPERFICIAL VAPOR VELOCITY.... | .51 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 14394. |
| PRANDTL NUMBER................ | 1.85 |
| TOTAL POWER(KW)............... | 13.44 |
| AVERAGE SURFACE TEMP(DEG C)... | 91.1 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .2039 | .0917 | .0775 | .1030 | 281.5 | .7105E+09 |
| 3.516 | .1843 | .0820 | .0666 | .0882 | 398.2 | .2725E+10 |
| 4.786 | .1646 | .0759 | .0601 | .0793 | 484.1 | .6873E+10 |
| 6.056 | .1881 | .0716 | .0557 | .0732 | 699.9 | .1392E+11 |
| 7.326 | .1639 | .0682 | .0523 | .0686 | 737.8 | .2465E+11 |
| 8.596 | .1418 | .0656 | .0497 | .0650 | 749.2 | .3981E+11 |
| 9.866 | | .0634 | .0476 | .0621 | | |
| 11.14 | | .0615 | .0458 | .0596 | | |
| 12.41 | | .0598 | .0442 | .0575 | | |
| 13.68 | | .0584 | .0429 | .0557 | | |
| 14.95 | | .0571 | .0417 | .0541 | | |
| 16.22 | .1184 | .0560 | .0406 | .0526 | 1179.5 | .2673E+12 |
| 17.49 | .0924 | .0549 | .0397 | .0513 | 992.3 | .3351E+12 |
| 18.76 | .0942 | .0540 | .0388 | .0502 | 1085.2 | .4136E+12 |
| 20.03 | .1050 | .0531 | .0381 | .0491 | 1292.4 | .5034E+12 |
| 21.30 | .0848 | .0523 | .0373 | .0481 | 1109.3 | .6054E+12 |
| 22.57 | .0921 | .0515 | .0367 | .0472 | 1277.2 | .7202E+12 |
| 23.84 | .0989 | .0508 | .0361 | .0464 | 1448.7 | .8488E+12 |
| 25.11 | | .0502 | .0355 | .0456 | | |



494 170


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7510
TOTAL POWER(KW) 13.4
AVERAGE VOID FRACTION 0.32
POWER DENSITY(CAL/CM*3 S) 0.18
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 22.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.51
THERMOCOUPLE READINGS, DEG C
1 95.0
2 94.5
3 93.9
4 94.7
5 94.0
6 93.2
7 .0
8 .0
9 .0
10 .0
11 .0
12 91.4
13 88.8
14 88.2
15 88.5
16 85.5
17 84.9
18 84.3
19 .0
20 27.3
21 44.8
22 53.9
23 60.8
24 59.4
25 58.0
26 57.1
27 101.0
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C) *10⁻²
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)



494 171

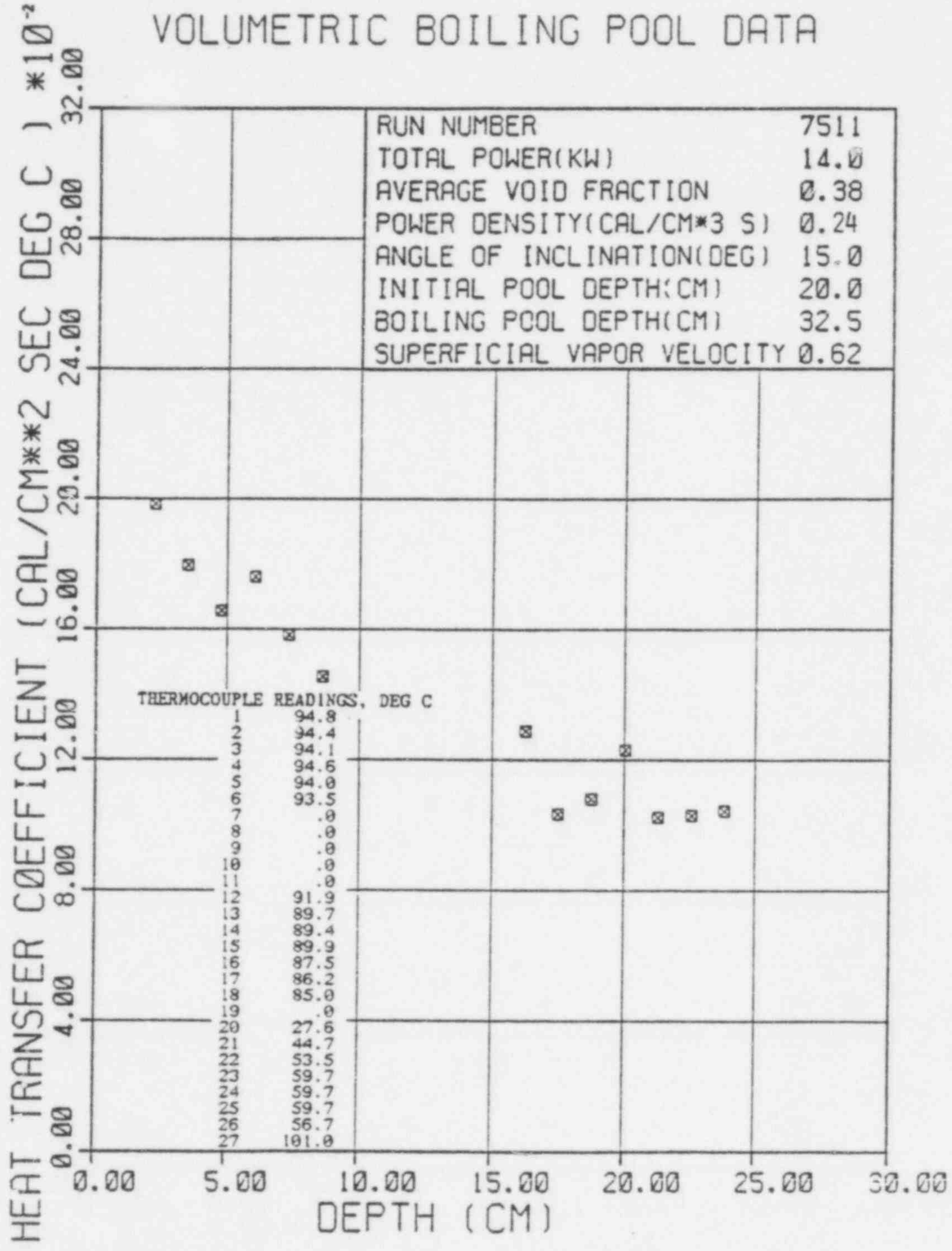
**RUN NUMBER... 7511**

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .38 |
| INITIAL POOL DEPTH(CM)........ | 20.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS. (CAL/CM3 SEC). | .24 |
| SUPERFICIAL VAPOR VELOCITY.... | .62 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 12989. |
| PRANDTL NUMBER................ | 1.84 |
| TOTAL POWER(KW)............... | 14.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 91.7 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .1984 | .0959 | .0826 | .1101 | 273.8 | .8482E+09 |
| 3.516 | .1795 | .0857 | .0709 | .0941 | 387.8 | .3253E+10 |
| 4.786 | .1656 | .0794 | .0640 | .0846 | 487.1 | .8204E+10 |
| 6.056 | .1760 | .0748 | .0592 | .0780 | 655.1 | .1662E+11 |
| 7.326 | .1582 | .0713 | .0556 | .0731 | 712.1 | .2942E+11 |
| 8.596 | .1455 | .0685 | .0528 | .0693 | 768.4 | .4753E+11 |
| 9.866 | | .0662 | .0505 | .0661 | | |
| 11.14 | | .0643 | .0486 | .0635 | | |
| 12.41 | | .0625 | .0469 | .0612 | | |
| 13.68 | | .0610 | .0455 | .0593 | | |
| 14.95 | | .0597 | .0442 | .0575 | | |
| 16.22 | .1289 | .0585 | .0431 | .0560 | 1284.2 | .3190E+12 |
| 17.49 | .1034 | .0574 | .0421 | .0546 | 1111.1 | .4000E+12 |
| 18.76 | .1081 | .0564 | .0412 | .0534 | 1245.4 | .4937E+12 |
| 20.03 | .1229 | .0555 | .0403 | .0522 | 1512.5 | .6009E+12 |
| 21.30 | .1024 | .0546 | .0395 | .0512 | 1339.2 | .7226E+12 |
| 22.57 | .1030 | .0539 | .0388 | .0502 | 1427.5 | .8597E+12 |
| 23.84 | .1043 | .0531 | .0382 | .0493 | 1527.7 | .1013E+13 |
| 25.11 | | .0524 | .0376 | .0485 | | |



494 172


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7511
TOTAL POWER(KW) 14.0
AVERAGE VOID FRACTION 0.38
POWER DENSITY(CAL/CM*3 S) 0.24
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 20.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.62
THERMOCOUPLE READINGS, DEG C
1 94.8
2 94.4
3 94.1
4 94.6
5 94.0
6 93.5
7 .0
8 .0
9 .0
10 .0
11 .0
12 91.9
13 89.7
14 89.4
15 89.9
16 87.5
17 86.2
18 85.0
19 .0
20 27.6
21 44.7
22 53.5
23 59.7
24 59.7
25 59.7
26 56.7
27 101.0
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10⁻²
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

494 173

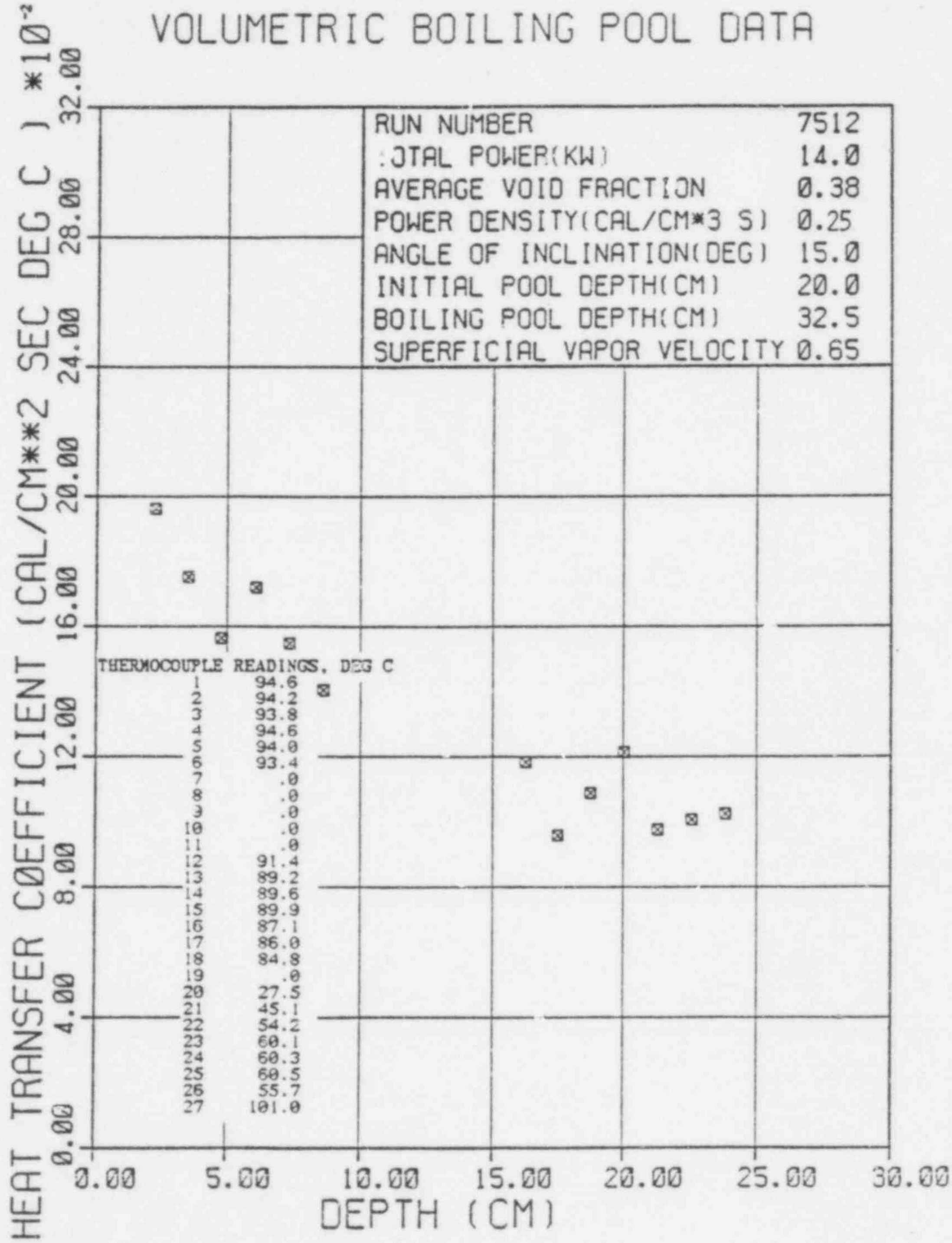
## RUN NUMBER... 7512

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .38 |
| INITIAL POOL DEPTH(CM)........ | 20.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .25 |
| SUPERFICIAL VAPOR VELOCITY.... | .65 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 12989. |
| PRANDTL NUMBER................ | 1.84 |
| TOTAL POWER(KW)............... | 14.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 91.5 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) | | | | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| | EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | | |
| 2.246 | 1962 | .0959 | .0833 | .1111 | 270.8 | .8474E+09 |
| 3.516 | .1752 | .0857 | .0715 | .0950 | 378.5 | .3250E+10 |
| 4.786 | .1565 | .0793 | .0645 | .0853 | 460.2 | .8197E+10 |
| 6.056 | .1720 | .0748 | .0596 | .0787 | 640.1 | [illegible]661E+11 |
| 7.326 | .1548 | .0715 | .0560 | .0737 | 696.9 | .[illegible]939E+11 |
| 8.596 | .1403 | .0685 | .0532 | .0698 | 741.1 | .4748E+11 |
| 9.866 | | .0662 | .0508 | .0667 | | |
| 11.14 | | .0642 | .0489 | .0640 | | |
| 12.41 | | .0625 | .0472 | .0617 | | |
| 13.68 | | .0610 | .0458 | .0597 | | |
| 14.95 | | .0597 | .0445 | .0580 | | |
| 16.22 | .1185 | .0585 | .0433 | .0564 | 1180.5 | .3188E+12 |
| 17.49 | .0958 | .0574 | .0423 | .0550 | 1028.8 | .3997E+12 |
| 18.76 | .1088 | .0564 | .0414 | .0538 | 1254.3 | .4932E+12 |
| 20.03 | .1215 | .0555 | .0406 | .0526 | 1494.7 | .6003E+12 |
| 21.30 | .0975 | .0546 | .0398 | .0515 | 1276.4 | .7220E+12 |
| 22.57 | .1007 | .0538 | .0391 | .0506 | 1395.6 | .8590E+12 |
| 23.84 | .1025 | .0531 | .0384 | .0497 | 1501.1 | .1012E+13 |
| 25.11 | | .0524 | .0378 | .0488 | | |



494 174


VOLUMETRIC BOILING POOL DATA
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10⁻²
DEPTH (CM)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
RUN NUMBER 7512
TOTAL POWER(KW) 14.0
AVERAGE VOID FRACTION 0.38
POWER DENSITY(CAL/CM*3 S) 0.25
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 20.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.65
THERMOCOUPLE READINGS, DEG C
1 94.6
2 94.2
3 93.8
4 94.6
5 94.0
6 93.4
7 .0
8 .0
9 .0
10 .0
11 .0
12 91.4
13 89.2
14 89.6
15 89.9
16 87.1
17 86.0
18 84.8
19 .0
20 27.5
21 45.1
22 54.2
23 60.1
24 60.3
25 60.5
26 55.7
27 101.0

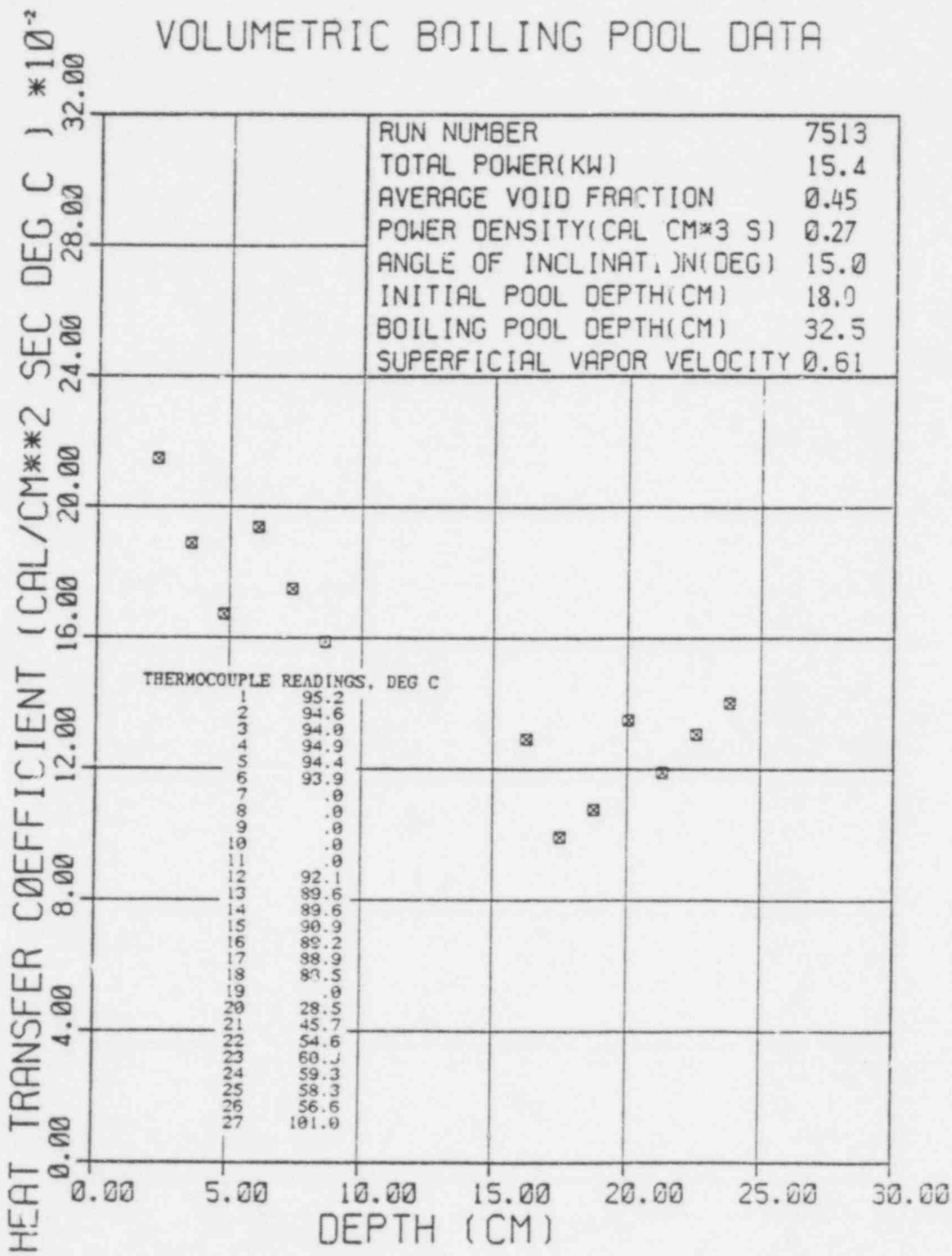
494 175

RUN NUMBER... 7513

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .45 |
| INITIAL POOL DEPTH(CM)........ | 18.0 |
| BOILING POOL DEPTH(CM)........ | 32.5 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .27 |
| SUPERFICIAL VAPOR VELOCITY.... | .61 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 11603. |
| PRANDTL NUMBER................ | 1.84 |
| TOTAL POWER(KW)............... | 15.4 |
| AVERAGE SURFACE TEMP(DEG C)... | 92.3 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 2.246 | .[illegible]9 | .1209 | .0959 | .12[illegible] | 296.5 | .2143E+10 |
| 3.516 | .[illegible]888 | .1081 | .0829 | .1086 | 407.9 | .8220E+10 |
| 4.786 | .1673 | .1001 | .0750 | .0979 | 491.8 | .2073E+11 |
| 6.056 | .1937 | .0943 | .0696 | .0905 | 720.7 | .[illegible]200E+11 |
| 7.326 | .1750 | .0900 | .0656 | .0850 | 787.4 | .7434E+11 |
| 8.596 | .1588 | .0864 | .0624 | .0806 | 838.8 | .1201E+12 |
| 9.866 | | .0835 | .0597 | .0770 | | |
| 11.14 | | .0810 | .0575 | .0741 | | |
| 12.41 | | .0789 | .0557 | .0715 | | |
| 13.68 | | .0770 | .0540 | .0693 | | |
| 14.95 | | .0753 | .0526 | .0673 | | |
| 16.22 | .1291 | .0738 | .0513 | .0655 | 1286.4 | .8062E+12 |
| 17.49 | .0991 | .0724 | .0501 | .0640 | 1064.7 | .1011E+13 |
| 18.76 | .1075 | .0711 | .0490 | .0625 | 1238.8 | .1247E+13 |
| 20.03 | .1350 | .0700 | .0481 | .0612 | 1660.7 | .1518E+13 |
| 21.30 | .1190 | .0689 | .0472 | .0600 | 1557.0 | .1826E+13 |
| 22.57 | .1306 | .0679 | .0464 | .0589 | 1809.9 | .2172E+13 |
| 23.84 | .1402 | .0670 | .0456 | .0579 | 2052.2 | .2560E+13 |
| 25.11 | | .0661 | .0449 | .0570 | | |

494 176


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7513
TOTAL POWER(KW) 15.4
AVERAGE VOID FRACTION 0.45
POWER DENSITY(CAL CM*3 S) 0.27
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 18.0
BOILING POOL DEPTH(CM) 32.5
SUPERFICIAL VAPOR VELOCITY 0.61
THERMOCOUPLE READINGS, DEG C
1 95.2
2 94.6
3 94.0
4 94.9
5 94.4
6 93.9
7 .0
8 .0
9 .0
10 .0
11 .0
12 92.1
13 89.6
14 89.6
15 90.9
16 89.2
17 88.9
18 83.5
19 .0
20 28.5
21 45.7
22 54.6
23 60.0
24 59.3
25 58.3
26 56.6
27 101.0
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DEPTH (CM)
0.00
5.00
10.00
15.00
20.00
25.00
30.00

494 177

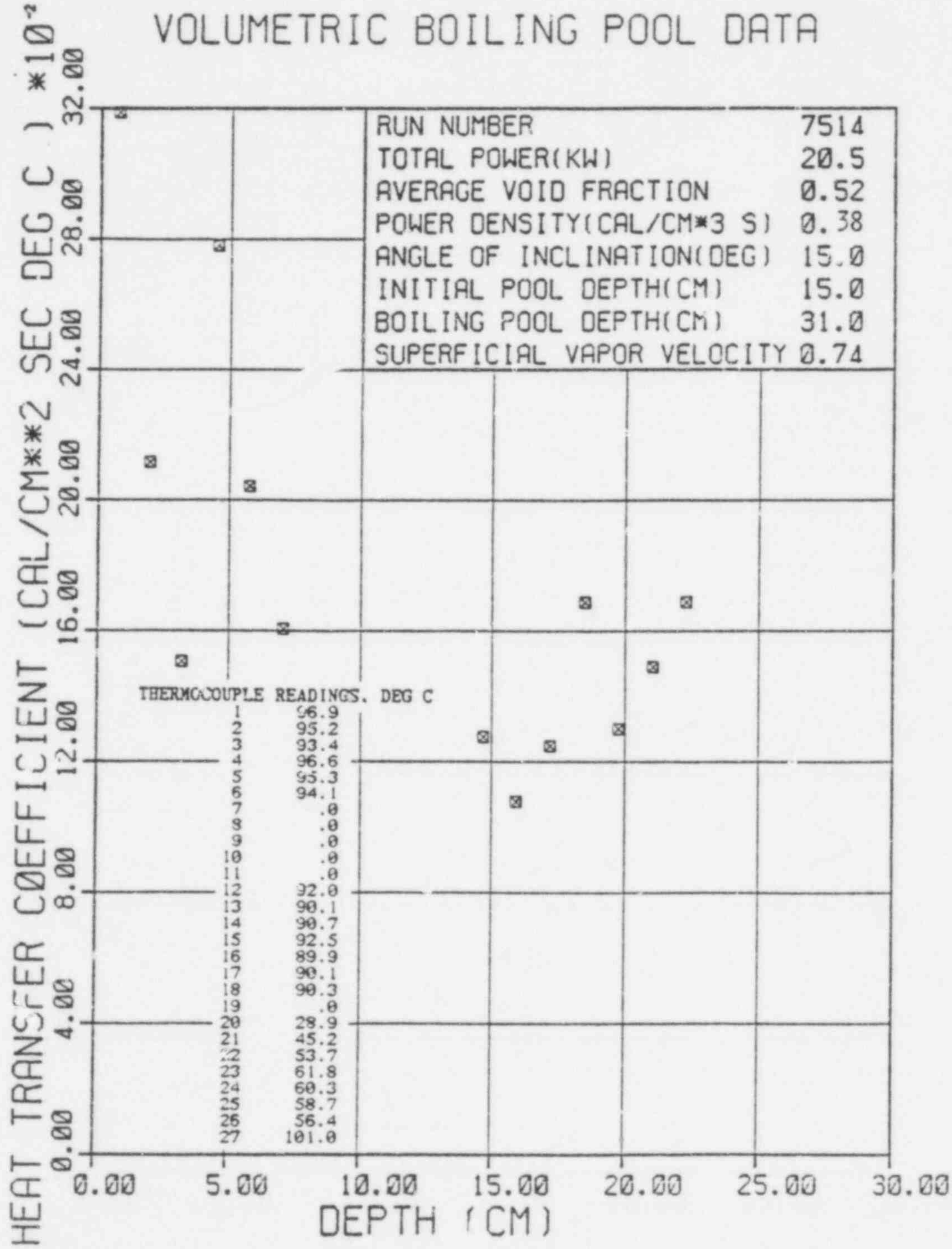
## RUN NUMBER... 7514

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .52 |
| INITIAL POOL DEPTH(CM)........ | 15.0 |
| BOILING POOL DEPTH(CM)........ | 31.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .38 |
| SUPERFICIAL VAPOR VELOCITY.... | .74 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 9560.6 |
| PRANDTL NUMBER................ | 1.83 |
| TOTAL POWER(KW)............... | 20.5 |
| AVERAGE SURFACE TEMP(DEG C)... | 93.2 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| .694 | .3189 | .1387 | .1355 | .1822 | 135.8 | .3372E+08 |
| 1.964 | .2117 | .1069 | .0938 | .1253 | 255.3 | .7652E+09 |
| 3.234 | .1507 | .0944 | .0791 | .1051 | 299.2 | .3417E+10 |
| 4.504 | .2781 | .0869 | .0767 | .0937 | 769.2 | .9232E+10 |
| 5.774 | .2043 | .0817 | .0651 | .0860 | 724.4 | .1945E+11 |
| 7.044 | .1606 | .0777 | .0610 | .0803 | 694.9 | .3532E+11 |
| 8.314 | | .0746 | .0578 | .0759 | | |
| 9.584 | | .0719 | .055[illegible] | .0724 | | |
| 10.85 | | .0697 | .0530 | .0694 | | |
| 12.12 | | .0678 | .0512 | .0669 | | |
| 13.39 | | .0662 | .0496 | .0647 | | |
| 14.66 | .1277 | .0647 | .0482 | .0627 | 115[illegible].1 | .3187E+12 |
| 15.93 | .1078 | .0634 | .0469 | .0616 | 105[illegible].0 | .4089E+12 |
| 17.20 | .1249 | .0622 | .0458 | .0595 | 1319.2 | .5146E+12 |
| 18.47 | .1689 | .0611 | .0448 | .0581 | 1916.2 | .6372E+12 |
| 19.74 | .1300 | .0601 | .0438 | .0568 | 1576.5 | .7779E+12 |
| 21.01 | .1491 | .0591 | .0430 | .0557 | 1924.0 | .9378E+12 |
| 22.28 | .1689 | .0583 | .0422 | .0546 | 2311.0 | .1118E+13 |
| 23.55 | | .0575 | .0415 | .0536 | | |



494 178


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7514
TOTAL POWER(KW) 20.5
AVERAGE VOID FRACTION 0.52
POWER DENSITY(CAL/CM*3 S) 0.38
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 15.0
BOILING POOL DEPTH(CM) 31.0
SUPERFICIAL VAPOR VELOCITY 0.74
THERMOCOUPLE READINGS, DEG C
1 96.9
2 95.2
3 93.4
4 96.6
5 95.3
6 94.1
7 .0
8 .0
9 .0
10 .0
11 .0
12 92.0
13 90.1
14 90.7
15 92.5
16 89.9
17 90.1
18 90.3
19 .0
20 28.9
21 45.2
22 53.7
23 61.8
24 60.3
25 58.7
26 56.4
27 101.0
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

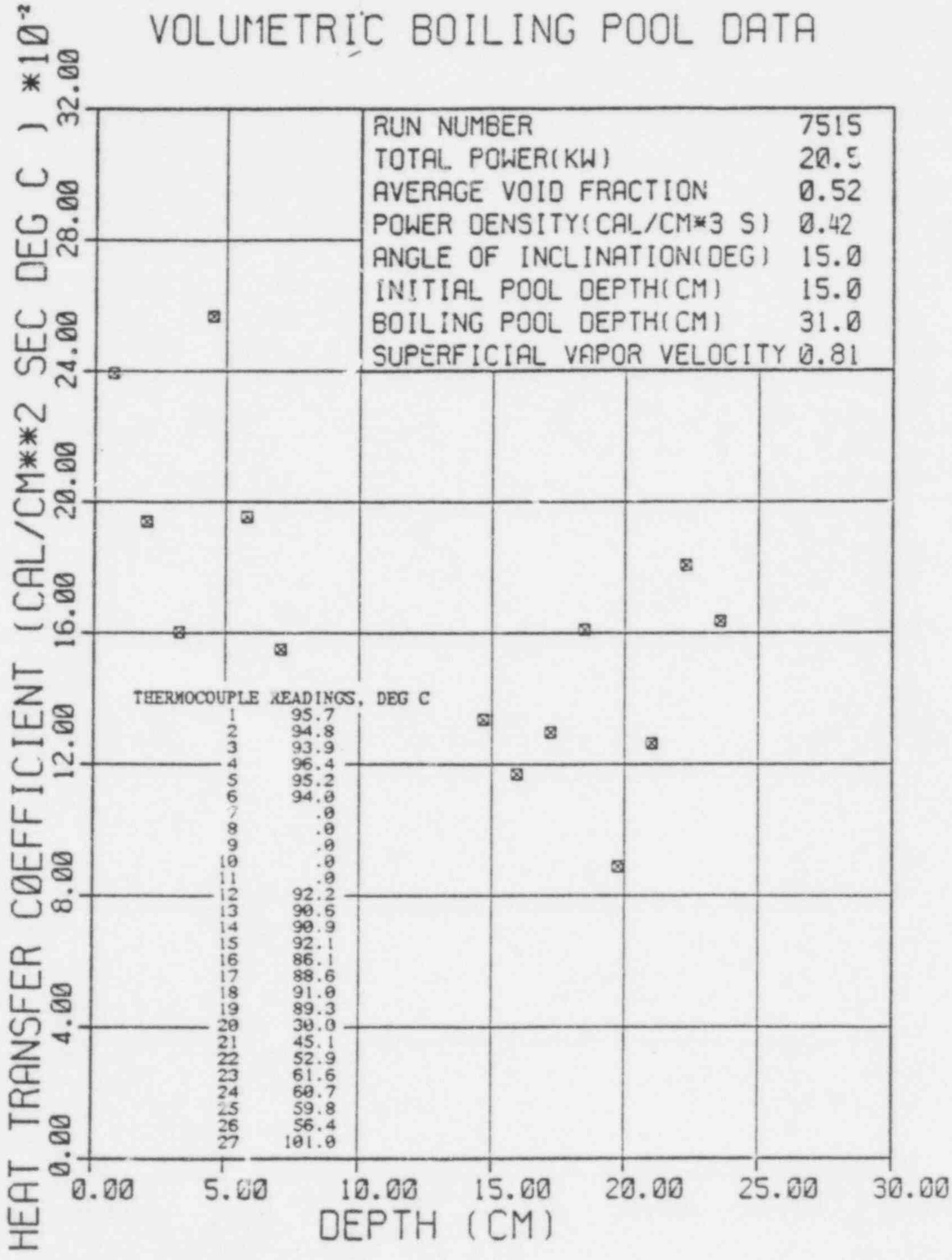
494 179

## RUN NUMBER... 7515

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .52 |
| INITIAL POOL DEPTH(CM)........ | 15.0 |
| BOILING POOL DEPTH(CM)........ | 31.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .42 |
| SUPERFICIAL VAPOR VELOCITY.... | .81 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 9560.6 |
| PRANDTL NUMBER................ | 1.83 |
| TOTAL POWER(KW)............... | 20.5 |
| AVERAGE SURFACE TEMP(DEG C)... | 92.7 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| .694 | .2394 | .1386 | .1382 | .1859 | 102.0 | .3364E+08 |
| 1.964 | .1940 | .1069 | .0954 | .1276 | 234.0 | .7635E+09 |
| 3.234 | .1602 | .0943 | .0803 | .1070 | 318.2 | .3410E+10 |
| 4.504 | .2569 | .0868 | .0718 | .0953 | 710.6 | .9211E+10 |
| 5.774 | .1954 | .0816 | .0661 | .0874 | 692.9 | .1941E+11 |
| 7.044 | .1550 | .0777 | .0619 | .0816 | 670.4 | .3524E+11 |
| 8.314 | | .0745 | .0586 | .0771 | | |
| 9.584 | | .0719 | .0559 | .0735 | | |
| 10.85 | | .0697 | .0537 | .0705 | | |
| 12.12 | | .0678 | .0518 | .0679 | | |
| 13.39 | | .0661 | .0502 | .0656 | | |
| 14.66 | .1335 | .0646 | .0487 | .0637 | 1202.8 | .3180E+12 |
| 15.93 | .1170 | .0633 | .0475 | .0619 | 1145.4 | .4079E+12 |
| 17.20 | .1298 | .0621 | .0463 | .0604 | 1371.3 | .5135E+12 |
| 18.47 | .1611 | .0610 | .0453 | .0589 | 1827.5 | .6358E+12 |
| 19.74 | .0888 | .0600 | .0443 | .0576 | 1077.3 | .7761E+12 |
| 21.01 | .1264 | .0591 | .0435 | .0565 | 1631.0 | .9357E+12 |
| 22.28 | .1807 | .0582 | .0427 | .0554 | 2473.1 | .1116E+13 |
| 23.55 | .1636 | .0574 | .0419 | .0544 | 2[illegible]67.3 | .1318E+13 |

494 180


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7515
TOTAL POWER(KW) 20.5
AVERAGE VOID FRACTION 0.52
POWER DENSITY(CAL/CM*3 S) 0.42
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 15.0
BOILING POOL DEPTH(CM) 31.0
SUPERFICIAL VAPOR VELOCITY 0.81
THERMOCOUPLE READINGS, DEG C
1 95.7
2 94.8
3 93.9
4 96.4
5 95.2
6 94.0
7 .0
8 .0
9 .0
10 .0
11 .0
12 92.2
13 90.6
14 90.9
15 92.1
16 86.1
17 88.6
18 91.0
19 89.3
20 30.0
21 45.1
22 52.9
23 61.6
24 60.7
25 59.8
26 56.4
27 101.0
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10⁻²
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00 5.00 10.00 15.00 20.00 25.00 30.00
DEPTH (CM)

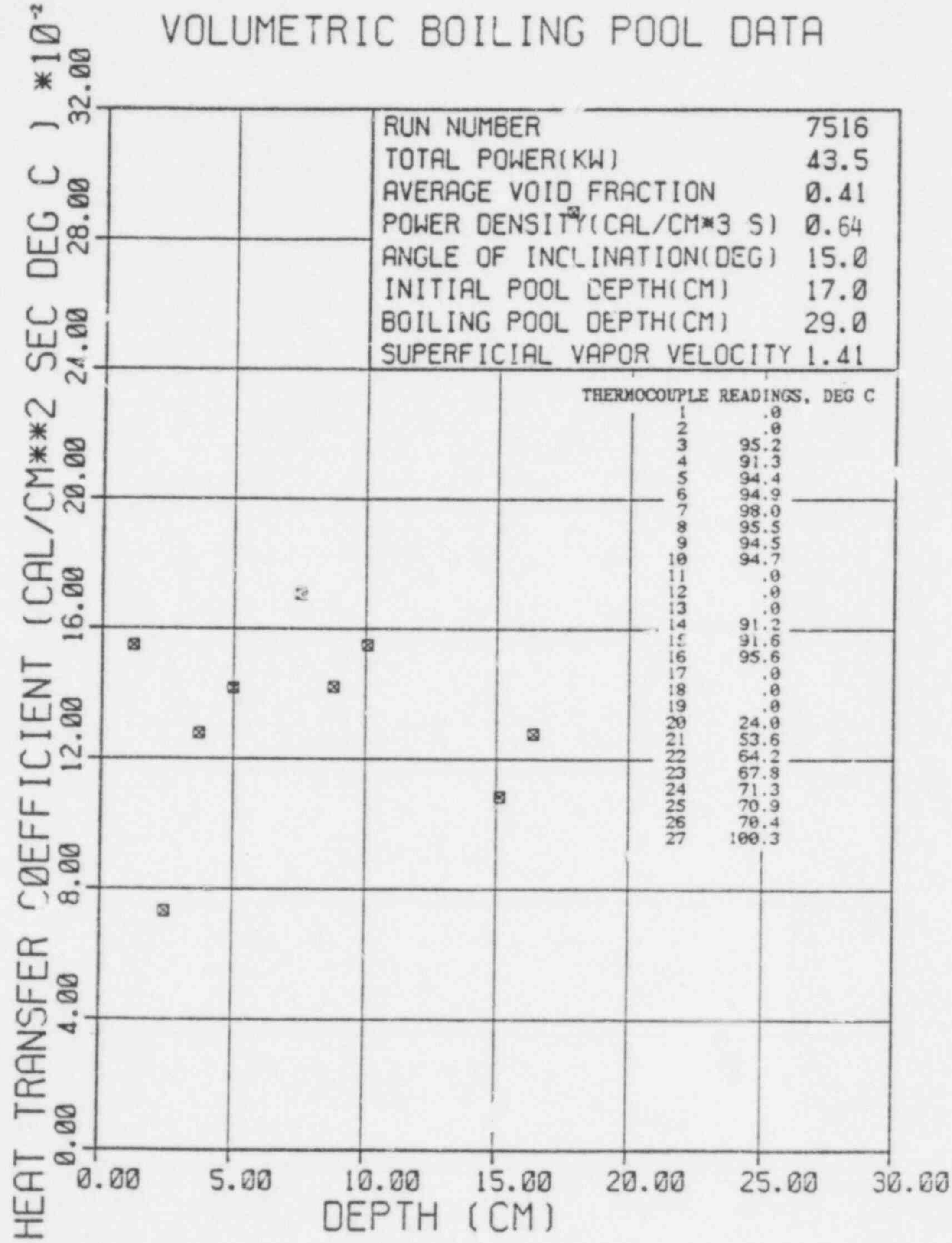
## RUN NUMBER... 7516

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .41 |
| INITIAL POOL DEPTH(CM)........ | 17.0 |
| BOILING POOL DEPTH(CM)........ | 29.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .64 |
| SUPERFICIAL VAPOR VELOCITY*... | 1.41 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 10917. |
| PRANDTL NUMBER................ | 1.83 |
| TOTAL POWER(KW)............... | 43.45 |
| AVERAGE SURFACE TEMP(DEG C)... | 93.4 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.163 | .1549 | .1153 | .1267 | .1707 | 110.6 | .1272E+09 |
| 2.433 | .0732 | .0958 | .0964 | .1297 | 109.4 | .1164E+10 |
| 3.703 | .1279 | .0863 | .0828 | .1112 | 290.8 | .4105E+10 |
| 4.973 | .1419 | .0802 | .0745 | .0999 | 433.4 | .9944E+10 |
| 6.243 | .3748 | .0757 | .0688 | .0921 | 1437.1 | .1967E+11 |
| 7.513 | .1706 | .0723 | .0645 | .0862 | 787.3 | .3429E+11 |
| 8.783 | .1421 | .0695 | .0611 | .0816 | 766.7 | .5478E+11 |
| 10.05 | .1551 | .0672 | .0583 | .0778 | 957.6 | .8214E+11 |
| 11.32 | | .0653 | .0559 | .0746 | | |
| 12.59 | | .0635 | .0540 | .0718 | | |
| 13.86 | | .0620 | .0522 | .0695 | | |
| 15.13 | .1083 | .0607 | .0507 | .0674 | 1006.9 | .2802E+12 |
| 16.40 | .1279 | .0595 | .0493 | .0655 | 1288.6 | .3568E+12 |
| 17.67 | .2885 | .0584 | .0481 | .0638 | 3131.7 | .4463E+12 |
| 18.94 | | .0574 | .0470 | .0623 | | |
| 20.21 | | .0565 | .0460 | .0609 | | |
| 21.48 | | .0556 | .0451 | .0596 | | |



494 182


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7516
TOTAL POWER(KW) 43.5
AVERAGE VOID FRACTION 0.41
POWER DENSITY(CAL/CM*3 S) 0.64
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 17.0
BOILING POOL DEPTH(CM) 29.0
SUPERFICIAL VAPOR VELOCITY 1.41
THERMOCOUPLE READINGS, DEG C
1 .0
2 .0
3 95.2
4 91.3
5 94.4
6 94.9
7 98.0
8 95.5
9 94.5
10 94.7
11 .0
12 .0
13 .0
14 91.2
15 91.6
16 95.6
17 .0
18 .0
19 .0
20 24.0
21 53.6
22 64.2
23 67.8
24 71.3
25 70.9
26 70.4
27 100.3
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00 5.00 10.00 15.00 20.00 25.00 30.00
DEPTH (CM)

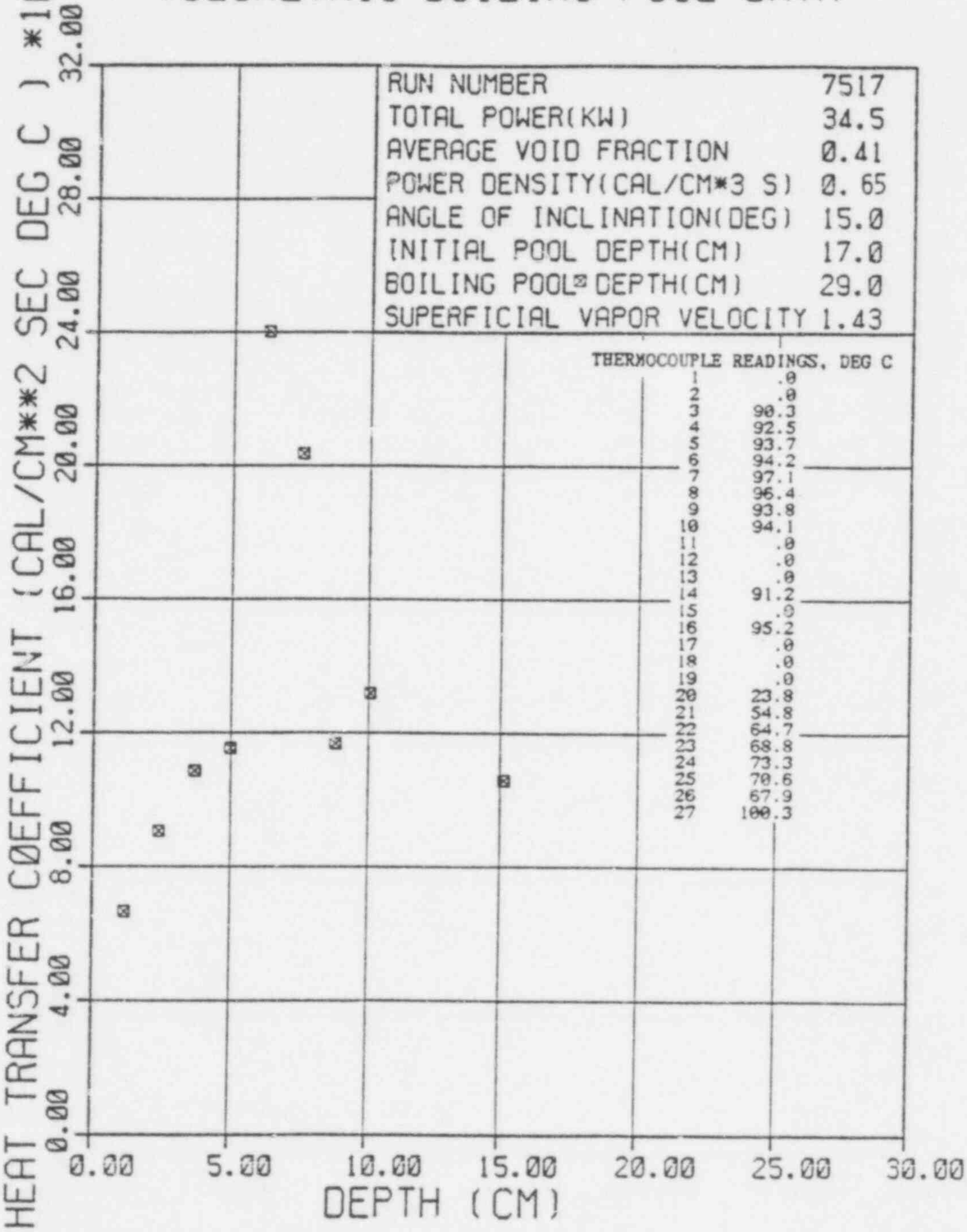
RUN NUMBER... 7517

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .41 |
| INITIAL POOL DEPTH(CM)........ | 17.0 |
| BOILING POOL DEPTH(CM)........ | 29.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .65 |
| SUPERFICIAL VAPOR VELOCITY.... | 1.43 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 10917. |
| PRANDTL NUMBER................ | 1.84 |
| TOTAL POWER(KW)............... | 34.5 |
| AVERAGE SURFACE TEMP(DEG C)... | 93.1 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.163 | .0665 | .1152 | .1271 | .1713 | 47.5 | .1270E+09 |
| 2.433 | .0906 | .0958 | .0966 | .1301 | 135.5 | .1163E+10 |
| 3.703 | .1086 | .0863 | .0830 | .1115 | 247.0 | .4100E+10 |
| 4.973 | .1154 | .0801 | .0747 | .1002 | 352.4 | .9930E+10 |
| 6.243 | .2401 | .0757 | .0689 | .0924 | 920.8 | .1965E+11 |
| 7.513 | .2036 | .0723 | .0646 | .0864 | 939.8 | .3424E+11 |
| 8.783 | .1167 | .0695 | .0612 | .0818 | 629.7 | .5471E+11 |
| 10.05 | .1317 | .0672 | .0584 | .0780 | 813.5 | .8203E+11 |
| 11.32 | | .0652 | .0561 | .0747 | | |
| 12.59 | | .0635 | .0541 | .0720 | | |
| 13.86 | | .0620 | .0523 | .0696 | | |
| 15.13 | .1057 | .0607 | .0508 | .0675 | 982.8 | .2798E+12 |
| 16.40 | | .0595 | .0494 | .0657 | | |
| 17.67 | .2557 | .0584 | .0482 | .0640 | 2776.3 | .4457E+12 |
| 18.94 | | .0574 | .0471 | .0624 | | |
| 20.21 | | .0564 | .0461 | .0611 | | |
| 21.48 | | .0556 | .0452 | .0598 | | |

494 184

VOLUMETRIC BOILING POOL DATA




494 185

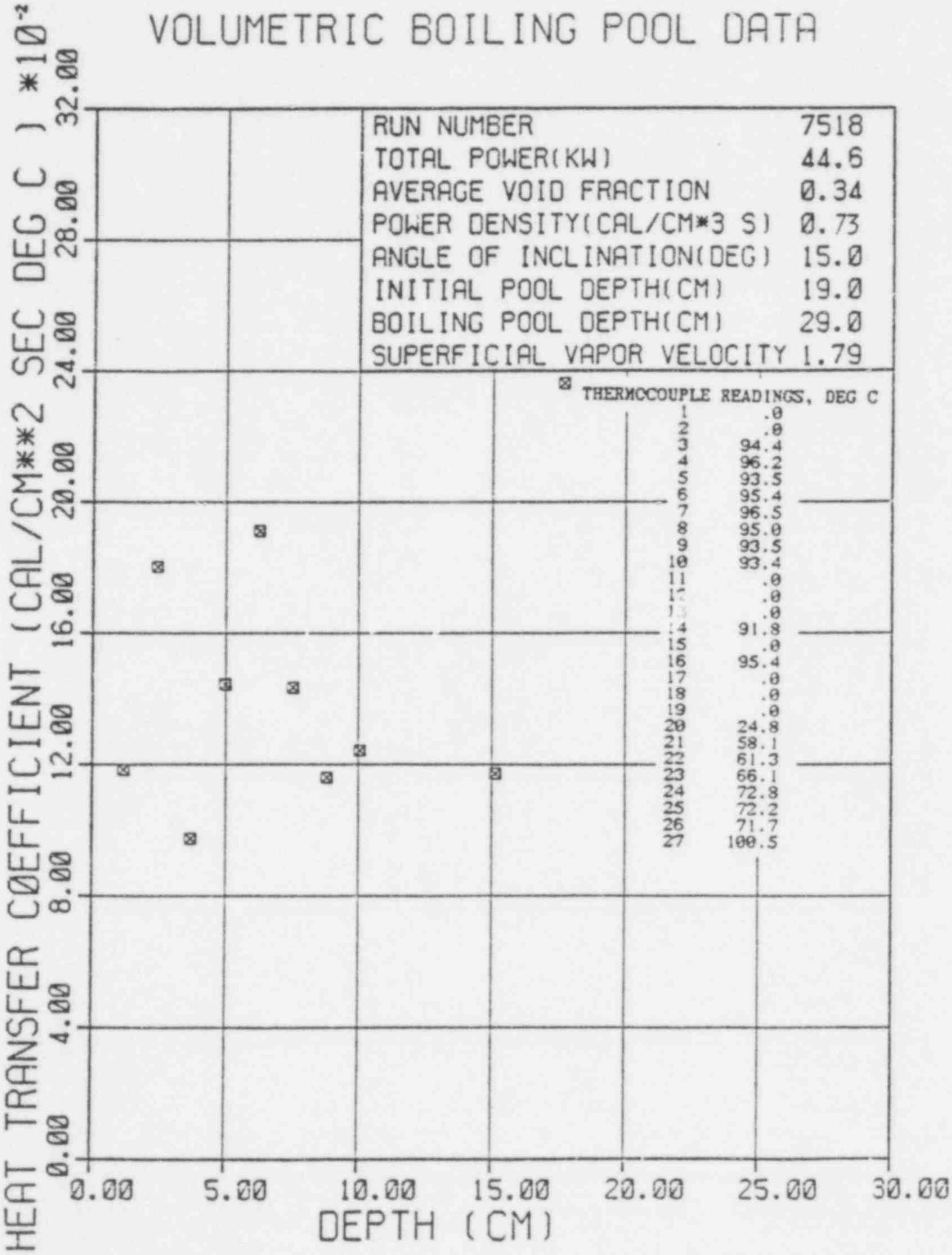
## RUN NUMBER... 7518

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .34 |
| INITIAL POOL DEPTH(CM)........ | 19.0 |
| BOILING POOL DEPTH(CM)........ | 29.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .73 |
| SUPERFICIAL VAPOR VELOCITY.... | 1.79 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 12293. |
| PRANDTL NUMBER................ | 1.82 |
| TOTAL POWER(KW)............... | 44.6 |
| AVERAGE SURFACE TEMP(DEG C)... | 94.5 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ14a | EQ 10 N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.163 | .1184 | .1103 | .1323 | .1780 | 84.5 | .1066E+09 |
| 2.433 | .1802 | .0917 | .0998 | .1345 | 269.2 | .9760E+09 |
| 3.703 | .0973 | [illegible] | .0854 | .1150 | 221.3 | .3441E+10 |
| 4.973 | .1443 | [illegible] | .0766 | .1031 | 440.7 | .8334E+10 |
| 6.243 | .1913 | .0725 | .0706 | .0949 | 733.3 | .1649E+11 |
| 7.513 | .1434 | .0692 | .0660 | .0887 | 661.7 | .2874E+11 |
| 8.783 | .1161 | .0666 | .0624 | .0838 | 626.0 | .4591E+11 |
| 10.05 | .1241 | .0643 | .0595 | .0798 | 766.3 | .6885E+11 |
| 11.32 | | .0625 | .0571 | .0765 | | |
| 12.59 | | .0608 | .0550 | .0736 | | |
| 13.86 | | .0594 | .0532 | .0711 | | |
| 15.13 | .1171 | [illegible] | .0516 | .0689 | 1088.5 | .2349E+12 |
| 16.40 | | .0569 | .0501 | .0670 | | |
| 17.67 | .2361 | .0559 | .0489 | .0653 | 2562.4 | .3741E+12 |
| 18.94 | | .0549 | .0477 | .0637 | | |
| 20.21 | | .0540 | .0467 | .0622 | | |
| 21.48 | | .0532 | .0457 | .0609 | | |



494 186


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7518
TOTAL POWER(KW) 44.6
AVERAGE VOID FRACTION 0.34
POWER DENSITY(CAL/CM*3 S) 0.73
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 19.0
BOILING POOL DEPTH(CM) 29.0
SUPERFICIAL VAPOR VELOCITY 1.79
THERMOCOUPLE READINGS, DEG C
1 .0
2 .0
3 94.4
4 96.2
5 93.5
6 95.4
7 96.5
8 95.0
9 93.5
10 93.4
11 .0
12 .0
13 .0
14 91.8
15 .0
16 95.4
17 .0
18 .0
19 .0
20 24.8
21 58.1
22 61.3
23 66.1
24 72.8
25 72.2
26 71.7
27 100.5
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)



494 187

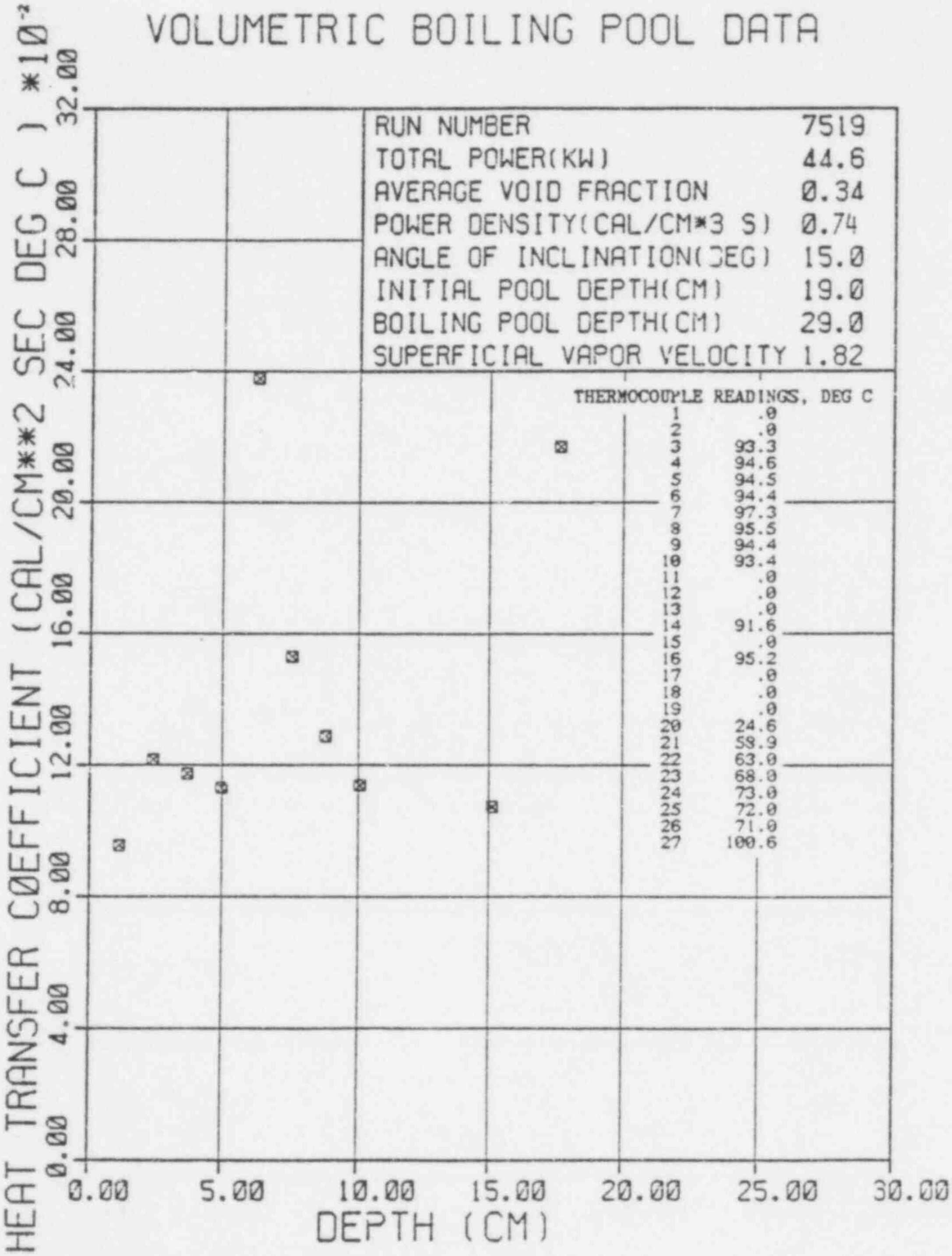
RUN NUMBER... 7519

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .34 |
| INITIAL POOL DEPTH(CM)........ | :9.0 |
| BOILING POOL DEPTH(CM)........ | 29.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .74 |
| SUPERFICIAL VAPOR VELOCITY.... | 1.82 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 12293. |
| PRANDTL NUMBER................ | 1.82 |
| TOTAL POWER(KW)............... | 44.6 |
| AVERAGE SURFACE TEMP(DEG C)... | 94.0 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0./ | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 1.163 | .0957 | .1103 | .1328 | .1787 | 68.3 | .1064E+09 |
| 2.433 | .1216 | .0917 | .1002 | .1350 | 181.7 | .9743E+09 |
| 3.703 | .1173 | .0825 | .0857 | .1154 | 266.8 | .3435E+10 |
| 4.973 | .1132 | .0767 | .0769 | .1035 | 345.6 | .8320E+10 |
| 6.243 | .2377 | .0724 | .0708 | .0952 | 911.4 | .1646E+11 |
| 7.513 | .1530 | .0692 | .0662 | .0890 | 705.8 | .2869E+11 |
| 8.783 | .1288 | .0665 | .0626 | .0841 | 694.7 | .4583E+11 |
| 10.05 | .1139 | .0643 | .0597 | .0801 | 703.1 | .6873E+11 |
| 11.32 | | .0624 | .0572 | .0767 | | |
| 12.59 | | .0608 | .0551 | .0738 | | |
| 13.86 | | .0593 | .0533 | .0714 | | |
| 15.13 | .1075 | .0581 | .0517 | .0692 | 999.0 | .2344E+12 |
| 16.40 | | .0569 | .0503 | .0672 | | |
| 17.67 | .2170 | .0558 | .0490 | .0655 | 2355.4 | .3734E+12 |
| 18.94 | | .0549 | .0478 | .0639 | | |
| 20.21 | | .0540 | .0468 | .0624 | | |
| 21.48 | | .0532 | .0458 | .0611 | | |



494 188



VOLUMETRIC BOILING POOL DATA
RUN NUMBER 7519
TOTAL POWER(KW) 44.6
AVERAGE VOID FRACTION 0.34
POWER DENSITY(CAL/CM*3 S) 0.74
ANGLE OF INCLINATION(DEG) 15.0
INITIAL POOL DEPTH(CM) 19.0
BOILING POOL DEPTH(CM) 29.0
SUPERFICIAL VAPOR VELOCITY 1.82
THERMOCOUPLE READINGS, DEG C
1 .0
2 .0
3 93.3
4 94.6
5 94.5
6 94.4
7 97.3
8 95.5
9 94.4
10 93.4
11 .0
12 .0
13 .0
14 91.6
15 .0
16 95.2
17 .0
18 .0
19 .0
20 24.6
21 58.9
22 63.0
23 68.0
24 73.0
25 72.0
26 71.0
27 100.6
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C) *10⁻²
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)



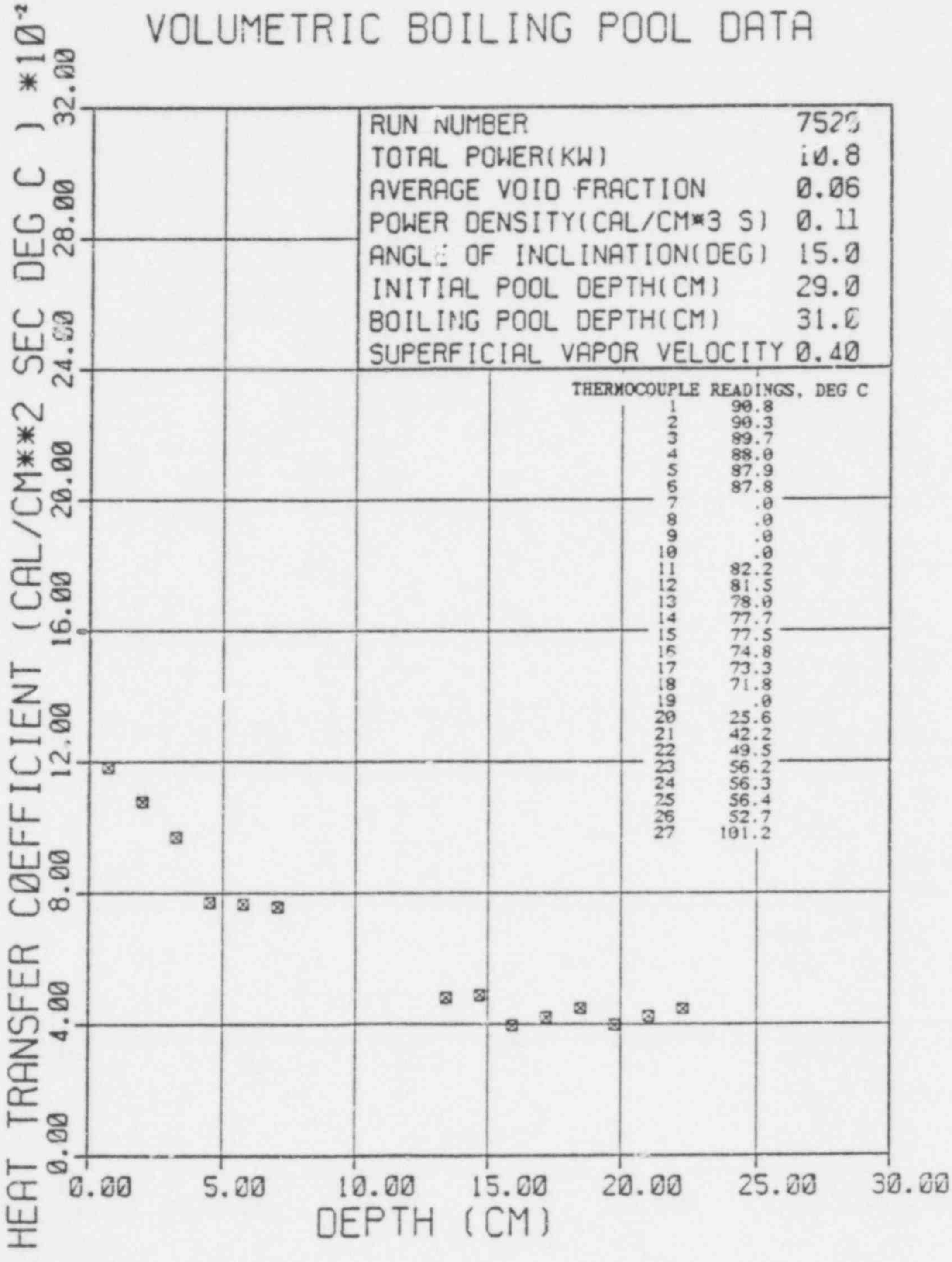

494 189

RUN NUMBER... 7520

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .06 |
| INITIAL POOL DEPTH(CM)........ | 29.0 |
| BOILING POOL DEPTH(CM)........ | 31.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .11 |
| SUPERFICIAL VAPOR VELOCITY.... | .40 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 19463. |
| PRANDTL NUMBER... ............ | 1.93 |
| TOTAL POWER(KW)............... | 10.8 |
| AVERAGE SURFACE TEMP(DEG C)... | 82.9 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| .694 | .1183 | .0813 | .0880 | .1185 | 50.5 | .4023E+07 |
| 1.964 | .1077 | .0627 | .0601 | .0807 | 130.2 | .9130E+08 |
| 3.234 | .0969 | .0553 | .0503 | .0674 | 193.0 | .4077E+09 |
| 4.504 | .0773 | .0509 | .0448 | .0599 | 214.3 | .1102E+10 |
| 5.774 | .0765 | .0479 | .0412 | .0549 | 272.1 | .2321E+10 |
| 7.044 | .0758 | .0456 | .0385 | .0512 | 328.7 | .4214E+10 |
| 8.314 | | .0437 | .0364 | .0483 | | |
| 9.584 | | .0422 | .0347 | .0460 | | |
| 10.85 | | .0409 | .033[illegible] | .0440 | | |
| 12.12 | | .0398 | .0321 | .0424 | | |
| 13.39 | .0480 | .0388 | .0310 | .0410 | 395.6 | .2897E+11 |
| 14.66 | .0488 | .0379 | .0301 | .0397 | 440.4 | .3802E+11 |
| 15.93 | .0397 | .0371 | .0293 | .0386 | 389.0 | .4878E+11 |
| 17.20 | .0421 | .0364 | .0286 | .0376 | 445.[illegible] | .6140E+11 |
| 18.47 | .0448 | .0358 | .0279 | .0367 | 509.2 | .7603E+11 |
| 19.74 | .0399 | .0352 | .0273 | .0359 | 484.6 | .9281E+11 |
| 21.01 | .0424 | .0347 | .0268 | .0351 | 548.4 | .1119E+12 |
| 22.28 | .0447 | .0342 | .0263 | .0344 | 612.6 | .1334E+12 |
| 23.55 | | .0337 | .0258 | .0338 | | |

# VOLUMETRIC BOILING POOL DATA



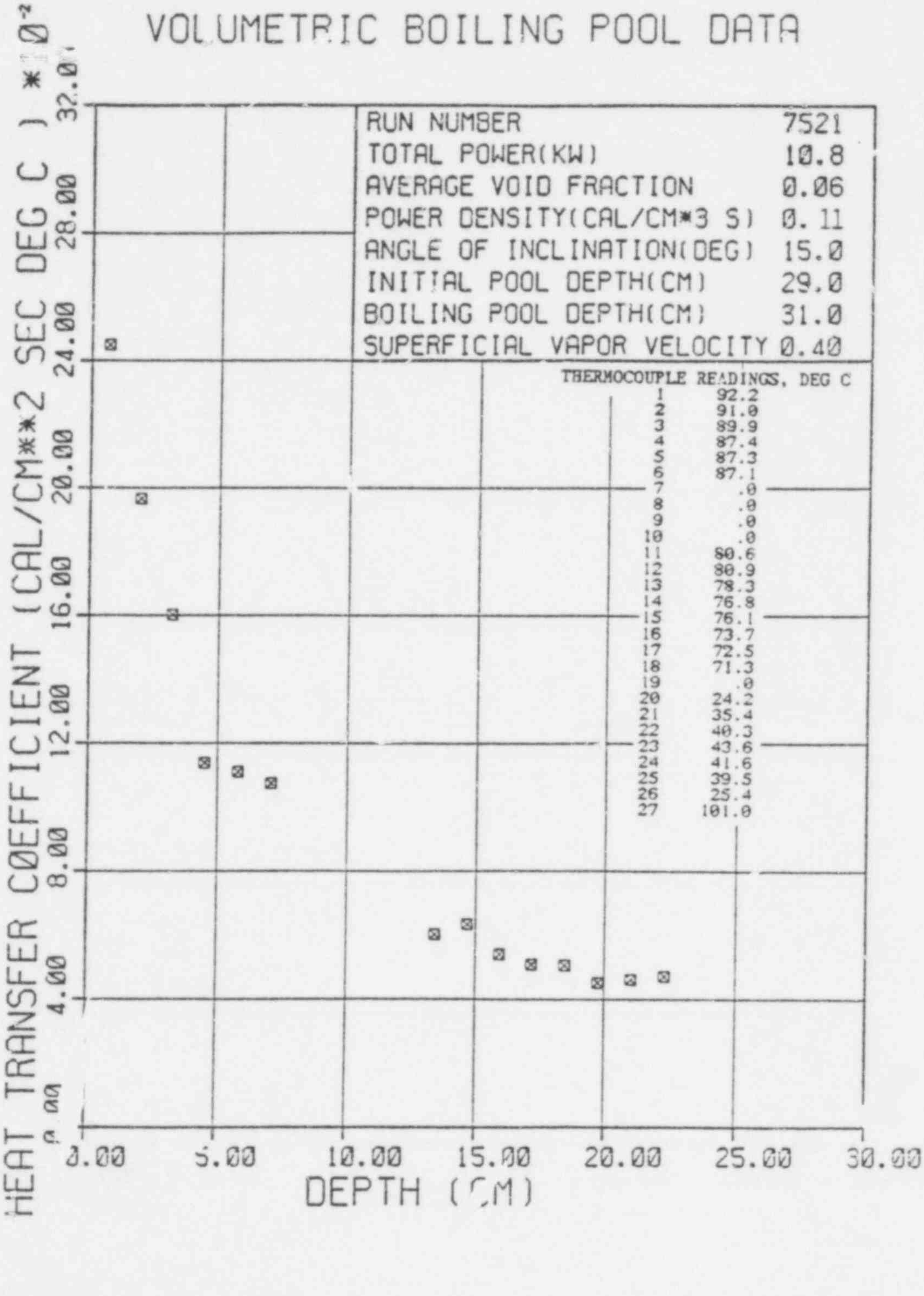
RUN NUMBER... 7521

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .06 |
| INITIAL POOL DEPTH(CM)........ | 29.0 |
| BOILING POOL DEPTH(CM)........ | 31.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .11 |
| SUPERFICIAL VAPOR VELOCITY.... | .40 |
| ANGLE OF INCLINATION(DEGREES). | 15.00 |
| POOL VOLUME(CM**3)............ | 19463. |
| PRANDTL NUMBER................ | 1.94 |
| TOTAL POWER(KW)............... | 10.8 |
| AVERAGE SURFACE TEMP(DEG C)... | 82.3 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| .694 | .2451 | .0812 | .0879 | .1184 | 104.7 | .4008E+07 |
| 1.964 | .1966 | .0626 | .0600 | .0806 | 237.7 | .9094E+08 |
| 3.234 | .1603 | .0553 | .0503 | .0673 | 319.1 | .4061E+09 |
| 4.504 | .1137 | .0509 | .0448 | .0596 | 315.3 | .1097E+10 |
| 5.774 | .1110 | .0478 | .0411 | .0548 | 394.6 | .2312E+10 |
| 7.044 | .1073 | .0455 | .0384 | .0511 | 465.4 | .4198E+10 |
| 8.314 | | .0437 | .0363 | .0482 | | |
| 9.584 | | .0421 | .0346 | .0459 | | |
| 10.85 | | .0408 | .0332 | .0440 | | |
| 12.12 | | .0397 | .0320 | .0423 | | |
| 13.39 | .0603 | .0388 | .0310 | .0409 | [illegible].3 | .288[illegible]E+11 |
| 14.66 | .0634 | .0379 | .0301 | .0397 | 572.9 | .3788E+11 |
| 15.93 | .0540 | .0371 | .0293 | .0385 | 538.3 | .4859E+11 |
| 17.20 | .0509 | .0364 | .0285 | .0376 | 538.9 | .6116E+11 |
| 18.47 | .0507 | .0358 | .0279 | .0367 | 576.2 | .7573E+11 |
| 19.74 | .0453 | .0352 | .0273 | .0358 | 550.7 | .9245E+11 |
| 21.01 | .0463 | .0346 | .0267 | .0351 | 598.5 | .1115E+12 |
| 22.28 | .0471 | .0341 | .0262 | .0344 | 646.8 | .1329E+12 |
| 23.55 | | .0337 | .0258 | .0338 | | |

494 192

## VOLUMETRIC BOILING POOL DATA

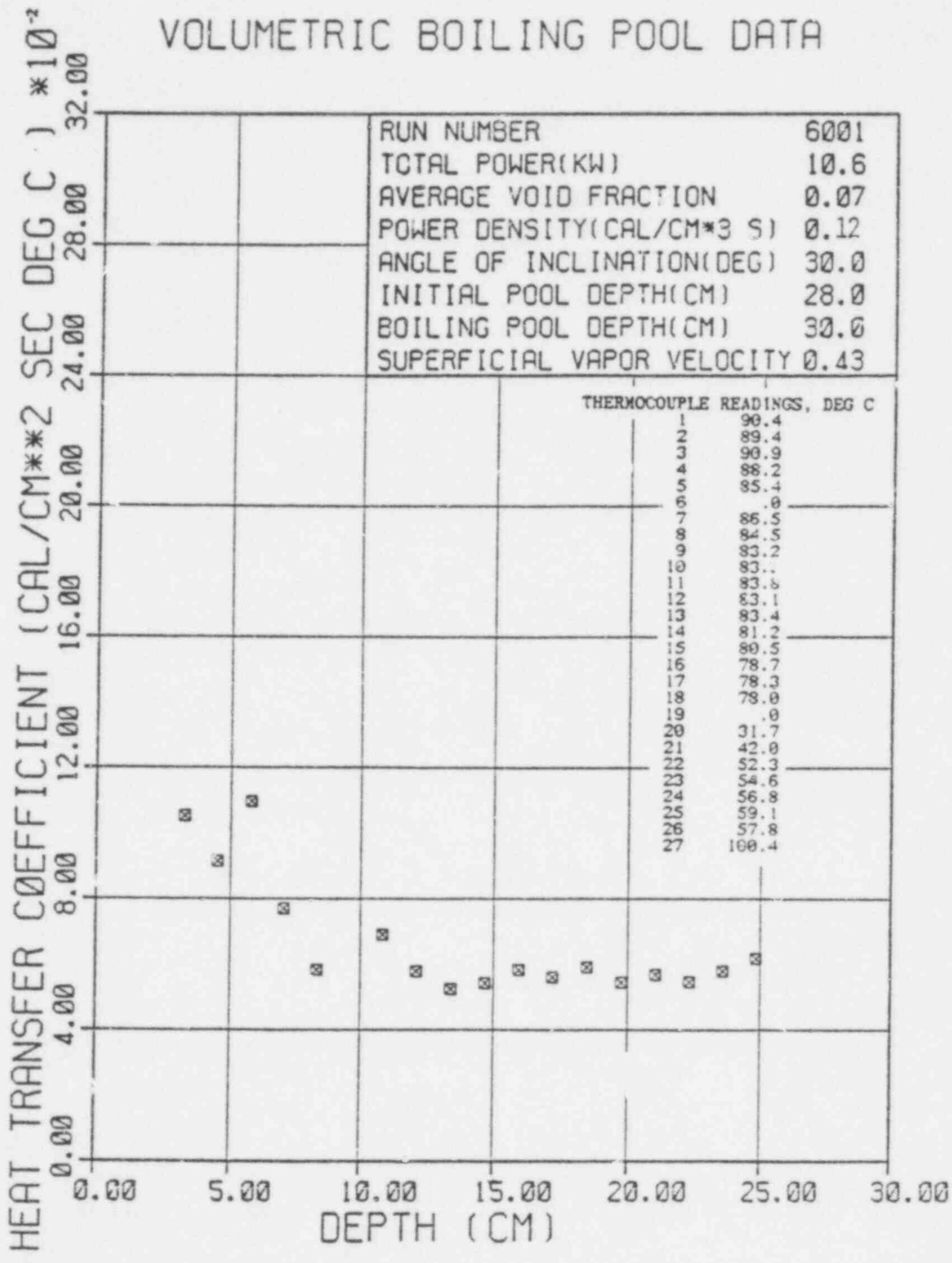



494 193

## RUN NUMBER... 6001

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .07 |
| INITIAL POOL DEPTH(CM)........ | 28.0 |
| BOILING POOL DEPTH(CM)........ | 30.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .12 |
| SUPERFICIAL VAPOR VELOCITY.... | .43 |
| ANGLE OF INCLINATION(DEGREES). | 30.00 |
| POOL VOLUME(CM**3)............ | 20907. |
| PRANDTL NUMBER................ | 1.93 |
| TOTAL POWER(KW)............... | 10.6 |
| AVERAGE SURFACE TEMP(DEG C)... | 83.3 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 3.241 | .1052 | .0557 | .0504 | .0677 | 210.0 | .3796E+09 |
| 4.511 | .0915 | .0513 | .0449 | .0601 | 254.1 | .1024E+10 |
| 5.781 | .1095 | .0482 | .0412 | .0550 | 389.9 | .2154E+10 |
| 7.051 | .0770 | .0459 | .0385 | .0513 | 334.3 | .3909E+10 |
| 8.321 | .0583 | .0440 | .0364 | .0484 | 298.5 | .6424E+10 |
| 9.591 | | .0425 | .0346 | .0460 | | |
| 10.86 | .0690 | .0412 | .0332 | .0441 | 461.3 | .1429E+11 |
| 12.13 | .0577 | .0401 | .0320 | .0424 | 431.2 | .1991E+11 |
| 13.40 | .0523 | .0391 | .0310 | .0410 | 431.6 | .2684E+11 |
| 14.67 | .0542 | .0382 | .0300 | .0397 | 489.5 | .3521E+11 |
| 15.94 | .0583 | .0374 | .0292 | .0386 | 572.0 | .4517E+11 |
| 17.21 | .0560 | .0367 | .0285 | .0376 | 593.9 | .5685E+11 |
| 18.48 | .0591 | .0361 | .0278 | .0367 | 672.1 | .7039E+11 |
| 19.75 | .0544 | .0355 | .0272 | .0359 | 661.2 | .8592E+11 |
| 21.02 | .0569 | .0349 | .0267 | .0351 | 736.3 | .1036E+12 |
| 22.29 | .0546 | .0344 | .0262 | .0344 | 749.4 | .1235E+12 |
| 23.56 | .0580 | .0339 | .0257 | .0338 | 842.0 | .1458E+12 |
| 24.83 | .0618 | .0335 | .0253 | .0332 | 944.6 | .1707E+12 |
| 26.10 | | .0331 | .0249 | .0326 | | |

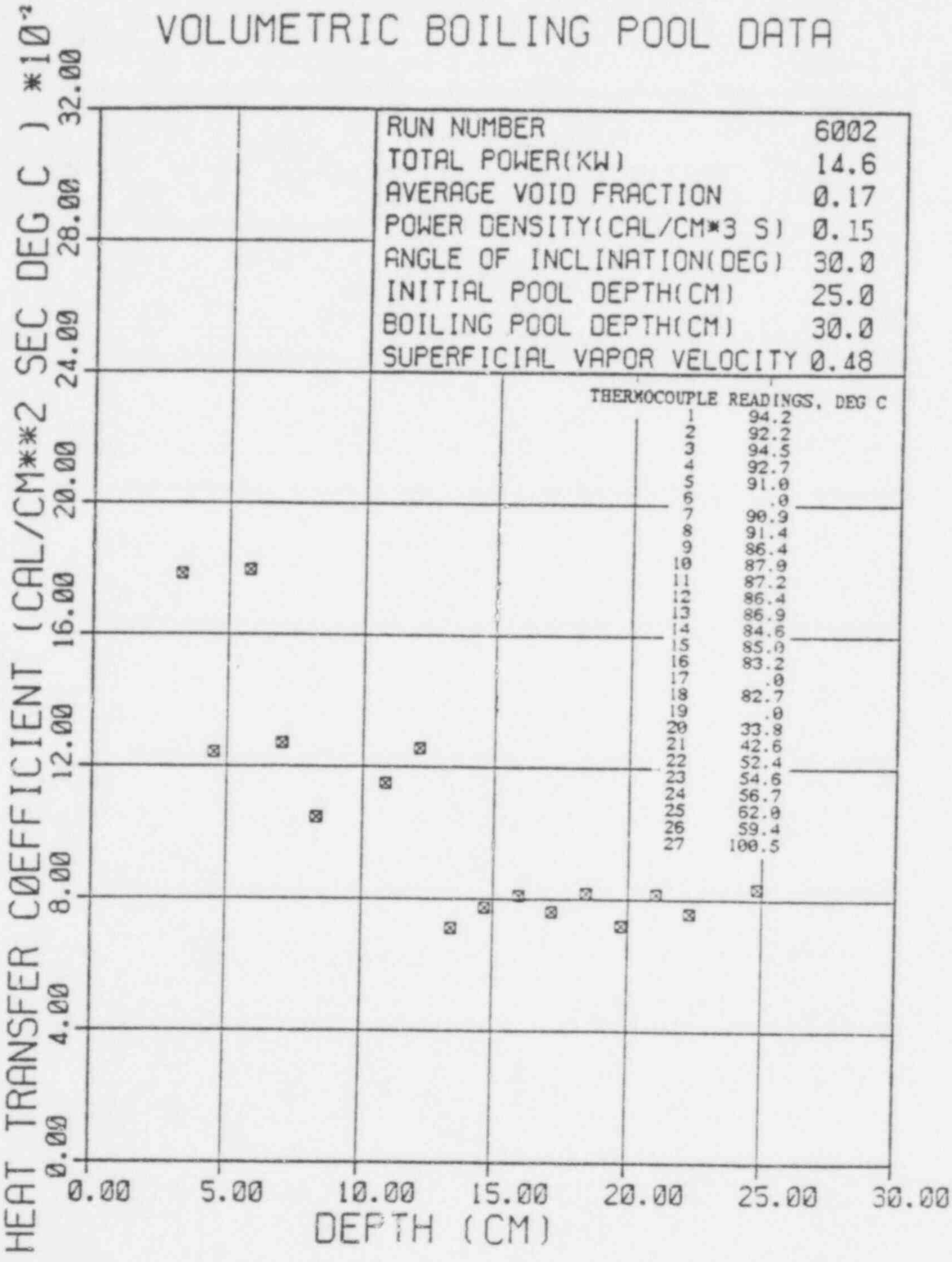

VOLUMETRIC BOILING POOL DATA
RUN NUMBER 6001
TOTAL POWER(KW) 10.6
AVERAGE VOID FRACTION 0.07
POWER DENSITY(CAL/CM*3 S) 0.12
ANGLE OF INCLINATION(DEG) 30.0
INITIAL POOL DEPTH(CM) 28.0
BOILING POOL DEPTH(CM) 30.0
SUPERFICIAL VAPOR VELOCITY 0.43
THERMOCOUPLE READINGS, DEG C
1 90.4
2 89.4
3 90.9
4 88.2
5 85.4
6 .0
7 86.5
8 84.5
9 83.2
10 83..
11 83.6
12 83.1
13 83.4
14 81.2
15 80.5
16 78.7
17 78.3
18 78.0
19 .0
20 31.7
21 42.0
22 52.3
23 54.6
24 56.8
25 59.1
26 57.8
27 100.4
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

494 195

## RUN NUMBER... 6002

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .17 |
| INITIAL POOL DEPTH(CM)........ | 25.0 |
| BOILING POOL DEPTH(CM)........ | 30.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .15 |
| SUPERFICIAL VAPOR VELOCITY.... | .48 |
| ANGLE OF INCLINATION(DEGREES). | 30.00 |
| POOL VOLUME(CM**3)............ | 18278. |
| PRANDTL NUMBER................ | 1.88 |
| TOTAL POWER(KW)............... | 14.6 |
| AVERAGE SURFACE TEMP(DEG C)... | 88.5 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) | | | | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| | EXPT | EQ 14a | EQ 10 N=1.0 | EQ10 N=0.7 | | |
| 3.241 | .1783 | .0706 | .0596 | .0795 | 355.4 | .9731E+09 |
| 4.511 | .1242 | .0650 | .0532 | .0708 | 344.5 | .2624E+10 |
| 5.781 | .1795 | .0611 | .0490 | .0649 | 636.2 | .5522E+10 |
| 7.051 | .1271 | .0581 | .0458 | .0606 | 550.9 | .1002E+11 |
| 8.321 | .1046 | .0558 | .0434 | .0573 | 535.0 | .1647E+11 |
| 9.591 | | .0538 | .0414 | .0545 | | |
| 10.86 | .1150 | .0522 | .0397 | .0523 | 768.1 | .3662E+11 |
| 12.13 | .1256 | .0508 | .0383 | .0503 | 935.8 | .5103E+11 |
| 13.40 | .0712 | .0495 | .0371 | .0487 | 586.8 | .6879E+11 |
| 14.67 | .0775 | .0484 | .0360 | .0472 | 699.0 | .9026E+11 |
| 15.94 | .0809 | .0474 | .0351 | .0459 | 793.1 | .1158E+12 |
| 17.21 | .0762 | .0465 | .0342 | .0447 | 806.1 | .1457E+12 |
| 18.48 | .0819 | .0457 | .0335 | .0437 | 930.7 | .1804E+12 |
| 19.75 | .0720 | .0449 | .0328 | .0427 | 874.6 | .2202E+12 |
| 21.02 | .0815 | .0443 | .0321 | .0418 | 1053.6 | .2655E+12 |
| 22.29 | .0758 | .0436 | .0315 | .0410 | 1038.5 | .3166E+12 |
| 23.56 | | .0430 | .0310 | .0403 | | |
| 24.83 | .0834 | .0424 | .0305 | .0396 | 1273.0 | .4376E+12 |
| 26.10 | | .0419 | .0300 | .0389 | | |


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 6002
TOTAL POWER(KW) 14.6
AVERAGE VOID FRACTION 0.17
POWER DENSITY(CAL/CM*3 S) 0.15
ANGLE OF INCLINATION(DEG) 30.0
INITIAL POOL DEPTH(CM) 25.0
BOILING POOL DEPTH(CM) 30.0
SUPERFICIAL VAPOR VELOCITY 0.48
THERMOCOUPLE READINGS, DEG C
1 94.2
2 92.2
3 94.5
4 92.7
5 91.0
6 .0
7 90.9
8 91.4
9 86.4
10 87.9
11 87.2
12 86.4
13 86.9
14 84.6
15 85.0
16 83.2
17 .0
18 82.7
19 .0
20 33.8
21 42.6
22 52.4
23 54.6
24 56.7
25 62.0
26 59.4
27 100.5
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

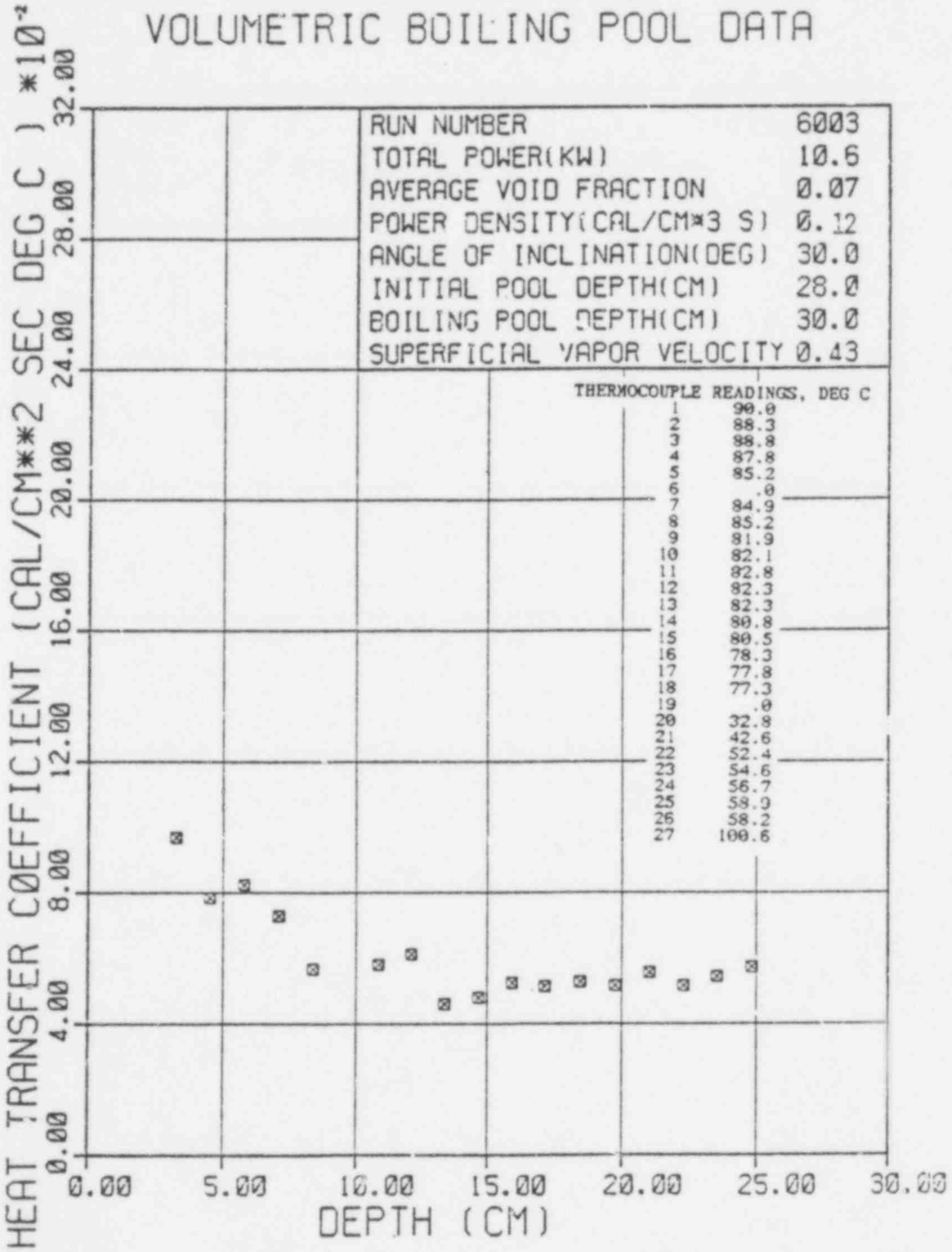
494 197

**RUN NUMBER... 6003**

AVERAGE VOID FRACTION......... .07
INITIAL POOL DEPTH(CM)........ 28.0
BOILING POOL DEPTH(CM)........ 30.0
VOL. POWER DENS.(CAL/CM3 SEC). .12
SUPERFICIAL VAPOR VELOCITY.... .43
ANGLE OF INCLINATION(DEGREES). 30.00
POOL VOLUME(CM**3)............ 20907.
PRANDTL NUMBER................ 1.93
TOTAL POWER(KW)............... 10.6
AVERAGE SURFACE TEMP(DEG C)... 83.7

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) | | | | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| | EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | | |
| 3.241 | .0969 | .0558 | .0505 | .0677 | 193.2 | .3807E+09 |
| 4.511 | .0784 | .0514 | .0449 | .0601 | 217.7 | .1027E+10 |
| 5.781 | .0824 | .0483 | .0412 | .0551 | 293.4 | .2161E+10 |
| 7.051 | .0729 | .0459 | .0385 | .0513 | 316.4 | .3920E+10 |
| 8.321 | .0567 | .0441 | .0364 | .0484 | 290.3 | .6443E+10 |
| 9.591 | | .0425 | .0347 | .0461 | | |
| 10.86 | .0580 | .0412 | .0332 | .0441 | 387.7 | .1433E+11 |
| 12.13 | .0612 | .0401 | .0320 | .0425 | 457.2 | .1996E+11 |
| 13.40 | .0459 | .0391 | .0310 | .0410 | 378.9 | .2691E+11 |
| 14.67 | .0480 | .0382 | .0301 | .0398 | 433.4 | .3531E+11 |
| 15.94 | .0525 | .0375 | .0292 | .0386 | 515.0 | .4530E+11 |
| 17.21 | .0[illegible]5 | .0367 | .0285 | .0376 | 545.2 | .5702E+11 |
| 18.48 | .0527 | .0361 | .0279 | .0367 | 600.1 | .7059E+11 |
| 19.75 | .0516 | .0355 | .0273 | .0359 | 627.8 | .8617E+11 |
| 21.02 | .0556 | .0350 | .0267 | .0352 | 719.9 | .1039E+12 |
| 22.29 | .0517 | .0344 | .0262 | .0345 | 709.2 | .1239E+12 |
| 23.56 | .0545 | .0340 | .0257 | .0338 | 790.0 | .1463E+12 |
| 24.83 | .0571 | .0335 | .0253 | .0332 | 873.4 | .1712E+12 |
| 26.10 | | .0331 | .0249 | .0327 | | |

494 198


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 6003
TOTAL POWER(KW) 10.6
AVERAGE VOID FRACTION 0.07
POWER DENSITY(CAL/CM*3 S) 0.12
ANGLE OF INCLINATION(DEG) 30.0
INITIAL POOL DEPTH(CM) 28.0
BOILING POOL DEPTH(CM) 30.0
SUPERFICIAL VAPOR VELOCITY 0.43
THERMOCOUPLE READINGS, DEG C
1 90.0
2 88.3
3 88.8
4 87.8
5 85.2
6 .0
7 84.9
8 85.2
9 81.9
10 82.1
11 82.8
12 82.3
13 82.3
14 80.8
15 80.5
16 78.3
17 77.8
18 77.3
19 .0
20 32.8
21 42.6
22 52.4
23 54.6
24 56.7
25 58.9
26 58.2
27 100.6
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)

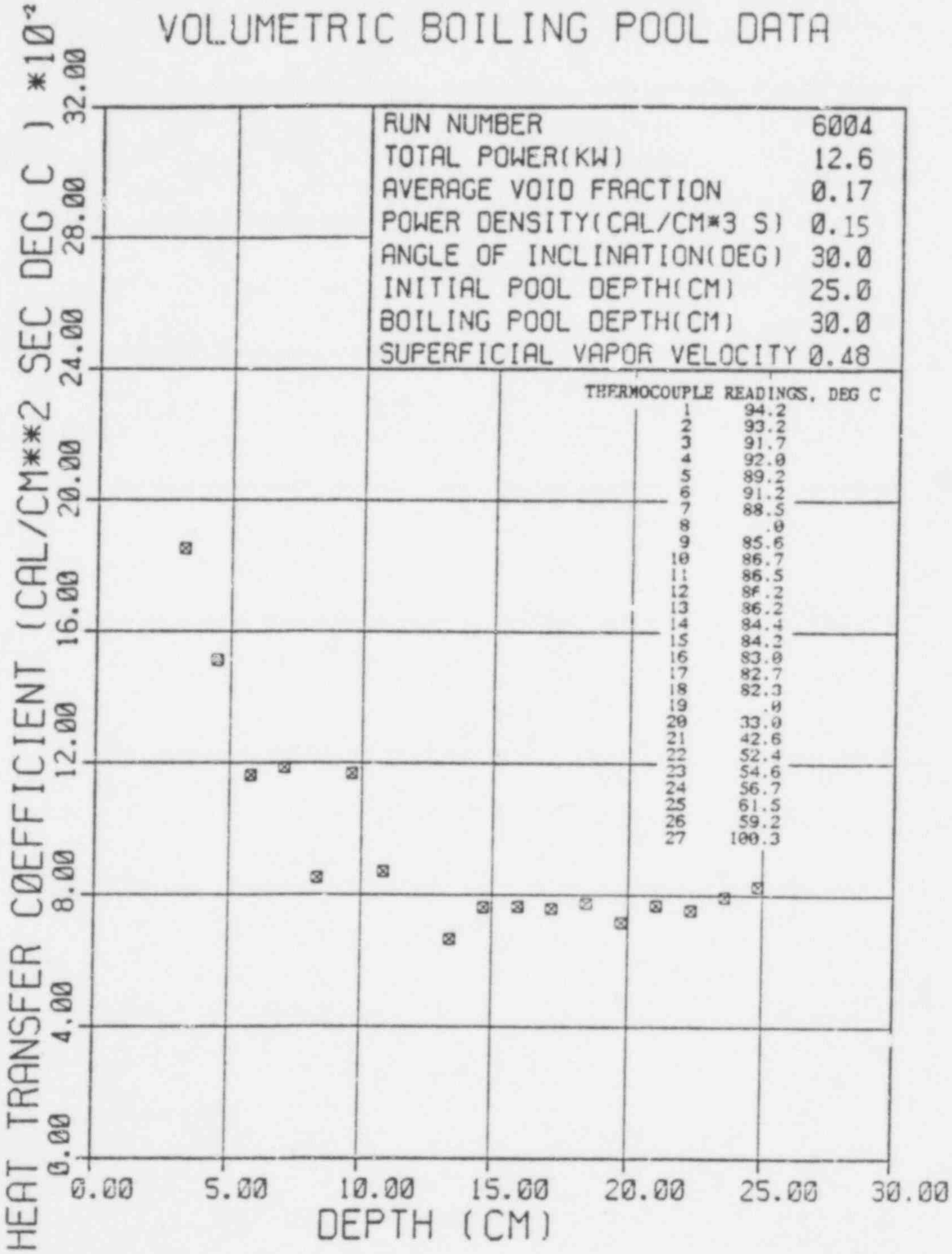
494 199

RUN NUMBER... 6004

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .17 |
| INITIAL POOL DEPTH(CM)........ | 25.0 |
| BOILING POOL DEPTH(CM)........ | 30.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .15 |
| SUPERFICIAL VAPOR VELOCITY.... | .48 |
| ANGLE OF INCLINATION(DEGREES). | 30.00 |
| POOL VOLUME(CM**3)............ | 18278. |
| PRANDTL NUMBER................ | 1.89 |
| TOTAL POWER(KW)............... | 12.6 |
| AVERAGE SURFACE TEMP(DEG C)... | 87.8 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 3.241 | .1852 | .0705 | .0595 | .0794 | 269.2 | .9691E+09 |
| 4.511 | .1511 | .0649 | .0532 | .0707 | 419.3 | .2613E+10 |
| 5.781 | .1162 | .0610 | .0489 | .0649 | 413.3 | .5500E+10 |
| 7.051 | .1166 | .0581 | .0458 | .0606 | 514.5 | .9979E+10 |
| 8.321 | .6852 | .0557 | .0433 | .0572 | 436.1 | .1640E+11 |
| 9.591 | .1167 | .0538 | .0413 | .0545 | 688.5 | .2511E+11 |
| 10.86 | .0870 | .0521 | .0397 | .0527 | 581.2 | .3647E+11 |
| 12.13 | | .0507 | .0383 | .0503 | | |
| 13.40 | .0565 | .0495 | .0371 | .0486 | 548.5 | .6851E+11 |
| 14.67 | .0762 | .0484 | .0360 | .0472 | 687.6 | .8989E+11 |
| 15.94 | .0763 | .0474 | .0350 | .0459 | 748.5 | .1153E+12 |
| 17.21 | .0757 | .0465 | .0342 | .0447 | 801.4 | .1451E+12 |
| 18.48 | .0774 | .0456 | .0334 | .0436 | 879.7 | .1797E+12 |
| 19.75 | .0716 | .0449 | .0327 | .0427 | 869.9 | .2193E+12 |
| 21.02 | .0769 | .0442 | .0321 | .0418 | 993.8 | .264<E+12 |
| 22.29 | .0754 | .0436 | .0315 | .0410 | 1033.6 | .3153E+12 |
| 23.56 | .0794 | .0430 | .0309 | .0402 | 1151.0 | .3723E+12 |
| 24.83 | .0827 | .0424 | .0304 | .0395 | 1262.7 | .4356E+12 |
| 26.10 | | .0419 | .0299 | .0389 | | |

494 200


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 6004
TOTAL POWER(KW) 12.6
AVERAGE VOID FRACTION 0.17
POWER DENSITY(CAL/CM*3 S) 0.15
ANGLE OF INCLINATION(DEG) 30.0
INITIAL POOL DEPTH(CM) 25.0
BOILING POOL DEPTH(CM) 30.0
SUPERFICIAL VAPOR VELOCITY 0.48
THERMOCOUPLE READINGS, DEG C
1 94.2
2 93.2
3 91.7
4 92.0
5 89.2
6 91.2
7 88.5
8 .0
9 85.6
10 86.7
11 86.5
12 8F.2
13 86.2
14 84.4
15 84.2
16 83.0
17 82.7
18 82.3
19 .0
20 33.0
21 42.6
22 52.4
23 54.6
24 56.7
25 61.5
26 59.2
27 100.3
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)



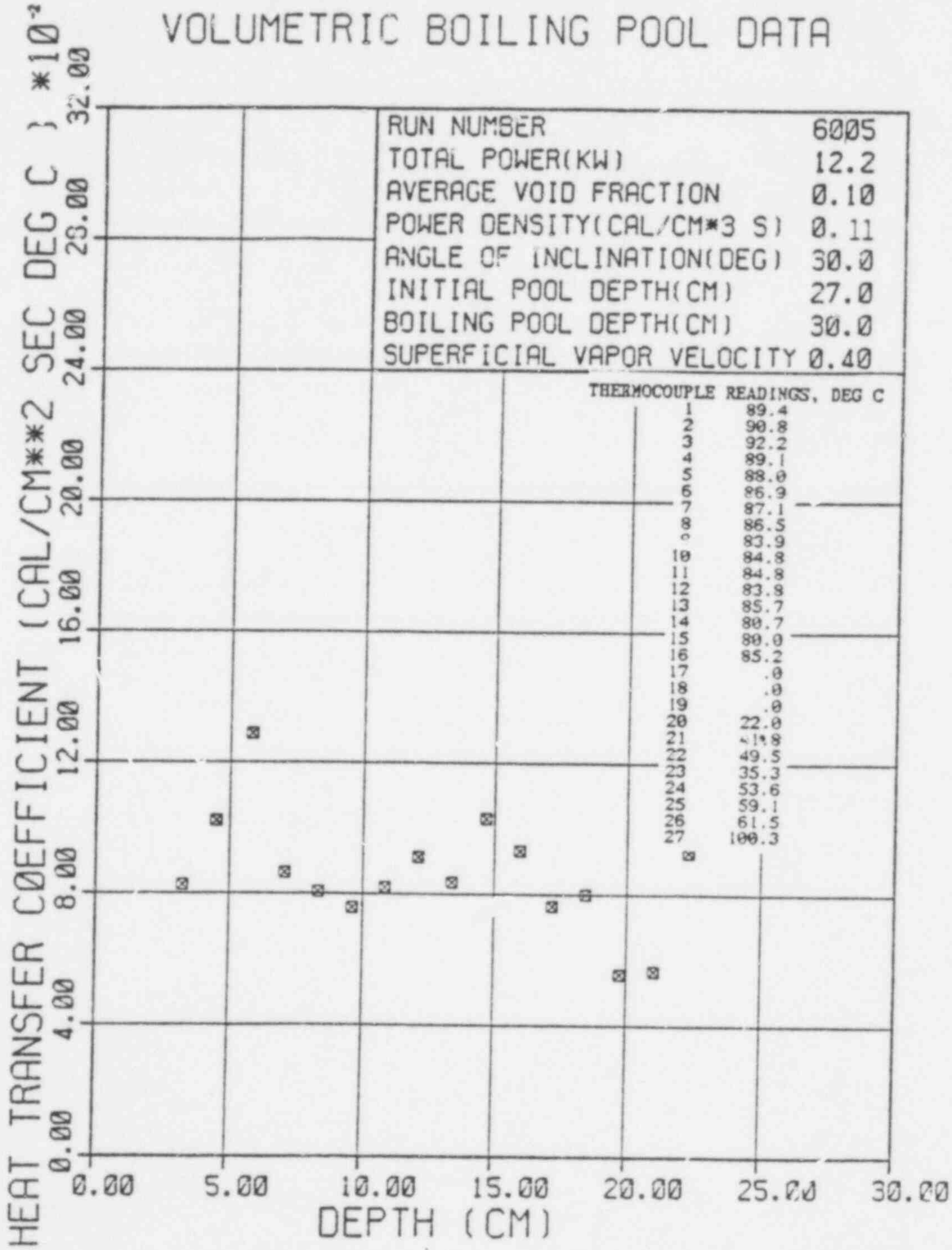
494 201

RUN NUMBER... 6005

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .10 |
| INITIAL POOL DEPTH(CM)........ | 27.0 |
| BOILING POOL DEPTH(CM)........ | 30.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .11 |
| SUPERFICIAL VAPOR VELOCITY.... | .40 |
| ANGLE OF INCLINATION(DEGREES). | 30.00 |
| POOL VOLUME(CM**3)............ | 20020. |
| PRANDTL NUMBER................ | 1.90 |
| TOTAL POWER(KW)............... | 12.24 |
| AVERAGE SURFACE TEMP(DEG C)... | 86.2 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 3.241 | .0826 | .0619 | .0530 | .0708 | 164.6 | .5772E+09 |
| 4.511 | .1023 | .0570 | .0473 | .0630 | 283.9 | .1556E+10 |
| 5.781 | .1287 | .0536 | .0435 | .0578 | 457.9 | .3275E+10 |
| 7.051 | .0865 | .0510 | .0407 | .0539 | 375.2 | .5943E+10 |
| 8.321 | .0807 | .0489 | .0385 | .0509 | 413.0 | .9768E+10 |
| 9.591 | .0758 | .0472 | .0367 | .0485 | 447.4 | .1496E+11 |
| 10.86 | .0819 | .0458 | .0353 | .0465 | 547.5 | .2172E+11 |
| 12.[illegible] | .0912 | .0445 | .0340 | .0448 | 681.0 | .3027E+11 |
| 13.40 | .0837 | .0434 | .0329 | .0433 | 689.8 | .4080E+11 |
| 14.67 | .1031 | .0425 | .0320 | .0420 | 930.7 | .5354E+11 |
| 15.94 | .0932 | .0416 | .0311 | .0408 | 914.5 | .6868E+11 |
| 17.21 | .0764 | .0408 | .0303 | .0398 | 808.8 | .8643E+11 |
| 18.48 | .0800 | .0401 | .0297 | .0388 | 910.2 | .1070E+12 |
| 19.75 | .0556 | .0394 | .0290 | .0380 | 67[illegible].9 | .1306E+12 |
| 21.02 | .0567 | .0388 | .0285 | .0372 | 733.0 | .1575E+12 |
| 22.29 | .0928 | .0382 | .0279 | .0364 | 1272.6 | .1878E+12 |
| 23.56 | | .0377 | .0274 | .0358 | | |
| 24.83 | | .0372 | .0270 | .0352 | | |
| 26.10 | | .0368 | .0266 | .0346 | | |

494 202



VOLUMETRIC BOILING POOL DATA
RUN NUMBER 6005
TOTAL POWER(KW) 12.2
AVERAGE VOID FRACTION 0.10
POWER DENSITY(CAL/CM*3 S) 0.11
ANGLE OF INCLINATION(DEG) 30.0
INITIAL POOL DEPTH(CM) 27.0
BOILING POOL DEPTH(CM) 30.0
SUPERFICIAL VAPOR VELOCITY 0.40
THERMOCOUPLE READINGS, DEG C
1 89.4
2 90.8
3 92.2
4 89.1
5 88.0
6 86.9
7 87.1
8 86.5
83.9
10 84.8
11 84.8
12 83.8
13 85.7
14 80.7
15 80.0
16 85.2
17 .0
18 .0
19 .0
20 22.0
21
22 49.5
23 35.3
24 53.6
25 59.1
26 61.5
27 100.3
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)


494 203

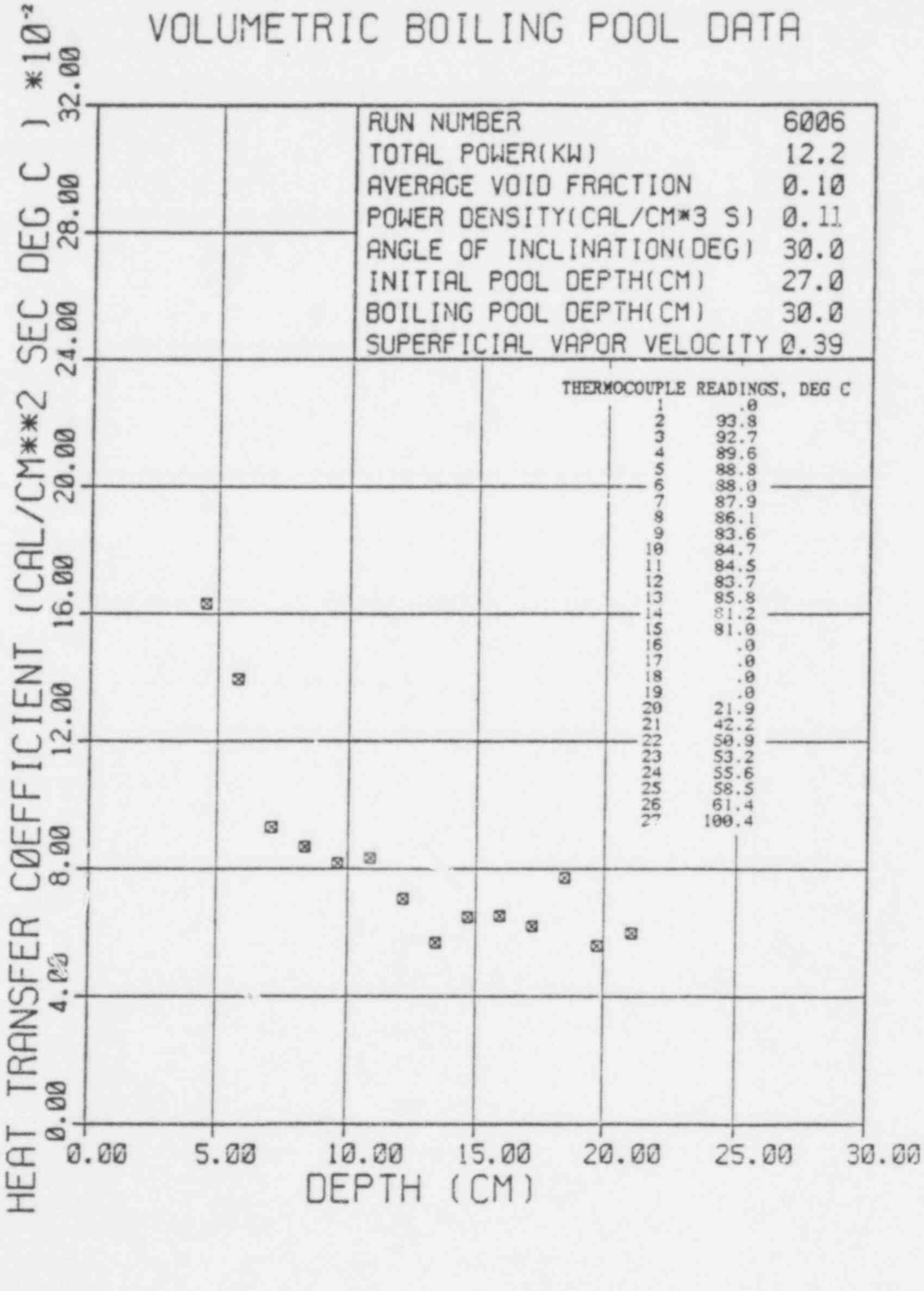
RUN NUMBER... 6006

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .10 |
| INITIAL POOL DEPTH(CM)........ | 27.0 |
| BOILING POOL DEPTH(CM)........ | 30.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .11 |
| SUPERFICIAL VAPOR VELOCITY.... | .39 |
| ANGLE OF INCLINATION(DEGREES). | 30.00 |
| POOL VOLUME(CM**3)............ | 20020. |
| PRANDTL NUMBER................ | 1.90 |
| TOTAL POWER(KW)............... | 12.24 |
| AVERAGE SURFACE TEMP(DEG C)... | 87.0 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 3.241 | | .0620 | .0528 | .0705 | | |
| 4.511 | .1632 | .0571 | .0472 | .0628 | 452.9 | .1563E+10 |
| 5.781 | .1393 | .0537 | .0434 | .0576 | 495.5 | .3289E+10 |
| 7.051 | .0930 | .0511 | .0406 | .0537 | 403.2 | .5968E+10 |
| 8.321 | .0870 | .0490 | .0384 | .0507 | 445.4 | .9808E+10 |
| 9.591 | .0818 | .0473 | .0366 | .0483 | 482.8 | .1502E+11 |
| 10.86 | .0834 | .0458 | .0352 | .0463 | 557.3 | .2181E+11 |
| 12.13 | .0707 | .0446 | .0339 | .0446 | 527.3 | .3039E+11 |
| 13.40 | .0569 | .0435 | .0328 | .0431 | 468.9 | .4097E+11 |
| 14.67 | .0648 | .0425 | .0319 | .0418 | 584.6 | .5376E+11 |
| 15.94 | .0671 | .0416 | .0310 | .0407 | 638.5 | .6896E+11 |
| 17.21 | .0619 | .0409 | .0303 | .0396 | 655.6 | .8679E+11 |
| 18.48 | .0772 | .0401 | .0296 | .0387 | 877.3 | .1075E+12 |
| 19.75 | .0558 | .0395 | .0290 | .0378 | 678.3 | .1312E+12 |
| 21.02 | .0597 | .0389 | .0284 | .0370 | 772.5 | .1581E+12 |
| 22.29 | | .0383 | .0279 | .0363 | | |
| 23.56 | | .0378 | .0274 | .0357 | | |
| 24.83 | | .0373 | .0269 | .0350 | | |
| 26.10 | | .0368 | .0265 | .0345 | | |



494 204


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 6006
TOTAL POWER(KW) 12.2
AVERAGE VOID FRACTION 0.10
POWER DENSITY(CAL/CM*3 S) 0.11
ANGLE OF INCLINATION(DEG) 30.0
INITIAL POOL DEPTH(CM) 27.0
BOILING POOL DEPTH(CM) 30.0
SUPERFICIAL VAPOR VELOCITY 0.39
THERMOCOUPLE READINGS, DEG C
1 .0
2 93.8
3 92.7
4 89.6
5 88.8
6 88.0
7 87.9
8 86.1
9 83.6
10 84.7
11 84.5
12 83.7
13 85.8
14 81.2
15 81.0
16 .0
17 .0
18 .0
19 .0
20 21.9
21 42.2
22 50.9
23 53.2
24 55.6
25 58.5
26 61.4
27 100.4
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)



494 205

RUN NUMBER... 6007

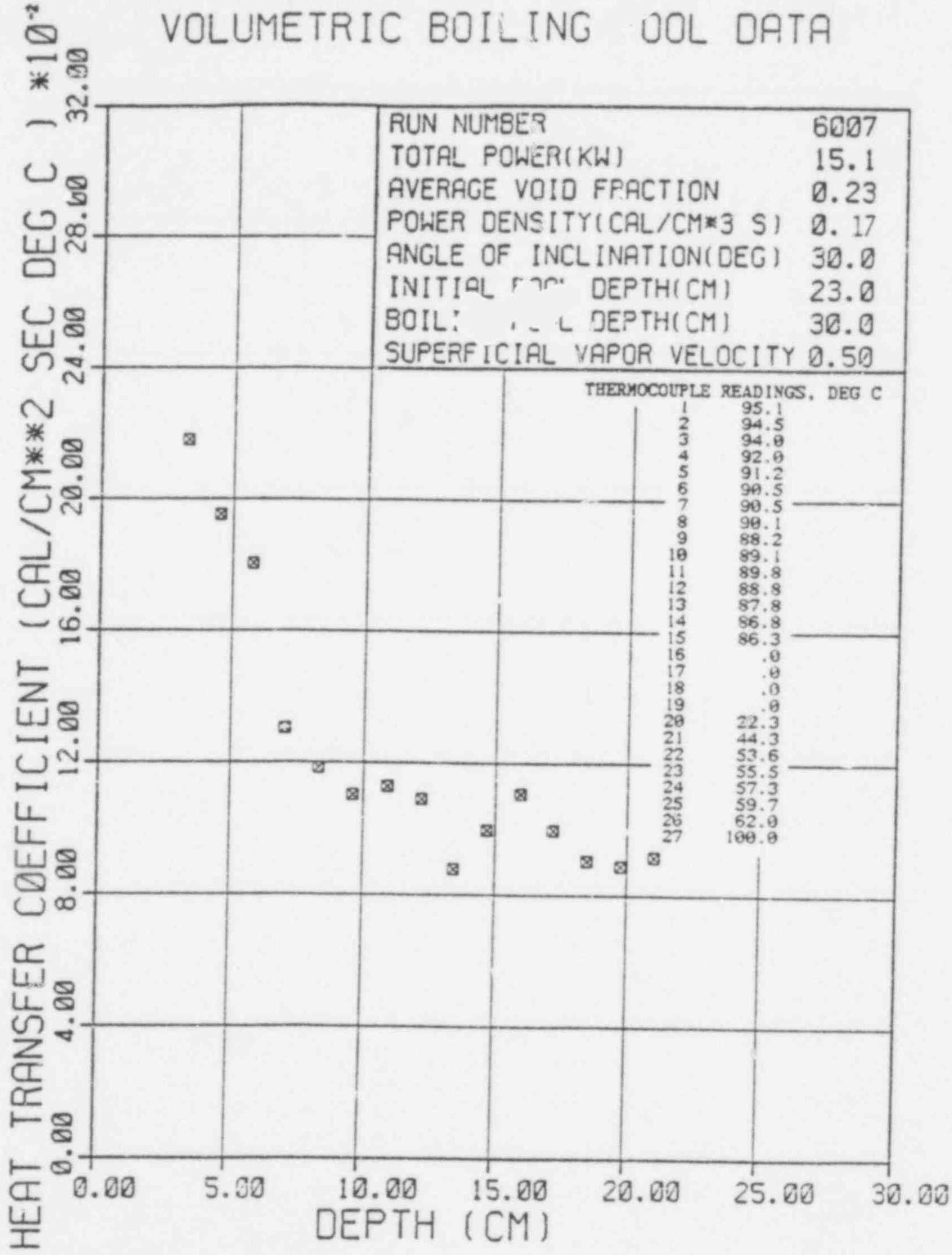
| | |
|---|---|
| AVERAGE VOID FRACTION......... | .23 |
| INITIAL POOL DEPTH(CM)........ | 23.0 |
| BOILING POOL DEPTH(CM)........ | 30.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .17 |
| SUPERFICIAL VAPOR VELOCITY.... | .50 |
| ANGLE OF INCLINATION(DEGREES). | 30.00 |
| POOL VOLUME(CM**3)............ | 16576. |
| PRANDTL NUMBER................ | 1.86 |
| TOTAL POWER(KW)............... | 15.12 |
| AVERAGE SURFACE TEMP(DEG C)... | 90.5 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 3.241 | .2181 | .0770 | .0634 | .0844 | 434.5 | .1372E+10 |
| 4.511 | .1953 | .0709 | .0567 | .0752 | 541.5 | .3698E+10 |
| 5.781 | .1804 | .0666 | .0522 | .0691 | 641.2 | .7784E+10 |
| 7.051 | .1303 | .0634 | .0489 | .0645 | 564.9 | .1412E+11 |
| 8.321 | .1185 | .0608 | .0463 | .0610 | 606.1 | .2321E+11 |
| 9.591 | .1101 | .0587 | .0442 | .0581 | 649.1 | .3555E+11 |
| 10.86 | .1128 | .0569 | .0425 | .0557 | 753.2 | .5162E+11 |
| 12.13 | .1089 | .0553 | .0410 | .0536 | 812.2 | .7193E+11 |
| 13.40 | .0878 | .0540 | .0397 | .0519 | 723.4 | .9696E+11 |
| 14.67 | .0995 | .0528 | .0386 | .0503 | 897.5 | .1272E+12 |
| 15.94 | .1106 | .0517 | .0376 | .0490 | 1083.4 | .1632E+12 |
| 17.21 | .0996 | .0507 | .0366 | .0477 | 1054.1 | .2054E+12 |
| 18.48 | .0905 | .0498 | .0358 | .0466 | 1028.1 | .2543E+12 |
| 19.75 | .0888 | .0490 | .0351 | .0456 | 1077.9 | .3104E+12 |
| 21.02 | .0917 | .0482 | .0344 | .0446 | 1184.5 | .3743E+12 |
| 22.29 | | .0475 | .0338 | .0438 | | |
| 23.56 | | .0469 | .0332 | .0430 | | |
| 24.83 | | .0463 | .0326 | .0423 | | |
| 26.10 | | .0457 | .0321 | .0416 | | |



494 206

# VOLUMETRIC BOILING OOL DATA



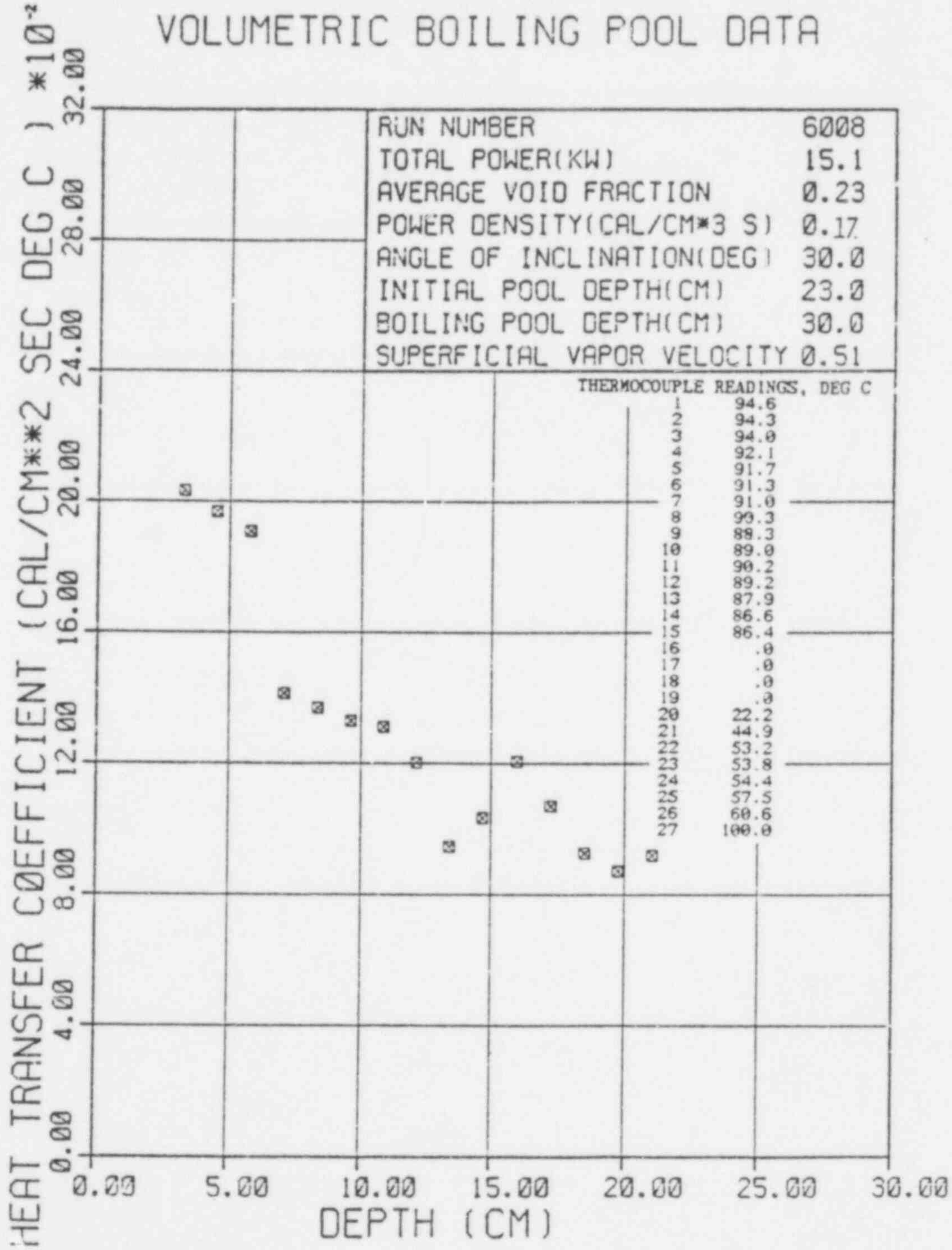



494 207

RUN NUMBER... 6008

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .23 |
| INITIAL POOL DEPTH(CM)........ | 23.0 |
| BOILING POOL DEPTH(CM)........ | 30.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .17 |
| SUPERFICIAL VAPOR VELOCITY.... | .51 |
| ANGLE OF INCLINATION(DEGREES). | 30.00 |
| POOL VOLUME(CM**3)............ | 16576. |
| PRANDTL NUMBER................ | 1.86 |
| TOTAL POWER(KW)............... | 15.12 |
| AVERAGE SURFACE TEMP(DEG C)... | 90.7 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 3.241 | .2033 | .0770 | .0637 | .0848 | 404.9 | .1373E+10 |
| 4.511 | .1967 | .0709 | .0569 | .0755 | 545.5 | .3702E+10 |
| 5.781 | .1908 | .0666 | .0524 | .0693 | 678.1 | .7791E+10 |
| 7.051 | .1414 | .0634 | .0491 | .0648 | 612.8 | .1414E+11 |
| 8.321 | .1370 | .0608 | .0465 | .0612 | 700.9 | .2323E+11 |
| 9.591 | .1331 | .0587 | .0444 | .0583 | 784.6 | .3558E+11 |
| 10.86 | .1313 | .0569 | .0426 | .0559 | 876.5 | .5167E+11 |
| 12.13 | .1201 | .0554 | .0411 | .0538 | 895.9 | .7199E+11 |
| 13.40 | .0946 | .0540 | .0398 | .0521 | 779.6 | .9705E+11 |
| 14.67 | .1033 | .0528 | .0387 | .0505 | 931.6 | .1273E+12 |
| 15.94 | .1206 | .0517 | .0377 | .0491 | 1181.4 | .1634E+12 |
| 17.21 | .1070 | .0507 | .0368 | .0479 | 1132.1 | .2056E+12 |
| 18.48 | .0926 | .0498 | .0359 | .0468 | 1051.7 | .2546E+12 |
| 19.75 | .0871 | .0490 | .0352 | .0457 | 1057.8 | .3107E+12 |
| 21.02 | .0919 | .0482 | .0345 | .0448 | 1188.0 | .3746E+12 |
| 22.29 | | .0475 | .0339 | .0439 | | |
| 23.56 | | .0469 | .0333 | .0431 | | |
| 24.83 | | .0463 | .0327 | .0424 | | |
| 26.10 | | .0457 | .0322 | .0417 | | |


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 6008
TOTAL POWER(KW) 15.1
AVERAGE VOID FRACTION 0.23
POWER DENSITY(CAL/CM*3 S) 0.17
ANGLE OF INCLINATION(DEG) 30.0
INITIAL POOL DEPTH(CM) 23.0
BOILING POOL DEPTH(CM) 30.0
SUPERFICIAL VAPOR VELOCITY 0.51
THERMOCOUPLE READINGS, DEG C
1 94.6
2 94.3
3 94.0
4 92.1
5 91.7
6 91.3
7 91.0
8 99.3
9 88.3
10 89.0
11 90.2
12 89.2
13 87.9
14 86.6
15 86.4
16 .0
17 .0
18 .0
19 .0
20 22.2
21 44.9
22 53.2
23 53.8
24 54.4
25 57.5
26 60.6
27 100.0
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)



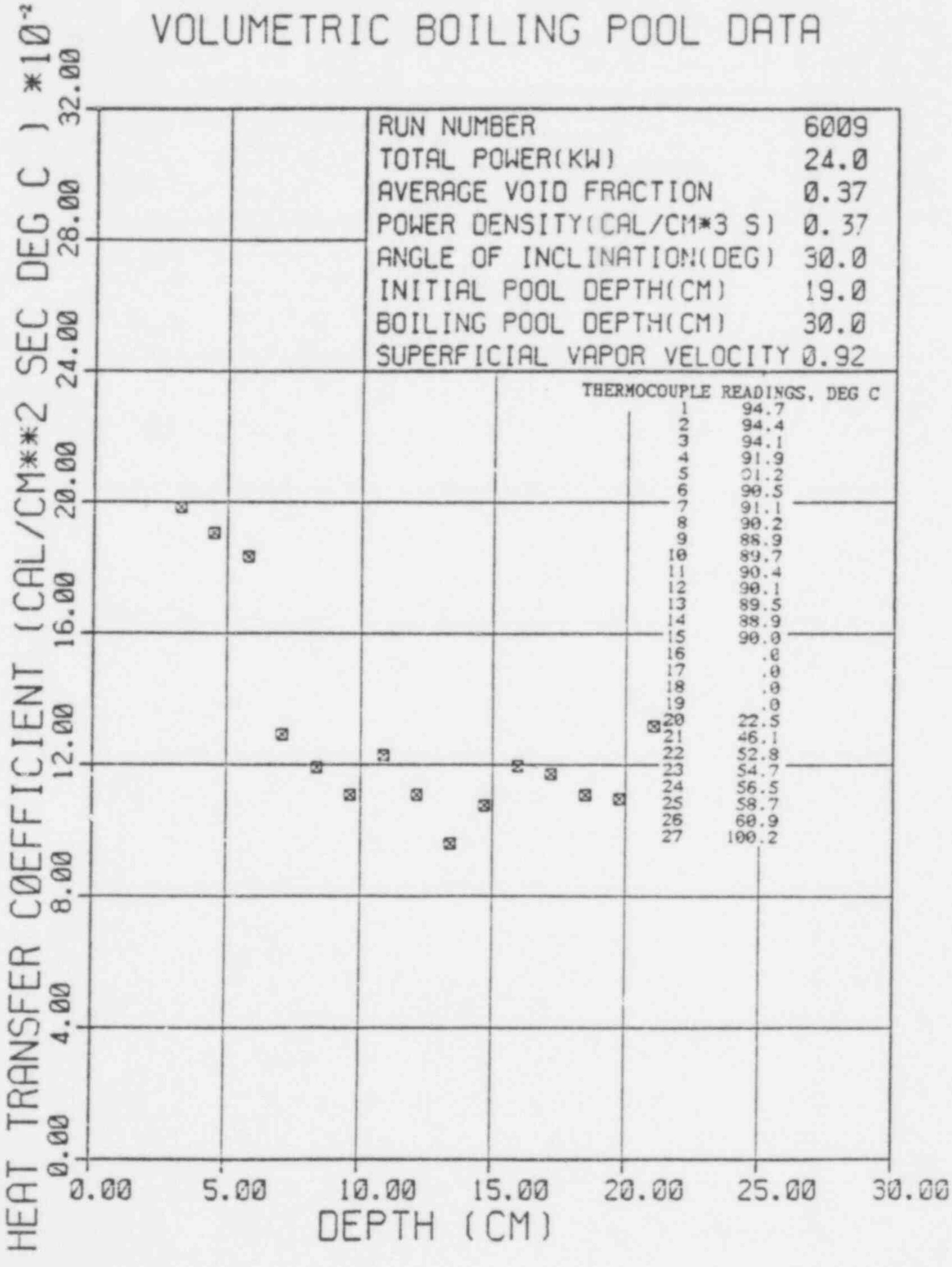
494 209

RUN NUMBER... 6009

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .37 |
| INITIAL POOL DEPTH(CM)........ | 19.0 |
| BOILING POOL DEPTH(CM)........ | 30.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .37 |
| SUPERFICIAL VAPOR VELOCITY.... | .92 |
| ANGLE OF INCLINATION(DEGREES). | 30.00 |
| POOL VOLUME(CM**3)............ | 13299. |
| PRANDTL NUMBER................ | 1.85 |
| TOTAL POWER(KW)............... | 24.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 91.4 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 3.241 | .1984 | .0863 | .0765 | .1025 | 395.2 | .2166E+10 |
| 4.511 | .1905 | .0795 | .0682 | .0911 | 528.2 | .5841E+10 |
| 5.781 | .1835 | .0747 | .0626 | .0835 | 651.8 | .1229E+11 |
| 7.051 | .1291 | .0711 | .0585 | .0779 | 559.6 | .2231E+11 |
| 8.321 | .1192 | .0682 | .0553 | .0735 | 609.6 | .3666E+11 |
| 9.591 | .1107 | .0658 | .0527 | .0699 | 652.6 | .5614E+11 |
| 10.86 | .1227 | .0638 | .0506 | .0670 | 819.3 | .8152E+11 |
| 12.13 | .1107 | .0621 | .0488 | .0645 | 825.5 | .1136E+12 |
| 13.40 | .0960 | .0605 | .0472 | .0623 | 790.5 | .1531E+12 |
| 14.67 | .1076 | .0592 | .0458 | .0604 | 979.2 | .2009E+12 |
| 15.94 | .1197 | .0580 | .0445 | .0587 | 1172.5 | .2578E+12 |
| 17.21 | .1172 | .0569 | .0434 | .0572 | 1239.6 | .3244E+12 |
| 18.48 | .1107 | .0559 | .0424 | .0558 | 1257.6 | .4016E+12 |
| 19.75 | .1095 | .0549 | .0415 | .0546 | 1329.3 | .4903E+12 |
| 21.02 | .1319 | .0541 | .0407 | .0534 | 1703.6 | .5910E+12 |
| 22.29 | | .0533 | .0399 | .0524 | | |
| 23.56 | | .0526 | .0392 | .0514 | | |
| 24.83 | | .0519 | .0386 | .0505 | | |
| 26.10 | | .0512 | .0379 | .0497 | | |

494 210


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 6009
TOTAL POWER(KW) 24.0
AVERAGE VOID FRACTION 0.37
POWER DENSITY(CAL/CM*3 S) 0.37
ANGLE OF INCLINATION(DEG) 30.0
INITIAL POOL DEPTH(CM) 19.0
BOILING POOL DEPTH(CM) 30.0
SUPERFICIAL VAPOR VELOCITY 0.92
THERMOCOUPLE READINGS, DEG C
1 94.7
2 94.4
3 94.1
4 91.9
5 91.2
6 90.5
7 91.1
8 90.2
9 88.9
10 89.7
11 90.4
12 90.1
13 89.5
14 88.9
15 90.0
16 .0
17 .0
18 .0
19 .0
20 22.5
21 46.1
22 52.8
23 54.7
24 56.5
25 58.7
26 60.9
27 100.2
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C) *10^-2
DEPTH (CM)
0.00 4.00 8.00 12.00 16.00 20.00 24.00 28.00 32.00
0.00 5.00 10.00 15.00 20.00 25.00 30.00



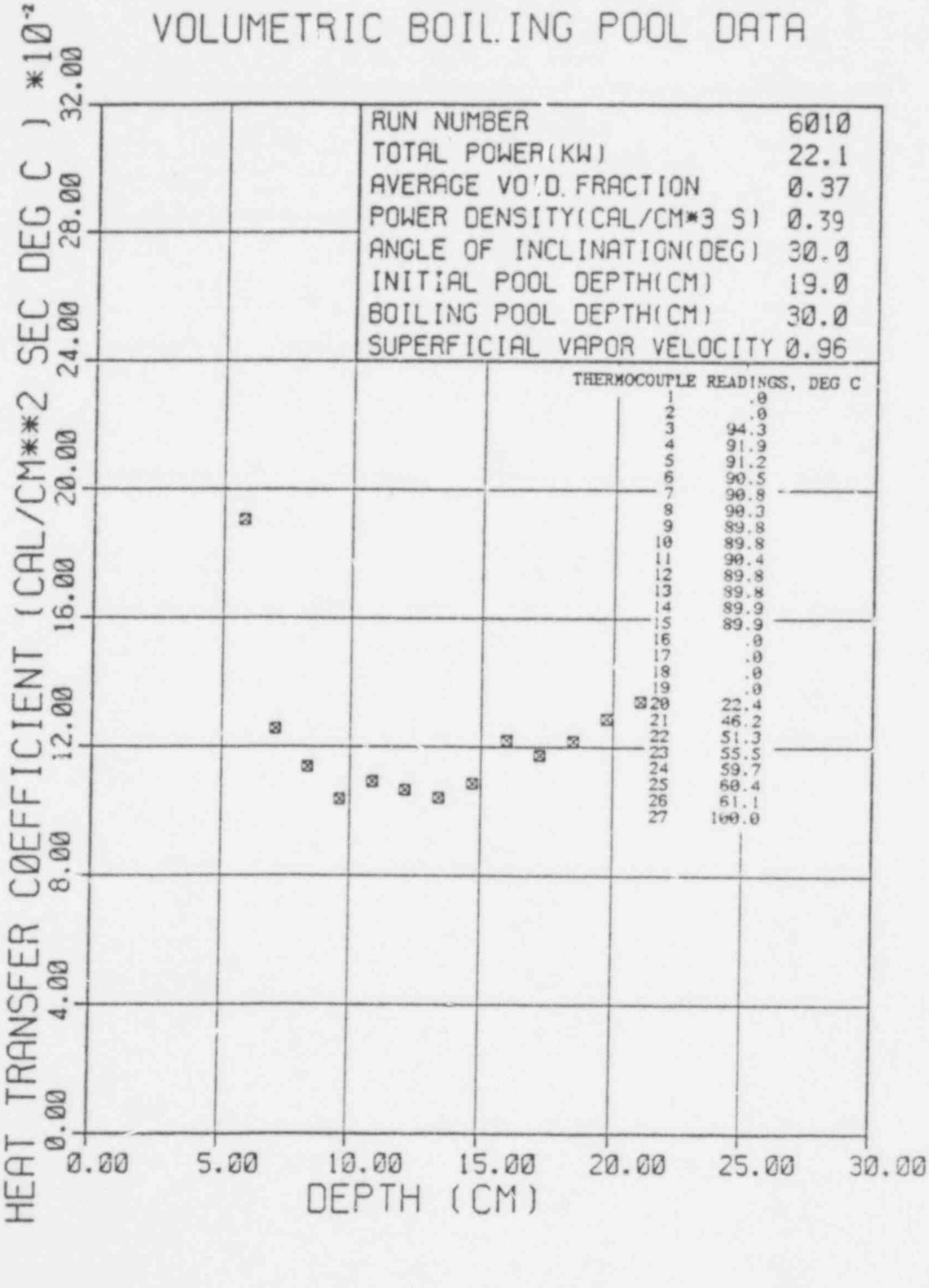
494 211

## RUN NUMBER... 6010

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .37 |
| INITIAL POOL DEPTH(CM)........ | 19.0 |
| BOILING POOL DEPTH(CM)........ | 30.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .39 |
| SUPERFICIAL VAPOR VELOCITY.... | .96 |
| ANGLE OF INCLINATION(DEGREES). | 30.00 |
| POOL VOLUME(CM**3)............ | 13299. |
| PRANDTL NUMBER................ | 1.85 |
| TOTAL POWER(KW)............... | 22.08 |
| AVERAGE SURFACE TEMP(DEG C)... | 91.9 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 1[illegible] N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| 3.24[illegible] | | .0863 | .0772 | .1035 | | |
| 4.511 | | .0795 | .0688 | .0920 | | |
| 5.781 | .1907 | .0747 | .0631 | .0842 | 677.4 | .1231E+11 |
| 7.051 | .1255 | .0711 | .0590 | .0786 | 544.0 | .2234E+11 |
| 8.321 | .1138 | .0682 | .0558 | .0741 | 582.1 | .3671E+11 |
| 9.591 | .1039 | .0658 | .0531 | .0705 | 612.2 | .5621E+11 |
| 10.86 | .1091 | .0638 | .0510 | .0676 | 728.4 | .8163E+11 |
| 12.13 | .1065 | .0621 | .0491 | .0650 | 793.9 | .1137E+12 |
| 13.40 | .1041 | .0606 | .0475 | .0628 | 857.5 | .1533E+12 |
| 14.67 | .1086 | .0592 | .0461 | .0609 | 978.7 | .2012E+12 |
| 15.94 | .1221 | .0580 | .0449 | .0592 | 1195.8 | .2581E+12 |
| 17.21 | .1174 | .0569 | .0437 | .0577 | 1241.9 | .3248E+12 |
| 18.48 | .1219 | .0559 | .0427 | .0563 | 1383.8 | .4022E+12 |
| 19.75 | .1288 | .0550 | .0418 | .0550 | 1563.4 | .4909E+12 |
| 21.02 | .1342 | .0541 | .0410 | .0539 | 1734.1 | .5918E+12 |
| 22.29 | | .0533 | .0402 | .0528 | | |
| 23.56 | | .0526 | .0395 | .0518 | | |
| 24.83 | | .0519 | .0388 | .0509 | | |
| 26.10 | | .0513 | .0382 | .0501 | | |

494 212


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 6010
TOTAL POWER(KW) 22.1
AVERAGE VOID FRACTION 0.37
POWER DENSITY(CAL/CM*3 S) 0.39
ANGLE OF INCLINATION(DEG) 30.0
INITIAL POOL DEPTH(CM) 19.0
BOILING POOL DEPTH(CM) 30.0
SUPERFICIAL VAPOR VELOCITY 0.96
THERMOCOUPLE READINGS, DEG C
1 .0
2 .0
3 94.3
4 91.9
5 91.2
6 90.5
7 90.8
8 90.3
9 89.8
10 89.8
11 90.4
12 89.8
13 89.8
14 89.9
15 89.9
16 .0
17 .0
18 .0
19 .0
20 22.4
21 46.2
22 51.3
23 55.5
24 59.7
25 60.4
26 61.1
27 100.0
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10^-2
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)



494 213

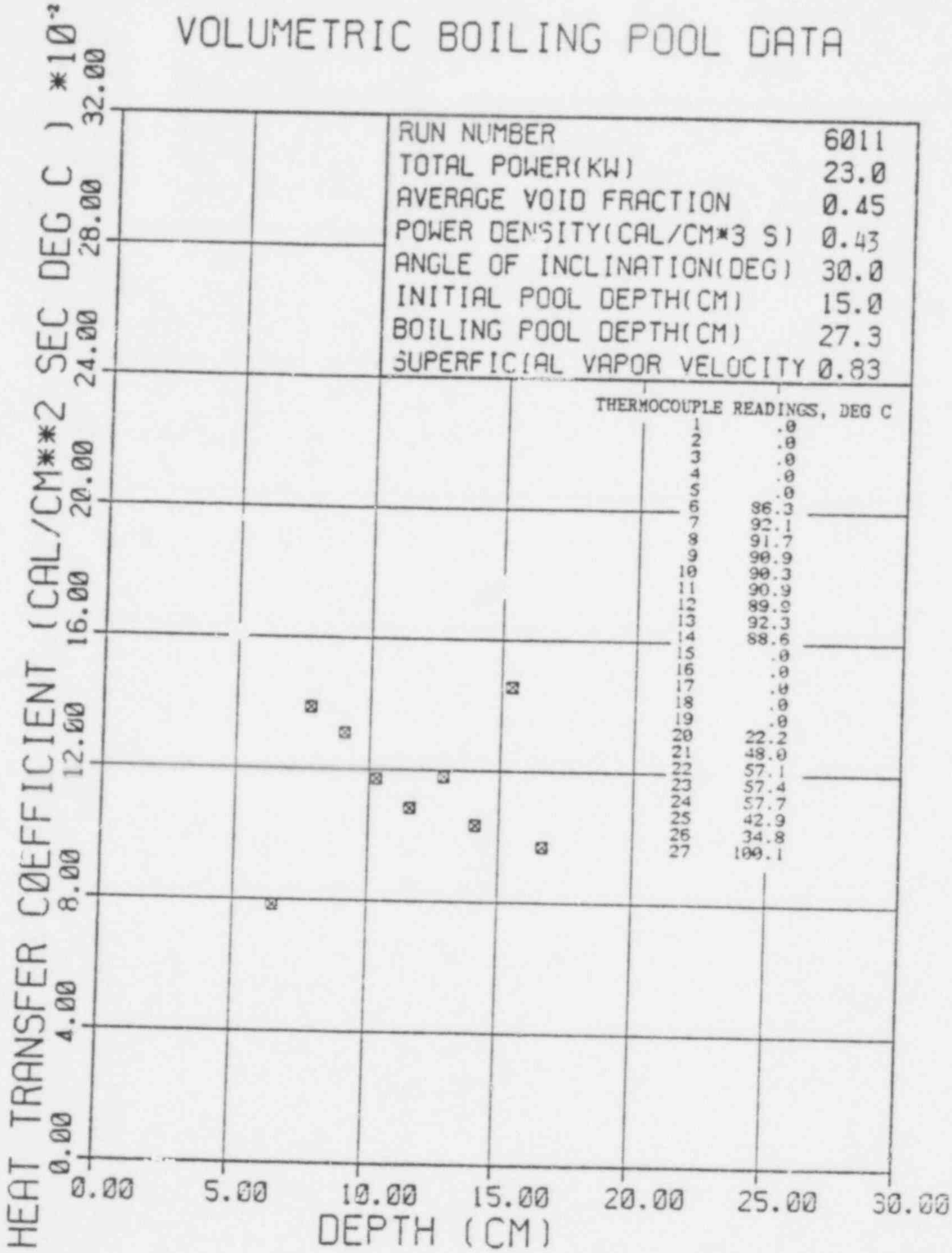
RUN NUMBER... 6011

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .45 |
| INITIAL POOL DEPTH(CM)........ | 15.0 |
| BOILING POOL DEPTH(CM)........ | 27.3 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .43 |
| SUPERFICIAL VAPOR VELOCITY.... | .63 |
| ANGLE OF INCLINATION(DEGREES). | 30.00 |
| POOL VOLUME(CM**3)............ | 10187. |
| PRANDTL NUMBER................ | 1.86 |
| TOTAL POWER(KW)............... | 23.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 90.7 |

| DEPTH (CM) | LOCAL HEAT TRANSFER CO... (CAL/CM2 SEC DEG C) EXPT | EQ 14a | EQ 10 N=1.0 | EQ10 N=0.7 | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| .123 | | .2055 | .2594 | .3481 | | |
| 1.393 | | .1121 | .1040 | .1397 | | |
| 2.663 | | .0953 | .0828 | .1107 | | |
| 3.933 | | .0865 | .0723 | .0964 | | |
| 5.203 | | .0806 | .0658 | .0874 | | |
| 6.473 | .0784 | .0764 | .0611 | .0810 | 312.1 | .2113E+11 |
| 7.743 | .1388 | .0730 | .0575 | .0761 | 660.7 | .3617E+11 |
| 9.013 | .1311 | .0703 | .0547 | .0723 | 726.1 | .5704E+11 |
| 10.28 | .1172 | .0680 | .0524 | .0691 | 740.8 | .8471E+11 |
| 11.55 | .1084 | .0661 | .0504 | .0664 | 769.6 | .1201E+12 |
| 12.82 | .1179 | .0644 | .0487 | .0641 | 929.3 | .1643E+12 |
| 14.09 | .1035 | .0629 | .0473 | .0620 | 896.5 | .2181E+12 |
| 15.36 | .1457 | .0615 | .0460 | .0603 | 1375.8 | .2825E+12 |
| 16.63 | .0969 | .0603 | .0448 | .0587 | 991.1 | .3585E+12 |
| 17.90 | | .0592 | .0437 | .0572 | | |
| 19.17 | | .0582 | .0428 | .0559 | | |
| 20.44 | | .0573 | .0419 | .0547 | | |
| 21.71 | | .0564 | .0411 | .0536 | | |
| 22.93 | | .0556 | .0404 | .0526 | | |



494 214


VOLUMETRIC BOILING POOL DATA
RUN NUMBER 6011
TOTAL POWER(KW) 23.0
AVERAGE VOID FRACTION 0.45
POWER DENSITY(CAL/CM*3 S) 0.43
ANGLE OF INCLINATION(DEG) 30.0
INITIAL POOL DEPTH(CM) 15.0
BOILING POOL DEPTH(CM) 27.3
SUPERFICIAL VAPOR VELOCITY 0.83
THERMOCOUPLE READINGS, DEG C
1 .0
2 .0
3 .0
4 .0
5 .0
6 86.3
7 92.1
8 91.7
9 90.9
10 90.3
11 90.9
12 89.9
13 92.3
14 88.6
15 .0
16 .0
17 .0
18 .0
19 .0
20 22.2
21 48.0
22 57.1
23 57.4
24 57.7
25 42.9
26 34.8
27 100.1
HEAT TRANSFER COEFFICIENT (CAL/CM**2 SEC DEG C ) *10⁻²
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
DEPTH (CM)



494 215

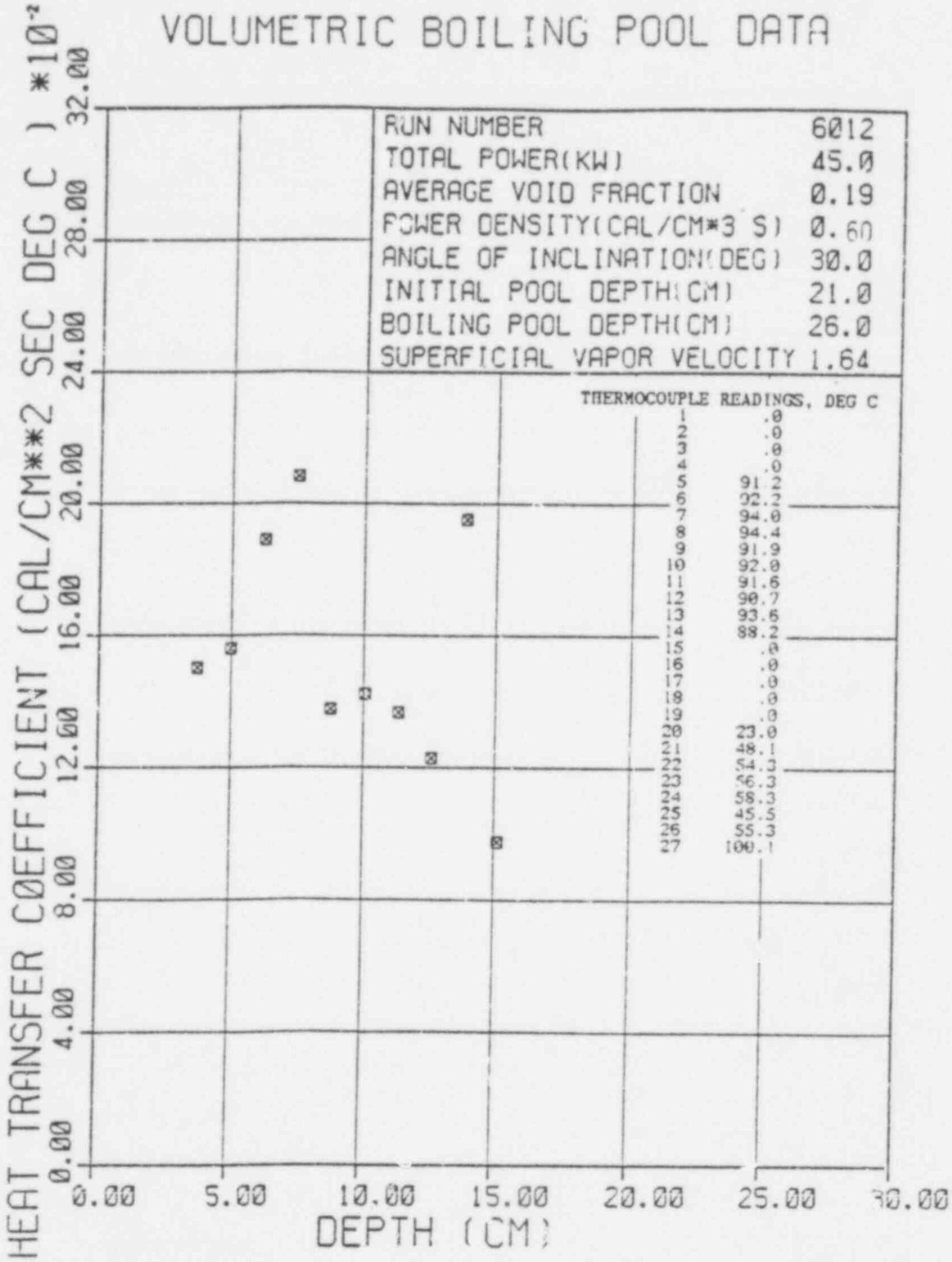
## RUN NUMBER... 6012

| | |
|---|---|
| AVERAGE VOID FRACTION......... | .19 |
| INITIAL POOL DEPTH(CM)........ | 21.0 |
| BOILING POOL DEPTH(CM)........ | 26.0 |
| VOL. POWER DENS.(CAL/CM3 SEC). | .60 |
| SUPERFICIAL VAPOR VELOCITY.... | 1.64 |
| ANGLE OF INCLINATION(DEGREES). | 30.00 |
| POOL VOLUME(CM**3)............ | 14917. |
| PRANDTL NUMBER................ | 1.85 |
| TOTAL POWER(KW)............... | 45.0 |
| AVERAGE SURFACE TEMP(DEG C)... | 92.2 |

| DEPTH (CM) | LOCAL HEAT TRANSFER COEFF (CAL/CM2 SEC DEG C) | | | | NUSSELT NUMBER | MODIFIED RAYLEIGH NUMBER |
|---|---|---|---|---|---|---|
| | EXPT | EQ 14a | EQ 10 N=1.0 | EQ 10 N=0.7 | | |
| 1.162 | | .0950 | .1193 | .1602 | | |
| 2.432 | | .0790 | .0895 | .1205 | | |
| 3.702 | .1503 | .0711 | .0763 | .1028 | 341.9 | .1699E+10 |
| 4.972 | .1560 | .0661 | .0683 | .0920 | 476.5 | .4115E+10 |
| 6.242 | .1889 | .0624 | .0628 | .0845 | 724.7 | .8143E+10 |
| 7.512 | .2082 | .0596 | .0587 | .0790 | 961.2 | .1419E+11 |
| 8.782 | .1375 | .0573 | .0554 | .0745 | 742.1 | .2268E+11 |
| 10.05 | .1423 | .0554 | .0528 | .0709 | 878.8 | .3400E+11 |
| 11.32 | .1366 | .0538 | .0505 | .0679 | 950.3 | [illegible] |
| 12.59 | .1227 | .0524 | .0486 | .0653 | 949.5 | .6684E+11 |
| 13.86 | .1952 | .0511 | .0470 | .0631 | 1662.5 | .8918E+11 |
| 15.13 | .0976 | .0506 | .0456 | .0611 | 907.2 | .1160E+12 |
| 16.40 | | .0490 | .0443 | .0594 | | |
| 17.67 | | .0481 | .0431 | .0578 | | |
| 18.94 | | .0473 | .0421 | .0564 | | |
| 20.21 | | [illegible] | .0411 | .0551 | | |
| 21.48 | | .0458 | .0403 | .0539 | | |

494 216

VOLUMETRIC BOILING POOL DATA



APPENDIX D

Algebraic Development of Equations 28 and 29.

In single phase natural convection heat transfer along a vertical flat plate, it has been determined that for Pr equal 2.0, the local free convection heat transfer correlations for laminar and turbulent flow are

$$Nu(x) = 0.42\ [Gr \cdot Pr]^{1/4} \qquad \text{(D-1)}$$

and

$$Nu(x) = 0.0295\ Gr^{2/5} Pr^{7/15} [1 + .494\ Pr^{2/3}]^{-2/5} \qquad \text{(D-2a)}$$

respectively. Equation D-2 may be reduced to the following approximate form by grouping $(Gr \cdot Pr)^{2/5}$ and letting Pr = 2.0;

$$Nu(x) \doteq 0.0245\ [Gr \cdot Pr]^{2/5} \qquad \text{(D-2b)}$$

In order to compare these results to average experimental heat transfer data, it has been necessary to convert these local heat transfer coefficients into the corresponding average values along the surface. By introducing the expression for the Grashof number into the above equations, it can be seen that the local heat transfer coefficient is proportional to the distance from the leading edge along the laminar boundary layer to the -1/4 power[25], i.e.,

$$h(x) \sim x^{-1/4} \qquad \text{(D-3a)}$$

and for the turbulent case, proportional to the distance from the leading edge along the boundary layer to the power 0.2[26], i.e.,

$$h(x) \sim x^{0.2} \qquad \text{(D-3b)}$$

It may be readily shown by integrating equations D-1 and D-2 a,b that the average heat transfer coefficient over the length of the plate, L, is related to the local coefficient at x = L as follows: for the laminar boundary layer (Eq. D-1),

$$\bar{h} = \frac{1}{L}\int_{o}^{L} h(x)dx = \frac{4}{3}\, h(x)\Big|_{x=L} \qquad \text{(D-4a)}$$

and for the turbulent boundary layer (Eqs D-2 a,b),

$$\bar{h} = \frac{1}{L}\int_{o}^{L} h(x)dx = \frac{h(x)}{1.2}\Big|_{x=L} \qquad \text{(D-4b)}$$

Thus, the local Nusselt relations (Eqs. D-1 and D-2 a,b,) may be modified to represent the average heat transfer behavior by substituting $\bar{h}$ for h(x), L for x, and multiplying the correlation coefficient, K, by the factor 1.33 (for laminar case) or .83 (for turbulent case). When this is done, Eqs. D-1, D-2a, and D-2b are transformed into the average correlations below, respectively,

$$\overline{Nu} = 0.56[Gr \cdot Pr]^{1/4} \qquad \text{(D-5)}$$

$$\overline{Nu} = 0.0246\ Gr^{2/5}\ Pr^{7/15}[1 + .494\ Pr^{2/3}]^{-2/5} \qquad \text{(D-6a)}$$

$$\overline{Nu} = 0.0210[Gr \cdot Pr]^{2/5} \qquad \text{(D-6b)}$$

These correlations are in excellent agreement with empirically derived relations in the literature.

The above conversion procedure is valid only in the case that the free stream properties are constant. In the case of boundary layer heat transfer from volume-heated boiling pools, it has been shown that there exists a vertical distribution of vapor fraction which is defined by the solution to Eq. 20. Thus, the integration demonstrated in Eqs. D-4 a,b will depend not only on the explicit spatial dependence in the Grashof number, but upon the implicit spatial variation in the void fraction distribution as well.

The forms of the local void distribution that will be considered are listed below:

a. $\alpha(x) = \overline{\alpha}$

b. $\alpha(x) = 2\ \overline{\alpha}(x/L)$

c. $\alpha(x) = 1.5\ \overline{\alpha}(x/L)^{1/2}$

d. $\alpha(x) = 3\ \overline{\alpha}(x/L)^{2}$

The procedure for determining the ratio of the average heat transfer correlation based upon $\overline{\alpha}$ to the local heat transfer correlation based upon $\alpha(x)$ is identical to that previously described. The results of the integration are presented in Table D-1 for both the laminar case ($Nu \sim Ra^{1/4}$) and the turbulent case ($Nu \sim Ra^{2/5}$).

The local heat transfer data from Ref. 12 has been correlated by both local and average void fraction with little observed sensitivity in the result, as demonstrated by Eqs. 14 a,b. On this justification, the local heat transfer data from this work was correlated on the basis of the average void fraction. As yet, only preliminary correlations of the data have been performed for laminar bubbly flow heat transfer. The results indicate quite close agreement with case d. Final results for local correlation of both laminar and turbulent bubbly flow data will be reported in the future.

TABLE D-1

SUMMARY OF LOCAL-TO-AVERAGE HEAT TRANSFER CORRELATION
CONVERSION UPON FREE STREAM VOID DISTRIBUTION

| | $K_{ave}/K_{local}$* | |
|---|---|---|
| VOID DISTRIBUTION FUNCTION | LAMINAR | TURBULENT |
| $\alpha(x) = \bar{\alpha}$ | 1.33 | .83 |
| $\alpha(x) = 2\,\bar{\alpha}(x/L)$ | 1.19 | .82 |
| $\alpha(x) = 1.5\,\bar{\alpha}\,(x/L)^{1/2}$ | 1.26 | .84 |
| $\alpha(x) = 3\,\bar{\alpha}(x/L)^2$ | 1.05 | .78 |

*$K_{ave}$ is the average heat transfer correlation coefficient, $\overline{Nu} = K_{ave}(Gr^* \cdot Pr)^n$ where n = 1/4 for laminar flow, n = 2/5 for turbulent flow.

*$K_{local}$ is the local heat transfer correlation coefficient, $Nu(x) = K_{local}(Gr^* \cdot Pr)^n$ where n = 1/4 for laminar flow, n = 2.5 for turbulent flow.

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