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ORNL - TM - 52
COPY NO. - 77
DATE - 9-26-61

# HYDRODYNAMIC TESTS OF CYLINDRICAL HRE-2 REPLACEMENT CORE MODEL

W. R. Mixon and C. G. Lawson

ABSTRACT

Fluid flow properties of a one-fifth scale slot entry flow model were studied to evaluate that design for use as an HRE-2 replacement core vessel.

Spatial residence time and velocity distributions were determined in the model and the data were extrapolated to full-scale temperature conditions. Corrosion rates, core side heat transfer film coefficients, and the spatial mean fluid temperature were estimated for the replacement vessel. Solids and gas removal tests were run.

Low core wall temperature and the high velocity of fluid at the wall make this vessel well suited for use as a reactor core.



**NOTICE**

## INTRODUCTION AND SUMMARY

Failure of the HRE-2 core vessel during high-power operation is believed to have been caused by a buildup or deposition of uranium on the wall.[1] Scrubbing of solids (or heavy liquid phase) from the core wall, temperature of the wall, temperature distribution of fluid within the vessel, and oscillation of core power level are factors which depend directly on fluid flow properties of the core. Tests of small scale flow models serve to screen proposed core designs with respect to flow properties.

Mean fluid age and velocity traverses were completed in a small lucite model, approximately one-fifth scale, of a proposed HRE-2 replacement core vessel. From these data, the spatial temperature distribution and the core wall corrosion rates were estimated for the full-scale core for various flow rates. The nuclear average temperature and core side heat transfer film coefficients were estimated and solids and gas removal tests were run. It was found that the maximum wall temperature could be maintained below the outlet temperature, and that the maximum fluid temperature would be limited to 300°C at a flow of 87 gpm/Mw.

Because the cool fluid entering the core is introduced in a manner which maintains a blanket of cool fluid near the core vessel wall, the core wall corrosion rates should be kept at a minimum.

## DESIGN OF FLOW MODEL

The Lucite flow model tested was geometrically scaled from the proposed HRE-2 replacement core vessel dimensions. It is basically a vertical cylinder with hemispherical heads of total L/D = 2.

A sketch of the flow model configuration showing the elevation of probe holes is shown in Fig. 1. A cross section of the header and one entrance slot is shown in Fig. 2. The two fluid entrance slots were 180° apart and ran the full length of the cylindrical section. Each hemispherical head had two inlet slots (shown in Fig. 2) which directed incoming fluid toward the ends at an angle of 45° from the horizontal. Water entered the model tangent to the wall and left through the outlet at the top of the vessel; a small outlet was provided at the bottom. Each slot header was fed by a separate rotameter to equalize the flow rate. The slot width and header cross section were constant at all elevations. Dimensions of the model and the proposed full size core are listed in the following table:

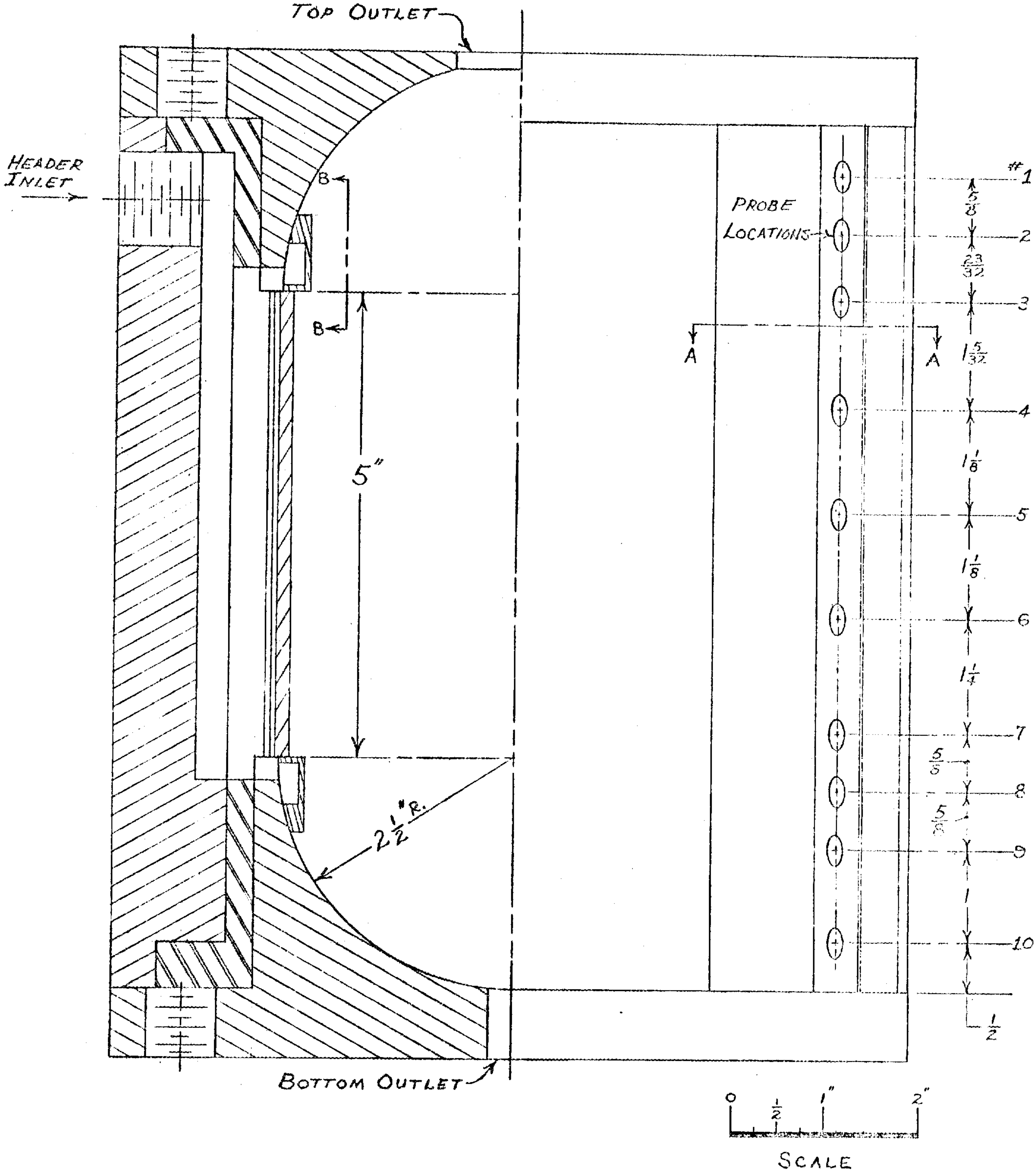


Fig. 1. Sketch of Flow Model With Probe Hole Elevations.

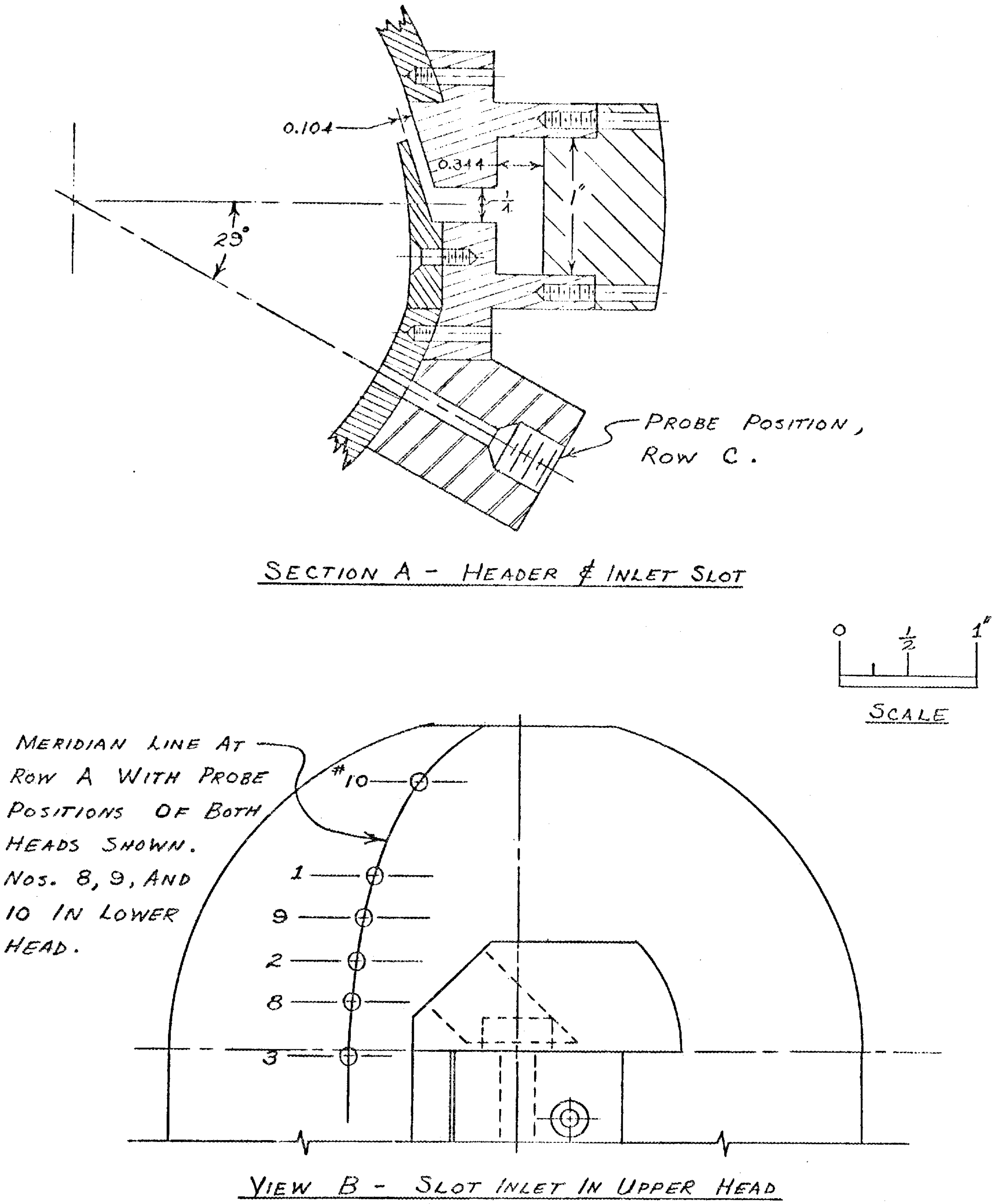


Fig. 2. Header Cross-Section and View of Inlet Slot in Heads.

| | Model | Full-Scale Core |
|---|---|---|
| Inside diameter | 5-in. | 24-in. |
| Inside over-all length | 10-in. | 48-in. |
| Single slot width | 0.104-in. | 0.50-in. |
| Volume | 0.093 $ft^3$ | 10.3 $ft^3$ |
| Flow rate | 8 gpm | 900 gpm |

Water flow rate was selected to give a mean residence time equal to that of the full-scale vessel running at 900 gpm.

## FLUID AGE MEASUREMENTS

### Theory

Fluid age measurements at points within the core model were obtained by use of conductivity probes. Mean fluid age at any point was calculated from the variation of local concentration of a tracer salt with time after a step concentration change of the inlet fluid. The relationship used is:

$$\tau_m = \frac{\int_0^\infty t \, \frac{\partial F}{\partial t} \, dt}{\int_0^\infty \frac{\partial F}{\partial t} \, dt} \qquad (1)$$

where $\tau_m$ = mean fluid age or, mean time that fluid at a point has been in the core before reaching that point,

$C(t)$ = concentration of salt at any time, t, at position of measurement,

$C(\infty)$ = concentration of salt as $t \to \infty$ for fluid located at position of measurement = concentration of salt at inlet for $t > 0$,

$F = \frac{C(\infty) - C(t)}{C(\infty)}$

$t$ = time in seconds measured from the instant a step change was introduced at the core inlet.

Assuming a constant and uniform heat generation rate throughout the core, the ratio of mean fluid age at a point to mean age at the outlet is equivalent to the ratio of mean temperature rise at that point to the mean temperature rise across the core. With the core inlet temperature and mean temperature rise known, the spatial temperature distribution within the core can be estimated from fluid age measurement traverses.

## Procedure and Apparatus

The step function change in inlet fluid conductivity was produced by pumping a $K_2Cr_2O_7$-water solution into the inlet water stream at a point far enough upstream from the model to insure a uniform mixture at the inlet. A 1.5 gpm Viking positive displacement rotary pump was used to inject salt solution to provide constant flow. A sharp step change was produced by use of solenoid valves in the salt inlet line.

Conductivity probes at the inlet, at the outlet, and at points of interest within the core were used to measure fluid conductivity, which was a linear function of $K_2Cr_2O_7$ concentration over the range of concentrations used. An eight-channel Sanborn instrument, composed of carrier preamplifier, driver amplifier with power supply, and recorder, supplied the 2400 cps A.C. probe excitation and received the probe signal through an external Wheatstone bridge. Philbrick amplifiers were built into three of the channels to calculate and record the time integral of the difference in signals from the inlet probe and the probe connected to that integrating channel. The value of the integral when $C(t) = C(\infty)$ was directly proportional to the mean fluid age. In practice, two values of the mean age were calculated from each run. One value was obtained from the step change when salt was injected and the other when salt injection was cut off.

## Fluid Age Results

Results of mean fluid age traverses at various elevations are shown in Figures 3, 4 and 5. The relative age ratios (mean fluid age at a point divided by mean age at outlet) are plotted versus distance along radii at each elevation. Table 1 lists the location of each probe fitting used in mean age and velocity traverses. Predicted fluid temperatures are plotted versus the flow rate to core power ratio in Fig. 6 for a 290 liter core with 250°C inlet fluid temperature. Mean fluid temperatures at points within the vessel, assuming uniform power density, are calculated from the expression

$$\text{Relative Age Ratio} = \frac{T - T_i}{T_o - T_i} \qquad (2)$$

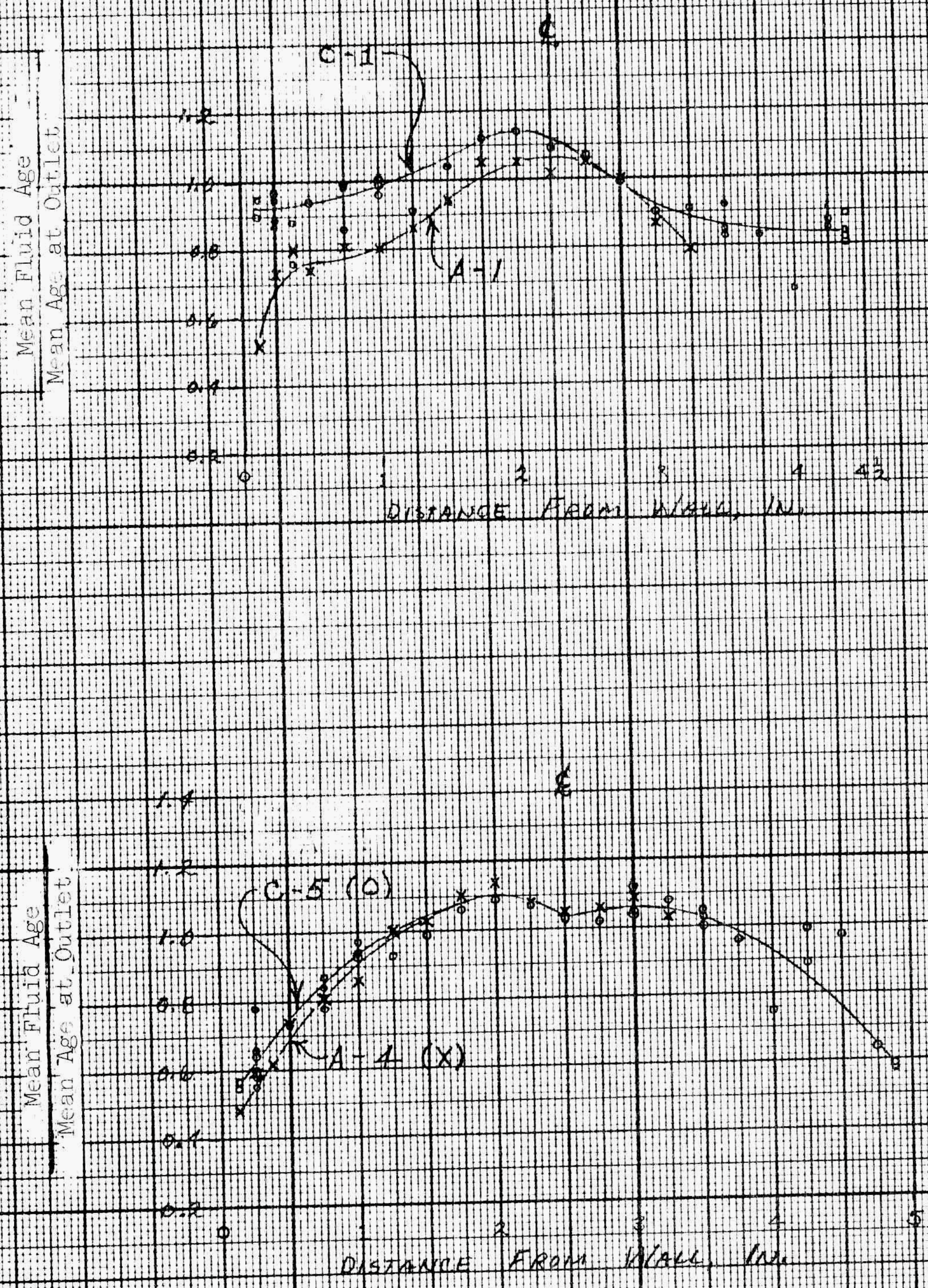


Fig. 3. Relative Age Ratio Profiles at Elevations 1, 4, and 5.

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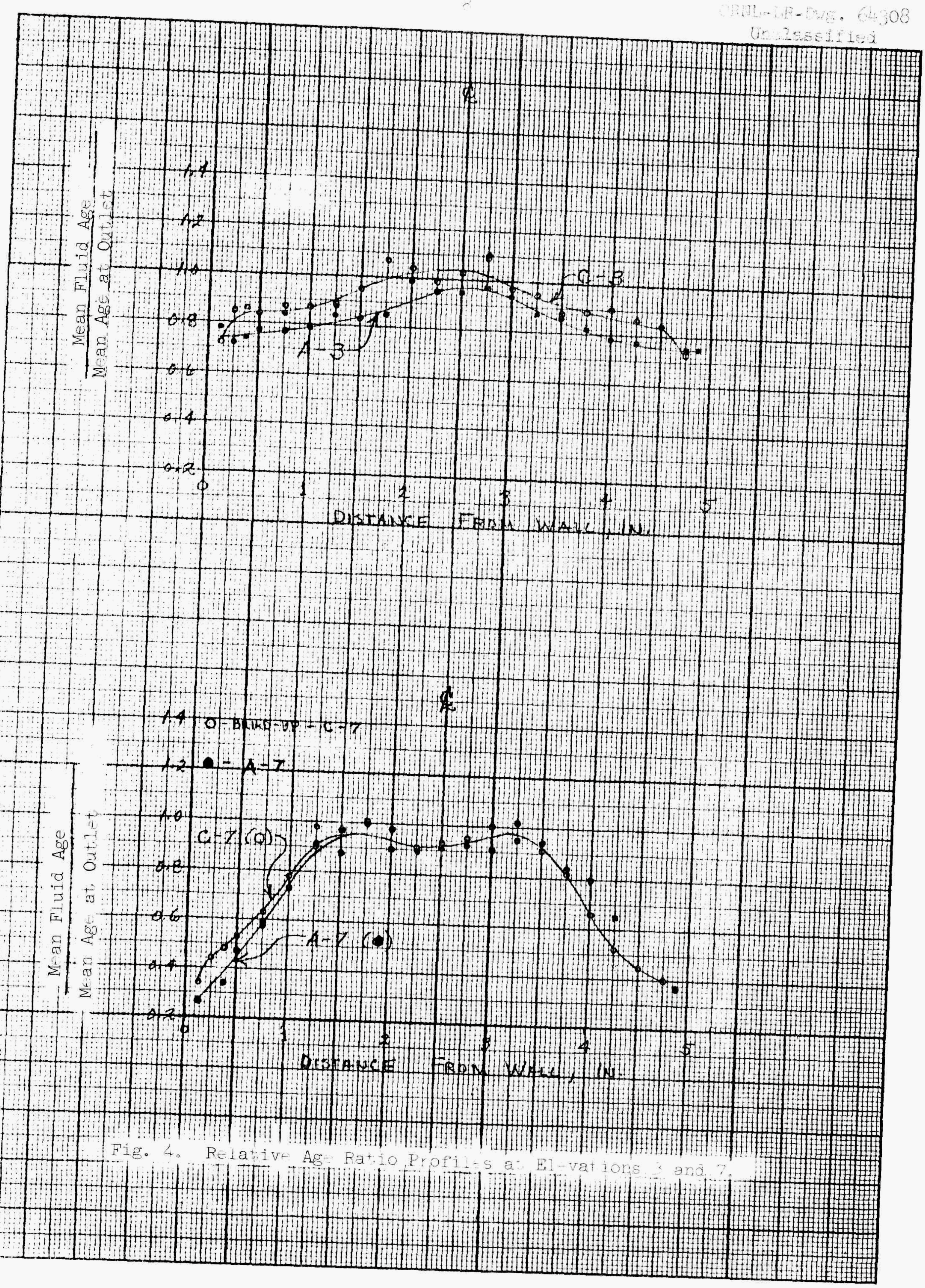


Fig. 4. Relative Age Ratio Profiles at Elevations 3 and 7.

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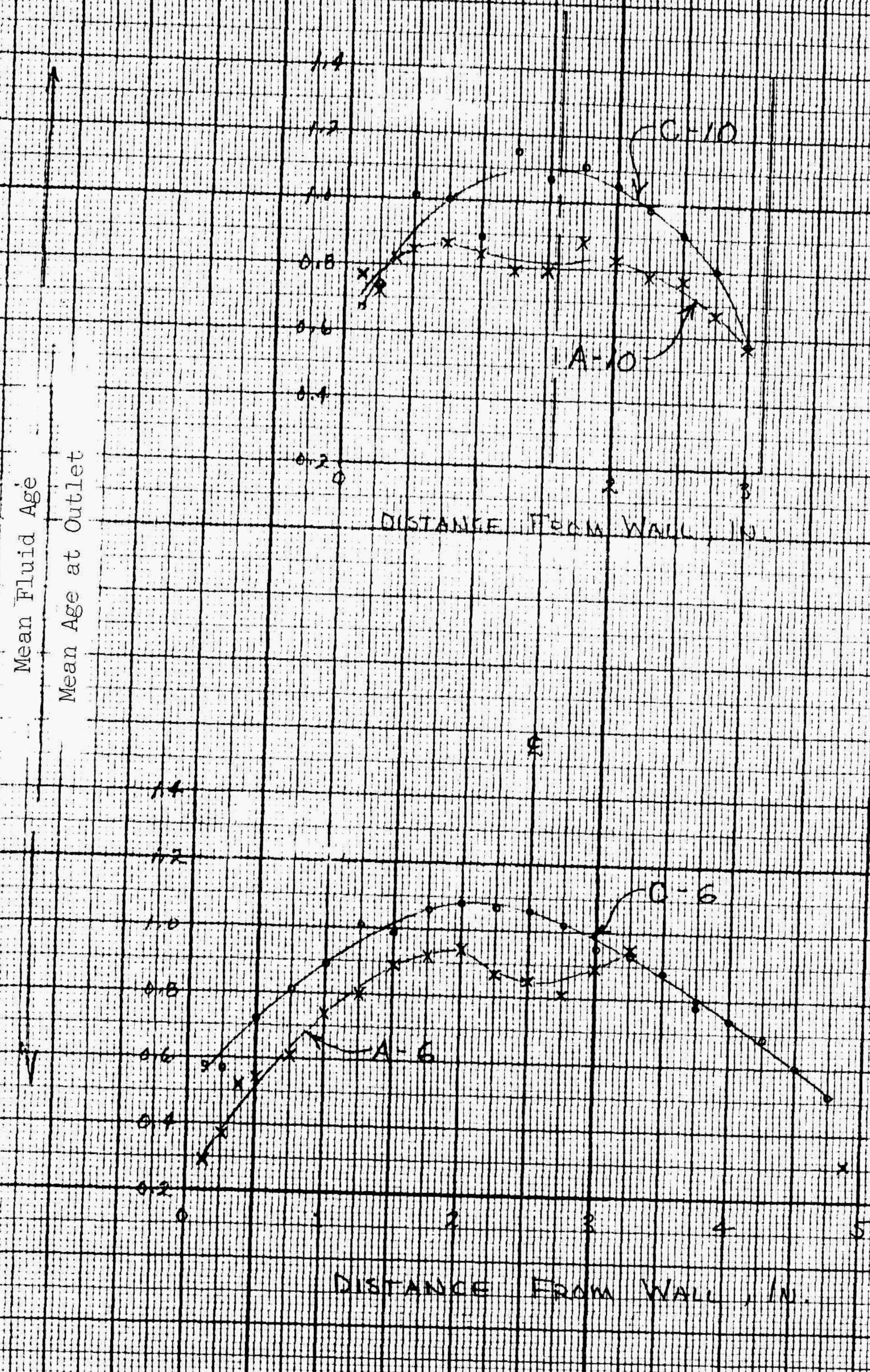


Fig. 5. Relative Age Ratio Profiles at Elevations 6 and 10.

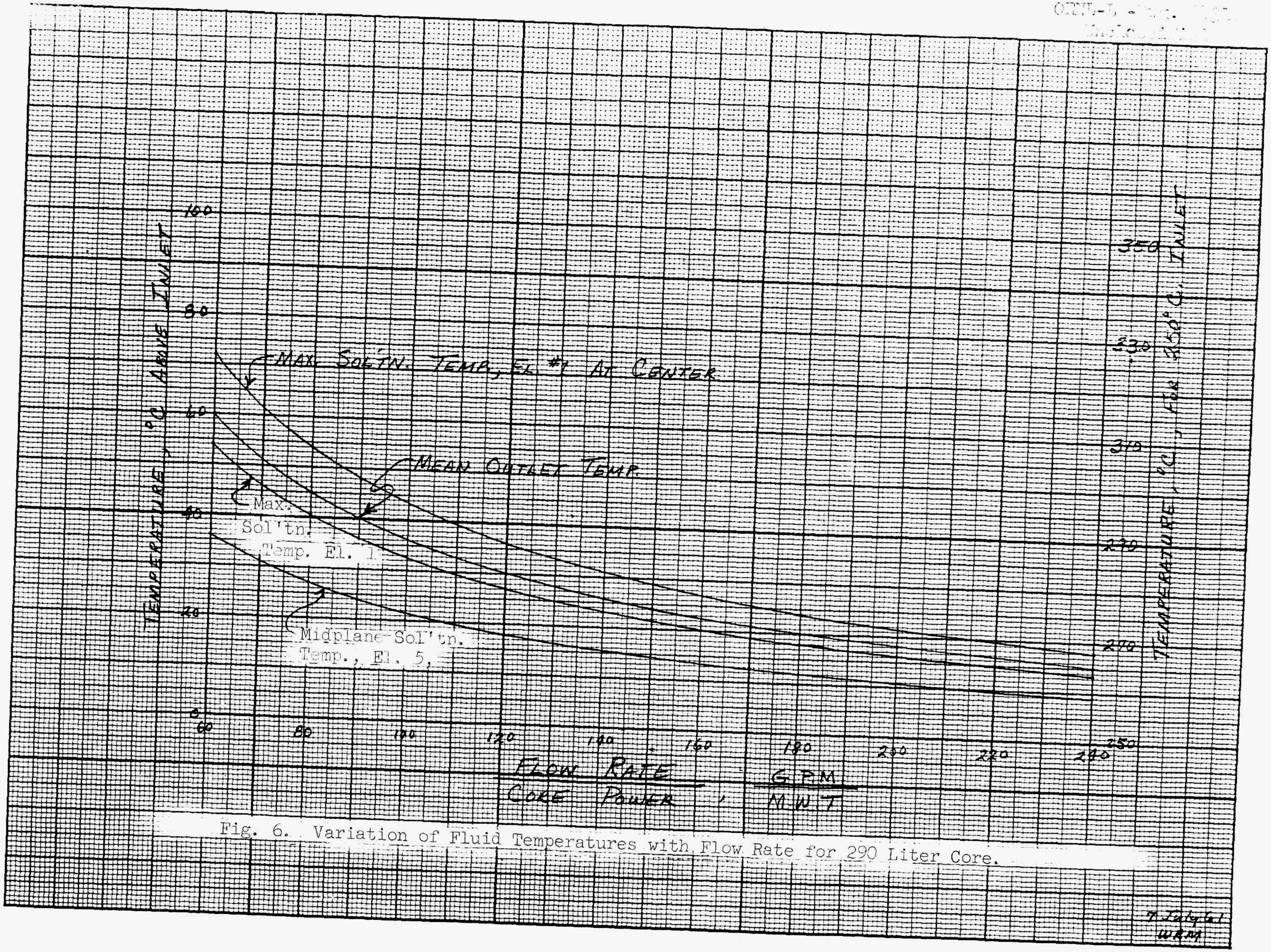


Fig. 6. Variation of Fluid Temperatures with Flow Rate for 290 Liter Core.

where $T$ = fluid temperature at point of measurement

$T_i$ = mean fluid temperature at point of measurement

$T_o$ = mean fluid outlet temperature

Fluid temperatures at the wall of the full scale replacement vessel at 10 Mwt core power (40°C mean core temperature rise, 250°C inlet temperature) are estimated to range from 266°C just above the bottom head to 286°C in the upper head. Fluid temperature at the wall in the lower head was 278°C. The maximum solution temperature of 296°C was near the axis of the core in the upper head. Maximum temperatures at each elevation were near the axis and varied only 6°C over the length of the core.

The expression for the spatial mean fluid temperature within the core ($\bar{T}$) was found to be

$$\frac{\bar{T} - T_i}{T_o - T_i} = 0.74. \qquad (3)$$

Discussion of Results

In extrapolating data from a 5-in. diameter model to a 24-in. diameter core, it was assumed that the spatial mean fluid age distributions were equal for the two sizes. The proposed reactor core and the flow model are geometrically similar with a difference in scale of 1:4.8. Geometrically similar vessels have equal gross fluid flow patterns, and hydrodynamic similarity is usually expected to depend on equality of Reynolds Numbers. Previous tests on a re-entrant core flow model[2] showed no appreciable change in the relative mean fluid age ratio distribution when the Reynolds number was increased by a factor of 2.8. Simulated power traces from flow properties of the reverse flow HRE-2 full scale flow model agreed closely to HRE-2 power oscillations.[3] The Reynolds number in the HRE-2 was about ten times higher than in the flow model. These tests indicate that the flow distribution properties measured are invariant with, or are a slow function of, Reynolds number as long as vessels operate in the turbulent flow regime.

The model flow rate was selected for equality of mean residence times (volume/flow rate) in the two vessel sizes; however, the mean inlet velocities were unequal. The higher velocity in the full scale core is balanced by the increased vessel circumference such that the angular velocities (radians/sec), and the mean fluid ages, should remain the same.

Temperature estimations from mean fluid age data do not take into account the effect of changing fluid physical properties upon the flow or heat source distributions.

The relative age ratios calculated from the salt decay end of the curves were generally lower than those calculated from the salt buildup ends; the maximum variation between the two being 20%. The reason for that difference has not been determined. The data plotted in Figs. 3, 4 and 5 were the higher values determined from the salt buildup curve.

Tests on the HRE-2 flow model have shown that hydraulic fluctuations which cause changes in the average residence time of fluid in the core by changing the fraction of fluid short circuiting, can cause neutron level fluctuations in the core.[3] The presence of changes in average fluid residence time was indicated by the shape of the conductivity versus time curve of outlet fluid after a step function salt concentration change of inlet fluid. The outlet probe conductivity curves for the slot entry flow model showed no fluid short circuiting directly to the outlet and no large fluctuations during salt concentration buildup, which indicates little or no power level fluctuations due to core flow conditions. In addition, the fluid was well mixed as it left the model (mean age just inside the outlet pipe varied only 0.6% from wall to center) and minor fluctuations within the model would not change the mean age of the mixed stream appreciably.

The maximum solution temperature curve in Fig. 6 illustrates that the core flow rate must be higher than 87 gpm/Mwt to keep the maximum solution temperature below 300°C for an inlet fluid temperature of 250°C.

It is believed that the axial variation in temperature at the wall could be reduced by varying the header cross section, or inlet slot width, over its length.

## FLUID VELOCITY MEASUREMENTS

Fluid velocity profiles were measured using 0.120-in. diameter, 3-dimensional (type DA) probes manufactured by the United Sensor and Control Corporation, Glastonbury, Connecticut. These probes indicate tangential, axial, and radial velocity components. The probe was positioned by the manufacturer's manual traverse unit with which the radial distance could be read to 0.01-in. and the yaw angle to 0.2°.

Plots of velocity components versus radial position for various elevations are shown in Figs. 7 and 8. The vector sums of tangential and axial velocity components are plotted versus position in Fig. 9.

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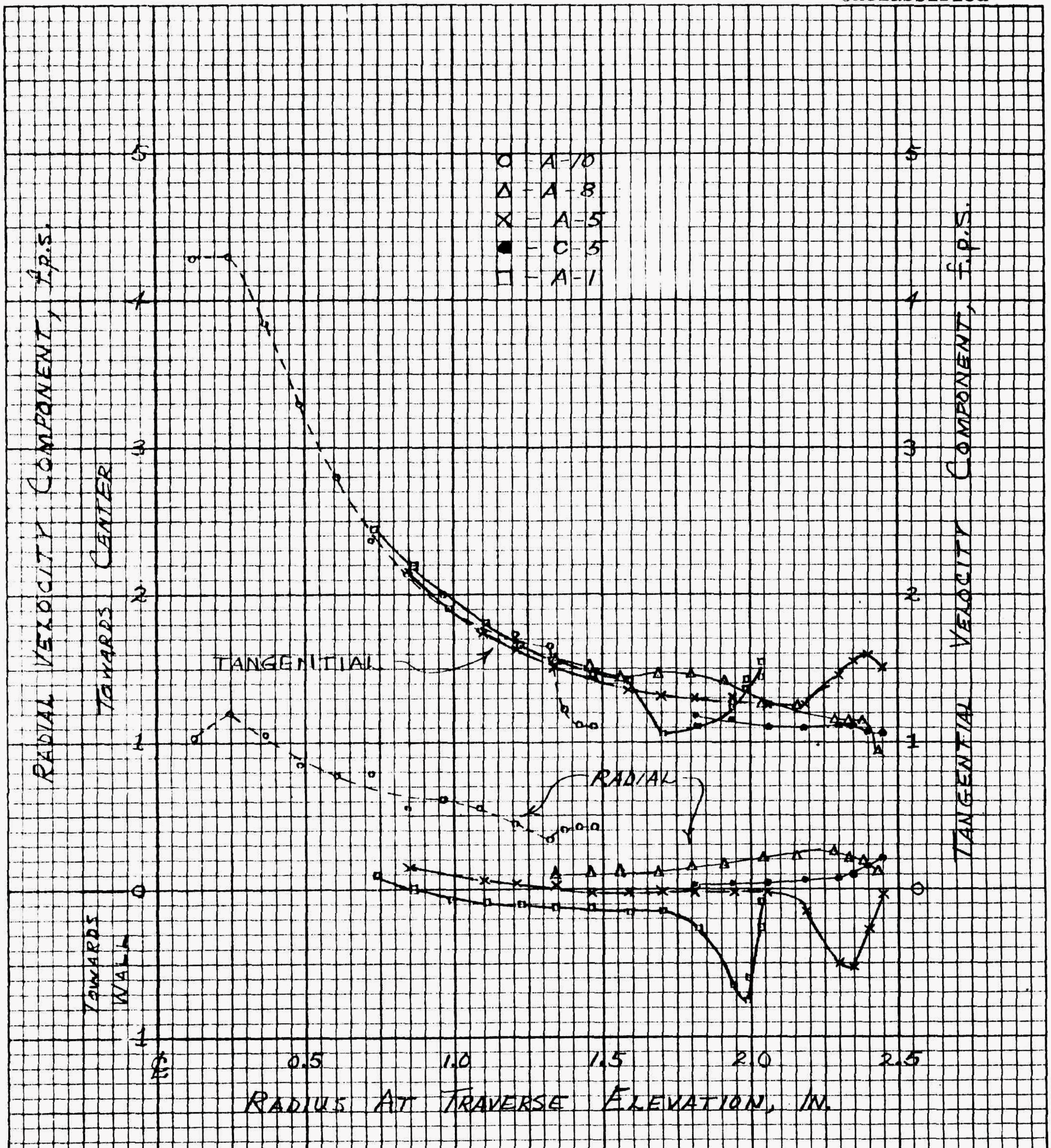


Fig. 7. Tangential and Radial Velocity Component Profile at Various Positions in the Model.

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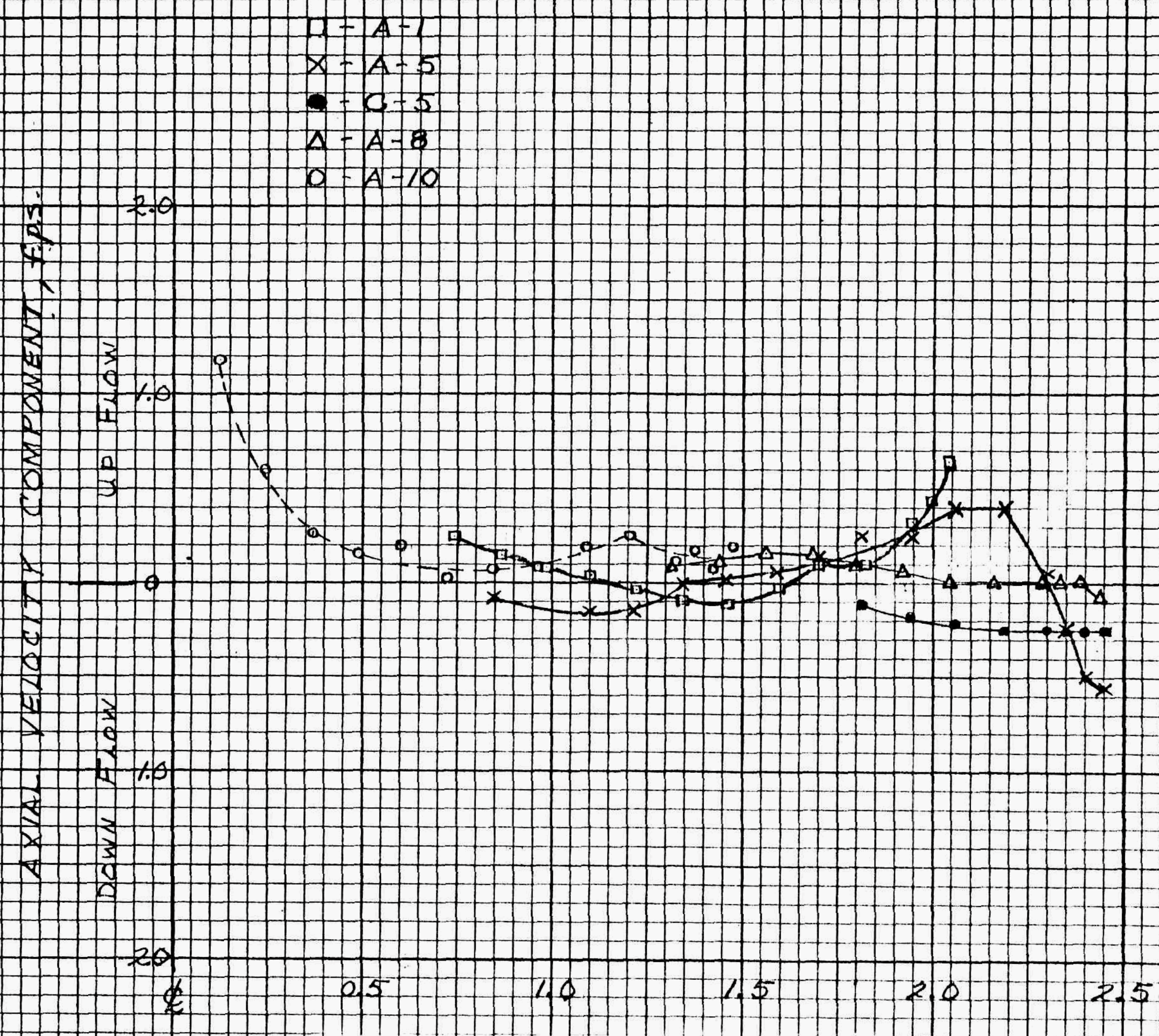


Fig. 8. Axial Velocity Component Profiles at Various Positions in the Model.

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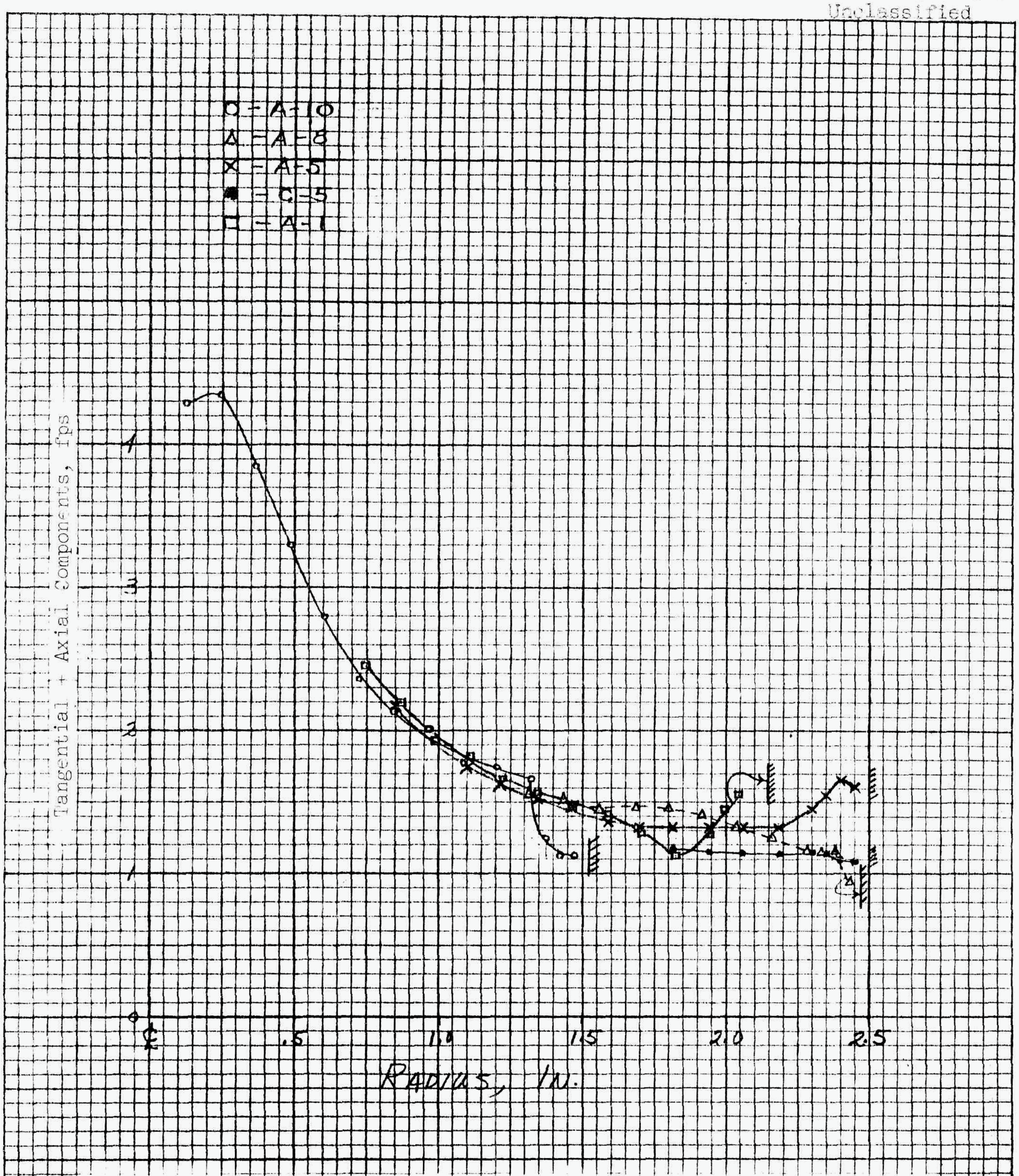


Fig. 9. Profiles of Vector Sum of Tangential and Axial Velocity Components in Model.

One velocity traverse, C-5, was taken on the row of probe fittings just behind an inlet slot. Minimum fluid wall velocity was estimated from these data. The low wall velocity found in traverse A-8 is considered to be due to the gap between the inlet slots in the head and in the cylinder. To eliminate a low velocity region at this elevation, a full scale core would probably have inlet slots extending continuously into the heads.

The direction of radial flow, as determined by DA probes (Fig. 7), was toward the wall for traverses A-1 and A-5 up to a position near the center. Tests with 1/16-in. diameter dye injection probes showed a radial flow toward the center at these positions. The reason for the contradictory results has not been determined.

A minimum fluid velocity of 1.1 fps near the wall (tangential plus axial components at C-5) was considered a good estimate for the flow model.

## CORROSION RATE ESTIMATE

Estimated core side corrosion rates of a full scale core wall, plotted versus core flow rate, are shown in Fig. 10. These estimates were made using G. H. Jenks' correlation[4] of in-pile loop and autoclave data for the corrosion of Zircaloy-2.

The relationship is:

$$\frac{1}{R} = \frac{2.3}{P\alpha} + 2.25 \times 10^{-11}\, e^{11,500/T} \qquad (4)$$

where $\alpha = \dfrac{4.8}{V^{0.6}} + 1$

V = fluid wall velocity, fps

P = power density at wall, watts/cc

T = wall temperature, $^{o}$K

R = corrosion rate, mpy

Fluid velocity at the wall of a full-scale core with 900 gpm flow rate was taken to be a factor of four (the ratio of core to model mean inlet velocities) higher than that found in the model. For other flow rates, velocity was assumed to vary directly with flow rate. Calculations were for the region of minimum velocity and maximum fluid temperature (row C) for each elevation in order to estimate the maximum corrosion rates.

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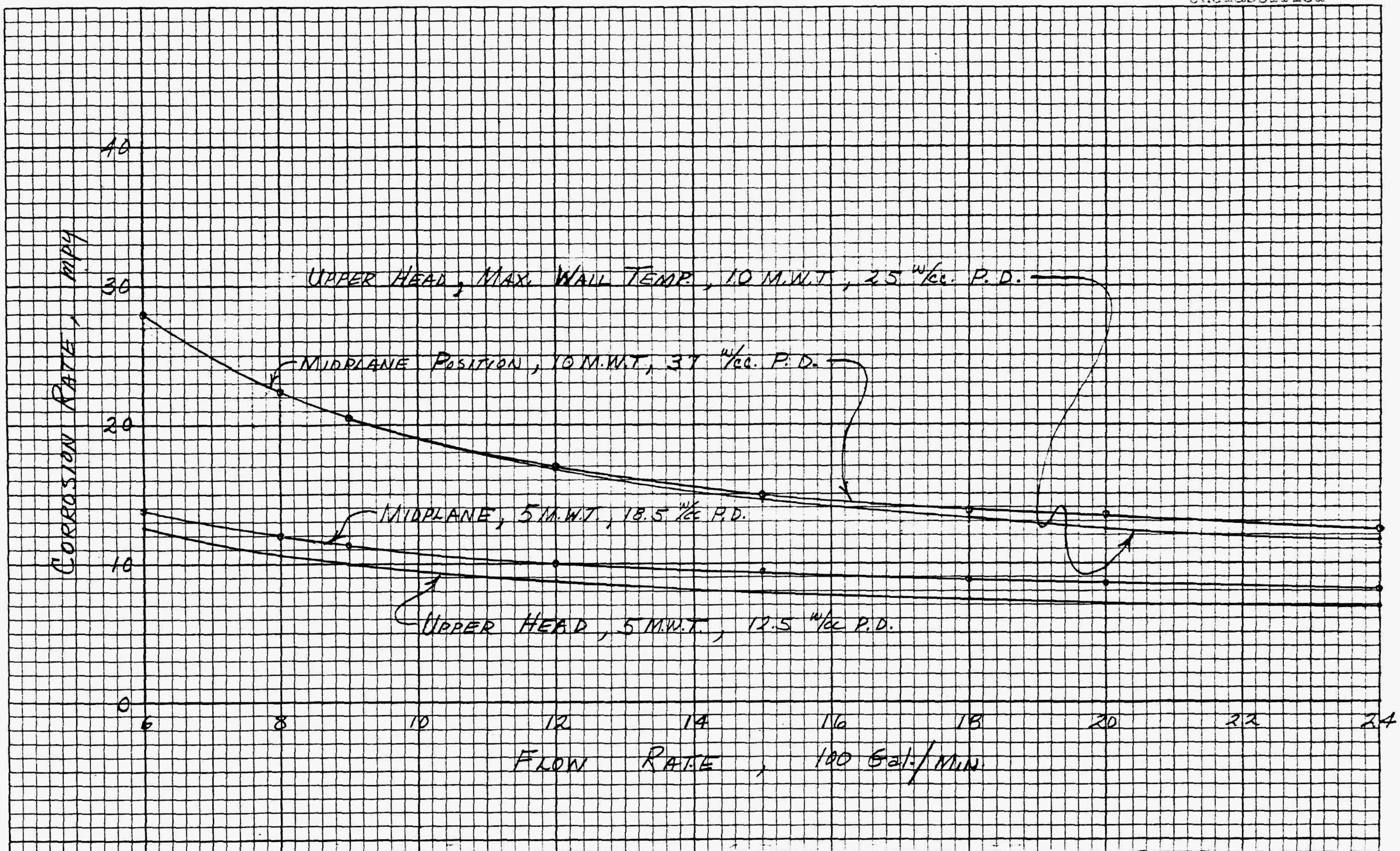


Fig. 10. Estimated Corrosion Rates for 290-Liter Core With 250°C Inlet Temperature for 5 and 10 Mwt Core Powers.

Wall temperatures were estimated from the spatial distribution of fluid temperature and velocity by use of H. F. Poppendiek's analyses[5] of forced convection heat transfer with a volume heat source within the fluid. It was assumed that gamma heat generated in the wall was removed by blanket side cooling (Appendix B) and that no uranium-bearing scale was present on the wall.

### Film Coefficients of Heat Transfer

Core-side heat transfer film coefficients were estimated from a plot of Nusselt modulus versus Reynolds modulus for turbulent heat transfer between parallel plates[5] for a core flow rate of 900 gpm. Reynolds modulus was calculated from the velocity profiles of the model by use of an equivalent parallel plate system with distance between plates equal to twice the distance from the model wall to the velocity peak near the wall. This distance was geometrically scaled up to core size. Mean channel velocity in the full-size reactor was estimated to be four times the mean velocity from vessel wall to the velocity peak found in the model.

Film coefficients at high temperature for locations in the core corresponding to probe locations in the model are listed in the following table:

| Location | Film Coefficient $Btu/hr \cdot ft^2 \cdot {}^\circ F$ |
|---|---|
| C-1 and C-5 | 1860 |
| A-1 and A-5 | 2620 |
| A-10 | 1970 |

## SOLIDS AND GAS REMOVAL

The ability to remove solids was tested by the addition of sand to one inlet pipe of the model. When fluid left through the top of the model only, most of the solids remained in the vessel, swirling around in the bottom head. When 10% of the flow left through the drain line at the bottom, the solids were quickly swept out of the model.

Air, continuously injected into the model, swirled towards the center and was removed through the outlet at the top without accumulating in the model.

## CONCLUSIONS

Tests on a 1/5 scale model indicated that the slot-entry core configuration will satisfy all known hydrodynamic criteria for a homogeneous reactor core vessel. Wall temperatures were below the mean outlet temperature and a recommended flow rate of 90 gpm/Mwt would keep the maximum solution temperature below 300°C. At this flow rate the maximum corrosion rate would be 11 and 20 mpy for 5 and 10 Mw thermal power, respectively, with a 250°C inlet temperature. A minimum core side heat transfer film coefficient of 1860 Btu/hr ft$^2$ °F was calculated from H. F. Poppendiek's analysis[5] for a core flow rate of 900 gpm. The expression for the spatial mean fluid temperature was found to be

$$\frac{\bar{T} - T_i}{T_o - T_i} = 0.74.$$

The test completed showed continuous removal of solids and gas with no accumulation in the vessel when 10% of the flow went through the bottom outlet. More complete tests, using sized particles of known density, to determine minimum flow rates for solids removal would be necessary if work is continued on a core of this type.

It is believed that the favorable results from the model tested justify construction of a full-scale flow model upon resumption of the homogeneous reactor project. Extrapolation of results from the model tests should be verified by full-scale core tests due to the undetermined effects of vessel scaleup.

## ACKNOWLEDGEMENT

Significant contributions to this project were made by S. J. Ball, I and C Division, who designed the integrates circuits and by B. J. Young, who assisted in running the experiments and calculating the data. The original development work of the conductivity probes was performed by M. Richardson.

# APPENDIX A

## Sample Calculations

### A. Mean Fluid Age

Typical Sanborn traces of the inlet probe, the traverse (or outlet) probe, and the integrating circuit output are represented in Fig. 11. "Probe Factor" and "Bias" potentiometers in the integrating circuit were set to make the Philbrick amplifier input signals from channels 1 and 2 equal when $C_1 = C_2 = 0$ and when $C_1 = C_2 = C(\infty)$.

The equation for mean fluid age at a point within the vessel is

$$\tau_m = \frac{\int_0^T t \frac{\partial F}{\partial t} dt}{\int_0^T t \frac{\partial F}{\partial t} dt}$$

where $$F = \frac{C(\infty) - C(t)}{C(\infty)}$$

$$C(t) = C(\infty) \text{ when } t \geqq T$$

Assuming that $C(\infty)$ is a constant and $C(t)$ is a function of time only, the equation reduces to

$$\tau_m = \frac{\int_0^{C(\infty)} t \, d\, C(t)}{\int_0^{C(t)} t \, d\, C(t)} = \frac{\int_0^{C(\infty)} t \, d\, C(t)}{C(\infty)}$$

Considering the inlet probe trace a perfect step function and integrating by parts gives

$$\tau_m = \frac{TC(\infty) - \int_0^{C(\infty)} C(t)\, dt}{C(\infty)} = \frac{A}{C(\infty)}$$

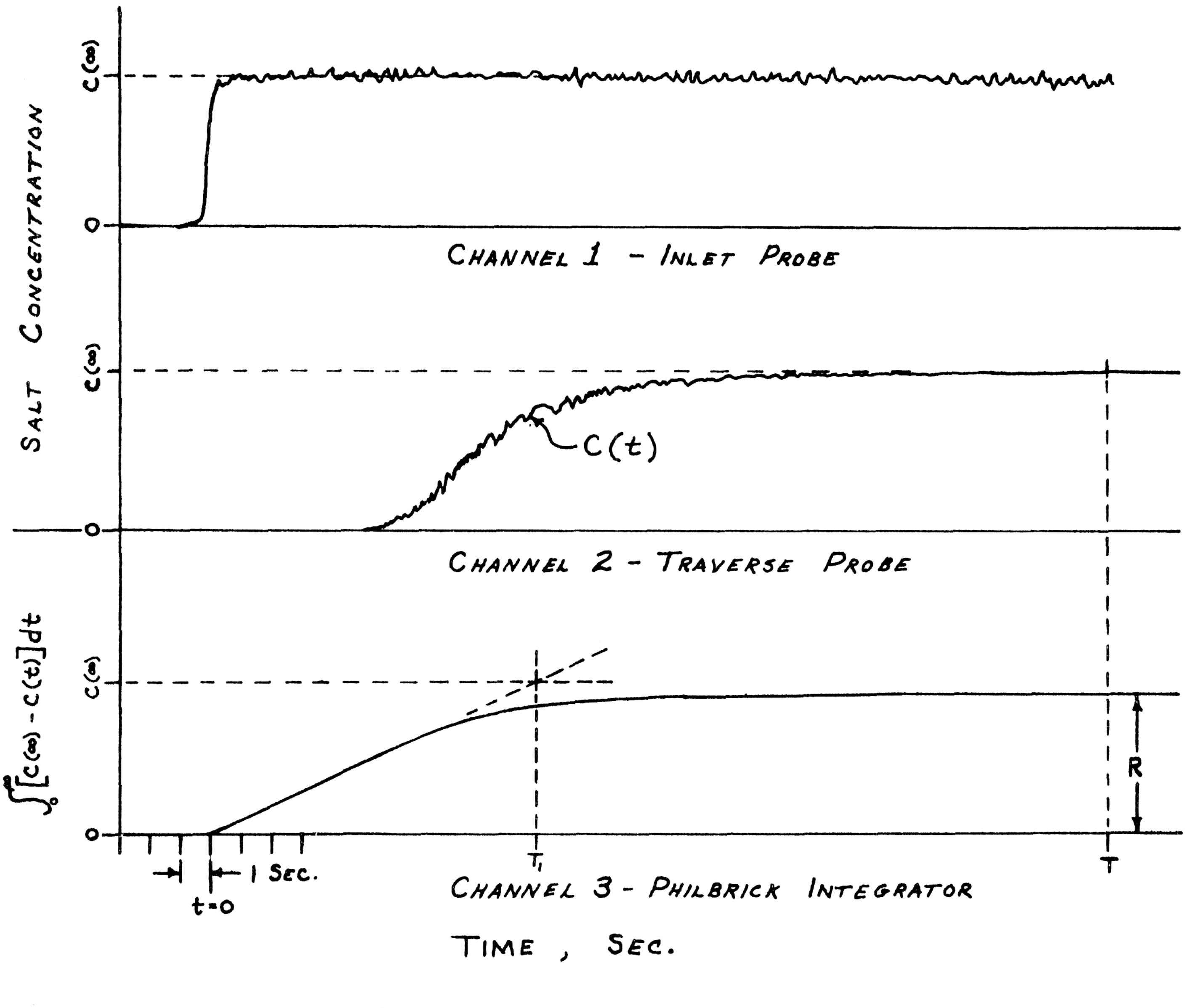


Fig. 11. Typical Sanborn Traces from Which Mean Fluid Age Was Calculated.

where: A = area bounded by the inlet step function, the lines $t = 0$ and $t = T$, and the curve $C(t)$ for $0 \leq t \leq T$.

The output of the integrator circuit is proportional to the area, A.

$R = kA$

where R = the chart reading of the integratos channel of equilibrium, when $C(t) = C(\infty)$.

k = proportionality constant

To evaluate k, consider the area under the step function alone ($C(t) = 0$). The trace of the integral is a straight line of slope m and the chart reading, r, at any time, t, is equal to mt. Then

$$mt = kA = kt\, C(\infty)$$

$$k = \frac{m}{C(\infty)} = \frac{1}{T_i}$$

where $T_i$ = the time interval from the beginning of the step function until $r = C(\infty)$ when $C(t) = 0$ ($r$ and $C(\infty)$ measured in cm above the chart base line).

Therefore $R\, T_i = A$

and $$\tau_m = \frac{R\, T_i}{C(\infty)}$$

In practice, R and $C(\infty)$ were read from the recorder traces and $T_i$ was calculated from the slope of the integral trace during the time that $C(t) = 0$ for each run.

B. Estimation of Wall Temperature and Heat Transfer Film Coefficient

This sample calculation is for position C-5 in the flow model.

In order to make use of published correlations[5] for forced convection heat transfer with volume heat sources within the fluids, the flow near the wall was considered analogous to flow between parallel plates. The distance from the model wall to the velocity peak near the wall, $r_o$, was taken as 1/2 the distance between plates. A mean velocity, $u_m$, in the channel was estimated from the measured velocity profile. At position C-5 in the model

$r_o$ = 0.20 in.

$u_m$ = 1.1 fps (axial and tangential components)

To extrapolate these data to full-scale core conditions, $r_o$ was scaled up geometrically by a factor equal to the ratio of vessel diameters and $u_m$ was increased by a factor equal to the ratio of mean inlet velocities.

$$R_o = \frac{1}{2} \text{ of channel thickness for full scale core} = \frac{(0.20)(4.8)}{12}$$

$$= 0.08 \text{ ft.}$$

$$u_m = \text{mean velocity for full scale core} = (1.1)(4)(60)$$

$$= 0.264 \text{ ft/hr}$$

$$\text{Reynolds modulus} = Re = \frac{4 R_o u_m}{\nu}$$

$$Re = 1.25 \times 10^6$$

where $\nu$ = kinematic viscosity of fuel solution, $ft^2/hr$

The Prandtl modulus, $P_r$ for fuel solution was calculated to be 0.73. By use of the calculated values of $P_r$ and Re and Fig. 5 of Reference 5, it was found that

$$\frac{(t_o - t_m)k}{w r^2} = 4.3 \times 10^{-5}$$

where $t_o$ = fluid temperature at plate walls, $^oF$

$t_m$ = mixed mean fluid temperature, $^oF$

k = fluid thermal conductivity, Btu/hr $ft^2$($^oF$/ft)

w = volume heat source, Btu/hr·$ft^3$

For reactor core power of 10 Mwt, a fluid volume heat source of 37 watts/cc was used to find

$$t_o - t_m = 2.8^oF = 1.6^oC$$

The value of $t_m$ was calculated from the measured value of the relative age ratio (equal to 0.60) at C-5, 1/8-in. from the wall for a 250°C fluid inlet temperature and 290°C fluid outlet temperature. Then

$$t_m = (0.60)(40) + 250 = 270^{\circ}C$$

and $t_o = 276^{\circ}C$

By use of Fig. 6 of Reference 5, it was found that

$$\frac{4\ h\ r_o}{k} = 1.7 \times 10^3$$

where $h$ = heat transfer film coefficient

$$h = 1860\ Btu/hr \cdot ft^2 \cdot {}^{\circ}F$$

C. Corrosion Rate Estimate

Corrosion rates of the inside wall surface of the reactor core vessel were estimated from the correlation[4]

$$\frac{1}{R} = \frac{2.3}{P\ \alpha} + 2.25 \times 10^{-11}\ e^{11,500/T}$$

with $\alpha = \frac{4.8}{V^{0.6}} + 1$

The corrosion rate at each flow rate was based on an inlet fluid temperature of 250°C and power densities at the wall of 37 and 25 w/cc in the cylindrical section and in the heads respectively. For a position in the reactor core corresponding to position C-5 in the model it was found (from the previous calculation) that

$$V = 4.4\ fps$$

$$T = 276^{\circ}C = 549^{\circ}K$$

for a flow rate of 900 gpm and a core $\Delta T$ of $40^{\circ}C$.

then $R = 20.4$ mpy

For other flow rates, the velocity of fluid at the wall was assumed to vary in proportion to the change in flow rate.

## APPENDIX B

### Removal of Gamma Heat by Blanket Side Cooling

The minimum blanket side film coefficient of heat transfer, $h_B$, necessary to remove all gamma heat generated in the core wall was estimated from the following conditions:

Blanket mean temperature, $t_B = 482^{\circ}F$

Core side wall temperature, $t_c$, at midplane = $525^{\circ}F$

$\gamma$ heat in wall, considered uniform = 3.7 w/cc

Core power = 10 Mwt

Wall thickness, h, = 7/16 in.

Thermal conductivity of Zircaloy = 7 $Btu/hr \cdot ft \cdot {}^{\circ}F$

Total heat flux to blanket, $\frac{q}{A} = (\gamma \text{ heat})(L) = 13{,}060 \; Btu/hr \cdot ft^2$

Considering the core side of the wall perfectly insulated, then

$$\frac{q}{A} = \frac{t_C - t_B}{\frac{1}{h_B} + \frac{L}{2\,k}}$$

$$13{,}060 = \frac{525 - 482}{\frac{1}{h_B} + \frac{(7/16)(1/12)}{2 \times 7}}$$

and $h_B = 1450 \; Btu/hr \cdot ft^2 \cdot {}^{\circ}F$

REFERENCES

1. H. C. Claiborne, "Hole Formation in the HRT Core Tank," ORNL CF-58-11-49, November 18, 1958.

2. W. R. Mixon, "Fluid Age Measurements in 5-in. Cylindrical Re-entrant Core Model with Swirling Flow," ORNL CF-60-10-86, October 11, 1960.

3. I. Spiewak _et al._, _HRP Prog. Rep. for Period from Dec. 1, 1960 to May 31, 1961_, ORNL-3167, p 14.

4. G. H. Jenks, personal communication.

5. H. F. Poppendiek and L. D. Palmer, "Forced Convection Heat Transfer Between Parallel Plates and in Annuli with Volume Heat Sources Within the Fluids," ORNL-1701, May 11, 1954.

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