TID-18474

QUARTERLY TECHNICAL REPORT

ON

HIGH ACCELERATION FIELD HEAT TRANSFER

FOR AUXILIARY SPACE NUCLEAR POWER SYSTEMS

(AEC CONTRACT NO. (04-3)-409)

Period

December 1, 1962 to February 28, 1963

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SUMMARY

This report outlines Geoscience's research results for the period of December 1, 1962 to February 28, 1963, (Contract No. AT(04-3)-409 with the Atomic Energy Commission).

The liquid metal heat transfer system, which is shortly to be used to investigate fundamental boiling and condensing phenomena in liquid metals, was sufficiently completed so that preliminary non-boiling water heat transfer experiments were conducted. The purpose of these studies was to establish the accuracy of the heat transfer instrumentation for the boiler test section, gain operating experience and obtain information on system integrity. Satisfactory heat balances were obtained and experimental heat transfer conductances for the boiler were found to be in agreement with predicted values. These experiments revealed that one boiler test section pressure tap had a leak in the weld.

The results of coolant heat and momentum transfer analyses for the liquid metal program are summarized. A number of forced-flow saturation boiling models for the cases of linear and rotational flow are compared with experimental linear flow water data; large differences in heat transfer and friction were found depending upon the flow type postulated. The evaluation of a previously described two-phase flow vortex decay solution was completed.

CONTENTS

I. MERCURY HEAT TRANSFER EXPERIMENT

A. System Description

With the exception of some minor details, the components of the liquid metal heat transfer system have been fabricated and the system assembled. Certain component modifications have been made since the last quarterly report.

In the subsequent parts of this section will be included a discussion of the behavior of the various system components under preliminary operation, testing and test section design changes which have been accomplished during this quarterly period.

Boiler and Preheater

The original boiler section was to be a thin wall (0.060") tantalum tube, plasma sprayed with BeO. The thermocouples were to be bare Pt, Pt-10% Rh wire placed in grooves with a plasma sprayed BeO insulation. The initial spraying of BeO proved to be unacceptable for the following two reasons: a) the BeO spray was of low density and had an unacceptable bond with the tantalum tube. This resulted in cracking during the heater element winding process, and b) during the spraying of the boiler section, the thermocouple wires became bent. This operation produced local heating as the spray material was applied thus causing the wires to break several times during spraying.

The boiler design was changed to that shown in Figure 1. Eight 0.040" diameter tantalum sheathed, BeO insulated, thermocouples were placed in hemispherical grooves (radius $\cong$ 0.020") in the 3/8 O.D. tantalum tube and then tantalum spray welded in place. The outer diameter was then increased by plasma spraying with tantalum to an outside diameter of approximately 0.90". The unit was then machined to a diameter of 0.800 ± .002. The alumina insulation was plasma sprayed and four tantalum heater elements were wrapped along the length. The plasma spraying was accomplished at Western Gear and the machining at Empire Research and Development Company. The preheater section was stripped of the BeO and resprayed with alumina and wrapped with tantalum wire. The completed boiler test section specially wound for water heat transfer tests is shown in Figure 2. The boiler, preheater

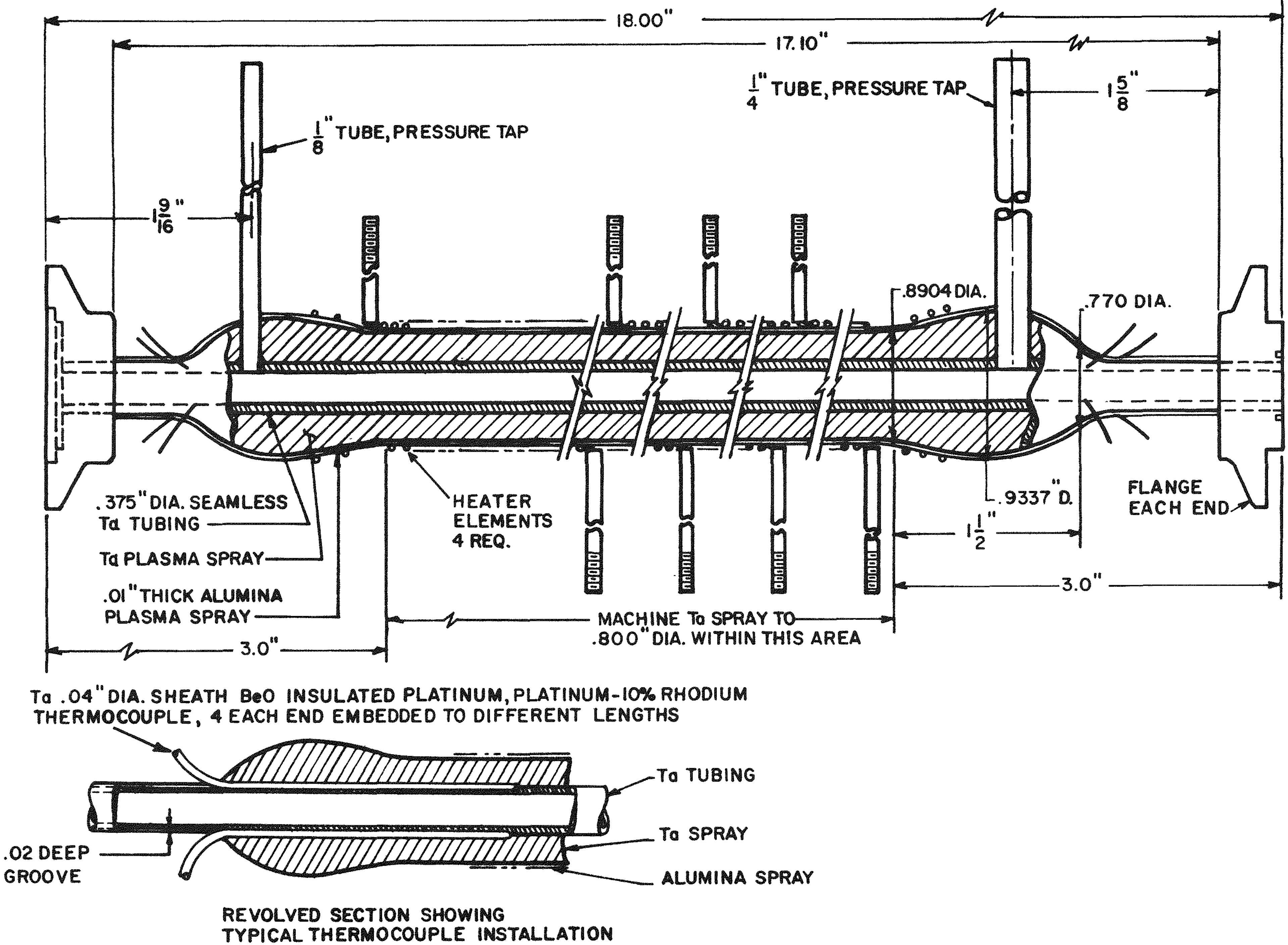

Figure 1. Thickwall Boiler Design

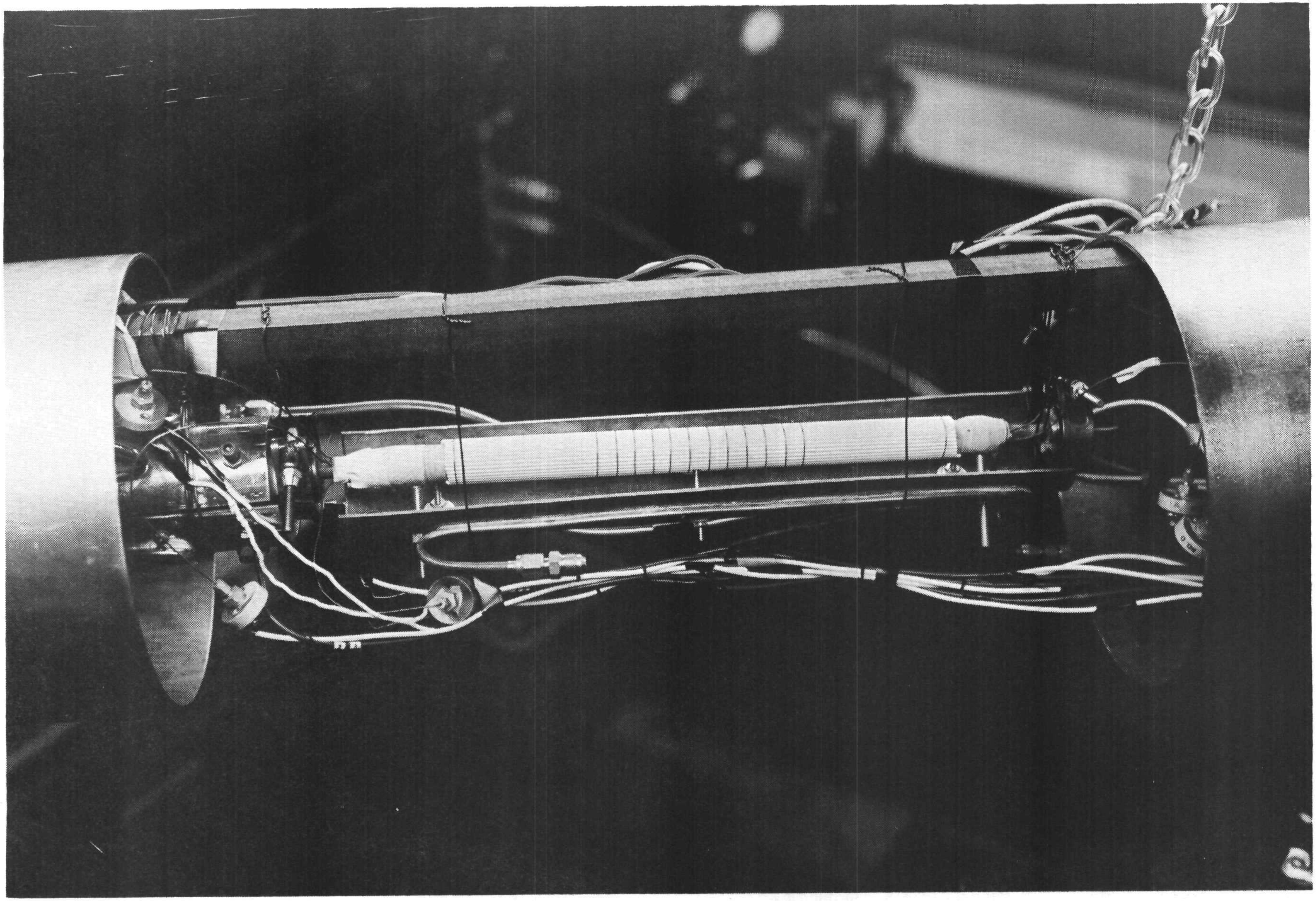

Figure 2. Assembled Boiler Test Section

and separator were installed in the containment vessel and several non-boiling water experiments were performed. Boiling and condensing liquid metal experiments will be performed with the boiler and condenser in the vertical position.

A partial view of the system is shown in Figure 3. It was noted that at low temperatures where conduction heat transfer was predominant, uneven heating existed because of thermal expansion. Several methods of eliminating this problem were studied. At present 0.09" alumina tubes have been closely positioned around the outer periphery of the heater wire and bound in place. An alumina tube heated in this manner indicated even temperature distributions.

Reservoir and Weigh System

Figure 3 also indicates the subcooled liquid and condensate tanks suspended from the load cells. A calibration of the load cell weighing system was made by applying known weights at various tare loads on the tank. Figure 4 shows an oscillograph trace of the calibration curves. The results indicate that the weighing system has sufficient gain and zero suppression to measure less than one pound out of one thousand pounds (one line of the brush recorder is one pound) at any tare value. Slight nonlinearity was observed at various tare weights. A system was therefore devised which will mechanically calibrate with a known weight at any time during operation. This eliminates error due to amplifier drift or cell nonlinearity.

Valves

The three tantalum control valves (Figure 5) were completed and connected to the pneumatic valve actuation system and tested with water. Controllability was excellent. To insure complete valve closure, the valves were fitted with manual shutoff controls.

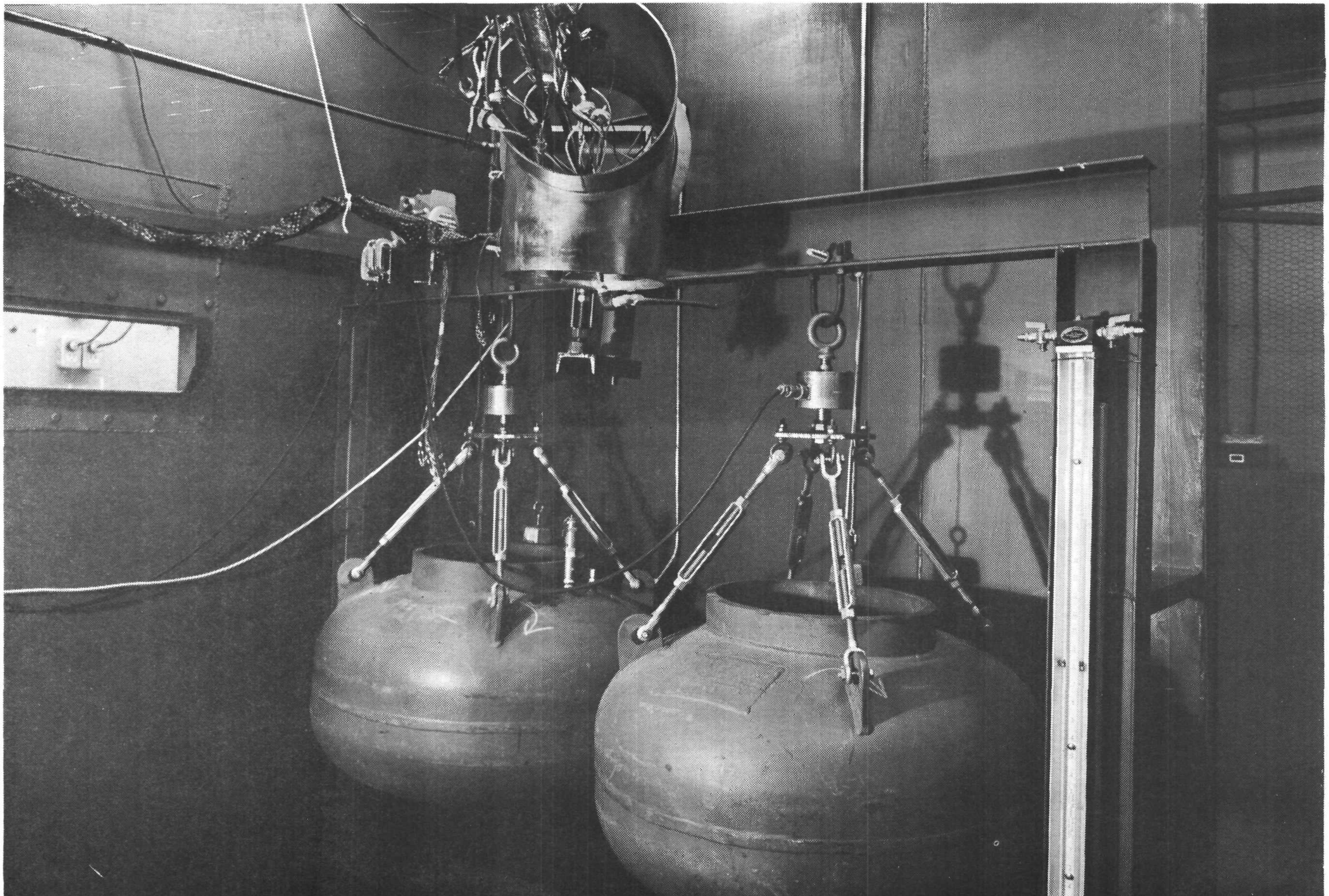

Figure 3. Weigh Tank and Partially Assembled System

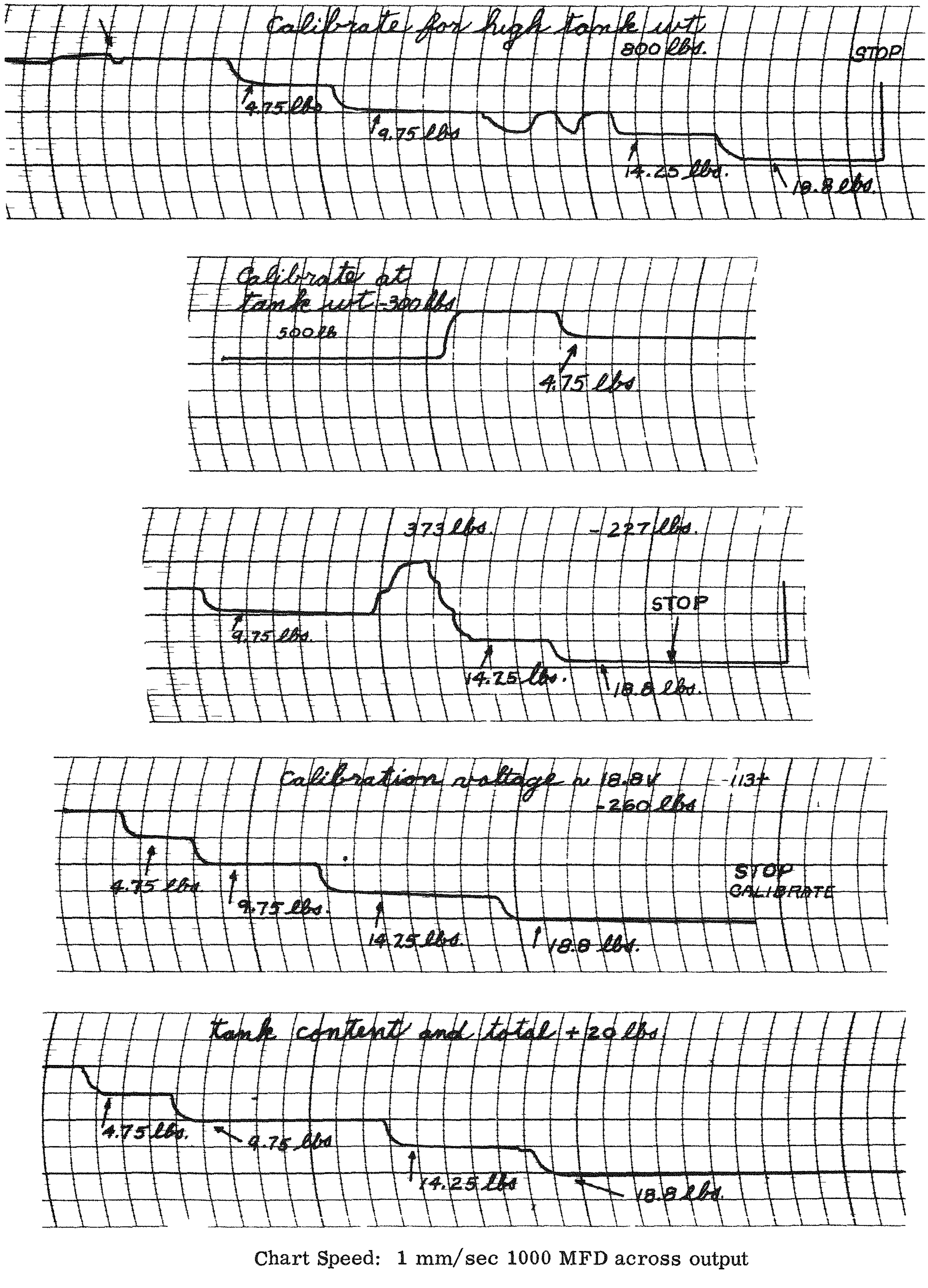

Chart Speed: 1 mm/sec 1000 MFD across output

Figure 4. Oscillograph Trace of Weight Tank Calibration

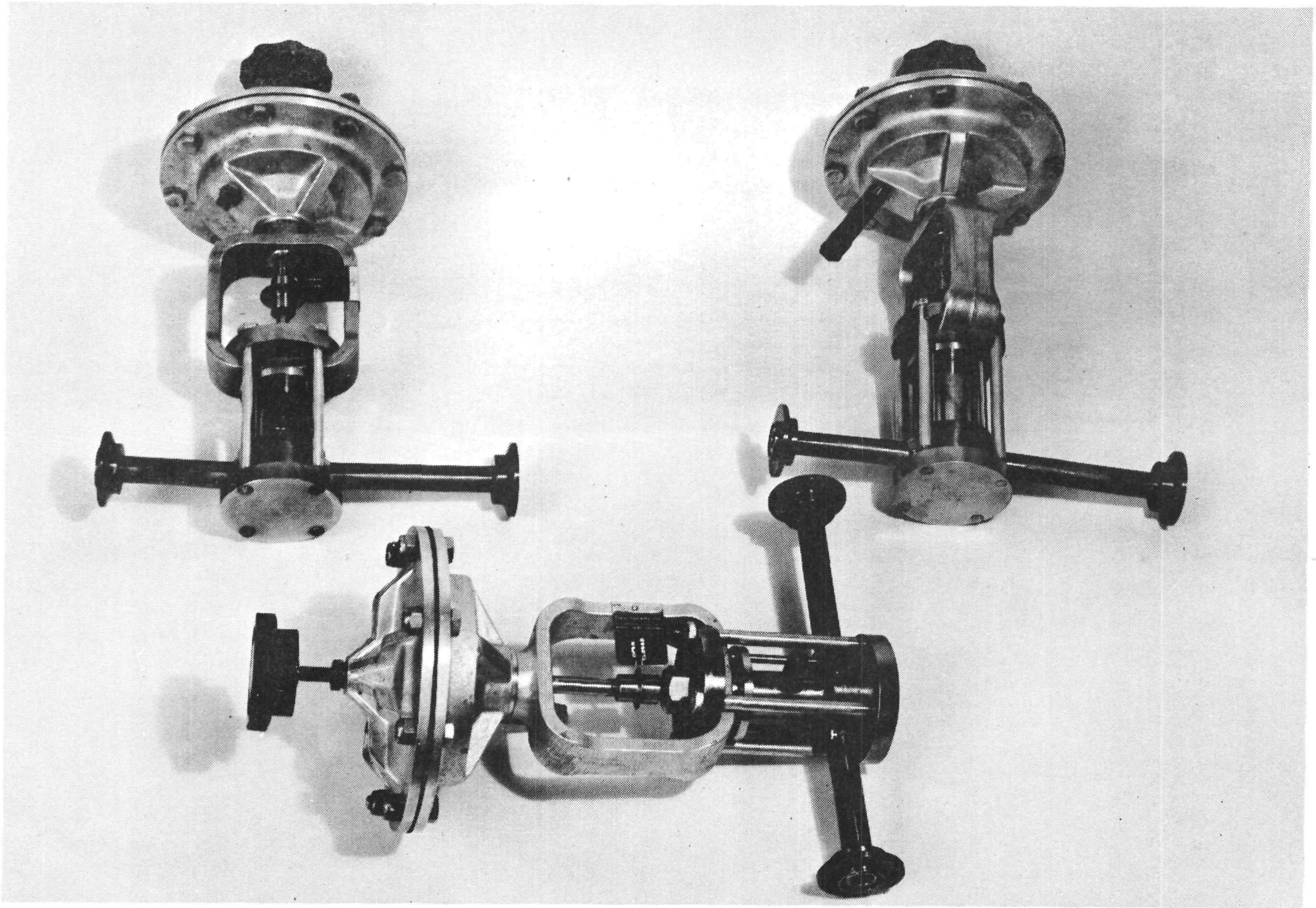

Figure 5. Control Valves

Separator

A flow test was made of the separator using argon and water. The volumetric water flow was adjusted from one half to twice that expected in the mercury experiment and the argon flow varied over a large range. No entrained water could be detected in the vapor indicating the successful separation of the liquid and vapor phases.

Thermocouple System

Two eight-couple channels of the five-channel thermocouple system were used in the water experiments. Two more eight-couple channels have been installed but not used.

Pressure System

The differential pressure across the test section and that used to indicate the mercury level in the upper tank, were measured on differential transducers. The output signal was demodulated and amplified in the Pace carrier demodulator and read on a d-c voltmeter. Preliminary tests indicate the test section differential pressure transducer can be used in ranges from 0-5 inches of water to 0-30 PSI. In order to successfully take advantage of this wide range as well as to insure no change in calibration, a system is being devised which will allow a direct reading of the transducer output on an accurate voltmeter. The differential pressure instrumentation was not used in the water experiments.

B. Preliminary Non-Boiling Water Heat Transfer Data

A number of non-boiling forced convection water heat transfer experiments were conducted. The flow rate range corresponded to Reynolds number variations from 1000 to 24,000. At high heater wire temperatures, (approximately 2000°F) nearly uniform heat fluxes of about 150,000 Btu/hr ft^2 were readily attained with the variable axial heater element design. Heat balances indicated that about 94% of the electrical heater power was transferred to the test section coolant. Experimental heat transfer conductances were in satisfactory agreement with predicted values over a range of flow rates. Current studies include test section entrance and exit effects and possible local scale deposits. A photograph of the boiler test section during operation (with shield removed) is shown in Figure 6.

Figure 6. Heated Test Section

II. ANALYTICAL STUDIES

A. Forced-Flow Saturated Boiling Heat Transfer Calculations

In the last quarterly report*, an idealized model which can be used to predict forced-flow saturated film boiling or condensation in a tube under zero gravity conditions was described. In this separated flow model, a vapor film grows at the wall with axial distance along the tube while the diameter of the liquid core diminshes with distance along the tube. A number of calculations have been made for local heat flux, pressure drop, vapor quality and film thickness. Similar analyses have been made for the rotational flow case where a liquid annulus exists contiguous to the wall and the central core is filled with vapor. The liquid layer thickness decreases and the vapor core thickness increases with axial distance. To date, the calculations have only been made for the entrance region of idealized boiler tubes where the vapor qualities are low. In the case of rotational flow, two types of radial heat transfer calculations were made. One type accounted for the laminar sublayer, buffer layer and turbulent core thermal resistances. The second type accounted only for the turbulent core resistance on the presumption that bubble generation completely removes the two boundary layer resistances. The latter model yielded heat fluxes that were about five-fold higher than the former. These higher heat fluxes were in general agreement with low quality linear-flow water boiling measurements. In the case of linear flow film boiling, the heat fluxes were found to be a thousand-fold lower than those for the rotational flow case. Linear flow film boiling, of course, represents the extreme lower bound. Another model that is being studied is defined by the adjacent slugs of liquid and vapor flowing through a boiler tube. Equations have been derived which describe average heat transfer behavior as well as temperature fluctuations in the wall of a boiler tube in which such flow occurs. These models are being evaluated by 1) making specific calculations for heat transfer, friction, and vapor quality and 2) comparing the results to available experimental data. The results can be used to estimate preliminary boiler

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* "High Acceleration Field Heat Transfer for Auxiliary Space Nuclear Power Systems (AEC Contract No. (04-3)-409), Sept. 1 to Nov. 30, 1962, GLR-11.

performance. These predictions will also help bound the experimental boiling heat transfer data to be obtained, and suggest additional experimental measurements.

B. Rotational Flow Decay Curves

In the last quarterly report, an analysis was presented for the velocity decay of thin, rotating layers in a stationary tube. Turbulent liquid layers are separated from the tube wall by a viscous gas film. Equation (14) in the previous report can be expressed as

$$\phi = f\left(\frac{Re}{Re_o},\ C,\ Re_o\right)$$

where

$$\phi = \frac{\nu t}{\delta^2}$$

$$Re = \frac{u 4 \delta}{\nu}$$

$$Re_o = \frac{u(t=o) 4 \delta}{\nu}$$

$$C = \frac{\delta_o \mu}{\delta \mu_o}$$

These results can be used to calculate the velocity decay of thin, unconstrained rotating liquid layers in boiler tubes under high quality conditions. The ratio $D = Re/Re_o$ was evaluated as a function of ϕ for the parameters C and Re_o and a constant friction factor ($\xi = 0.032$) in Figure 7.

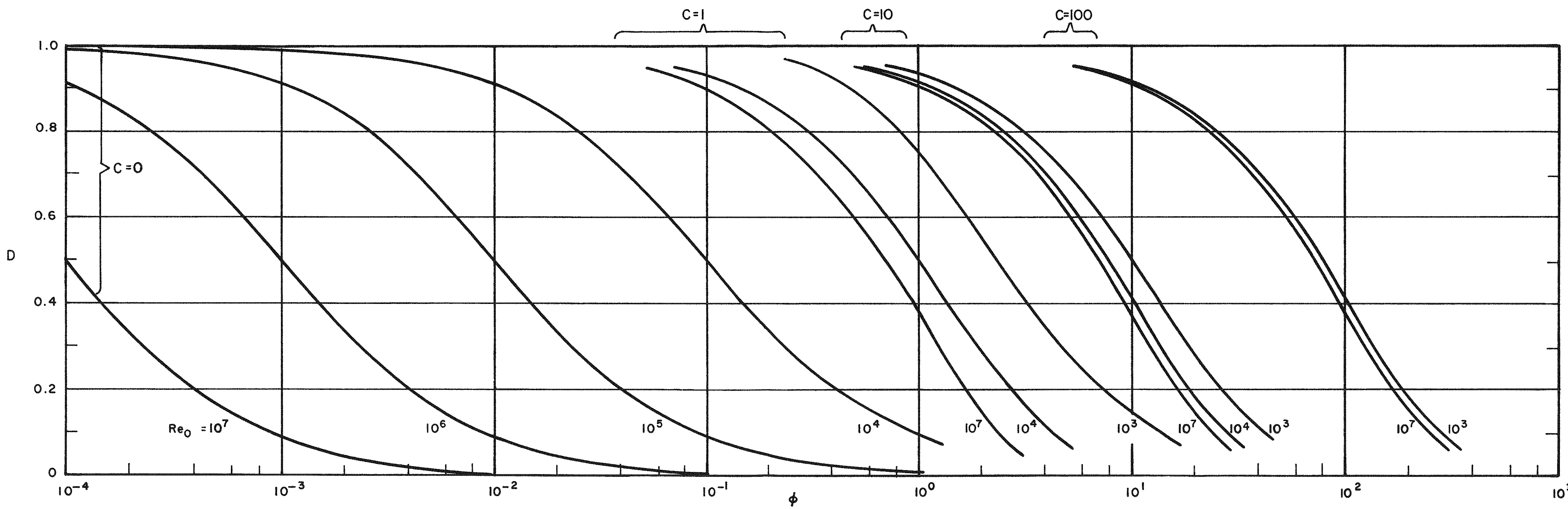

Figure 7. Re/Re_o vs. ϕ for Various Values of C and Re_o.

III. STUDIES TO BE REPORTED IN NEXT QUARTERLY

Prior to charging the liquid metal system with mercury, the components will be cleaned as follows:

1. Degrease in clean trichlorethylene or acetone.
2. Chemically clean with 63% water, 7% hydrofluoric acid, 30% nitric acid.
3. Rinse ten minutes in water.
4. Dry in air or wash with clean acetone.

The system will then be assembled and a final cleaning of MEK performed before charging with the mercury. An initial charge of only 84 pounds of mercury will be used for final cleaning. Several runs will be made and the mercury analyzed for impurities before the final filling of the system.

Further forced-flow, saturated boiling analyses under zero gravity and rotational flow-conditions will be made. Detailed analysis of the expected preliminary mercury boiling measurements will also be made.