COO-2802-1

GRAPHITE CURTAIN VACUUM OUTGASSING AND HEAT TRANSFER

QUARTERLY PROGRESS REPORT NO. 1

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1.0 INTRODUCTION

Several concepts have been proposed for using graphite fiber protective curtains placed between the plasma and first wall in the vacuum chamber of controlled thermonuclear reactors (CTR's). Thin curtains reduce plasma contamination due to first wall sputtering and protect the 1st wall against blistering and erosion. Thicker graphite curtains shape the neutron spectrum impinging on the 1st wall, providing protection against neutron damage.

Graphite fiber properties critical to their application in the vacuum chamber include: (1) thermal conductivity, (2) vacuum outgassing and (3) chemical reactivity with hydrogen. Measured property data are either non-existent or are available in only the most rudimentary form. Energy from the fusion reaction is converted to heat within the protective curtain and this heat must be transported to the first wall by conduction, radiation, or by more complicated methods such as heat pipes. The feasibility of using the thicker curtains hinges on the ability to transport large amounts of heat; therefore, techniques for maximizing heat transfer within and from the curtain must be identified and evaluated.

If the curtain materials contain large amounts of gas, either adsorbed on the surface or held in the bulk, the initial acquisition of a high vacuum may be compromised. Again, if the materials adsorb gases, such as hydrogen and helium during the high pressure cycle of the CTR operation and slowly desorb them at the low pressure part of the cycle, an adequate vacuum could be difficult to maintain. Especially significant is the effect of neutron irradiation on the vacuum properties of fibrous graphite.

An additional factor important for graphite curtains is the possibility that chemical reactions may occur between the graphite and hydrogen to form gaseous hydrocarbon products and thus limit the life of the curtains. Many studies have been made of these reactions but none have been conducted under the low pressure conditions that exist in a fusion reactor. Furthermore, it is not clear from these studies whether the reactions will take place at all and if so, to what extent they will proceed.

The objectives of the thermal analysis are (1) to measure the thermal conductivity of graphite fiber composites and (2) to identify and evaluate means for improving or augmenting heat transfer within the graphite curtain and to the reactor wall. The objectives of the vacuum outgassing study are (1) to measure the gas absorption properties for various irradiated and unirradiated graphite fibers to determine more completely their gas absorption characteristics, and (2) measure the chemical reactivity between hydrogen and graphite fibers.

Progress reported this quarter includes fabrication of a heat pipe and test fixture to study the operation of a heat pipe in a magnetic field, preparation of graphite fiber samples for thermal conductivity measurement tests, and preparing for vacuum outgassing and sticking probability determinations.

2.0 PROGRESS DURING THIS REPORTING PERIOD

2.1 Heat Pipe Performance in a Magnetic Field

One of the methods of transporting heat from the graphite curtain to the first wall is by the use of heat pipes. Heat pipes are attractive as heat transfer augmentation devices because they are simple passive devices and can be designed to carry considerable heat loads. Through the selection of a suitable working fluid, wick, and container, they can withstand the temperatures encountered by the curtain and first wall.

Particularly attractive as heat pipe working fluids are the liquid metals, which also are being considered as first wall coolants. Unfortunately, the flow of electrically conducting liquids in the CTR magnetic field environments induces magnetohydrodynamic (MHD) pressure losses in a liquid metal heat pipe. Carlson and Hoffman (Reference 1) conclude that the MHD pressure losses induced in the presence of a magnetic field always result in lower maximum heat flux capacity. The MHD pressure drop is affected by heat-pipe geometry, materials, electrical and fluid properties, and is extremely sensitive to flow path orientation through the magnetic fields.

One of the objectives of this program is to experimentally explore the performance of a liquid metal heat pipe in the presence of a magnetic field and to verify the analytical work described in the literature (Reference 1). To this end, a sodium-filled heat pipe has been fabricated for evaluation and testing. The heat pipe is made from 5/8 inch OD non-magnetic stainless steel tubing, 9 inches in length. The wick is classified as multitube, double pedestal, and central artery and is fabricated from fine mesh stainless steel screen. The sodium working fluid was charged through a 1/4-inch OD stainless steel fill tube welded to one end of the heat pipe. Details of a self-contained test fixture that heats the heat pipe at one end and extracts heat from the other end and can be placed between the pole faces of an electromagnet is discussed in the following section.

2.2 Heat Pipe Test Fixture For Magnetic Field Test

The test fixture for the magnetic field tests has been fabricated and the sodium filled heat pipe incorporated into the fixture. Figures 1 through 7 are photographs and sketches of the heat pipe and the components of the test fixture.

Figure 1 is a photograph of the heat pipe - 5/8 inch OD by 9 inches long. The 1/4 inch tube at one end is the fill tube which was pinched off after filling and inspection. Figures 2 and 3 are photographs of the assembled fixture mounted in an aluminum channel. The heat pipe will be tested by heating one end (evaporator section - the end opposite the fill tube) by radiation from a spiral wound resistance heater designed to deliver 600 watts when the heat pipe temperature is 1000°F. Figure 4 is a sketch of the heater winding and Figure 5 shows the heater and thermal insulation. Six thermocouples are mounted on the heat pipe in the evaporator section to monitor temperatures. The locations are shown in Figure 6. Heat is removed from the other end of the heat pipe (condenser end) by wrapping cooling coils around that part of the heat pipe. Temperature control of the heat pipe is maintained primarily by a thin Astroquartz insulation covering the heat pipe at the condenser end. Figure 7 shows the details of the cooling section.

Testing in a 1 tesla field will be performed during the next quarter.

2.3 Sample Preparation for Thermal Conductivity Measurement

Four specimens of T-50S graphite fiber bundles have been prepared for thermal conductivity measurement tests. The DYNATECH Company of Cambridge, Massachusetts has been selected to make the measurements. The measurements are to be made with the fibers parallel to the direction of heat flow (axial) and perpendicular to heat flow (transverse). For each case, there will be two configurations: (1) non-rigidized fiber bundles and (2) rigidized fiber bundles. The parallel and perpendicular orientation of the fibers should produce the extremes to be expected in the thermal conductivity. The thermal conductivity for combinations of fiber orientations and designs can be estimated accordingly. Photographs of the specimens are presented in Figure 8 and drawings are presented in Figures 9 and 10 for the non-rigidized and rigidized configurations, respectively.

All four specimens were made from a single bundle of fibers fabricated by winding T50-S yarn around the spindles of a "bundle" or "winding" board, shown in Figure 11. The "wound" bundle is removed from the spindles, compacted, and then held together with a tight braid of Kevlar yarn. The non-rigidized specimens were cut from the braided bundle and the remaining bundle impregnated with SC1008 phenolic resin. The impregnated bundle was cured and the phenolic resin then pyrolyzed above 2000°F. Figure 12 shows how the four specimens were cut from the single bundle.

The table in Figure 13 presents the specimen fiber weight and density. The specimen densities are lower than anticipated because the T-50S yarn has a twist to the filaments rather than the filaments being unidirectional which would pack tighter. The initial fiber bundle was compacted by hand, but the bundle for the non-rigidized, transverse specimen was further compacted in a wooden form, which accounts for the increased density of this bundle.

2.4 Vacuum Outgassing and Sticking Probability

The test matrix for the vacuum outgassing and sticking probability determination is presented in Figure 14. This matrix is based on the availability of specimens exposed to a neutron flux in the EBR-II reactor that are large enough for testing. In an experiment conducted by W. J. Gray of Battelle Northwest, specimens of carbon and graphite yarn and cloth, provided by MDAC-E, were exposed to fast neutrons in the EBR II test reactor. The samples consisted of a bundle of yarns, one inch long, and cloth discs, one inch in diameter. Two sets of samples were exposed. The first for 6 months at a total fluence of about 5×10^{21} neutrons per cm^2. The second set is being exposed for 12 months to a fluence of 1×10^{22} neutrons/cm^2. Exposure temperature is about 1200°C. The first set has been removed from the reactor and has been examined visually which revealed limited radiation damage. This information has been received informally. A report on these samples will be available shortly.

Recent work by Balooch and Olander (Reference 2), published since our proposal submittal, indicates that the molecular form of hydrogen is very unreactive towards graphite. Therefore, we will determine sticking probabilities using atomic hydrogen. Olander's work also shows a "non-reactive window" in the temperature region from 800°K to 1100°K. As temperature decreases below 800°K, the probability for methane formation increases and the probability for acetylene formation increases as the temperature increases above 1100°K. These two hydrocarbons were the only reaction products observed over a wide temperature range. Figure 15 shows Olander's results.

3.0 WORK PLANNED FOR THE NEXT REPORTING PERIOD

3.1 Heat Pipe Magnetic Field Tests

Operation of a sodium filled heat pipe in the presence of a maximum 1 tesla magnetic field will be studied by testing during the next reporting period. It is anticipated that two magnet facilities will be used. One magnet facility is operated by the McDonnell Douglas Research Laboratories (MDRL) in St. Louis and the other magnet is operated at the Lawrence Livermore Laboratory in Livermore, California. The test procedure in the MDRL facility will be to increase the magnetic field strength for a fixed orientation and heat load on the heat pipe. The magnetic field strength at the time the wick structure begins to dry-out, as indicated by overheating of the thermocouples, will be recorded. The procedure in the Livermore facility will be to mount the heat pipe in a horizontal position, fix the heat load and the magnetic field strength, and then elevate the evaporator end of the heat pipe until dry-out occurs. The magnetic pressure drop can be computed from the difference in angle at which dry-out occurs between operating without the influence of a magnetic field and at identical conditions in the presence of a magnetic field.

3.2 Thermal Conductivity of Graphite Fibers

The thermal conductivity of the four graphite fiber specimens will be determined during the next reporting period. The measurements will be carried out by the DYNATECH Company of Cambridge, Massachusetts in a comparative measurement device. The thermal conductivity of each sample will be determined at six mean temperatures in the range from 500°C to 1400°C under vacuum conditions.

3.3 Vacuum Outgassing and Sticking Probability

The equipment and apparatus to make the outgassing and sticking probability determinations are being assembled during this reporting period. Shake down of the set-up and initial measurements will take place during the next reporting period.

3.4 Heat Transfer and Thermal Analysis

An analytical study to computer code the operation of a heat pipe, using an electrically conducting working fluid, in the presence of a magnetic field will be made during the next reporting period assuming the test results support the usefulness of such a computer code. Our present heat pipe computer program will be modified and expanded to accommodate the results of the experimental study as well as provide the foundation for the additional computer code. The performance characteristics for a variety of conditions will be determined.

The spectral shaper thermal analysis study will begin during the next reporting period after the results of the thermal conductivity measurements on the graphite fibers become available.

4.0 REFERENCES

1. Carlson, G. A., and Hoffman, M. A., "Heat Pipes in the Magnetic-Field Environment of A Fusion Reactor," Journal of Heat Transfer, Trans. ASME, Series C, Vol. 94, No. 3, August 1972, pp. 282-288.

2. Balooch, M., and Olander, D. R., "Reactions of Modulated Molecular Beams with Pyrolytic Graphite, III, Hydrogen," Journal of Chemical Physics, Vol. 63, No. 11, 1 December 1975.

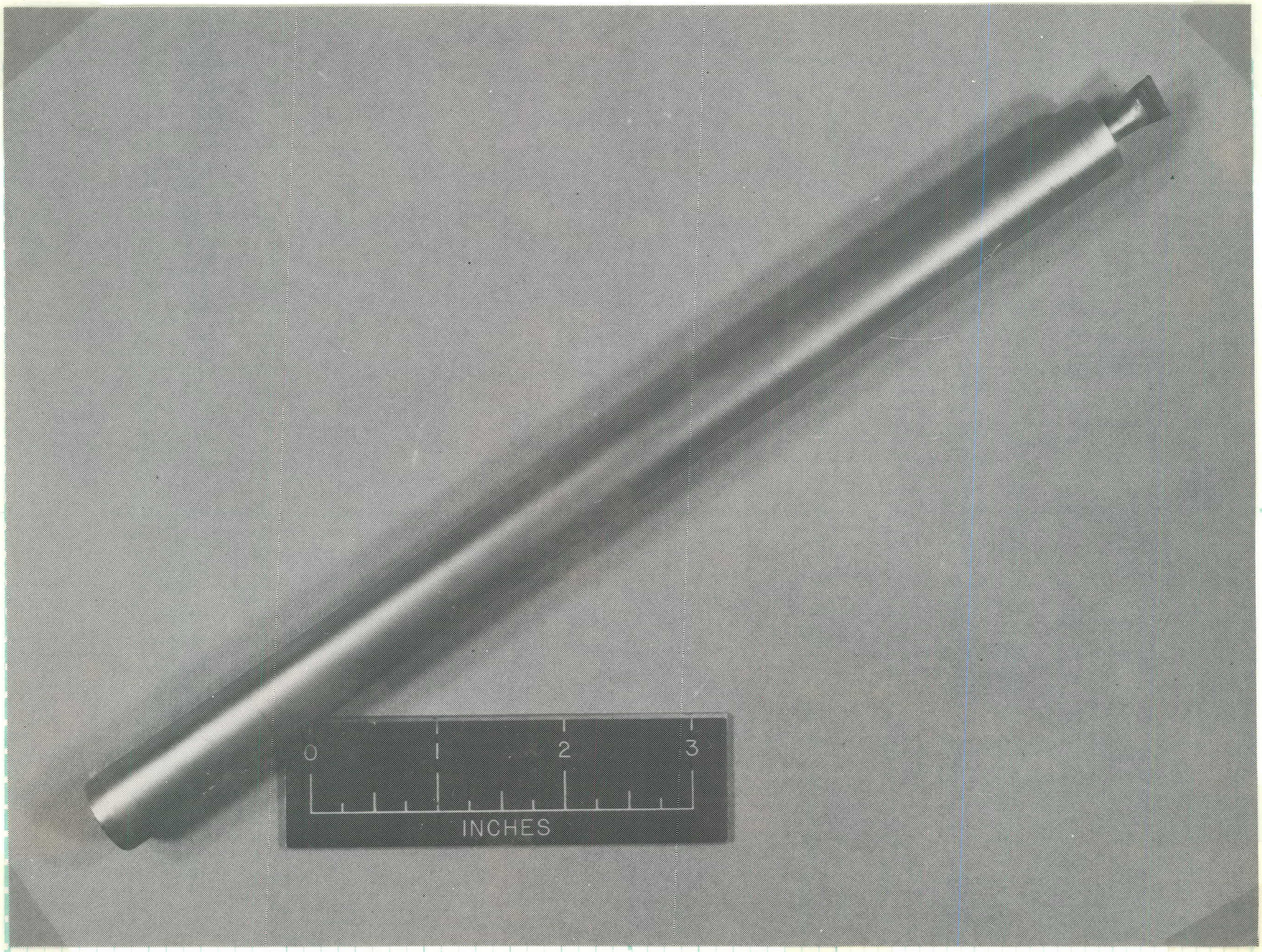

FIGURE 1 HEAT PIPE

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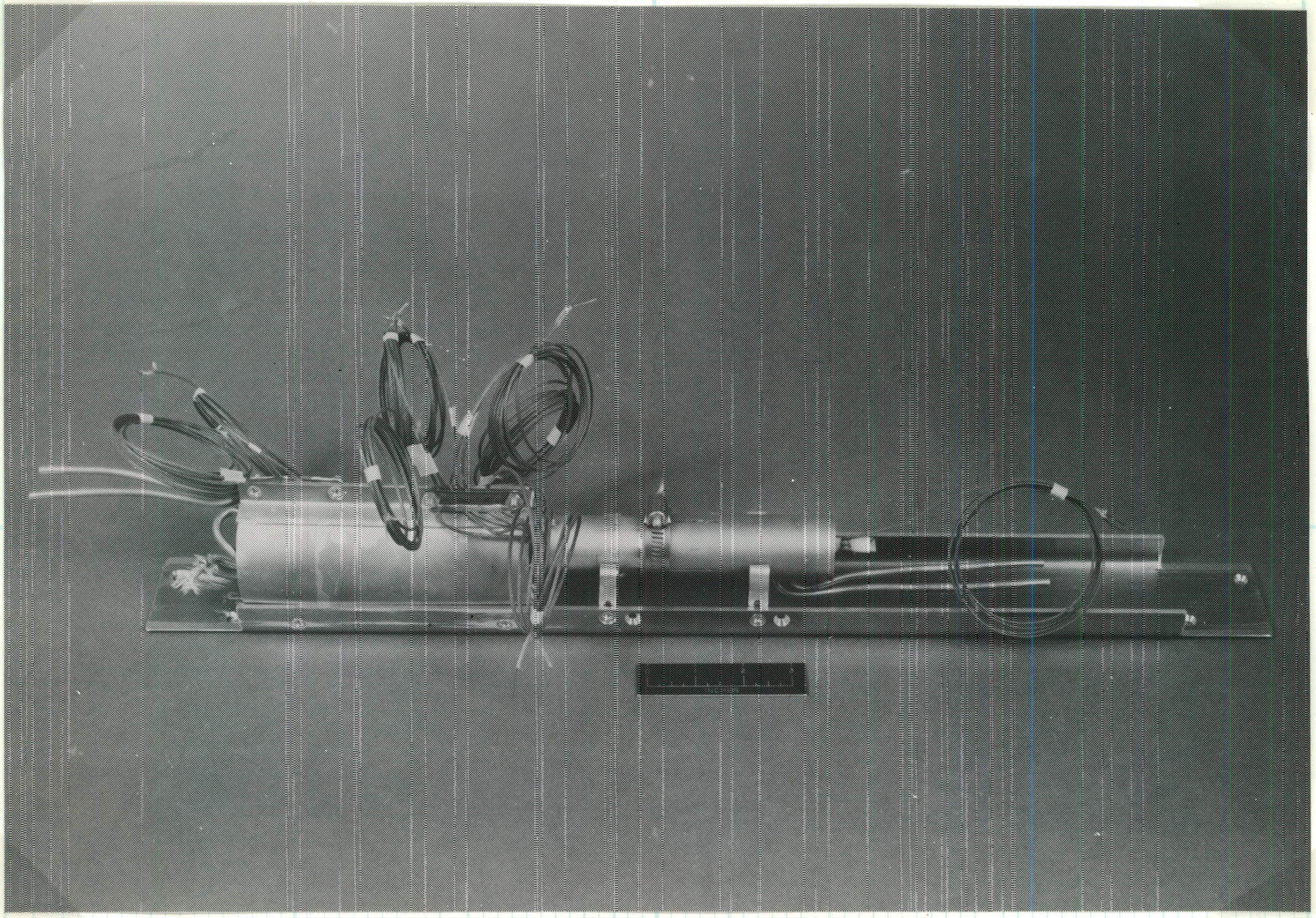

FIGURE 2 MAGNETIC FIELD TEST FIXTURE

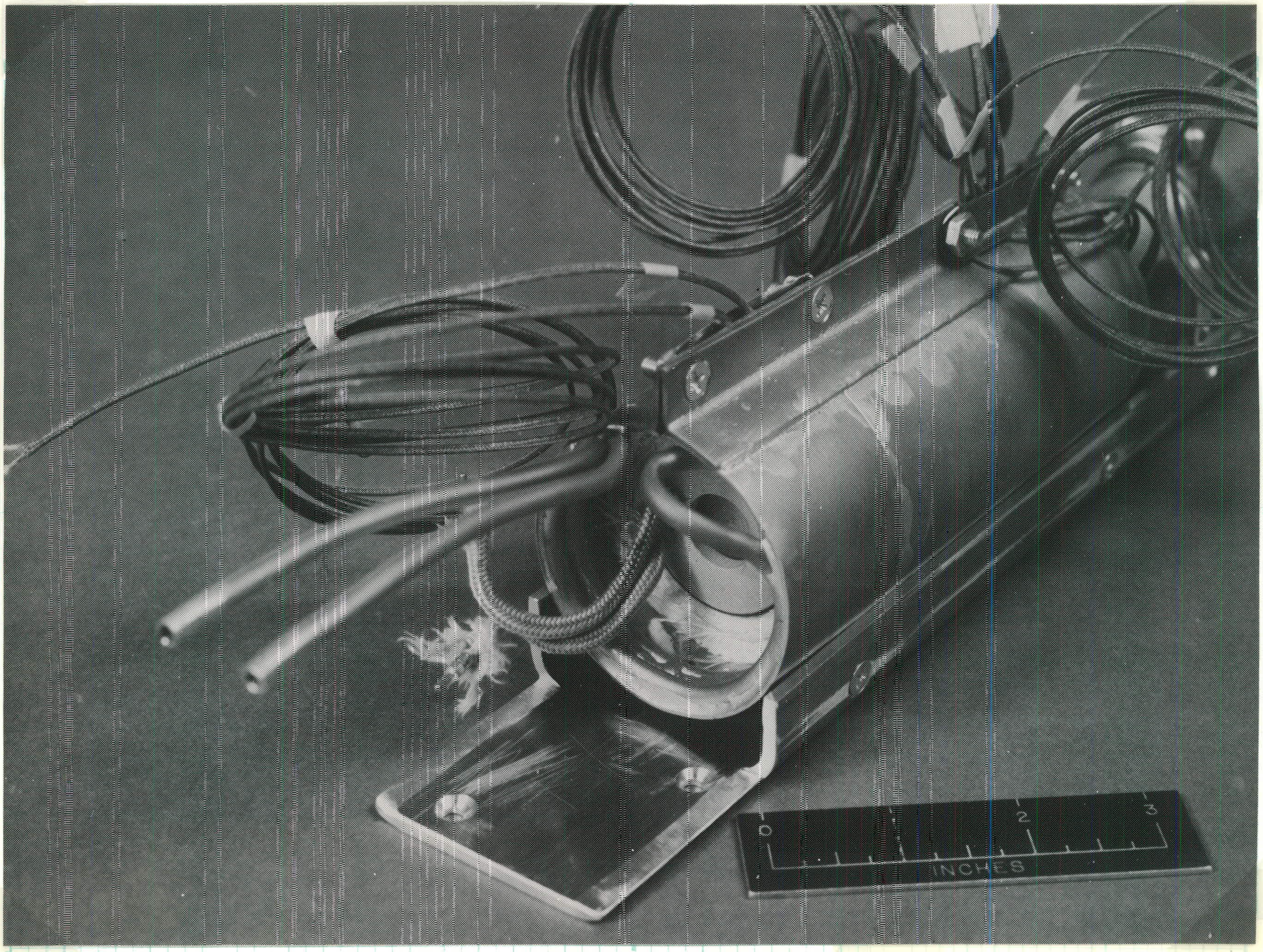

FIGURE 3 HEAT PIPE TEST FIXTURE EVAPORATOR SECTION

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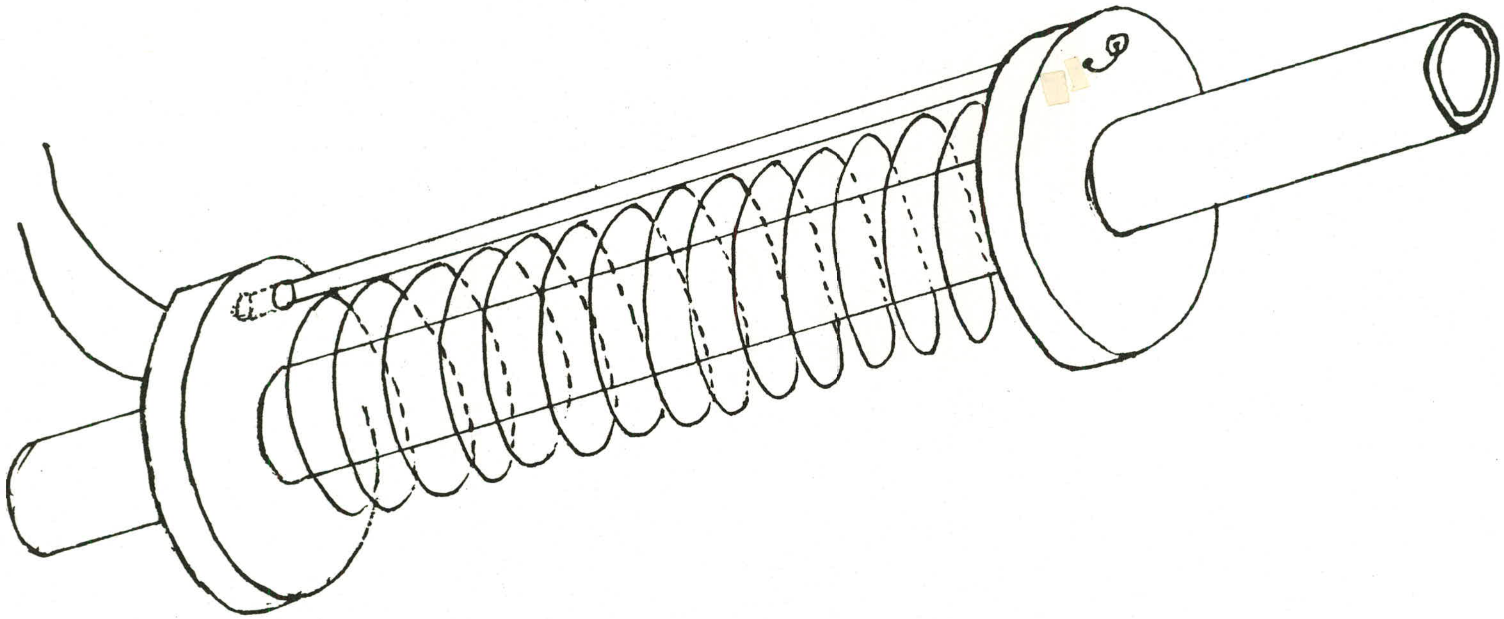
RESISTANCE HEATER WINDING



OPERATION AT 110V. 600 WATTS
24 GAGE NICHROME WIRE (22 MIL-DIAM)
REQ'D. LENGTH OF WIRE - 13.17 FT.
13 TURNS/INCH COIL DIAM. - 1.0 INCH

FIGURE 4

MCDONNELL DOUGLAS CORPORATION

HEAT PIPE RESISTANCE HEATER AND INSULATION DESIGN

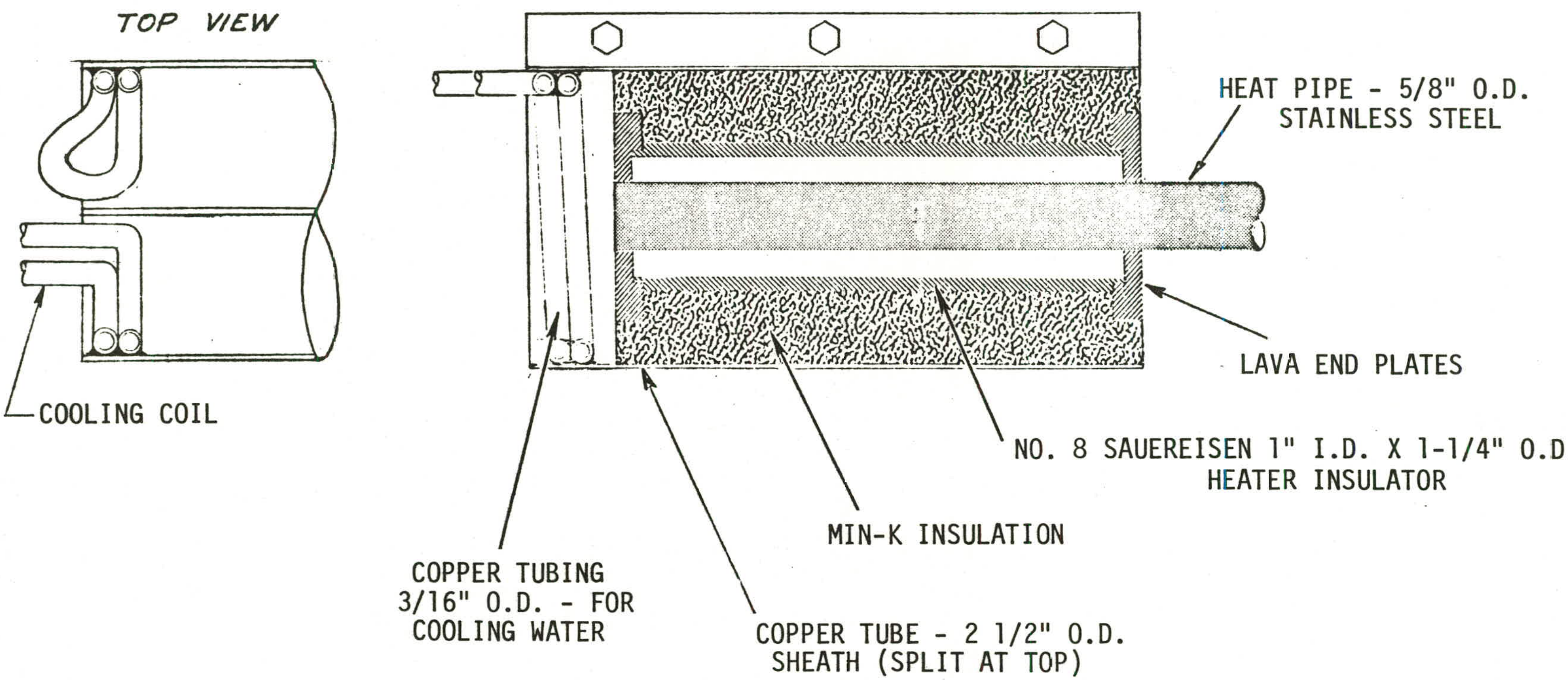


FIGURE 5

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HEAT PIPE THERMOCOUPLES
EVAPORATOR SECTION

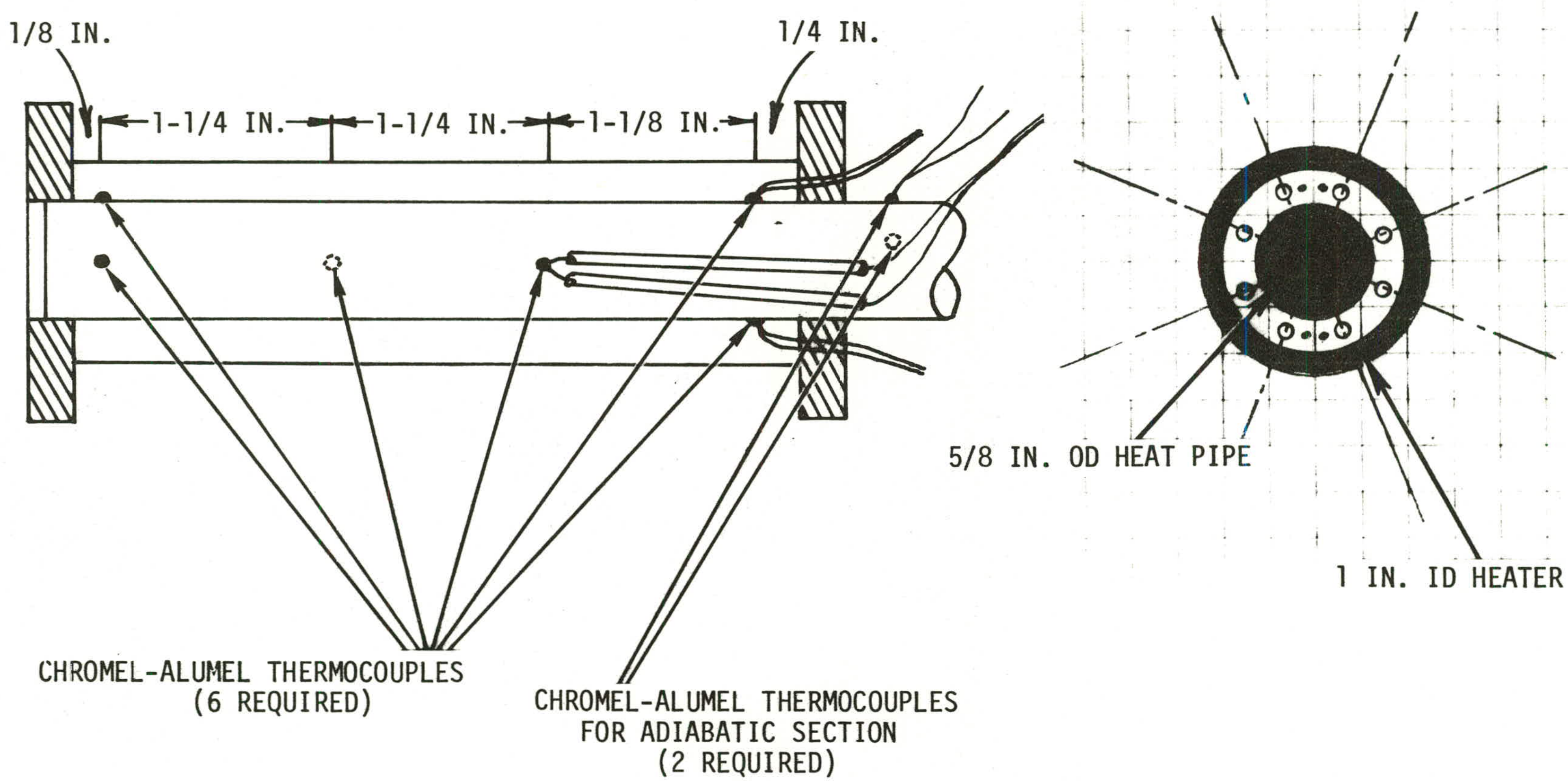

FIGURE 6

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HEAT PIPE WATER COOLED HEAT SINK

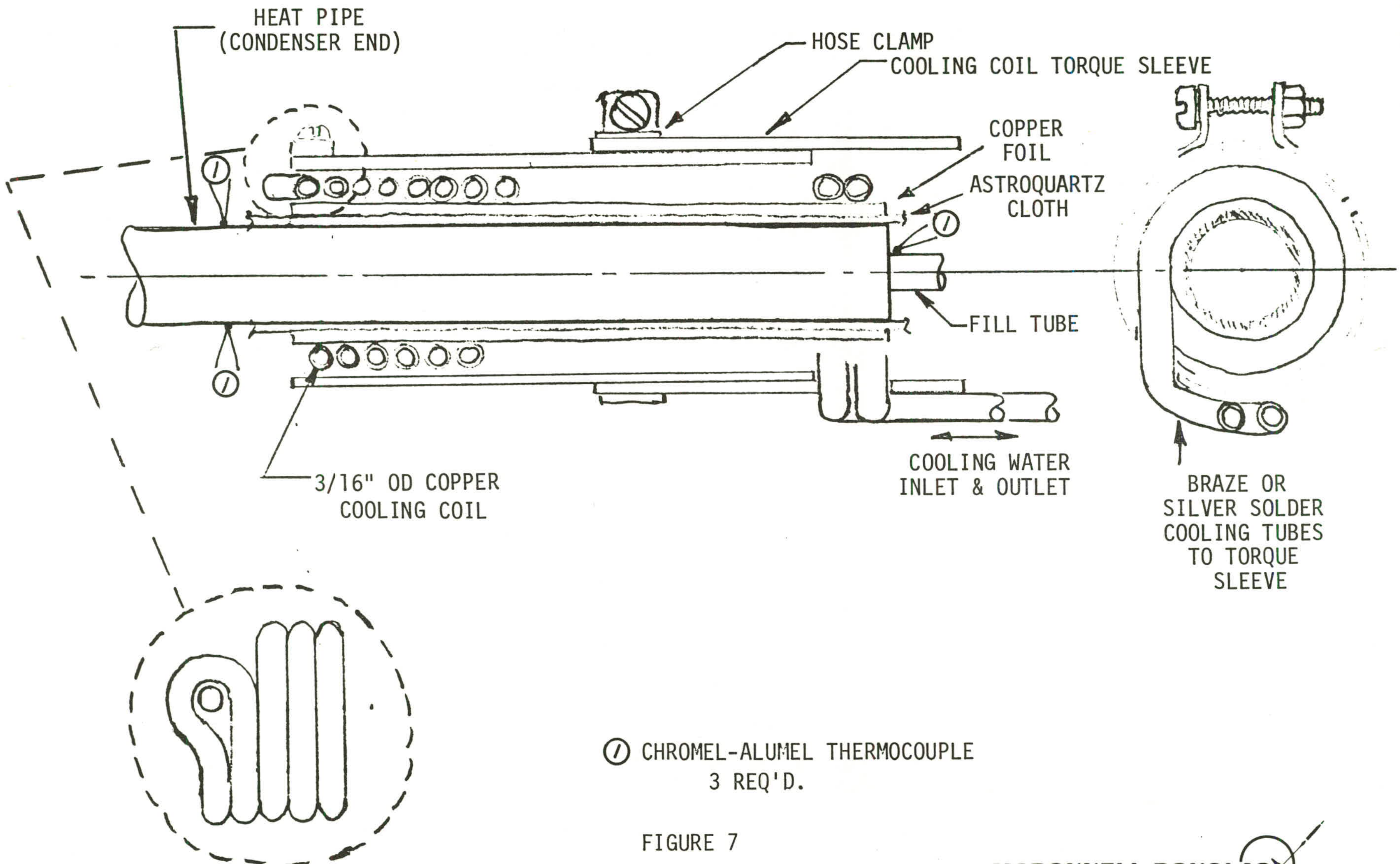

FIGURE 7

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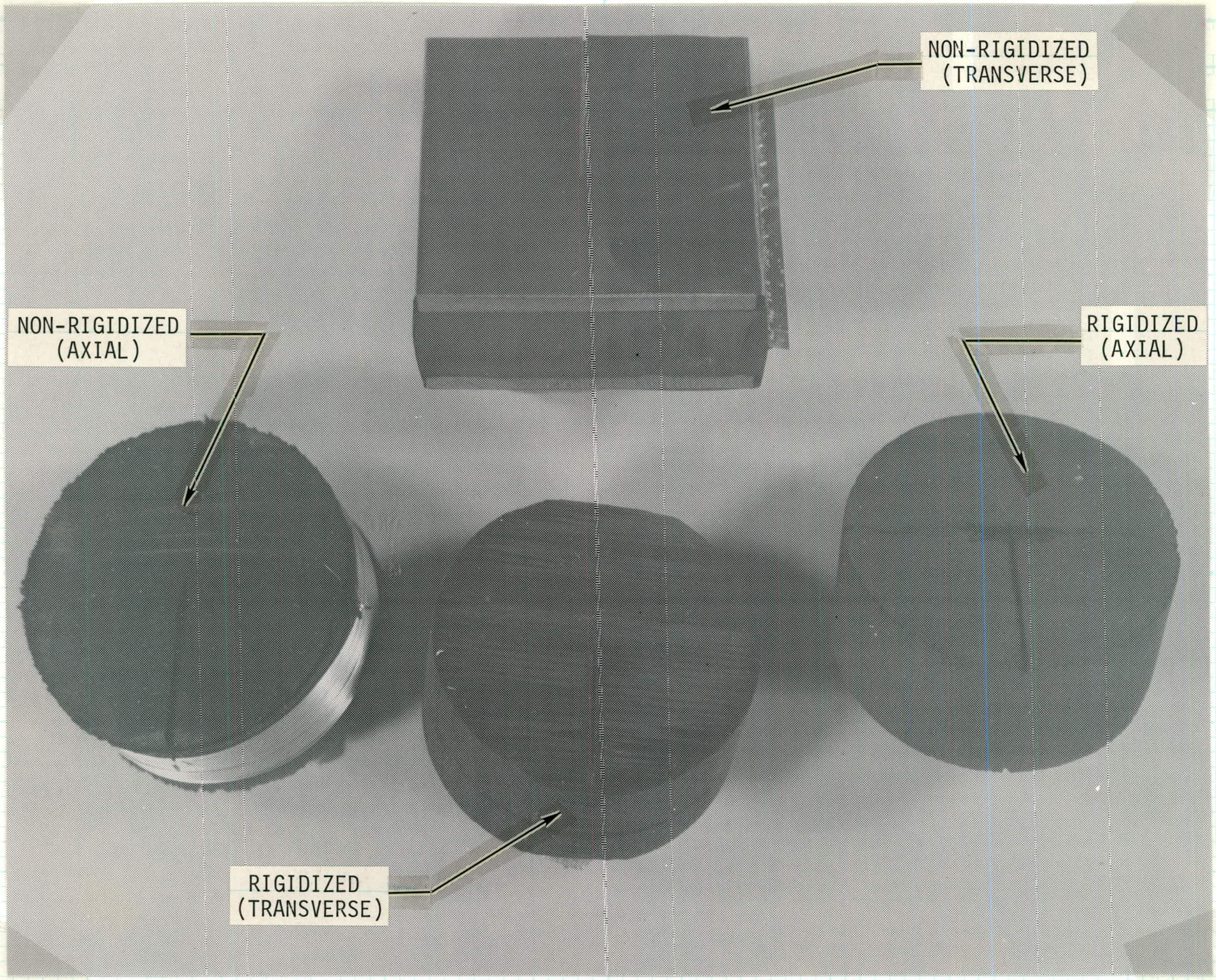

FIGURE 8 THERMAL CONDUCTIVITY TEST SPECIMENS

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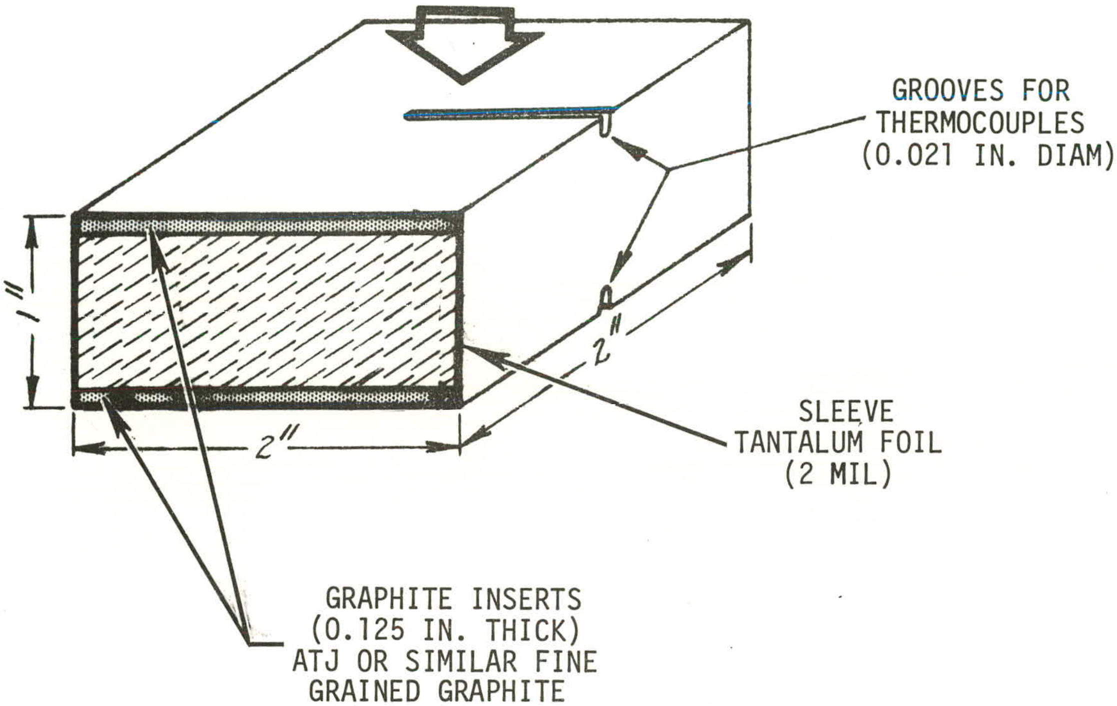
SAMPLE PREPARATION FOR THERMAL CONDUCTIVITY MEASUREMENT T-50 GRAPHITE FIBER BUNDLES

FIBER BUNDLE (TRANSVERSE)



FIBER BUNDLE (AXIAL)

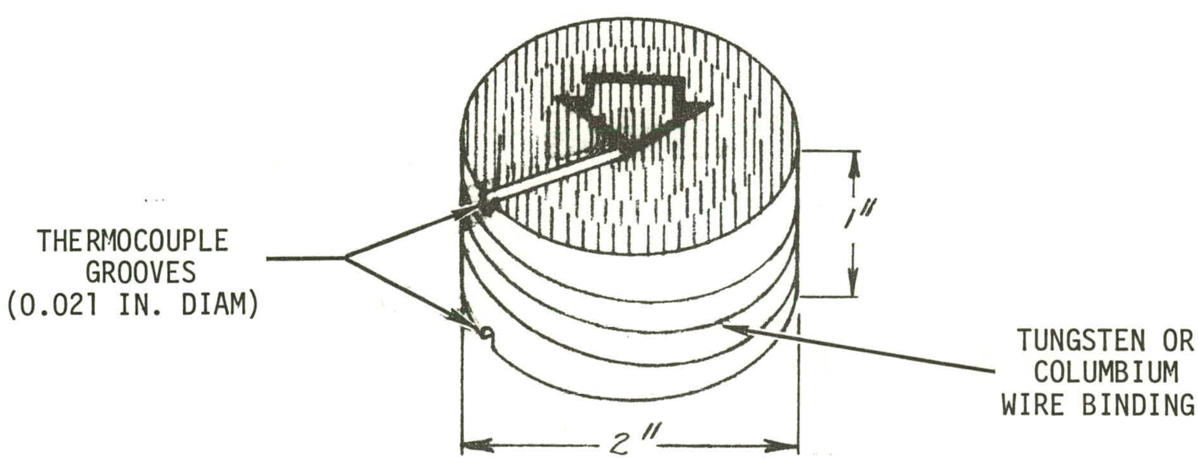


FIGURE 9

SAMPLE PREPARATION FOR THERMAL CONDUCTIVITY MEASUREMENT

T-50 GRAPHITE RIGIDIZED FIBER BUNDLES

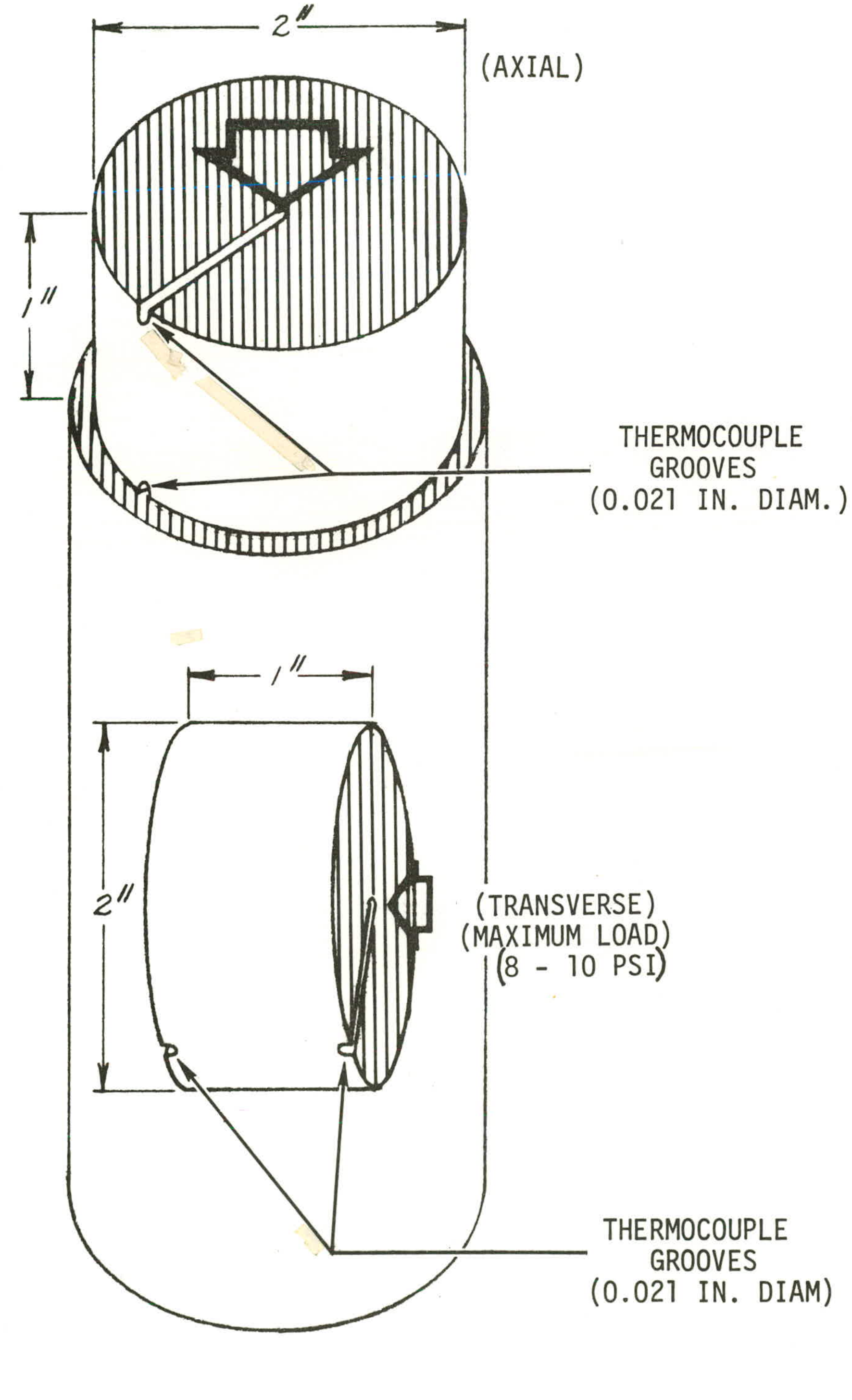
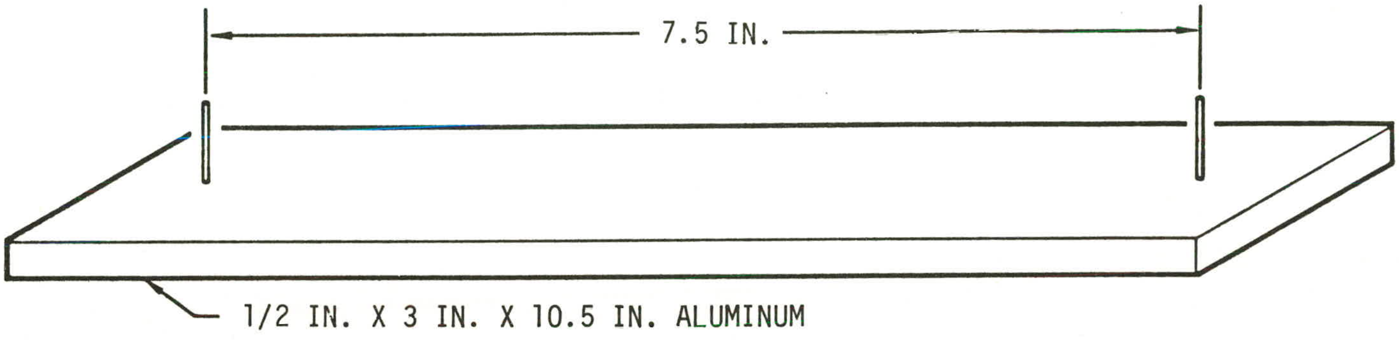
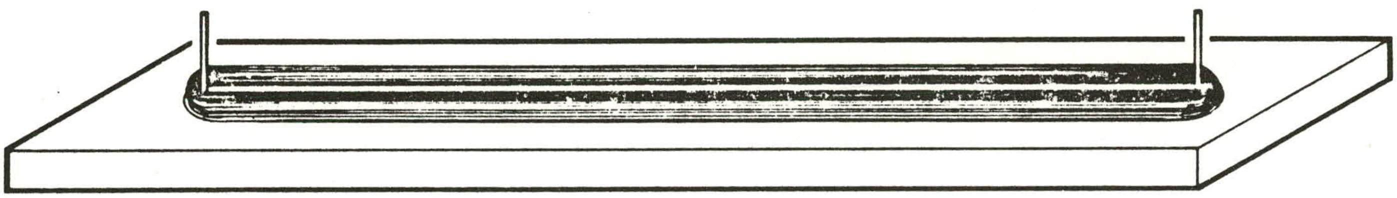


FIGURE 10



Bundle Board



Hand Wound Bundle on Winding Board

FIGURE 11 FIBER BUNDLE WINDING BOARD

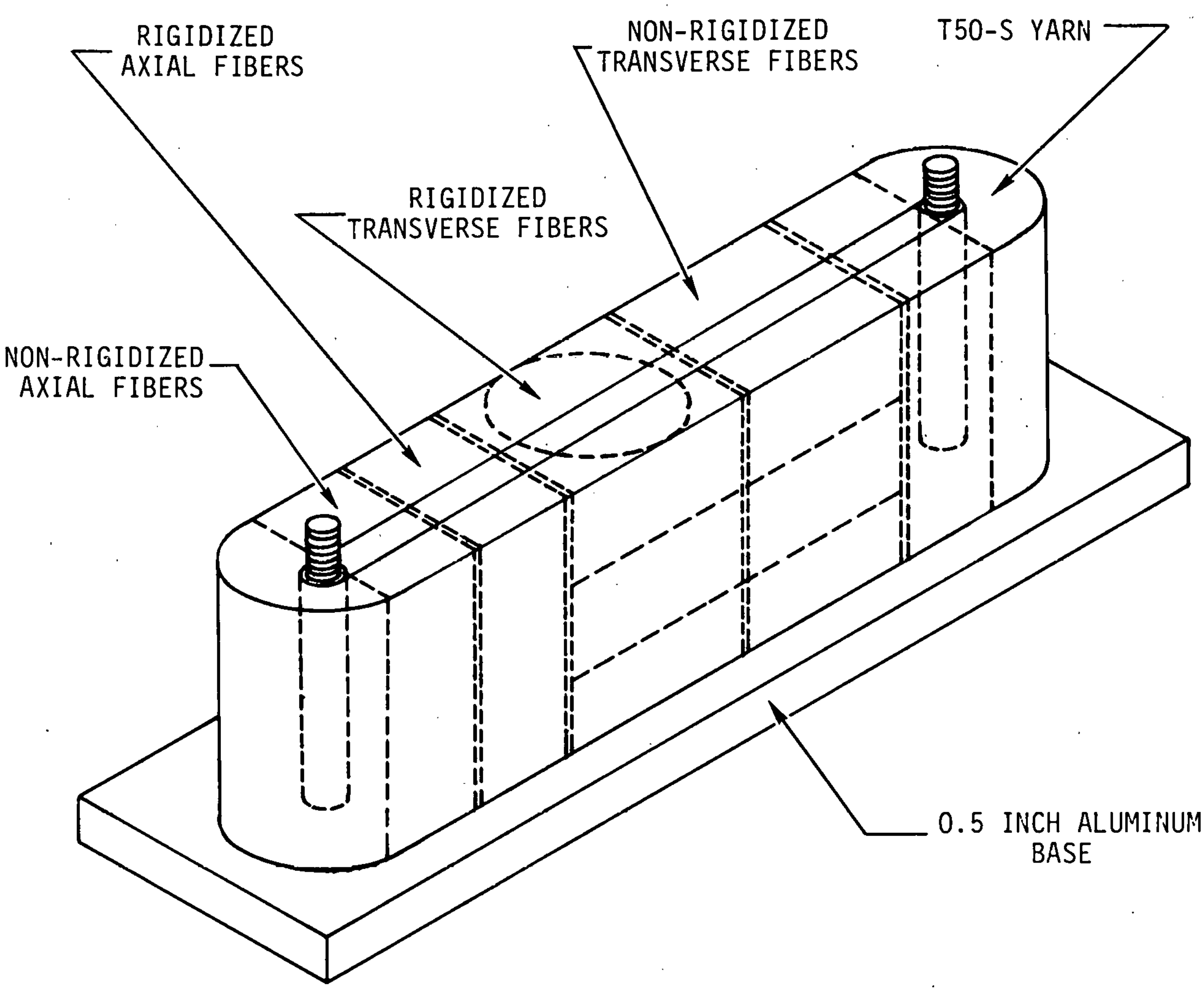


FIGURE 12 SPECIMEN LOCATION IN FIBER BUNDLE

CONFIGURATION	ORIENTATION	FIBER WEIGHT (GMS)	DENSITY (LB/FT^3)	PERCENT THEORETICAL DENSITY
NON-RIGIDIZED	AXIAL	44.7	55.8	55.2
	TRANSVERSE	40.3	61.3	60.6
RIGIDIZED	AXIAL	56.0	68.6	68.0
	TRANSVERSE	56.3	67.8	67.2

FIGURE 13 FIBER BUNDLE DENSITY

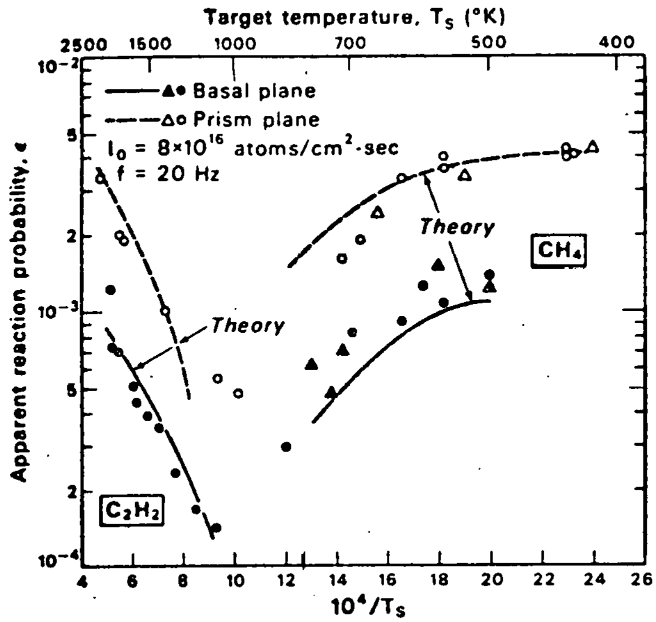
Carbon/ Graphite Material Designation	FIBERS AS MANUFACTURED				FIBERS AFTER EXPOSURE TO NEUTRONS			
	Gas Content	Sticking Probability for		Elect. Conduct-ivity	Gas Content	Sticking Probability for		Elect. Conduct-ivity
		H	He			H	He	
T-50 (Cloth)	Samples (1) *				Samples (1)			
T-300P (Yarn)	(1)				o	o	o	o
GSCC (Cloth)	(1)				(1)			
GSGC (Cloth)	(1)				(1)			
WYB (WCA)(Cloth)	(1) *				(1)			
Poco Graphite	(1)			o	o	o	o	o

Mass spectrographic determination of the composition of gases removed shall be made on 6 representative runs.

* Indicates determinations completed in a previous program.

o Indicates no measurements to be made.

FIGURE 14 PROPERTY MEASUREMENT MATRIX



NOTE: TRIANGLES AND CIRCLES REPRESENT DUPLICATE RUNS

FIGURE 15 TEMPERATURE DEPENDENCE OF THE APPARENT REACTION PROBABILITIES FOR METHANE AND ACETYLENE