GRAPHITE CURTAIN VACUUM OUTGASSING AND HEAT TRANSFER

QUARTERLY PROGRESS REPORT NO. 2

For The Period 1 April 1976 to 30 June 1976
Submitted under Contract E(11-1)-2802

Prepared For
CTR Materials Branch
U.S. Energy Research and Development Administration

Prepared by: H. J. Fivel
H. J. Fivel
Lead Engineer, Thermodynamics

G. P. Lang
G. P. Lang
Senior Engineer, Materials and Processes

Approved by: D. L. Kummer
D. L. Kummer
Chief Design Engineer
Materials and Processes

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY - EAST

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

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 portion of the CTR operation cycle and slowly desorb them in 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 testing a sodium-filled heat pipe in a magnetic field and vacuum outgassing and sticking probability measurements.

2.0 PROGRESS DURING THIS REPORTING PERIOD

2.1 Heat Pipe Performance In A Magnetic Field

A sodium filled heat pipe was tested in a magnetic field of up to 1 Tesla in the McDonnell Douglas Research Laboratories (MDRL) magnet facility. A photograph of the test fixture mounted in the magnet facility is presented in Figure 1. Details of the heat pipe and test fixture design were reported in the previous progress report. At a power level of 462 watts, no difference in heat pipe performance was observed when operating with or without the effect of the 1 Tesla magnetic field. A summary of the test data is presented in Appendix A.

An analysis of the heat pipe operation for this particular design was made and is shown in Figure 2 as the wicking limit power level. The wicking limit is obtained by equating the liquid phase and gaseous phase pressure drops and gravity head to the capillary pumping power. Following the analysis of Hoffman and Carlson in Reference 1, the presence of a transverse magnetic field affects only the liquid phase pressure drops for a liquid metal or electrically conducting heat pipe working fluid (magnetohydrodynamic, or MHD, effects). Increasing the magnetic field increases the liquid phase pressure drop and decreases the wicking limit.

The MHD pressure drop is calculated as a function of the Hartmann number, which includes effects of the magnetic field strength and a characteristic flow area dimension parallel to the lines of magnetic flux. The complex wick structure of the MDAC heat pipe design, with its central artery, double pedestal configuration, make the selection of the characteristic dimension for the Hartmann number questionable. We have used individually capillary pore size, capillary diameter, and central artery diameter in computing the main axial MHD pressure effects, with pedestal and wall screen MHD effects based on either screen thickness or screen mesh size. Each analysis is shown on Figure 2. Since the heater for the evaporator section was restricted in size by the configuration of the magnet facility, thereby limiting the input power below the wick capability, it is indicated from Figure 2 that a stronger magnetic field should affect the operation of the heat pipe at the test power condition. It is suggested, then, that tests be conducted in another facility. Operation of the heat pipe at different power levels would define an operating curve from which empirical constants could be derived to satisfy the analysis.

2.2 Thermal Conductivity of Graphite Fibers

Scheduling difficulties and equipment unavailability at the DYNATECH Company have caused the thermal conductivity measurement tests to be slipped into the next reporting period.

2.3 Vacuum Outgassing and Sticking Probability

Gas content, electrical conductivity, and atomic hydrogen and helium sticking probability measurements on three materials as received from the manufacturer have been completed. These are shown as the shaded items on the property measurement matrix of Figure 3.

The vacuum property measurements are made in a 12-inch diameter, bakable, stainless-steel vacuum chamber connected by means of an orifice of known conductance to a pumping chamber. The quantity of gas pumped is proportional to the difference of pressures in the two chambers and is determined from the time integration of the ΔP following the thermal desorption of a sample. Figure 4 shows the vacuum chamber and accompanying apparatus.

The samples are mounted between cooled copper electrodes to enable the samples to be heated resistively. A detailed photograph of the specimen holder is shown in Figure 5. Sample temperatures above 750°C were measured by an optical pyrometer. The gas adsorbed on the fibers was then measured as a function of fiber temperature by heating the sample resistively to a measured temperature, pumping out the resulting adsorbed gases while continually measuring pressure in the two chambers, until the initial pressures were again obtained. The initial pressure was typically 3×10^{-6} torr. The sample was then heated to a higher temperature and the measurement repeated. The chemical analysis of the desorbed gas was performed with a mass spectrometer. A typical mass spectrometer trace for T-300P yarn showing particular species composition at 2 temperatures is presented in Figure 6.

After the samples had been completely desorbed of gases by heating to 1900°C or higher - a point at which measurable carbon sublimation occurs - , the sticking probability for atomic hydrogen was measured by exposing the fibers to atomic hydrogen at around 10^{-5} torr pressure for 1 minute or more at either room temperature or at about 800°C. The excess or non-adsorbed hydrogen was removed from the chamber by pumping the chamber down to a pressure of 10^{-6} torr. The adsorbed gas was then removed by flash heating the fibers to 1600°C or higher, and the desorbed gas content measured as before. A sticking probability was calculated defined as the number of molecules of hydrogen adsorbed divided by the total number of molecules of hydrogen impinging on the sample during the exposure period. Sticking probabilities for helium are determined in the same manner as for atomic hydrogen except the exposure pressure is 10^{-3} torr.

Reduction of the data measured during this reporting period will be performed during the next period.

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 6 Tesla magnetic field will be studied by testing during the next reporting period. The C-1 magnet facility at Oak Ridge National Laboratory (ORNL) will be used. The test fixture used to test at 1 Tesla in the McDonnell Douglas Research Laboratories (MDRL) magnet facility in St. Louis will be modified to fit the ORNL C-1 magnet envelope.

The test procedure in the ORNL facility will be the same as that conducted in the MDRL facility. For a fixed orientation and heat load on the heat pipe, the magnetic field strength will be increased. The magnetic field strength at the time the wick structure begins to dry out, as indicated by overheating of the thermocouples, will be recorded.

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 vacuum outgassing and atomic hydrogen and helium sticking probability measurements will be completed during the next reporting period.

3.4 Heat Transfer and Thermal Analysis

Empirical correlations will be developed during the next reporting period to aid in the analysis of the operation of a heat pipe, using an electrically conducting working fluid, in the presence of a magnetic field, assuming the test results support the usefulness of such an analysis. Our present heat pipe computer program will be modified and expanded to accommodate the results of the experimental study. The performance characteristics for a variety of conditions can then 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.

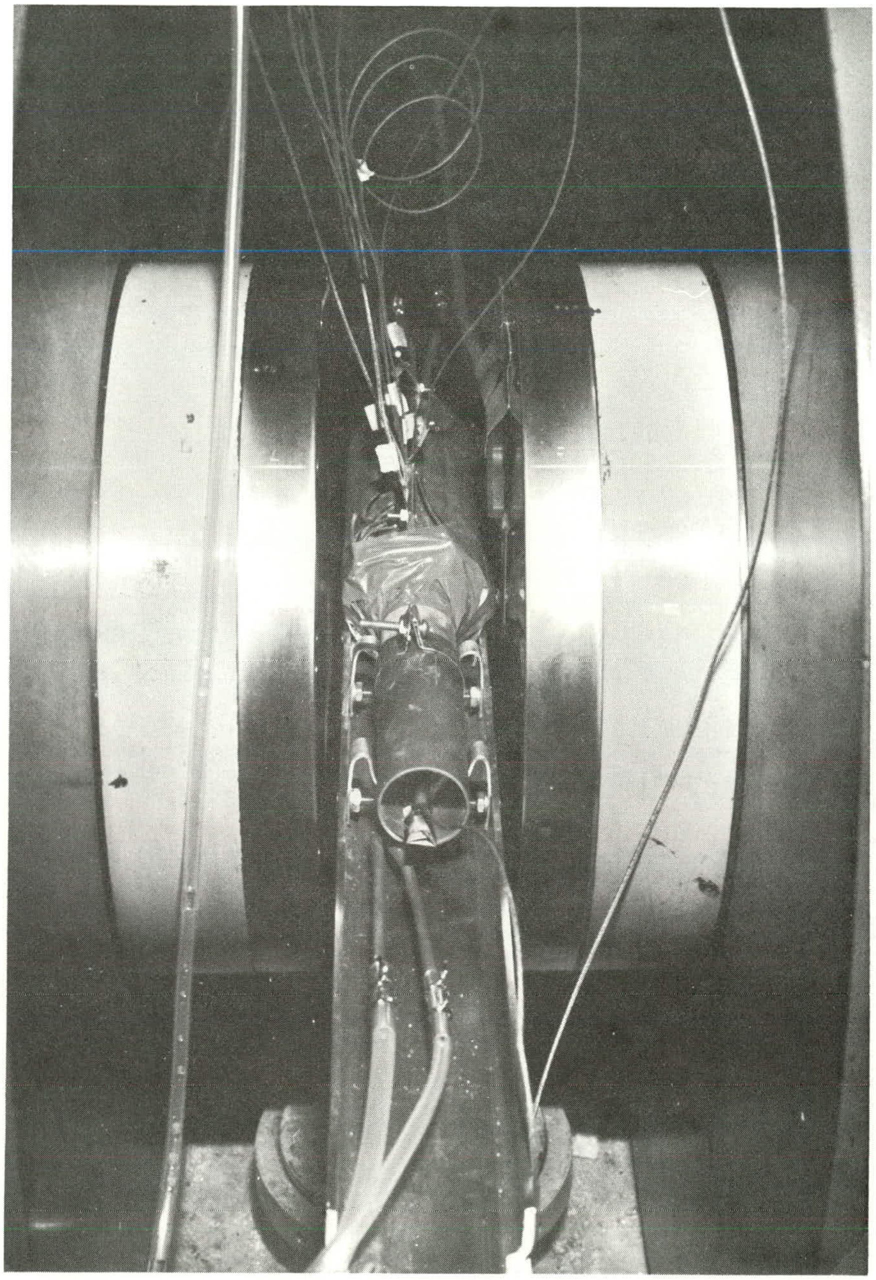
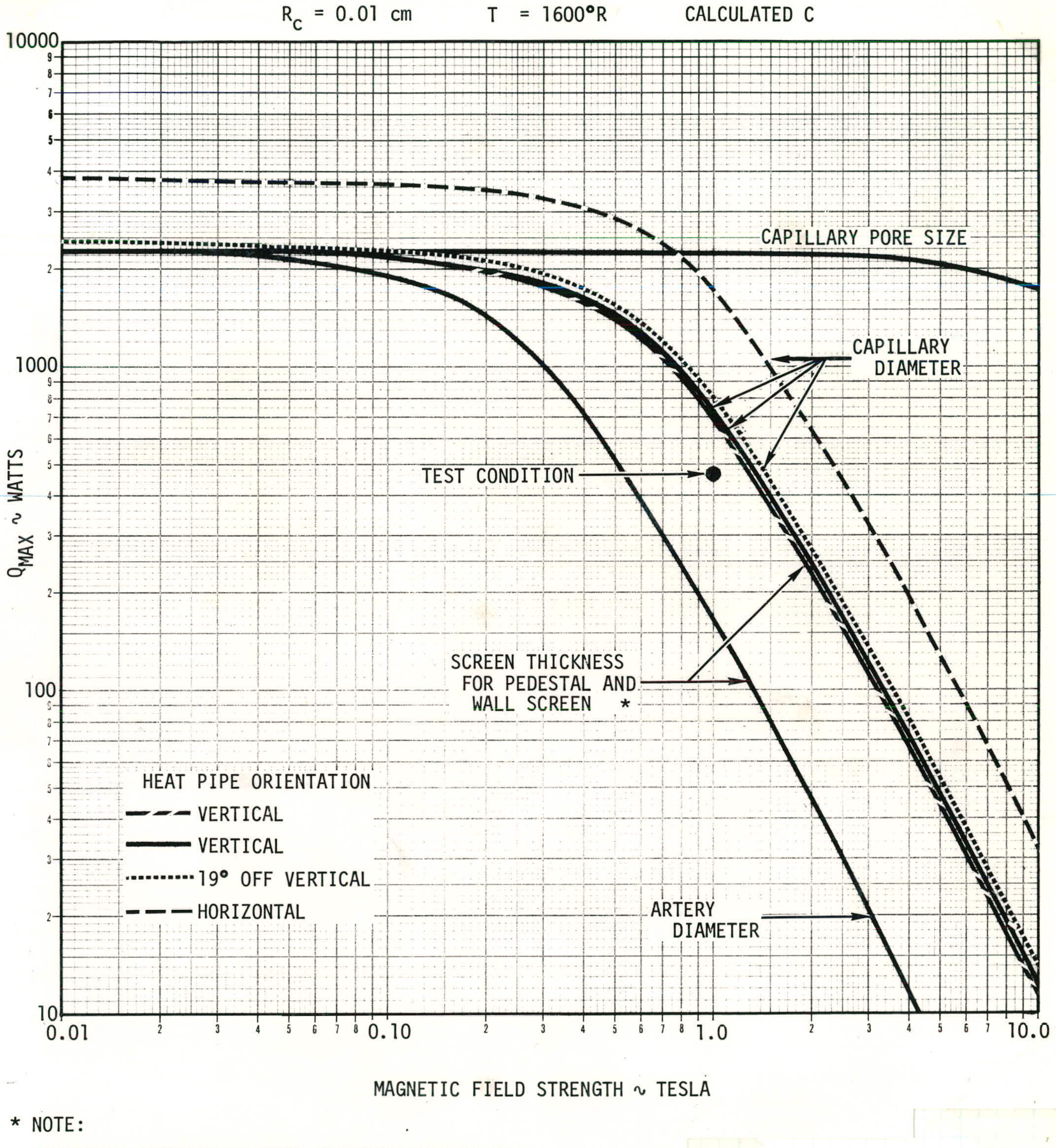


FIGURE 1 HEAT PIPE TEST FIXTURE MOUNTED IN MDRL MAGNET FACILITY



* NOTE:

PEDESTAL AND WALL SCREEN HARTMANN NUMBER USE SCREEN MESH SIZE UNLESS OTHERWISE NOTED

FIGURE 2 EFFECT OF CHARACTERISTIC DIMENSION FOR CENTRAL ARTERY HARTMANN NUMBER ON MDAC HEAT PIPE WICKING CAPABILITY

Carbon/ Graphite Material Designation	FIBERS AS MANUFACTURED				FIBERS AFTER EXPOSURE TO NEUTRONS			
	Gas Content	Sticking Probability for H	Sticking Probability for He	Elect. Conduct-ivity	Gas Content	Sticking Probability for H	Sticking Probability for He	Elect. Conduct-ivity
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.

[shaded box] Runs Completed

FIGURE 3 VACUUM PROPERTY MEASUREMENT MATRIX

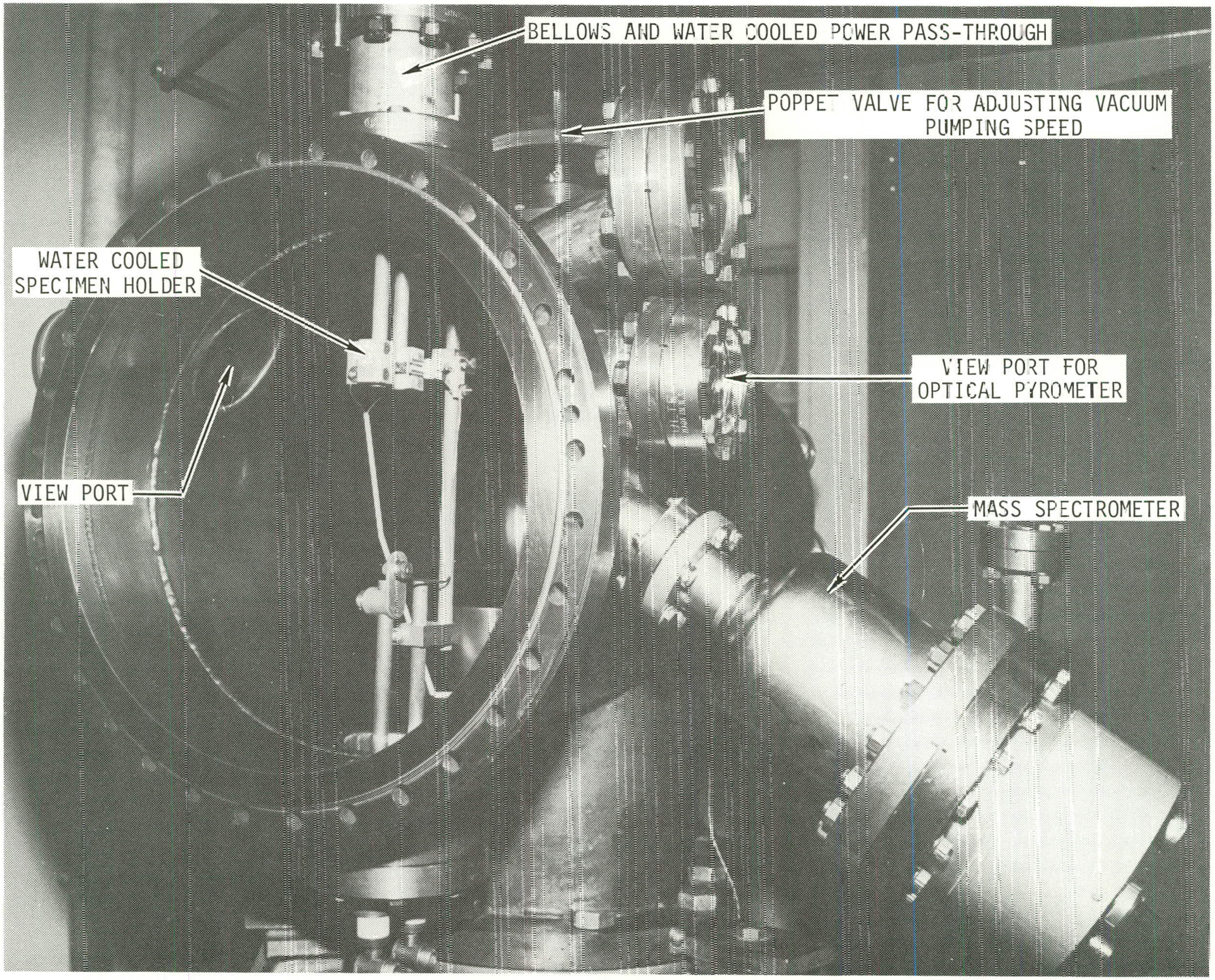


FIGURE 4 APPARATUS FOR VACUUM OUTGASSING AND STICKING PROBABILITY MEASUREMENTS

MCDONNELL DOUGLAS CORPORATION

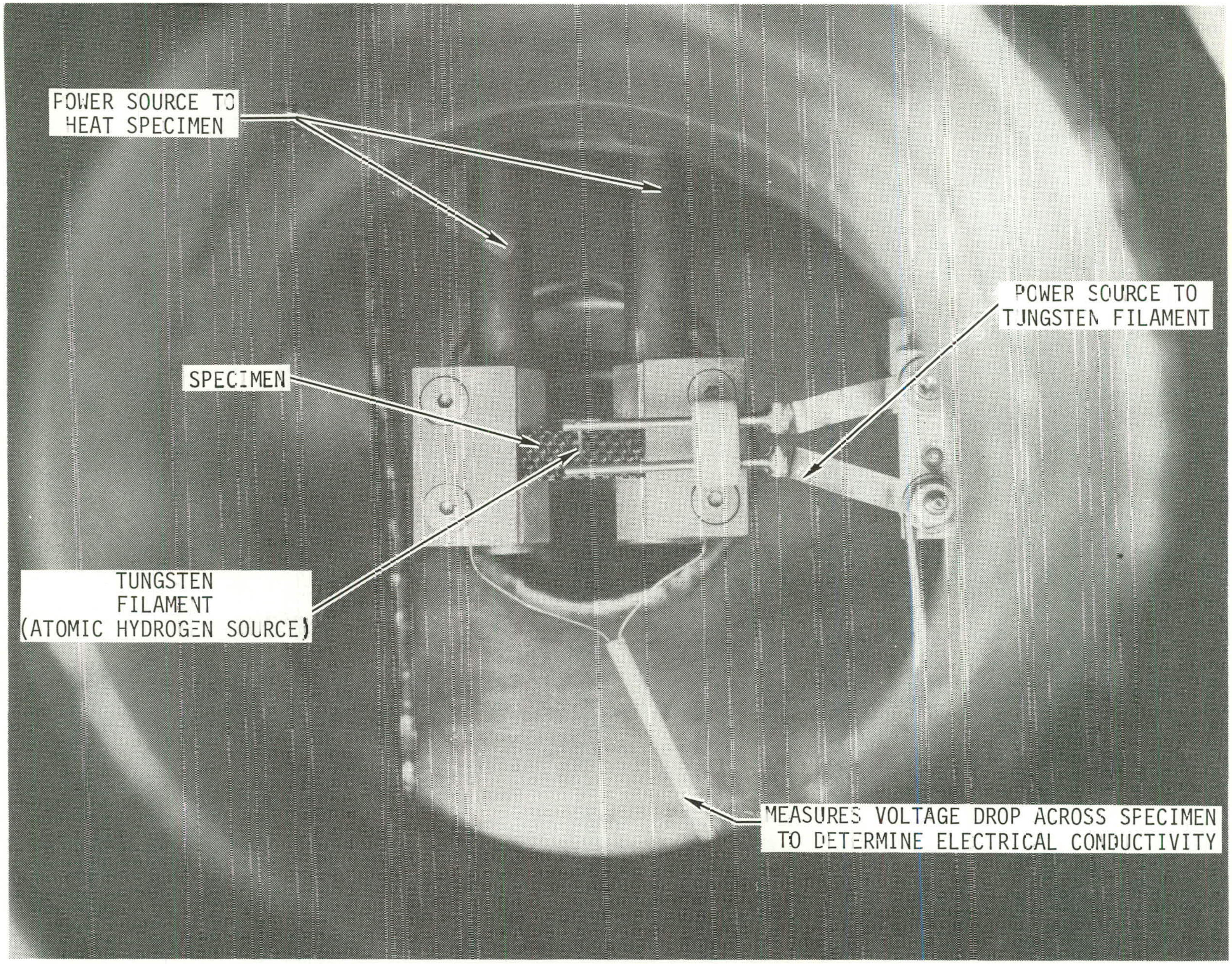


FIGURE 5 WATER COOLED SPECIMEN HOLDER
WITH SPECIMEN IN PLACE

MCDONNELL DOUGLAS
CORPORATION

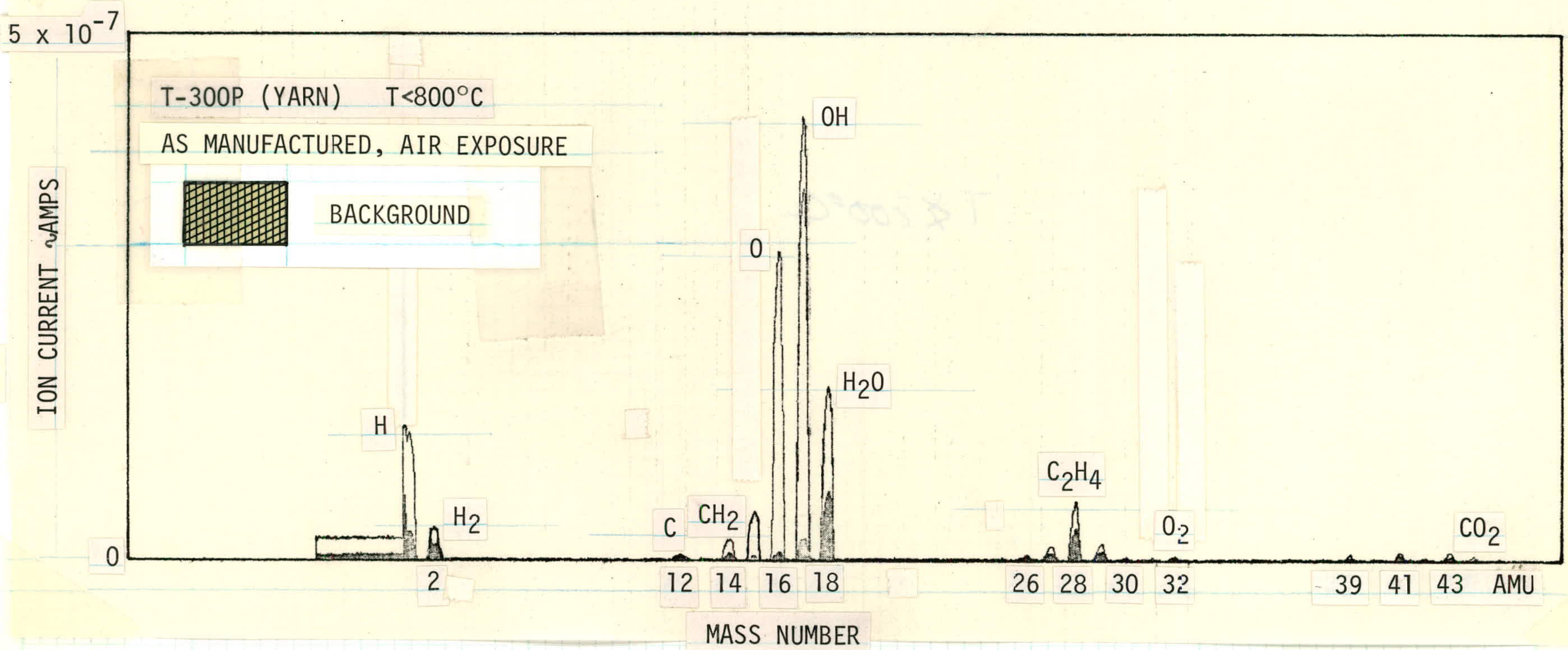


FIGURE 6(a) MASS SPECTROMETER ANALYSIS OF DESORBED GAS ON T-300P YARN AT T<800°C

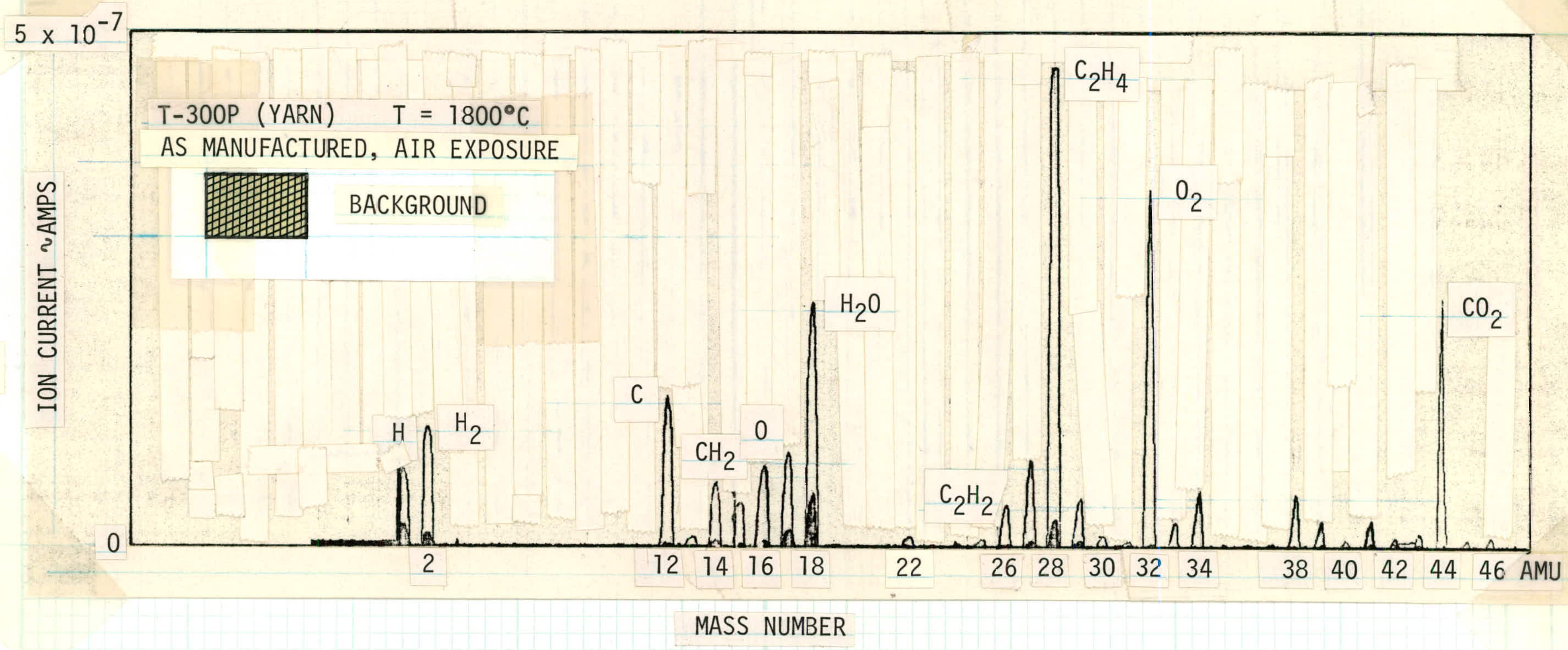


FIGURE 6(b) MASS SPECTROMETER ANALYSIS OF DESORBED GAS ON T-300P YARN AT T=1800°C

MCDONNELL DOUGLAS CORPORATION

APPENDIX A

This appendix presents a summary of the test data and some calculated results for the performance test of the MDAC designed sodium filled heat pipe in the presence of a magnetic field. The MDRL magnet facility, capable of generating a uniform field of up to 1 Tesla, was used. Included in the table of Figure A-1 are:

1. Heat pipe orientation
2. Heater input power to the evaporator section
3. Insulation thickness around the condenser section
4. Magnetic field strength in the direction transverse to the heat pipe axis
5. Temperature readings along the surface of the heat pipe.
6. Power transmitted to the condenser section computed from the condenser cooling water temperature rise
7. Heat losses from the heater section computed from the cooling sleeve water temperature rise.
8. Calculated additional heat losses from the test fixture

CASE	HEAT PIPE ORIENT. FROM HORIZ. (DEG.)	HEATER POWER (WATTS)	INSULAT. THICK. AROUND CONDENSR SECTION (MIL)	MAGNETIC FIELD STRENGTH (TESLA)	HEAT PIPE SURFACE TEMPERATURES (°F) — HEATER SECTION TC-1	TC-2	TC-3	TC-4	TC-5	TC-6	ADIABATIC SECTION TC-7	TC-8	CONDENSR SECTION TC-9	HEAT PIPE POWER FROM CONDENSER SECTION ΔT_{COOL} (°C)	$\dot{m}_{COOL}$ (GM/SEC.)	$\dot{q}$ (WATTS)	HEAT LOSSES — MEASURED FROM HEATER COOLING SLEEVE ΔT_{COOL} (°C)	$\dot{m}_{COOL}$ (GM/SEC)	$\dot{q}$ (WATTS)	ADDTNL. CALC. $\dot{q}$ (WATTS)	TOTAL LOSSES (WATTS)
1-A	0	334	23.0	0.0	1078	1077	1074	1075	1075	1042	1032	1032	1026	4.5	11.97	225	-	-	52*	50	102
1-B	↓	↓	↓	1.0	1100	1098	1093	1098	1098	1091	1053	1053	1045	4.5	11.97	225	-	-	53*	52	105
1-C	71	↓	↓	0.0	1105	1101	1100	1101	1101	1098	1065	1065	1039	3.1	15.40	220	-	-	53*	53	106
1-D	↓	↓	↓	1.0	1109	1105	1101	1106	1106	1099	1069	1069	1042	3.1	15.40	200	-	-	53*	54	107
1-E	90	↓	↓	0.0	1102	1101	1099	1101	1100	1098	1067	1064	1045	3.0	15.29	192	-	-	53*	53	106
1-F	↓	↓	↓	1.0	1112	1111	1105	1111	1111	1105	1079	1072	1055	3.0	15.29	192	-	-	54*	55	109
1-G	↓	↓	↓	0.0	1178	1174	1171	1175	1175	1170	1144	1141	1119	3.8	15.29	243	-	-	58*	40	98
1-H	↓	↓	↓	1.0	1183	1181	1177	1182	1183	1177	1149	1147	1128	3.8	15.29	243	-	-	58*	41	99
2-A	71	303	14.5	0.0	1000	1002	1001	1005	990	992	945	946	884	2.975	14.56	181	1.325	8.09	45	43	88
2-B	↓	303	↓	0.0	1018	1019	1019	1021	1011	1004	970	982	927	3.075	14.56	187	1.425	8.09	48	43	91
2-C	↓	334	↓	0.0	1100	1100	1099	1100	1100	1094	1065	1069	1037	3.450	14.56	210	1.575	8.09	53	44	97
2-D	↓	367	↓	0.0	1172	1173	1169	1173	1173	1167	1139	1141	1110	3.800	14.84	236	1.700	8.15	58	45	103
2-E	↓	408	↓	0.0	1234	1233	1230	1235	1235	1228	1200	1203	1170	4.250	14.84	264	1.700	8.15	58	45	103
2-F	↓	408	↓	0.0	1272	1272	1267	1270	1271	1267	1230	1239	1204	4.325	14.84	268	1.775	8.15	60	46	106
2-G	↓	453	↓	0.0	1358	1358	1350	1355	1355	1350	1311	1321	1286	4.775	14.84	296	1.950	8.15	67	47	114
2-H	↓	498	↓	0.0	1450	1450	1442	1447	1447	1443	1400	1410	1377	5.300	14.81	328	2.125	8.15	73	49	122
2-I	↓	498	↓	0.5	1447	1446	1440	1442	1442	1440	1397	1407	1373	5.300	14.81	328	2.200	8.15	75	49	124
2-J	↓	498	↓	1.0	1445	1446	1435	1440	1442	1436	1393	1406	1373	5.250	14.81	325	2.100	8.15	72	49	121
2-K	↓	534	↓	0.0	1471	1471	1464	1470	1470	1465	1422	1432	1400	5.450	14.81	338	2.150	8.15	73	49	122
2-L	↓	534	↓	0.0	1498	1500	1489	1494	1496	1490	1446	1457	1420	5.600	14.81	347	2.125	8.15	73	50	123
2-M	↓	573	↓	0.0	1535	1535	1526	1532	1531	1528	1481	1496	1455	5.85	14.81	362	2.200	8.15	75	50	125
2-N	↓	573	↓	0.0	1561	1562	1551	1559	1560	1552	1509	1519	1479	6.05	14.81	375	2.175	8.15	74	51	125
3-A	71	533	0.0	0.0	-	1136	1122	1127	1127	1108	-	1086	1052	6.1	14.93	381	2.075	6.20	54	22	76
3-B	↓	572	↓	0.0	-	1187	1172	1176	1182	1160	-	1139	1109	6.7	14.93	418	2.225	6.20	58	22	80
3-C	↓	615	↓	0.0	-	1230	1212	1217	1217	1202	-	1179	1152	7.4	14.93	462	2.475	6.20	64	22	86
3-D	↓	615	↓	1.0	-	1230	1212	1217	1217	1202	-	1179	1152	7.4	14.93	462	2.475	6.20	64	22	86

* ESTIMATED FROM CASES 2 AND 3.

FIGURE A-1 SUMMARY OF SODIUM-FILLED HEAT PIPE TEST TEST DATA IN MDRL MAGNET FACILITY

MCDONNELL DOUGLAS CORPORATION