https://ntrs.nasa.gov/search.jsp?R=19660008892 2020-03-16T23:33:10+00:00Z

ADVANCED TECHNOLOGY LABORATORIES

N66-18181 (ACCESSION NUMBER)
204 (PAGES)
CR-65233 (NASA CR OR TMX OR AD NUMBER)
(THRU)
1 (CODE)
15 (CATEGORY)
FACILITY FORM 602

GPO PRICE $
CFSTI PRICE(S) $
Hard copy (HC) 6.00
Microfiche (MF) 1.25
ff 653 July 65

Technical Report No. 1

EVALUATION OF THIN WALL SPACECRAFT WIRING

Volume II: Test Results

BY

L. J. FRISCO
K. N. MATHES

JULY 28, 1965

LIBRARY COPY
NOV 30 1965
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

GENERAL ELECTRIC

TECHNICAL REPORT NO. 1

EVALUATION OF THIN WALL SPACECRAFT ELECTRICAL WIRING

VOLUME II: TEST RESULTS AND FACILITIES

July 28, 1965

Contract No. NAS 9-4549
Control No. 509-0022

Report Prepared by:

L.J. Frisco
K.N. Mathes

Advanced Technology Laboratories
General Electric Company
Schenectady 5, N.Y.

Report Prepared for:

NASA
Manned Spacecraft Center
Houston, Texas

Tests Conducted By:

J.M. Atkins
Q.L. Barton
P.H. Brisbin
G.P. Brown
J.R. Gambino
R.L. Gingrich
R.W. Hardt
W.J. Heffernan
L.J. Hogue
E.J. McGowan
W.V. Olszewski
G.P. Schacher
M.A. Spodnewski
W.T. Starr
J. Wormuth

Volume II

Test Results

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Cont'd)

LIST OF TABLES (Cont'd)

LIST OF FIGURES

III. DESCRIPTION OF TEST SAMPLES

Wire No. 1

Extruded FEP nominal 5 mils with ML coating. #20 nickel plated copper 19/32 strands.

Wire No. 2

Extruded 7 mil TFE with ML coating. #20 nickel plated copper 1/32 strands.

Wire No. 3

Double wrap H-film. First wrap: ½ lap HF tape (1 mil H, ½ mil FEP); second wrap: 1/3 lap FHF tape (½ mil FEP, 1 mil H, ½ mil FEP). 6 mil wall with ½ mil TFE dispersion overcoat with red pigment. #20 nickel plated copper 19/32 strands.

Wire No. 4

Single wrap H-film. ½ lap HF tape (1 mil H, ½ mil FEP) 3 mil wall. #20 nickel plated copper 19/32 strands.

Wire No. 5

Single wrap H-film. ½ lap FHF tape (½ mil FEP, 1 mil H, ½ mil FEP) 4 mil wall. #20 nickel plated copper 19/32 strands.

Wire No. 6

Double wrap H-film. First wrap: ½ lap HF tape (1 mil H, ½ mil FEP), second wrap: ½ lap FHF tape (½ mil FEP, 1 mil H, ½ mil FEP) with ½ mil TFE dispersion overcoat. #20 silver plated copper 19/32 strands.

Wire No. 7

Irradiated modified polyolefin 9.3 mils with polyvinylidene fluoride jacket. #20 tin plated copper 19/32 strands.

Wire No. 8

Irradiated modified polyolefin 9.2 mils. #20 tin plated copper 19/32 strands.

Wire No. 9

Type E TFE per MIL-W-16878D, 9.5 mils. #20 nickel plated copper 19/32 strands.

Wire No. 10

Single wrap H-film. 2/3 lap 3 layers of HF tape (1 mil H, ½ mil FEP). #20 nickel plated copper 19/32 strands.

Wire No. 11

Single wrap H-film. ½ lap 2 layers of ½ mil H-film with 2.5 mil TFE over-wrap. #20 nickel plated copper 19/32 strands.

Wire No. 12

Silicone rubber SE-9029 insulation. Wire has not been received. Will be described in detail in Final Report.

Wire No. 13

Silicone rubber (SE-9029) with polyvinylidene fluoride jacket. Wire has not been received. Will be described in detail in Final Report.

Wire No. 14

Silicone rubber (SE-9029) with overwrap of H-film. Wire has not been received. Will be described in detail in Final Report.

IV. TEST DATA

1. Insulation Resistance - Total Sample

The results of the insulation resistance measurement on immersed spools of wire are given in Tables I to X. The values are given in units of ohms per 1000 feet for each spool of wire. The wire was packaged with one piece per spool.

The first observation that should be made is that most of the samples were supplied in several short lengths This makes it appear, of course, that the wire manufacturers could not produce continuous lengths of 1000 to 1200 feet that would pass the immersion test. The other possible explanation is that the samples consisted of odds and ends that were accumulated in regular production runs. The reason for the apparent inability to maintain acceptable quality on long lengths should be determined before procurement specifications are established. In particular, it should be determined if the spark test and subsequent insulation resistance (3-day water immersion) followed by a 1600 volt withstand test are too severe in light of the present production capabilities and the actual application requirements.

The insulation resistance values are shown for 1 minute and 5 minute electrification times. In general, if there is no water penetration due to a defect, the five minute value will be somewhat higher than the one minute value. Sensitive measurements show this to be true even for a high resistivity, low-loss material such as TFE (see Table VIII). In spite of the increased electrification time, which allows transient absorption currents to decay, several specimens did not pass the acceptance criterion of 3×10^{10} ohms per 1000 feet. Here again, consideration should be given to the severity of the test. Because of the difficulty encountered in obtaining samples that could pass this test, instructions were received from NASA to proceed with further evaluation of all wires despite their failure to pass the acceptance tests.

On specimen of each wire sample was tested more thoroughly at the end of the 3-day immersion to determine the resistance vs. time of voltage application (current decay) characteristics. The precise interpretation of such measurements for the subject specimens and test conditions (water immersion) are complex, but the observed changes do give an indication of the dielectric losses at very low frequencies. Such "absorption" measurements can be used as a figure of merit in the absence of data on a-c properties. They are sometimes useful in interpreting other observed behavior in terms of impurities, cure, or other processing variables.

In cases such as Wires #4 and 5, where the insulation resistance decreased continuously over the three day period, it is evident that moisture is being absorbed.

Further evidence is provided by the absorption measurements, which show no large change in resistance after 20 minutes, even though the values are low at the outset. This indicates ionic conductivity caused by water absorption.

TABLE I

INSULATION RESISTANCE - TOTAL SAMPLE

Wire #1

Length feet	Resistance per 1000 ft. (ohms) 1 Hour
406	6.9×10^5
610	7.9×10^5
145	1.2×10^{11}

Wire returned to vendor.

Retest

Length feet	Resistance per 1000 ft. (ohms) 1 Hour 1 minute	1 Day 1 min.	1 Day 5 min.	3 Days 1 min.	3 Days 5 min.
100	1.3×10^{11}	3.3×10^{10}	6.7×10^{10}	1.3×10^{10}	3.3×10^{10}
100	1.3×10^{11}	1.7×10^{10}	7.1×10^{10}	2.5×10^{10}	3.6×10^{10}
100	7.5×10^{10}	5.6×10^{10}	1.3×10^{11}	2.3×10^{10}	7.8×10^{10}
145	1.4×10^{11}	6.5×10^{10}	3.8×10^{11}	7.2×10^{10}	2.8×10^{11}
43	2.5×10^{11}	———	2.6×10^{11}	6.9×10^{10}	5.6×10^{11}
56	2.0×10^{11}	9.6×10^9	1.3×10^{10}	4.0×10^9	5.6×10^9
56	1.7×10^{11}	2.8×10^{10}	4.2×10^{10}	1.0×10^{10}	1.2×10^{10}

Resistance vs. Time of Applied Voltage

Length - 43 feet

Time Minutes	I.R. ohms/1000 ft.	Time Minutes	I.R. ohms/1000 ft.
1	6.9×10^{10}	8	1.2×10^{12}
2	1.7×10^{11}	9	9.0×10^{11}
3	3.6×10^{11}	10	1.2×10^{12}
4	4.7×10^{11}	12	1.8×10^{12}
5	5.6×10^{11}	13	1.2×10^{12}
6	7.6×10^{11}	15	1.9×10^{12}
7	1.4×10^{12}		

TABLE II

INSULATION RESISTANCE - TOTAL SAMPLE

Wire #3

	Resistance per 1000 feet (ohms) (measured after 1 minute)		
Length (ft.)	1 Hour	1 Day	3 Days
40	8.7×10^{10}	1.8×10^{11}	1.2×10^{11}
83	3.0×10^{10}	4.2×10^{10}	5.2×10^{10}
58	6.7×10^{10}	1.5×10^{11}	9.3×10^{10}
220	7.8×10^{10}	1.5×10^{11}	1.2×10^{11}
412	9.8×10^{10}	7.8×10^{10}	1.2×10^{11}
432	6.8×10^{10}	2.9×10^{11}	1.4×10^{11}

Resistance vs. Time of Applied Voltage

Length - 40 feet

Time (minutes)	I.R. ohms/1000 ft.
1	1.2×10^{11}
2	2.4×10^{11}
3	4.8×10^{11}
5	9.2×10^{11}
8	1.3×10^{12}
12	1.8×10^{12}
17	1.8×10^{12}
25	2.0×10^{12}

TABLE III

INSULATION RESISTANCE - TOTAL SAMPLE

Wire #4

Resistance per 1000 ft. (ohms)

Length feet	1 Hour 1 Minute	1 Day 1 min.	1 Day 5 min.	3 Days 1 min.	3 Days 5 min.
944	3.4×10^{9}	1.0×10^{8}	3.6×10^{8}	1.8×10^{7}	2.6×10^{7}
253	3.9×10^{9}	2.4×10^{9}	8.4×10^{9}	8.6×10^{7}	1.1×10^{8}
60	2.7×10^{9}	4.1×10^{9}	1.7×10^{10}	2.2×10^{8}	3.0×10^{8}

Resistance vs. Time of Applied Voltage

Length - 253 feet

Time (minutes)	I.R. (ohms/1000 ft.)
1	8.6×10^{7}
2	9.6×10^{7}
4	1.1×10^{8}
9	1.2×10^{8}
20	1.3×10^{8}

TABLE IV

INSULATION RESISTANCE - TOTAL SAMPLE

Wire #5

Resistance per 1000 ft. (ohms)

Length feet	1 Hour 1 minute	1 Day 1 min.	1 Day 5 min.	3 Days 1 min.	3 Days 5 min.
150	2.4×10^{10}	1.1×10^{10}	2.8×10^{10}	1.9×10^{8}	2.5×10^{8}
52	2.4×10^{10}	1.5×10^{10}	5.0×10^{10}	4.3×10^{8}	5.2×10^{8}
188	2.5×10^{10}	2.6×10^{10}	5.5×10^{10}	6.0×10^{8}	8.1×10^{8}
51	1.4×10^{10}	8.2×10^{9}	1.8×10^{10}	1.1×10^{8}	2.6×10^{7}
233	1.5×10^{10}	1.8×10^{9}	4.4×10^{9}	1.8×10^{7}	2.6×10^{7}
217	2.1×10^{10}	9.8×10^{9}	3.0×10^{10}	5.4×10^{8}	8.5×10^{8}
245	1.5×10^{10}	1.0×10^{10}	3.7×10^{10}	3.7×10^{8}	4.9×10^{8}

Resistance vs. Time of Applied Voltage

Length - 188 feet

Time (minutes)	I.R. ohms/1000 ft.
1	6.0×10^{8}
2	7.0×10^{8}
3	7.3×10^{8}
5	8.1×10^{8}
10	9.0×10^{8}
20	9.8×10^{8}

TABLE V

INSULATION RESISTANCE - TOTAL SAMPLE

Wire #6

Length feet	Resistance per 1000 ft. (ohms) 1 Hour 1 Minute	1 Day 1 Minute	3 Days 1 min.	3 Days 5 min.
55	5.8×10^{10}	8.8×10^{10}	3.9×10^{10}	1.4×10^{11}
548	5.6×10^{10}	3.5×10^{10}	1.6×10^{10}	4.2×10^{10}
570	5.7×10^{10}	5.7×10^{10}	2.4×10^{10}	8.0×10^{10}

Resistance vs. Time of Applied Voltage

Length - 548 feet

Time (Minutes)	I.R. ohms/1000 ft.
1	1.6×10^{10}
2	2.6×10^{10}
3	3.3×10^{10}
5	4.2×10^{10}
8	5.4×10^{10}
11	6.6×10^{10}
15	7.7×10^{10}
20	8.8×10^{10}
28	1.8×10^{11}

TABLE VI

INSULATION RESISTANCE - TOTAL SAMPLE

Wire #7

Length feet	1 Hour 1 Minute	1 Day 1 min.	1 Day 5 min.	3 Days 1 min.	3 Days 5 min.
275	2.3×10^{10}	3.3×10^{10}	1.5×10^{11}	2.3×10^{10}	7.1×10^{10}
365	1.8×10^{10}	2.9×10^{10}	8.8×10^{10}	2.3×10^{10}	5.8×10^{10}
252	1.3×10^{10}	4.8×10^{10}	1.7×10^{11}	1.9×10^{10}	4.3×10^{10}

Resistance per 1000 ft. (ohms)

Resistance vs. Time of Applied Voltage

Length - 275 feet

Time (Minutes)	I.R. ohms/1000 ft.
1	2.3×10^{10}
2	3.6×10^{10}
3	4.9×10^{10}
5	7.1×10^{10}
7	9.1×10^{10}
11	1.2×10^{11}
15	1.6×10^{11}
20	2.0×10^{11}
25	2.5×10^{11}

TABLE VII

INSULATION RESISTANCE - TOTAL SAMPLE

Wire #8

Length feet	1 Hour 1 Minute	Resistance per 1000 ft. (ohms) 1 Day 1 min.	1 Day 5 min.	3 Days 1. min.	3 Days 5 min.
892	1.3×10^{10}	2.1×10^{10}	7.9×10^{10}	1.4×10^{10}	6.8×10^{10}

Resistance vs. Time of Applied Voltage

Length - 892 feet

Time (Minutes)	I.R. ohms/1000 ft.
1	1.4×10^{10}
2	2.9×10^{10}
3	4.2×10^{10}
5	6.8×10^{10}
7	8.9×10^{10}
10	1.2×10^{11}
15	1.9×10^{11}
20	2.4×10^{11}
25	3.0×10^{11}

TABLE VIII

INSULATION RESISTANCE - TOTAL SAMPLE

Wire #9

Length (ft.)	Resistance per 1000 feet (ohms) (measured after 1 minute) 1 Hour	1 Day	3 Days
158	3.2×10^{11}	1.2×10^{12}	9.2×10^{11}
172	4.3×10^{11}	8.8×10^{11}	1.8×10^{11}
71	1.8×10^{11}	3.0×10^{11}	3.5×10^{11}
82	2.1×10^{11}	2.2×10^{11}	3.0×10^{11}
126	6.3×10^{11}	1.5×10^{12}	7.1×10^{11}
100	8.2×10^{10}	1.4×10^{11}	1.6×10^{11}
115	3.0×10^{11}	4.5×10^{11}	3.8×10^{11}
22	4.6×10^{11}	6.8×10^{11}	3.7×10^{11}
68	2.7×10^{11}	3.1×10^{11}	2.9×10^{11}
160	3.3×10^{11}	7.3×10^{11}	6.8×10^{11}

Resistance vs. Time of Applied Voltage

Length - 100 feet

Time (Minutes)	I.R. ohms/1000 ft.
½	1.52×10^{11}
1	1.56×10^{11}
2	1.79×10^{11}
3	2.27×10^{11}
5	4.17×10^{11}
7	7.58×10^{11}
10	1.39×10^{12}
13	1.92×10^{12}
17	2.63×10^{12}
20	3.45×10^{12}

TABLE IX

INSULATION RESISTANCE - TOTAL SAMPLE

Wire # 10

Resistance per 1000 ft. (ohms)

Length feet	1 Hour 1 min.	1 Hour 5 min.	1 Day 1 min.	1 Day 5 min.	3 Days 1 min.	3 Days 5 min.
274	4.1×10^{10}	7.1×10^{10}	2.4×10^{10}	3.8×10^{10}	7.7×10^{9}	1.5×10^{10}
75	3.6×10^{10}	9.8×10^{10}	1.2×10^{10}	4.1×10^{10}	7.2×10^{9}	1.4×10^{10}
434	4.8×10^{10}	9.1×10^{10}	8.3×10^{9}	2.0×10^{10}	8.7×10^{8}	8.7×10^{8}
311	4.7×10^{10}	8.7×10^{10}	3.1×10^{10}	5.6×10^{10}	7.4×10^{9}	1.6×10^{10}
50	3.5×10^{10}	8.0×10^{10}	1.3×10^{10}	2.9×10^{10}	5.0×10^{9}	1.1×10^{10}

Resistance vs. Time of Applied Voltage

Length - 274 feet

Time (minutes)	I.R. ohms/1000 ft.
1	7.7×10^{9}
2	1.1×10^{10}
3	1.2×10^{10}
4	1.4×10^{10}
5	1.5×10^{10}
8	2.1×10^{10}
10	2.2×10^{10}
13	2.5×10^{10}
15	2.6×10^{10}

TABLE X

INSULATION RESISTANCE - TOTAL SAMPLE

Wire #11

Length feet	Resistance per 1000 ft. (ohms) 1 Hour 1 min.	1 Hour 5 min.	1 Day 1 min.	3 Days 1 min.	3 Days 5 min.
300	$< 3 \times 10^4$	removed from test			
402	"	"			
52	2.6×10^{10}	9.4×10^{10}	1.5×10^{11}	1.5×10^{11}	4.9×10^{11}
371	failed on test				

Returned to vendor

Retest

Length feet*	Resistance per 1000 ft. (ohms) 1 Hour 1 min.	1 Hour 5 min.	1 Day 1 min.	1 Day 5 min.	3 Days 1 min.	3 Days 5 min.
402	1.5×10^{10}	8.0×10^{10}	3.8×10^{9}	4.9×10^{9}	intermittant	short
300	2.1×10^{10}	9.3×10^{10}	4.2×10^{10}	1.8×10^{11}	4.2×10^{10}	1.4×10^{11}
371	1.9×10^{10}	9.3×10^{10}	2.2×10^{10}	9.6×10^{10}	3.7×10^{10}	1.6×10^{11}

Resistance vs. Time of Applied Voltage

Length - 371 feet*

Time (Minutes)	I.R. ohms/1000 ft.
0.5	2.0×10^{10}
1	3.7×10^{10}
2	7.0×10^{10}
3	9.6×10^{10}
5	1.6×10^{11}
8	2.3×10^{11}
10	2.6×10^{11}
15	3.7×10^{11}

*footage marked on spools returned after respooling by vendor. Same footage as returned.

Failure in original sample appeared to be the result of mechanical damage to inside wire ends caused by improper packaging.

2. Voltage Withstand

The voltage withstand test consists of applying an alternating voltage of 1600 volts for a period of one minute at the conclusion of the insulation resistance measurements. The specimens remain immersed in water, and the voltage is applied between the water and the wire conductor.

The results are summarized in Table XI. Half of the samples (wire types) passed the test. The other samples exhibited one or more failures. It should be noted that Wire No. 1 (ML coated FEP) had been rejected because it failed the insulation resistance test. The defects were removed by the manufacturer and approximately half of the original sample was resubmitted for further evaluation. The results shown in Table XI indicate that 5 of the 7 reels that were returned failed the voltage withstand test.

After encountering numerous failures, it was agreed that the voltage withstand test would not be used as a criterion for acceptance in the evaluation program.

TABLE XI

Voltage Withstand Test
(1600 volts rms for 1 minute)

Wire #	Length (feet)	Observation
1	56	Intermittent failure
	43	No failure
	56	Failed after 50 sec.
	145	Failed after 15 sec.
	100	Failed after 4 sec.
	100	Failed immediately at 1600 volts
	100	No failure
3	---	No failure
4	60	No failure
	944	Failed at 1000 V.
	253	No failure
5	---	No failure
6	---	No failure
7	---	No failure
8	---	No failure
9	158	No failure
	172	No failure
	71	No failure
	82	No failure
	126	No failure
	100	No failure
	115	No failure
	22	No failure
	68	No failure
	160	Failed immediately at 1600V. Failure removed. Two remaining pieces passed 1600 volt test.
10	---	No failure
11	402	Failed
	300	No failure
	371	No failure

3. Insulation Resistance - Cabled Specimen

Cabled specimens were aged for 15 days at 50°C in 15 psia oxygen at 100% RH + dew, as described in Section III-3. Insulation resistance measurements (one minute electrification) were made after exposure for 1 hour, 8 hours, 1, 2, 5 and 15 days. The results are summarized in Table XII.

Excellent agreement among specimens of the same wire was obtained. The results are in line with the immersion tests of the previous section, where Wires #4 and 5 showed adverse effects of moisture absorption. The decreases in insulation resistance exhibited by these wires during exposure to wet oxygen are caused by moisture, rather than the high concentration of oxygen at 50°C.

In general, the taped constructions (Wires 3, 4, 5, 6 and 10) showed significant decreases in insulation resistance, while the extruded wires (7, 8 and 9) were unaffected.

TABLE XII

INSULATION RESISTANCE - CABLED SAMPLES (OHMS)

Specimen Number	Time in Wet Oxygen at 50C					
	1 Hour	8 Hours	1 Day	2 Days	5 Days	15 Days
Wire 3-1	2.8×10^{13}	1.9×10^{13}	1.9×10^{13}	1.6×10^{13}	1.1×10^{13}	7.4×10^{12}
-2	3.6×10^{13}	1.7×10^{13}	1.9×10^{13}	1.4×10^{13}	1.3×10^{13}	1.1×10^{13}
-3	4.8×10^{13}	2.9×10^{13}	1.9×10^{13}	1.9×10^{13}	1.4×10^{13}	1.1×10^{13}
-4	5.3×10^{13}	1.8×10^{13}	2.0×10^{13}	1.4×10^{13}	1.1×10^{13}	7.6×10^{12}
Wire 4-1	4.0×10^{13}	1.9×10^{11}	3.7×10^{10}	3.0×10^{10}	2.2×10^{10}	2.0×10^{10}
-2	3.2×10^{13}	1.4×10^{11}	1.6×10^{10}	1.6×10^{10}	1.2×10^{10}	1.0×10^{10}
-3	2.6×10^{13}	1.7×10^{11}	3.9×10^{10}	2.8×10^{10}	2.9×10^{10}	2.8×10^{10}
-4	3.3×10^{13}	9.6×10^{11}	8.6×10^{10}	7.5×10^{10}	6.9×10^{10}	8.1×10^{10}
Wire 5-1	1.0×10^{14}	8.2×10^{11}	4.0×10^{10}	3.9×10^{10}	3.5×10^{10}	3.3×10^{10}
-2	5.4×10^{13}	2.6×10^{11}	3.5×10^{10}	3.8×10^{10}	3.7×10^{10}	3.3×10^{10}
-3	8.9×10^{13}	1.1×10^{12}	5.0×10^{10}	5.8×10^{10}	3.6×10^{10}	3.6×10^{10}
-4	1.0×10^{14}	2.9×10^{11}	5.6×10^{10}	5.8×10^{10}	6.3×10^{10}	4.5×10^{10}
Wire 6-1	1.4×10^{13}	1.9×10^{13}	2.4×10^{12}	9.6×10^{11}	9.6×10^{11}	1.1×10^{12}
-2	3.3×10^{13}	1.8×10^{13}	2.9×10^{12}	1.0×10^{12}	8.2×10^{11}	7.8×10^{11}
-3	2.4×10^{13}	2.0×10^{13}	3.5×10^{12}	1.1×10^{12}	1.0×10^{12}	1.1×10^{12}
-4	2.0×10^{13}	2.1×10^{13}	3.6×10^{12}	1.1×10^{12}	7.0×10^{11}	7.1×10^{11}

Specimen Number	1 Hours	8 Hours	1 Day	3 Days	15 Days
Wire 7-1	2.2×10^{13}	2.2×10^{13}	2.5×10^{13}	3.1×10^{13}	2.9×10^{13}
-2	1.5×10^{13}	2.3×10^{13}	1.1×10^{13}	2.0×10^{13}	1.9×10^{13}
-3	1.3×10^{13}	1.6×10^{13}	1.3×10^{13}	1.0×10^{13}	1.0×10^{13}
-4	9.8×10^{12}	1.9×10^{13}	2.0×10^{13}	1.8×10^{13}	1.4×10^{13}
Wire 8-1	8.3×10^{12}	2.9×10^{12}	9.3×10^{12}	9.3×10^{12}	1.5×10^{13}
-2	$>10^{14}$	1.4×10^{13}	1.0×10^{13}	1.0×10^{13}	1.4×10^{13}
-3	2.9×10^{13}	1.4×10^{13}	1.4×10^{13}	1.5×10^{13}	1.5×10^{13}
-4	2.2×10^{13}	1.2×10^{13}	1.2×10^{13}	1.3×10^{12}	1.3×10^{13}

TABLE XII (Cont'd)

Specimen Number	1 Hour	8 Hours	1 Day	3 Days	15 Days
Wire 9-1	$>10^{14}$	$1.4x10^{14}$	$5.2x10^{13}$	$8.3x10^{13}$	$1.9x10^{14}$
-2	$>10^{14}$	$5.7x10^{13}$	$5.6x10^{13}$	$8.6x10^{13}$	$2.1x10^{14}$
-3	$>10^{14}$	$6.9x10^{13}$	$5.0x10^{13}$	$1.2x10^{14}$	$1.9x10^{14}$
-4	$>10^{14}$	$3.6x10^{13}$	$5.0x10^{13}$	$1.7x10^{14}$	$5.0x10^{14}$

Specimen Number	1 Hour	8 Hours	1 Day	2 Days	5 Days	15 Days
Wire 10-1	$1.9x10^{13}$	$6.1x10^{12}$	$2.0x10^{12}$	$1.5x10^{12}$	$1.0x10^{12}$	$5.7x10^{11}$
-2	$3.6x10^{13}$	$4.8x10^{12}$	$1.7x10^{12}$	$1.4x10^{12}$	$1.1x10^{12}$	$4.8x10^{11}$
-3	$7.8x10^{12}$	$4.5x10^{12}$	$2.0x10^{12}$	$1.6x10^{12}$	$1.0x10^{12}$	$5.7x10^{11}$
-4	$3.3x10^{13}$	$4.5x10^{12}$	$1.7x10^{12}$	$1.3x10^{12}$	$8.6x10^{11}$	$4.7x10^{11}$

4. Corona Measurements

Corona inception voltage (c.i.v.) and corona extinction voltage (c.e.v.) was measured on the cabled specimens that were aged in wet oxygen at 15 psia for 15 days in the insulation resistance tests. The measurements were made in wet oxygen at 15 psia and a dry oxygen at 5 psia.

Corona measured in wet conditions seeks out faults and makes them evident. Whenever the corona extinction voltage drops far below corona inception voltage a fault is indicated. In this test, the c.e.v. may sometimes be observed to climb above the c.i.v. The distribution of moisture is altered by the corona itself. This is taken as evidence of a good sample especially when the c.i.v. and c.e.v.'s are both high. Extreme variability of either the c.e.v. or c.i.v. is a bade indication only when some of the values are very low. The variability may be due to the particular way the moisture droplets lie on the surface of the particular sample.

The corona inception voltage and the corona extinction voltage are measured in a way that would naturally tend to make c.e.v.'s lower than c.i.v.'s. The corona inception voltage is the minimum voltage (with increasing voltage) at which continuous corona is noted. The corona extinction voltage is the maximum voltage (with decreasing voltage) at which sporadic corona is noted. The sporadic corona is judged to have ceased when none appears in a 10 second time interval. Therefore, when the c.e.v. is higher than the c.i.v., a definite change in the specimen has occurred due to the presence of corona.

Corona is known to be an extremely effective drying agent. It distorts water droplets and sprays them off the surface. Thus in Table XIII, when we note that for specimens #4 and #6 that c.e.v.'s are higher than c.i.v.'s, this is taken as evidence of drying due to corona.

The measurements in dry oxygen at 5 psia (Table XIV) are much more reproducible and, of course, indicate reduced inception and extinction voltages.

In comparing different wire samples, the insulation wall thicknesses must be considered because the voltage at which the critical field strength exists is a fraction of geometry. The average thicknesses are as follows:

Wire #	Wall Thickness (mils)
3	7.1
4	3.1
5	3.4
6	5.5
7	9.2
8	9.2
9	9.4
10	3.5

The poor showing of wires 4, 5, and 10 are probably associated with their thin walls. With wire #8, however, the two values of c.e.v. (500 and 600 V) in Table XII are the result of faults in the relatively thick wall. In general, the results correlate with insulation thickness and the values are high for such thin wall insulation.

The low values of c.e.v. at 5 psia are extremely important in applications where alternating voltages exceeding 400 volts are contemplated. At lower pressures the c.e.v. would be reduced even further because of decreased gas density.

TABLE XIII

CORONA MEASUREMENTS IN WET OXYGEN AT 15 PSIA, 23°C

Corona Inception Voltage

Wire 3	Wire 4	Wire 5	Wire 6	Wire 7	Wire 8	Wire 9	Wire 10
1120	550	800	1250	7000	1250	900	900
1240	550	650	1000	1700	2000	1300	770
1400	550	700	850	1900	1600	1500	800
1150	500	800	1400	1250	1900	1800	1100

Corona Extinction Voltage

Wire 3	Wire 4	Wire 5	Wire 6	Wire 7	Wire 8	Wire 9	Wire 10
1120	700	700	1400	1800	500*	900	850
1120	770	650	1150	1650	1500	1200	750
1100	700	700	1300	1650	600*	1100	750
1300	500	750	800	1100	1500	1600	1100

*Very dense corona pattern suggesting a partial breakdown.

TABLE XIV

CORONA MEASUREMENTS IN DRY OXYGEN AT 5 PSIA O_2 23C

Corona Inception Voltage

Wire 3	Wire 4	Wire 5	Wire 6	Wire 9	Wire 10
800	680	600	800	1100	560
900	640	680	850	1120	560
800	620	630	800	1050	700
870	600	600	600	1070	640

Corona Extinction Voltage

Wire 3	Wire 4	Wire 5	Wire 6	Wire 9	Wire 10
750	570	570	750	950	510
750	570	570	750	970	510
750	570	570	750	920	550
750	570	570	730	970	600

5. Dielectric Strength in Wet, 5 Psia Oxygen at 25C

The results of the fast and slow rate of rise tests are given in Tables XV and XVI. Averages and standard deviations have been calculated for each type of wire. These tests are on the wire as received.

Some trouble was experienced with flashover from the clips to the tank on tests of #6 wire. The unfailed specimens were given a second test. The results of the second test were slightly lower than the flashover voltage on the first test as is expected.

Wire #6 exhibited the highest voltage breakdown strength for both the fast and slow rates of rise. In general, the values are lower for the slow rate of rise where more time is allowed for corona attack to occur.

It should be pointed out that the greatest value in the voltage breakdown test lies in its usefulness in detecting faults and degradation. Wire #4, for instance, had one failure at 1.2 KV. This specimen undoubtedly contained a fault, which may have been adjacent hole or a conducting particle opposite a hole. Throughout the program, voltage breakdown tests are used to detect the effects of exposure in various environments. The actual breakdown values, however as shown in Tables XV and XVI, are so high that they have little design significance.

TABLE XV

Voltage Breakdown (KV rms) of Twisted Pairs
in 5 PSIA O_2, Wet, 25°C

Fast Rate of Rise 500 Volts per Sec

	Wire #3	Wire #4	Wire #5	Wire #6 1st Test	Wire #6 2nd Test	Wire #[illegible]
	22.5	12.0	14.5	>23.0	18.0	17.0
	25.0	14.5	13.0	>18.0	21.0	21.0
	25.0	10.5	15.5	>24.5	21.5	15.6
	18.6	13.0	18.0	>24.5	25.0	17.5
	25.0	12.5	17.5	26.5		16.0
	18.5	11.5	17.0	21.5		18.5
	26.5	11.0	14.5	21.0		18.4
	2.4	14.5	13.0	>27.5	23.5	22.6
	16.5	11.2	17.5	23.5		17.0
Mean	22.4	12.3	15.5			18.2
Std. Dev.	3.23	1.31	1.77			2.15

TABLE XVI

Voltage Breakdown (KV rms) of Twisted Pairs
in 5 PSIA O_2, Wet, 23°C

Slow Rate of Rise 100 Volts per Sec.

	Wire #3	Wire #4	Wire #5	Wire #6	Wire #9
	16.0	10.2	11.5	21.0	10.0
	17.2	10.5	14.3	19.0	11.5
	16.5	10.6	15.2	20.0	12.2
	16.5	9.9	14.5	18.2	13.2
	14.0	10.5	12.5	19.6	11.3
	16.5	10.5	12.9	19.7	13.2
	16.7	10.8	16.2	19.5	11.1
	18.0	1.2	13.0	21.6	12.1
	17.0	11.2	16.5	19.5	17.0
Mean	16.5	10.5*	14.1	19.8	11.8** 12.4***
Std. Dev.	0.97	0.34*	15.4	0.90	0.96** 1.79***

* 1.2 value omitted in the calculation.

** 17.0 value omitted in the calculation.

*** 17.0 value included in the calculation.

6. Voltage Flashover

Four replicates of each wire were tested for flashover voltage in 5 psi wet oxygen with a wire wrapped electrode spaced 3/16" from the cut end of the insulation. Test results are summarized in Table XVII.

The test results are well within the variability which might be expected from the inherent inaccuracy in setting the 3/16" creepage distance and small differences in the pressure. Moreover, the flashover voltage of all the wires except for #5 and #6 is the same within the expected variability. No explanation can be offered for the higher values with wires #5 and #6 since flashover voltage should depend more upon the nature of the atmospheric gas and its pressure than on the character of the wire insulation (large differences in dielectric constant or in the insulation thickness could account for such differences but did not exist). While the flashover voltage is higher than the expected operating voltage, it is well within the range of possible overvoltages. Care should be used in spacecraft to keep flashover distances at a maximum and to guard against discontinuities in installed wiring.

Careful observation was maintained but no flame or fire was observed in any of the tests. The absence of combustion is reassuring since in previous programs with somewhat different materials in 15 psi oxygen rapid combustion has taken place.

The tendency for tracking with Ml coatings and with H-film was expected because of the aromatic character of polyimide resin base for these materials. It is interesting that the very thin layer of ML enamel on the track resistant FEP substrate in wire #1 tracks very quickly. TFE Teflon (wire #9), however, never tracks as would be expected on the basis of previous experience. Even the relatively thin TFE dispersion coating on wire #3 resists tracking to some extent. Unfortunately, the very thin FEP dispersion coating on wire #6 does not appreciably help resistance to tracking.

It should be recognized that tracking is progressive and one established, it very greatly decreases the voltage at which surface dielectric failure takes place. Examination of the H-film taped samples indicated that the black, low resistance, dendritic, paths characteristic of tracking occurred not only on the surface of the wire, but in some cases at the interfaces of the H-film tapes as well.

TABLE XVII

COMPARISON OF WIRES FLASHOVER VOLTAGE

Wire #	Initial Flashover Voltage KV Over 3/16" Spacing 5 psi Wet Oxygen			Comments
	Avg.	Max.	Min.	
1	1.54	1.62	1.44	Tracks quickly.
3	1.51	1.61	1.32	Generally tracks only after repeated flashover.
4	1.48	1.72	1.38	Tracks after several flashovers.
5	1.8	1.92	1.70	Tracks quickly.
6	1.98	1.8	2.15	Tracks quickly.
9	1.58	1.72	1.44	Never tracks -- arc tends to extinguish.

7. Outside Diameter

The outside dimension measurements that were made with a hand micrometer are given in Tables XVIII to XXVII. The average, maximum and minimum values for each of ten specimens is given for each wire. In addition, the average, maximum and minimum for the total samples are also given.

Initial attempts to measure dimensions using x-ray technique have not been successful for x-ray energies down to 60 KVP except for wires 7 and 8 and to a lesser degree wire #3, which has a pigmented dispersion. The results for wires 7 and 8 are given in Table XXVIII.

Arrangements have been made for additional x-ray examination to be made at lower energies. Wires will also be given a metallic coating in an effort to obtain the required contrast between the insulation and the background. Further results will be given in the Final Report.

TABLE XVIII

OUTSIDE DIAMETER (MILS), HAND MICROMETER

Wire #1

Specimen	Average	Maximum	Minimum
1-1	50.57	51.8	49.8
1-2	50.76	51.5	49.8
1-3	49.72	50.3	49.3
1-4	50.38	50.9	49.8
1-5	49.88	50.7	49.6
1-6	50.17	50.7	49.8
1-7	49.80	50.6	49.3
1-8	50.42	50.9	49.3
1-9	50.23	50.7	49.9
1-10	49.69	50.3	49.4

Total Sample

Average	50.16
Maximum	51.8
Minimum	49.3

TABLE XIX

OUTSIDE DIAMETER (MILS), HAND MICROMETER

Wire #3

Specimen

	Average	Maximum	Minimum
3-1	55.43	55.8	54.8
3-2	54.15	54.7	53.7
3-3	54.85	55.8	54.2
3-4	54.07	54.3	53.6
3-5	53.22	55.5	50.0
3-6	53.13	53.8	52.6
3-7	53.50	53.9	52.8
3-8	53.98	54.3	53.6
3-9	54.43	54.8	54.1
3-10	55.08	55.6	54.6

Total Sample

Average	54.18
Maximum	55.8
Minimum	52.6

TABLE XX

OUTSIDE DIAMETER (MILS), HAND MICROMETER

Wire #4

Specimen

	Average	Maximum	Minimum
4-1	46.28	46.8	45.7
4-2	46.45	46.9	46.1
4-3	46.25	46.7	45.7
4-4	46.33	46.7	46.2
4-5	46.52	46.7	46.3
4-6	46.15	46.5	45.9
4-7	45.68	46.0	45.4
4-8	45.70	45.9	45.4
4-9	46.45	46.9	46.2
4-10	45.47	45.8	45.1

Total Sample

Average	46.13
Maximum	46.9
Minimum	45.1

TABLE XXI

OUTSIDE DIAMETER (MILS), HAND MICROMETER

Wire #5

Specimen

	Average	Maximum	Minimum
5-1	46.55	47.0	46.2
5-2	46.48	46.9	45.9
5-3	46.40	46.8	46.1
5-4	46.05	46.3	45.7
5-5	46.45	46.7	46.1
5-6	46.30	46.7	45.9
5-7	48.12	48.6	47.7
5-8	47.57	48.2	47.1
5-9	48.23	48.9	47.1
5-10	46.35	46.9	46.0

Total Sample

Average	46.75
Maximum	46.3
Minimum	45.9

TABLE XXII

OUTSIDE DIAMETER (MILS), HAND MICROMETER

Wire #6

Specimen

	Average	Maximum	Minimum
6-1	51.23	51.6	50.8
6-2	51.75	51.9	51.5
6-3	50.82	51.1	50.5
6-4	50.77	51.2	50.5
6-5	50.72	50.8	50.6
6-6	51.03	51.6	50.4
6-7	50.70	50.9	50.5
6-8	50.95	51.5	50.4
6-9	51.33	51.4	50.1
6-10	50.73	51.1	50.4

Total Sample

Average	51.00
Maximum	51.9
Minimum	50.4

TABLE XXIII

OUTSIDE DIAMETER (MILS), HAND MICROMETER

Wire #7

Specimen

	Average	Maximum	Minimum
7-1	58.37	59.9	57.9
7-2	58.37	58.8	57.7
7-3	58.27	58.8	57.9
7-4	58.47	58.8	58.1
7-5	58.57	59.3	58.0
7-6	58.37	58.7	58.0
7-7	58.55	58.9	58.2
7-8	58.37	58.7	58.1
7-9	58.57	58.9	58.1
7-10	58.63	58.9	58.2

Total Sample

Average	58.45
Maximum	[illegible].9
Minimum	[illegible].7

TABLE XXIV

OUTSIDE DIAMETER (MILS), HAND MICROMETER

Wire #8

Specimen

	Average	Maximum	Minimum
8-1	58.43	58.6	58.0
8-2	58.30	58.8	57.6
8-3	58.57	58.7	58.3
8-4	58.42	58.8	58.1
8-5	58.57	59.0	58.3
8-6	58.35	58.7	58.1
8-7	58.52	58.7	58.3
8-8	58.50	58.9	58.2
8-9	58.46	58.7	57.9
8-10	58-45	58.7	58.0

Total Sample

Average	58.46
Maximum	59.0
Minimum	57.6

TABLE XXV

OUTSIDE DIAMETER (MILS), HAND MICROMETER

Wire #9

Specimen

	Average	Maximum	Minimum
9-1	59.00	59.3	58.6
9-2	59.20	59.4	58.9
9-3	58.72	59.1	58.1
9-4	58.58	59.2	57.9
9-5	58.53	59.0	58.1
9-6	59.03	59.5	58.5
9-7	58.57	59.4	57.9
9-8	58-35	58.9	57.9
9-9	59.05	59.4	58.4
9-10	58.88	59.4	58.5

Total Sample

Average	58.79
Maximum	59.5
Minimum	57.9

TABLE XXVI

OUTSIDE DIAMETER (MILS), HAND MICROMETER

Wire #10

Specimen

	Average	Maximum	Minimum
10-1	47.58	48.1	47.1
10-2	47.12	47.7	46.4
10-3	46.45	46.9	46.2
10-4	46.48	46.9	46.2
10-5	47.42	47.8	47.1
10-6	47.38	47.8	47.1
10-7	46.00	46.3	45.7
10-8	46.65	46.9	46.1
10-9	46.70	47.7	46.3
10-10	47.18	47.7	46.7

Total Sample

Average	46.90
Maximum	48.1
Minimum	45.7

TABLE XXVII

OUTSIDE DIAMETER (MILS), HAND MICROMETER

Wire #11

Specimen

	Average	Maximum	Minimum
11-1	46.55	47.3	45.7
11-2	45.67	46.3	45.2
11-3	46.28	46.6	45.8
11-4	46.17	46.5	45.9
11-5	45.70	46.1	45.5
11-6	45.58	46.0	45.3
11-7	45.68	45.9	45.5
11-8	45.72	46.1	45.5
11-9	46.15	46.5	45.6
11-10	46.18	46.5	45.7

Total Sample

Average	45.97
Maximum	47.3
Minimum	45.2

TABLE XXVIII

OUTSIDE DIAMETER (MILS), X-RAY EXAMINATION WITH MEASURING MICROSCOPE
(Average of 30 Measurements)

<u>Wire #7</u>

Average	59.7 mils
Maximum	64.5 mils
Minimum	55.1 mils

<u>Wire #8</u>

Average	58.4 mils
Maximum	61.8 mils
Minimum	51.6 mils

8. Concentricity

Concentricity calculations based on the measurements made on x-ray photographs have been made for wires 7 and 8. These are summarized in Table XXIX. Similar results will be given for the other wires in a subsequent report.

For each specimen, the concentricity is calculated by dividing the minimum wall thickness by the maximum wall thickness. These two values will usually not be associated with locations that occur opposite each other on the wire. Therefore, the concentricity values can be low just as the result of an overall change in wall thickness over a portion of the wire. In example, if two cross sections were examined and were found to have different, but uniform, wall thicknesses, calculated concentricity would be less than 100% even if each cross section was a perfectly concentric arrangement.

A truer indication of concentricity would result from calculating concentricity for each pair of adjacent wall thickness measurements and reporting average, maximum and minimum values.

9. Conductor Dimensions

Conductor dimensions for wires 7 and 8 are given in Table XXX. Values for the other wires will be given in a subsequent report after improved x-rays are obtained.

TABLE XXIX

CONCENTRICITY (%)

Wire #7

Sample Number		Concentricity (%)
7-1		62.3
7-2		67.4
7-3		71.3
7-4		71.8
7-5		80.3
7-6		79.1
7-7		79.1
7-8		66.9
7-9		57.7
7-10		62.3
	Average	69.8
	Maximum	80.3
	Minimum	57.7

Wire #8

Sample Number		Concentricity (%)
8-1		78.9
8-2		88.7
8-3		71.8
8-4		73.7
8-5		66.9
8-6		65.8
8-7		46.6
8-8		68.0
8-9		58.8
8-10		73.7
	Average	69.3
	Maximum	88.7
	Minimum	46.6

TABLE XXX

CONDUCTOR DIAMETER (mils)
(Average of 30 Measurements)

Wire #7

Average	39.3 mils
Maximum	43.7 mils
Minimum	36.6 mils

Wire #8

Average	39.0 mils
Maximum	40.9 mils
Minimum	37.0 mils

10. Weight per 1000 Feet.

TABLE XXXI

Weight per 1000 Feet, (Pounds)

Wire No.	Average	Maximum	Minimum
1	4.500	4.511	4.482
3	4.802	4.844	4.766
4	4.216	4.232	4.189
5	4.359	4.436	4.309
6	4.450	4.501	4.427
7	4.651	4.657	4.644
8	4.648	4.655	4.642
9	5.431	5.481	5.360
10	4.208	4.267	4.104
11	4.213	4.225	4.202

11. Stripability

The results of the stripability tests are summarized in Table XXXII. It should be noted that the insulation was damaged by the jaws of the stripper in several cases. During flashover tests, this kind of damage resulted in voltage breakdown of the insulation.

12. Solderability

Wires 1, 3, 4, 5, 6, 7, 8, 9, 10, and 11 were examined. Zinc chloride flux was used with the nickel plated conductors. All wires were easily soldered, wetting the entire surface. No insulation damage as the result of heating was observed.

13. Color Durability

Observations on color changes are reported in the results of the various aging tests. Conclusions will be summarized in the Final Report.

14. Marking Legibility

Marked specimens were not available during the period covered in this report. Results will be given in the Final Report on specimens that are received in time to be tested.

15. Compatability with Potting Compounds

Three compounds have been received, and specimens potted with these materials are being aged. Results will be given in a subsequent report. The fourth compound has not been delivered.

TABLE XXXII

STRIPABILITY

Wire No.	Mechanical Hand Stripper	Thermal Stripper
1	Easily stripped No conductor damage Insulation damaged from holding grip.	Easily stripped. No conductor damage. Melting and charring at edge of insulation.
3	Not easily stripped. Some nicks and scrapes and broken wires. Outer insulation punctured by holding grip.	Slow. Slight scraping of conductor. Melting and charring at edge of insulation.
4	Could not be stripped with hand stripper. Insulation damaged.	Same as 3.
5	Easily stripped. Some nicks and scrapes on conductor. Insulation indented with holding grip.	Same as 3.
6	Easily stripped. Very little scraping of conductor. Insulation indented with holding grip.	Same as 3.
7	Same as 6.	Easily stripped. Insulation discolored and flared at edge.
8	Easily stripped. Very little scraping of conductor. Insulation deeply indented with holding grip.	Same as 7.
9	Same as 8.	Easily stripped. Slight flare at edge of insulation.
10	Same as 6.	Same as 3.
11	Could not be stripped. Outer insulation punctured by holding grip.	Same as 3.

16. Flexibility

(a) Mandrel Flexibility

As mentioned in the test description, the mandrel flexibility test is most useful when the "kind" of failure in flexure is observed. Table XXXIV provides a code to describe the failure. This code is used in Table XXXV to provide a comparison of the different wires. These unaged wires have been tested both at 23°C and after immersion in liquid nitrogen.

All of the wires are quite flexible at room temperature. Several of the wires can be wrapped on themselves (1X mandrel) without any evidence of damage. The taped samples tend to wrinkle slightly at 1X and those with jackets or dispersion coating may craze at the surface. All of the wires show no damage when reverse flexed on a .075 in. diam. mandrel.

As expected, much greater differentiation is achieved in liquid nitrogen. The Kynar jacket of wire #7 cracks on a 1 3/4" mandrel, the ML enamel of wire #1 crazes on a 1 in. mandrel and the TFE dispersion coating on wire #3 cracks on a ½ inch mandrel before the underlying insulation cracks.

The irradiated polyolefin (wire #8) is by far the most brittle of the insulations evaluated at -196°C. This wire cracks on the largest mandrel used - 3 inch - and spalls completely off the wire on a 1 3/4" mandrel. It is interesting that the polyolefin with the Kynar jacket (wire #7) is superior to wire without the jacket (wire #8).

The H-film taped samples #4, 5 and 6 all exhibit superior flexibility in liquid nitrogen confirming the results reported in another contract (NAS 8-2442). Even with the FEP dispersion overcoat, wire #6 performs very well and is superior to extruded Teflon (wire #9).

It should be noted that ML enamel applied to copper wire showed remarkable flexibility in the earlier program (NAS 8-2442). Unfortunately, the same superior performance apparently cannot be achieved when the ML enamel is applied over an extruded coating such as FEP (wire #1). The results for ML over a TFE extrusion (wire #2) are awaited with interest. It is postulated that inadequate adherence of the ML enamel to the substrate is at least in part responsible for its relatively poor performance.

b. Repeated Flexure Test

Five tests to failure with each type of wire were made with the modified MIT fold endurance tester. During the progress of the work, so much equipment trouble occurred that the flexing angle was reduced from 270° to 180°. This change has alleviated, but not overcome entirely, the problem encountered. The change did permit a comparison of results at the two flexure angles as reported in Table XXXV. All of the tests have been made at 23°C and 50% RH. Unfortunately, the problems encountered in test have made low temperature tests very difficult and these are not yet completed.

With two exceptions - the maximum value for wire #5 and the minimum value for wire #6 - the decrease in the flexure angle increased the cycles to failure. The increase in the average ranged from 7 to 51% with no apparent reason for the differences.

It is difficult to determine if insulation failure in some cases may precede failure of the conductor. Such a situation has never been observed. On the other hand, with a very pliable (low modulus) insulation such as the extruded TFE Teflon of wire #9, the conductor may break and the insulation stretch under the tensile load with no failure in flexure. The somewhat more rigid FEP Teflon exhibits somewhat the same effect except that in this case the insulation does fail shortly after the conductor failure.

It is interesting to consider the reason for the differences in the failure of the conductors. All of the conductors are nickel plated #20 sranded copper wire except for wire #6 which is silver plated. Wires #3, 4, 5 and 9 were all made by the same manufacturers. It is, of course, possible (perhaps likely) that the silver plated copper wire is softer and less liable to fatigue failure than the nickel plated copper. The reason for the superiority of wire #3 is difficult to understand. It is possible that the very low modulus TFE Teflon in wire #9 does not support or strengthen the conductor which may, therefore, fail earlier in test. The reasons for the differences encountered may need to await the results on additional types of wire.

The test parameters used in the present test are completely arbitrary. A smaller bending mandrel or a change in tension in the wire during test will change the values obtained and might even change the order of comparison between wires. A much more thorough evaluation of the test parameters is needed before sound conclusions should be drawn and before wires should be selected on the basis of repeated flexure data.

TABLE XXIII

CODE FOR FLEXIBILITY TESTS

W	-	Wrinkling
Cr	-	Crazing (Fine Cracks)
C	-	Cracking
S	-	Spalled Completely Off Wire
Sp	-	Splitting Longitudinally
Ls	-	Loosening of Wrap
J	-	Jacket or Coating
Slt	-	Slight or Some

TABLE XXIV

COMPARISON OF MANDREL FLEXIBILITY UNAGED WIRES

Flexed at 23C Mandrel Dia.-In.	Wire # 1	3	4	5	6	7	8	9	10
1X	Cr in J	(1)	W	W	OK	W Cr in J	OK	OK	W Ls
.075	OK	(1)	OK	OK		OK			

(1) "Mud flat" cracking exists in the FEP dispersion coating as received. Flexing "opens up" these cracks.

Flexed at -196°C In Liquid N_2 Mandrel Dia.-In.	Wire # 1	3	4	5	6	7	8	9	10
.075			Cr Slt.S	S					
.0125			W	W Ls					
1/4		C	OK	OK	S Sp			S	W Slt.C
1/2	C	J-Cr			OK			C	Slt.W Ls
3/4	J-Cr Slt.C							Slt. C	OK
1	J-Cr							OK	
1 1/4									
1 1/2									
1 3/4						C J-S	S		
2						OK	C		
3							J-C		

Note: See Table XXIV for code.

TABLE XXXV

COMPARISON OF WIRES IN REPEATED FLEXURE TEST

Cycles to Conductor Failure

	180° Bend			270° Bend		
Wire #	Avg.	Max.	Min.	Avg.	Max.	Min.
1	2,570	7,630	2,510			
3	5,037	7,802	3,492	3,333	4,555	2,654
4	1,866	2,004	1,785	1,614	1,727	1,538
5	2,240	2,604	1,575	2,098	3,971	1,016
6	6,081	7,115	4,382	5,122	5,448	4,784
9	1,818	2,400	1,520	1,414	1,590	1,100

Cycles to Insulation Failure

#1	2,733	2,833	2,632			
#9	Did not fail 5,000			Did not fail 5,000		

17. Scrape Abrasion

Four test loads of 500, 700, 800, and 1000 grams have been used with the NEMA (GE) repeated scrape abrasion tester in evaluating wires #3, 4, 5, 6, and 9. Three loads of 500, 800, and 1000 grams have been used with wires #1, 7, 8, 10, and 11. At least three test results have been obtained with every wire sample and, in many cases, more. The test results are summarized in Table XXXVI.

Prior work with film-coated, magnet wire has indicated that the number of scrapes to failure is a power function of the load:

$$S = \frac{K}{p^n}$$

where,

S = scrapes to failure

p = load in grams

K = constant

n = power function

To check this relationship for the wires in this program, the log of the average scrapes to failure have been plotted versus log load in Figures 37 and 38. The vertical scale in the second of these two figures has been shifted one decade so as to include the wires with a low number of scrapes to failure. If the power function is valid linear plots should result. It is immediately apparent from Figure 37 that with perhaps some exceptions (wires #5, 6 and 8) linear plots are in fact reasonable. It is apparent also that two types of slope are involved with the curves for wires 4, 10, and 11 having relatively low slopes and those for wires 3 and 9 with a high slope. The calculated values of the slopes are given in Table XXXVII.

In Table XXXVII, wires #5, 6, and 8 have an appended (?). Considering first wire #5, it is possible to plot the results in two ways with different slopes as shown in Figures 37 and 38. With #6, 7, and 8, it would appear that perhaps two slopes are involved although the data are really insufficient for such an observation.

The results for wires #7 and #8 are particularly interesting since both are insulated with irradiated polyolefin and #7 has an extruded jacket of hard polyvinylidene fluoride (Kynar). The results for these wires are plotted in Figure 39 along with comparative results for extruded TFE Teflon (Wire #9). In this figure, the maximum and minimum as well as the average value have been plotted. This chart illustrates the tremendous importance of considering the effect of load when comparing the abrasion resistance of different wires. In fact, the order of superiority may reverse at different loads as shown. It is particularly interesting that a single, relatively low scrape value is obtained for the Kynar jacketed wire #7 at each of the two higher loads. It can be postulated that in these two cases the jacket lost adhesion and was more readily abraded away.

In reviewing all of the data, it is apparent that the slippery Teflon surfaces provide good abrasion resistance, particularly at low loads. At higher loads, the relative softness of the Teflon may cause the relatively less superiority as compared to the harder material, such as Kynar. It should be recognized that wire #3 with a dispersion coating of TFE Teflon and wire #6 with an FEP Teflon dispersion coating, act very much like extruded Teflon (wire #9). In fact, the fairly slippery polyolefin #8 also acts much like the extruded Teflon. Wire #11 has a fused TFE Teflon taped coating, but this coating is so soft that it is even readily removed with the fingernail.

The ML coating over an FEP Teflon extrusion (wire #1) does not provide good abrasion resistance. The particularly poor performance at high loads may be related to poor adhesion of the ML coating to the FEP substrate. The one high value obtained at the 500 gram load may indicate the potential with good adhesion.

The H-film taped wires #4, 5, and 10 without dispersion coatings, are inferior to extruded TFE Teflon (wire #9) and the taped wires with good dispersion coatings, at least at low abrading loads. It is possible that this inferiority of the H-film tape might disappear at higher abrading loads and even reverse. (The H-film has high cut through resistance.)

Observations on the Test Procedure

It is obvious that as many test loads as feasible should be used to fairly assess the abrasion resistance of a hook-up wire. (A maximum of 3 loads was agreed to in this contract.) It is probable also that an abrading needle of a different diameter would change the character of the abrasion-load curve.

Some comment about reproducibility is also pertinent. Table XXXVI gives the range of values obtained and the range is also plotted for the values in Figure 39. It should, of course, be recognized that the abrasion resistance of the test specimen may be intrinsically very variable. In illustration, with wire #9 very little variability was encountered at the 800 gram load. However, considerable variability was noted at the 700 and 1000 gram loads. The individual values are plotted on normal probability paper in Figure 40. Curve B at the 1000 gram load plots reasonably well as a normal arithmetic distribution. Thus, the wide range in this case seems reasonable. At the 700 gram load, it is possible to plot the results in two ways as shown by curves A and A'. Plot A is the more reasonable and also shows that a wide range of test results can be expected.

Another probability plot for wire #1 is drawn in Figure 41. This plot justified the exclusion of the 368 scrap value. Such curves are useful for such purposes when used with care and judgment.

If the repeated scrape abrasion test is to be used for specification purposes, the wide range of results to be expected must be recognized. It should be noted also that wire diameter and insulation thickness will be very important factors. The quantitative effect of such variables is not now known and needs to be investigated.

TABLE XXXVI

COMPARISON OF WIRES RESISTANCE TO SCRAPE ABRASION, NO. OF SCRAPES TO FAILURE

	Load											
	500 gms			700 gms			800 gms			1000 gms		
Wire No.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.
1	508	579	423				54(4)	368	16	6(2)	10	4
3	28,119(1)	15,213	41,024	2,043(2)	3,206	976	855(3)	1,337	472	284(2)	305	269
4	215	236	183	55	60	46	40(3)	47	32	14(6)	18	10
5	1,255(2)	1,630	885	159	183	82	49(3)	78	26	68(1)	91	50
6	10,347	11,092	9,139	657	734	606	539(3)	683	452	285(3)	322	221
7	1,546	1,744	1,384				682(5)	828	70	787(8)	995	26
8	6,391	8,522	3,653				319	360	255	188	229	151
9	>50,000			12,519(3)	19,614	6,511	4,325	4,730	4,118	941(3)	1,487	445
10	386	463	326				79	86	69	23	26	19
11	33	41	26				7	9	5			

Average is for 3 test values except as noted below.

(1) Two test values

(2) Five test values

(3) Six or seven test values

(4) A plot on normal probability paper indicates a probable average of 67. The maximum value of 368 has not been included in the calculation of the average.

(5) The minimum value of 70 is so far out of line with the remaining 4 values, that it is not included in the average.

(6) Ten test values

(7) Eight test values

(8) The minimum value of 26 is out-of-line with the remaining 3 values and has not been included in the average.

TABLE XXXVII

CALCULATED SLOPE OF LOG LOAD/LOG SCRAPES TO FAILURE

Wire No.*	Calculated Slope = n
#3	6.3
#4	4.0
#5	4.3(?) and 6.9(?)
#6	5.9(?)
#8	6.3(?)
#9	7.4
#10	5.9
#11	3.0

$$S = \frac{K}{p^n}$$

where,

S = scrapes to failure

p = load grams

K = constant

n = power function

*Curves could not be plotted for wires #1 and #7

(?)See text

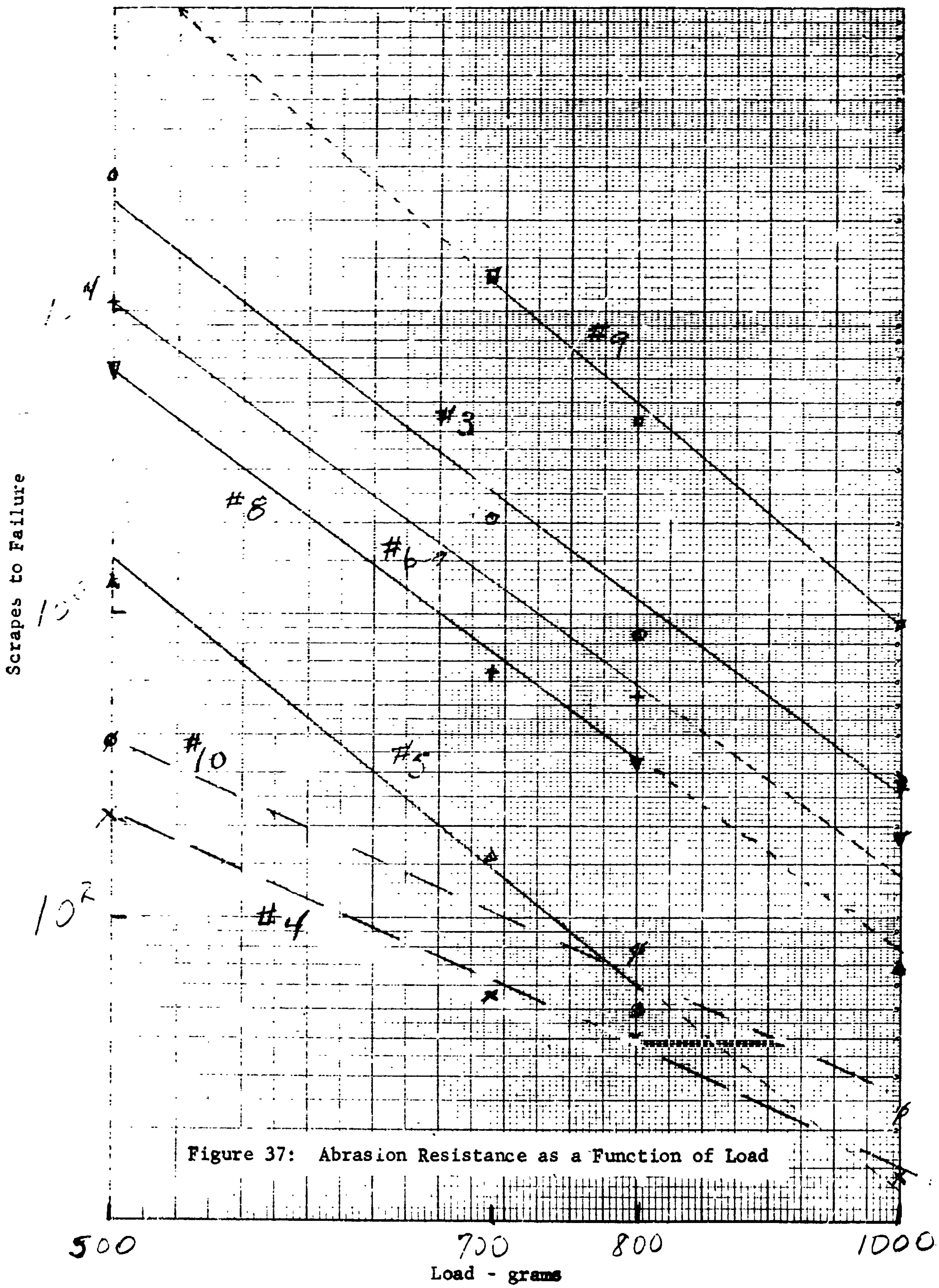

Figure 37: Abrasion Resistance as a Function of Load

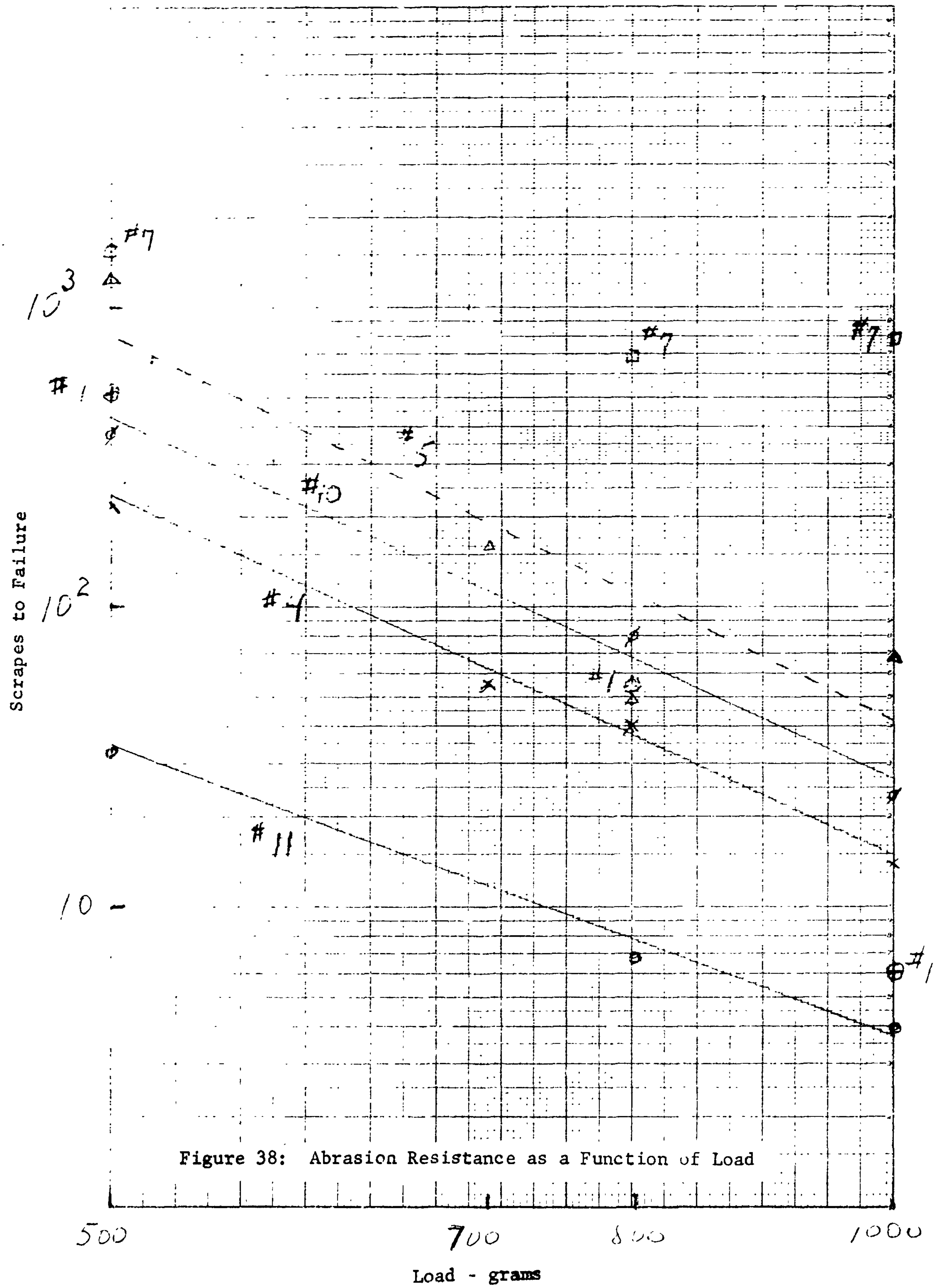

Figure 38: Abrasion Resistance as a Function of Load

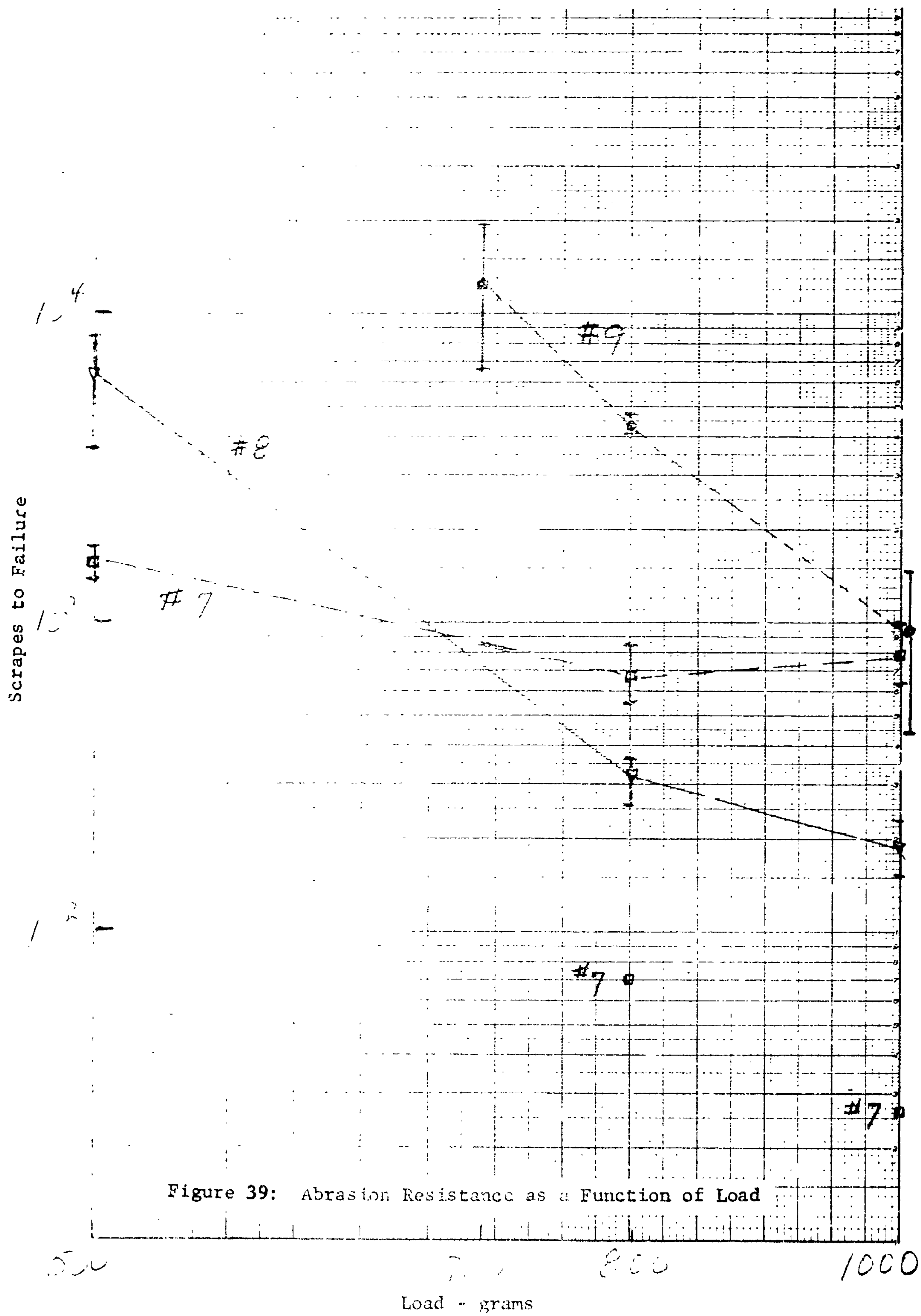

Figure 39: Abrasion Resistance as a Function of Load

Scrapes to Failure

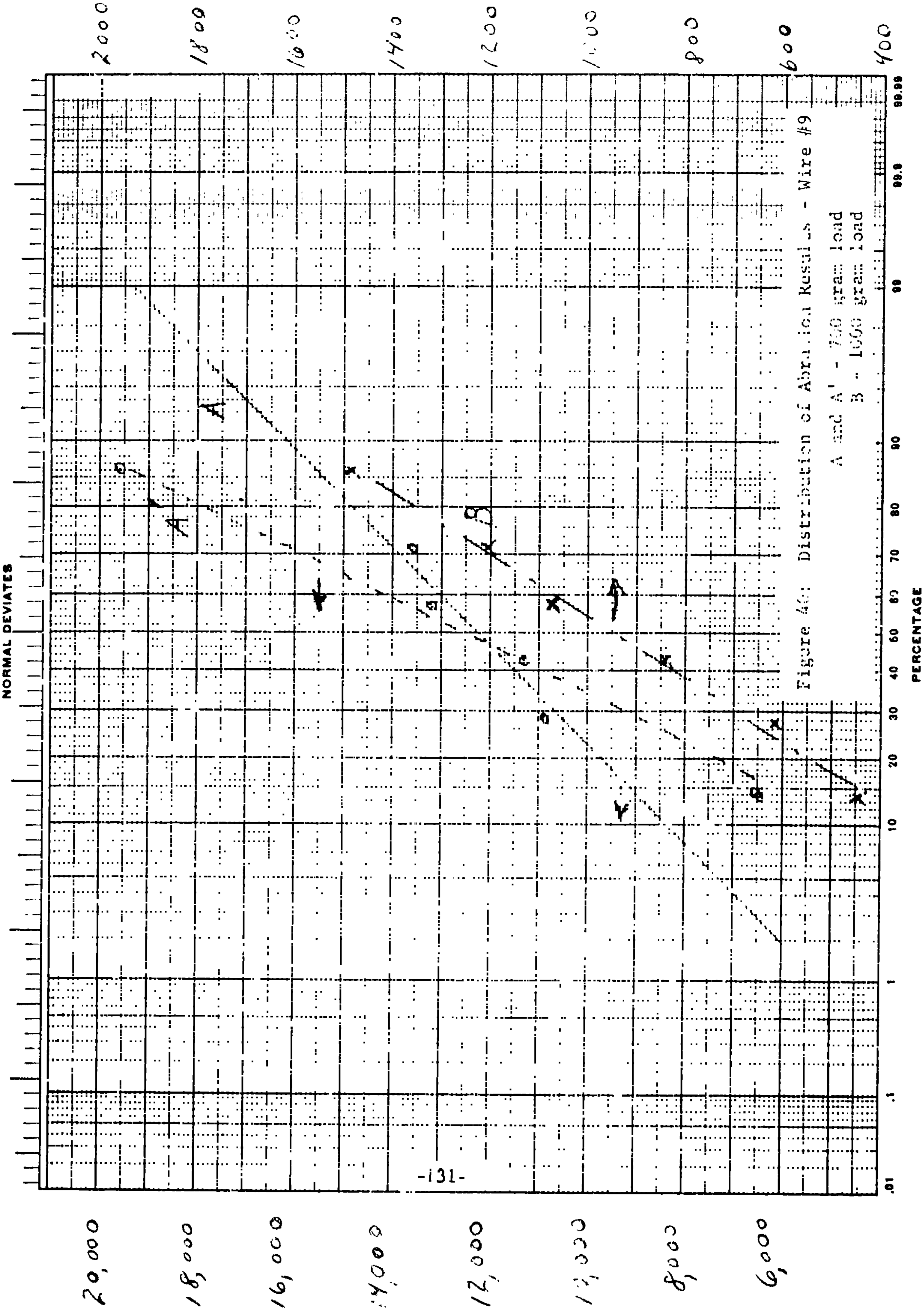

Figure 46: Distribution of Abrasion Results - Wire #9

A and A' - 750 gram load
B - 1000 gram load

Scrapes to Failure

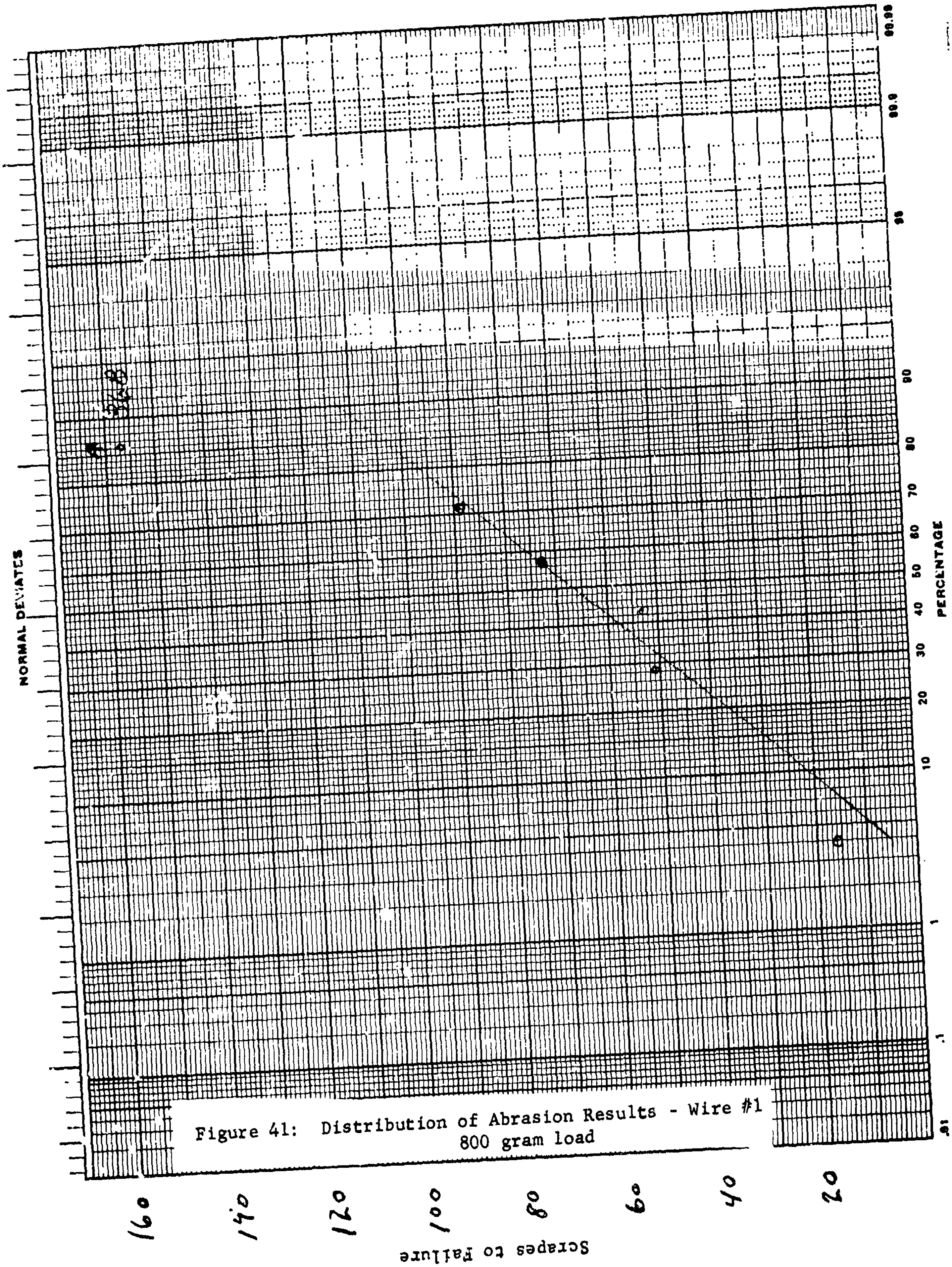

Figure 41: Distribution of Abrasion Results - Wire #1
800 gram load

18. Blocking

Evidence of blocking is reported in the results of other tests. Conclusions regarding each wire will be summarized in the Final Report.

19. Cut-Through

Cut-through results are reported as the failure load, where failure is detected by electrical continuity between the conductor and the cut-through paddle. The load is applied at a fixed cross-head speed of 0.005 inches per minute. Values are given for 23°C and 149°C.

The results demonstrate the superior cut-through strength of H-film (Wires 3, 4, 5, 6 and 10) in comparison to the thermoplastic insulation (Wires 7, 8 and 9). The irradiated polyolefins were most sensitive to temperature change, showing exceptionally poor cut-through strength at 149°C. The Kynar jacket (Wire 7) does increase cut-through strength over the plain polyolefin (Wire 8). The lowest strengths among the H-film samples were exhibited by Wires 3 and 4, which also have the thinnest walls.

TABLE XXXVIII

CUT-THROUGH FAILURE LOAD (POUNDS) CROSS-HEAD SPEED 0.005 INCHES/MINUTE

Wire No.		23°C Failure Load (Lbs.)		149°C Failure Load (Lbs.)
3		106		62.1
		112		55.9
		115		41.9
	Avg.	111	Avg.	53.3
4		72.0		27.8
		91.0		34.7
		87.5		36.2
	Avg.	83.5	Avg.	32.9
5		64.2		33.0
		95.2		33.5
		39.2		35.2
	Avg.	66.2	Avg.	33.9
6		91.8		47.0
		116		57.1
		140		59.0
	Avg.	118.9	Avg.	54.4
7		20.4		3.6
		18.6		3.3
		20.0		2.0
	Avg.	19.7	Avg.	3.0
8		17.5		0.6
		17.6		0.6
		14.1		0.7
	Avg.	16.4	Avg.	0.6
9		26.6		8.1
		24.1		8.3
		24.6		7.6
	Avg.	25.1		8.0
10		124		89.0
		103		82.3
		125		63.8
	Avg.	117	Avg.	78.4

20. Thermal Creep

The suggested method of evaluating thermal creep required that a standard load be applied to each specimen and the time to failure reported. The load was defined as that which caused Type E Teflon (wire #9) to fail in one hour. As discussed in Section II-20, the test procedure was modified somewhat, but the one hour failure loads for wire #9 was determined at 23°C and 149°C, and these loads were used on those wires that would fail in a reasonable time. Of the wires tested thus far, only the irradiated polyolefins exhibited such poor creep characteristics, failing in only a few minutes at the standard loads.

Many tests were required to determine the one hour failure loads for the Teflon wire at the two temperatures because a considerable spread in results is encountered when measuring the time to failure for a fixed load. The standard loads were established as 116 pounds at 23°C and 33 pounds at 149°C.

The H-film constructions, with their superior cut-through strengths, would run for unreasonable lengths of time with either of the standard loads. To obtain comparative data, a short time test, where the load was applied at a constant rate of .002 inches per minute, was conducted. The fixed load for the first creep test was taken as 75% of the short-time failure load. This load was applied for one hour and then increased in steps, as described in Section II-20. The data obtained using this technique are given in Table XXXIX.

In Table XXXIX the fixed load that was applied for the first hour is shown as the withstand value. In each case where failure did not occur during this period, the load was increased by about 10% and held for 15 minutes. This procedure was continued until failure occurred. The final failure load is shown for each specimen, but the incremental loads are not tabulated.

From the data of Table XXXIX it is possible to estimate the one-hour failure load for each wire. These values are given in Table XL. From this analysis, the wires can be ranked in the following order:

74°C	149°C
6	6
3	3
5	4, 5
4	9
9	

Again, the thinner walled wires (4 and 5) do not perform as well as the thicker H-film constructions (3 and 6), but they are superior to the Teflon (wire #9). There seems to be no apparent reason, however, for the better performance of wire #6 over wire #3. The cut-through strengths of the two wires did not differ greatly, particularly at 149°C, where wire #6 shows much better creep behavior.

TABLE XXXIX

THERMAL CREEP

Fixed Load Applied for Period Shown, Then Increased by Approx. 10% in 15 Minute Interals to Failure Load.

Wire #	Temperature (°C)	Specimen	Withstood (lbs. - min.)		Failed (lbs.)
3	23	1	116	75	400
		2	116	60	350
		3	116	60	335
		4	116	60	325
3	149	1	105	60	130
		2			120 (6 min.)
		3	110	60	150
4	23	1	150	60	185
		2			170 (50 Min.)
		3	160	60	175
4	149	1	85	80	115
		2			100 (36 min.)
		3			90 (47 min.)
5	23	1	200	60	275
		2	210	60	240
		3	200	60	250
5	149	1	75	60	105
		2	90	60	105
		3	90	60	100
6	23	1	400	60	450
		2			425 (3 min.)
		3	410	60	425
		4	410	60	450
6	149	1	185	60	245
		2	225	60	245
		3			240 (3 min.)
10	23	1			270 (3 min.)
		2	200	60	300
		3			275 (50 min.)
		4	275	60	350
10	149	1	180	60	240
		2	210	60	240
		3	225	60	270

TABLE XXXIX (Cont'd)

Wire #	Temperature (°C)	Specimen	Withstood (lbs. - min.)		Failed (lbs.)
11	23	1	110	60	225
		2	175	60	200
		3			185 (3 min.)
		4			185 (4 min.)
		5			175 (53 min.)
11	149	1	70	60	70 (37 min.)
		2	70	60	125
		3	70	60	90

Note: Wires 7 and 8 failed in 3 minutes or less during load application. Loads were less than 96 lbs. at 23°C and 23 lbs. at 149°C.

TABLE XL

THERMAL CREEP

Estimated One Hour Failure Loads (Pounds)

Wire #	23°C	149°C
3	300-325	110-130
4	160-170	85-100
5	210-275	90-100
6	410-425	225-240
9	116	33

21. Wicking

The results of the wicking test are summarized in Table XLI. The specimens were dipped in the dye solution to a depth of two inches, so those values less than two inches in Table XLI indicate that the solution did not even penetrate along the conductor to the liquid level in the container. This occurred with the irradiated polyolefin wires (7 and 8). In addition to having extruded insulation that is relatively well bonded to the conductor, these wires have tin plated conductors which may not have wet as readily as the nickel or silver plated conductors.

The taped specimens definitely wicked to greater lengths than the extruded wires. This is to be expected because of the absence of a bond between the insulation and the conductor.

It should be noted that the weight gain data do not correlate well with the wicking measurements. Wires 7 and 9, for instance, showed little wicking, but gained a considerable amount of weight. Moisture absorption and adsorption would be expected to increase the insulation weight of all of the specimens, even if no wicking occurred. The results show that the fluorescent dye technique is an effective means of detecting wicking

TABLE XLI

WICKING

Six Inch Specimen Vertically Immersed to a Depth of Two Inches.

Wire No.	% Wt. Gain	Total Length Wicked (inches)
1-1	1.9	4¼
1-2	1.6	2 3/4
1-3	1.5	3½
3-1	2.1	6
3-2	1.7	5
3-3	2.2	6
4-1	2.8	6
4-2	2.1	6
4-3	2.6	6
5-1	1.3	4½
5-2	1.4	4 3/4
5-3	1.2	4¼
6-1	.96	3 3/4
6-2	.95	3 3/4
6-3	.55	4¼
7-1	.99	1/8 - ¼
7-2	.90	1/8 - ¼
7-3	.59	1/8 - ¼
8-1	.97	¼
8-2	.93	¼
8-3	1.04	¼
9-1	.62	2¼
9-2	.63	2 3/8
9-3	.57	2 3/8
10-1	1.5	6
10-2	1.9	6
10-3	2.4	4
11-1	1.2	3
11-2	1.4	2 7/8
11-3	1.0	2 3/4

22. Thermal Aging

Three criteria have been used to judge the effect of thermal aging in vacuum and in 15 psia oxygen:

	In Vacuum	In Oxygen
Mandrel Flexibility	Table XLII	Table XLV
Voltage Breakdown	Table XLIII	Table XLVI
Insulation Resistance	Table XLIV	Table XLVII

Mandrel flexibility was measured at 23°C and 50% RH and also while immersed in liquid nitrogen at -196°C. Insulation resistance (1 min. at 500 volts DC) and short time voltage breakdown were measured with the same specimens at 23°C and 50% RH. Three replicates were used for all tests. In each table the test results, after aging, are compared to similar values before aging. Observations will be made on each table in turn.

Table XLII - Mandrel Flexibility

After aging in vacuum for 15 days at 150°C, very little change is indicated for wires #3 through 10 except that at -196°C wires #5, 6 and 10 appear to be slightly more brittle. It is difficult to judge whether this change is significant. It should be noted that flexibility tests at -196°C are extremely sensitive in indicating the effect of aging.

Table XLIII - Voltage Breakdown

Aging in vacuum at 150°C for 15 days appears to have no significant effect on voltage breakdown for any of the wires tested.

Table XLIV - Insulation Resistance

Aging in vacuum at 15°C increases insulation resistance of all the wires. This improvement is to be expected since the moisture would be removed.

Table XLV - Mandrel Flexibility

Flexibility of the irradiated polyolefin insulated wires #7 (with Kynar jacket) and #8 is markedly reduced at both 23°C and -196°C after aging in oxygen at 150C. Flexibility at -196°C with wires #4, 6 and 9 is decreased slightly. Curiously, wire #10 appears to be adversely affected a bit at 23°C, but not at -196°C.

XLVI - Voltage Breakdown

Aging in oxygen at 150°C for 15 days does not significantly effect the voltage breakdown of any of the wires - #3 through #10. This test is not sensitive to the aging effects determined with mandrel flexibility.

XLVII - Insulation Resistance

Aging in oxygen increases insulation resistance, as would be expected, for all wires, #3 through #10

TABLE XLII

EFFECT OF THERMAL AGING - 15 DAYS IN VACUUM AT 150°C ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - Exposed/Unaged

Wire #	No Damage Flexed at 23°C	No Damage Flexed at -196°C	Slight Damage Flexed at 23°C	Slight Damage Flexed at -196°C	Severe Damage Flexed at -196°C
3	1X*/1X	-	-	0.5/0.5	-
4	-	-	1X/1X	-	.125/.075
5	-	-	1X/1X	.25/.125	.125/.075
6	1X/1X	-	-	.50/.25	-
7	1X/.075	-	-	-	1.75/1.75
8	1X/1X	-	-	-	3.0/3.0
9	1X/1X	-	-	0.75/0.75	-
10	-	-	1X/1X	0.5/0.25	-

*"Mud flat" cracking in the unflexed FEP coating opens with flexing.

TABLE XLIII

EFFECT OF THERMAL AGING - 15 DAYS IN VACUUM AT 150°C ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unaged

Wire #	Max. Values	Min. Values
3	27 / 28.5	/ 25.5
4	18 / 18	17 / 17.5
5	19.5/ 19.5	18 / 13.0
6	31 / 30	27 / 25.5
7	28.3/ 25.5	25.6/ 21
8	35.8/ 29	27.2/ 26
9	23.7/ 20.5	17.2/ 14.5
10	18.5/ 23	16.5/ 18

TABLE XLIV

EFFECT OF THERMAL AGING - 15 DAYS IN VACUUM AT 150°C ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unaged

Wire #	Max. Values	Min. Values
3	$>10^{15}$ / $6x10^{14}$	/ $2.5x10^{14}$
4	$1x10^{15}$ / $5x10^{13}$	/ $3.8x10^{13}$
5	$>10^{15}$ / $2.5x10^{15}$	/ $5.9x10^{14}$
6	$>5x10^{15}$ / $3.6x10^{14}$	/ $2.3x10^{14}$
7	$1.1x10^{14}$ / $8.9x10^{12}$	/ $3.6x10^{12}$
8	$6.3x10^{14}$ / $6.3x10^{13}$	/ $8.3x10^{12}$
9	$3.6x10^{15}$ / $1.1x10^{15}$	/ $3.6x10^{14}$
10	$8.3x10^{14}$ / $1x10^{14}$	/ $1.5x10^{13}$

TABLE XLV

EFFECT OF THERMAL AGING - 15 DAYS IN 15 PSI OXYGEN AT 150C ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - Exposed / Unaged

Wire #	No Damage Flexed at 23°C	No Damage Flexed at -196°C	Slight Damage Flexed at 23°C	Slight Damage Flexed at -196°C	Severe Damage Flexed at -196°C
3	1X* / 1X	-	-	0.5 / 0.5	-
4	.075 / .075	-	1X / 1X	.125 / .075	-
5	.075 / .075	-	1X / 1X	0.125 / 0.125	-
6	1X / 1X	-	-	0.5 / 0.25	-
7	1X / .075	-	-	-	3.0 / 1.75
8	0.5 / 1X		0.25 / .075	-	3.0 / 3.0
9	1X / 1X	-	-	[illegible]	-
10	.125 / .075	0.75 / 0.75	.075 / 1X	0.5 / 0.5	-

*"Mud flat" cracking in the unflexed FEP coating opens with flexure.

TABLE XLVI

EFFECT OF THERMAL AGING - 15 DAYS IN 15 PSI OXYGEN AT 150°C ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Radio of Breakdown Voltage (KV) - Exposed/Unaged

Wire #	Max. Values	Min. Values
3	29 / 28.5	26 / 25.5
4	18 / 18	16.5 / 17.5
5	20 / 19.5	19.5 / 13.0
6	32 / 30	30.5 / 25.5
7	25.5/ 25.5	20.0 / 21
8	27 / 29	20 / 26
9	25.3/ 20.5	16.1 / 14.5
10	19.5/ 23	17 / 18

TABLE XLVII

EFFECT OF THERMAL AGING - 15 DAYS IN 15 PSI OXYGEN AT 150°C ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unaged

Wire #	Max. Values	Min. Values
3	$1.3x10^{15}$ / $6x10^{14}$	/ $3.5x10^{14}$
4	$>10^{15}$ / $5x10^{13}$	/ $3.8x10^{13}$
5	$>10^{15}$ / $2.5x10^{15}$	/ $5.9x10^{14}$
6	$>10^{15}$ / $3.6x10^{14}$	/ $2.3x10^{14}$
7	$1.3x10^{14}$ / $8.9x10^{12}$	/ $3.6x10^{12}$
8	$1.1x10^{14}$ / $6.3x10^{13}$	/ $8.3x10^{12}$
9	$2x10^{16}$ / $1.1x10^{15}$	/ $3.6x10^{14}$
10	$2.5x10^{14}$ / $1x10^{14}$	/ $1.5x10^{13}$

23. Ultra-Violet Radiation

Specimens are being exposed to ultra-violet radiation for 30 days in vacuum and in oxygen. The first specimens are now ready for testing, and results will be given in a subsequent report.

24. X-Ray Irradiation

X-ray exposure data will be included in a subsequent report. Arrangements have been made to have all specimens irradiated in a single series of exposures.

25. Flammability

In conducting the flammability tests, it was suggested that many possible variables existed. Consequently, an effort has been made to vary the different tests somewhat (particularly the replicates) so as to investigate the effect of small variations in the test procedure. At the same time, the procedures were standardized sufficiently so as to permit comparisons between wires.

As described under methods of test, three types of procedure have been used.

I. An external heater around the wire brings the wire temperature up to between 480 and somewhat over 500°C. After 5 minutes, sufficient current is passed through the wire to bring the wire up to at least 600°C.

IIA. A suddenly applied fixed value of current (40, 45 or 50 amperes) brings the wire very rapidly to a very high temperature which depends primarily on the current but also apparently on other factors. The very rapid rise in temperature after a 50 ampere current starts to flow is illustrated in Figure 42.

IIB. The current is increased in steps of nominal 20, 30, 32.5, 35, 37.5, 40, 42.5, 45, 47.5 and sometimes 50 amperes. Actual recorded current and the associated voltage drop (for a 1 inch section of wire) for a typical test is shown in Figure 43. The measured wire temperature is given in

Figure 44. It can be seen that the temperature in this case rises more slowly to a maximum value in about 30 minutes. The variables intrinsic in the method are clearly apparent from the results shown in Figure 43. However, the small changes involved do not seem to affect the course of the test in major fashion.

Three replicates of wires #3, 4, 5, 6 and 9 have been tested in flowing wet 5 psi oxygen using the three types of flammability tests described in the foregoing. The detailed results of each flammability test are appended to this section. Some general observations can be summarized here.

(a) In two out of three tests TFE Teflon (wire #9) burned continuously with an almost invisible blue flame when an external heater was used and current was used to bring the wire temperature to over 600°C (Test Procedure I). The energized spark-gap initiated combustion which progressed along the surface of the wire until all of the Teflon burned away. TFE Teflon did not burn under the conditions of the other two test procedures.

(b) Two of three specimens of wire #3 appeared to burn with a small yellow flame at high temperatures only with test procedure IIB in which the temperature was increased relatively slowly. Combustion occurred at intervals and lasted only for a few seconds at a time. It seemed to be confined to small pieces of charred insulation which had separated slightly from the conductor. The flame did not progress.

(c) Except for the two situations described in (a) and (b) above, no true ignition was encountered. Some occasional limited flashing of off-gassing products did occur on rare occasion with the H-film wrapped wires.

(d) TFE Teflon never produced visible smoke or vapor under any test condition. White deposits did condense to give evidence that TFE Teflon produced non-visible vapors (probably partially depolymerized TFE).

(e) The H-film taped specimens did produce smoke which was most apparent with test procedure II-A in which a high initial current was applied.

(f) The TFE Teflon undergoes a phase transition at 327°C. Below this temperature the Teflon appeared to expand. At high temperatures (probably just above 327°C0 rapid contraction takes place. At somewhat higher temperatures, the TFE Teflon evidently became physically very weak. The coating seemed to split and spall, coming off the wire in shreds. Sometimes whole sections of coating would loosen and slip down the wire. The TFE Teflon never blackened and changed only slightly in appearance as the falmmability tests progressed.

(g) H-film insulation first seemed to shrink and then blackened and appeared to char as the flammability test progressed. Little real difference appears to exist between wires #3, 4, 5 and 6 as shown in the Summary Table, XLVIII. The charred insulation does seem to maintain a degree of physical integrity at temperatures well above those temperatures at which TFE Teflon is completely destroyed. Ultimately, the H-film tape loosens, partly unwraps and the fragile char finally falls completely away leaving the wire bare.

(h) Beads of resin form on the H-film taped samples as the temperature increases. The beads take somewhat different forms with the various wires, but are probably traceable to the FEP Teflon used as a bond. (FEP is considerably more thermoplastic than TFE). There is evidence that, as with TFE Teflon, invisible vapors from the FEP also condense in the cooler areas.

It can be concluded from the foregoing that both extruded TFE Teflon and H-film taped wires are remarkably flame resistant. Unfortunately, the calculated values of temperature (Tests IIA and B) appear, in general, to be lower than actual. The values of the current provide generally more useful information. (In the continuing program, temperature will be measured directly with a thermocouple). The H-film taped wires are apparently somewhat superior. Perhaps the most significant advantage of the H-film tape lies in its tendency to slowly char and maintain some physical integrity even at extremely high temperatures. Condensible, off-gassing products may be a problem with all of the wires. The condensable products in these flammability tests are not likely to be detected since they may condense before reaching the analysis bottle. (Results of chemical analysis are described in another section).

In future programs, the electrical characteristics of the insulation should be determined as the flammability test proceeds. It is probable that Teflon maintains good electrical properties up to the point of physical degradation. How much electrical isolation is provided by the hot charred H-film cannot be estimated and may be very important.

Addena - Detailed Rest Results

See pages 157-192.

TABLE XLVIII

COMPARISON OF WIRES
PHYSICAL DEGRADATION DURING FLAMMABILITY TEST
(CURRENT INCREASED SLOWLY - TEST SERIES IIB)

Values are Amperes at which Degradacion as Described Appeared

	Wire No.			
	3	4	5	6
Wire Darkens	35	35	33	37.5
	37	38	34	37.5
		41	34.5	
Wire Blackens and Starts to Char	45	45	43	45
			45	

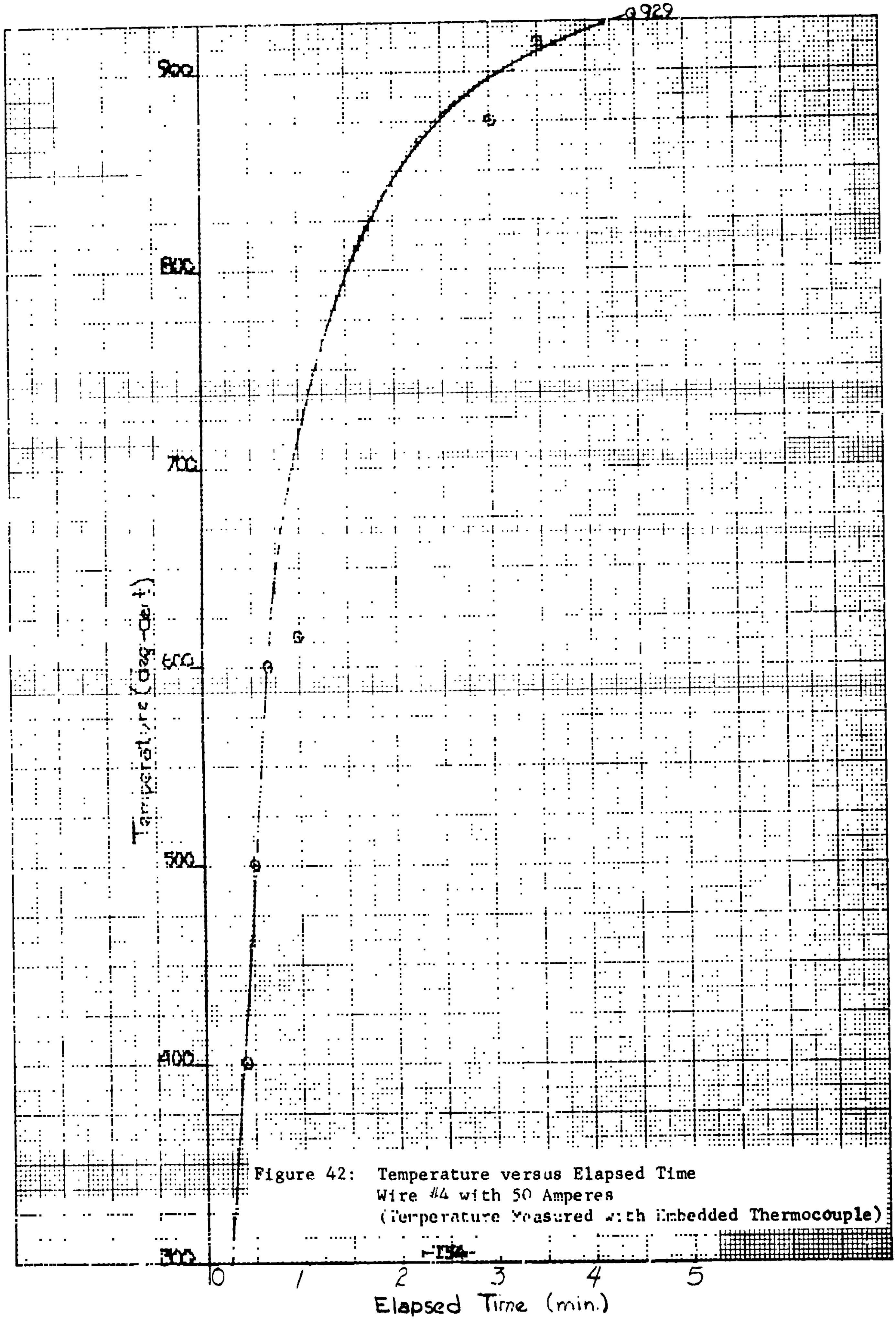

Figure 42: Temperature versus Elapsed Time
Wire #4 with 50 Amperes
(Temperature Measured with Embedded Thermocouple)

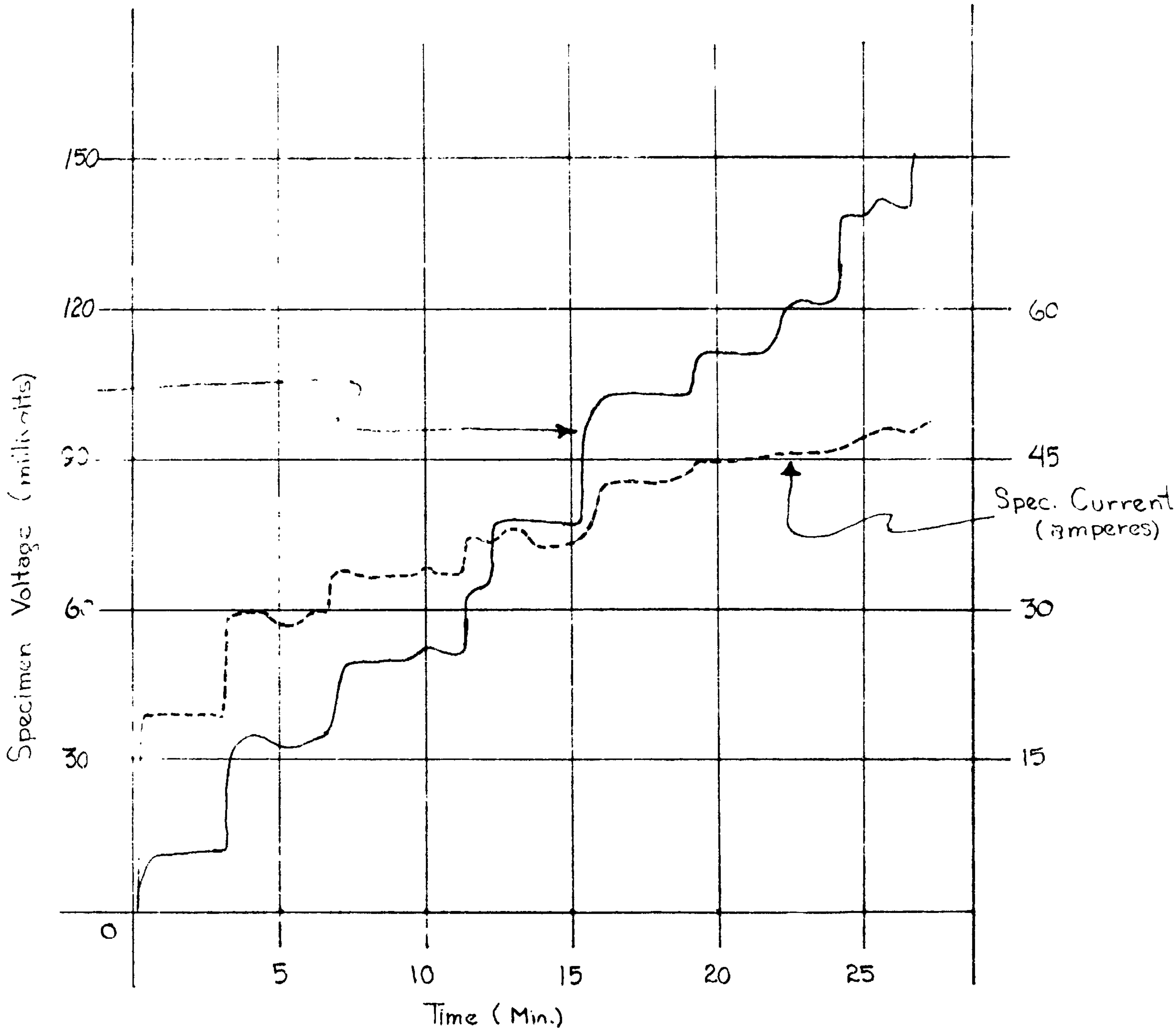

Figure 43: Typical Chart of Current and Voltage Drop versus Elapsed Time

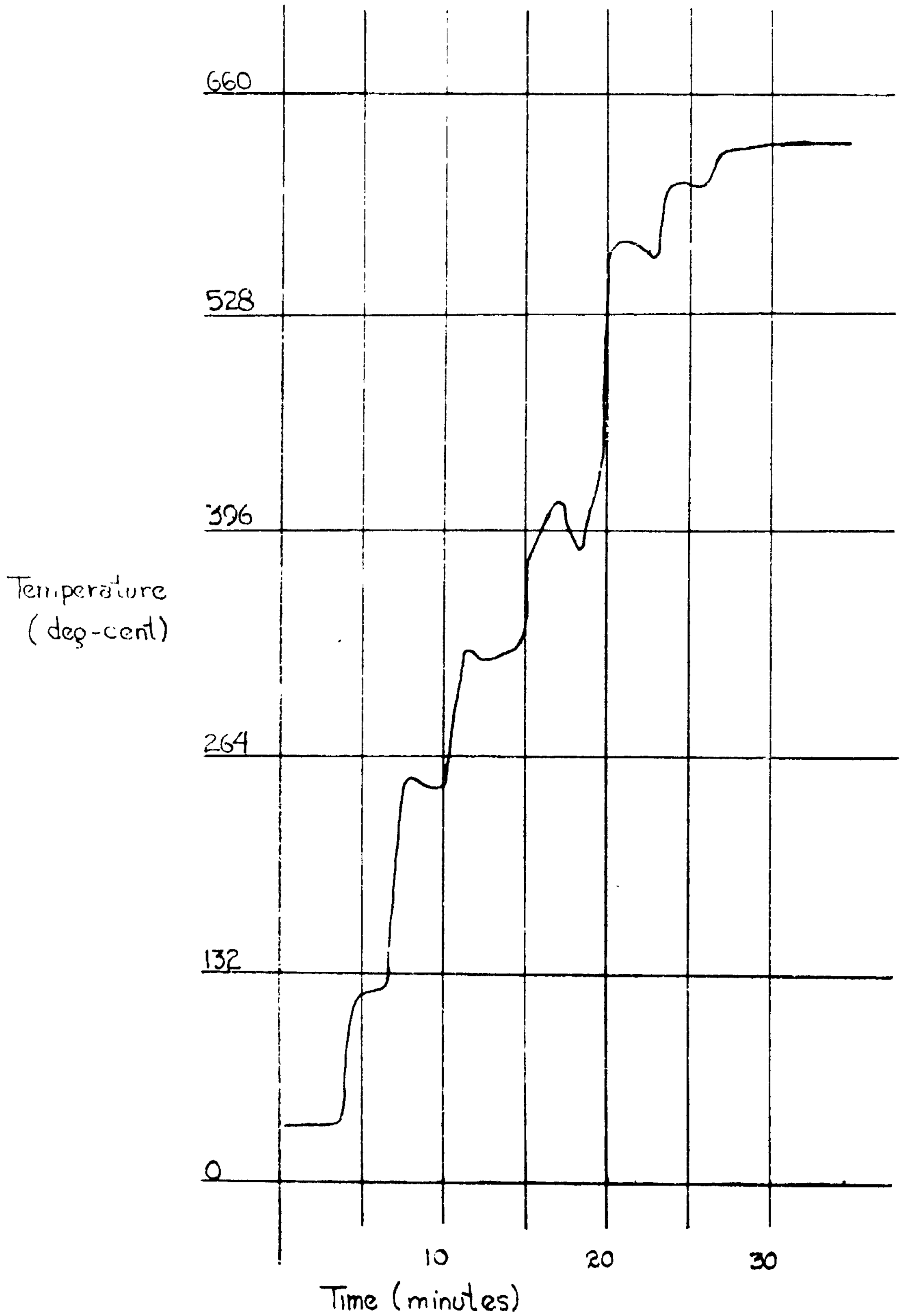

Figure 44: Chart of Temperature versus Elapsed Time for Test Described in Figure 43

Wire No. 3 (3-I-1)

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I* (amperes)	Max. Temp. (°C)	Remarks
Start			The wire temperature increased to 489C and held -- spark gap energized periodically
2.5			A flash occurred -- extinguished immediately
5			Temperature increased to at least 568C when current was passed through the wire -- specimens charred and shriveled -- bare sections of wire show where the insulation had flaked off
11	Off		No fire -- insulation destroyed around entire center section

*In this first test, current was applied after five minutes of test but was not recorded as it was in the tests to follow.

Wire No. 3 (3-I-2)

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start		528	The wire temperature increased to 528C within 30 sec. -- no visible effect
3.5			Some slight darkening
5	28.5	>600	Temperature increased to greater than 600C -- the wire sagged against the heater coil
15	33.8		White smoke appeared then disappeared almost immediately
25	33.8		Specimen was badly damaged near the coil area
25	Off		

Wire No. 3 (3-I-3)

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (^{o}C)	Remarks
Start			Coil temperature was raised to indicate 489C then rose slowly to 504C
2		504	Slight darkening
5	26.2	600	
6			Wire insulation is black and blistered with white deposit on insulation inside coil
8			Flickering occurs at spark gap
10			Off

Wire No. 4 (4-I-1)

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (^{o}C)	Remarks
Start			Temperature increased to 489C and then overshot to 528C. Heater voltage was reduced slightly
2.5		492	
2.75			Discoloration
4.5			Electrode burn-off
5.5	24	603	
7			Insulation quite dark, beads form on surface
8		580	
9	21	566	
10	26.2	624	
11			Electrode burns off*
13			Temperature is greater than 660C flashes appear on heater coil
15	Off		Insulation completely removed from the center of the specimen

*Apparently volatilized material deposits on the spark-plug electrodes, sparks and burns off. The spark does not propogate and the gases do not burn. This phenomenon occurred in many of the tests to follow.

Wire No. 4 (4-I-2)

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (^{o}C)	Remarks
Start			
1			Temperature increased to 490C in 20 sec.
1.5			Electrode burn off
3		475	
5.25	30	620	
5.75	26.2	655	
6			Specimen very dark
7		634	
7.25			Flicker at spk. gap electrode
8	26.2	600	
9	30	660+	
10			Bare spots on conductor show
11	Off		

Wire No. 4 (4-I-3)

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (^{o}C)	Remarks
Start			Temperature increased to 489C in 45 sec.
1		497	
2		499	
4		490	
5		483	
5.5	23.2	640	
6			Specimen very dark
6.5			Insulation black, but intact
7.5		623	Temperature varys
8			Insulation removed from the wire
8 min. 22 sec.	Off	644	No flashing at electrodes -- no smoke, insulation removed near center of wire

Wire No. 5 (5-I-1)

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Time (°C)	Remarks
Start			Temperature reached 528C in 35 sec.
1		539	
2		540	
3		541	Slight discoloration
4			Shrinking about area surrounded by coil
8			No spark gap reaction
9			Very dark, but intact
10	22.5	646	
11			Specimen still in fair physical shape
12	Off		Beads formed around insulation

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (^{o}C)	Remarks
Start			Temperature reached 488 in 25 sec. overshot to 527C. Heater coil voltage reduced
1		488	
2.5			Little discoloration
3		486	
5.5	30.7	646	
6			Insulation darkening
6.5	30	634	
6.75			Shrinks
7.5	28.5	625	
8	31.5	646	
8.75			Take wrap lossens
10			Immediately adjacent to upper part of heater coil there is bubbling on surface
10.5			No reaction to spark
11			Thermocouple leads have failed
12			Insulation strips away from specimen
12	42.7		Smoke -- wire glows
13.5	52.5		Wire became brilliant and melted, some smoke present, no ignitable products -- insulation almost completely gone -- no flame

Wire No. 5 (5-J-3)

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start			Temperature reached 495C in 15 sec.
1		528	
4		489	
5.5	30	625	
6			Specimen darkens
7			Very dark -- shrinking
7.5	30	614	
9.5			Beads form between wraps below coil -- not bubbling
12		601	
13	37.5		
13.5		704	Bubbles at wraps
15			Insulation flakes off
18			With the current in the specimen at 45 amperes the temperature increased to approx. 810C. Smoke and vapors appeared which flashed in the spark gap but were not affected by the now incandescent heater wire -- self extinguishing when the spark gap was de-energized
18.3			Insulation was almost completely destroyed -- test off

Wire No. 6 (6-I-1)

Chamber Pressure - 242 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	0		Wire temperature increased rapidly to 482C no effect on wire surface
5	33.8	*	Darkening of insulation
6			Shrinking inside of coil, spark gap caused no ignition of off-gassing products
10	Off		

A whitish material flowed around a thermocouple lead and solidified

*Thermocouple broke before temperature could be measured.

Wire No. 6 (6-I-2)

Chamber Pressure - 254 mm.
Current - Steady
Heater Coil Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start			Wire temperature increased with heating coil to 505C
2			No apparent surface effect
4			Discoloration around center of wire
5	26.3		
6		594	
7			Quite dark near center
7.75			One flash when spark gap was energized
8		600	Very dark near center
9			Almost black at the center
10	30		
11		646	
12	Off	654	Black at center

No smoke, no flame, apparent deposit burned off electrode when spark gap was energized. After the test there were whitish drops on the insulation surface.

Wire No. 6 (6-I-3)

Chamber Pressure - 267 mm.
Current - As Specified Below
Heater - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start			Temperature reached 490C in 25 sec.
5		496	No Reaction to spark plug
5	30		
6		572	
6.5			Insulation discolored
6.75	37.5		
7.5		626	Insulation black, electrode burned off some deposited material
9	37.5	634	
10.5			Insulation sagged
11	Off		

Beads of a whitish material appeared around the wire near the area of the coil.

Wire No. 9 (9-I-2)

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start			
1		264	Insulation swelled
2		438	
3		488	
4			A section of insulation fell away -- exposing a fresh section -- the wire insulating appeared as an outer skin had fallen off
5		482	
6	37.5	>660	

Temperature increased to greater than 660C. When the spark gap was energized a very blue flame appeared and progressed up the insulation. The flame was quite like a hydrogen flame in color and general appearance and was not extinguished until all three sources of heat were de-energized. Small bright sparks accompanied the burning gas.

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start			Temperature increased to 488C in 15 sec.
0.5		528	
1.5		541	
2			Conductor has sagged against heater coil
3		535	
4.5			Several turns of heater coil shorted by sagging conductor, temperature increased to >650C
5.75			Shorted turns opened and temperature decreased
6.5	27		Current was passed through wire
7		653	
7.5			Insulation stripps away
8	24.8	645	
8.5	37.5		
8.75-9.25			Insulation stripped away and shreds fell on incandescent heating coil. Spark gap was energized and a very blue flame resulted and progressed down the insulation until all sources were removed.

Wire No. 9 (9-I-4)

Chamber Pressure - 254 mm.
Current - As Specified Below
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start			Temperature reached 48°C after 0.5 min.
2-4			Spark gap causes no reaction, temperature has increased to 531C
5	32.5	581	Electrode burns off, Insulation splits
7.5	35	660	
9	37.5	>660	Insulation strips badly
12	40		Insulation hangs in shreds
15	42.5		Entire center section is bare -- pieces of hanging insulation are melting
17.5	45		Within 30 seconds the conductor melted -- no fire resulted

Spark gap showed some burn off -- but no fire or flame resulted.

Wire No. 3 (3-IIA-1)

Chamber Pressure - 267 mm.
Current - Steady
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	50		
12 sec.	50		Shrinks
20 sec.	50		Melts
30 sec.	50		Flashes at spark gap
40 sec.	50		Flashes at spark gap
1	51	590	
1 min. 20 sec.	51		Smoke
1 min. 30 sec.	51		Conductor glows red
1 min. 45 sec.	51		Flashing at spark gap
2 min. 35 sec.	51		Insulation falls off
3 min. 40 sec.		Off	

White powder deposited -- some acrid odor from decomposition products was noted.

Wire No. 3 (3-IIA-2)

Chamber Pressure - 254 mm.
Current - Steady
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max.* Temp. (°C)	Remarks
Start	50		
25 sec.	50		Shrinks
29 sec.	50		Swells
40 sec.	50		Insulation melts
56 sec.	50		Chars
66 sec.	50		Smoke
1 min. 25 sec.	50		Flashes at spark gap
1 min. 30 sec.	50		Conductor glows red
1 min. 45 sec.	50		
2 min.	50		
2 min. 45 sec.	50		Yellow flame -- self ignited appears as a glow in pieces of insulation separated slightly from the conductor

*Temperature rose too rapidly to be recorded accurately. Maximum temperature at the conclusion of the test is about 900°C.

Wire No. 3 (3-IIA-3)

Chamber Pressure - 254 mm.
Current - Steady
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp.* (°C)	Remarks
Start	50		
20 sec.	50		Black
55 sec.	50		Smoke
1 min. 10 sec.	50		Much smoke
2 min.	50		Insulation almost entirely gone at this time
2 min. 50 sec.	50		Insulation glows and appears to burn at intervals

During these tests a very distinctive acrid odor was noticed.

*Temperature rose too rapidly to be recorded accurately. Maximum temperature at the conclusion of the test is about 900°C.

Wire No. 4 (4-IIA-1)

Chamber Pressure - 254 mm.
Current - Steady
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	40		
4	40.5	395	Slight darkening
7	45		
7.5	45		Increased darkening, bright flashes appear when spark gap is energized
8.0		673	
8.5	46.4		
10	Off		Wrap is coming off

Wire No. 4 (4-IIA-2)

Chamber Pressure - 254 mm.
Current - Steady
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Temp. (°C)	Remarks
Start	40		
0.5		393	
1	40		Discoloration of surface
2	40		Increased darkening
2.5		510	
4		510	
5	45		No reaction to spark discharge
5.5	45		Very dark -- swelling
5.75	45		Unwrapping of surface
6.5		620	
7.5	45		Wrap opens to expose bare conductor at upper section
8	45		Insulation flakes off
9	Off	655	Insulation continues to flake off until test is concluded

Wire No. 4 (4-IIA-3)

Chamber Pressure - 254 mm.
Current - Steady
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	45		
1	45	685	Very dark -- unwrapping no gap reaction to spark discharge
2	43.5	725	
2.5	44.2	750	Shrinks where drop leads are attached
3			Pressure decreased to 127 mm.
5	45	>800	Insulation almost completely destroyed at center of the specimen

Whitish deposit on the terminal blocks was noticed afte all tests on this type wire.

Wire No. 5 (5-IIA-1)

Chamber Pressure - 254 mm.
Current - Steady
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	40		
.5		225	
0.75			Darkens
1	40.1	308	Shrinks
5	40.9	475	Continues to darken
5.25	45		
5.5	45	490	Very black, starting to unwrap
6			Insulation is very black, shrunken badly, no flaking and seems not to unwrap further
7.5	45	533	Unwraps at bottom section
9	Off		White deposit on specimen terminal blocks

Wire No. 5 (5-IIA-2)

Chamber Pressure - 254 mm.
Current - Steady
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	40		
0.5	39.4	385	Darkens
1.5	39.2	402	Shrinks
2		410	
2.5			Very dark -- starting to unwrap
3	39.7	395	
4		430	
5	40.1	435	
5.25	42.5		
6	42.8	520	Very black -- starting to swell -- continues to unwrap
7		508	
7.5	45		Drop lead broke
9			Flickers at spark gap electrodes
10	Off		

Whitish deposit on specimen terminal blocks. Beads of material formed on surface of the insulation.

Wire No. 5 (5-IIA-3)

Chamber Pressure - 254 mm.
Current - Steady
Heater Coil - Energized

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	40		
1	39.7	340	Darkens
2	39.8	380	Shrinks
4	40.4	380	Wrap loosens
5	42.5		
5.5	42.4	468	Very dark -- unwrapping
7.5	45		
8		560	
8.25			Wrap loosens badly -- conductor glows
9	45	560	Spark gap -- no reaction
10	Off		

Wire No. 6 (6-IIA-1)

Chamber Pressure - 254 mm
Current - Steady
Heater - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	40		
1	40		Darkens - drop leads failed
3.5	40		Shrinks
13	40		Wire quite dark nearer center
15	42.5	*665	No change
17.5	45		No change
20	47.5	*875	No change
20.5			Appears to shrivel
20.75			Drips
21			Bare wire shows
21.5			Spark discharge ignites a by-product
23	50		
24			Off

No flame at any time - apparently the FEP melts and allows the H-film to unwrap.

*Maximum temperature has been estimated from current-temperature plot. Voltage drop leads burned off.

Wire No. 6 (6-IIA-2)

Chamber Pressure - 242 mm.
Current - Steady
Heater - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	40		
2			Center portion and lower portion darkens - no reaction to spark discharge.
5	40		Continues to darken.
6.5	39.8	408	
7.5			Very dark.
9.0	42.8	477	
12	43.4	473	
15	42.7	465	
17	50		Very black - starts to drip - bare wire shows through dripping area - no reaction to spark discharge
18			Off

No flame, no reaction to spark discharge.

Wire No. 6 (6-11A-3)

Chamber Pressure - 254 mm
Current - Steady
Heater - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	50		
0.33	50		Center darkens.
55 sec.	50		Smoke
1 min. 25 sec.	50		Shrinks - very black
1.5	51		
2		680	Insulation flakes off - very black
2.25			Wire glows.

No flame, no reaction to spark discharge. After each of the three tests, a white powdery deposit was noticed around the upper block of the specimen holder.

Chamber Pressure - 254 mm. O_2
Current - Steady
Heater - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	40		
1	37.5	325	Shrinks
5	40.1	425	Electrode burnoff.
6.0	45		
6.5	45	532	Rapid shrinking
6.75			Insulation splits.
8			Insulation slipped and rests on lower drop lead.
9	43.1	560	Conductor glows.
10.25	48.8	>800	Conductor glows brightly.
11.75			Conductor melted No flame - test off

The insulation first shrunk from around the area split to receive the drop leads. As the temperature increased, the insulation split longitudinally and slipped down the conductor until it was stopped by the lower drop lead. It finally split away until the entire 1 inch center section was bare, meanwhile the insulation split above and below the drop leads until the conductor melted. The spark discharge indicated that a residue was formed and this "burned off" the electrodes when energized. There was no apparent smoke or falme at any time.

Chamber Pressure - 254 mm. O_2
Current - Steady
Heater - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	40		
1	39.4	485	Shrinks
1.25			Electrode burn-off
6	45.8	612	Rapid shrinking Insulation splits
7	43.5		Insulation slipped
7.25			Insulation falls off, conductor has a dull red glow
8		745	
8.5	44.6		Wire glows brightly
9	45.4	>800	Insulation is in shreds - spark discharge still indicates burn-off, no flame
10.75	48.8	>800	Insulation melts away from upper part
12	54	>800	Wire very brillant - insulation is almost completely gone for entire length except near terminal blocks.
12.75	56.2	>800	Conductor melted - no flame

The insulation reacted very similar to the first replicate. Current was increased until the conductor melted. At failure there was no smoke or flame.

Wire No. 9 (9-IIA-3)

Chamber Pressure 254 mm. O_2
Current - Steady
Heater - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	45		
25 sec.	45		Shrinks
0.5	44.2	440	
1.0		598	
1.13			Splits around center
1.75	45	665	
2			Shrinks
2.5			Center slipped down
3	44.2	705	Insulation falling off - conductor shows red - bare spots.
3.75		740	
4.5	45		Insulation continues to split and fall off - no flame
5			Off

This specimen was tested with a constant current of 45 amperes which would produce a temperature of 765°C at the center of the conductor. From the previous two tests at steady current condition, it was apparent that rapid degradation of the insulation would occur.

Wire No. 3 (3-IIB-1)

Chamber Pressure - 254 mm.
Current - Increasing
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
2.5	30		
5.0	32.5		
7.5	35		
10.0	37.5		Slight darkening
11	37.5	310	Spark discharge causes gap flickering
12.5	40		Dark and swells
15	42.5	340	Bare spot showing at center
18	45		Drops formed
20	47.5		
20.5	47.2	655	Conductor glows
21	47.2		Very small yellow flame appeared - extinguished itself
23	Off		

Wire No. 3 (3-IIB-2)

Chamber Pressure - 254 mm.
Current - Increasing
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
		115	
2.5	30		
5	32.5		
7.5	35		
9	35	347	Shrinks
10	37.5		
12	37.5	457	Drips
12.5	40		
14	40	490	Swells
15	42.5		
16	43.1	573	Surface appears uneven - insulation loosening at wraps
17	42.4		
17.5	45		Flicker at spark gap electrode
18	45	608	Shrivels and chars
19	45		Very black - flakes
20	47.5		
21	48.8	>800	Large bare spots - wire glows

Wire No. 3 (3-IIB-3)

Chamber Pressure - 254 mm.
Current - Increasing
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
2.5	30		
5	32.5	192	
7.5	35	212	Shrinks
10	37.5		Some darkening
11	37.5	288	Blisters or drips
12.5	40		
13	40.5	355	Splitting of portion above upper drop lead
15	42.5		Sputtering around electrode of spark gap
17	42	568	
17.5	45		
18.5	45		Insulation flaking off-glowing
19	45.8	>800	

Note: Some strands of the conductor were damaged during stripping

Chamber Pressure - 22[illegible] mm.
Current - Increasing
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C) Calculated	Measured*	Remarks
Start	20			
3	30			
5.0	32.5			
7.5	35			
8.5	34.9	318		Slight darkening
10	37.5		425	
12.5	40		570	
13		448		Dark brown - shrinks at drop leads
15	42.5		656	
16		475		
16.5	42.5			Unwraps at the lower end
17		543		
17.5	43.5			Unwrapping continues
18.5	44.2	590	760	Insulation almost gone at center
19	Off			

*The "measured" temperatures are taken from a calibration run with #4 wire. The differences between the measured temperatures and those calculated from the voltage drop points up the problem involved in temperature measurements. See the text for more details.

Wire No. 4 (4-IIB-2)

Chamber Pressure - 254 mm.
Current - Increasing
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C) Calculated	Measured*	Remarks
Start	20			
2.5	30			
5	32.5			
7.5	35			
10	37.5		470	
12	38.2	218		Discoloration
12.5	40		570	
14.5		253		
15	42.5		656	Quite dark - shrinking - unwrapping
16	42	333		
16.25				Shrinks - unwrapping - very dark
17		373		
17.5	45		760	Wire appearance increased from dull to bright red as current to 50.2 amperes was increased
	Off			

*See comment on previous chart, 4-IIB-1

Wire No. 4 (4-IIB-3)

Chamber Pressure - 254 mm.
Current - Increasing
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C) Calculated	Measured*	Remarks
Start	20			
2.5	30			
5.0	32.5			
7.5	35			
10	37.5			
12.5	40			
13	41.2		600	Darkening - shrinks
14	40.5			No spark gap reaction
15	42.5			
15.5				Very dark
16	42.4		659	Swells - black
17	42			Unwraps
17.5	45		760	
18	45	@800		Badly unwrapped - almost black - conductor glows
19	Off			

*See comment on previous chart, 4-IIB-1

Wire No. 5 (5-IIB-1)

Chamber Pressure - 254 mm.
Current - Increasing
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
2.5	30		
4.5		205	
5.0	32.5		
7.5	35		
8	34.5	312	Slight darkening
9	37.5		Tape unwraps - darkens
11	37.5	370	Continues to unwrap
11.5	40		
12.5	39.8	440	Shrinks
14	42.5		
16.5	45		
17.5	42	650	Very black - wire glows, insulation appears to glow
18.5	Off		Insulation is almost totally destroyed.

White beads have formed on the insulation surface

Wire No. 5 (5-IIB-2)

Chamber Pressure - 254 mm.
Current - Increasing
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
2.5	30		
5.0	32.5		
6	33	252	Slight darkening
7	33	258	Some loosening of wrap
7.5	35		
10	37.5		
11	38	280	Shrinks
12.5	40		
13	39.8	385	Quite dark
14	39	375	Insulation loosens
15	42.5		
16	42.8	525	Center is black
17	42.8	505	White beads have formed
18			Wire glows - dull red
18.25	45	600	Unwrapping progresses as wire blackens
19	45	605	Insulation appears almost fluid
20			Off

White beads again have formed

Wire No. 5 (5-IIB-3)

Chamber Pressure - 254 mm.
Current - Increasing
Heating Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
2.5	30		
5.0	32.5		
7.5	35		
9.0		240	
10	37.5		Slight discoloration
12.5	40		
13	39.8	350	Darkening - unwrapping
14		397	
15	42.5		Very dark, shrinking at ends loosening
17.5	45		No apparent beading
18		512	
18.25	45		Whitish beads forming an insulation surface
18.5	45		Wire glowing
19.5	Off		

Spark gap energized through tests - showed no reaction except a burn-off of deposits on electrode tips

Wire No. 6 (6-IIB-1)

Chamber Pressure - 254 mm.
Current - Increasing
Heater - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
2		212	
2.5	30		
4		333	
5	32.5		
6		340	
7.5	35.5		
10	37.5		
12		435	
12.5	40		
15	42.5		Wire dark at center
17.5	45		Shrinks - black
19		655	
20	47.5		Very black - bare wire shows through - shrinking
21		>800	
22	48		Off

Spark gap energized periodically throughout the test - no reaction apparent

Wire No. 6 (6-IIB-2)

Chamber Pressure - 267 mm.
Current - Increasing
Heater - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
2		125	
2.5	30		
5	32.5		
7.0		358	
7.5	35		
9		377	
10	37.5		Slight darkening
14	40		Quite dark
15	42 5		Very dark
16	43.1		Wrap appears loose
17.5	45		
18.5	45	638	Conductor showing - insulation black
20	49.5		Unwrapping badly - FEP
21	Off	>800	Wire melted - no reaction to spark discharge ignition

Chamber Pressure - 254 mm.
Current - Increasing
Heater - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
2		226	
2.5	30		
5	32.5		
6		358	
7.5	35		
10	37.5		
11	36.8	453	Specimen darkening
12.5	40		
13	40.9	555	Very dark
15	42.5		Shrinks
17. 5	45		
18	45	626	Very black - drips
19	45		Unwraps
20	47.5		
20.5	47.2	790	Bare conductor shows where insulation is unwrapped
22	48.0	>800	Badly unwrapped
22.5	50.1		Considerable conductor shows - wire glows - no smoke - no ignition with spark discharge

Chamber Pressure - 254 mm.
Current - Increasing
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
2.5	30		
3.0		158	
5	32.5		
5.5 - 6.5		259	Insulation swells
7.5	35		
8		292	Insulation shrinks
10	37.5		
10.25			Shrinks rapidly
12.5	40		
14		427	
15	42.5		
15.5			Insulation at center slid down conductor - stopped at lower voltage drop lead
16	48.8		Current jumped to this value momentarily - electrode burn-off, insulation is stripping rapidly
17.5	45		Current was reduced immediately from 48.8 to 42.5, then the rate of increase was resumed
18	46.5	480	Wire - cherry red

At the lower current (32.5 amps.) the insulation swelled - this was apparent from the decrease in width of the slits in the insulation made to accommodate the voltage drop leads. Then at a temperature very little above that causing swelling, shrinking occurred slowly and then at the next step much more rapidly. There was no flame, smoke or any indication of ignitable gases. The only noticeable effect of the spark gap was to burn off what was apparently a deposit that was formed on the electrode.

Chamber Pressure - 254 mm.
Current - Increasing
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
2.5	30		
3.5		195	
5	32.5		
5.5			Insulation swells
6.5		248	
7.5	35		
7.75			Insulation shrinks
10	37.5		
12		370	
12.5	40		Rapid shrinking continues
15	42.5		
17		537	
17.5	45		
17.75			Insulation melts -- splits along axis of wire -- conductor red
18.5		620	
18.75			Entire center section of insulation is gone -- rest hangs in long shreds
19.25	Off		

No flames or smoke apparent with spark gap energized periodically throughout test.

Chamber Pressure - 254 mm.
Current - Increasing
Heater Coil - Not Used

Elapsed Time (min.)	I (amperes)	Max. Temp. (°C)	Remarks
Start	20		
2.5	30		
3.5		215	Possible start of swelling
5	32.5		
6		292	Insulation swells
7.5	35	430	Insulation shrinks immediately
9		322	
10	37.5	412	
12.5	40		Shrinking continues through last two steps
14		535	
15	42.5		Insulation at center slipped
16		662	
16.25			Insulation strips off -- turns translucent
17			
17.5	45	758	Electrodes burn-off with discharge
17.75			Insulation almost completely gone -- wire glows
19			Remaining insulation is in strips

26. Chemical Compatibility

Many types of chemicals may affect hook-up wire in many ways. Mandrel flexibility (23°C and -196°C) (flex.), voltage breakdown (Bd.) and insulation resistance (IR) have been used to detect and measure such degradation. It should be noted that changes in physical dimension (swelling) and other tests such as abrasion resistance and cut-through might also have been used. Some observations such as change in color, will be reported. Even with just three types of test, an enormous number of measurements had to be made and the results are reported in the next 47 tables.

To serve as a basis for comparison, reference is made to Table XXIV in the section on mandrel flexibility, which gives a summary of the mandrel flexibility lists for unaged and unexposed wires. Tables XLIX and L are included here to provide a similar basis for comparing results of voltage breakdown and insulation resistance. The twisted pair specimen has been used because it is convenient and also subjects the wire to a degree of stretch and compression such as might be encountered in service. The values obtained from the twisted pair tests are not intended to have functional significance but merely provide a basis for comparison so that the affect of chemicals on the wire can be measured quantitatively (at least to some degree). It should be noted here also, that considerable variability is encountered in both voltage breakdown and insulation resistance, so that maximum and minimum values have been used in making comparisons. Even so judgment and experience are involved.

With so much data it has been necessary to separate the results into three sections and to provide a summary sheet for each section in the following.

Degradation from Exposure to Fuels

The degradation from 20 hour immersion in four fuels is compared in a semi-quantitative fashion in Table LI. The detailed quantitative results with the three types of tests are given in tables as follows:

Fuel	Mandrel Flexibility	Voltage Breakdown	Insulation Resistance
UDMH	LII	LIII	LIV
MMH	LV	LVI	LVII
Hydrazine	LVIII	LIX	LX
A-50	LXI	LXII	LXIII

The following observations can be made:

a. All of the fuels degrade H-film if they come in contact with it with some evidence that the unsymetrical dimethyl hydrazine (UDMH) has the least effect.

b. TFE Teflon is completely unaffected by these four fuels and even when used as a thin dispersion coating (wire #3) provides essentially complete protection to the underlying H-film despite the fact that the dispersion coating had "mud flat) cracks in it. It is possible that under vibrational or other stresses that the TFE dispersion coating might not provide protection.

c. The thin FEP Teflon dispersion coating on wire #6 provides some degree of protection for the underlying H-film and only hydrazine and A-50 show appreciable attack on wire #6.

d. The FEP laminated to the H-film used in constructing wires #4 and #5 is apparently not in itself damaged by the fuel. However, the seal provided by the fusion of the FEP in the laminate does not provide adequate protection-at least with these particular wires.

Generally the degradation from the fuels is indicated by all three tests. However, when the attack is not pronounced, one or another of the tests may give the indication of attack.

Degradation from Exposure to Oils and Salt Solutions

Table LXIV summarizes the degradation occurring in 14 days exposure to lubricating oil, hydraulic oil and also after immersion in a 5% solution of sodium chloride in water and exposure to salt fog. The detailed quantitative results with the three types of test are given in tables as follows:

Exposed to	Mandrel Flexibility	Voltage Breakdown	Insulation Resistance
Lube oil	LXV	LXVI	LXVII
Hydraulic Oil	LXVIII	LXVIX	LXX
5% NaCl	LXXI	LXXII	LXXIII
Salt Fog	LXXIV	LXXV	LXXV.

The following observations can be made:

a. The two oils adversely affect mandrel flexibility at -196°C probably because they penetrate H-film taped wires #4 and #5 and enter the space between the jacket and its substrate with wire #7.

b. With wires #4 and #5, voltage breakdown is somewhat increased probably because it fills voids in the structure. The increase in voltage breakdown from exposure to hydraulic oil with irradiated polyolefin wire #8 may be due to slight swelling of the insulation.

c. The slight decrease in resistivity encountered after oil immersion is difficult to explain unless the oils themselves have a low resistance and increase the dielectric area in contact.

d. The degradation noted after exposure to the sodium chloride solution is undoubtedly due to penetration into wires #4 and #5 and absorption in the irradiated polyolefin (wire #8). In the latter case absorption probably is caused by a high percentage of filler. This phenomenon has been noted in other tests as well. The salt solution appreciably decreases voltage breakdown with wire #8 and this degradation is probably functionally significant. The absence of an associated decrease in insulation resistance is difficult to understand.

e. The salt-fog test produces severe degradation in H-film taped wires #4 and #5 and some degradation even in wire #6. These wires are crazed even before test particularly where they have been under strain during exposure. The degradation is characteristic of molecular, hydrolytic scission and is probably caused by moisture and the relatively high temperature of the salt fog test. The TFE dispersion cooling on wire #3 appears to provide considerable protection to the underlying H-film.

f. The salt-fog test also causes considerable degradation in voltage breakdown with polyolefin insulated wire #8 and even some degradation in wire #7 despite the protection of the Kynar jacket. As with the salt solution, the insulation resistance surprisingly is unaffected.

Overall it is apparent that degradation is evaluated in different ways with the different types of test. Curiously the improvement of voltage breakdown in wire #8 after exposure to oil probably indicates attack. The abrasion resistance or cut through tests might have shown degradation in this case. Conversely, the improvement of voltage breakdown with oil immersion of wires #5 and #6 probably is due to elimination of voids and does not indicate degradation. Thus such changes must be interpreted with care and a background of experience.

Degradation from Exposure to Solvents

Table LXXVII summarizes the degradation occurring in 14 days exposure to a variety of organic solvents. The detailed quantitative results are given in tables as follows:

Solvent	Mandrel Flexibility	Voltage Breakdown	Insulation Resistance
Ethyl Alcohol	LXXVIII	LXXIX	LXXX
JP-4	LXXXI	LXXXII	LXXXIII
Freon 114	LXXXIV	LXXXV	LXXXVI
Trichloroethylene	LXXXVI-A	LXXXVII	LXXXVIII
Acetone	LXXXIX	XC	XCI
Freon 113	XCII	XCIII	XCIV

The following observations can be made:

a. These solvents sometimes affect flexibility of the wires at -196°C because they are absorbed and freeze to brittle solids. This penetration probably is functionally significant only when such wires after exposure will be operated in very low temperature ambients.

b. The improvement in the voltage breakdown of wires #7 and particularly #8 with several solvents is undoubtedly due to absorption and probably associated swelling. Degradation of mechanical strength may well result but is not measured in this program.

c. The increase in the voltage breakdown of TFE Teflon (wire #9) in several solvents is startling. In two cases insulation resistance also increases. Perhaps even the sintered Teflon structure can be impregnated with these materials.

Overall it is again apparent that the different types of test appraise resistance to solvents in different ways. It is therefore desirable to use such tests as separate criteria of chemical degradation.

Overall Observations

Chemical resistance constitutes a complex and varied problem as the foregoing indicates. The remarkable superiority of TFE Teflon (wire #9) to such a wide variety of chemical contaminants is noteworthy. The TFE dispersion coating of wire #3 also provides remarkable protection. The recent NASA decision to replace the FEP coating of wires like #6 with TFE is probably very wise. However, the importance of producing a continuous, defect-free coating cannot be underestimated.

Unfortunately, problems have been encountered in tests with fluorine and the tests in nitrogen tetroxide are in progress as this report "goes to press". The tests with the ethylene glycol solution are also underway. The fluorine exposures are being made again and all of these late results will be reported as soon as possible.

TABLE XLIX

COMPARISON OF WIRES
VOLTAGE BREAKDOWN - TWISTED PAIRS

(Unaged Specimen in Air at 23°C-50% RH)

Wire #	Breakdown Voltage - KV Avg.	Max.	Min.	Nominal Insulation Thickness, (mils)
1	25.0	29	19	
3	27.2	28.5	25.5	7.1
4	17.8	18.0	17.5	3.1
5	15.7	19.5	13.0	3.4
6	28.8	30.0	25.5	5.5
7	23.7	25.5	21	9.2
8	27.6	29	26	9.2
9	17.5	20.5	14.5	9.4
10	20.6	23	18	3.5
11	12.3	13.5	10.5	

TABLE L

COMPARISON OF WIRES - INSULATION RESISTANCE - TWISTED PAIRS

(Unaged Specimens in Air at 23°C-50% RH)

Wire #	Insulation Resistance - ohms Max.	Min.
1	$2.8x10^{13}$	$8.6x10^{12}$
3	$6.0x10^{14}$	$2.5x10^{14}$
4	$5.0x10^{13}$	$3.8x10^{13}$
5	$2.5x10^{15}$	$5.9x10^{14}$
6	$3.6x10^{14}$	$2.3x10^{14}$
7	$8.9x10^{12}$	$3.6x10^{12}$
8	$6.3x10^{13}$	$8.3x10^{12}$
9	$1.1x10^{15}$	$3.6x10^{14}$
10	$1.0x10^{14}$	$1.5x10^{13}$
11	Values above $6x10^{14}$	

TABLE LI

SUMMARY, DEGREE OF DEGRADATION FROM EXPOSURE TO FUELS

Chemical	Test	Wire #3	Wire #4	Wire #5	Wire #6	Wire #9
UDMH	Flex.	None	Some	Some	None	None
	Bd.	None	None	None	None	None
	IR	None	None	Some	None	None
MMH	Flex.	None	Severe	Severe	Slight	None
	Bd.	None	Severe	Severe	Slight	None
	IR	Trace	Some	Severe	Trace	None
Hydrazine	Flex.	None	Severe	Severe	Slight	None
	Bd.	None	Severe	Severe	Some	None
	IR	None	None(?)	Severe	Some	None
A-50	Flex.	None	Severe	Severe	None	None
	Bd.	None	Severe	Severe	Some	None
	IR	Trace	Severe	Severe	Slight	None

(?) Result Questioned

TABLE LII

EFFECT OF 20 HOURS EXPOSURE TO UDMH ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - Exposed/Unexposed

Wire #	No Damage Flexed at 23°C	No Damage Flexed at -196°C	Slight Damage Flexed at 23°C	Slight Damage Flexed at -196°C	Severe Damage Flexed at -196°C
3	1X* / 1X	---	---	0.5 / 0.5	---
4	---	---	0.25 / 1X	1.0 / .125	---
5	---	---	1X / 1X	0.50 / .125	0.25 / .075
6	1X / 1X	---	---	---	0.25 / 0.25
9	1X / 1X	---	---	---	0.50 /

*"Mud flat" cracking in the unflexed FEP coating opens with flexing

TABLE LIII

EFFECT OF 20 HOURS EXPOSURE TO UDMH ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	30.5/28.5	29.5/25.5
4	18.5/18.0	16.5/17.5
5	23.0/19.5	14.3/13.0
6	33.2/30.0	30.5/25.5
9	23.4/20.5	21.2/14.5

TABLE LIV

EFFECT OF 20 HOURS EXPOSURE TO UDMH ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	$6.6 \times 10^{14}/6 \times 10^{14}$	$3.1 \times 10^{14}/2.5 \times 10^{14}$
4	$1.4 \times 10^{14}/5 \times 10^{13}$	$9.6 \times 10^{13}/3.8 \times 10^{14}$
5	$1.4 \times 10^{13}/2.5 \times 10^{15}$	$4.2 \times 10^{12}/5.9 \times 10^{14}$
6	$1.2 \times 10^{14}/3.6 \times 10^{14}$	$5.3 \times 10^{13}/2.3 \times 10^{14}$
9	$9.3 \times 10^{14}/1.1 \times 10^{15}$	$4.2 \times 10^{14}/3.6 \times 10^{14}$

TABLE LV

EFFECT OF 20 HOURS EXPOSED TO MMH ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam.- Exposed/Unexposed

	No Damage Flexed at		Slight Damage Flexed At		Severe Damage Flexed at
Wire #	23°C	-196°C	23°C	-196°C	-196°C
3	1X* / 1X	---	---	0.5 / 0.5	---
4	Too damaged to tests- H-film degraded to a yellow-green powder				
5	Too damaged to tests- H-film degraded to a yellow-green powder				
6	.075 / 1X	---	---	0.50 / 0.25	---
9	1X / 1X	---	---	---	0.50 / 0.50

*"Mud flat" cracking in the unflexed FEP coating opens with flexing.

Note: Wire #6 exhibits small yellow spots of degraded H-film.

TABLE LVI

EFFECT OF 20 HOURS EXPOSURE TO MMH ON VOLTAGE BREAKDOWN- TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	29.2/28.5	28.2/25.5
4	1.5/18.0	1.0/17.5
5	4.1/19.5	2.0/13.0
6	26.0/30.0	23.0/25.5
9	20.8/20.5	17.0/14.5

Note: Breakdown in #5 wire is accompanied by flame after exposure to MMH.

TABLE LVII

EFFECT OF 20 HOURS EXPOSURE TO MMH ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	$1.3 \times 10^{14}/6 \times 10^{14}$	$7.8 \times 10^{13}/2.5 \times 10^{14}$
4	$2.2 \times 10^{12}/5 \times 10^{13}$	$1.2 \times 10^{11}/3.8 \times 10^{14}$
5	$3.9 \times 10^{12}/2.5 \times 10^{15}$	$2.3 \times 10^{11}/5.9 \times 10^{14}$
6	$1.5 \times 10^{14}/3.6 \times 10^{14}$	$5 \times 10^{13}/2.3 \times 10^{14}$
9	$1.5 \times 10^{15}/1.1 \times 10^{15}$	$1.1 \times 10^{15}/3.6 \times 10^{14}$

TABLE LVIII

EFFECT OF 20 HOURS EXPOSURE TO HYDRAZINE ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - Exposed / Unexposed

Wire #	No Damage Flexed at 23°C	No Damage Flexed at -196°C	Slight Damage Flexed at 23°C	Slight Damage Flexed at -196°C	Severe Damage Flexed at -196°C
3	1X* / 1X	-	-	0.5 / 0.5	-
4	Too damaged to test - H-film degraded to a yellow powder.				
5	Too damaged to test - H-film degraded to a yellow powder.				
6	.50 / 1X	-	-	.50 / .25	-
9	1X / 1X	-	-	.75 / .75	-

*"Mud flat" cracking in the unflexed FEP coating opens with flexing.

TABLE LIX

EFFECT OF 20 HOURS EXPOSURE TO HYDRAZINE ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	29.5/28.5	26.5/25.5
4	4.1/18.0	3.6/17.5
5	5.1/19.5	3.0/13.0
6	16.6/30.0	15.3/25.5
9	22.4/20.5	17.0/14.5

Note: Breakdown with wires #4 and #5 is accompanied by a brilliant flame after specimens have been exposed to hydrazine.

TABLE LX

EFFECT OF 20 HOURS EXPOSURE TO HYDRAZINE ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	$5.6 \times 10^{14}/6 \times 10^{14}$	$2.9 \times 10^{14}/2.5 \times 10^{14}$
4	$5 \times 10^{13}/5 \times 10^{13}$	$2.3 \times 10^{13}/3.8 \times 10^{13}$
5	$2.5 \times 10^{13}/2.5 \times 10^{15}$	$2 \times 10^{10}/5.9 \times 10^{14}$
6	$7.8 \times 10^{13}/3.6 \times 10^{14}$	$3.9 \times 10^{12}/2.3 \times 10^{14}$
9	$3.0 \times 10^{15}/1.1 \times 10^{15}$	$1.2 \times 10^{15}/3.6 \times 10^{14}$

TABLE LXI

EFFECT OF 20 HOURS EXPOSURE TO A-50 ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - $\frac{\text{Exposed}}{\text{Unexposed}}$

Wire #	No Damage Flexed at 23°C	No Damage Flexed at -196°C	Slight Damage Flexed at 23°C	Slight Damage Flexed at -196°C	Severe Damage Flexed at -196°C
3	1X*/1X	-	-	0.5/0.5	-
4	Too damaged to test - H-film degraded to a brigh yellow powder.				
5	Too damaged to test - H-film degraded to a yellow-gold powder.				
6	1X/1X	-	-	0.25/0.25	-
9	1X/1X	-	-	-	0.50/0.50

*"Mud flat" cracking in the unflexed FEP coating opens with flexing.

Note: Wire #6 exhibits yellow spots of degraded H-film plus extensive crazing in the yellow areas.

TABLE LXII

EFFECT OF 20 HOURS EXPOSURE TO A-50 ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	28.4/28.5	24.0/25.5
4	4.4/18.0	4.0/17.5
5	4.1/19.5	2.0/13.0
6	23.0/30.0	15.5/23.5
9	22.3/20.5	18.4/14.5

TABLE LXIII

EFFECT OF 20 HOURS EXPOSURE TO A-50 ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	$1.4 \times 10^{14} / 6 \times 10^{14}$	$6.6 \times 10^{13} / 2.5 \times 10^{14}$
4	$1.4 \times 10^{12} / 5 \times 10^{13}$	$5 \times 10^{10} / 3.8 \times 10^{13}$
5	$2.3 \times 10^{11} / 2.5 \times 10^{15}$	$8.9 \times 10^{10} / 5.9 \times 10^{14}$
6	$6 \times 10^{13} / 3.6 \times 10^{14}$	$1.8 \times 10^{13} / 2.3 \times 10^{14}$
9	$1 \times 10^{15} / 1.1 \times 10^{15}$	$6 \times 10^{14} / 3.6 \times 10^{14}$

TABLE LXIV

SUMMARY, DEGREE OF DEGRADATION FROM EXPOSURE TO OILS AND SALT SOLUTIONS

Chemical	Test	Wire #1	Wire #2	Wire #3	Wire #4	Wire #5	Wire #6	Wire #7	Wire #8	Wire #9	Wire #10
Lube Oil	Flex			None	Some	Some	Trace	Some	?	None	
	Bd.			None	None	None	*	None	None	None	
	IR			Trace	Trace	Slight	Trace	None	None	Slight	
Hydraulic Oil	Flex			None	Slight	Slight	None	Some	?	None	
	Bd.			None	None	*	*	None	X	None	
	IR			Trace	Trace	Some	Trace	None	None	Slight	
5% NaCl	Flex			None	Slight	Some	None	None	?	None	
	Bd.			None	Some	Trace	None	Trace	Some	None	
	IR			Trace	Trace	Some	Trace	None	None	None	
Salt Fog	Flex	Slight		Slight	Severe	Some	Some	None	?	None	
	Bd.	Slight		None	Severe	Severe	Some	Slight	Some	Slight	
	IR	None		Slight	Some	Some	Slight	None	None	None	

*Improved Somewhat

TABLE LXV

EFFECT OF 16 DAYS EXPOSURE TO LUBE OIL ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - Exposed/Unexposed

	No Damage Flexed at		Slight Damage Flexed at		Severe Damage Flexed at
Wire #	23°C	-196°C	23°C	-196°C	-196°C
3	1X / 1X	---	---	0.5 / 0.5	---
4	---	---	1X / 1X	.25 / .125	---
5	---	---	1X / 1X	0.50 / .125	0.25 / .075
6	1X / 1X	---	---	0.50 / 0.25	---
7	1X / .075	---	---	---	3.0 / 1.75
8	1X / 1X	---	---	---	3.0 / 3.0
9	1X / 1X	---	---	---	0.5 / 0.5

TABLE LXVI

EFFECT OF 14 DAYS EXPOSURE TO LUBE OIL ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	31 / 28.5	27.4/ 25.5
4	26 / 18	24.4/ 17.5
5	20.8/ 19.5	14 / 13
6	38.4/ 30	35.2/ 25.5
7	23 / 25.5	18 / 21
8	34 / 29	29 / 26
9	21.5/ 20.5	19.5/ 14.5

TABLE LXVII

EFFECT OF 14 DAYS EXPOSURE TO LUBE OIL ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	$2.0 \times 10^{13}/6 \times 10^{14}$	$1.4 \times 10^{13}/2.5 \times 10^{14}$
4	$6 \times 10^{12}/5 \times 10^{13}$	$4.2 \times 10^{12}/3.8 \times 10^{13}$
5	$1.3 \times 10^{13}/2.5 \times 10^{15}$	$8.9 \times 10^{12}/5.9 \times 10^{14}$
6	$3.6 \times 10^{13}/3.6 \times 10^{14}$	$2.2 \times 10^{13}/2.3 \times 10^{14}$
7	$2.3 \times 10^{13}/8.9 \times 10^{12}$	$3.6 \times 10^{12}/3.6 \times 10^{12}$
8	$1.3 \times 10^{13}/6.3 \times 10^{13}$	$1.2 \times 10^{13}/8.3 \times 10^{12}$
9	$3.9 \times 10^{13}/1.1 \times 10^{15}$	$23 \times 10^{13}/3.6 \times 10^{14}$

TABLE LXVIII

EFFECT OF 14 DAYS EXPOSURE TO HYDRAULIC OIL ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - Exposed/Unexposed

Wire #	No Damage Flexed at 23°C	No Damage Flexed at -196°C	Slight Damage Flexed at 23°C	Slight Damage Flexed at -196°C	Severe Damage Flexed at -196°C
3	1X/1X	---	---	0.5/0.5	---
4	---	---	1X/1X	.25/.125	---
5	---	---	1X/1X	.25/.125	---
6	1X/1X	0.50/0.50	---	---	---
7	1X/.075	---	---	---	3.0/1.75
8*	1X/1X	---	---	---	3.0/3.0
9	1X/1X	---	---	---	0.5/0.5

*Insulation stained - pink color

TABLE LXIX

EFFECT OF 14 DAYS EXPOSURE TO HYDRAULIC OIL ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	31.4/28.5	28.9/25.5
4	23.7/18	19.3/17.5
5	25 /19.5	20 /13
6	36.2/30	35 /25.5
7	25.2/25.5	18.4/21
8	35.1/29	30 /26
9	19.9/20.5	18.7/14.5

TABLE LXX

EFFECT OF 14 DAYS EXPOSURE TO HYDRAULIC OIL

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	$1.4 \times 10^{13} / 6 \times 10^{14}$	$3.9 \times 10^{12} / 2.5 \times 10^{14}$
4	$1.1 \times 10^{13} / 5 \times 10^{13}$	$6.1 \times 10^{12} / 3.8 \times 10^{13}$
5	$9.8 \times 10^{12} / 2.5 \times 10^{15}$	$8.3 \times 10^{12} / 5.9 \times 10^{14}$
6	$1.1 \times 10^{13} / 3.6 \times 10^{14}$	$6.8 \times 10^{12} / 2.3 \times 10^{14}$
7	$2.3 \times 10^{13} / 8.9 \times 10^{12}$	$1.5 \times 10^{13} / 3.6 \times 10^{12}$
8	$1.6 \times 10^{13} / 6.3 \times 10^{13}$	$1.4 \times 10^{13} / 8.3 \times 10^{12}$
9	$2.9 \times 10^{13} / 1.1 \times 10^{15}$	2.0×10^{13} 3.6×10^{14}

TABLE LXXI

EFFECT OF 14 DAYS EXPOSURE TO 5% NaCl ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - Exposed/Unexposed

	No Damage Flexed at		Slight Damage Flexed at		Severe Damage Flexed at
Wire #	23°C	-196°C	23°C	-196°C	-196°C
3	1X/1X	---	---	0.50/0.50	---
4	---	---	1X/1X	0.25/.125	---
5	---	---	0.25/1X	---	0.25/.075
6	1X/1X	---	---	0.25/0.25	---
7	1X/.075	2.0/2.0	---	---	---
8	1X/1X	---	---	---	3.0/3.0
9	1X/1X	---	---	---	0.5/0.5

TABLE LXXII

EFFECT OF 14 DAYS EXPOSURE TO 5% Na Cl ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (kv) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	26.5/ 28.5	25.5/ 25.5
4	16.6/ 18	8.7/ 17.5
5	15 / 19.5	12.5/ 13
6	29.5/ 30	27 / 25.5
7	20.5/ 25.5	19.5/ 21
8	24 / 29	17 / 26
9	20.5/ 20.5	1[illegible].5/ 14.5

TABLE LXXIII

EFFECT OF 14 DAYS EXPOSURE TO 5% Na Cl ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Max Values	Min. Values
3	$2.1 \times 10^{14} / 6 \times 10^{14}$	$7.8 \times 10^{13} / 2.5 \times 10^{14}$
4	$1.9 \times 10^{13} / 5 \times 10^{13}$	$2.8 \times 10^{12} / 3.8 \times 10^{13}$
5	$1.6 \times 10^{12} / 2.5 \times 10^{15}$	$8.6 \times 10^{11} / 5.9 \times 10^{14}$
6	$3.5 \times 10^{13} / 3.6 \times 10^{14}$	$2.3 \times 10^{13} / 2.3 \times 10^{14}$
7	$2.5 \times 10^{13} / 8.9 \times 10^{12}$	$1.7 \times 10^{13} / 3.6 \times 10^{12}$
8	$6.3 \times 10^{13} / 6.3 \times 10^{13}$	$1.9 \times 10^{13} / 8.3 \times 10^{12}$
9	$7.1 \times 10^{14} / 1.1 \times 10^{15}$	$2.9 \times 10^{14} / 3.6 \times 10^{14}$

TABLE LXXIV

EFFECT OF 14 DAYS EXPOSURE TO SALT FOG ON MANDREL FLEXIBILITY

Ratio of Mandrel Dias. - Exposed/Unexposed

	No Damage Flexed at		Slight Damage Flexed at		Severe Damage Flexed at
Wire #	23°C	-196°C	23°C	-196°C	-196°C
3	1X/1X	---	---	0.75/0.50	---
4	---	---	0.25/1X	---	1.75/.075
5	---	---	.075/1X	---	1.0/.075
6	1X/1X	---	---	1.0/0.25	---
7	075/.075	---	---	---	1.75/1.75
8	1X/1X	---	---	---	3.0/3.0
9	11X/1X	---	---	---	0.5/0.5
10	---	---	1X/1X	0.50/0.50	---
1	1X/1X	---	1X/1X	---	1.0/0.5

TABLE LXXV

EFFECT OF 14 DAYS EXPOSURE TO SALT FOG ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (kv) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	27 / 28.5	21.5 / 25.5
4	2 / 18	1.25 / 17.5
5	6 / 19.5	2.5 / 13
6	23 / 30	21.5 / 25.5
7	21 / 25.5	18 / 21
8	15 / 29	15 / 26
9	24 / 20.5	22 / 14.5
10	18.5 / 23	17 / 18
1	20.5 / 29	14.5 / 19

TABLE LXXVI

EFFECT OF 14 DAYS EXPOSURE TO SALT FOG ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	3.9×10^{13} / 6×10^{14}	2.5×10^{13} / 2.5×10^{14}
4	2.3×10^{9} / 5×10^{13}	3.9×10^{8} / 3.8×10^{13}
5	1.5×10^{13} / 2.5×10^{15}	1.9×10^{9} / 5.9×10^{14}
6	1.7×10^{13} / 3.6×10^{14}	5.9×10^{11} / 2.3×10^{14}
7	2×10^{13} / 8.9×10^{12}	1.9×10^{13} / 3.6×10^{12}
8	3.9×10^{13} / 6.3×10^{13}	1.8×10^{13} / 8.3×10^{12}
9	$> 10^{14}$ / 1.1×10^{15}	$> 10^{14}$ / 3.6×10^{14}
10	4.2×10^{13} / 1×10^{14}	2.9×10^{11} / 1.5×10^{13}
1	1.8×10^{13} / 2.8×10^{13}	1.4×10^{13} / 8.6×10^{12}

TABLE LXXVII

SUMMARY - DEGREE OF DEGRADATION FROM EXPOSURE TO SOLVENTS

Solvent	Test	Wire # 3	4	5	6	7	8	9
Ethyl Alcohol	Flex.	None	Some	Some	Slight	Slight	?	None
	Bd.	None	None	None	None	None	Slight	None
	IR	None	*	None	None	*	*	None
JP-4	Flex.	None	Slight	Slight	Slight	Slight	?	None
	Bd.	None	None	*	None	Some	**	*
	IR	None	None	Slight	Slight	*	*	None
Freon 114	Flex.	None	None	None	Slight	Slight	?	Slight
	Bd.	None	None	None	None	None	None	None
	IR	None	None	Trace	Trace	*	*	None
Trichloroethylene	Flex.	None	Some	Some	Some	Slight	?	None
	Bd.	None	None	None	None	*	**	*
	IR	None	None	Trace	None	*	*	None
Acetone	Flex.	Slight	Some	Slight	Slight	-	-	None
	Bd.	None	None	None	None	-	-	*
	IR	None	None	Some	Slight	-	-	*
Freon 113	Flex.	None	Some	Slight	None	Slight	?	Slight
	Bd.	None	None	None	*	*	**	*
	IR	Trace	*	Trace	Trace	*	*	*

*Improved somewhat

** Improved markedly

TABLE LXXVIII

EFFECT OF 14 DAYS EXPOSURE TO ETHYL ALCOHOL ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - Exposed / Unexposed

Wire #	No Damage Flexed at 23°C	No Damage Flexed at -196°C	Slight Damage Flexed at 23°C	Slight Damage Flexed at -196°C	Severe Damage Flexed at -196°C
3	1X / 1X			0.5 / 0.5	
4			1X / 1X	0.5 / .125	
5			1X / 1X		0.25 / .075
6	1X / 1X			0.50 / 0.25	
7	.075 / .075				2.0 / 1.75
8	1X / 1X				3.0 / 3.0
9	1X / 1X				0.5 / 0.5

TABLE LXXIX

EFFECT OF 14 DAYS EXPOSURE TO ETHYL ALCOHOL ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	29.0/28.5	28.0/25.5
4	18.0/18.0	16.5/17.5
5	18.0/19.5	15.0/13.0
6	32.0/30.0	29.5/25.5
7	27.7/25.5	25.2/21.0
8	21.9/29.0	21.2/26.0
9	23.0/20.5	18.0/14.5

TABLE LXXX

EFFECT OF 14 DAYS EXPOSURE TO ETHYL ALCOHOL ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	$1.1 \times 10^{15}/6.0 \times 10^{14}$	$2.1 \times 10^{14}/2.5 \times 10^{14}$
4	$2.4 \times 10^{14}/5.0 \times 10^{13}$	$1.0 \times 10^{14}/3.8 \times 10^{13}$
5	$8.3 \times 10^{14}/2.5 \times 10^{15}$	$4.2 \times 10^{14}/5.9 \times 10^{14}$
6	$3.1 \times 10^{14}/3.6 \times 10^{14}$	$1.4 \times 10^{14}/2.3 \times 10^{14}$
7	$1.9 \times 10^{13}/8.9 \times 10^{12}$	$1.1 \times 10^{13}/3.6 \times 10^{12}$
8	$1.4 \times 10^{14}/6.3 \times 10^{13}$	$1.0 \times 10^{14}/8.3 \times 10$[illegible]
9	$4.2 \times 10^{14}/1.1 \times 10^{15}$	$3.6 \times 10^{14}/3.6 \times 10^{14}$

TABLE LXXXI

EFFECT OF 14 DAY EXPOSURE TO JP-4 ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - Exposed/Unexposed

Wire #	No Damage Flexed at 23°C	No Damage Flexed at -196°C	Slight Damage Flexed at 23°C	Slight Damage Flexed at -196°C	Severe Damage Flexed at -196°C
3	1X/1X	---	---	0.5/0.5	---
4	---	---	1X/1X	.250/.125	---
5	---	---	1X/1X	.250/.125	---
6	1X/1X	---	---	0.50/0.25	---
7	1X/.075	---	---	---	2.0/1.75
8	1X/1X	---	---	---	2.0/3.0
9	1X/1X	---	---	---	0.5/0.5

TABLE LXXXII

EFFECT OF 14 DAYS EXPOSURE TO JP-4 ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	27.5/28.5	26.5/25.5
4	18.0/18.0	17.5/17.5
5	23.0/19.5	21.5/13.0
6	31.0/30.0	27.5/25.5
7	18.5/25.5	16.5/21.0
8	35.0/29.0	32.5/26.0
9	24.0/20.5	17.5/14.5

TABLE LXXXIII

EFFECT OF 14 DAYS EXPOSURE TO JP-4 ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	$6.3 \times 10^{14}/6 \times 10^{14}$	$3.6 \times 10^{14}/2.5 \times 10^{14}$
4	$1.3 \times 10^{14}/5 \times 10^{13}$	$5.6 \times 10^{13}/3.8 \times 10^{13}$
5	. $5 \times 10^{13}/2.5 \times 10^{15}$	$3.2 \times 10^{13}/5.9 \times 10^{14}$
6	$9.8 \times 10^{13}/3.6 \times 10^{14}$	$1.5 \times 10^{12}/2.3 \times 10^{14}$
7	8.[illegible] $\times 10^{13}/8.9 \times 10^{12}$	$2 \times 10^{13}/3.6 \times 10^{12}$
8	$2.4 \times 10^{14}/6.3 \times 10^{13}$	$2.3 \times 10^{14}/8.3 \times 10^{12}$
9	$4.2 \times 10^{14}/1.1 \times 10^{15}$	$3.1 \times 10^{14}/3.6 \times 10^{14}$

TABLE LXXXIV

EFFECT OF 14 DAYS EXPOSURE TO FREON 114 ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - Exposed/Unexposed

Wire #	No Damage Flexed at 23°C	No Damage Flexed at -196°C	Slight Damage Flexed at 23°C	Slight Damage Flexed at -196°C	Severe Damage Flexed at -196°C
3	1X/1X	-	-	0.5/0.5	-
4	-	-	1X/1X	.125/.125	
5	-	-	1X/1X	.125/.125	
6	1X/1X	-	-	.05/0.25	
7	1X/1X	-	-	-	2.0/1.75
8	1X/1X	-	-	-	3.0/3.0
9	1X/1X	-	-	-	0.75/0.50

TABLE LXXXV

EFFECT OF 14 DAYS EXPOSURE TO FREON 114 ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	27 / 28.5	24.5 / 25.5
4	19 / 18	17.5 / 17.5
5	24 / 19.5	13.5 / 13
6	31 / 30	29.5 / 25.5
7	24.5/ 25.5	22 / 21
8	30 / 29	22 / 26
9	24 / 20.5	15.5 / 14.5

TABLE LXXXVI

EFFECT OF 14 DAYS EXPOSURE TO FREON 114 ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	5.6×10^{14} / 6×10^{14}	2.9×10^{14} / 2.5×10^{14}
4	3.8×10^{13} / 5×10^{13}	1.1×10^{13} / 3.8×10^{13}
5	3.1×10^{14} / 2.5×10^{15}	1.1×10^{14} / 5.9×10^{14}
6	2.3×10^{14} / 3.6×10^{14}	6.4×10^{13} / 2.3×10^{14}
7	1.4×10^{13} / 8.9×10^{12}	9.3×10^{12} / 3.6×10^{12}
8	4.4×10^{14} / 6.3×10^{13}	1.6×10^{13} / 8.3×10^{12}
9	$>10^{15}$ / 1.1×10^{15}	8.3×10^{14} / 3.6×10^{14}

TABLE LXXXVI-A

EFFECT OF 14 DAYS EXPOSURE TO TRICHLOROETHYLENE ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - Exposed / Unexposed

Wire #	No Damage Flexed at 23°C	No Damage Flexed at -196°C	Slight Damage Flexed at 23°C	Slight Damage Flexed at -196°C	Severe Damage Flexed at -196°C
3	1X / 1X	---	---	0.5 / 0.5	---
4	---	---	1X / 1X	---	1.0 / .075
5	---	---	1X / 1X	---	0.125 / .075
6	1X / 1X	---	---	0.75 / 0.25	---
7	.075 / .075	---	---	---	2.0 / 1.75
8	1X / 1X	---	---	---	3.0 / 3.0
9	1X / 1X	---	---	---	0.5 / 0.5

TABLE LXXXVII

EFFECT OF 14 DAYS EXPOSURE TO TRICHLOROETHYLENE ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	26.5/28.5	24.5/25.5
4	17 /18	15 /17.5
5	22 /19.5	12.5/13
6	34 /30	27.5/25.5
7	35 /25.5	28 /21
8	46 /29	40 /26
9	27.5/20.5	22 /14.5

TABLE LXXXVIII

EFFECT OF 14 DAYS EXPOSURE TO TRICHLOROETHYLENE ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	$1.3 \times 10^{15}/6 \times 10^{14}$	$1.8 \times 10^{14}/2.5 \times 10^{14}$
4	$1.3 \times 10^{14}/5 \times 10^{13}$	$3.6 \times 10^{13}/3.8 \times 10^{13}$
5	$5 \times 10^{14}/2.5 \times 10^{15}$	$2.5 \times 10^{14}/5.9 \times 10^{14}$
6	$3.6 \times 10^{14}/3.6 \times 10^{14}$	$9.3 \times 10^{13}/2.3 \times 10^{14}$
7	$1.7 \times 10^{13}/8.9 \times 10^{12}$	$1.6 \times 10^{13}/3.6 \times 10^{12}$
8	$1.8 \times 10^{14}/6.3 \times 10^{13}$	$5 \times 10^{13}/8.3 \times 10^{12}$
9	$4.8 \times 10^{14}/1.1 \times 10^{15}$	$2.6 \times 10^{14}/3.6 \times 10^{14}$

TABLE LXXXIX

EFFECT OF 14 DAYS EXPOSURE TO ACETONE ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - $\frac{\text{Exposed}}{\text{Unexposed}}$

Wire #	No Damage Flexed at 23°C	No Damage Flexed at -196°C	Slight Damage Flexed at 23°C	Slight Damage Flexed at -196°C	Severe Damage Flexed at -196°C
3	.075 / 1X	---	---	0.50 / 0.50	---
4	---	---	1X / 1X	0.5 / .125	---
5	---	---	1X / 1X	0.25 / .125	---
6	1X / 1X	---	---	0.50 / 0.25	---
7	Incomplete				
8	Incomplete				
9	1X / 1X	---	---	---	0.5 / 0.5

TABLE XC

EFFECT OF 14 DAYS EXPOSURE TO ACETONE ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	25/28.5	23 /25.5
4	16/18	16 /17.5
5	18/19.5	11 /13
6	31/30.0	28.5/25.5
7	Incomplete	
8	Incomplete	
9	38/20.5	27.5/14.5

TABLE XCI

EFFECT OF 14 DAYS EXPOSURE TO ACETONE ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Max. Values	Min. Values
3	$1.7 \times 10^{15}/6 \times 10^{14}$	$6.3 \times 10^{14}/2.5 \times 10^{14}$
4	$7.1 \times 10^{13}/5 \times 10^{13}$	$1.6 \times 10^{13}/3.8 \times 10^{13}$
5	$5 \times 10^{13}/2.5 \times 10^{15}$	$4.2 \times 10^{13}/5.9 \times 10^{14}$
6	$5 \times 10^{13}/3.6 \times 10^{14}$	$3.3 \times 10^{13}/2.3 \times 10^{14}$
7	Incomplete	
8	Incomplete	
9	$7.1 \times 10^{15}/1.1 \times 10^{15}$	$5.9 \times 10^{15}/3.6 \times 10^{14}$

TABLE XCII

EFFECT OF 14 DAYS EXPOSURE TO FREON 113 ON MANDREL FLEXIBILITY

Ratio of Mandrel Diam. - $\frac{\text{Exposed}}{\text{Unexposed}}$

	No Damage Flexed at		Slight Damage Flexed at		Severe Damage Flexed at
	23°C	-196°C	23°C	-196°C	-196°C
3	1X/1X	---	---	0.5/0.5	---
4	---	---	1X/1X	0.5/.125	---
5	---	---	1X/1X	0.25/.125	---
6	1X/1X	---	---	0.25/0.25	---
7	1X/1X	---	---	---	2.0/1.75
8	1X/1X	---	---	---	3./3.0
9	1X/1X	---	---	---	0.75/0.50

TABLE XCIII

EFFECT OF 14 DAYS EXPOSURE TO FREON 113 ON VOLTAGE BREAKDOWN - TWISTED PAIRS

Ratio of Breakdown Voltage (KV) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	29.0/28.5	26.0/25.5
4	18.5/18.0	18.0/17.5
5	22.0/19.5	16.0/13.0
6	33.0/30.0	29.5/25.5
7	29.5/25.5	24.0/21.0
8	37.0/29.0	35.0/26.0
9	24.0/20.5	21.5/14.5

TABLE XCIV

EFFECT OF 14 DAYS EXPOSURE TO FREON 113 ON INSULATION RESISTANCE - TWISTED PAIRS

Ratio of Insulation Resistance (ohms) - Exposed/Unexposed

Wire #	Maximum Values	Minimum Values
3	$4.2 \times 10^{13}/6 \times 10^{14}$	$7.8 \times 10^{13}/7.5 \times 10^{14}$
4	$1.8 \times 10^{14}/5 \times 10^{13}$	$8.5 \times 10^{13}/3.8 \times 10^{13}$
5	$5.0 \times 10^{14}/2.5 \times 10^{15}$	$1.9 \times 10^{14}/5.9 \times 10^{14}$
6	$1.8 \times 10^{14}/3.6 \times 10^{14}$	$8.5 \times 10^{13}/2.3 \times 10^{14}$
7	$2.4 \times 10^{14}/8.9 \times 10^{12}$	$7.6 \times 10^{13}/3.6 \times 10^{12}$
8	$4.2 \times 10^{14}/6.3 \times 10^{13}$	$2.3 \times 10^{14}/8.3 \times 10^{12}$
9	$> 10^{15}/1.1 \times 10^{15}$	$6.7 \times 10^{14}/3.6 \times 10^{14}$

27. Offgassing in Oxygen

The results of weight loss measurements in 5 psia oxygen are summarized in Table XCV. The times shown are the intervals between measurements. The tabulated temperatures are those of the specimen during the time interval shown. The weight loss is shown as the cumulative weight loss over the entire experiment.

Wires 5, 6, and 9 show no significant weight loss up to 300°C after the initial equilibrium is reached at 150°C. The over-all changes, as indicated by analytical balance readings, are between 0.1 and 0.4 mg in about 400 mg (.025 to .1%). These measurements are made at room condition, before and after the experiment, so the changes can be due to changes in residual moisture alone.

Wire #4 showed a small, but significant weight loss as it was heated above 150°C, but it stabilized quickly even at 300°C.

Wire #3 showed the largest weight losses of the H-film construction. Three specimens lost 0.65, 0.70, and 1.0 mg, which represent losses of 0.25% or less.

With wires 3, 4, 5, 6, and 9, it must be concluded that offgassing in 5 psia is not a serious problem at temperatures up to 300°C. Two of the H-film constructions (5 and 6) were as stable as Teflon (9).

Preliminary results indicate that the polyolefin wires lose considerably more weight, even at 150°C. Further results will be given in the Final Report.

The gas analysis in oxygen is presented in Section IV-29.

TABLE XCV

OFFGASSING IN OXYGEN

Wire	Time (hrs:min.)	Temp (°C)	Cumulative Loss (mg)	Analytical Balance Wt. Initial mg	Final mg	Loss mg
3	0:15	25-147	0.20	407.8	406.7	1.1
	2:00	153	0.40			
	14:30	153	0.40			
	0:30	204	0.50			
	0:30	297	0.90			
	2:30	297	1.00			
3	0:17	31-145	0.20	406.4	404.6	1.8
	15:30	152	0.20			
	0:30	201	0.25			
	0:30	249	0.45			
	0:30	293	0.60			
	2:30	293	0.65			
3	0:17	31-144	0.20	404.8	403.5	1.3
	1:00	151	0.20			
	16:45	151	0.20			
	0:30	203	0.25			
	0:30	256	0.55			
	0:10	297	0.70			
4	0:15	25-152	0.30	406.2	405.3	0.9
	18:15	152	0.30			
	0:30	204	0.30			
	0:30	255	0.35			
	0:30	296	0.40			
	0:15	296	0.40			
4	0:15	30-147	0.15	404.6	403.8	0.8
	15:45	152	0.15			
	0:30	198	0.15			
	0:30	253	0.25			
	3:07	298	0.25			
4	0:15	29-149	0.30	406.2	405.1	1.1
	18:00	151	0.30			
	0:30	203	0.35			
	0:30	256	0.40			
	0:30	299	0.50			
	0:15	299	0.50			

TABLE XCV (Continued)

OFFGASSING OXYGEN

Wire	Time (hrs:min.)	Temp (°C)	Cumulative Loss (mg)	Analytical Balance Wt. Initial mg	Final mg	Loss mg
5	0:15	25-152	0.25	205.8	205.6	0.2
		No further loss to 295°C				
5	0:15	28-153	0.15	407.6	407.7	+0.1
		No loss to 254°C				
	0:45	295°C	0.15			
6	0:15	25-151	0.40	406.8	406.7	0.1
		No further loss to 297°C				
6	0:15	25-155	0.30	405.8	405.6	0.2
		No further loss to 297°C				
9	0:18	26-149	0.15	406.8	406.7	0.1
		No further loss to 292°C				
9	0:18	26-145	0.05			
		No further loss to 300°C		402.8	402.4	0.4

28. Volatility In Vacuum

The weight changes in vacuum at 150°C are shown in the curves of Figures 46 to 49. Most of the weight loss in each case occurred during the early stages of exposure. The weight of each specimen and the weight loss, as measured with an analytical balance after the specimen was removed from the microbalance, is given in Table XCVI.

Weight measurements that are made at room condition, before and after vacuum exposure, are dominated by the removal or absorption of moisture.

Part of the weight loss during pump-down is regained when the specimen is returned to room condition.

The rate of weight loss for each of the wires tested was less than the required 0.0025% per hour.

The weight loss during pump-down and again during refilling of the chamber could not be determined with suitable reliability. The microbalance is too sensitive to spurious forces that occur during the transition period.

The gas analysis data is discussed in Section IV-29.

TABLE XCVI - Weight Loss at 150C in Vacuum

Wire No.	Specimen Length, mm	Specimen weight, mg	Analytical Balance Weight Loss, mg	Microbalance Weight Loss, *mg	$x10^2$ % Loss
3A	114	805.4	0.1	0.44	5.5
3B	115	811.4	0.5	0.41	5.1
4A	130	813.6	0.3	0.26	3.2
4B	130	807.3	0.6	0.28	3.5
5A	123	810.0	0.7	0.64	7.9
5B	123	807.5	0.4	0.81	10.0
6A	122	811.6	0.8	0.60	7.4
6B	122	809.8	0.8	0.63	7.8
9A	100	805.3	0.0	0.28	3.5
9B	99	809.1	0.0	0.28	3.5

*During heating at 150C.

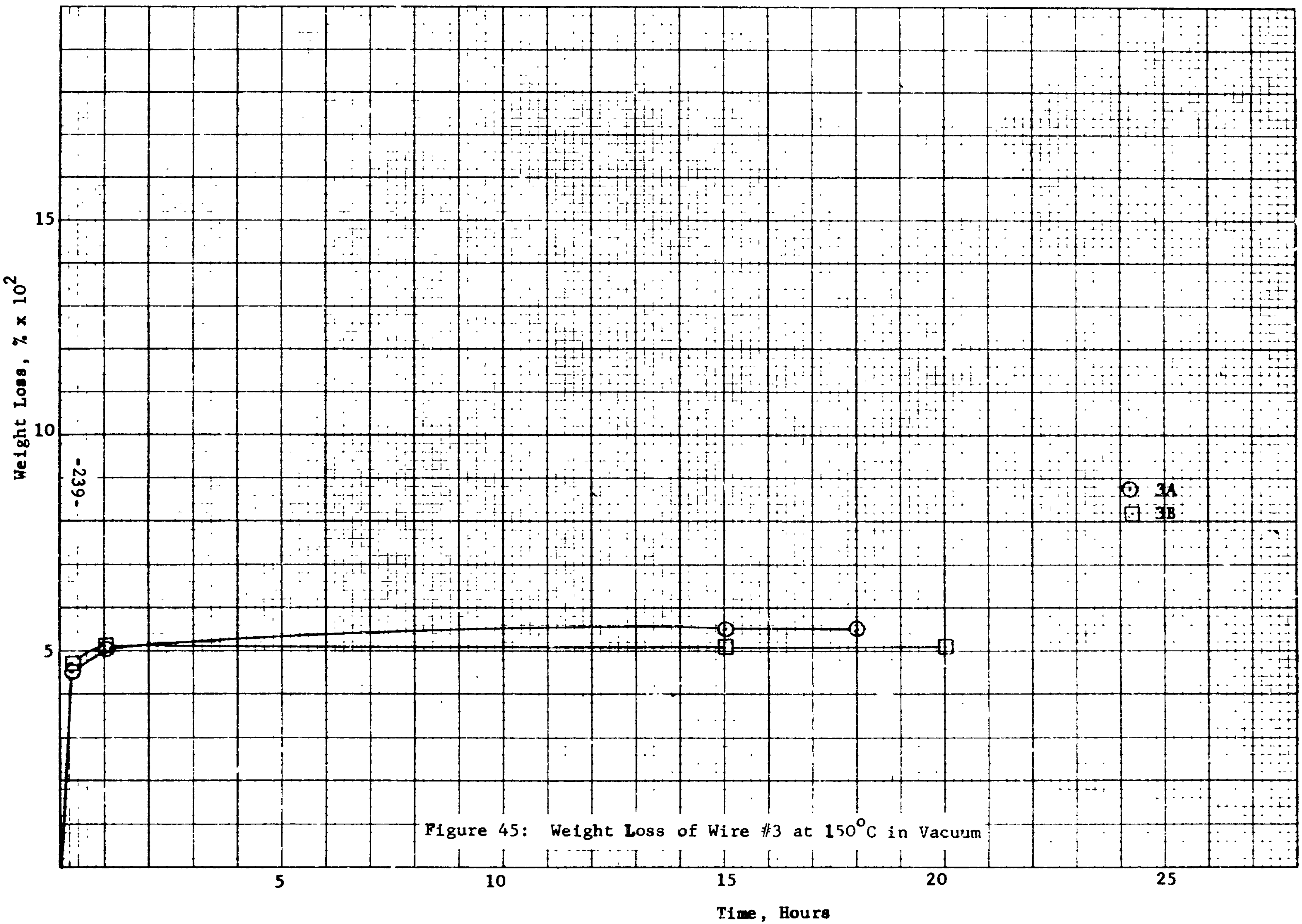

Figure 45: Weight Loss of Wire #3 at 150°C in Vacuum

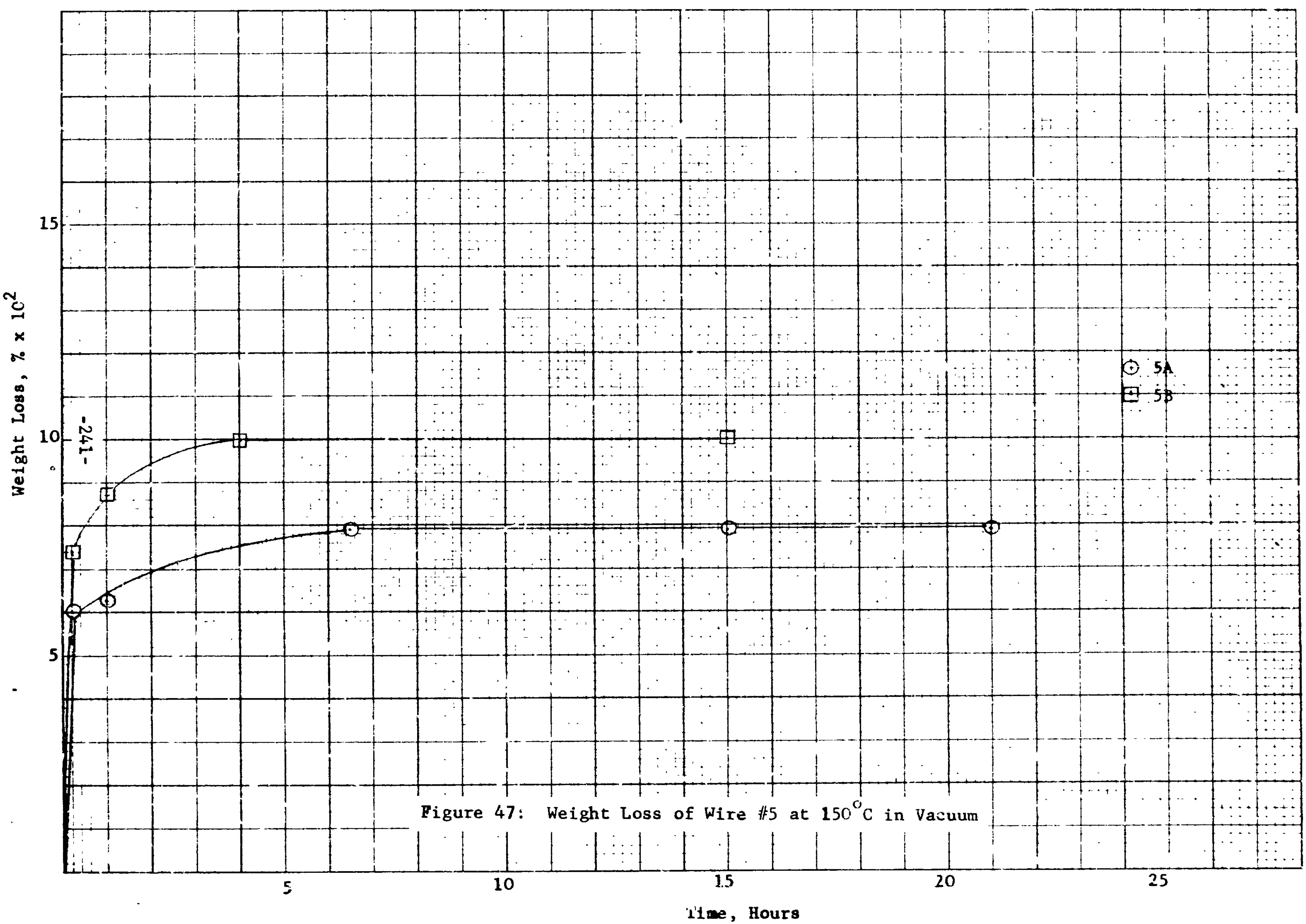

Figure 47: Weight Loss of Wire #5 at 150°C in Vacuum

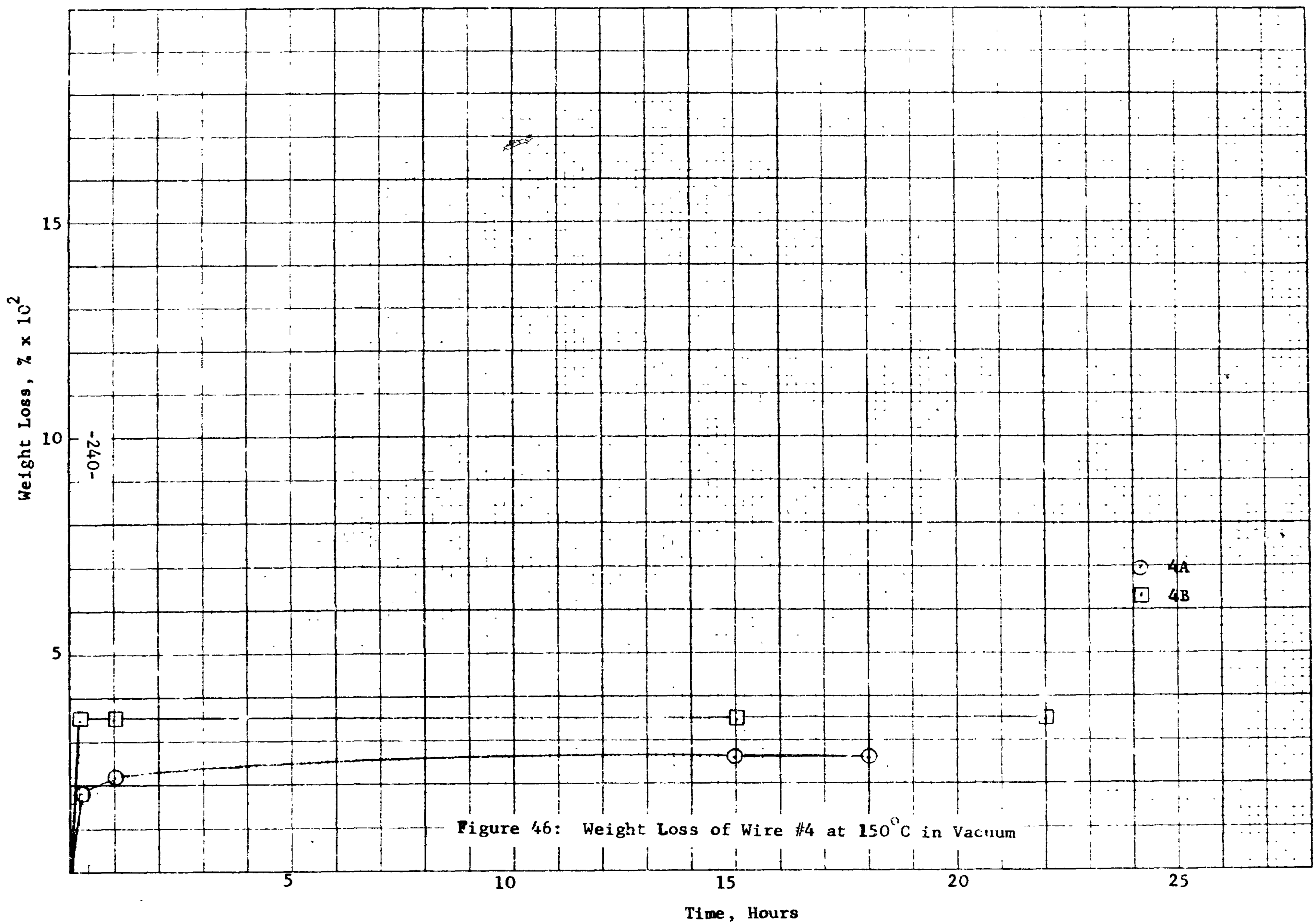

Figure 46: Weight Loss of Wire #4 at 150°C in Vacuum

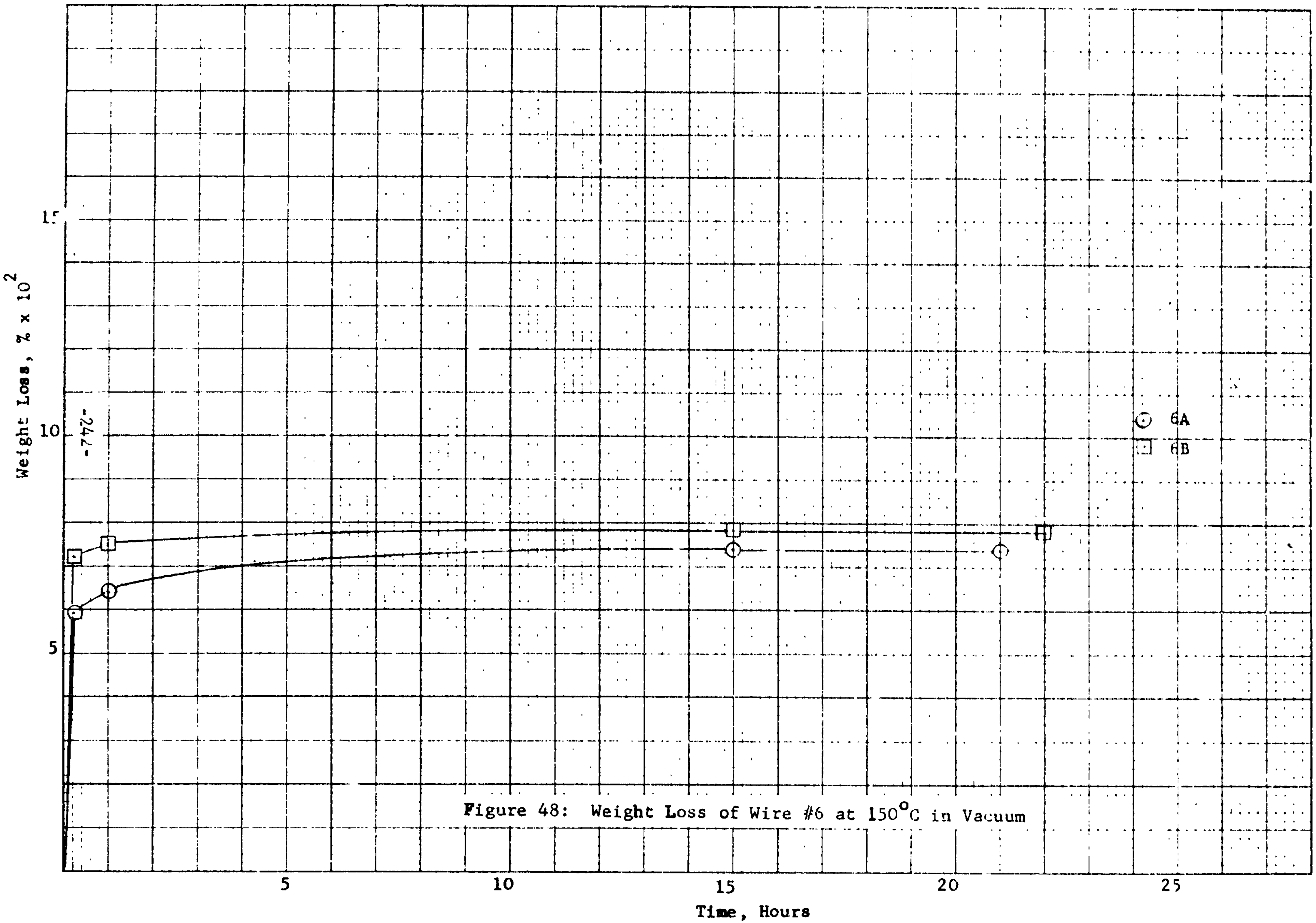

Figure 48: Weight Loss of Wire #6 at 150°C in Vacuum

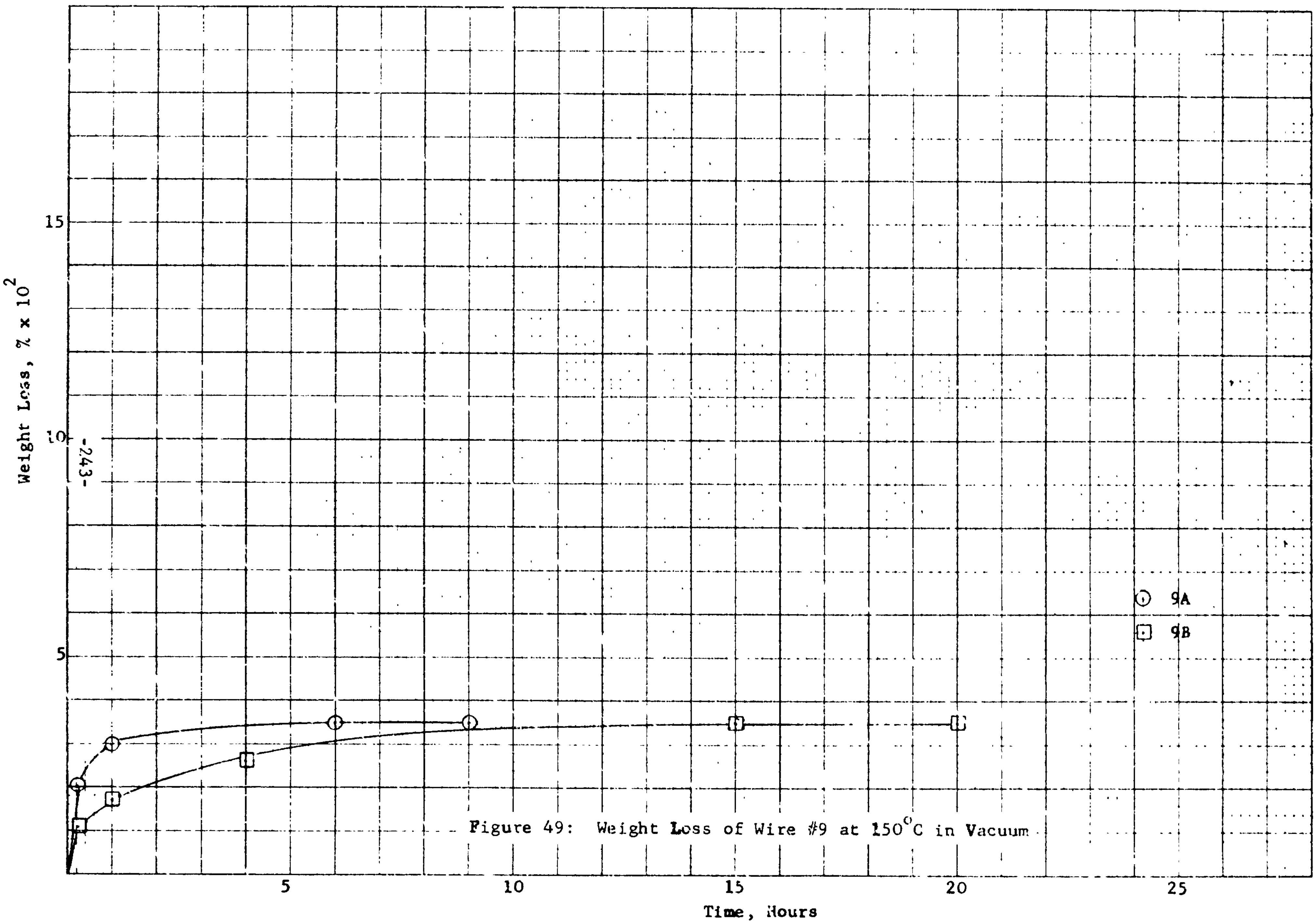

Figure 49: Weight Loss of Wire #9 at 150°C in Vacuum

29. Gas Analysis

The mas spectrographic analyses of the off-gassing products from wires #3, 4, 5, 6, and 9 are reported in Tables XCIII through CI . With perhaps one exception, the character and quantity of the gases evolved does not appear to merit further chromatographic investigation.

Analysis of these data and visual comparison of the test specimens from this work with those from thermogravimetric test has raised doubts about the temperature of the test specimens. All of the wires from the mass spectrographic test after about 2 hours in 5 psi oxygen at 300°C are at least a little darker than the corresponding samples from the thermogravimetric test of 3 hours at 300°C. With the mass spectrographic tests, wire #5 in particular appears to be charred and TFE Teflon insulated wire #9 is discolored, has blocked together, and has shrunk appreciably. Wire #3 with a TFE Teflon jacket also has blocked (stuck together) without any externally applied pressure. Since TFE Teflon generally does not shrink nor stick together below the second order transition at 327°C, it is concluded that this temperature has been exceeded. It is apparent that the temperature control of the test chamber must be investigated and that all of the tests to-date must be rerun at the correct temperature with adequate temperature control. Nevertheless, the data obtained to-date are interesting and useful in that the desired temperature has been exceeded and even more off-gassing would be expected. Comparison between wires may be less meaningful.

Keeping in mind the question of test temperature* a number of general observations can be made on these analyses.

a. The quantities of gas evolved (with the exception of wire #5 in oxygen at 300°C+) are very small. The mass spectrograph approach is far more sensitive in this respect than thermogravimetric techniques.

*This uncertainty makes quantitative comparison with the thermogravimetric data of doubtful value.

b. The nitrogen evolved most likely was dissolved in the insulation and is not a degradation product.

c. The principle products evolved are water and carbon dioxide. A more detailed discussion will follow later.

d. No fluorocarbons evolved at 150°C. The fluorocarbons are undoubtedly degradation products from the FEP and TFE Teflon resins. Wire #9 contains only TFE Teflon but its evolved gases include hexafluoropropylene as well as tetrafluoroethylene.

e. Tetrafluoroethylene was evolved only with wires #3 and #9 which contained TFE Teflon.

f. The presence of silicon tetrafluoride can probably be traced to the evolution of hydrogen fluoride which reacted with the quartz walls of the contrainer or possibly in some cases with fillers in the wire insulation.

g. The presence of several interesting materials in small amounts such as hydrazine and methyl amine can undoubtedly be traced to the polyimide resin (H-film).

h. The generally small quantities of hydrocarbons evolved are predominantly C_4 and further analysis seems unnecessary.

No extensive analysis of the mechanism of degradation has been attempted to date partly because of the uncertainty over test temperature. Likewise the degree of toxicity has not been discussed since this subject is very involved.

In order to compare the results for the different wires, the following tables have been compiled.

Quantity of Gas Evolved	-	Table CII
Water Evolved	-	Table CII
Carbon Dioxide Evolved	-	Table CIV
Carbon Monoxide Evolved	-	Table CV
Hydrocarbons Evolved	-	Table CVI
Silicon Tetrafluoride Evolved	-	Table CVII

These tables will be discussed in turn.

Table CII

The amount of gas evolved may well be affected by the questionable temperature control and the ** results are obviously minor. The amount of gas evolved is small in any case and particularly so for TFE Teflon (wire #9). Only at 300°C do the amounts evolved in oxygen appear to be consistently greater than in vacuum.

Table CIII

It seems likely that the water evolved at 150°C is physically absorbed in the insulating materials. At 300°C the water in wires #3 through 6 might come from continuing condensation of the polyimide resin but this is an impossible source with the TFE Teflon in wire #9. Why the water evolved is comparatively much less in an oxygen atmosphere than in vacuum at 300°C is baffling. It should be remembered that physically absorbed water may continue to evolve above 150°C although the amount seems surprisingly large.

Table CIV

Carbon dioxide is most likely a degradation product and it is not surprising to find greater quantities in an oxygen atmosphere. However carbon dioxide cannot be a degradation product of the TFE Teflon (at least in vacuum). Most likely in this case the CO_2 is absorbed although it could come from the decomposition of some residual hydrocarbon extrusion lubricant not removed in manufacture.

Table CV

No carbon monoxide was evolved under vacuum conditions even at 300°C. Formation of CO as an oxidative degradation product is plausible. Carbon monoxide, however, evolved in oxygen even at 150°C with wires #3 and #5. Measurable decomposition of either Teflon or H-film at 150°C seem very unlikely. Certainly the amount of CO evolved did not increase markedly at 300°C as would be expected for a degradation reaction. Perhaps small amounts of impurities in the H-film are involved. As would be expected no CO evolved from wire #9.

Table CVI

The hydrocarbon evolved from the TFE Teflon (wire #9) may well be traced to the extrusion lubricant and most of it disappears at 150°C. (It should be remembered that the total gas evolved with wire #9 is larger in O_2 so that the smaller mole % of hydrocarbons can be explained). The relatively large amount of hydrocarbon indicated by the double asterisk ** in the table may be due to accidental comtamination with oil or grease which could give the C_4 breakdown products. If so, the specimen in the oxygen atmosphere was not similarly contaminated.

Table CVII

Since all of the wires contained fluorocarbons, evolution of SiF_4 is not unexpected. The large amounts for wire #5 in oxygen is without much question due to the excessive temperature experienced by this sample as discussed earlier. With this exception and in view of the very small quantities and the possible associated quantitative error, the amount of SiF_4 evolved in vacuum and in oxygen atmosphere are much the same as would be expected.

Flammability Tests

Efforts were made to collect off-gassing products from the flammability tests described earlier and the data obtained as presented in Table XVIII. The technique of sampling is not now considered and changes have been made so as to place the vacuum bottle much closer to the space to be sampled.

From the presence of nitrogen and argon it is evident in every case that some degree of air contamination was involved. After several tests, actual air leaks in the collection system were discovered which have now been corrected. In consequence great effort has not been expended upon these analyses. As would be expected CO_2 is always present. The irradiated polyolefin burned furiously (it was not one of the wires described earlier). The CO and the relatively large amount of CO_2 is expected in this case.

TABLE XCVII

WIRE #3 - COMPOSITION OF EVOLVED GASES, MASS SPECTROGRAPH

	Vacuum		Oxygen			
Mol. %	150°C	300°C	Total 150°C	Liq. N_2 Cond. 150°C	Total 300°C	Liq. N_2 Cond. 300°C
Hydrogen	---	0.3	---	---	---	---
Nitrogen	1.7	7.8	---	---	0.5	---
Oxygen	---	---	96.5	---	91.9	---
Carbon Monoxide	---	---	0.[illegible]	---	1.7	---
Carbon Dioxide	3.9	23.8	[illegible].8	11.1	4.5	83.1
Water	91.3	10.3	[illegible].0	78.0	1.1	9.7
Hydrocarbons	1.7	37.2*	[illegible].1	7.3	0.04	0.6
Methyl Amine	0.2	---	---		---	0.2
Silicon Tetrafluoride	---	9.2	---	---	0.2	5.8
Hexafluoropropylene	---	8.1	---	---	---	0.2
Tetrafluoroethylene	---	3.1	---	---	---	---
Octafluoropropane	---	0.2	---	---	---	---
Difluoroethylene	---	---	---	---	---	0.3
Oxygenated Hydrocarbons	---	---	---	1.8	---	0.1
Wgt. of Sample (gms)	3.297			3.229		
Quantity of Gas Evolved (Std. cc)	2.6	3.6		3.3		3.6
Quantity of Gas (cc) Evolved per gram of Insulation	2.9	4.0		4.0		4.4

*Contamination Suspected

TABLE XCVIII

WIRE #4 - COMPOSITION OF EVOLVED GASES, MASS SPECTROGRAPH

	Vacuum		Oxygen			
Mol. %	150°C	300°C	Total 150°C	Liq. N_2 Cond. 150°C	Total 300°C	Liq. N_2 Cond. 300°C
Hydrogen	---	0.4	---	----	---	----
Nitrogen	---	2.3	---	----	1.5	----
Oxygen	---	---	98.5	----	92.6	----
Carbon Monoxide	---	---	---	----	---	----
Carbon Dioxide	4.7	28.0	0.5	95.8	5.1	86.8
Nitric Oxide	---	---	---	----	---	0.5
Water	94.6	64.1	1.0	3.6	0.7	11.1
Hydrocarbons	0.5	2.3	---	0.6	---	----
Methyl Amine	0.2	0.2	---	---	---	----
Silicon Tetrafluoride	--	1.1	---	---	0.1	1.6
Hexafluoropropylene	---	0.2	---	---	---	----
Difluoroethylene	---	0.3	---	---	---	----
Oxygenated Hydrocarbons	---	1.1	---	---	---	----
Wgt. of Sample (gms)		2.880			2.898	
Quantity of Gas Evolved (Std. cc)	0.7	0.7		0.07		1.7
Quantity of Gas (cc) Evolved per gram of Insulation	1.5	1.5		0.14		3.4

TABLE XCIX

WIRE #5 - COMPOSITION OF EVOLVED GASES, MASS SPECTROGRAPH

	Vacuum		Oxygen			
Mol. %	150°C	300°C	Total 150°C	Liq. N_2 Cond. 150°C	Total 300°C	Liq. N_2 Cond. 300°C
Nitrogen	1.1	3.5	---	---	---	---
Oxygen	---	---	96.4	---	20.3	---
Carbon Monoxide	---	---	0.3	---	9.2	---
Carbon Dioxide	0.6	21.0	1.8	47.4	54.3	74.5
Water	97.7	71.5	1.4	50.8	0.4	0.7
Hydrocarbon	---	2.0	0.1	1.6	0.5	---
Methyl Amine	---	0.3	---	0.2	---	---
Dimethyl Amine	0.6	0.5	---	---	---	---
Hydrazine	---	---	---	---	---	0.2
Dimethyl Hydrazine	---	---	---	---	0.1	---
Silicon Tetrafluoride	---	1.2	---	---	14.5	24.6
Wgt. of Sample (gms)	3.093				2.911	
Quantity of Gas Evolved (std. cc)	2.5	1.3		1.2		35
Quantity of Gas (cc) Evolved per gram of Insulation	3.6	1.9		2.4		69

TABLE C

WIRE #6 - COMPOSITION OF EVOLVED CASES, MASS SPECTROGRAPH

	Vacuum		Oxygen			
Mol. %	150°C	300°C	Total 150°C	Liq. N_2 Cond. 150°C	Total 300°C	Liq. N_2 Cond. 300°C
Hydrogen	---	1.0	---	---	---	---
Nitrogen	1.1	---	1.0	---	---	---
Oxygen	---	---	97.0	---	81.0	---
Carbon Monoxide	---	---	---	---	1.6	---
Carbon Dioxide	0.2	41.4	0.8	25.3	14.1	81.6
Nitric Oxide	---	---	---	---	---	0.4
Water	98.7	44.4	1.2	74.5	1.4	7.6
Hydrocarbons	---	---	---	---	---	---
Methyl Amine	---	1.1	---	0.2	0.1	---
Dimethyl Amine	---	5.5	---	---	---	0.5
Hydrazine	---	0.5	---	---	---	0.1
Silicon Tetrafluoride	---	2.4	---	---	1.8	9.7
Hexafluoro Propylene	---	0.3	---	---	---	0.08
Difluoroethylene	---	0.2	---	---	---	0.05
Oxygenated Hydrocarbons (acetic acid)	-	3.2	---	---	---	---
Wgt. of Sample (gms) (18 in.)		3.101			3.097	
Quantity of Gas Evolved (std. cc)	1.5	0.8	---	1.3	---	5.6
Quantity of Gas Evolved (std. cc)	1.5	0.8	---	1.3	---	5.6
Quantity of Gas (cc) Evolved per gram of Insulation	2.1	1.1		1.9		8.0

TABLE C1

WIRE #9 - COMPOSITION OF EVOLVED GASES, MASS SPECTROGRAPH

	Vacuum		Oxygen			
Mol. %	150°C	300°C	Total 150°C	Liq. N_2 Cond. 150°C	Total 300°C	Liq. N_2 Cond. 300°C
Nitrogen	14	35.2	4.4	---	3.7	---
Oxygen	--	---	95.2	---	95.8	---
Carbon Monoxide	--	---	--	---	--	---
Carbon Dioxide	14	26.4	0.1	33.5	0.3	13.3
Water	49	33.4	0.2	62	0.2	1.9
Hydrocarbons	23	2.8	0.1	4.5	---	0.9
Silicon Tetrafluoride	--	1.8	-	---	---	6.1
Tetrafluoroethylene	--	0.4	--	---	---	65.7
Hexafluoropropylene	--	---	--	---	---	11.1
Wgt. of Sample (gms) (18 in.)		3.714			3.699	
Quantity of Gas Evolved (std. cc)	0.01	0.07	--	0.07	---	3.1
Quantity of Gas (cc) Evolved per gram of Insulation	.0075	.05	--	.05	---	2.4

TABLE CII

MASS SPECTROGRAPHIC ANALYSIS QUANTITY OF GAS EVOLVED PER GRAM OF INSULATION (STANDARD cc)

	1 Hr. in Vacuum		1 Hr. in Oxygen*	
Wire #	at 150°C	Additional at 300°C	at 150°C	Additional at 300°C
3	2.9	4.0	4.0	4.4
4	1.5	1.5	1.4	3.4
5	3.6	1.9	2.4	69**
6	2.1	1.1	1.3	5.6
9	.0075	.05	.05	2.4**

*Four condensibles in liquid nitrogen.

**These results are questioned and may be due to overshoot in the test temperature to well above 300°C (See Text).

TABLE CIII

MASS SPECTROGRAPHIC ANALYSIS MOLE % WATER EVOLVED

	1 Hr. in Vacuum		1 Hr. in Oxygen*	
Wire #	at 150°C	Additional at 300°C	at 150°C	Additional at 300°C
3	91.3	10.3	78.0	9.7
4	94.6	64.1	3.6	11.1
5	97.7	71.5	50.8	0.7
6	98.7	44.4	74.5	7.6
9	49	33.4	62	1.9

*From condensibles in liquid nitrogen

TABLE CIV

MASS SPECTROGRAPHIC ANALYSIS MOLE % CARBON DIOXIDE EVOLVED

	1 Hr. in Vacuum		1 Hr. in Oxygen*	
Wire #	at 150°C	Additional at 300°C	at 150°C	Additional at 300°C
3	3.9	23.8	11.1	83.1
4	4.7	28.0	95.8	86.8
5	0.6	21.0	47.4	74.5
6	0.2	41.4	25.3	81.6
9	14	26.4	33.5	13.3

*From condensibles in liquid nitrogen

TABLE CV

MASS SPECTROGRAPHIC ANALYSIS CARBON MONOXIDE EVOLVED

	Mole %*			
	1 Hr. in Oxygen		Ratio - CO/CO_2	
Wire #	at 150°C	Additional at 300°C	at 150°C	Additional at 300°C
3	17	21	0.75	.38
4	---	---		
5	8	11	0.17	0.17
6	---	8		0.11
9	---	---		

*Calculated to exclude the oxygen

TABLE CVI

MASS SPECTROGRAPHIC ANALYSIS MOLE % HYDROCARBONS EVOLVED

Wire #	1 Hr. in Vacuum at 150°C	1 Hr. in Vacuum Additional at 300°C	1 Hr. in Oxygen* at 150°C	1 Hr. in Oxygen* Additional at 300°C
3	1.7	37.2**	7.3	0.6
4	0.5	2.3	0.6	---
5	---	2.0	1.6	---
6	---	---	---	---
9	23	2.8	4.5	0.9

*From condensibles in liquid nitrogen

**Contamination is suspected in this case

TABLE CVII

MASS SPECTROGRAPHIC ANALYSIS MOLE % SILICON* TETRAFLUORIDE EVOLVED

Wire #	1 Hr. in Vacuum at 300°C	1 Hr. in Oxygen** at 300°C
3	9.2	5.8
4	1.1	1.6
5	1.2	24.6
6	2.4	9.7
9	1.8	6.1

*Hydrogen fluoride most likely evolved first and reacted with the quartz walls of the collection tube or possibly with fillers to give the silicon tetrafluoride.

**From condensibles in liquid nitrogen

TABLE CVIII

ANALYSIS OF OFF-GASSING IN THE FLAMMABILITY TEST, MASS SPECTROGRAPHIC ANALYSIS

Test No.*	3I3	3IIA2	4IIA2	5IIA3	6IIA2	6IIA3	8IIA2	9IIB1
Wire No.	3	3	4	5	6	6	8	9
Mole %								
Nitrogen	12.2	71.4[(1)]	16.9	24.6	68.6[(1)]	42.0	31.1	23.2
Oxygen**	86.8	27.5	82.1	74.8	30.1	57.3	48.9	75.8
Argon	0.7	0.9	0.4	0.5	1.0	0.6	1.0	0.5
Carbon Dioxide	0.3	0.2	0.5	0.2	0.3	0.1	18.3	0.5
Carbon Monoxide	---	---	---	---	---	---	0.7	---

*See the flammability test results for full details.

**Tests were run in 5 psi oxygen.

(1) Evident air contamination - see text.