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PROPULSION & FIRE PROTECTION BRANCH ANA-420

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DATA REPORT NO. 98

SMOKE EMISSION BY BURNING AIRCRAFT WIRING

PROJECT NO. 184-732-04X

Prepared by: John F. Marcy

Purpose

The intention of this effort was to (1) study the smoke emission characteristics of a selected number of aircraft electrical wiring with different types of plastic insulation coverings and (2) develop minimum performance standards from an analysis of the test results and other technical data that may be useful to Flight Standards Service in preparing a Notice for Proposed Rule Making (NPRM) limiting the maximum allowable smoke emission from interior materials within safe and/or reasonable levels.

Background

Electrical wiring in the past was not included in federal safety regulations as a cabin interior material. Although cabin furnishings and interior finishing materials since 1947 have had to meet certain minimum flammability standards to qualify for the designation of "flame resistant" (i.e., maximum horizontal burn rate of 4 inches per minute), no flammability requirements were considered for aircraft wiring. It is only recently that the terminology of interior materials has been extended to include everything installed in the cabin, even the wiring. Also, it has been the practice since 1966 to establish different flammability standards according to the classification assigned to the particular material dependent on its use and location within the cabin. Thus certain materials, such as floor and ceiling paneling, were required to meet more severe flammability requirements than others.

The first mention of flammability standards for certification of aircraft wiring appeared in an NPRM 69-33, dated 30 August 1969. This NPRM established a separate category and test method for wiring which is more severe than those imposed on any other category. Maximum allowable burn length for wiring is only 3 inches compared to 6 or 8 inches for categories (a) and (b), respectively, for the more typical materials. The NPRM was finally adopted as Amendment 25-32, Crashworthiness and Evacuation Standards: Transport Category Airplanes - Section FAR 25.1359 and Appendix F, effective 1 May 1972.

Although present regulations contain restrictions on the degree of flammability permitted for the materials, no restrictions, except those voluntary on the part of the major airframe manufacturers, have been extended to include smoke. However, following the experience of the Salt Lake City B-727 crash fire in November 1965, it became obvious that there was a need for reducing the smoke and toxic effects on passengers by burning materials to insure more rapid evacuation and greater survivability in the event of another cabin fire. An extensive test program to develop suitable laboratory apparatus to measure smoke and develop a large body of data for aircraft materials was initiated and funded by FAA at the National Bureau of Standards from 1966 to 1968. The results of this study, which include measurements on some 140 materials of (1) the specific optical index (D_s) for smoke and (2) concentrations of toxic gases in air (PPM) at the time of maximum smoke density, are contained in Report FAA-NA-68-36 (AD 675513) titled "Smoke and Gases Produced by Burning Aircraft Interior Materials," June 1968. This report which received very wide circulation both as an FAA report and later as a reprint of an NBS report was followed by an Advanced Notice for Proposed Rule Making (ANPRM) 69-30, titled "Compartment Interiors: Smoke Emission," dated 30 July 1969.

The document had a tremendous impact not only on the aviation industry but also on the plastics industry in general. Although, in answer to FAA's request for comments there was some favorable reaction, most of the respondents felt that a smoke rule would be premature at that time based on the limited experience with this problem. However, the FAA announcement which forecasted future smoke controls for interior materials stimulated industry to acquire the NBS test apparatus and use it either in the development of new low-smoke materials or, as in the case of Boeing and Lockheed, use it in the selection of materials for the B-747 and L-1011. Instead in the case of Douglas, the Rohm & Haas XP2 test apparatus was used to select low-smoke materials for the DC-10. The state of the art of smoke measurement has rapidly advanced since 1969. This has occurred largely from the success achieved by FAA in promoting the NBS apparatus for smoke measurement. The number of such apparatus, which was limited to about four, has grown during the past 3 years to over 70 since it became commercially available from an instrument company (AMINCO). Also during the past two years, 20 different laboratories have taken part in round-robin tests under the direction of NBS to establish the reproducibility of the smoke data as part of the procedure for obtaining the approval of the test method by a technical society or government agency.

As various government agencies both civilian and military as well as users of plastic materials became more conscious of the smoke problem, an increasing number of materials specifications began to appear with the purpose of restricting smoke within certain visibility limits as determined by the NBS test method. This was best exemplified by the efforts of the major airplane companies to select low-smoke materials consistent with meeting the new flammability requirements. Based largely on an analysis of industry data, recommendations for rule making were made to Flight Standards

Service. These were in accordance with the findings contained in Propulsion Branch Data Report No. 76 titled "Analysis of Industry Furnished Smoke Emission Data on New Cabin Interior Materials," January 1971.

Compared to the extensive smoke data available for a large variety of cabin interior materials from different test facilities, similar data for wiring are scarce. Much of the work in the area of testing wiring for smoke emission has been performed by the DuPont Company which supplied the material and specimen holders used in the NAFEC tests. Although not a wire manufacturer, DuPont Company supplies high-temperature plastics such as Teflon and Kynar that are used in aerospace applications as wire covering.

Test Procedure

The NBS Smoke Density Chamber described in NBS Technical Note 708 issued December 1971 was used to conduct tests on 11 different types of wiring supplied by the DuPont Company. Tests on wiring differ from those performed on typical interior large flat surface materials because of their peculiar physical dimensions. In addition electrical wiring would not only be exposed to an external fire as other materials but might overload or short. Thus it has been necessary to vary the method of mounting the specimen to be tested. In contrast, typical interior materials present no problem since these are cut in 3-inch-square test specimens from a representative piece of fabric or sheet material in the thickness used, up to one-half inch, in the cabin.

The test procedure used to obtain the smoke data was developed by the DuPont Company. It is only one of a number of possible alternate methods that could be designed for smoke measurements. The DuPont Company has also built a fixture which resembles an open cylindrical bird cage 8 inches in diameter and 8 inches in length around which the wiring is wrapped. In this type of test, the heat which produces the pyrolysis of the insulation and resulting smoke emission is supplied entirely from self-heating, generated by an electrical overload.

The method of mounting the wiring inside the NBS standard specimen holder is shown in Figure 1. Two different gages of wires were tested. A 5-foot length of AWG 12 and a 10-foot length of AWG 20 wire were wrapped separately around a 2 7/8-inch-square open frame backed by aluminum foil placed inside the 3-inch-square holder. After this operation of mounting the wiring, the test was conducted under standard procedure as with other materials.

Test Results

Flammability and smoke data obtained from tests on wiring are presented in Tables 1 and 2.

The results of the flammability tests obtained by DuPont Company show that the plastic insulation of the wiring far exceeds the FAA requirements in all respects - burn length, flameout time, and absence of drippings. The most flame-resistant wiring judged by the burn length were those using fluorinated plastic insulation such as Teflon.

The results of the smoke tests obtained at NAFEC show an extreme range of smoke densities from no detectable smoke (D_s of 0) to extremely dense smoke (D_s of 678). Except for the PVC insulated wiring in Tests Nos. 10 and 11, much denser smoke was produced under the flaming condition of exposure as compared to smoldering combustion of the material. Wiring showing the least smoke were the Teflon covered wire and most smoke the PVC covered wire.

A plot of smoke accumulation with time of fire exposure for the different wiring is shown in Figures 2 and 3. The most notable difference in the wiring smoke curves, compared to curves for the typical interior materials presented in past reports, is that of the much slower rise in the smoke levels with time of exposure. Smoke density curves for the high-temperature fluorinated plastic insulation in Tests 4, 5, and 6, as shown in Figure 2, continue to show a steep rise in reading even at the end of 20 minutes' testing, which is maximum according to standard test procedures. Under smoldering conditions of exposure as presented in Figure 3, smoke is seen to accumulate at even a slower pace than under flaming conditions. The test criteria of 1.5 and 4.0 minutes' fire exposure for setting maximum allowable smoke limits proposed for interior materials are seen to be inadequate. Under such short-term exposure, very little smoke would be produced except for the PVC and rubber compound wire insulation.

Very low smoke accumulation within the first 4 minutes fire exposure is shown to occur in Tests Nos. 1, 2, 3, 4, and 5 with the fluorocarbon coated wiring. A desirable Specific Optical Density (D_s) of less than 16 corresponding to an attentuation of a light beam in a 3-foot distance from 100- to 75-percent transmittance has been considered as an eventual goal in setting standards. The extreme smoke accumulation by some of the wiring can be better visualized by a conversion of D_s values into light transmittance levels through a 3-foot optical path. Lowest transmittance readings caused by smoke obscuration registered only 0.005 percent of the original light beam intensity.

Summary Remarks

The NBS chamber with the DuPont Company's method of exposing a given length of electrical wiring to the effects of radiant and flaming combustion to measure the smoking characteristics of the insulation materials is considered as a practical test procedure for regulatory action. The test is judged acceptable on the basis of the wide range in smoke density values obtained for the different types of wiring investigated. This permits a meaningful selection and grading of wiring which very dramatically illustrates the tremendous reduction in smoke made possible by the increased use of wiring in aerospace with high-temperature plastic insulation. With some types of Teflon covered wiring, visible smoke is practically eliminated.

Smoke accumulation by wiring as reported herein occurs at a slower rate than it does for the more typical cabin materials, perhaps, in part because of heat losses by the copper conductor. To correct this situation a much longer test duration of 20 minutes or more appears to be necessary to insure essentially complete pyrolysis of the plastic covering. A more realistic test method for generating faster smoke buildup would be to connect the wiring under test to an electrical supply to simulate both a normal and overload condition as desired. This would eliminate the long test periods needed to reach maximum smoke density readings and provide an alternate method for testing wiring.

Unlike the experience with some cabin interior materials where it may be necessary to trade off more smoke for less flammability, it is comforting to observe that the wiring rated least flammable based on a short burn length is also the least smoky based on a low optical density reading.

TABLE 1 - FLAMMABILITY DATA FOR AIRCRAFT WIRING BY NEMA 60° INCLINED TEST METHOD

Test No.	Materials	Description	Burn Length (in.)	Flameout Time (sec)	Flaming Drippings	Meets FAR 25 Section 25-1359 Requirements (1)
	DuPont Desig.	Type Insulation and Wire Size				
1.	TFE-20	Tetrafluoroethylene AWG #20 19/32 .009 in. coating	0.6	0	No	Yes
2.	EE	Tetrafluoroethylene AWG #12 19/25 .014 in. coating	0.5	0	No	Yes
3.	18001	Abrasion Resistant TFE AWG #20 19/32 .018 in. coating	1.3	0	No	Yes
4.	FEP	Fluorinated Ethylene Propylene AWG #20 19/32 .009 in. coating	0.6	0	No	Yes
5.	22759/13	Fluorinated Ethylene Propylene and Polyvinylidene Fluoride AWG #20 19/32 .006 in. FEP + .005 in. PVF_2 coatings	0.8	0	No	Yes
6.	FEP/Kynar	Fluorinated Ethylene Propylene and Polyvinylidene Fluoride AWG #20 19/32 .005 in. FEP + .003 in. PVF_2 coatings	0.6	0	No	Yes
7.	SRL-12	Modified Fluorocarbon AWG #20 19/32 .010 in. coating	0.8	0	No	Yes
8.	IMP/Kynar	Irradiated Modified Polyolefin with Polyvinylidene Fluoride AWG #20 19/32 .010 in. IMP + .005 in. PVF_2 coatings	1.0	0	No	Yes
9.	8433343	Ethylene Propylene Rubber and Chlorosulfonated Polyethylene AWG #12 19/25 .042 in. coating	0.8	1	No	Yes
11.	PVC-IRR	Irradiated Polyvinyl Chloride AWG #20 19/25 .017 in. coating	1.3	0	No	Yes

Note: (1) FAR 25 requirements are that (1) Burn Length be less than 3 inches, (2) Drippings cease to flame 3 seconds after falling, and (3) Flaming ceases within 30 seconds after removal of the burner flame.

TABLE 2 - SMOKE EMISSION DATA FOR AIRCRAFT WIRING BY NBS TEST METHOD (TECHNICAL NOTE 708)

Test No.	Materials DuPont Desig.	Description Insulation & Wire Size	Type of Fire (1) Exposure	Specific Optical Smoke Density (D_s) Exposure (2) 1.5 min	Exposure 3.0 min	Exposure 4.0 min	Exposure max	Max. Specific Optical Smoke Density (D_m) Corrected	Time to reach D_s of 16 (min)	Time to reach D_m (min)	Remarks
1.	TFE-20	Tetrafluoroethylene AWG #20 19/32 .009 in. coating	F	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	NR (3)	20	One test only.
			S	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	NR	20	No visible smoke or flame.
2.	EE	Tetrafluoroethylene AWG #12 19/25 .014 in. coating	F	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	NR	20	One test only.
			S	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	NR	20	No visible smoke or flame.
3.	18001	Abrasion Resistant TFE AWG #20 19/32 .018 in. coating	F	0.1	0.1	0.2	3.9	3.3	NR	20	Av. of 2 tests.
			S	No test - Insufficient wire					NR	20	Very light smoke.
4.	FEP	Fluorinated Ethylene Propylene AWG #20 19/32 .009 in. coating	F	0.1	0.2	0.3	6.3	5.5	NR	20	Av. of 3 tests.
			S	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	NR	20	One test only.
5.	22759/13	Fluorinated Ethylene Propylene and Polyvinylidene Fluoride AWG #20 19/32 .006 in. FEP + .005 in. PVF_2 coatings	F	< 0.1	0.1	0.5	98	95	9.2	20	Av. of 2 tests. Medium heavy smoke. Flame 2 to 3 inches.
			S	No test - Insufficient wire							
6.	FEP/Kynar	Fluorinated Ethylene Propylene and Polyvinylidene Fluoride AWG #20 19/32 .005 in. FEB + .003 in. PVF_2 coatings	F	0.1	0.4	1.1	76	73	8.9	20	Av. of 2 tests. Small flames.
			S	< 0.1	< 0.1	< 0.1	1.1	0.8	NR		Av. of 3 tests. Light smoke.
7.	SRL-12	Modified Fluorocarbon AWG #20 19/32 .010 in. coating	F	0.4	2.1	8.4	476	459	4.5	20	One test only. Very heavy smoke.
			S	0.3	0.3	0.4	46	44	14.8	20	One test only. Flame 3 to 4 inches.
8.	IMP/Kymar	Irradiated Modified Polyolefin with Polyvinylidene Fluoride AWG #20 19/32 .010 in. IMP + .005 in. PVF_2 coatings	F	0.2	38	76	316	315	2.5	9.5	Av. of 3 tests.
			S	0.1	0.1	0.1	5.6	4.5	NR	20	Av. of 2 tests. Light smoke for smoldering condition.
9.	8433343	Ethylene Propylene Rubber and Chlorosulfonated Polyethylene AWG #12 19/25 .042 in. coating	F	20	106	210	710	678	1.4	13.0	One test only. Extremely heavy smoke.
			S	No test - Insufficient wire							
10.	Special	Irradiated Polyvinyl Chloride AWG #20 Unknown thickness	F	93	239	306	358	355	0.6	9.0	Av. of 2 tests. Heavy smoke.
			S	0.9	6.4	15	234	226	4.1	17.8	Av. of 2 tests. Heavy smoke.
11.	PVC-IRR	Irradiated Polyvinyl Chloride AWG #20 19/25 .017 in. coating	F	102	165	280	337	335	0.7	8.5	Av. of 2 tests. Heavy smoke.
			S	1.0	5.8	12	241	234	4.5	17.5	One test only. Heavy smoke.

Notes: (1) F signifies flaming combustion (radiant heat & gas burner flames). S signified smolering combustion (radiant heat alone).

(2) Proposed NPRM requirements for limiting smoke emission by interior materials are that (1) Specific Optical index (D_s) be less than 100 for 1.5-minutes fire exposure and (2) less than 200 for 4-minutes fire exposure.

(3) NR signifies never reached specific smoke level.

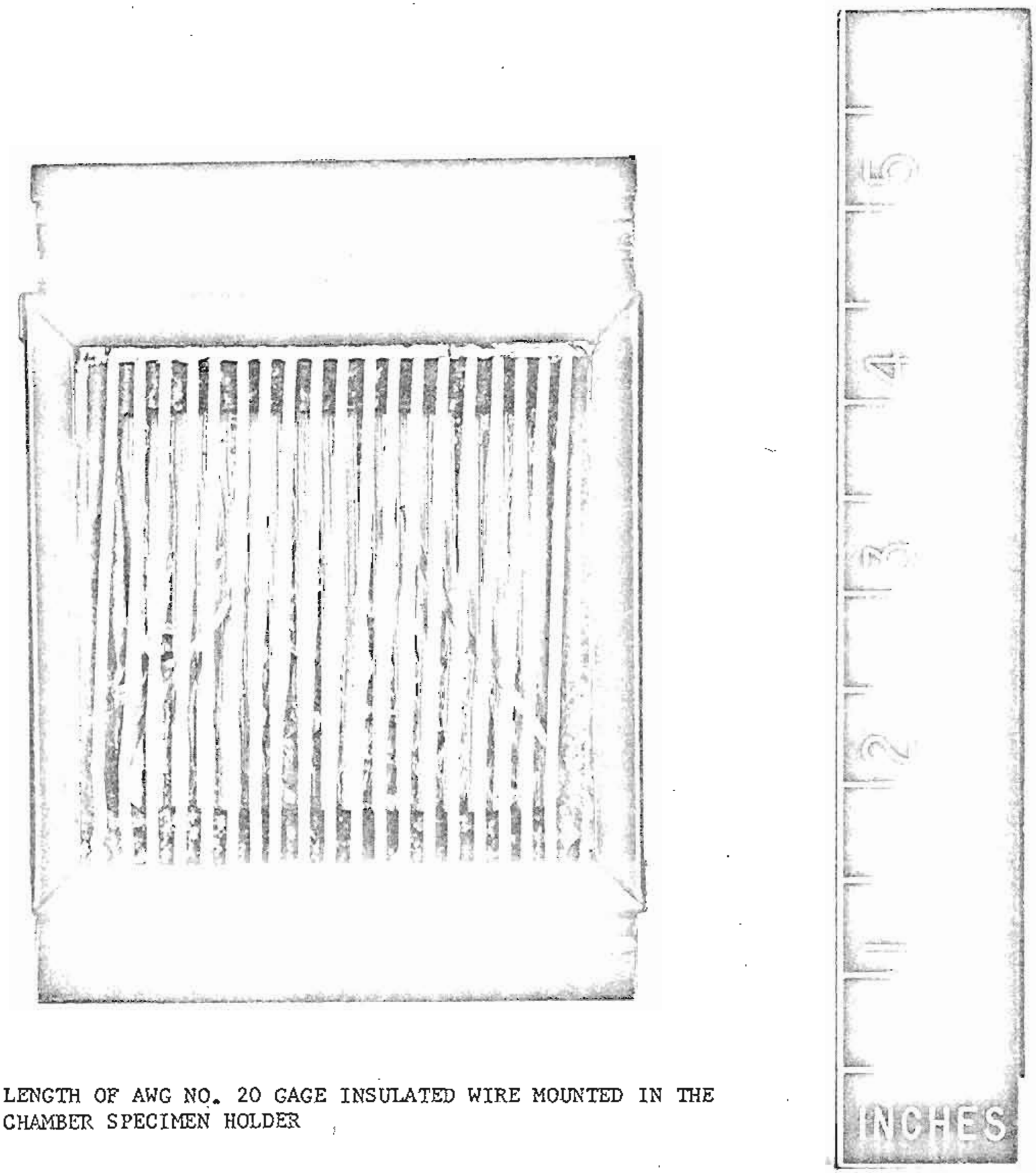

FIG. 1 - A 10-FOOT LENGTH OF AWG NO. 20 GAGE INSULATED WIRE MOUNTED IN THE NBS SMOKE CHAMBER SPECIMEN HOLDER

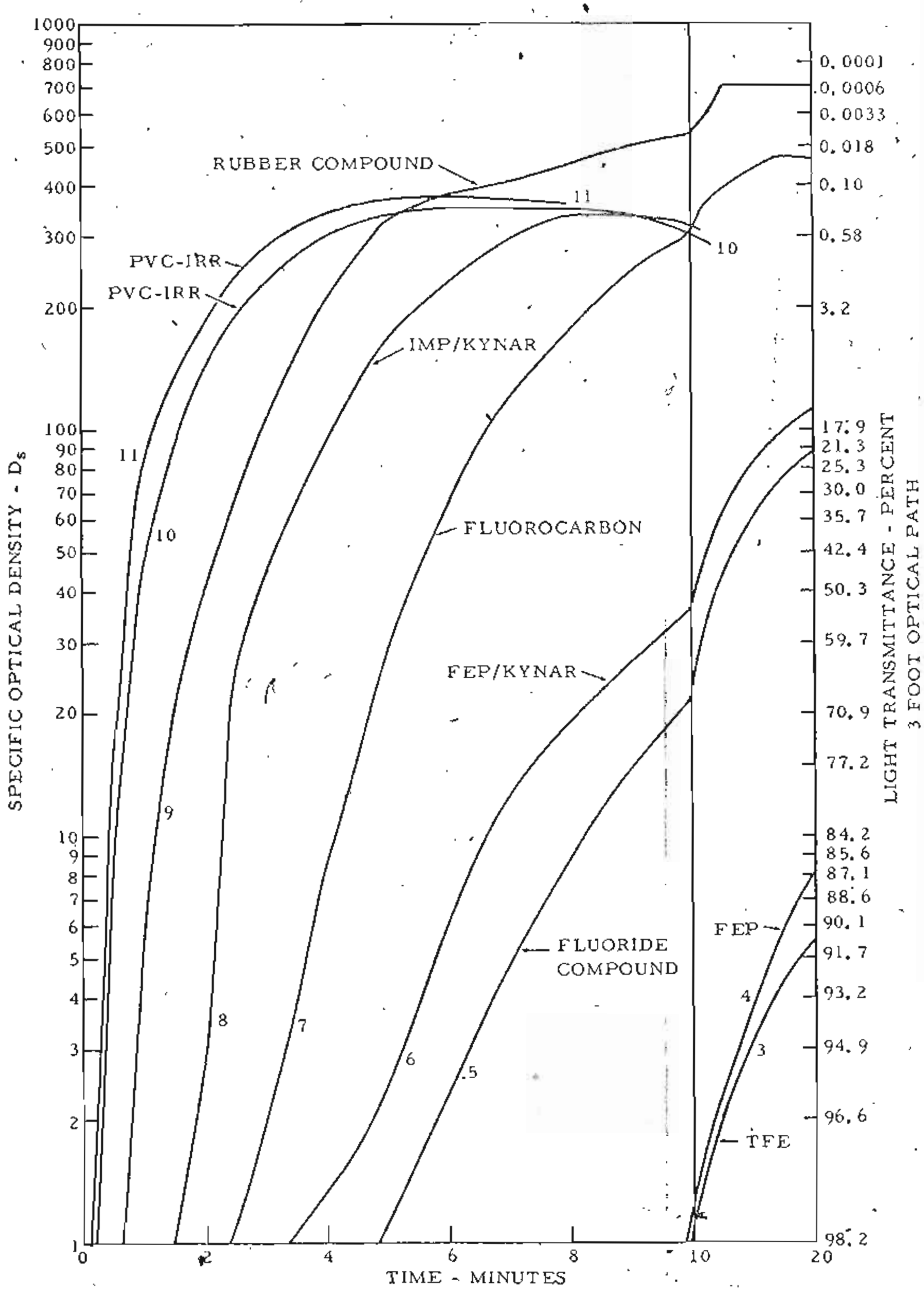

FIG. 2 - SMOKE EMISSION BY AIRCRAFT WIRING UNDER FLAMING CONDITION OF FIRE EXPOSURE - NBS TEST METHOD.

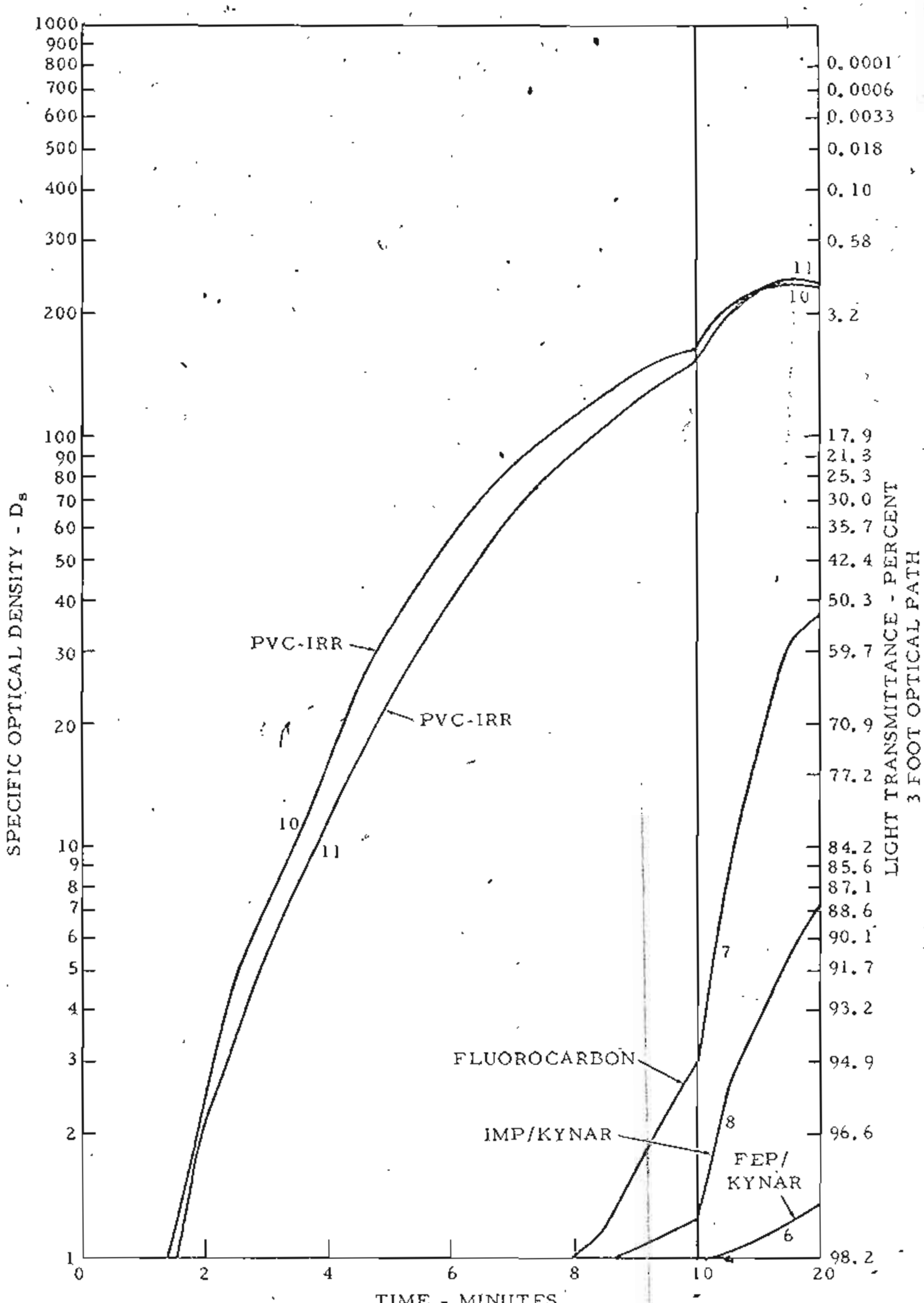

FIG. 3 - SMOKE EMISSION BY AIRCRAFT WIRING UNDER SMOLDERING CONDITION OF FIRE EXPOSURE - NBS TEST METHOD

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ADDENDUM
DATA REPORT NO. 98

SMOKE EMISSION BY BURNING AIRCRAFT WIRING

PROJECT NO. 184-732-04X

Prepared by: John F. Marcy

Purpose

The intention of this report was to provide additional smoke data furnished by the Lockheed Company on the smoke emission characteristics of aircraft wiring insulation. The new test data complements and extends previous work at NAFEC in this area of proposing an alternate smoke test method which utilizes an overload electrical current for heating the wire specimens instead of an external fire source.

Background

The Lockheed Company furnished the NAFEC project manager, during his visit on 16 October 1972 to the R & D Rye Canyon Facility, with a set of smoke emission curves on aircraft wiring with plastic insulation similar to that used in the NAFEC tests. Since the size of the wire AWG No. 20, length of the wire - 10 feet, and method of testing and mounting inside the 3-inch square holder used in the NBS smoke chamber were identical in the NAFEC and Lockheed tests, a comparison of the data between the two laboratories is possible. The only factor that was different was that of the type of heat exposure for the wire specimen under test. In the NAFEC tests, the wire insulation was pyrolyzed using an external radiant heat source of 2.5 watts/cm^2 as well as direct flame impingement. Instead, in the Lockheed tests, the wire insulation was heated internally by an electrical overload current of 35 to 45 amps through the AWG No. 20 copper conductor.

Results

Smoke data curves for six different types of aircraft wiring comparable to the wiring in the NAFEC tests both in physical dimensions and chemical composition of the plastic insulation are attached herein.

A very wide range in the smoke levels obtained by the different types of plastics are shown. Pyrolysis of the Teflon/Polyimide type of insulation by the burning of the test specimen from an overload current produced very low Specific Optical Indices (D_s), while very high smoke indices were produced by the vinyl plastics.

The value of the overload current used to pyrolyze the plastic insulation was shown to be critical in the range of 35 to 45 amps for AWG No. 20 gage wire. Pyrolysis of the plastic insulation from an overload current in the range selected occurs much more rapidly than in the NAFEC tests using an external radiant and flame source for heating as specified for the NBS apparatus. This is evident from a comparison of the time base for the two sets of smoke curves obtained under conditions of internal and external heating of the wire insulation. In the NAFEC tests for the higher temperature fluorinated plastics, no smoke was registered until after 10 minutes exposure indicating a low rate of heating of the test specimen. In contrast, in the Lockheed electrical overload tests, smoke developed within one minute after application of a current of 45 amps. An examination of some of the curves representing vinyl plastics show an almost vertical rise in smoke indicative of the much greater heating rate of the test specimen.

Although the Lockheed materials lack sufficient identification and some of the curves cover too short a time span for heat exposure to provide closer correlation of the smoke curves, the comparative results were believed to be of sufficient interest to be included in the overall test program. The test method provides an attractive alternative for smoke measurements of electrical wiring.

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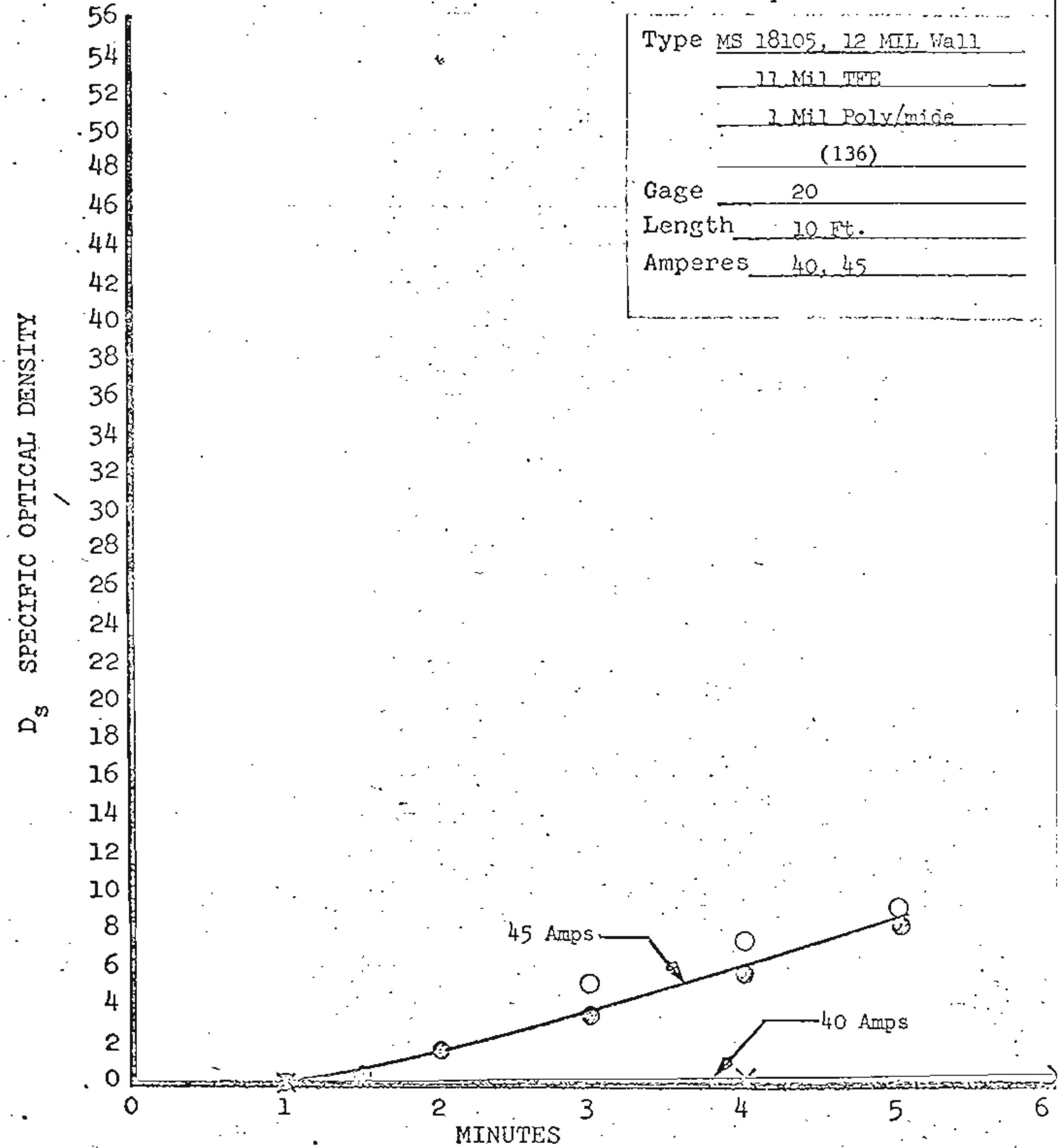
REPORT NO. ______
PAGE NO. ______

RYE CANYON RESEARCH LABORATORY
Wire Insulation Smoke Test
In NBS Type Smoke Chamber

Wire Specimen Data

Type MS 18105, 12 MIL Wall
11 Mil TFE
1 Mil Polyimide
(136)
Gage 20
Length 10 Ft.
Amperes 40, 45



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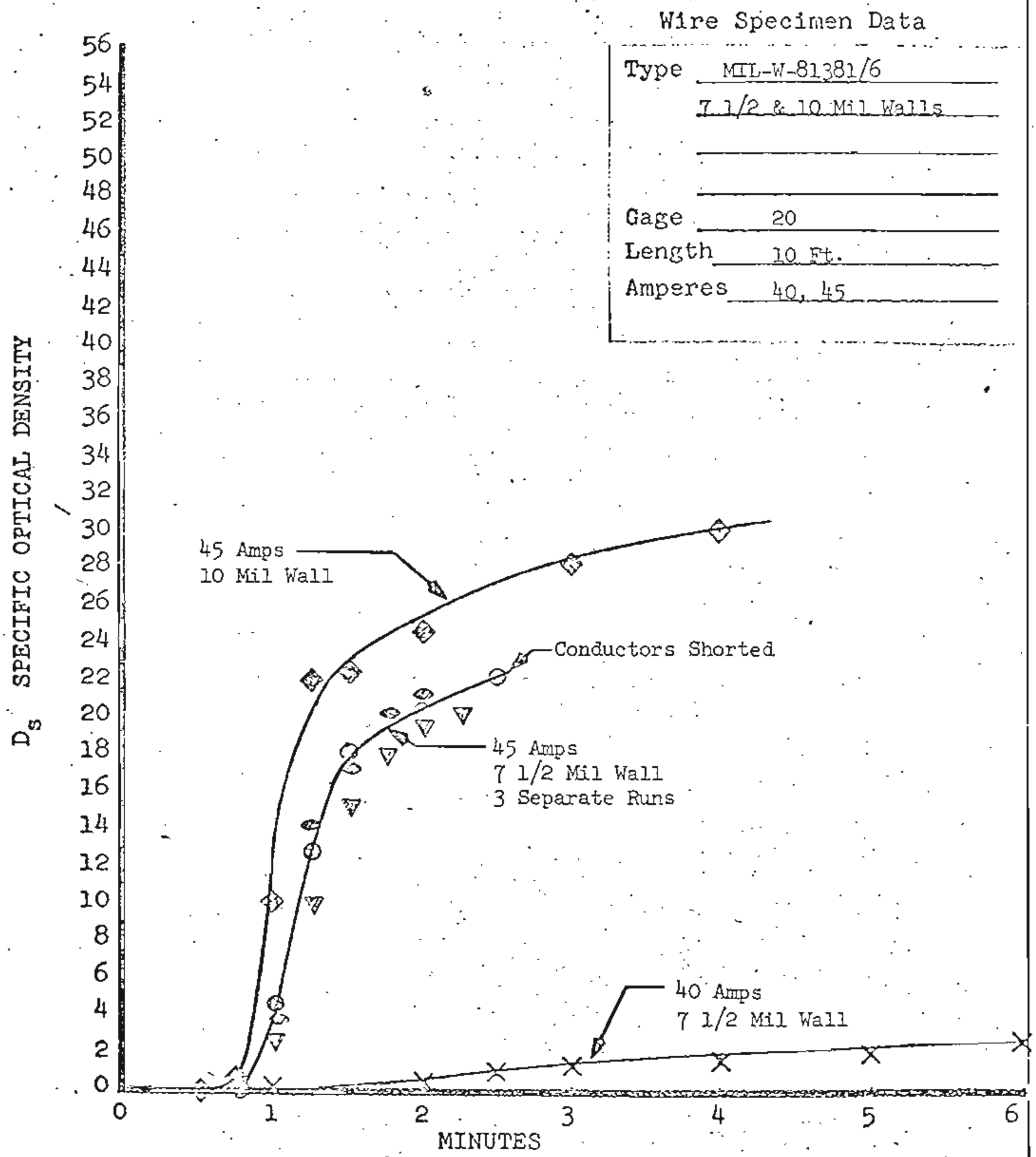
REPORT NO.
PAGE NO.

RYE CANYON RESEARCH LABORATORY
Wire Insulation Smoke Test
In NBS Type Smoke Chamber



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REPORT NO.
PAGE NO.

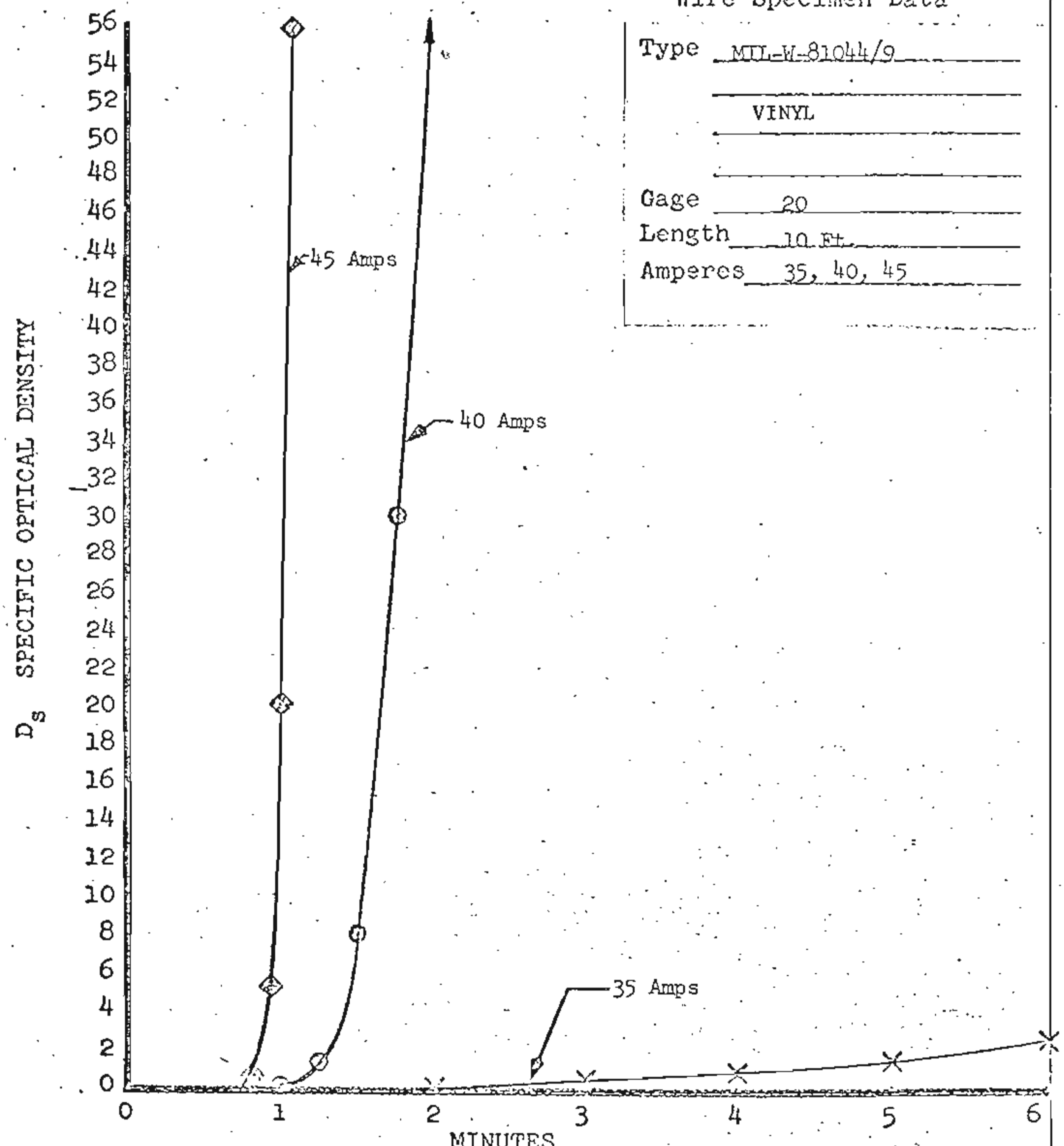
RYE CANYON RESEARCH LABORATORY
Wire Insulation Smoke Test
In NBS Type Smoke Chamber

Wire Specimen Data

Type MIL-W-81044/9

VINYL

Gage 20
Length 10 Ft.
Amperes 35, 40, 45



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REPORT NO. ____________

PAGE NO. ____________

RYE CANYON RESEARCH LABORATORY
Wire Insulation Smoke Test
In NBS Type Smoke Chamber

Wire Specimen Data

Type: MS 17412
MS 18001
TFE

Gage: 20
Length: 10 Ft.
Amperes: 45 Amps