USN MARINE ENGINEERING LABORATORY

Annapolis, Maryland

Cable Insulation Thermal Life Studies

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This paper has been presented at the Fifteenth Annual Wire and Cable Symposium sponsored by the Department of the Army, U. S. Electronics Command, 7-9 December 1966, at the Shelburne Hotel, Atlantic City, New Jersey.

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Introduction.

The need for lighter wire and cable in air space vehicles is based upon the economy of weight reduction for the vehicle. Weight reduction of cables and wires is being accomplished through the reduction in weight of insulation, for instance, 1000 feet of AWG 22 insulated with H-film weighs only 2.76 pounds. Weight savings in terms of insulation reduction requires more confidence in thermal life ratings. At present the thermal rating system is very weak; for instance, an H-film will be evaluated (MIL-W-22759) for 120 hours at $270^{\circ}C$. There is no concept here of any rate reaction in determining the thermal rating. In the thermal rating of magnet wires, the rate concept is taken into consideration. The thermal rating is based upon a 20,000 hour extrapolated life for magnet wires. With such a thermal-life rating it is possible to explore mechanisms of degradation of polymer insulation and at the same time upgrade polymeric insulation materials in thermal-life rating. Using a similar system of thermal-life rating which is summarized in Table I and Figure 1, (Ref. 1 and 2), thermal-life ratings may be determined for cables and wire. In some cases a thermal life rating will not be obtained in an expected temperature range. This may be indicative of a material incompatability such as an adhesive failure in a tape system. Such modifications in cable construction as paper separators can lead to a reduction in thermal-life rating, and by analogy with definitions in magnet wire studies, would be considered as an incompatable modification.

The Thermal Rating of H-Film.

The H-film is polyimide film. In cable it can be applied as HF and HI, where the designations F and I signify the type of adhesion used in constructing a wrapped tape cable. The F stands for the FEP type teflon film, the I stands for a polyimide adhesive. An attempt to attain a thermal rating of the HF cable using temperature points $320^{\circ}C$, $300^{\circ}C$, $280^{\circ}C$, and $260^{\circ}C$ was not successful due to unravelling of the tape which was caused by adhesion failure of the FEP between tape laps. A thermal rating for HI is being developed. The 320°, 300°, 280°, 260°C points are in the process of being obtained (see Table II). The use of this thermal-life rating would then put more weight upon an HI construction in terms of a thermal-life rating. The choice of adhesive technique in a tape is very important in thermal-life ratings.

S. D. Bruck (3) discussed thermal stability of H-films in terms of purity of the film (degree of conversion) (Figure 2). A study was then made by MEL using infrared analysis to measure the degree of conversion from the polyamic acid to the polyimide form. This degree of conversion was then related to the thermal-life rating of the polyimide film with source of manufacture (see Figures 2, 3, and 4). This data was obtained for magnet wires and will be of value for cables.

In addition weight loss data at 200°C for 2 hours was obtained for polyimide films. There was a variation in weight loss depending upon source of manufacture (see Figure 5). The weight loss represented mainly retained solvent used to cast the films. Present day art of film casting on wire has reduced weight loss to less than 1 per cent under these conditions.

The Thermal-Life Rating of Teflon

An attempt to get a thermal-life rating for a teflon cable (see Table II) using the 320°, 300°, 280°, and 260°C points was unsuccessful due to the shrinkage of the insulation. To achieve a thermal-life rating using these temperature points would require a teflon material that did not shrink. See Figure 6 for the shrinkage effect. It would be difficult to rate this material for 260°C service unless the shrinkage factor were eliminated.

The Thermal-Life Rating of Ethylene Propylene Wires

The thermal-life rating for ethylene propylene wires shown in Figure 7 and 8 are respectively 132°C and 112°C. The reduction in thermal-life rating is due to the paper separator. The paper separator has two effects on the insulation which may effect the thermal-life rating. One is the chemical interaction of the paper and the insulation, and the second is elimination of adhesion between the conductors and the insulation. The modification of a wire can affect the thermal-life rating. Modifications to improve stripability should be balanced against changes in thermal-life rating.

Cut Through on H-Film Data.

Table III summarizes the cut through data on H-film using a ¼ inch mandrel with 3 pound weights at 320oC. It would be difficult to relate this cut through with thermal-life rating.

A cut through test is necessary to test for the hot-flow phenomenon of cable insulation. In addition results could be obtained much more rapidly than the thermal-aging data and still simulate those conditions found aboard ship or aircraft.

The test presently in use consists of a cable suspended in an oven over a mandrel with weights on both ends of the cable. The size of the mandrel and the weights is dependent upon the size of the cable. A potential of 115 volts a.c. is applied between the mandrel and the cables. Failure occurs when a three amp series fuse blows triggering a timer to indicate the number of hours of life. The test presently used has proven inadequate because it has not accomplished the goals stated above. A set of cables successfully withstood the test for 952 hours, however, the insulation had carbonized and fell off the cables when they were removed from the mandrel. This material had obviously failed as an insulation but had withstood the test. The same material run at the same temperature on the thermal-aging test was stopped at 264 hours because of the severe shrinkage and unravelling of the insulation. Some sort of movement was necessary between the cables and the mandrel to prevent this from occuring. A new test has been proposed containing a vibration to simulate conditions aboard ship or aircraft. To provide this vibration the cable will be suspended over a mandrel which is a part of a transformer or reactor. The vibration will have a primary frequency of 120 or 800 cycles per second corresponding to an excitation potential of 60 or 400 cycles per second, respectively. Suspending the cables in an oven would now be impossible because the insulation of the transformer or reactor would not withstand the elevated temperature. To obtain the elevated temperature a current, controlled by sensing the temperature of the cable, will be passed through the cable. In addition, a stress potential, isolated electrically from the heating current, would be applied between the cable through a 3 amp fuse and a timer. The criteria for failure would remain the same as it was for the original test. It should be noted, however, that this test is still in the development stage.

Acknowledgements.

This work was carried out with the support of the Naval Air Systems Command and the Marine Engineering Laboratory In House Research Program.

References.

1. Campbell, F. J. and Broncato, E. L., "Determination and Application of Thermal-Life Characteristics of Aerospace Wires, Parts I and II," Insulation, October and November 1963.

2. Campbell, F. J. and Baggett, C. L., "Investigations of Thermal Aging Characteristics of Aerospace Wires" presented at BUWEPS Symposium on Advanced Wiring Techniques for Naval Aircraft Electrical Systems, 14-16 October 1963.

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Table I

Summary of Functional Aging Cycle

Step	Condition	Magnitude	Duration
1	Heat Exposure	Prescribed temperature	10% of estimated lifetime
2	Cool	Room Temperature	One hour, gradually
3	Mandrel Bend	Approximately 50 times wire dia	Bend twice in each direction
4	Humidity Exposure	100% Relative Humidity	24 hours
5	Voltage Stress (at 100% Relative Humidity)	3000 Volts RMS	15 seconds
6	Drying Period	Room Temperature below 50% Relative Humidity	4 hours

Table II

Thermal Aging Studies of "H" Film Cable

Cable Designation	Construction 1st layer	Construction 2nd layer	Construction 3rd layer	Thermal Aging Temperature	Hours to Date	Failures to Date	Status	Remarks
1	55% over-lap HI film	48% cross-wrap HI film	-	260	2016	0	Running	None
	"	"	-	280	2352	0	Running	None
	"	"	-	300	936	0	Running	None
	"	"	-	320	600	7	Running	Hrs. of failures 288, 336, 384, 432, 480, 480, 528
2	"	"	48% over-lap HI film	260	2016	0	Running	None
	"	"	"	280	2016	0	Running	None
	"	"	"	300	936	0	Running	None
	"	"	"	320	600	6	Running	Hrs. of failures 288, 288, 288, 336; Ins. becoming brittle at 312 hrs. 384, and 432
3	53% over-lap 1:½ HF film	48% over lap ½:1:½ FHF film	--	260	1008	0	Stopped	Cable insulation unravelling about 1" from end of cable
	"	"	-	280	1008	0	Stopped	After first cycle (672 hrs) in oven insulation unravelled and shrunk away from terminal at top and bottom 2 to 6 inches
	"	"	-	300	480	0	Stopped	All cables after 288 hrs. unravelling and shrinking exposing 6 to 8 inches of bare conductor
	"	"	-	320	264	0	Stopped	Insulation unravelling and shrinking 4" to 6" after 48 hrs of aging

Table II (Contd)

Thermal Aging Studies of "H" Film Cable

Cable Desig-nation	Construction 1st layer	2nd layer	3rd layer	Thermal Aging Temper-ature	Hours to Date	Failures to Date	Status	Remarks
4	"	"	Crosslap 48% ½:1:½ FHF film	260	2016	0	Run-ning	None
	"	"	"	280	2016	0	Run-ning	Insulation shrink-ing from end of cable as with cable 3 after 672 hours
	"	"	"	300	936	0	Run-ning	Insulation shrink-ing away from end of cable as with 99A from ½ to 1" after 576 hours
	"	"	"	320	600	0	Run-ning	All layers un-ravelling after 552 hrs. After 48 hrs. ½" to 1½" shrinkage occurred
5	Teflon	-	-	260	1512	0	Run-ning	None
	"	-	-	280	1680	0	Run-ning	None
	"	-	-	300	744	0	Run-ning	Teflon shrink-age 1" after 288 hrs. Shrinkage increasing to a distance of 4" after 744 hrs. both ends
	"	-	-	320	80	4	Stop-ped	Shrinkage ½ to 4" after 24 hrs. some cable had shrinkage to 10" after 48 hrs. shrinkage in-creased with aging time

TABLE III

CUT THROUGH STUDIES OF "H" FILM CABLE

¼" ROUND MANDREL 3# WEIGHT AT 320°C

	Construction			Hours of aging at end of test	Status	Remarks
	1st layer	2nd layer	3rd layer			
6	2/3 over-lap 1:½ HF film	Ex-truded teflon	-	991.8	Failed	Both lay-ers of insulation broken and wire ex-posed; the H film cracked axially
7	2/3 over-lap 1:½ HF film	Cross lap ½ over lap ½: 1:½ FHF film	Ex-truded teflon	1003.2	OK	Outer insulation flowed a-way; the inner in-sulation showing movement
3	53% over-lap 1: ½ HF film	48% over-lap ½: 1:½ FHF film	-	952.2	OK	Outer lay-er unravel-led at the end of ca-ble; outer layer sep-arated from inner lay-er
4	"	"	Crosslap 48% ½:1: ½ FHF film	1003.2	OK	Outer lay-er unravel-ling at end of cable; the outer layer sep-arated from

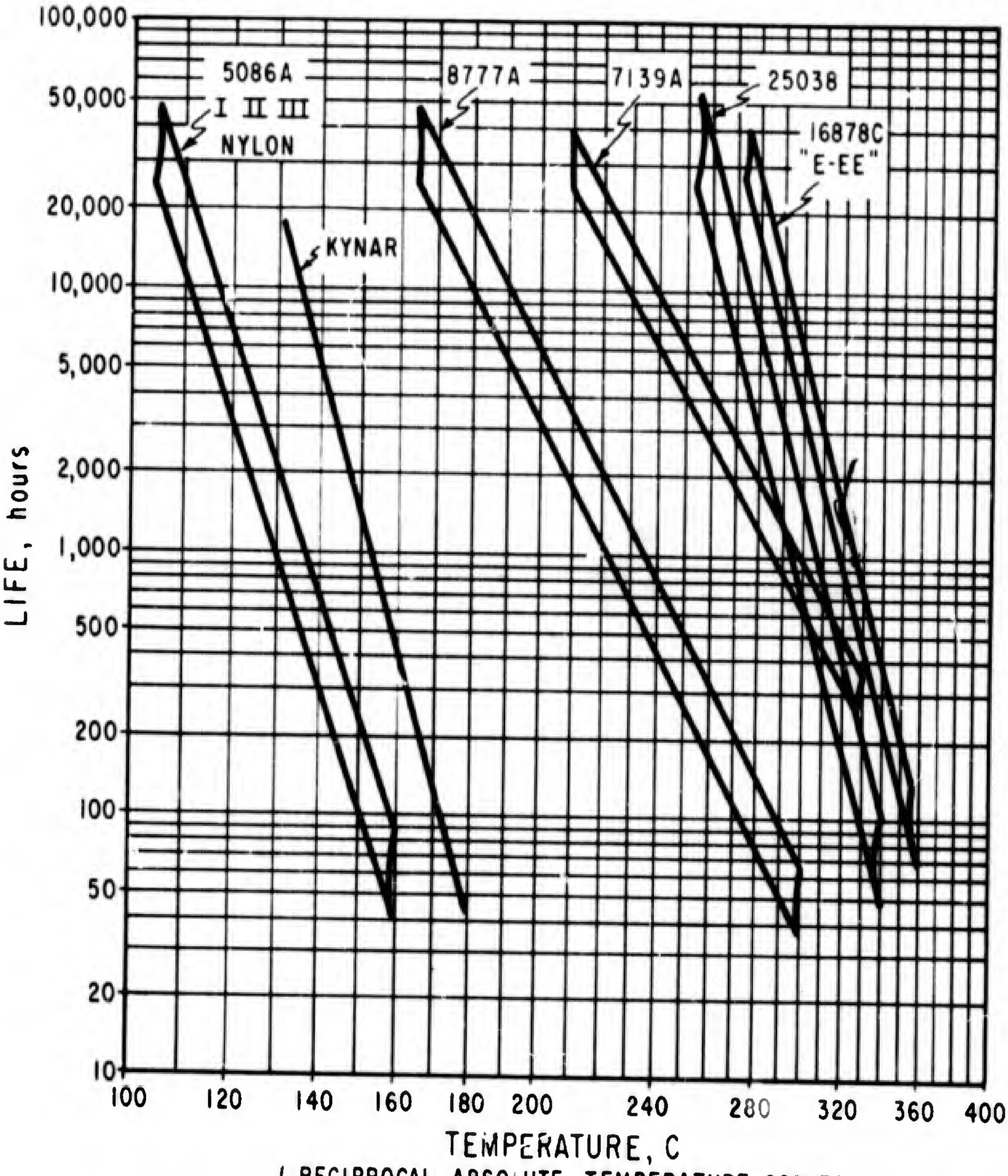

Figure 1
Summary Graph - Ranges of Life Temperature
Curves of Mil-Specification Wires

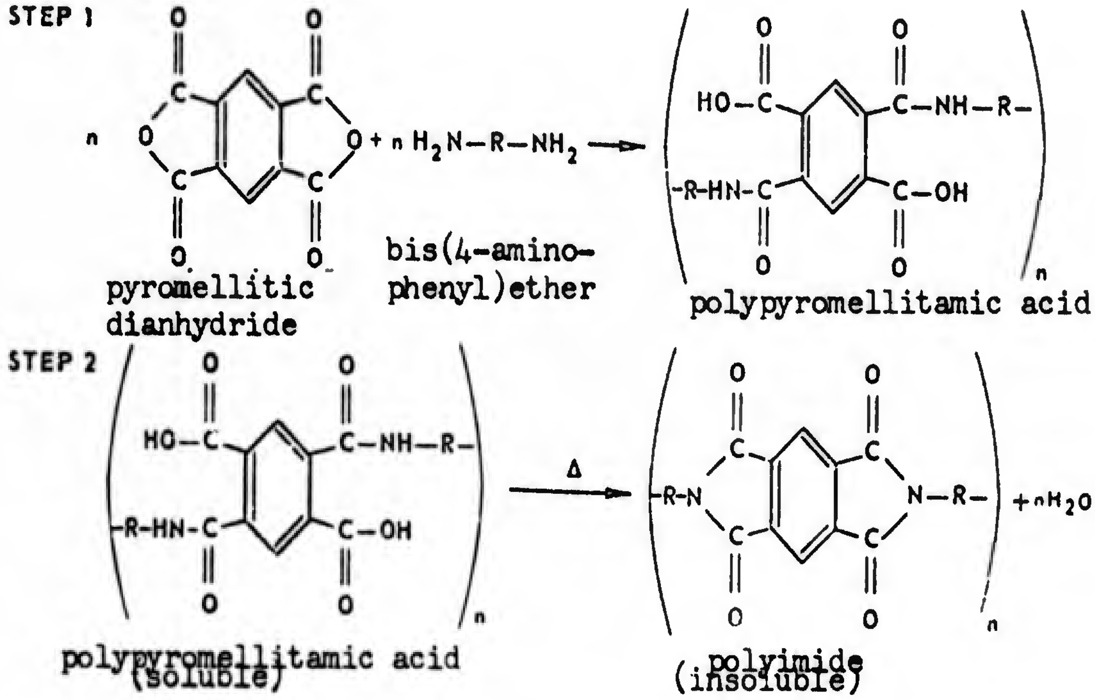

Figure 2

Polyimide Reaction

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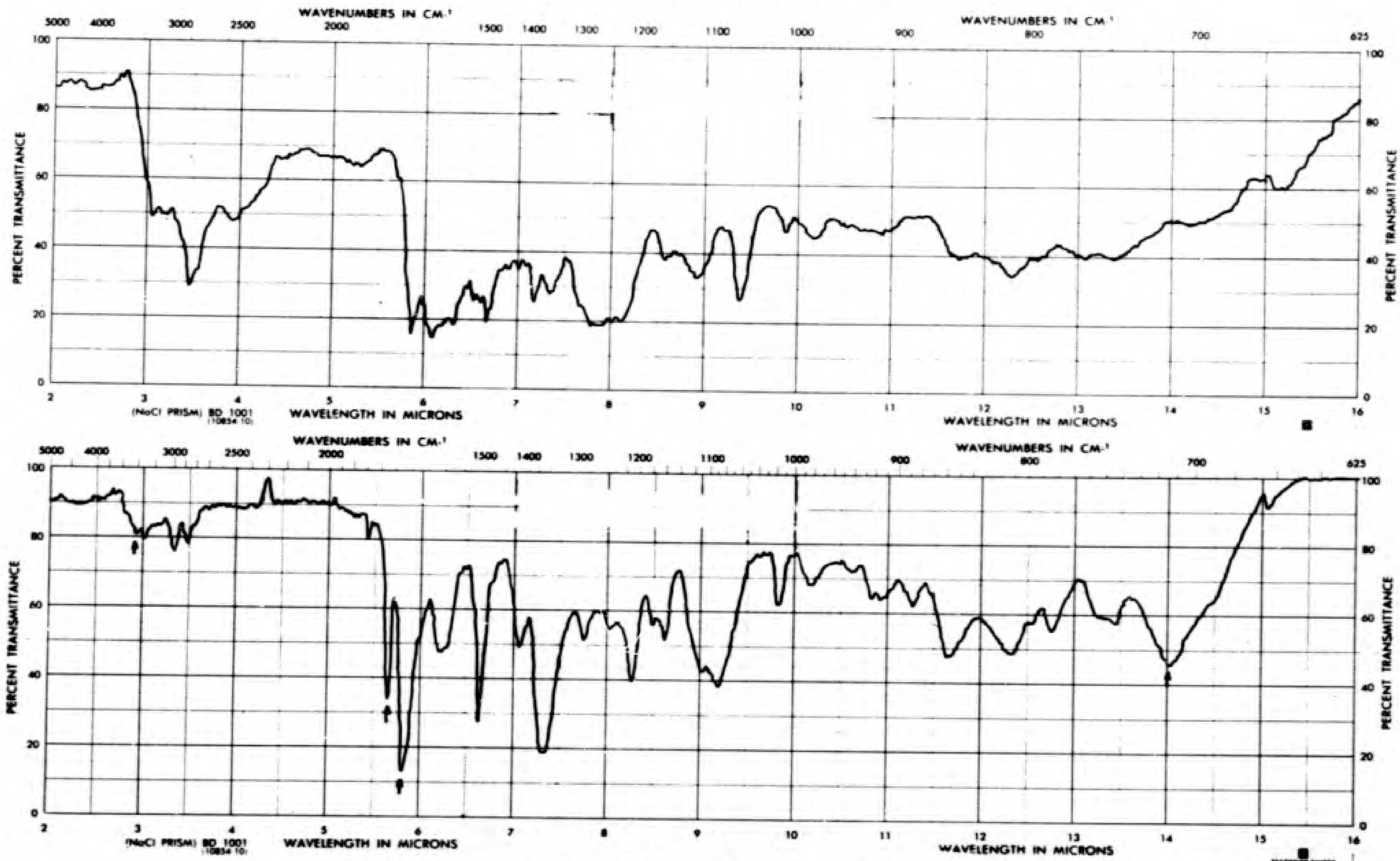

Figure 3 - Polyimide Enamel Film

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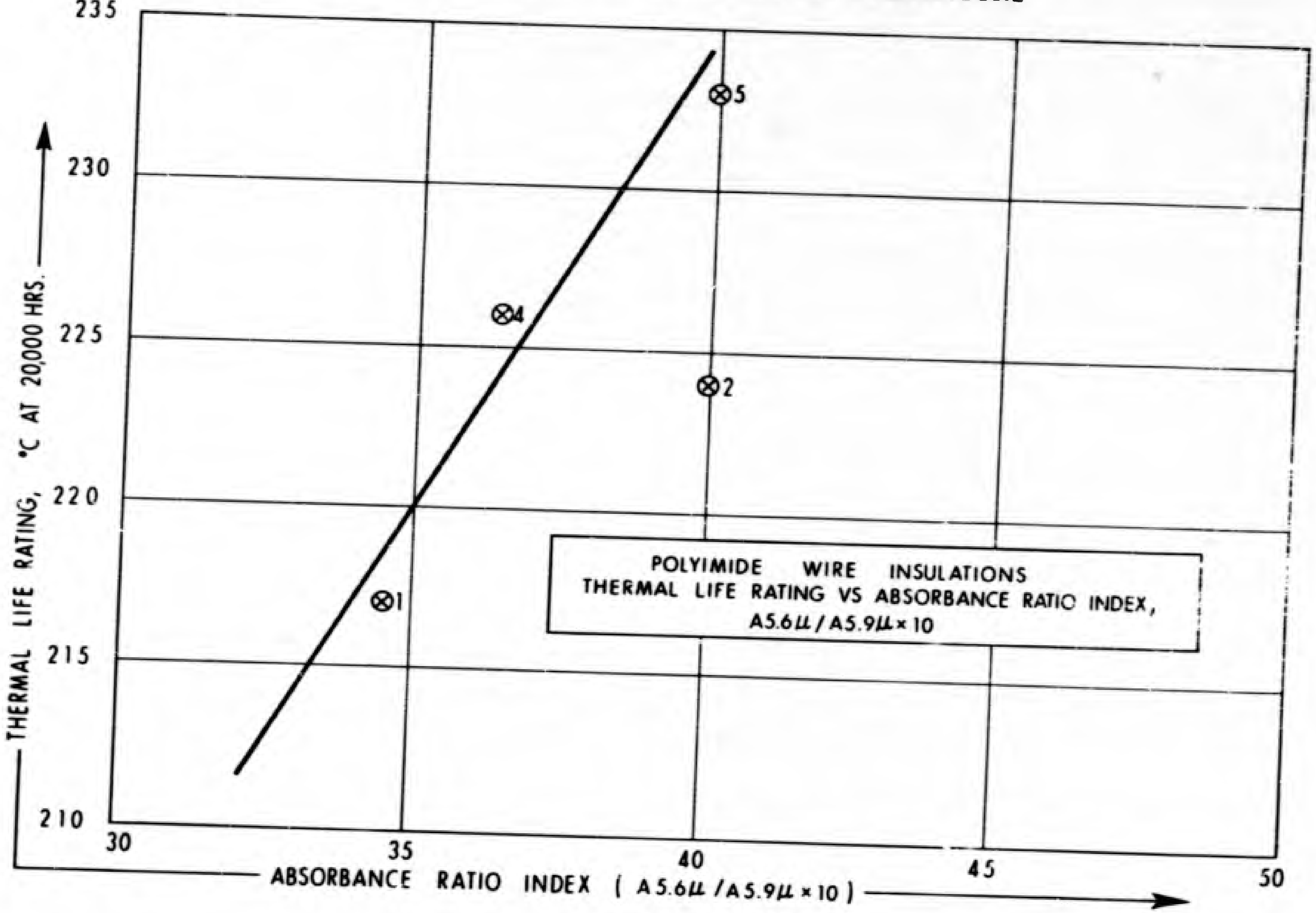

Figure 4

Polyimide Enamel Life Rating
vs. Absorbance Ratio Index

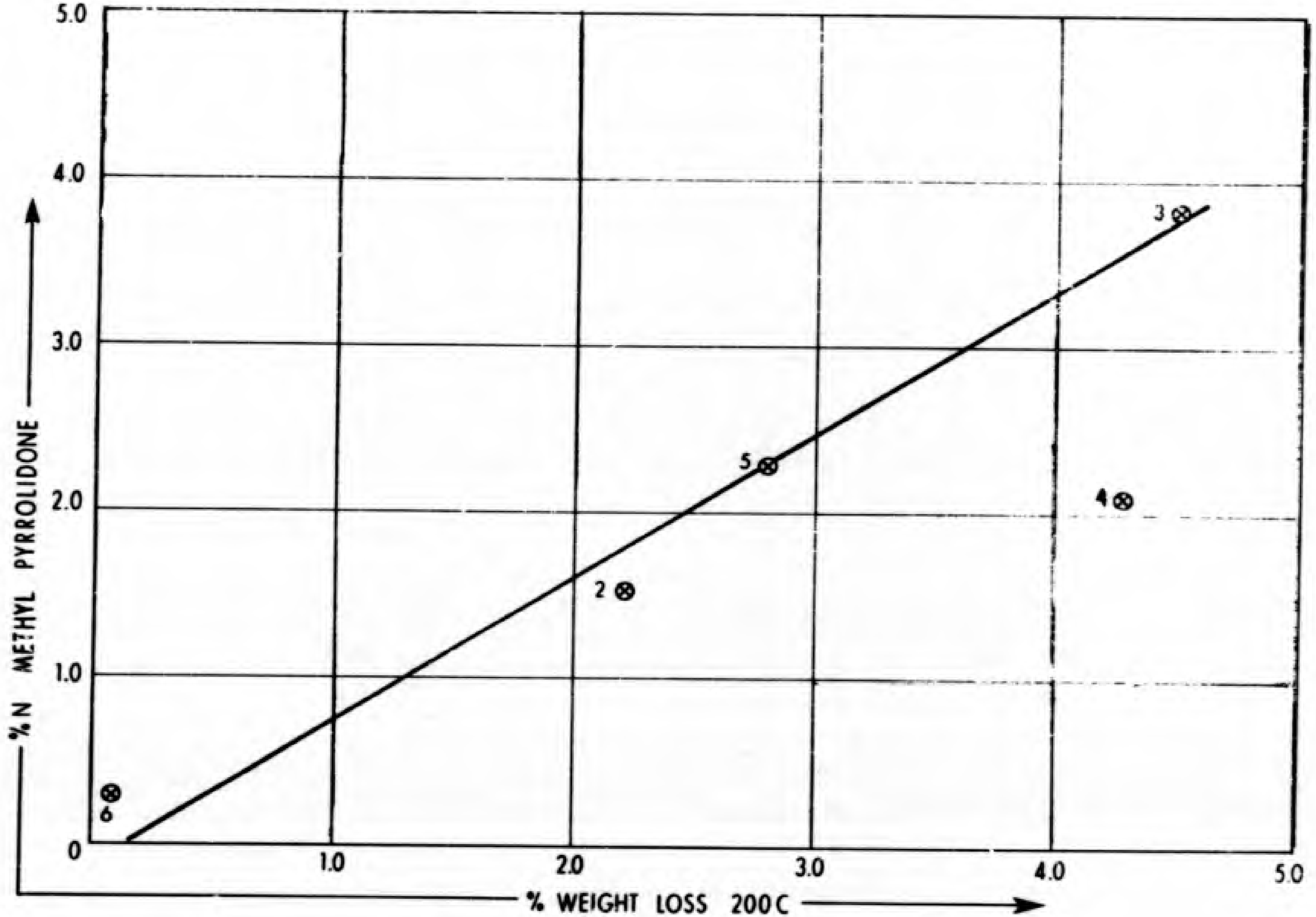

Figure 5
Polyimide Enamel Weight Loss
vs. Solvent Retention

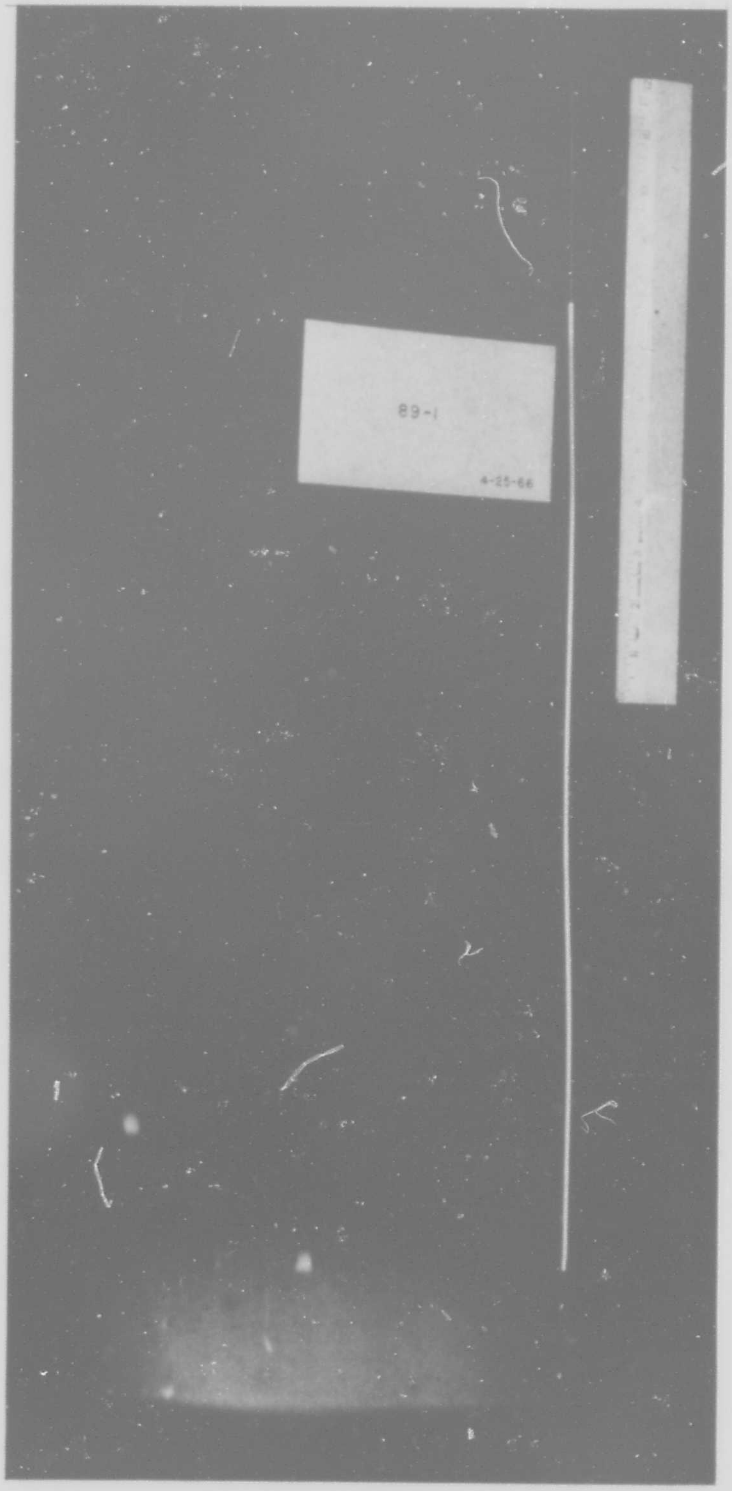

Figure 6
An Example of Shrinkage of Teflon Cable Insulation

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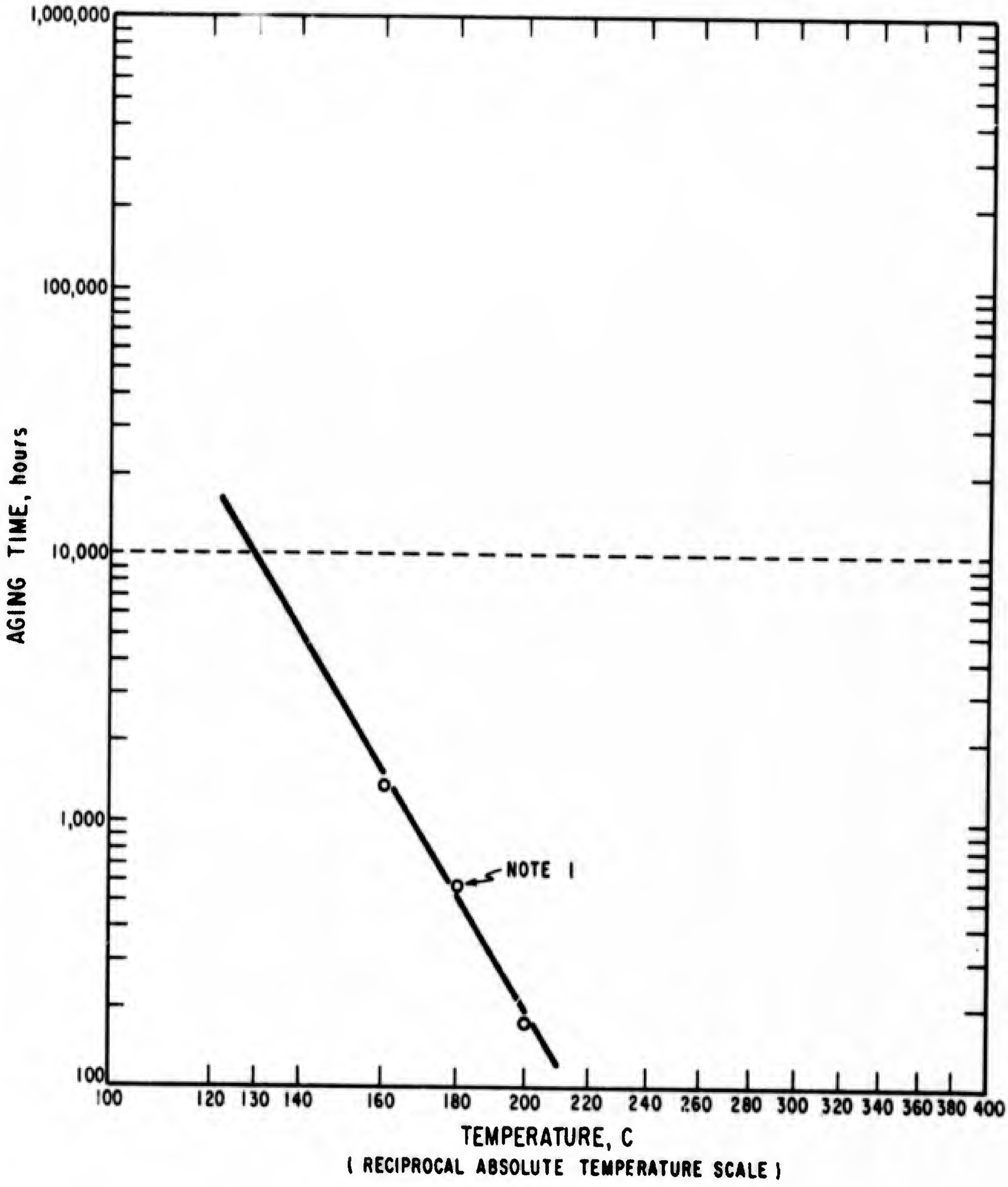

Note: Estimated average life (7 failures)

Figure 7
Ethylene Propylene No. 18 Lead Wire

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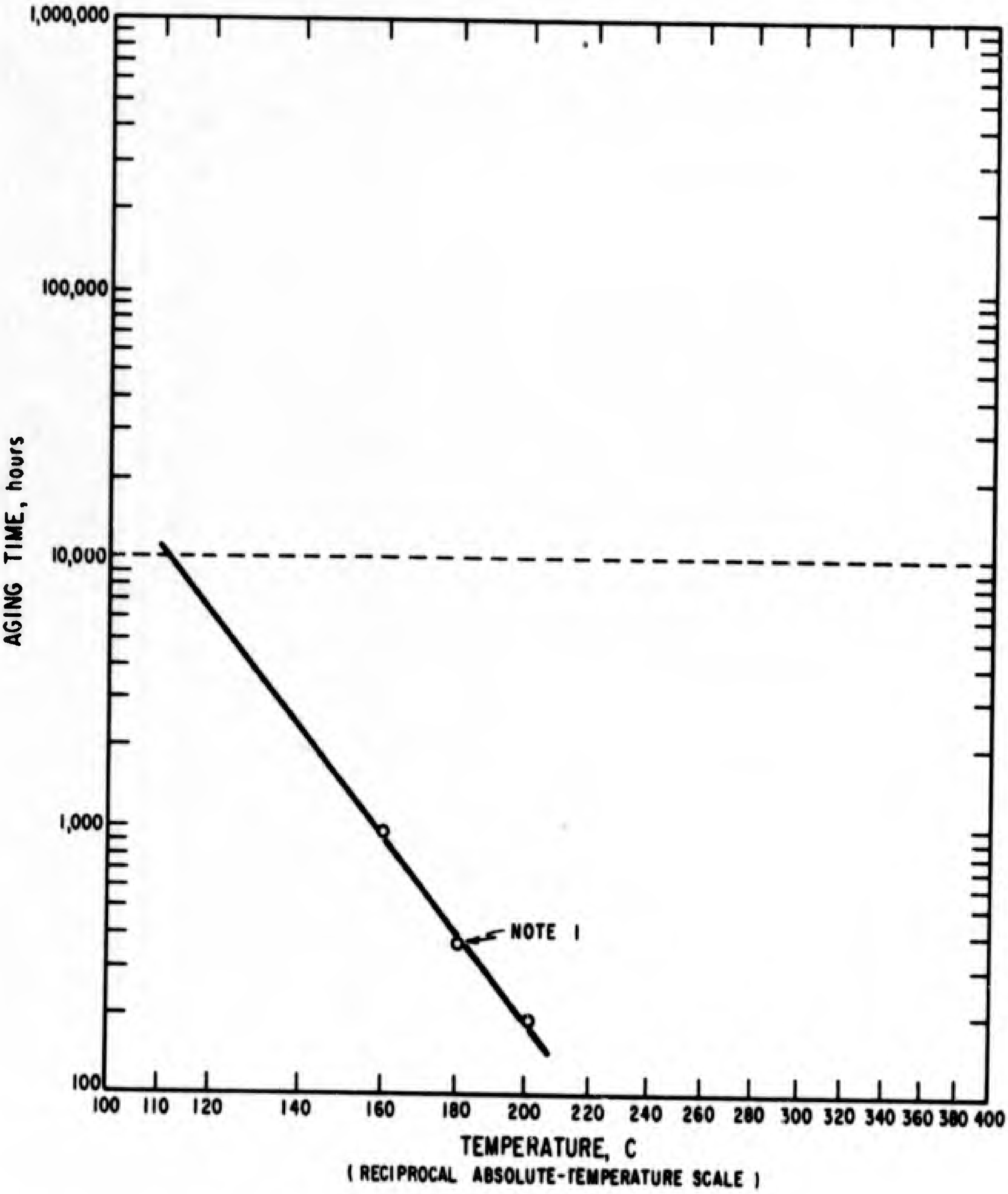

Note: Estimated average life (6 failures)

Figure 8
Ethylene Propylene No. 8 Lead Wire
With Paper Separator