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EVALUATION OF GOES ENCODER LAMPS

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ABSTRACT

Aging characteristics and life expectancies of currently produced, flight quality, tungsten filament, encoder lamps are similar to those of "commercial" grade gas filled lamps of similar construction, filament material and filament temperature. The aging and final failure by filament burnout are caused by single crystal growth over large portions of the filament with the concomitant development of facets and notches resulting in reduction of cross section and mechanical weakening of the filament. The life expectancy of presently produced lamps is about one year at their nominal operating voltage of 5 volts d.c. At 4.5 volts, it is about 2 years. These lifetimes are considerably shorter, and the degradation rates of lamp current and light flux are considerably higher, than were observed in the laboratory and in orbit on lamps of the same type manufactured more than a decade ago. It is speculated that the filaments of these earlier lamps contained a crystallization retarding dopant, possibly thorium oxide. To obtain the desired life expectancy of $\geq$ 4 years in present lamps, operating voltages of $\leq$ 4 volts d.c. would be required.

EVALUATION OF GOES ENCODER LAMPS

1. INTRODUCTION

This report discusses the results of diagnostic and long-term life tests of tungsten filament encoder lamps which are from the same lot as those presently in the encoders of GOES-5 and GOES-F.*

The long-term evaluation of these lamps represents the first part of a joint endeavor between Santa Barbara Research Center and Goddard Space Flight Center to develop space qualified lamps which meet the long duration mission requirements of meteorological satellites and to define the operating conditions under which these requirements can be met.

Previously encountered lifetimes on identical encoders in the meteorological satellite series have varied by a factor of four, from 59 months for the redundant encoder on SMS-2 to 15 months for the redundant encoder on GOES-3 (Reference 1, Memo, dated December 7, 1981, VAS Instrument Manager, L. Rouzer, to GOES Project Manager). The causes of failure ranged from filament burnout to decrease of light intensity below the encoder threshold, which causes the encoder to "stumble."

In the course of the Tiger Team investigation of scan mirror drive system problems on GOES-2 and GOES-3 (Reference 2, Final Report, "Tiger Team for Investigation of the GOES-2 and GOES-3 Scan Mirror Drive System Problems," May 1980), and prior to launching of GOES-4, it became apparent that lamps provided by the vendor (Hertzog Lamp Company, New York) at that time were substantially inferior to earlier lamps as evidenced by early burnout, rapid darkening of the envelope, and excessive fallout in the screening process performed by the encoder manufacturer (Baldwin Electronics). (For details, see Reference 2, Tiger Team Report).

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* In keeping with the established practice, GOES satellites are designated by letter (A, B, C...) before launch and by number (1, 2, 3...) after launch.

1

In addition, it was learned that earlier filaments were made from tungsten of unknown origin which was no longer available and that newer filaments were made from commercial GE-218 wire.

Darkening of the envelope accompanied by rapid loss of light flux is caused by the so-called "water cycle," in which water molecules dissociate at the hot filament into hydrogen and oxygen followed by the formation and transport of tungsten oxide to the lamp envelope; there free hydrogen reduces the oxide to metallic tungsten and recombines with the oxygen into water again. Removal of water from the back fill gas (krypton) to levels which are orders of magnitude below the analytical detection limit of $\leqslant 10$ parts per million by careful drying of the gas and by vacuum bakeout of the lamp assembly prior to backfill and sealing is most critical for obtaining high reliability and long life lamps. Because of inadequate attention to this problem by Hertzog and because of extreme schedule pressures for GOES-E and GOES-F, Santa Barbara Research Center decided to perform the bakeout, back-fill, and sealing in-house as the final steps in the lamp manufacturing process.

Flight quality lamps are selected after a 21 day burn-in at 5 volts d.c. with a minimum allowable lamp current degradation of $\leqslant 1$ percent over the last 14 days. In addition, selection is based on specified criteria of filament straightness, uniformity of pitch, and number of turns.

The lamps made available to GSFC for testing purposes, although not the best in regard to all specified criteria (the best were reserved for GOES-E and -F flight encoders), did meet the acceptance criteria and thus are representative of the lamps on GOES-5 and GOES-F.

II. OBJECTIVES

Within the overall program objective of regaining long life expectancy encoder lamps by strict manufacturing process control, filament material selection, and de-rated d.c. or a.c. voltage operation, the specific objectives of the present tests were as follows:

- Determine lamp aging characteristics as a function of voltage

- Determine the ultimate lamp life as a function of voltage

- Compare laboratory results to in-orbit experience

- Predict operational lifetimes for GOES-5 and GOES-F encoders

- Find operational conditions which will maximize the useful life of a lamp

III. EXPERIMENT

1. Description of Lamp

The lamp, as shown in Figure 1, has a straight singly coiled filament of nominally 4.0 milli-meter (mm) length wound from 38 micrometer (μm) diameter tungsten wire on a 135 μm mandrel with a pitch of 16 turns per mm and a total number of 62 turns. The glass envelope of cylindrical shape has a diameter of about 12 mm and is 17 mm long. The lamp is soldered into a brass base for precision mounting and positioning. The fill gas is krypton at 1 atmosphere pressure. The lamps contain a getter material (zirconium-aluminum) for removing traces of oxygen and water; however, the getter was not intentionally activated by overheating the filament, as was done previously, to avoid overstressing the filament. It is felt that the stringent bakeout and gas drying are sufficient.

2. Description of Test

The lamps are mounted face down in aluminum test fixtures (see Figure 2) in order to provide mechanical stability, proper heat sinking and the same orientation relative to the gravity vector as in the encoders in orbit. Both thermal and gravitational effects determine convection currents in gas filled lamps and thereby lead to preferential transport of tungsten in the anti-gravity direction by the "water cycle."

The test fixtures also accommodate two silicon photovoltaic light detectors for each lamp. They are mounted such that one measures the light flux through the face of the lamp, the other through the side. These detectors are 2 cm x 2 cm N on P silicon solar cells, fabricated from

3

10 ohm-cm material. Their short circuit current is measured by a Keithley Model 173A digital multimeter with an accuracy of ±0.1 percent. Each lamp is powered by its individual, d.c., regulated (±0.01 percent), low drift (< 0.1% per year) power supply (Lambda, Model LLS-2-01). Lamp currents are measured periodically by switching a low impedance digital multimeter (Fluke, Model 8502A) sequentially into each lamp circuit. Long term accuracy of the meter is better than 0.1%.

3. Lamp Parameters

The voltage dependence of various lamp parameters, such as current (i) power (P) light flux (Φ) absolute filament temperature (T) lamp efficacy (e = Φ/P) and filament life (τ) can be described by power laws of the general form:

$$\frac{f}{f_o} = \left(\frac{V}{V_o}\right)^s \tag{1}$$

where V is the voltage, f, is the parameter in question, and s is the exponent appropriate for the parameter f. These power laws are valid over a limited voltage range. The exponent and the range over which each law is valid must be determined experimentally. The exponent and range will depend on lamp type and, in the case of the light flux, on the lamp-detector combination.

IV. RESULTS

1. Power Laws for Lamp Parameters and Their Relationships

Before starting the life tests, the voltage dependence of lamp current and of light flux were determined over the range of 4.0 to 6.0 volts on each lamp and lamp-detector pair. The following relationships hold over this range:

$$\frac{i}{i_o} = \left(\frac{V}{V_o}\right)^t ; t = 0.466 \pm 0.011 \tag{2}$$

$$\frac{\Phi}{\Phi_o} = \left(\frac{V}{V_o}\right)^k ; k = 2.97 \pm 0.01 \tag{3}$$

4

From these, other relationships can be calculated:

$$\frac{P}{P_o} = \left(\frac{V}{V_o}\right)^n \quad ; n = t + 1 = 1.47 \pm 0.01 \qquad (4)$$

$$\frac{T}{T_o} = \left(\frac{V}{V_o}\right)^h \quad ; h = \frac{n}{4} = 0.367 \pm 0.011 \qquad (5)$$

and

$$\frac{e}{e_o} = \left(\frac{V}{V_o}\right)^g \quad ; \; g = k\text{-}n = 1.50 \pm 0.02 \qquad (6)$$

Of particular interest is the relationship between light flux and lamp power:

$$\frac{\Phi}{\Phi_o} = \left(\frac{P}{P_o}\right)^{k/n} \quad ; \; k/n = 2.02 \pm 0.02 \qquad (7)$$

from which follows:

$$\frac{\Phi}{\Phi_o} = \left(\frac{i}{i_o}\right)^{k/n} \quad \text{at constant voltage} \qquad (8)$$

and

$$\frac{\Delta\Phi}{\Phi_o} = \frac{k}{n}\left(\frac{i}{i_o}\right)^{\frac{k}{n}-1} \frac{\Delta i}{i_o} \qquad (9)$$

so that the ratio of light flux degradation rate to current degradation rate

$$\rho = \frac{\dfrac{\Delta\Phi}{\Phi_o \Delta t}}{\dfrac{\Delta i}{i_o \Delta t}} = \frac{k}{n}\left(\frac{i}{i_o}\right)^{\frac{k}{n}-1} \qquad (10)$$

is equal to k/n (≈ 2) in the early stages of operation (when $\frac{i}{i_o} \approx 1$). The ratio ρ becomes smaller than k/n, in time, as $\frac{i}{i_o}$ becomes < 1.

If darkening of the envelope due to "water cycling" occurs, ρ will be larger than expected from equation (10).

2. Lamp Parameter Degradation

Current degradation curves are shown in Figure 3 for the lamps operated at the lowest (4.48V) and the highest (5.0V) voltages of the steppable voltage range of GOES-5. Similar curves for the intermediate voltages are omitted for clarity. Included in Figure 3 are the results obtained from two lamps operated at 5.0 volts in a previous experiment (Experiment 1, lamps 5 and 6, labeled as 1/5 and 1/6 respectively). The lamps had processing, burn-in, and screening identical to those of Experiment 2–the present experiment.

As can be seen, lamp 1/6 failed after 400 days with a total current degradation of 11 percent. Lamp 1/5 current degraded by 13 percent after 360 days followed by recovery, an irregular current pattern, and burn-out at day 496. Visual observation of lamp 1/5 indicated severe distortion of the filament and extreme temperature non-uniformity during this period of irregular current; therefore, we consider this lamp to have failed at day 360.

Of the two 5 volt lamps in Experiment 2, one (2/11) failed after 350 days and with total current degradation of 8 percent. The other (2/12) is still burning at 375 days after a 13 percent current degradation.

Of the four 4.48V lamps, three are still burning with current degradations of 5 to 8 percent at day 375, and one has failed after 328 days with a total current degradation of 6.5 percent.

The six lamps being tested at the intermediate voltages of 4.67V and 4.86V, exhibit current degradation rates between those at 5V and 4.48V. Except for one, they are still burning after

375 days. One lamp at 4.67V failed after 362 days with a total current degradation of 7 percent. All three of the 4.86V lamps are still operating after 375 days with current degradations ranging from 8 to 11 percent.

We consider the two low voltage burnouts as anomalous and believe that filament failures occur typically after the lamp current has degraded by twelve to fifteen percent.

The degradation rates of lamp current and of light flux as a function of voltage are given in Figure 4 along with their respective error bands. It is apparent that the degradation rates, and their variation between lamps, increase with increasing voltage. Average degradation rates for the lamp currents and light fluxes, and their standard errors are tabulated in Table 1. The ratio of light output degradation rate to current degradation rate is 2:1 signifying the absence of envelope darkening (but not implying the absence of the "water cycle" phenomenon).

3. Total Filament Life

Recent studies at Philips Central Research Laboratories (Aachen, Germany) on low voltage lamps (Ref. 3, Philips Research Reports, Vol. 32 (1977), p. 82) have established two distinct regimes of life determining mechanisms in inert gas filled lamps. These investigations were performed on straight coil filament lamps which are sufficiently similar to the Hertzog lamps to be of comparative interest. The pertinent parameters for both lamps are listed in Table 2.

By plotting the logarithms of the lifetimes as a function of T^{-1} (T = absolute filament temperature), two curves of different slope -- or activation energy -- emerge (see Fig. 6). Above 2700K, tungsten evaporation, characterized by an activation energy of 238K cal mol^{-1}, is the life determining process; below 2700K, the growth of single crystal regions over large portions of the filament, accompanied by faceting and the development of notches (reduced diameter), leads to eventual mechanical instability and filament breakage. A typical example is shown in Figure 7. The activation energy for this process is $\simeq$ 95K cal mol^{-1}.

7

Table 1

Summary of Experimentally Determined Degradation
Rates of Lamp Current and Light
Flux for circa 1980 Lamps

Lamp Voltage (Volts)	Light Flux Degradation Rate (per day)	Lamp Current Degradation Rate (per day)	Ratio of Light Flux Rate to Current Rate
4.48	$(4.4 \pm 0.1) \cdot 10^{-4}$	$(1.9 \pm 0.2) \cdot 10^{-4}$	2.3
4.67	$(5.3 \pm 0.5) \cdot 10^{-4}$	$(2.6 \pm 0.3) \cdot 10^{-4}$	2.0
4.86	$5.7 \pm 0.7 \cdot 10^{-4}$	$(2.9 \pm 0.4) \cdot 10^{-4}$	2.0
5.0	$5.9 \pm 1.0 \cdot 10^{-4}$	$(3.2 \pm 0.6) \cdot 10^{-4}$	1.8

Table 2

Lamp Parameters for Hertzog/SBRC and Philips Lamps

Filament Material	Philips Tungsten	GOES, Hertzog/SBRC Tungsten, GE218
Wire Diameter	37 μm	38 μm
Coil Length	7.3 mm	4.0 mm
Coil Diameter (ID) (OD)	70 μm 107 μm	135 μm 160 μm
Coil Pitch	18 turns/mm	16 turns/mm
Number of Turns	130	62
Operating Voltage	12V	6V
Filament Current	420 mA	360 mA
Filament Resistance	9 ohms	17 ohms
Getter Material	zirconium	zirconium-aluminum
Fill Gas and Pressure	argon, 11 psi	krypton, 14 psi

8

In Figure 8 we have re-plotted the low temperature d.c. Philips data, GOES encoder lamp data obtained at Baldwin Electronics, Inc. in 1966 and 1969 (G. Barnett, SBRC, private communication), and data for "commercial" lamps quoted by Baldwin (see Ref. 1, p. 36). It is interesting to note that our present lamp data and the GOES-5 data point coincide with the extrapolated Philips curves, whereas the SMS-1 and GMS values are in line with the 1969 BEI laboratory data.

The 1966 and 1969 data are not only characterized by higher activation energies (170 K cal mol $^{-1}$ and 120 K cal mol $^{-1}$ respectively) but by significantly smaller rates of recrystallization and correspondingly longer lifetimes than the Philips lamps and the circa 1980 Hertzog/SBRC lamps, which have filaments of pure tungsten. We surmise, therefore, that the old filament material contained crystallization retarding dopants such as thorium oxide.

If the voltage dependence of filament life, τ, is expressed in the form

$$\frac{\tau}{\tau_0} = \left(\frac{V_0}{V}\right)^m \tag{11}$$

the 1966 data give m = 10, the 1969 data m = 6, and the circa 1980 data m = 5.6.

4. Flight Data

Based on the operational lifetimes of the various SMS and GOES encoders in orbit (Ref. 1), one can estimate the degradation rates of lamp current and light flux, or their upper limits, as tabulated in Table 3. From the encoder threshold voltages, V_{th}, recorded before launch, one can calculate the corresponding light flux margin, using equation (3), as follows:

$$\frac{\Delta\Phi}{\Phi_0} = 1 - \frac{\Phi}{\Phi_0} = 1 - \left(\frac{V_{th}}{V_{op}}\right)^{2.97} \tag{12}$$

where V_{op} is the lamp supply voltage of the encoder. The light flux degradation rate is:

Table 3

Summary of In-Orbit Data and of Corresponding Calculated Light Flux and
Lamp Current Degradation Rates

Spacecraft	Encoder P=primary R=redundant	Threshold at Launch (volts)	Time to Failure (months)	Calculated Degradation Rate of Light Flux (per day)	Calculated Degradation Rate of Current (per day)	Year of Lamp Manufacture	Remarks	Failure Mode
SMS-1	R	Not known, Assume ≤4.50	>24	<$3.8 \cdot 10^{-4}$	<$2 \cdot 10^{-4}$	1970		Not lamp related
SMS-2	R	Not known, Assume ≤4.35	59	≤$1.9 \cdot 10^{-4}$	<$1 \cdot 10^{-4}$	1970		Open filament
GOES-1	R	Not known, Assume ≤4.50	>24	<$3.8 \cdot 10^{-4}$	<$2 \cdot 10^{-4}$	1970		Lamp(s) still OK, Standby
GOES-2	R	4.50	18	$5 \cdot 10^{-4}$ ($29 \cdot 10^{-4}$)	$2.8 \cdot 10^{-4}$	1976	Anomalous	Open filament
	P	4.85	1			1976		Low lamp intensity
GOES-3	P	4.6	15	$4.9 \cdot 10^{-4}$	<$2.5 \cdot 10^{-4}$	1974	Current degradation based on $\frac{\partial \Phi}{\partial t} = 2\frac{\partial i}{\partial t}$	Low lamp intensity(stumble)
	R	4.7	17	$3.3 \cdot 10^{-4}$	<$1.6 \cdot 10^{-4}$	1974		Low lamp intensity(stumble)
GOES-4	P	4.35	>26	<$4.35 \cdot 10^{-4}$	<$2 \cdot 10^{-4}$	1974	Not operated	Not lamp related
	R	—	—	—	—	—		
GOES-5	R	3.95	20	$5.2 \cdot 10^{-4}$*	<$2.5 \cdot 10^{-4}$*	1980	1st step of stepped voltage was 4.48 V	Still operating / Stepped voltage mode
GMS-1	R(?)	Not known, Assume ≤4.35	>50	<$2.25 \cdot 10^{-4}$	<$1 \cdot 10^{-4}$	1974		Not known

* 4.48V initial operating voltage

10

$$\dot{\Phi} = \frac{\Delta\Phi}{\tau_{st}} \qquad\qquad (13)$$

where τ_{st} is the time to "stumble".

In most cases, one can only arrive at upper limits, because the thresholds were not recorded (SMS and GOES-1), the failure was not lamp related (SMS-1 and GOES-4), or the encoder is still working (GOES-1).

Upper limits for the current degradation rates can be estimated by assuming that, at the end of life (burnout), the increase of filament resistance is typically no greater than 12 to 15 percent (Ref. 3, Philips Research Reports, Vol. 32 (1977), p. 82).

In the case of GOES-3, where both encoders failed due to low light flux and the thresholds were well known, good estimates for the light flux degradation can be obtained. The upper limits for the current degradation are then based on the 2:1 ratio of flux to current degradation.

The results are grouped in Fig. 5 according to the year in which the lamps were manufactured and compared with the present laboratory data on circa 1980 Hertzog/SBRC lamps and with GOES-5, which has lamps of that vintage.

It appears that there has been a steady and continuous decline in lamp quality over the decade of 1970 to 1980.

V. GOES-5 & GOES-F PROJECTIONS

1. Projection Tolerances

Using Figure 4 and equations (12) and (13), times to stumble have been calculated as a function of lamp operating voltage for different threshold voltages as shown in Figure 9. Due to the

variation between lamps, an error band of ±15 percent in time and ±5 percent in threshold voltage should be applied to these curves as indicated for the V_{th} = 4V curve.

The error band on the total filament life is considerably broader, reflecting the lamp to lamp variations in the current degradation rates plus the lamp to lamp variation in total current change at end of life.

2. Predictions for GOES-5

The GOES-5 encoder, which for the first time employed the stepped voltage mode, was launched with a redundant encoder threshold of 3.96V and an initial lamp operating voltage of 4.47V. The first indications of "stumbling" occurred after 600 days, or at 90 percent of the predicted time – well within the overall error band. Stepping the lamp to 4.62V (with threshold now at 4.47V) should yield another 150 to 200 days of useful life before "stumbling" occurs again; however, the lamp is now within the error band of total life and could fail at any time. The primary encoder had a threshold of 4.24V and an initial lamp operating voltage of 4.47V. It is expected to operate for about 300 ± 50 days before "stumbling". Stepping the lamp voltage to 4.60V would give about an additional 175 ± 30 days before "stumbling" again. Stepping the lamp voltage to 4.74V would give about another 150 ± 25 days before burnout for a total of about 625 ± 105 days. The two encoders should provide a total operational life of approximately 3¾ years ± ¼ year.

3. Predictions for GOES-F

The prospects for GOES-F, which has dual lamp stations on both the primary and redundant encoder and can be stepped in approximately 0.1V increments, are as follows:

(1) Primary encoder, lamp 1, with threshold of 4.40V, and redundant encoder, lamp 2, with threshold of 4.35V, if started at 4.6V, would each yield about 300 ± 50 days for the first interval before "stumbling". Stepping the lamp voltage to 4.7V would yield about an additional 150 ± 25 days.

12

Stepping then to 4.8V would yield another 120 ± 20 days for a total of about 570 ± 95 days for each lamp, at which point filament burnout is to be expected.

(2) Primary encoder, lamp 2, with threshold of 4.25V, and redundant encoder, lamp 1, with threshold of 4.22V, if started at 4.5V, are each expected to operate for about 350 days ± 60 days before "stumbling". Stepping the lamp voltage to 4.6 volts would give about an additional 175 ± 30 days before "stumbling" again. Stepping the lamp voltage to 4.7 volts would then give an additional 125 ± 20 days for a total of about 650 ± 110 days for each lamp, at which point end of life by burnout is to be expected.

(3) The four lamps should provide a total operational life of approximately 6½ years ± 1 year.

4. Extended Lamp Life

In order to obtain filament lives of > 4 years, the present lamps (1980/82, Hertzog/SBRC) should clearly be operated at voltages of < 4 volts. This would require encoder thresholds of ≤ 3.6 volts. Corresponding light fluxes would be about half of what is typical at present. A simple gain adjustment of a factor of 2 in the amplifier should readily accommodate such change.

VI. CONCLUSIONS

Encoder lamps manufactured by Hertzog with GE 218 tungsten filaments and backfilled at SBRC show aging characteristics and life expectancies which are typical of "commercial" gas filled lamps of similar construction, filament material, and filament temperatures. The aging and filament burnout are caused by single crystal growth over large portions of the filament, the development of facets and notches, and mechanical weakening of the filament. The life of these lamps at the nominal encoder lamp voltage of 5V d.c. is about one year. At the lowest level of the stepped voltage range (4.48V), it is about 2 years.

These lifetimes are considerably shorter, and the degradation rates of lamp current and light flux are considerably higher, than those observed in the laboratory and in orbit with lamps

13

which were manufactured circa 1970 from presumably different filament material. The early filaments had higher activation energies than the present filaments; therefore, we surmise that the early filaments contained an unknown crystallization retarding dopant, possibly thorium oxide.

There are two options to regain the earlier long operational lifetimes of encoders:

1. Investigate systematically the effect of crystallization retarding, intentionally added, dopants, then manufacture and qualify longer life expectancy lamps.

2. Use well screened lamps of the present variety (circa 1980, Hertzog/SBRC) and lower the encoder threshold to less than 3.6 volts; thus, the lamps can be operated at 3.8 to 4.0 volts with projected life expectancies in excess of four years. The light flux at 4.0 volts is about half of its value at 5.0 volts, which should be compensated for by gain adjustments in the detector circuit.

ACKNOWLEDGEMENTS

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GOES Encoder Lamp

Fig. 1. GOES Encoder Lamp

15

Fig. 2. GOES Encoder Lamp Test Facility
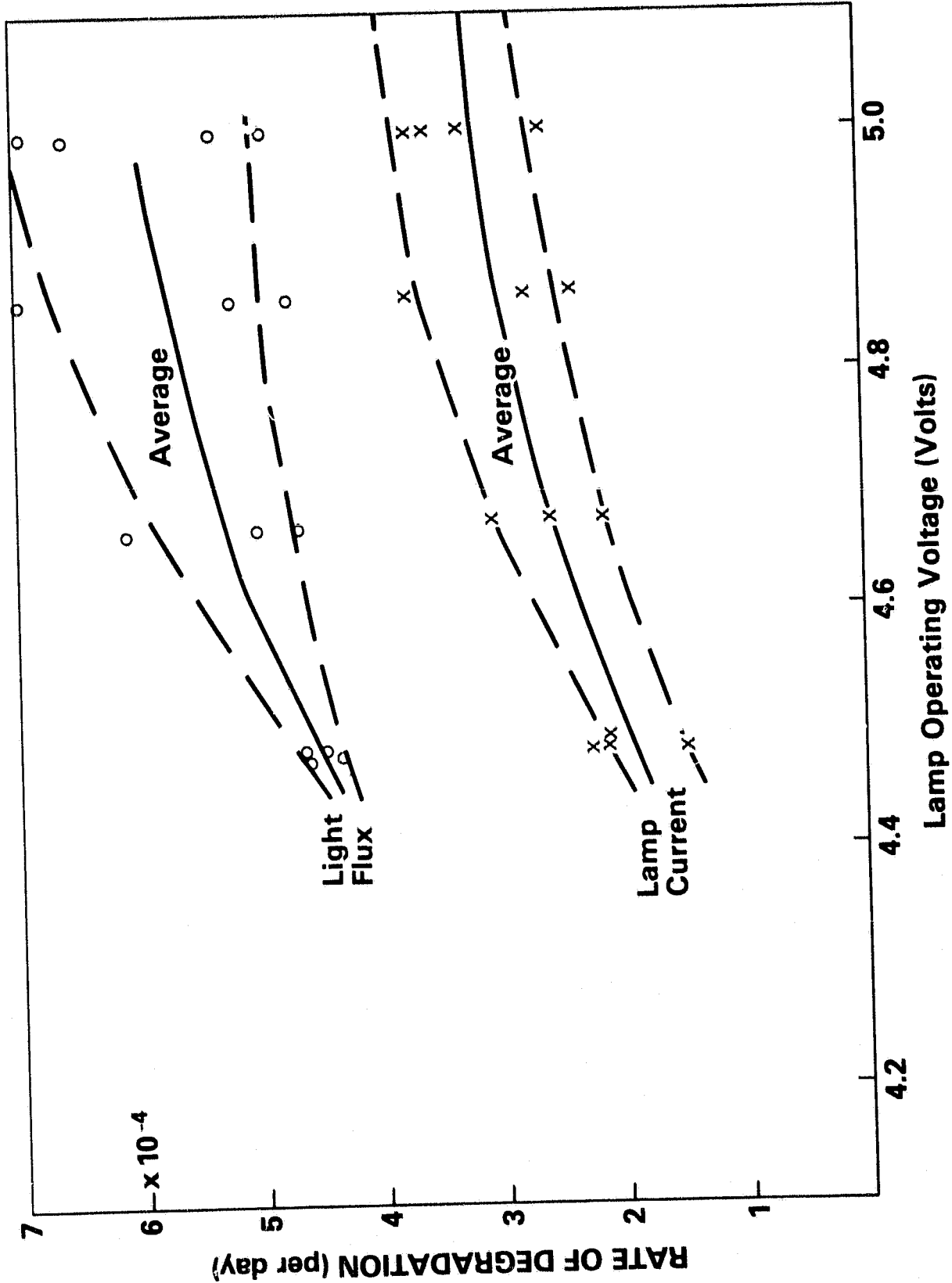
16
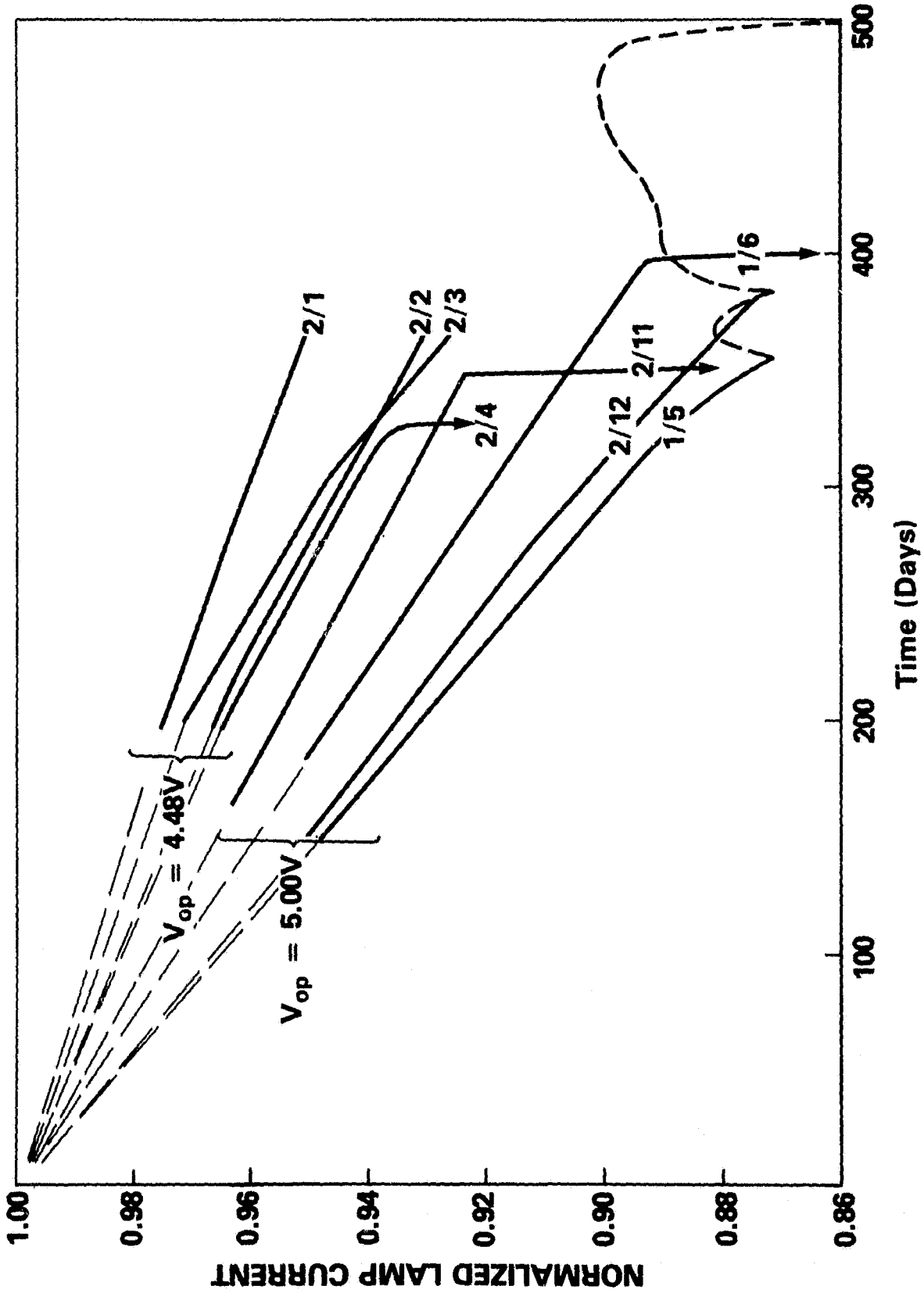
Fig. 3. Lamp Current vs. Time, for 5.00 Volt and 4.48 Volt Operation

17

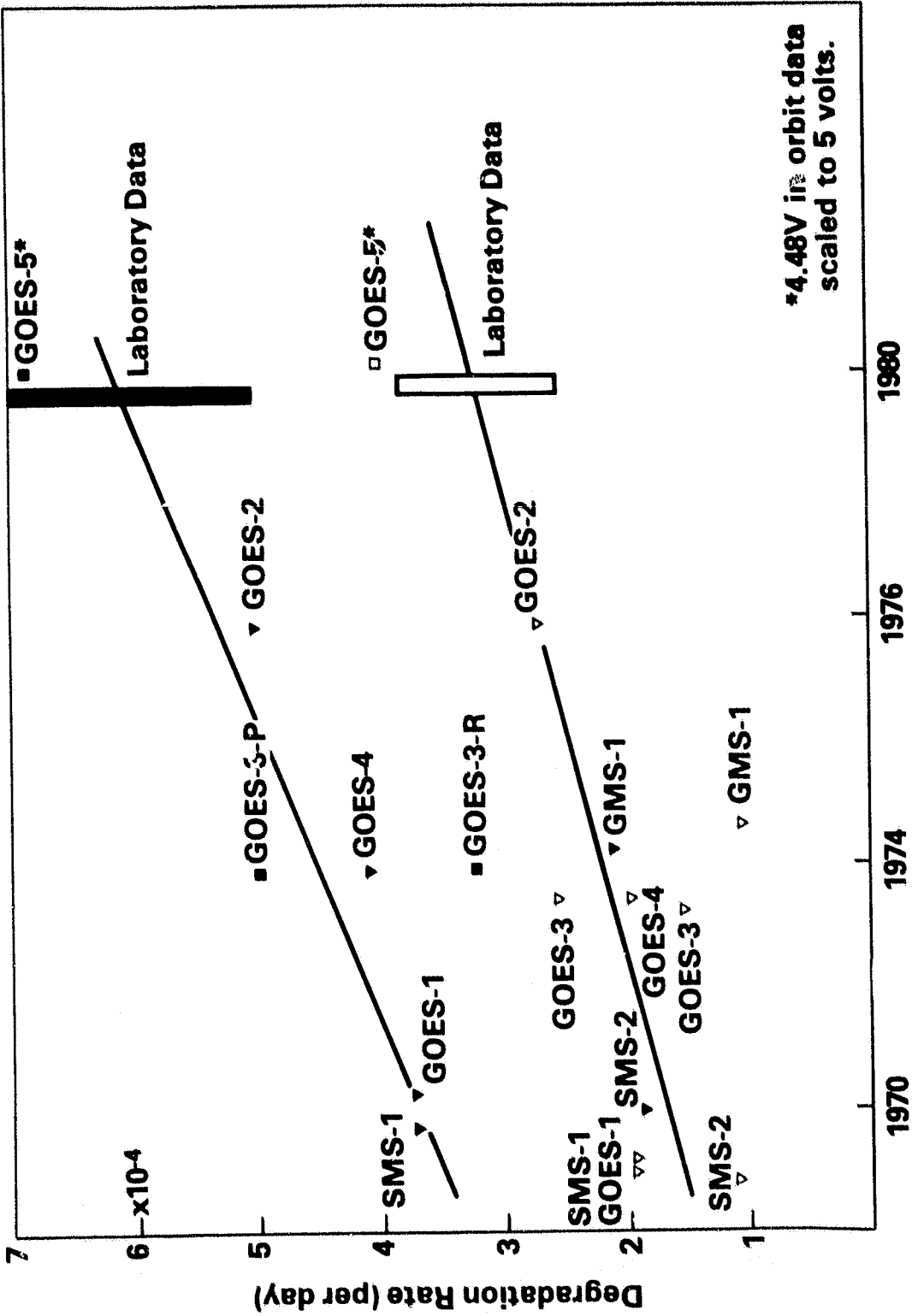Fig. 4. Degradation Rates of Light Flux and Lamp Current as Functions of Lamp Operating Voltage

18

Fig. 5. Calculated In-Orbit Lamp Degradation Rates for SMS and GOES Series. (Open Symbols Denote Lamp Currents; Closed Symbols Denote Light Flux; ▽ or ▼ are Upper Limits)
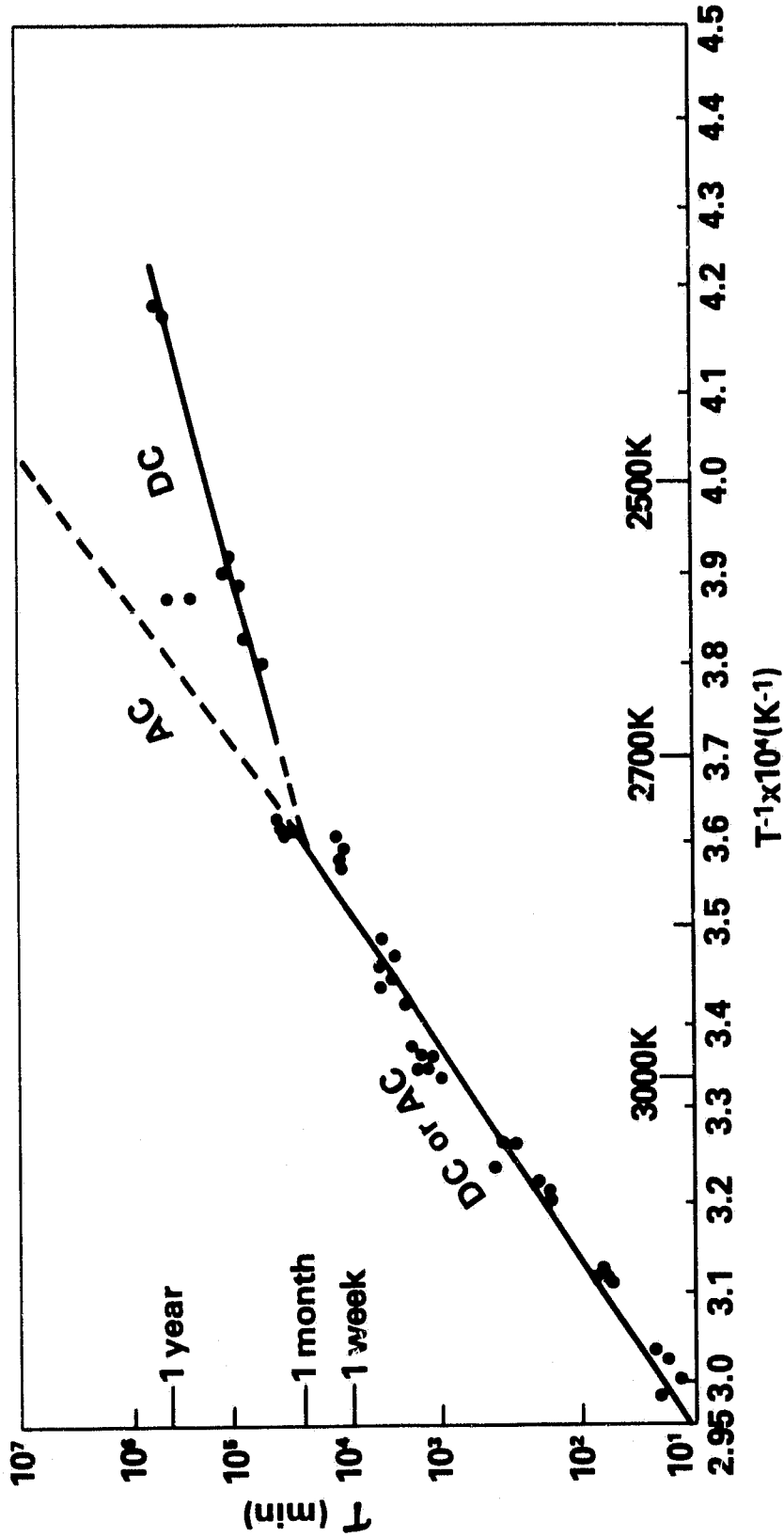
Fig. 6. Lamp Life as a Function of Temperature as Reported by Philips Central Research Laboratories

20
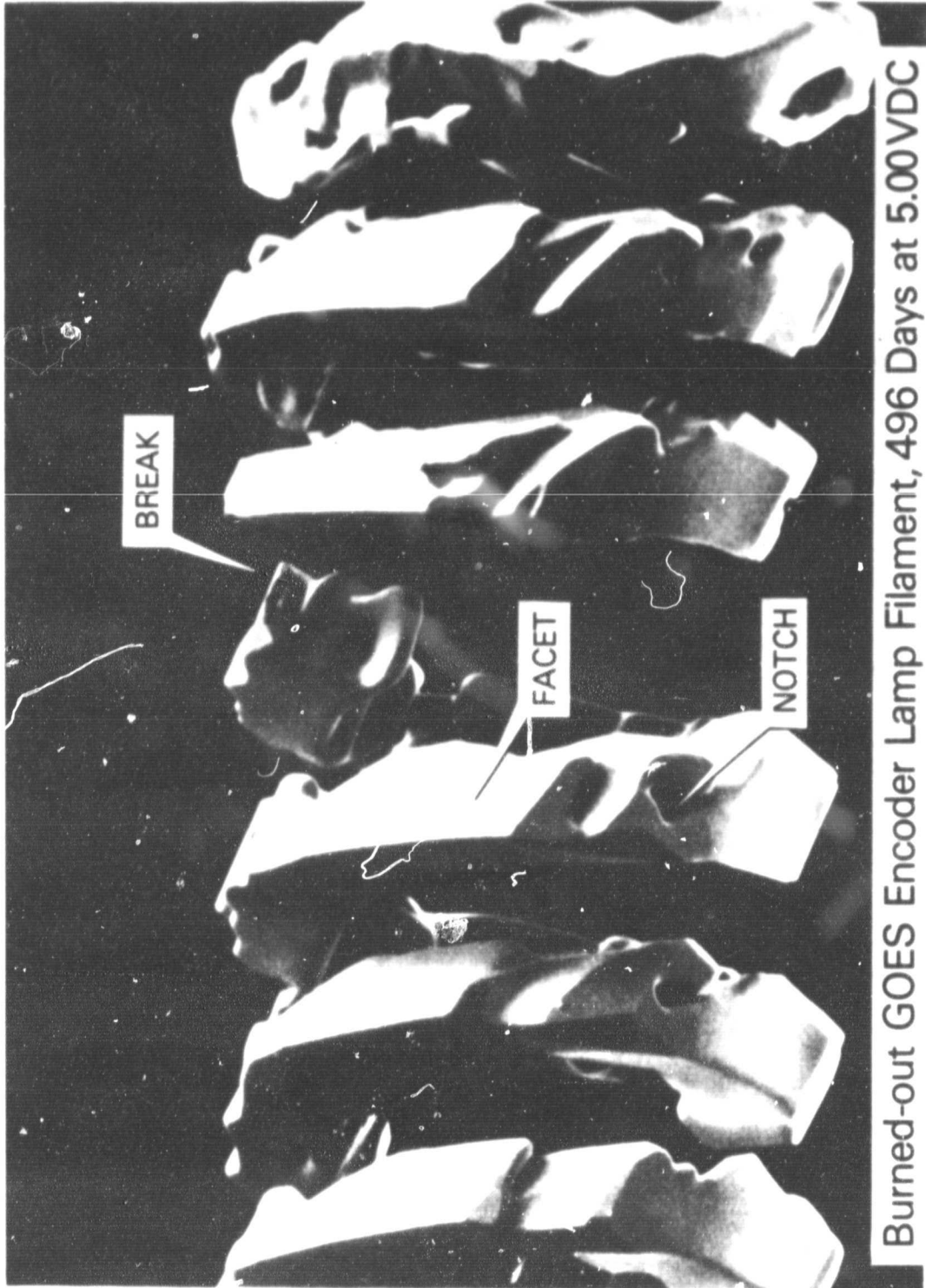
Burned-out GOES Encoder Lamp Filament, 496 Days at 5.00VDC

Fig. 7. Scanning Electron Micrograph of Burned-out Filament. (Lamp Failed After 496 Days of Operation at 5.00V d.c.; Filament Temperature was 2265K)
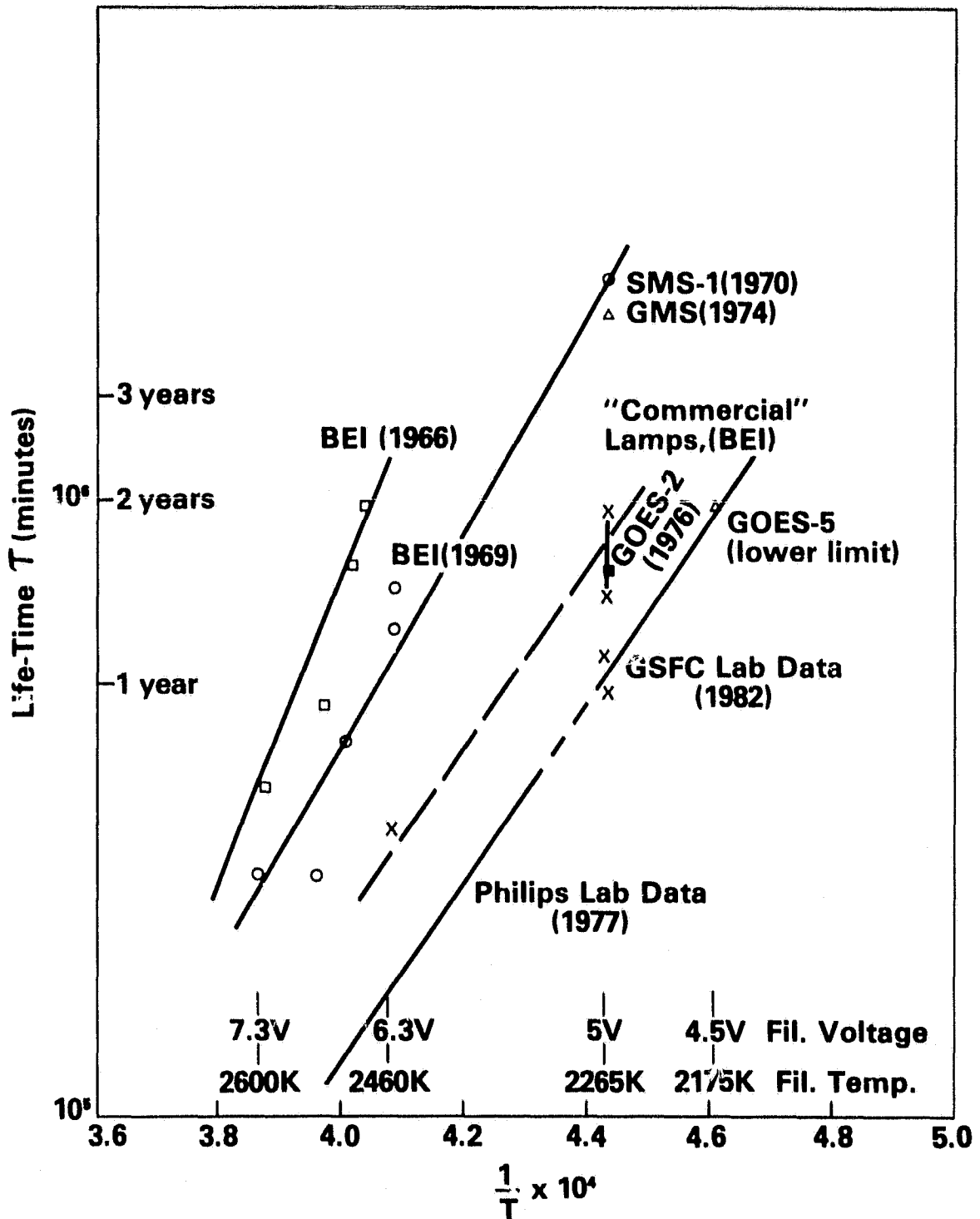
Fig. 8. Arrhenius Plots (log τ vs. T^{-1}) of Lamp Life Tests Performed in 1966 and 1969 at Baldwin and in 1982 at GSFC. (Philips Data (Ref. 3) and Life Times Quoted for "Commercial" Baldwin Encoder Lamps are also Shown)
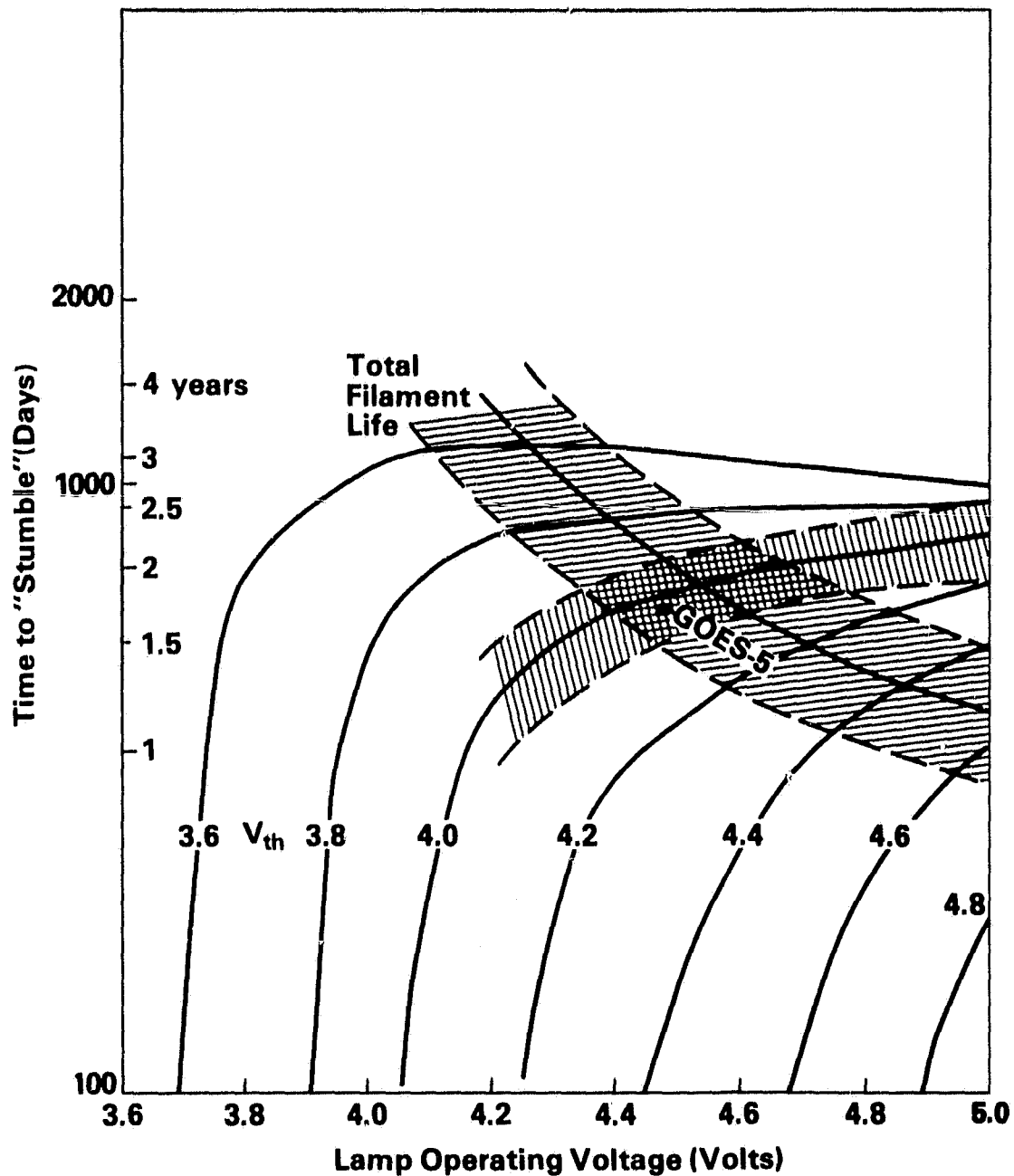
Fig. 9. Calculated Times to "Stumble" and Filament Life to Burnout as Functions of Lamp Operating Voltage, V_{op}, and Encoder Threshold, V_{th}. (Calculations are Based on Experimentally Determined Degradation Rates, and Lifetime Projections are Based on Extrapolation of Lab data as Shown in Figure 8)