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REPORTS

66" LENS
THERMAL SENSITIVITY TESTS

PRELIMINARY

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66" f/5 LENS

THERMAL SENSITIVITY TESTS

P R E L I M I N A R Y

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66" f/5 LENS THERMAL SENSITIVITY TESTS

PURPOSE

The purpose of the test series is to define the relationship between the lens optical performance and thermal environment; the results of which would be used to predict and interpret camera system performance.

INTRODUCTION

The test program was divided into three general phases as follows:

1) Uniform temperature coefficient
2) Thermal gradient coefficient
3) The effect of a simulated thermal transient environment

TEST EQUIPMENT

The thermal test set-up consists of a temperature controlled mounting flange to which the lens cell is mounted and two cylindrical temperature jackets mounted on each side of the cell (see Figure 1).

The 35mm recording camera is referenced to the cell support flange by a steel bar. The bar is insulated from the flange by a piece of phenolic. The temperature of the bar was controlled and thus its length is not expected to be influenced by the temperature jackets, however, its temperature change was monitored and the data corrected accordingly.

This test fixture was lined up directly with the DRT collimator and focus determined by making a series of exposures at different

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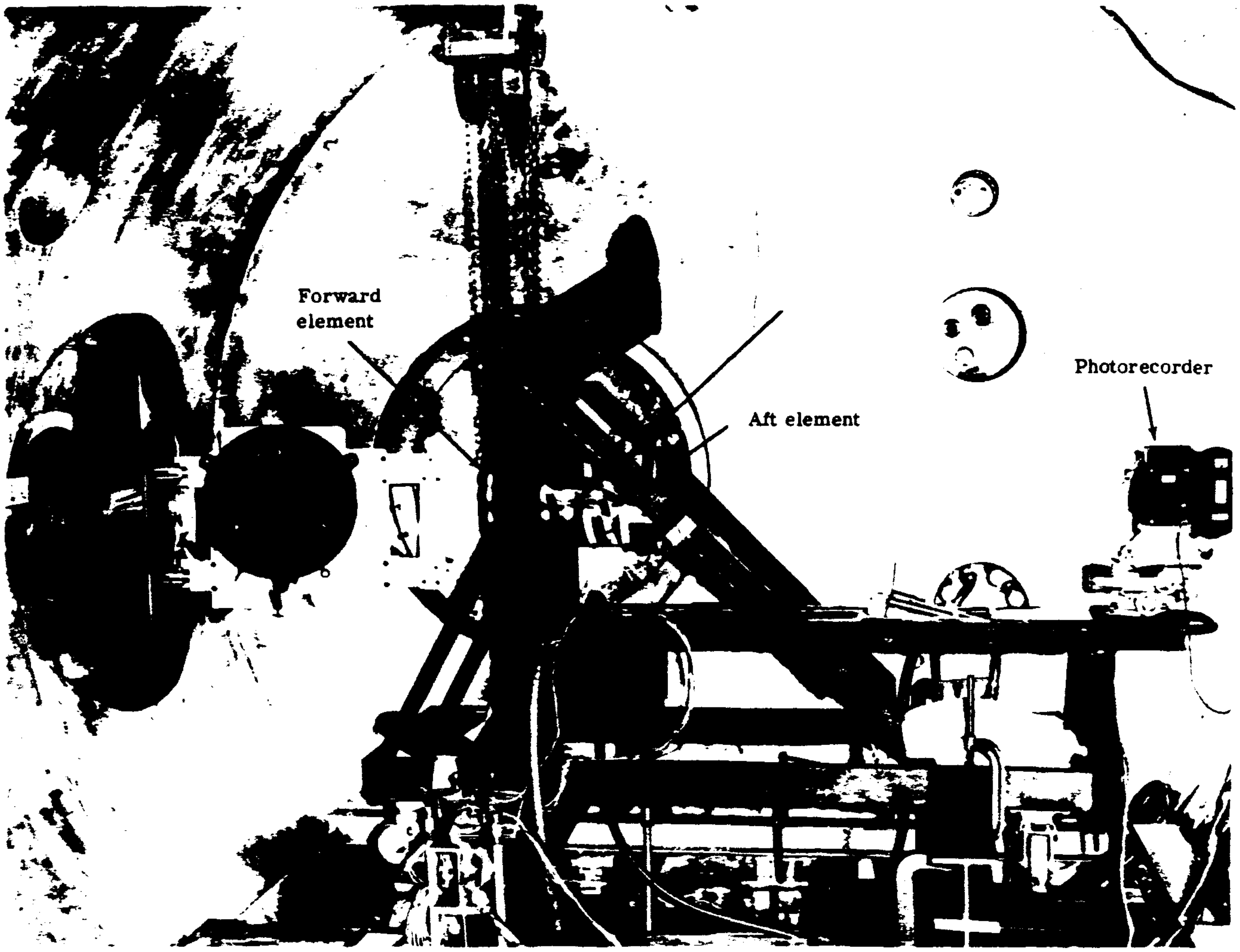

Fig. 1 - Thermal Optical Test Setup (Lens)

Lens barrel wrapped with 20 layers of NRC-2 insulation (not shown in picture)

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collimator settings or target positions. (Through Focus Runs)

The temperature jackets (shown installed in Figure 2) enclose 95% of the radiation area seen by the lens and thus are the primary factor in controlling its thermal environment.

The temperature transducers were all calibrated at the same reference temperature level prior to the tests. This calibration, including the read-out equipment, indicated data scatter of $\pm$ 1^{O}F for any one transducer.

In order to better understand the results of these tests, a short description of the test set-up, conduct of the tests, and interpretation of the results obtained is necessary.

The fixture and thermal blankets used for these tests, provided a means of thermal control of four separate parameters: 1) the cell mounting plate, 2) the camera support arm, 3) the forward cell thermal blanket, and the aft cell thermal blanket. This allowed us to simulate various combination temperature environments, and at the same time maintain the position of the camera relative to the cell mounting plate.

Each of the tests were run in a similar manner and consisted of three phases:

1) An atmospheric baseline thru-focus at room temperature.
2) A vacuum thru-focus baseline before the application of temperature controls.
3) Periodic thru-focus runs after the application of temperature controls. These serve to justify the stabilized condition.

Once a test was started, the vacuum chamber was sealed and the film was not removed until the conclusion of all three phases, thus

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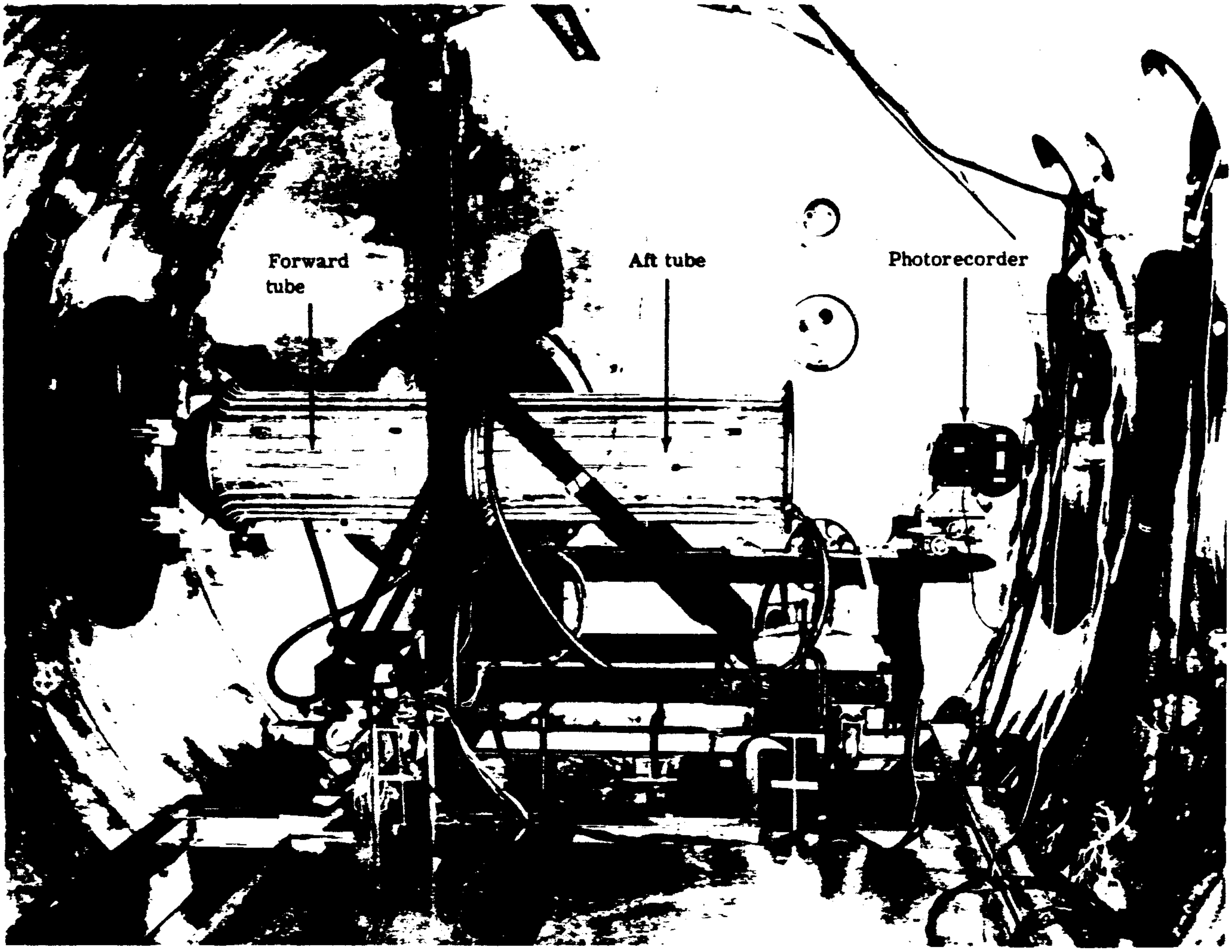

Fig. 2 - Thermal Optical Test Setup (thermal tube mounted over lens)

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minimizing relative focus errors due to the possibility of accidental movement of the test set-up. In most cases the test would continue until the cell temperature seemed to stabilize at the desired temperature.

The data obtained from the atmospheric baseline run verified proper cell operation and also gave a focus reading at room temperature. The vacuum baseline data before the introduction of temperature allowed us to verify the proper focus shift due to vacuum alone.

LENS TEMPERATURE COEFFICIENT TEST

A high contrast target was inserted in the collimator. Using So-132 film with processing in D-19 at 85°F at 5 ft/min. in the Fisher Processor, a baseline was performed on HAPL lens #13. It was determined that it was a representative sample and that installation of temperature sensors in the center of the front and rear element had no measurable effect on the photographic resolution measurements.

For each series, a thru-focus baseline was established at atmospheric conditions, the chamber was pumped down so that the lens was in vacuum, and a thru-focus baseline photo run was made. Vacuum focus shift of 0.019" was confirmed.

The temperature controls were then adjusted to stabilize the complete lens assembly at temperatures cooler and warmer than the baseline. Thru-focus runs were made periodically. Figure 3a is a composite plot representing the resolution vs. relative focus for an atmospheric and vacuum baseline at about 74° and a 66°, 59°, 85°, and 80°F stabilized condition. It is evident that the shape of the curves is generally the same and the peak resolution nearly identical although the cool lens seemed to be slightly lower probably due to increased strain because of beryllium cell contraction. From this, the overall conclusion is that the principle effect is a focus shift with temperature.

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EFFECT OF TEMPERATURE ON FOCAL SHIFT

RESOLUTION SIGNATURE

EAPL 13

CONDITIONS

TYPE . . . . . **AUTOMAX**

PRESSURE . . . **VAC - 4**

EXPOSURE TIME . . . **1/400**

TARGET . . . . **PI SINGLE**

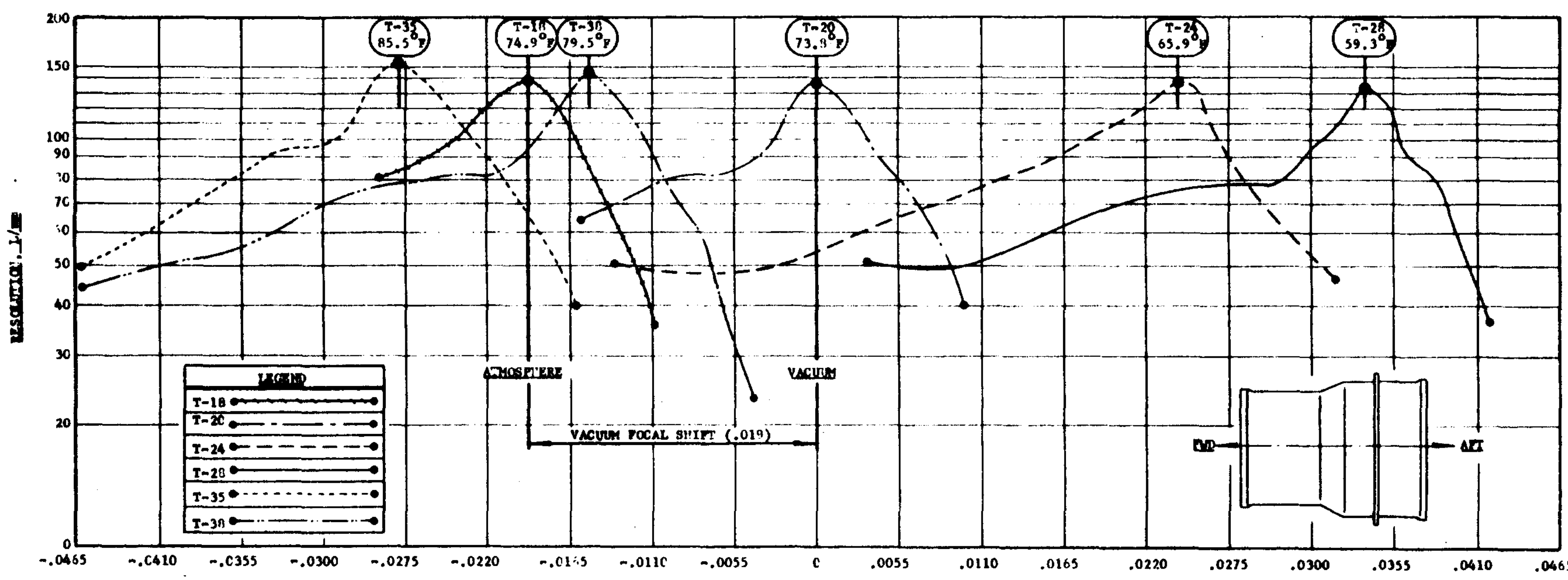

FIGURE 3a

[redacted]

Figure 3b is a plot of change in focus vs. temperature of all runs made where a stabilized condition was achieved. Focus data is only valid to about ± 0.0015" and temperature data to about ± 1° but is smoothed out by drawing a straight line through all data points achieving a 2.4 thousandths per degree Fahrenheit temperature coefficient.

Figures 4a through 4f are plots of individual temperature sensors on the lens, the glass, the thermal jacket and the reference focus arm vs. real time. In addition, photo run data is summarized by plotting relative focus and labeling it as atmospheric or vacuum together with peak resolution at best focus. Figure 4a was low (3:1) contrast.

THERMAL GRADIENT COEFFICIENT

In a manner similar to the uniform temperature coefficient test photographic baselines were established and the thermal blanket was controlled to place various longitudinal gradients on the lens.

For the steady state conditioning the focal shift of the lens can be expressed as follows:

1) $$\triangle \text{FOCUS} = C_T\ (T_L - T_{Ref}) + C_g\ (T_{aft} - T_{fwd})$$

T_L = Temperature of lens barrel

T_{Ref} = Temperature of reference

$(T_{aft} - T_{fwd})$ = Thermal gradient

C_T = Temperature coefficient for uniform environment

C_g = Thermal gradient coefficient

C_g being a function of the type of gradient that exists. This thermal gradient has a three dimensional distribution, thus would be very

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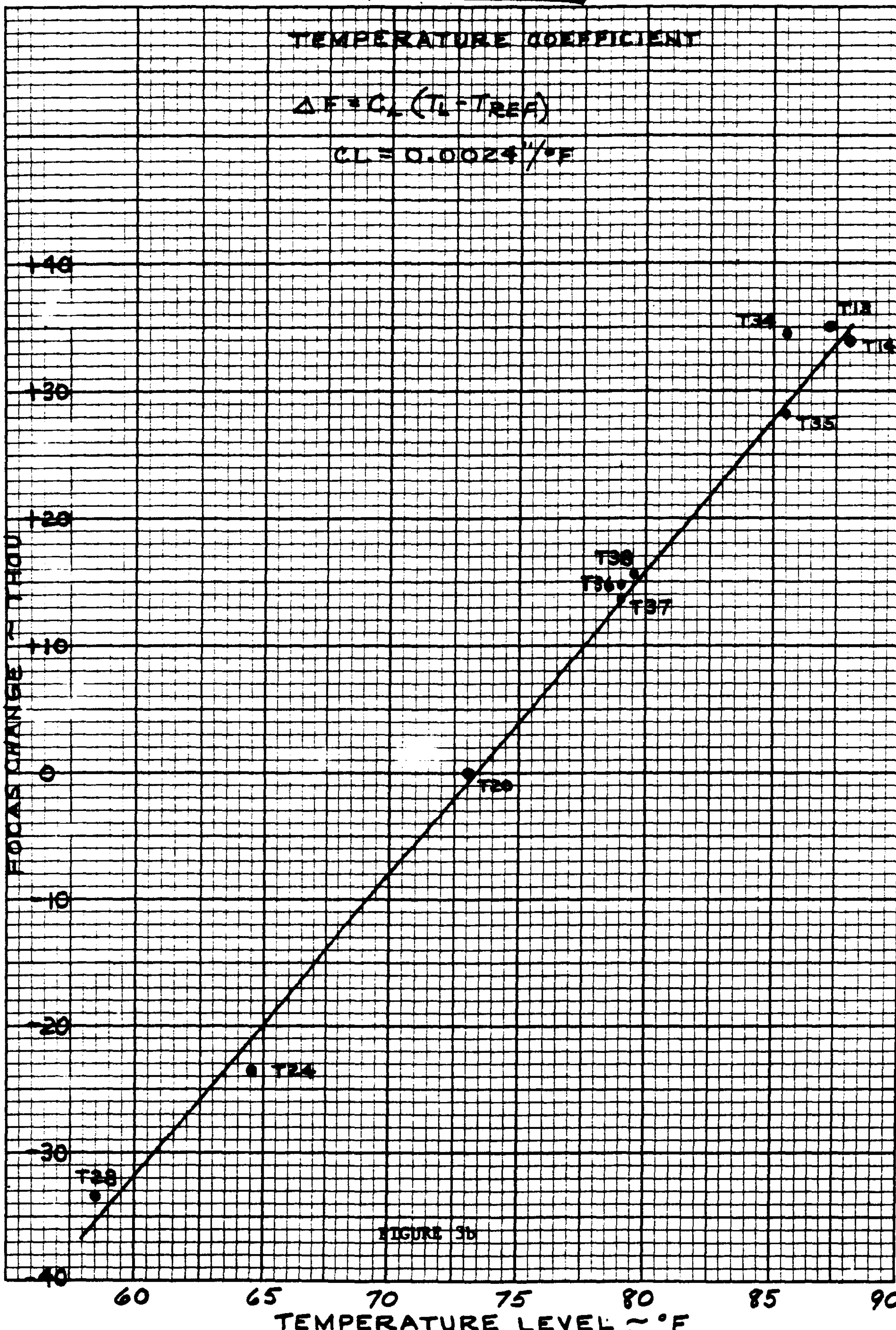

FIGURE 3b

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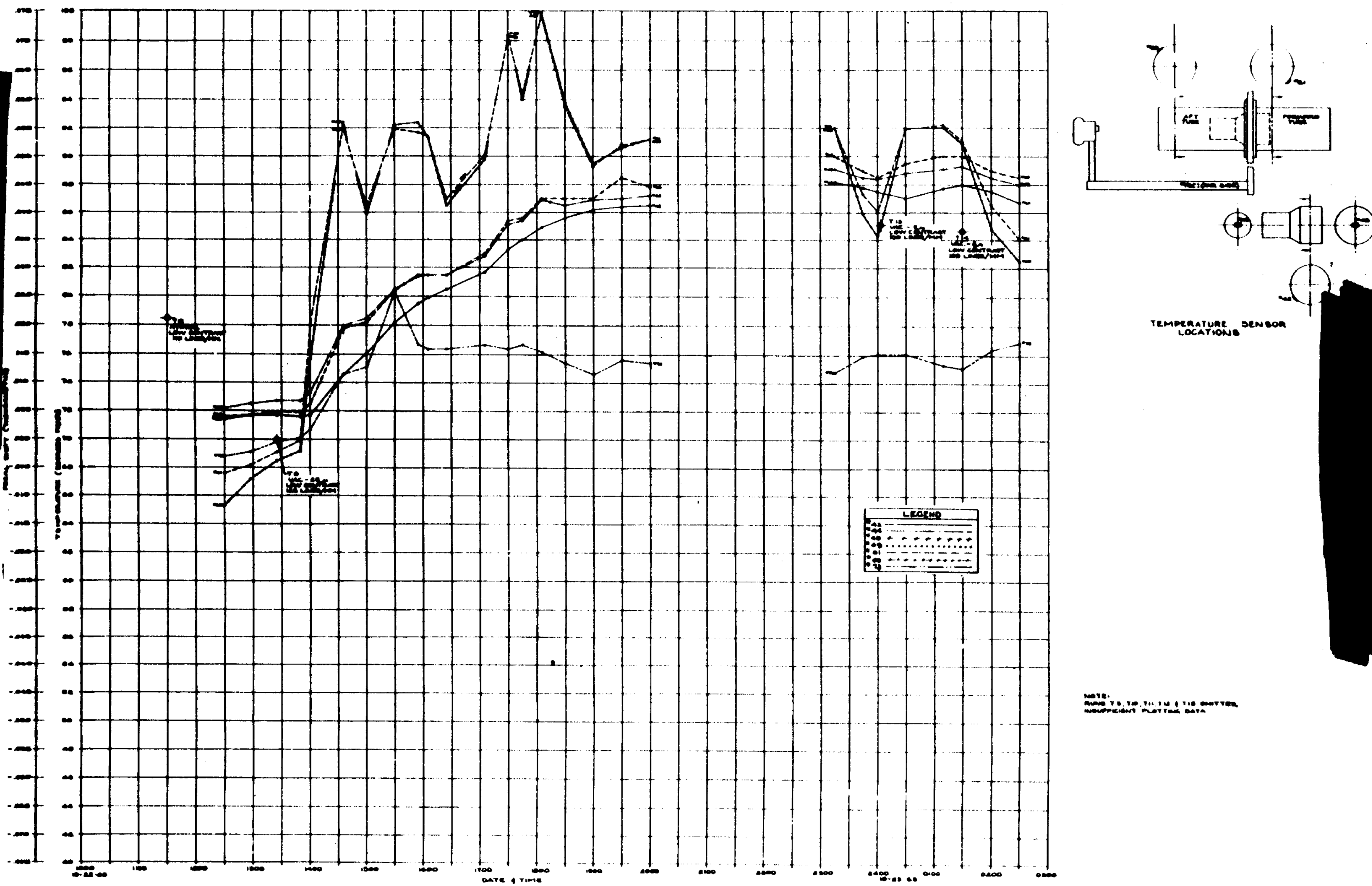

Fig. 4a — Lens temperature coefficient test, test "T," HAPL no. 13, series 1 (T-8, T-9, T-13, T-14)

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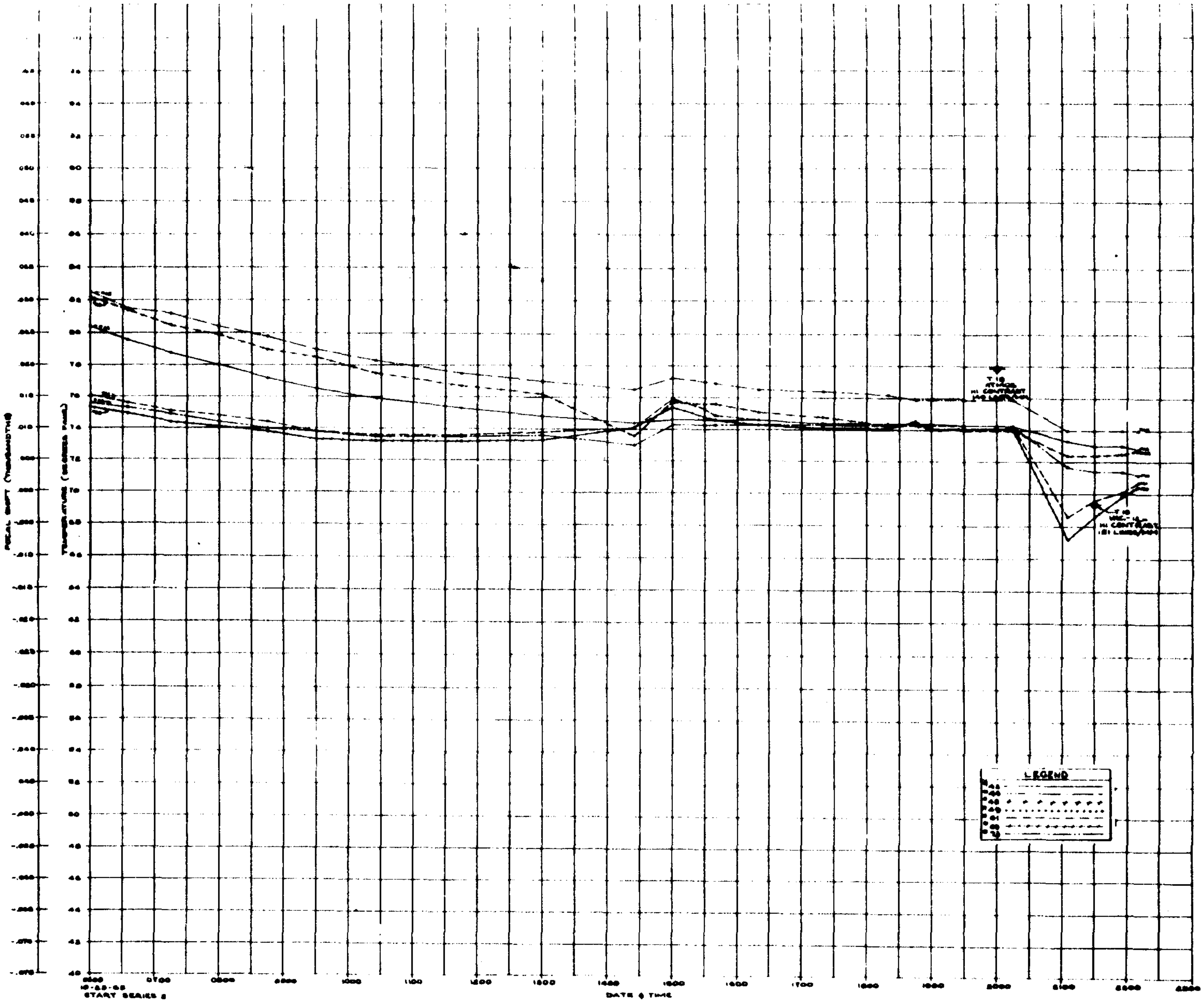

Fig. 4b — Lens temperature coefficient test, test "T," HAPL no. 13, series 2 (T-18, T-19)

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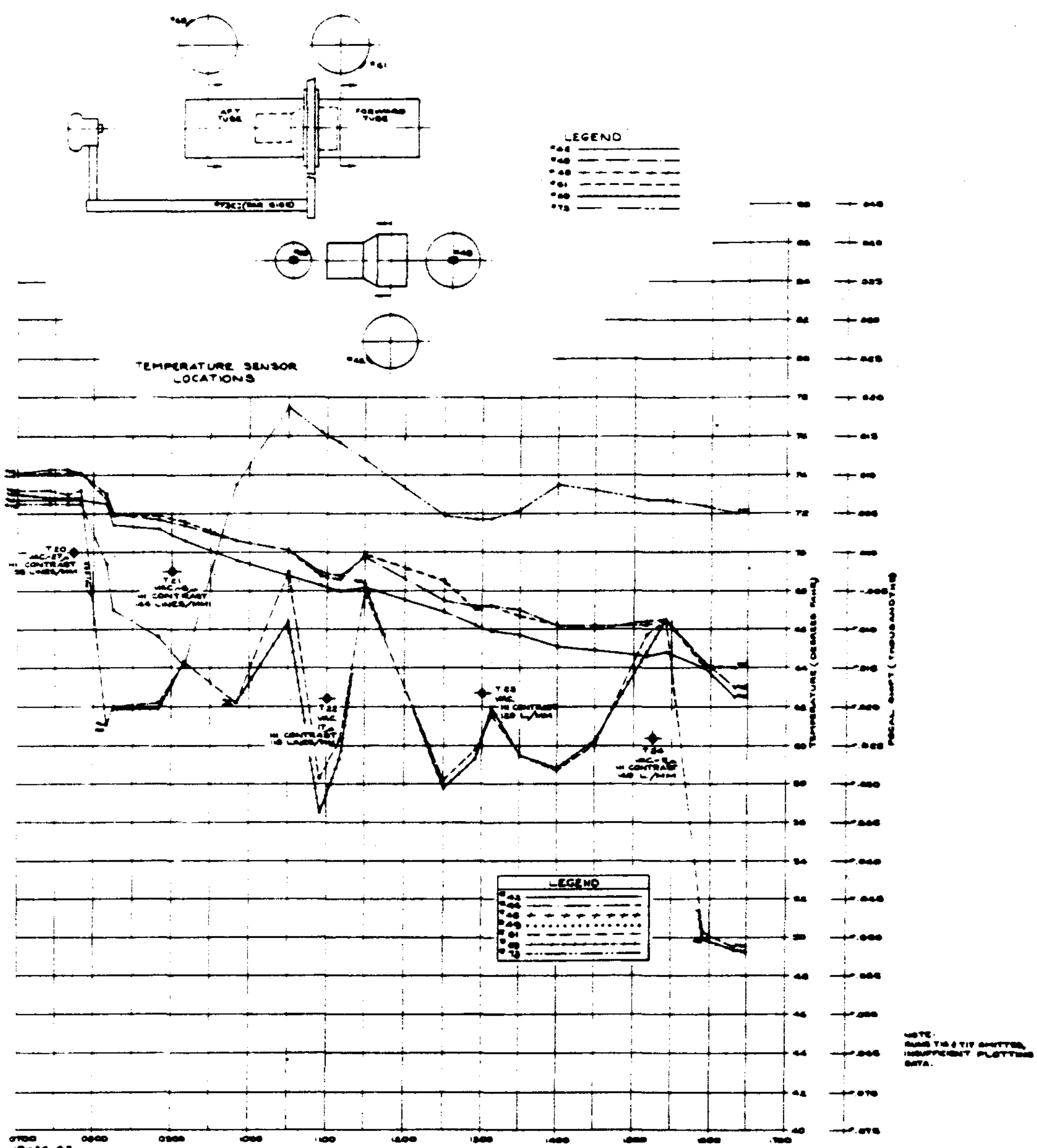

Fig. 4c — Lens temperature coefficient test, test "T," HAPL no. 13, series 2 (T-20 through T-24)

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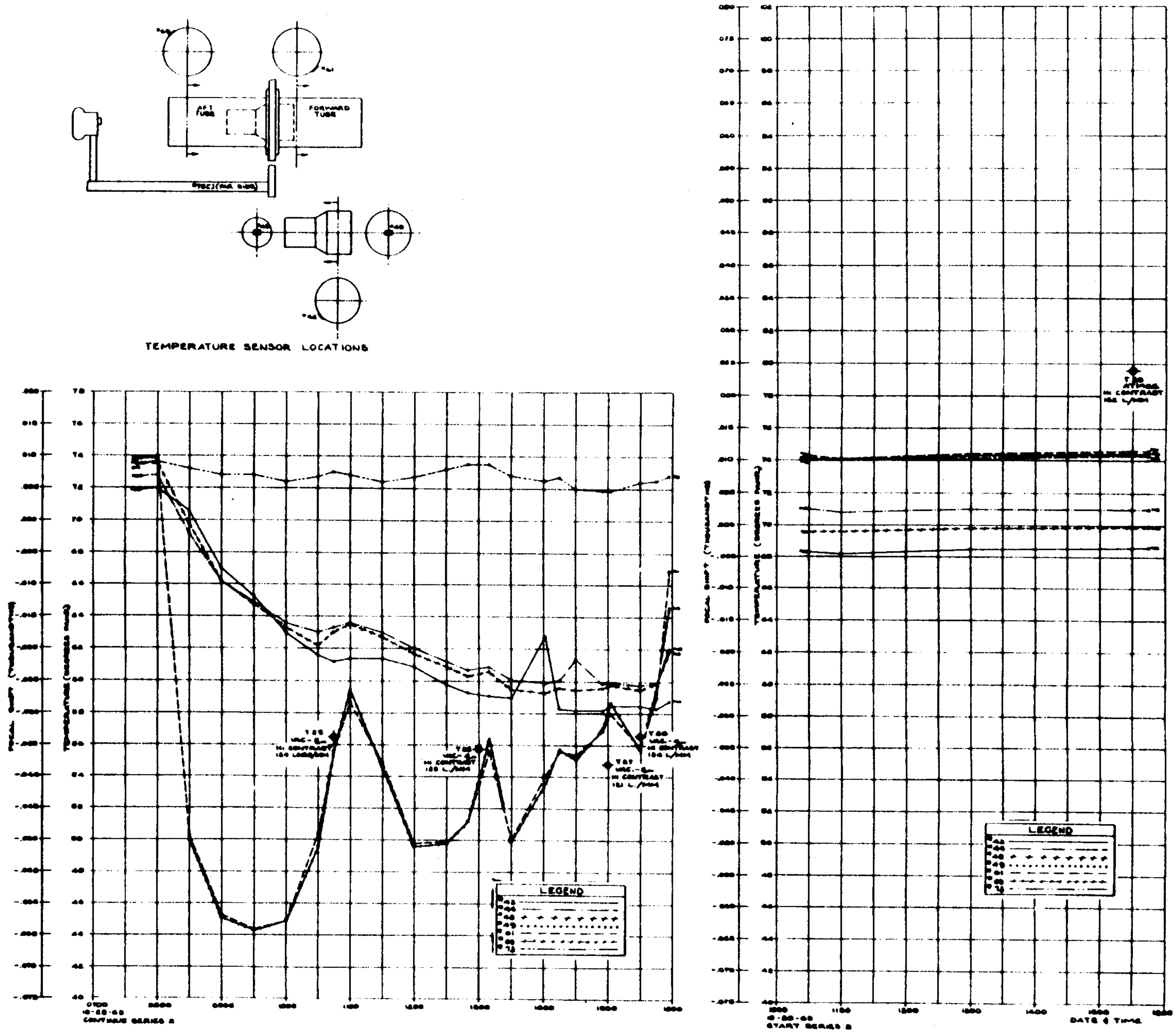

Fig. 4d — Lens temperature coefficient test, test "T," HAPL no. 13, series 2 (T-25 through T-28)

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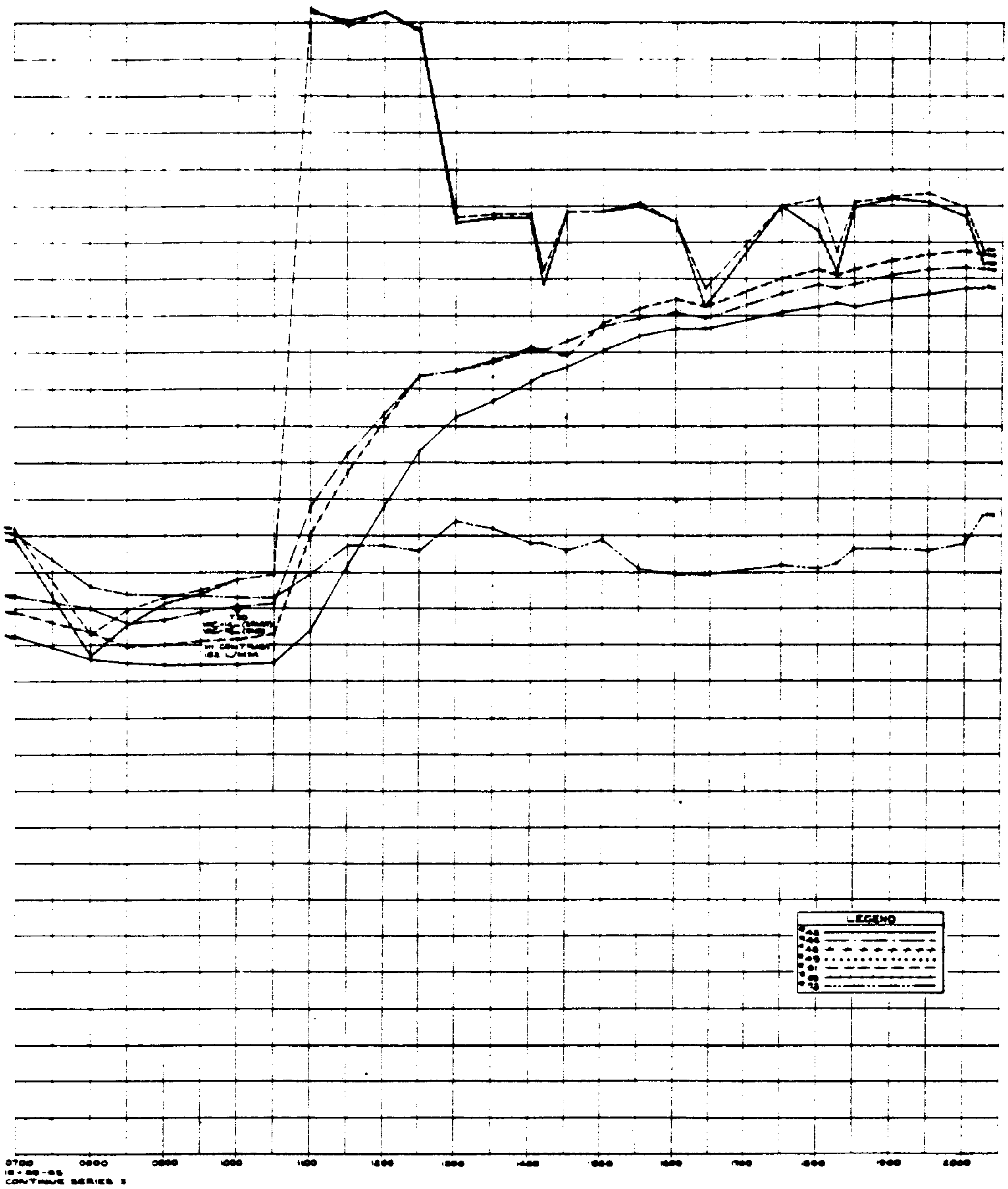

Fig. 4e — Lens temperature coefficient test, test "T," HAPL no. 13, series 3 (T-29, T-30)

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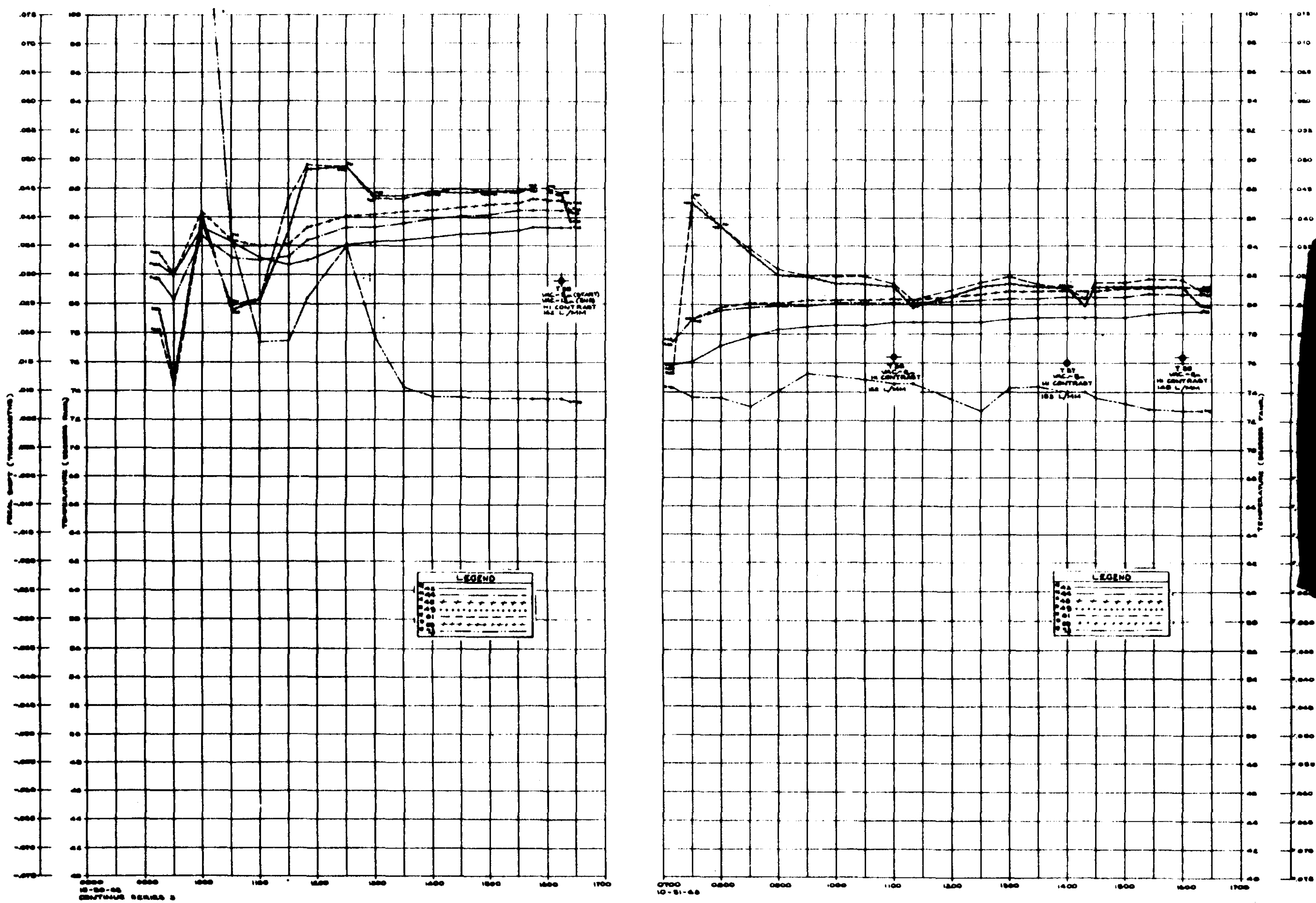

Fig. 4f — Lens temperature coefficient test, test "T," HAPL no. 13, series 3 (T-35 through T-38)

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difficult to measure or to express in simple terms. It is to be noted, however, that this temperature distribution is defined by thermal boundary conditions which can be defined as follows:

1) Lens barrel temperature
2) Temperature of the forward lens element or the forward tube
3) The temperature of the aft lens element or aft tube

$$C_g = f\,(T_{barrel},\ T_{fwd\ element}\ \ T_{aft\ element})$$

or

$$C_g = f\,(T_{barrel},\ T_{fwd\ tube},\ T_{aft\ tube})$$

The heat transfer characteristics within the lens assembly is a combination of conduction and radiation. The radiation mode of heat transfer can be linearized to within approximately 10% for the range of temperatures covered herein (45 to 80 forward and 65 to 95 aft). It is therefore reasonable to consider the integrated heat transfer characteristics to be a linear function. Thus, the relative temperature distribution is defined by the following dimensionless parameter, independent of temperature level.

$$(T_{aft} - T_{barrel})\ (T_{aft} - T_{fwd})$$

T_{aft} and T_{fwd} can refer to either element temperatures or tube temperatures, depending on the definition of T_{aft} and T_{fwd}. The magnitude of the gradient is defined by the magnitude of the differences. Since this gradient has a definite contribution to the mechanical strains within the assembly the optical effect is also directly related to the thermal gradient.

T_{aft} and T_{fwd} used herein refer to aft and fwd tube temperatures rather than the elements temperatures. The temperature transducers used on the elements were not as well mounted or calibrated as those

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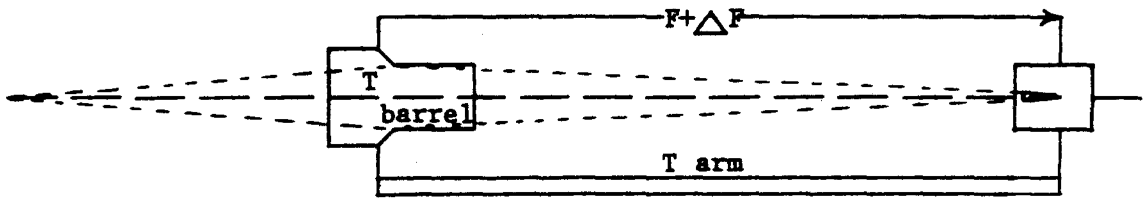
of the tubes. Using the element temperatures for defining the gradient resulted in a larger degree of data scatter.

The results of the steady-state gradient test are presented in Chart (1) and Figure (1). Figure (1) presents the gradient coefficient as a function of the system parameter. This coefficient was obtained as follows.



$$\Delta F = C_L (T_L - T_{L\ ref}) - C_a (T_a - T_{a\ ref}) + C_g (T_{aft} - T_{fwd})$$

$$C_g = \frac{F - C_L (T_L - T_{L\ ref}) + C_a (T_a - T_{a\ ref})}{(T_{aft} - T_{fwd}) \text{ Tubes}}$$

$C_g \sim$ gradient coef.

$C_a \sim$ thermal expansion of 66" steel beam

The scatter of this data represents a focus scatter of less than ± .003" for the gradient conditions expected in flight. It is to be noted that this data scatter includes any error that exists in the temperature coefficient, that is, the tolerances from the two tests should not be added.

In the operational environment the thermal relationship of cell temperature and the environmental condition have been approximated in this test. That is, the parameter ($T_{aft} - T_{cell}$ $T_{aft} - T_{fwd}$) in flight is between -.05 and +.2, based upon thermal analysis and flight data, for this reason most data points are within this range.

Chart (2) is a summary tabulation of gradient temperatures and relative focus changes for stabilized conditions. Chart (3) tabulates

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CHART (1)

SUMMARY OF DATA

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SERIES #	RUN #	BASELINE TEMP. T_{Cell}	BASELINE TEMP. T_{Arm}	TEMP. FOR FINAL TEST T_{Arm}	Aft Tube	Aft El.	Barrel	Fwd El.	Fwd Tube	FOCUS CHANGE
		$T_{L\ Ref}$	$T_{a\ Ref}$	T_A	T_{aft}		T_L		T_{fwd}	$\overline{}$ F
1		70.0	70.0	79.0	86.8		74.2	59.0	46.0	-.0243
2		74.4	72.8	75.8	86.0	81.8	74.2	56.8	46.0	-.0002
3		75.7	74.9	75.7	80.0	78.2	74.8	56.4	46.2	-.002
4		73.5	72.3	76.2	77.0	77.0	74.7	56.4	46.0	+.0025
5		75.7	75.0	75.0	71.0	72.5	70.2	55.7	46.0	-.0115
6*	x43	73.5	73.2	74.4 75.0	77.0 77.0	75.5 76.4	73.5 74.5	56.7 59.0	45.0 52.0	-.003 0
7		74.0	73.0	74.4	91.7	89.8	87.5	70.0	65.4	+.0296
8		74.0	73.0	74.5	95.9	92.0	87.6	57.9	46.8	+.032
R-1		80.8	80.3	74.3	76.3	75.2	74.8	56.3	45.2	-.0145
R-2		71.4	71.0	82.0	78.1	75.5	74.3	66.5	61.0	+.0099
R-3		71.4	71.0	74.4	81.0	79.0	75.1	64.6	60.8	+.0057

*Series No. 6 includes a steady-state gradient followed by thermal cycling.

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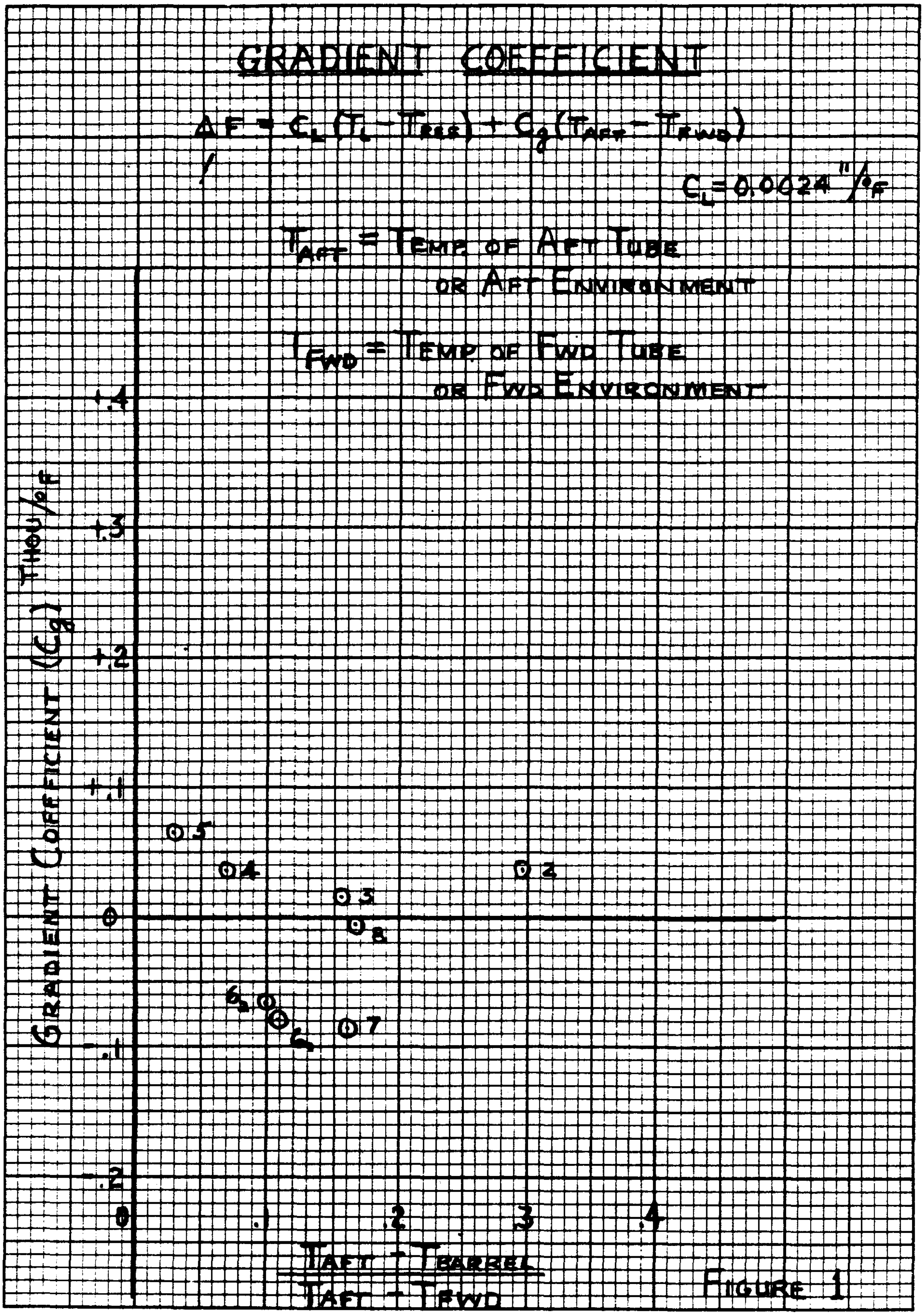

FIGURE 1

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CHART 3

AT TIME OF REPORT PREPARATION

THE ANALYSIS OF THERMAL GRADIENT TESTS

IS INCOMPLETE

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the constants of the gradient coefficients and indicates the relative deviation of predicting focus change vs. the experimental results for all stabilized runs.

Figures 3a through 5h are plots of individual temperature sensors and relative focus vs. time for all runs which have been summarized previously.

L-3 ANALYSIS

Table I summarizes lens and average platen support tube temperatures vs. Rev.#. Using the temperature coefficient of the magnesium platen support tube, film motion is computed and tabulated. In addition, the lens focus change vs. cell temperature is computed using 2.4 rather than 1.2 thousandths per ^{o}F. Also, front and rear element temperatures are estimated from lab experience and Vidya math model predictions and the additional gradient effect is computed. The resulting out of focus is then used with the final L-4 pre-ship photo run (Figure 6) to compute a percentage of peak resolution value. This is plotted as a predicted L-3 resolution vs. time in Figure 7. The average Rev. R.E.S. measurement data is also plotted for comparison.

L-4 THERMAL FOCUS CONTROL SYSTEM

From the lens thermal test data it is obvious that with temperature sensors on the lens an active thermal control system (shown schematically in Figure 8) will remove first order out of focus effects to eliminate the major problem of L-3.

The system is being built and is currently in test. It is proposed to furnish a set of parts for field installation in Unit 06 (L-9) and an identical set be installed in a Boston Unit to be subjected to a system environmental evaluation series.

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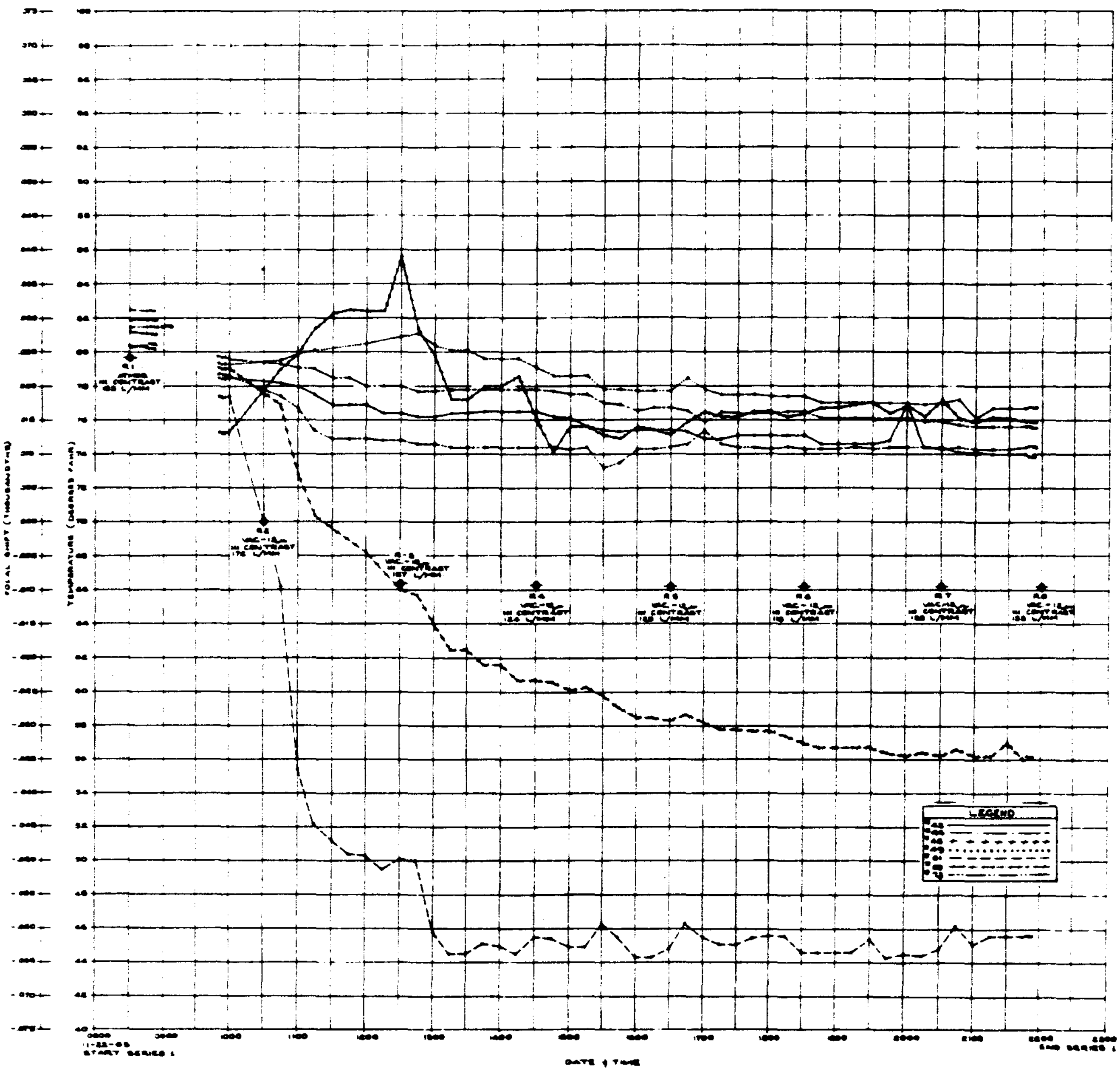

Fig. 3a — Lens temperature coefficient test, test "R," HAPL no. 13, series 1 (R-1 through R-8)

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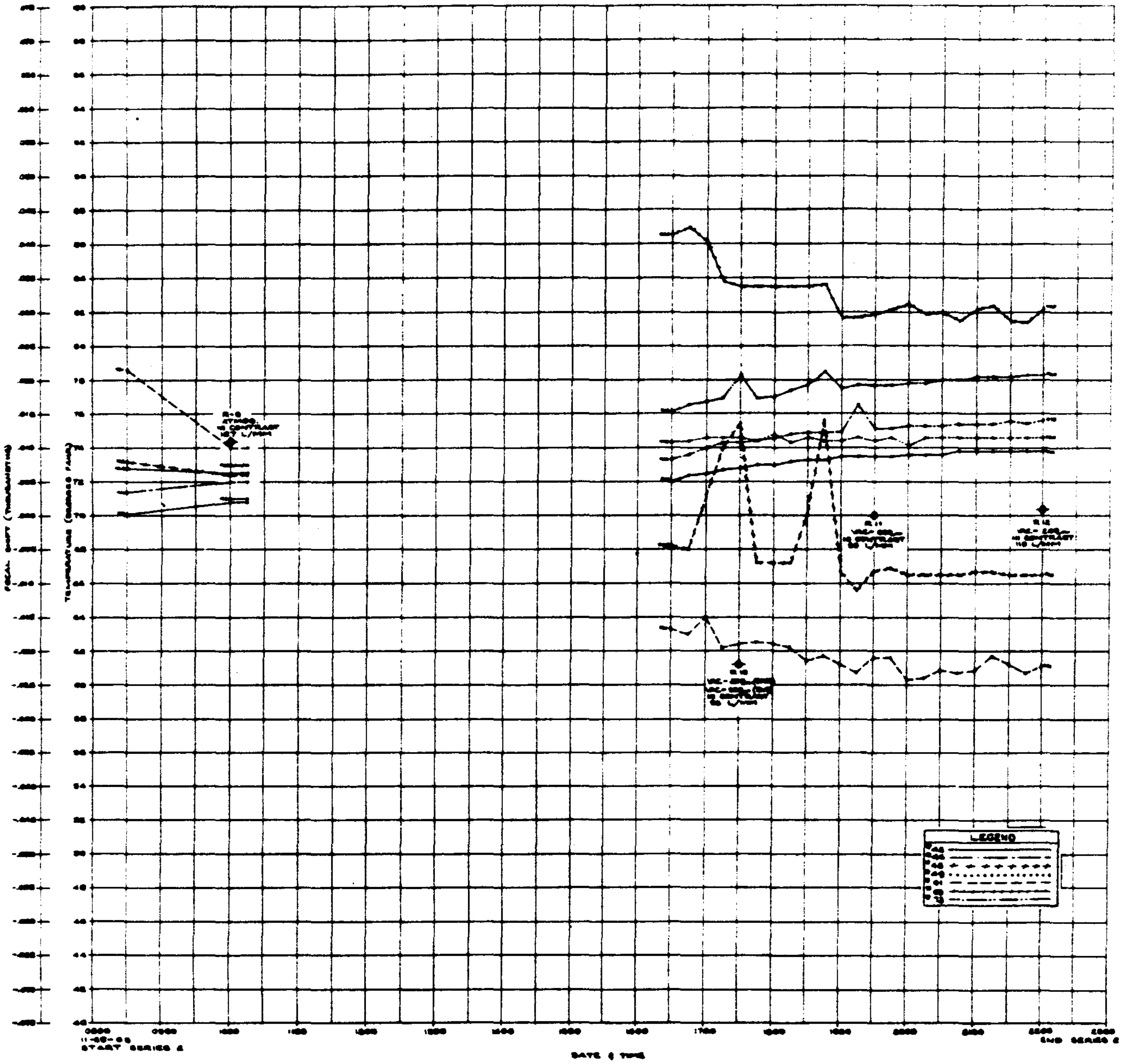

Fig. 3b — Lens temperature coefficient test, test "R," HAPL no. 13, series 2 (R-9 through R-12)

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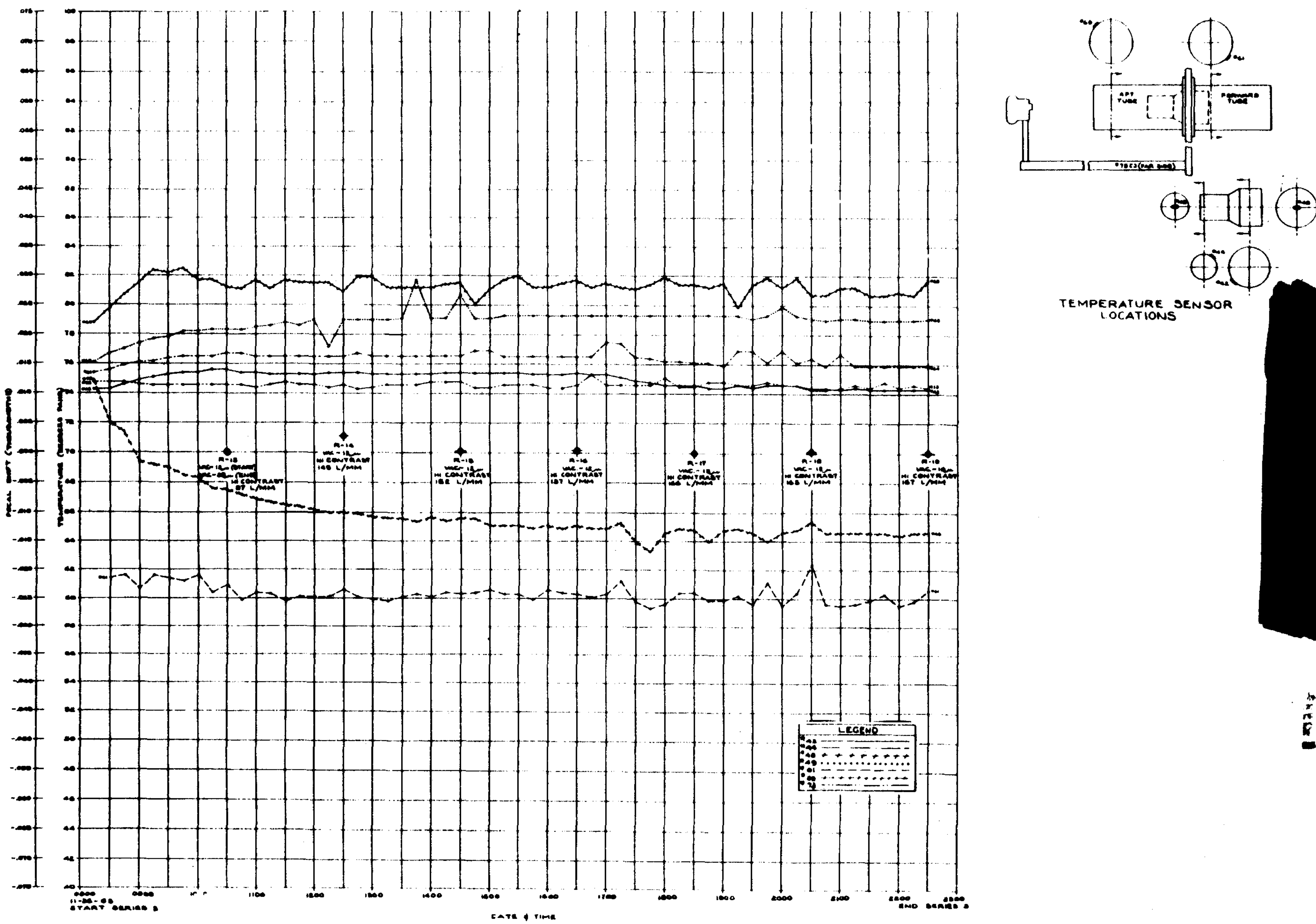

Fig. 3c — Lens temperature coefficient test, test "R," HAPL no. 13, series 3 (R-13 through R-19)

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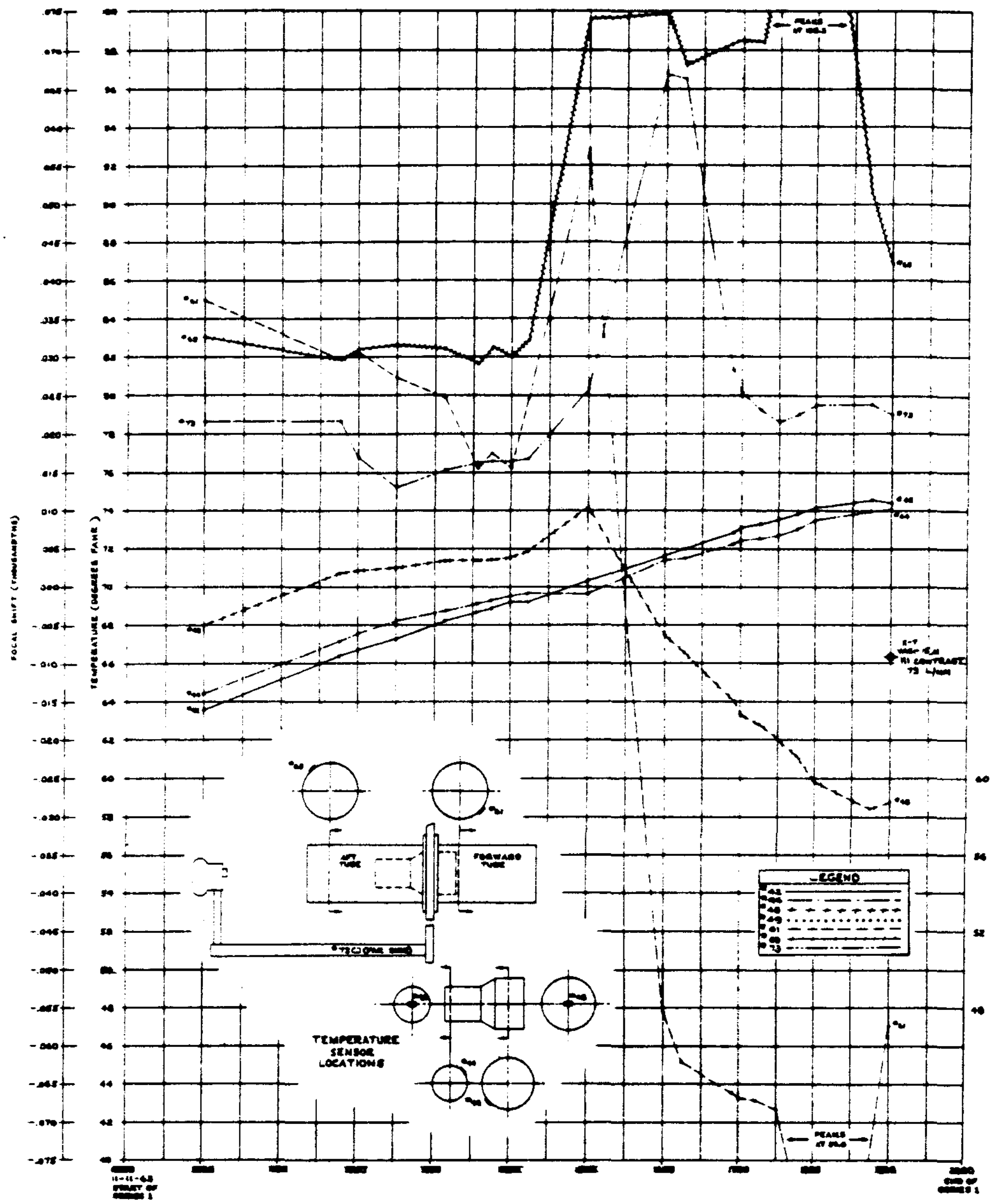

Fig. 5a — Lens temperature coefficient test, test "X," HAPL no. 13, series 1 (X-6, X-7)

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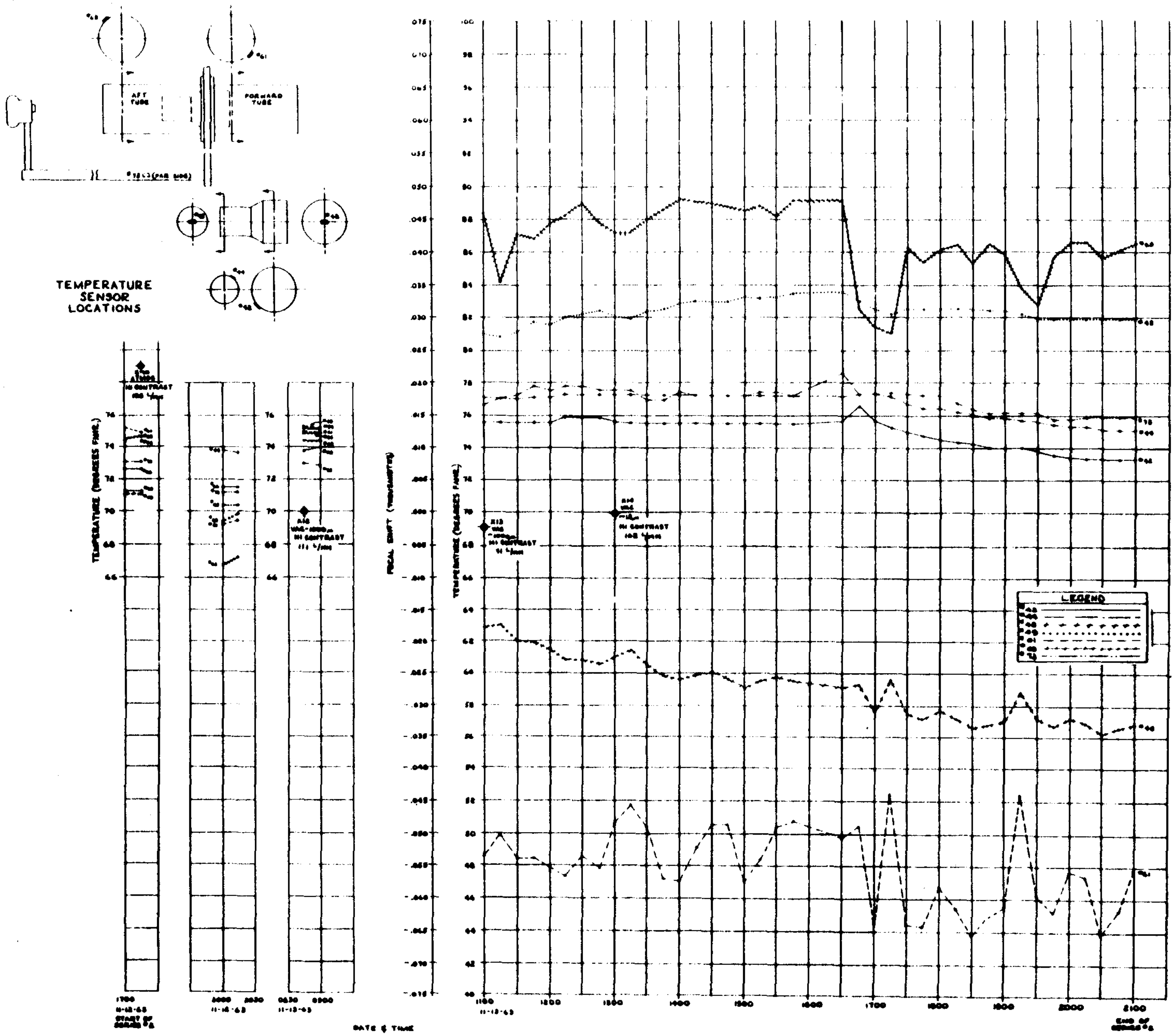

Fig. 5b — Lens temperature coefficient test, test "X," HAPL no. 13, series 2 (X-10 through X-15)

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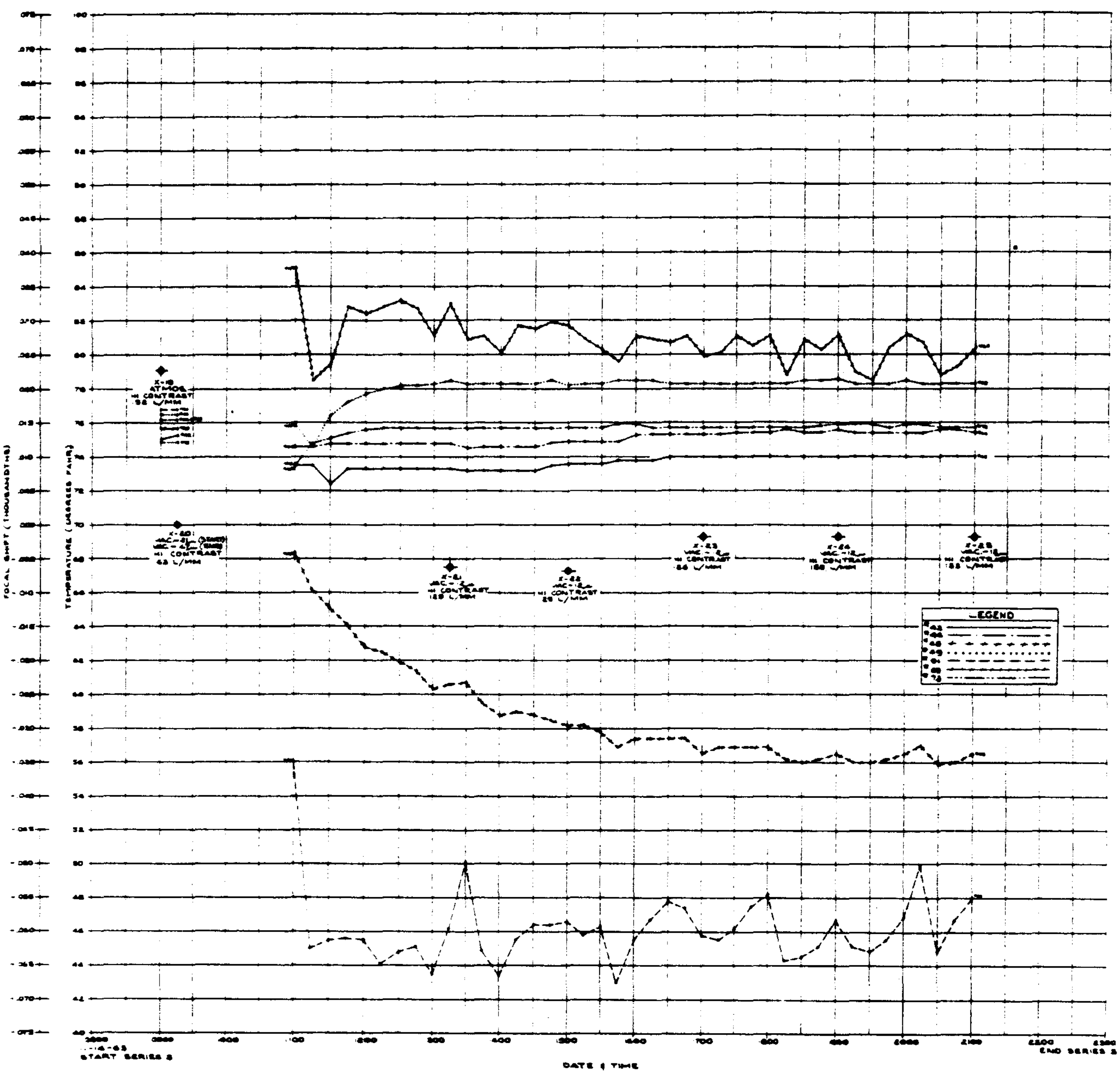

Fig. 5c — Lens temperature coefficient test, test "X," HAPL no. 13, series 3 (X-19 through X-25)

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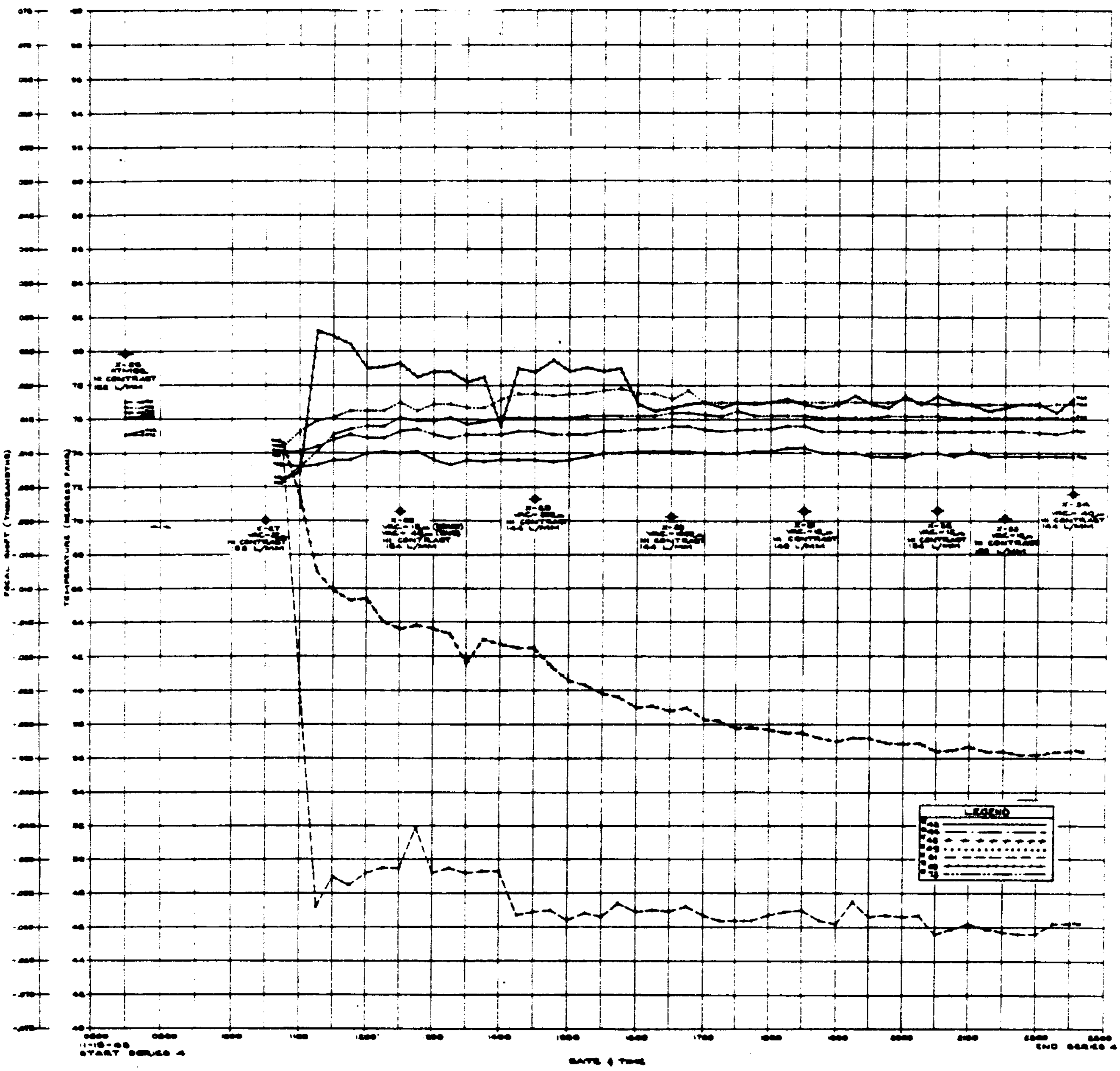

Fig. 5d — Lens temperature coefficient test, test "X," HAPL no. 13, series 4 (X-26 through X-34)

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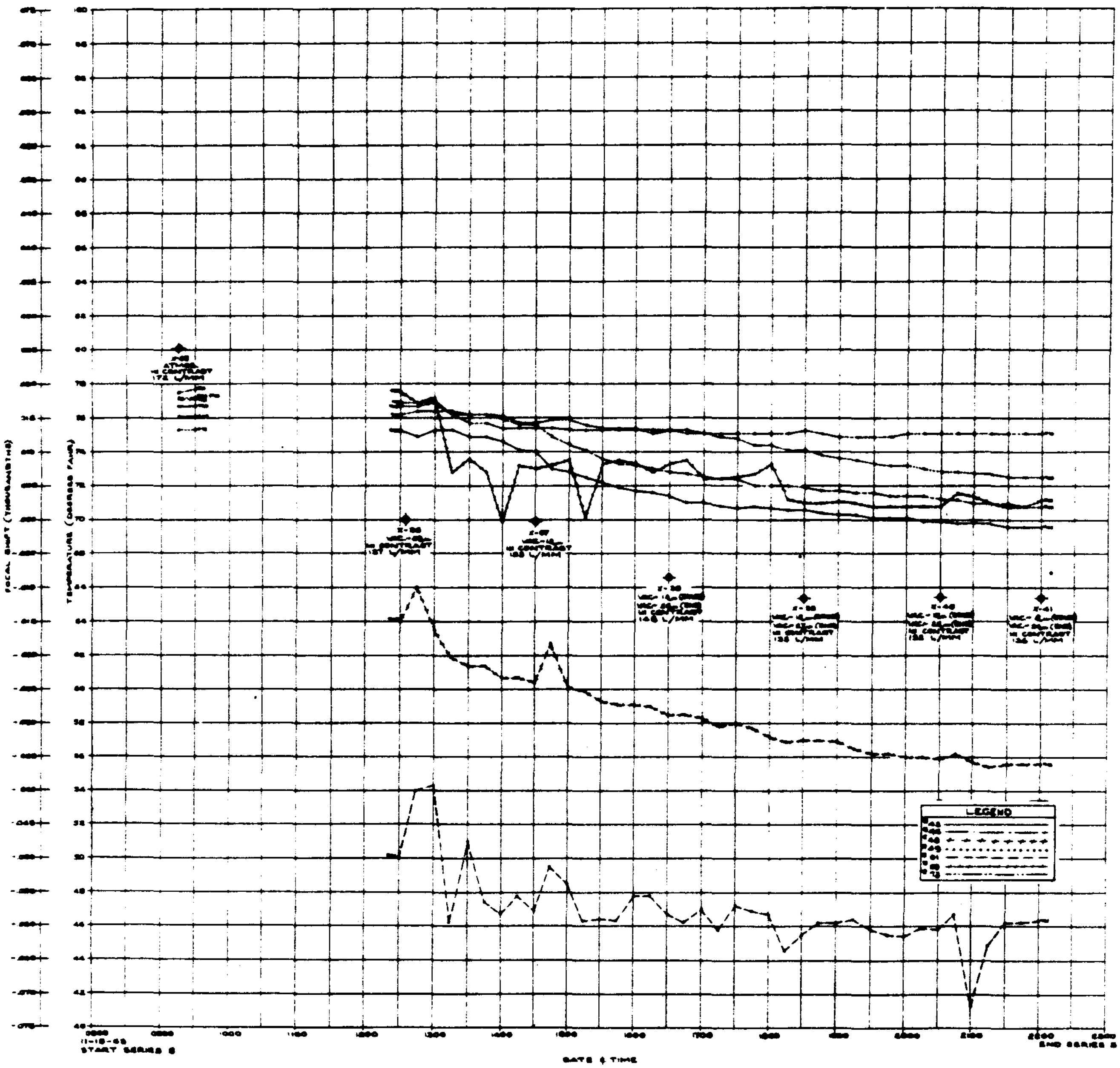

Fig. 5e — Lens temperature coefficient test, test "X," HAPL no. 13, series 5 (X-35 through X-41)

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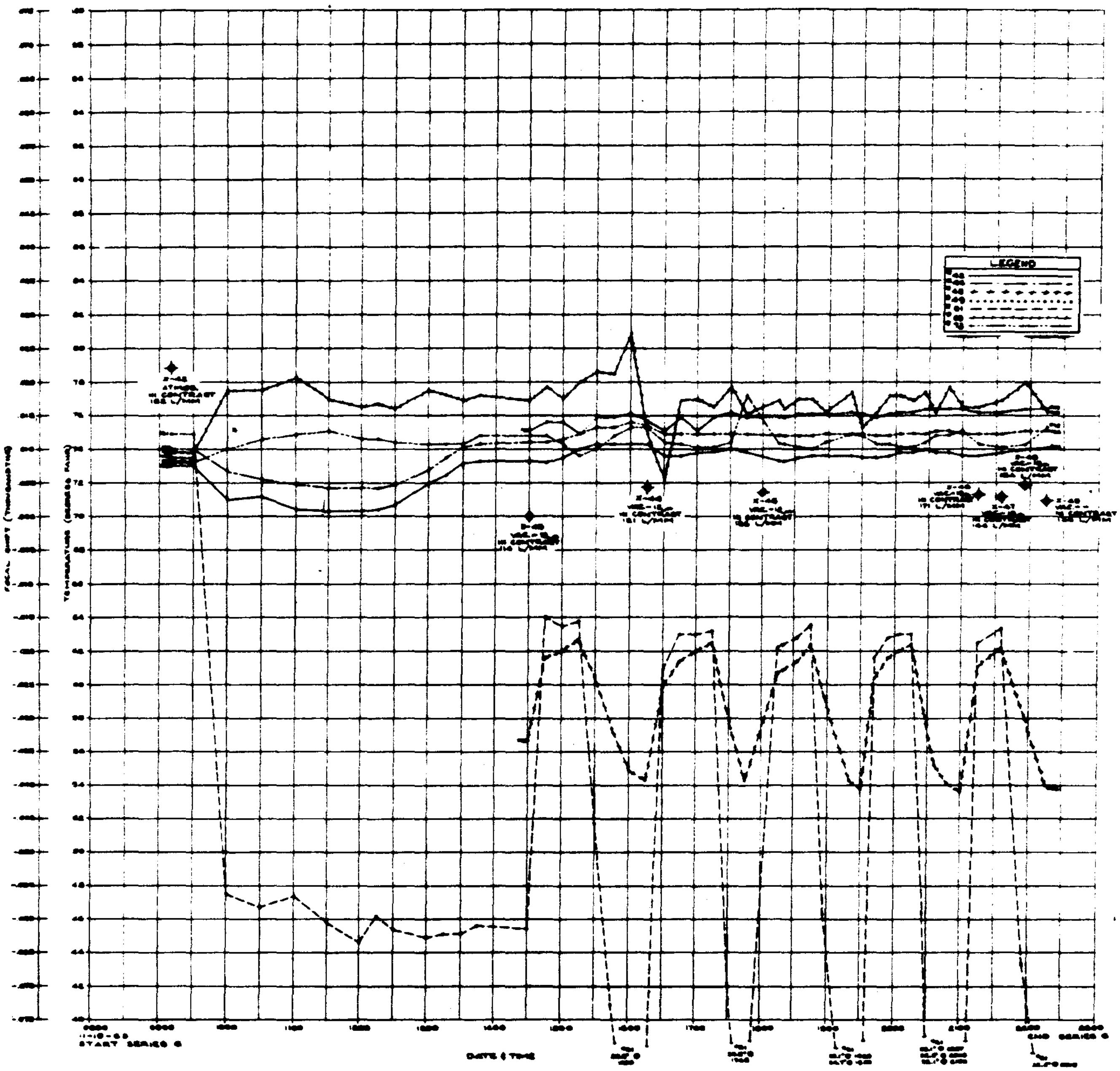

Fig. 5f — Lens temperature coefficient test, test "X," HAPL no. 13, series 6 (X-42 through X-49)

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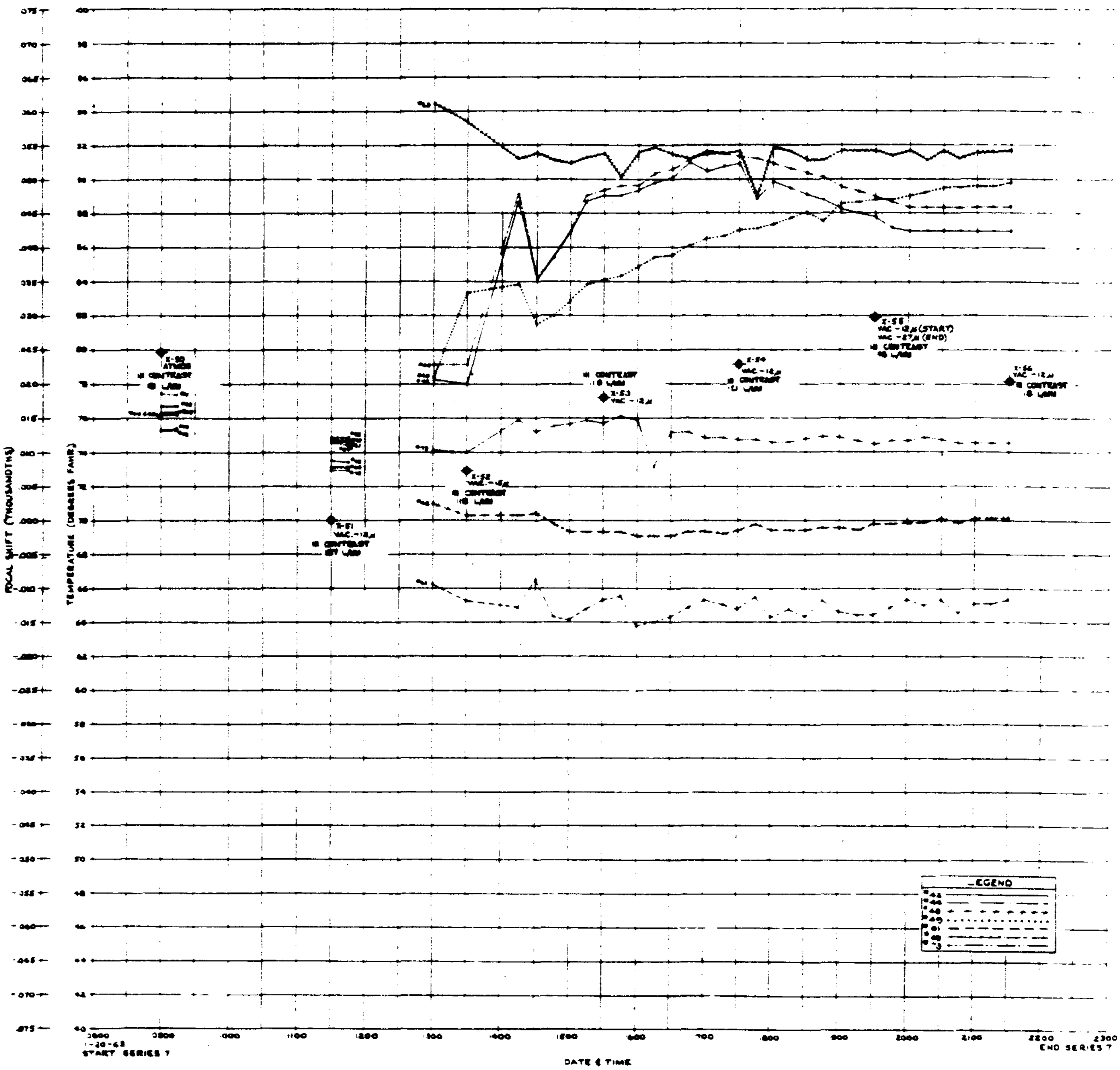

Fig. 5g — Lens temperature coefficient test, test "X," HAPL no. 13, series 7 (X-50 through X-56)

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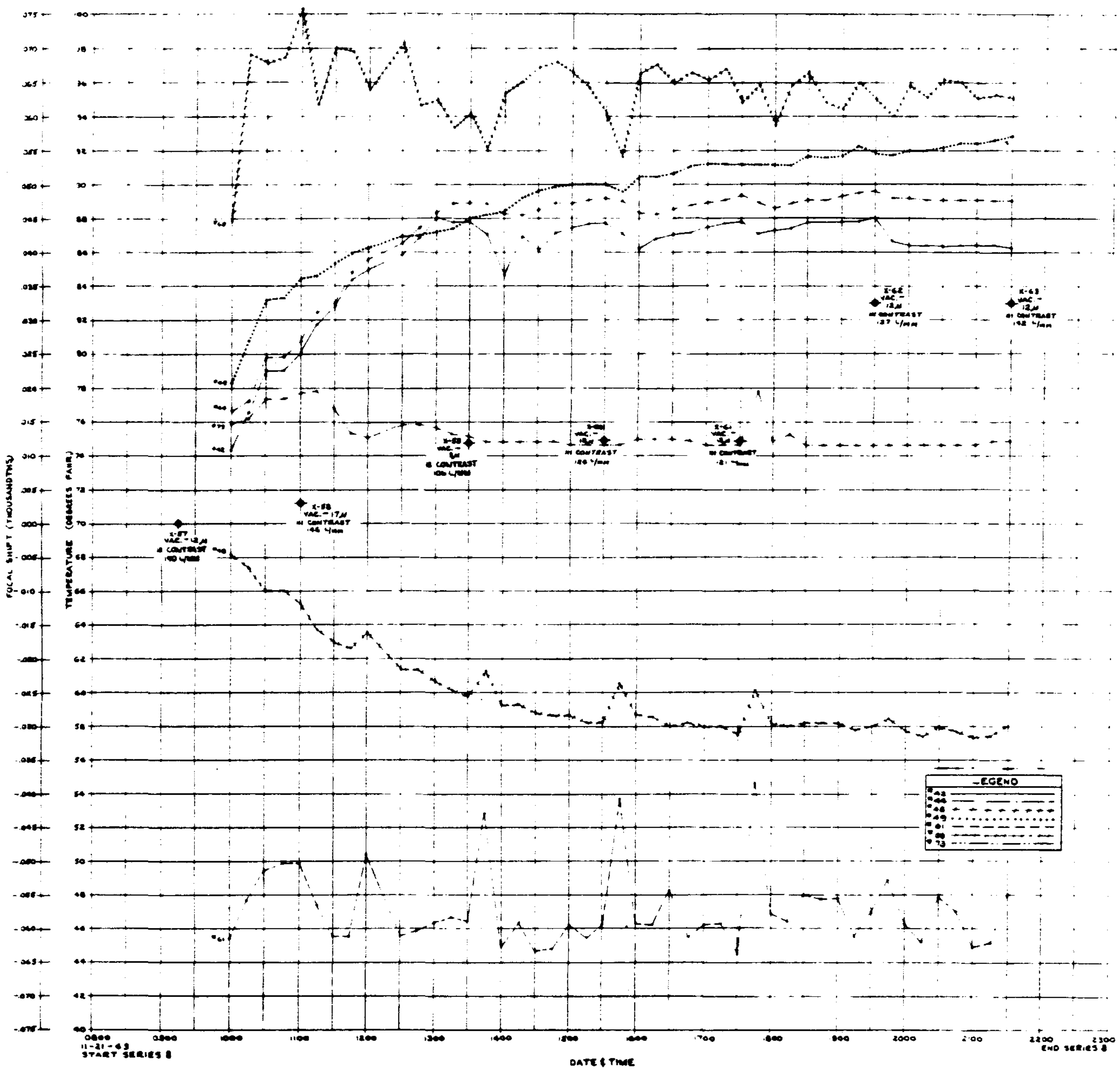

Fig. 5h — Lens temperature coefficient test, test "X," HAPL no. 13, series 8 (X-57 through X-63)

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TABLE I

L-3 THERMAL AND RELATIVE FOCUS

REV #	LENS TEMPERATURE °F	PLATEN SUPPORT TEMPERATURE °F	△PS	△f @ 2.4	OUT OF FOCUS	PERCENTAGE OF PEAK RESOLUTION
BOS DRT	73	73	0		0	
W/C DRT	71	71	1.8	- 4.8		
LAUNCH	72	72	.9	- 2.4		
1	74	94.5	-19.3	+ 2.4	-16	22
2	78	94.5	-19.3	+12.0	- 7	59
3	80	94.5	-19.3	+16.8	- 2.5	96
4	82	95	-19.8	+21.6	+ 1.8	100
6	86	95	-19.8	+31.2	+11.4	29
8	88	95	-19.8	+36	+16.2	18.5
12	88	96	-20.7	+36	+15.3	22
17	88	94	-18.9	+36	+17.1	15
22	88	92.5	-17.6	+36	+18.4	12

BOSTON DRT @ 73°F BEST FOCUS OBTAINED

[redacted]

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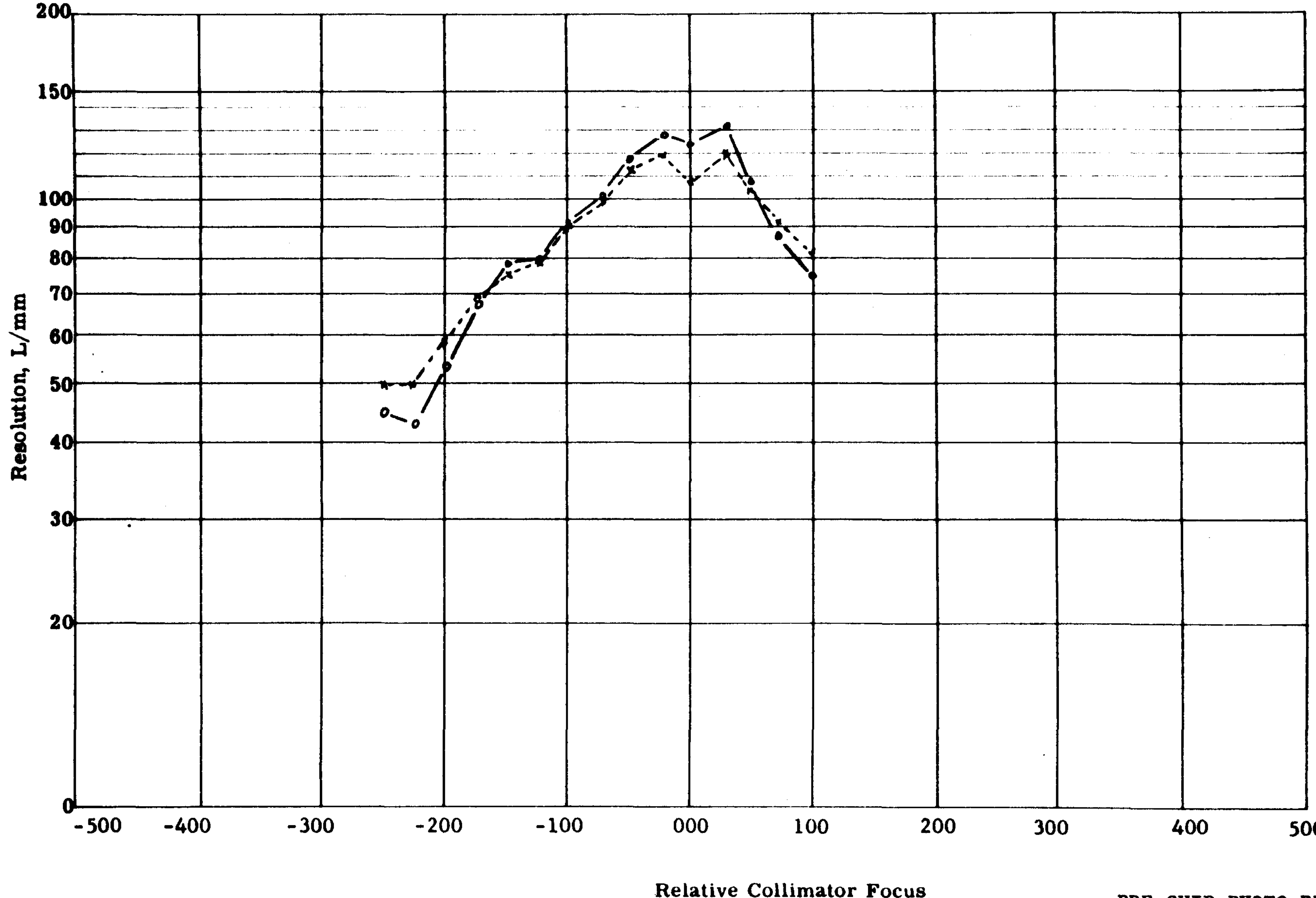
RESOLUTION SIGNATURE

——o—— IMC
----x---- SCAN
UNIT 06 - L4
HAPL 8
B_e 10

TEMPERATURE:
LAB
LENS
P.S.T.

CONDITIONS

RUN NO. 9
TYPE DYN
PRESSURE ATMOS
LOCAL FOCUS 225
REMOTE FOCUS ______
DATE 10-22-63
UNIT V/h 100%
SLIT NO. 5
EXPOSURE TIME 1/400
TARGET TIGER



PRE-SHIP PHOTO RUN
FIGURE 6

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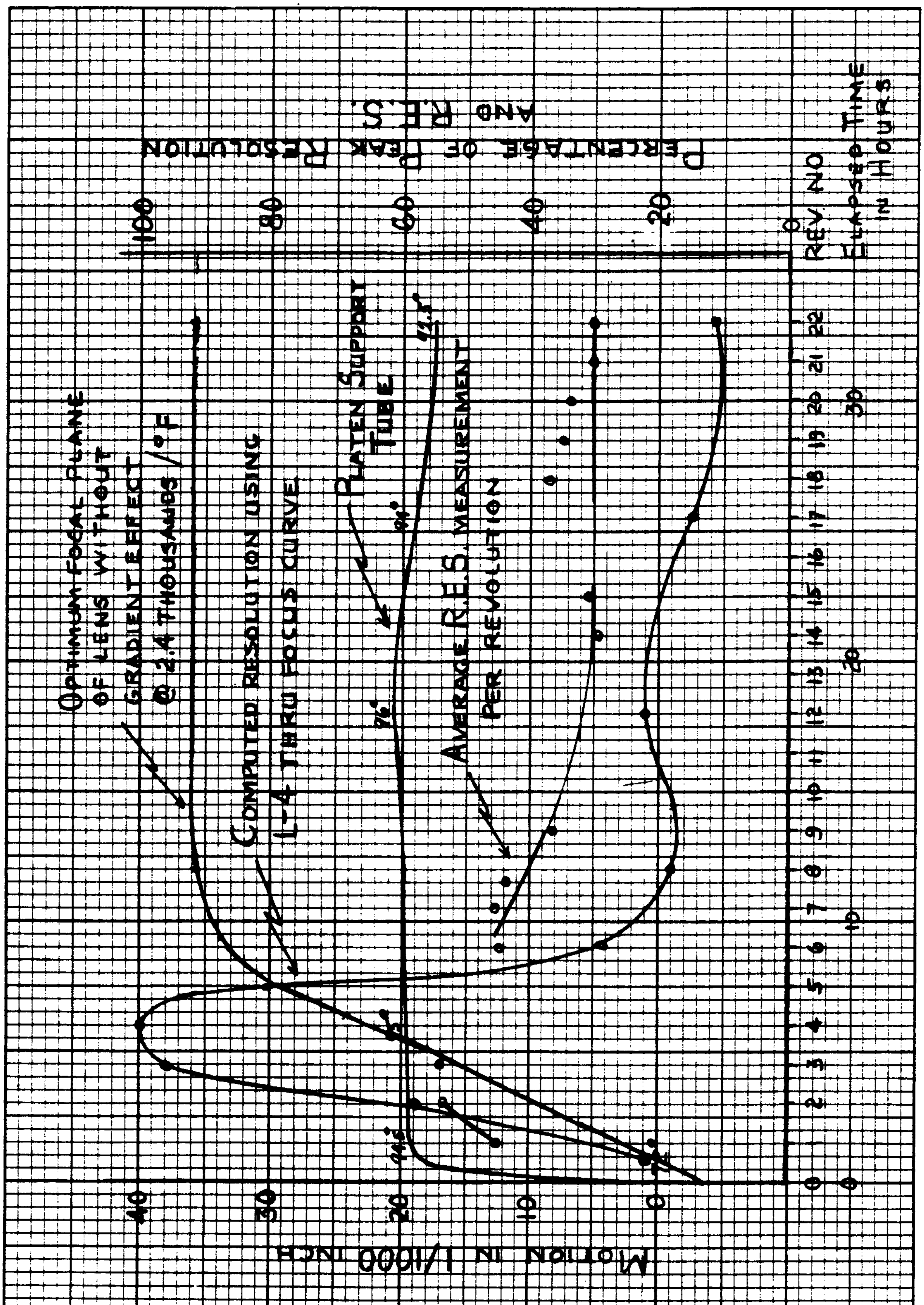

FIGURE 7

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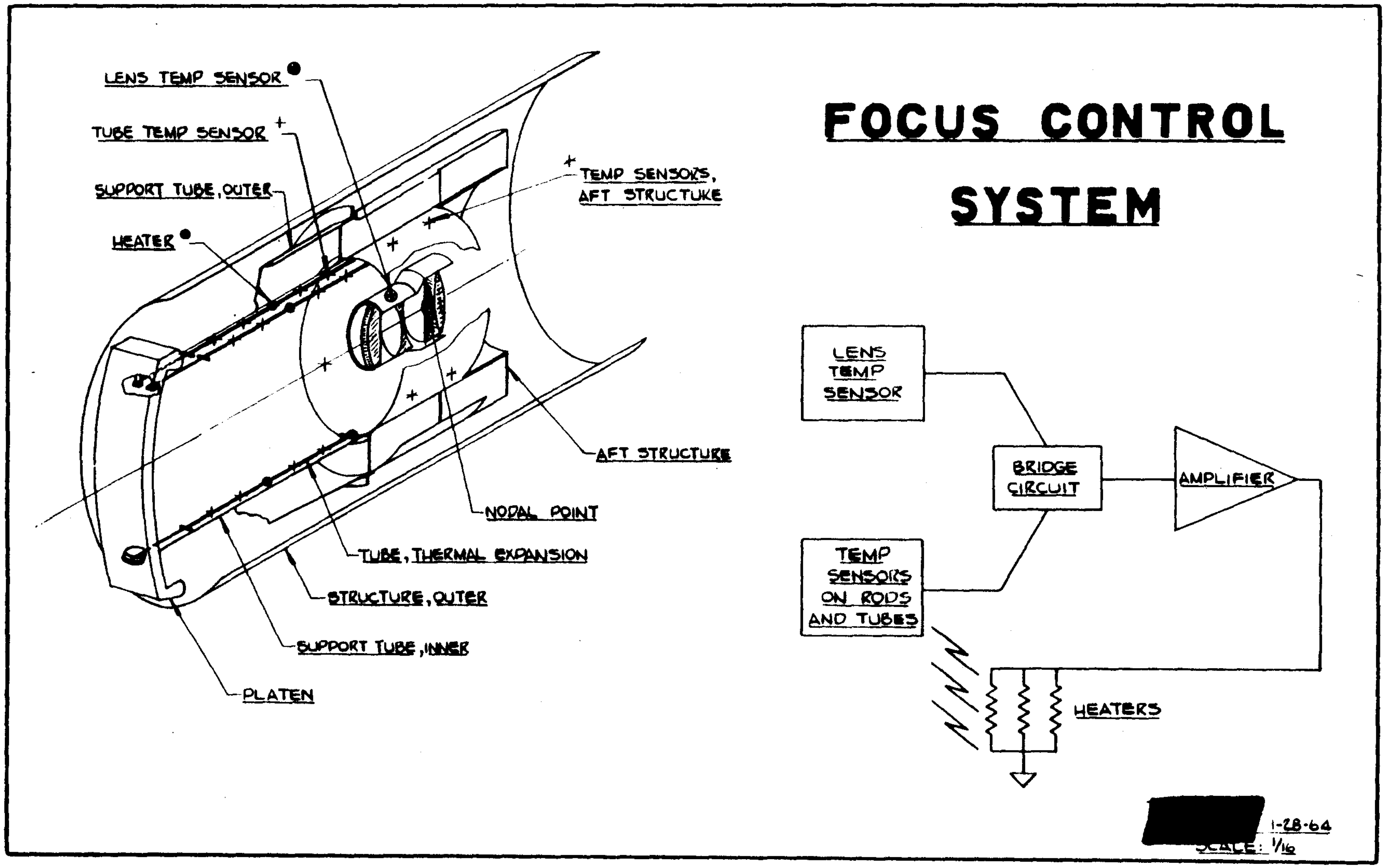

FIGURE 8

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