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Operations Report - IET #17
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IET #17

HTCE-2 Insert LQE-1 Cartridge Operations Report

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TITLE

HTRE-2 Insert L2E-1 Cartridge Operations Report

ABSTRACT:

This report presents the results of the power testing of the L2E-1 insert cartridge in the HTRE-2 reactor. The test was implemented to evaluate the high temperature characteristics of coated (Al_2O_3) fueled ceramic (BeO) tubes.

The operations were started in November 10, 1959, when the design temperature of 2500°F was achieved at a total reactor power of 10.5 megawatts. In successive power operations 105.99 hours were accumulated at this temperature. During this time there was essentially no change in test conditions from initial values.

Throughout the test the release of fission products from the insert was monitored. Data indicated that the fractional release of I^{131} and I^{135} did not vary significantly from L2A-1 values, indicating the ineffectiveness of the coating in reducing the release of iodines. However the gross release activity showed a reduction of between a factor of 3 and 4 from L2A-1 (same geometry with no coating) data suggesting that the Al_2O_3 coating is effective in reducing or delaying the evolution of some fission products.

The post operational examination of the L2E-1 fueled tubes showed very small amounts of crystal deposits or growths compared to the L2A-1 and occurring at random locations in the hot regions of the insert. These data suggest that the Al_2O_3 coating is effective, for the times and temperatures involved, in reducing to a minimum the BeO hydrolysis.

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HTRE -2 - INSERT L2E-1 CARTRIDGE OPERATIONS REPORT

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HTRE-2 INSERT L2E-1 CARTRIDGE OPERATIONS REPORT

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1.0 INTRODUCTION

The L2E-1 insert cartridge was emplemented to further evaluate in a nuclear reactor the high temperature operations of fueled ceramic tubes. The power operation was conducted in light of insert 2B and insert L2A-1 cartridge operations wherein modifications to the fuel tubes (including an ID coating of alumina) were included to reduce or eliminate BeO hydrolysis and crystal growths (redeposition) as well as fission product releases.

The insert cartridge was designed to operate at a maximum fuel tube indicated temperature of 2515°F at a total reactor power 12 megawatts. The design temperature was achieved for the first time on November 10, 1959, at a total reactor power of 10.5 megawatts. Temperature distributions in the cartridge were essentially as expected. The operation was conducted in several successive power tests to accumulate 105.99 hours at the design maximum temperature. During this time there was essentially no change in test conditions from initial values.

Throughout the endurance testing the release of fission products was monitored. Data indicated that the fractional releases of iodine 131 and 135 did not vary significantly from initial on test values and in comparison to initial L2A-1 data was slightly lower.

Samples of gross stack activity showed a reduction of between a factor of 3 and 4 from the L2A-1 operation indicating that the Al_2O_3 coating is apparently effective in reducing or delaying the evolution of some fission products.

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At the conclusion of the endurance testing the HTRE-2 was returned to the Hot Shop where the insert cartridge was removed and examined. A general visual examination of the fueled stages showed no crystal growth or whitening of the tubes however an examination of some of the tube ID's using high magnification showed the presence of hair-like crystal formations, of a globular deposit having the appearance of grains of sand, and of a clinker like growth. The magnitude of these deposits would be when compared to the L2A-1 very small having a more or less random distribution.

In general it would appear from the results of the post operational examinations performed to date and from test data that the ID coating of Al_2O_3 as far as performance is concerned, is effective in preventing fuel tube corrosion and BeO deposit formation. The fact that some deposit was observed, however, suggests that (at least for these particular tubes) continued operation, over several hundred hours, may produce deposits of an extent sufficient to effect performance.

1.1 GENERAL DESCRIPTION OF L2E-1 AND OPERATING SPECIFICATIONS

The L2E-1 insert cartridge was made up of bundle of round fueled and unfueled BeO (ceramic) tubes arranged in a hexagonal pattern. The tubes are stacked one on top of the other to form the complete fuel cartridge which is composed of a front reflector of unfueled BeO tubes 12.305 inches long, a fueled region 29.743 inches long, and a rear reflector of unfueled BeO tubes 4.435 inches long. The tubes in the fueled region are staggered such that no two tube joints line up. The unfueled tubes in the front and rear reflectors have nominal lengths of 3.435 and 4.435 inches, and fueled tubes have a nominal length of 4.249 inches except

for tubes required to adjust for tube staggering which have lengths of 1.417 inches and 2.832 inches. See figure 1.1-1 for cartridge assembly.

The fueled tubes of the L2E-1 have a nominal OD of 0.368 inches and a nominal ID of 0.277 inches. The ID includes a 0.0015 inch thick coating of Al_2O_3 on the fueled tubes. The tube bundle is contained in an insulation liner support tube made up of layers (inside out) of Hastelloy X, thermoflex and 304 Stainless Steel. The Hastelloy liner is 0.005 inches thick and is designed to operate at a maximum temperature of 2000°F, the thermoflex is 0.250 inches thick and the stainless steel liner-support tube is 0.012 inches thick. The liner is made into two halves which are pinned together making possible easy assembly and disassembly. The tube bundle and liner are supported at the bottom through a 0.750 inch thick Hastelloy X grid plate and a 3.667 inch long Hastelloy X support tube which rests on retractable latches fixed to the L2 insert "can". An instrumentation disconnect is fitted to the front end of the cartridge and is capable of handling 24 thermocouples. An air orificing plate is also designed into the cartridge disconnect for the purpose of measuring and metering air flow.

The fuel loading of the L2E-1 tubes was varied per a nuclear analysis for the purpose of flattening the radial power generation. Table 1.1-1 presents the fuel concentration by weight for the various tube rows. The tube bundle contains 127 tubes in cross section 56 of which are fueled, and 5 of which are instrumentation tubes, see figure 1.1-2. Figure 1.1-2 also shows the thermocouple locations.

Table 1.1-2 presents the volume fractions of the various materials in the insert cartridge. Figure 1.1-3 shows a photograph of the partially assembled tube bundle.

TABLE 1.1-1

RADIAL FUEL VARIATION

Tube Row	Representative Number of Tubes Per stage	Weight % of UO_2
1 and 2	7	7.31
3	12	6.89
4	18	6.33
5	24	6.00

TABLE 1.1-2

L2E-1 MATERIALS CONTENT

Material	Volume Fraction, %	Weight, lbs.	Specific Gravity
BeO	4.99	16.88	2.88
UO_2	.0463	.5930	10.9
Y_2O_3	.1565	.889	4.84
304 Stainless Steel	.185	1.72	7.94
Thermoflex Insulation	3.59	.944	0.224
Hastelloy	0.3268	3.159	8.23
Void	13.5		
Al_2O_3	.0097	.0398	3.5

Volume fractions based on a 3252 in^3 HTRE-2 test hole volume.

The following is a list of the predicted parameters for the L2E-1 operation:

1.	Maximum total reactor power (dependant on ambient conditions)	10-14 MW
2.	Design reactor power	12 MW
3.	Maximum insert cartridge power	200-300 KW
4.	Maximum insert temperature (initial) single reliable thermocouple	2515°F
5.	Insert average exit air temperature	1650°F
6.	Parent core fuel cartridge temperature	1300°F to 1500°F
7.	Parent core maximum fuel element temperature	1750°F
8.	Parent core fuel cartridge exit air temperature	1000°F to 1100°F
9.	Compressor discharge air weight flow at 7500 RPM	59.9 lb/sec
10.	Reactor inlet pressure	54.2 psia
11.	Reactor inlet temperature	344°F
12.	Reactor pressure drop	8.0 psi
13.	Pressure drop across tube bundle	4 psi
14.	Pressure drop across orifice plate	4 psi
15.	Insert total weight flow (including 10% leakage)	0.75 lbs/sec

1.2 L2E-1 OPERATIONS DATA

A. Initial Increase to Full Power

The test program for the L2E-1 insert cartridge was conducted in three phases.

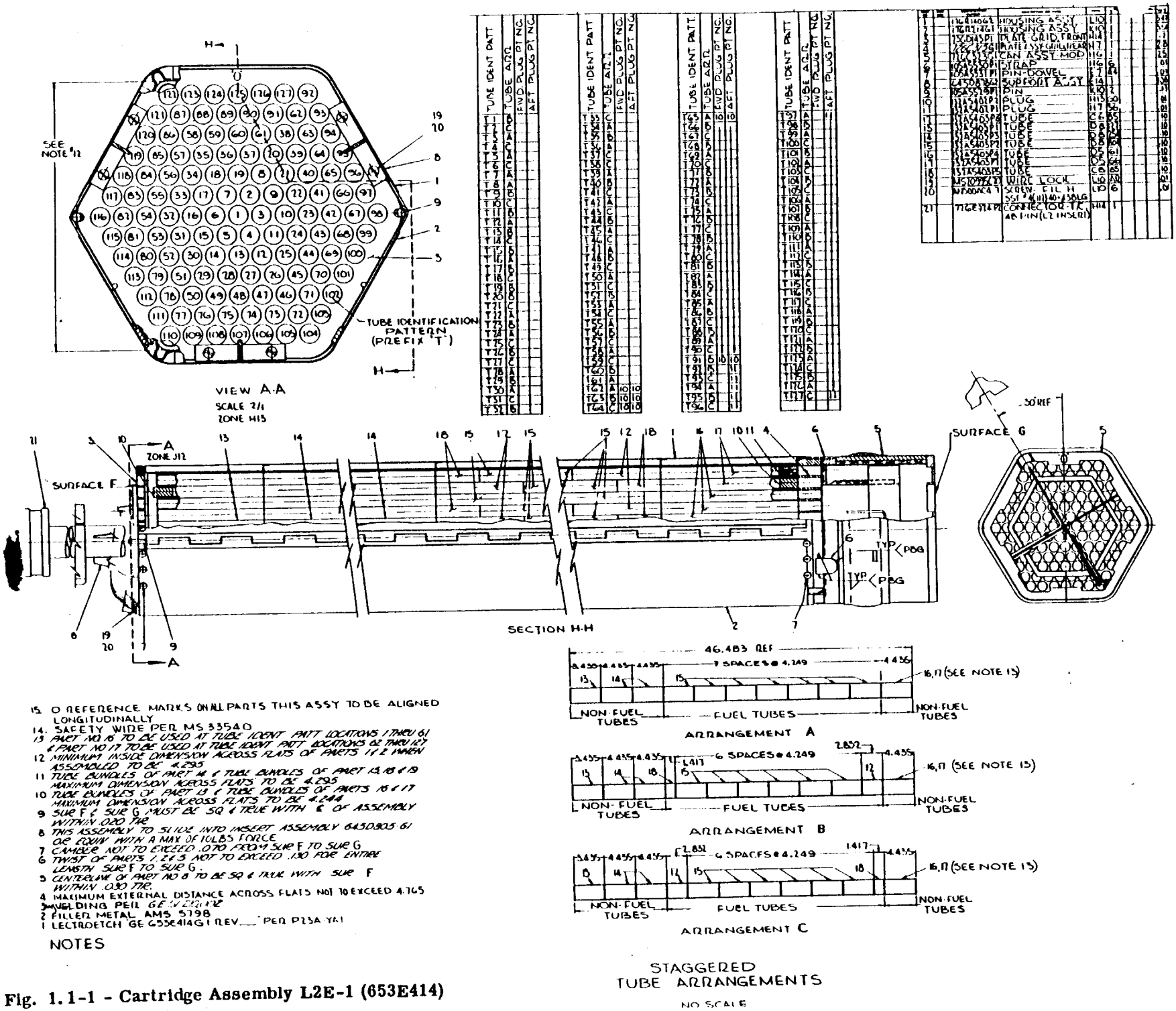
1. Initial checkout of instrumentation, engines and reactor.
2. Increase to full power.
3. Endurance at full power, and precipitator evaluation.

The increasing power phase of the test program was devised to gradually bring

the reactor to full power, in a sequence of power-temperature steps so that the behavior of the system could be observed before design conditions were reached. For the L2E-1 operation twelve power and temperature steps were specified 1 KW, 10 KW, 100 KW, and 1 MW and 1000°F, 1400°F, 1700°F, 2000°F, 2200°F, 2350°F, 2500°F, and 2600°F. (The 2600°F step being specified to extend a curve of fission product release versus temperature.) The on test condition was established at 2515°F maximum indicated fuel temperature. (2515°F being a thermocouple reading incorporating an added 15°F to account for a calculated rise through the fuel tube wall).

Figure 1.2-1 shows a plot of temperature data from the hottest insert and parent core thermocouples for the increasing power steps. On the same graph is plotted the predicted curve. A comparison of these data with the prediction as the power is increased, gives a means of forecasting success or failure of reaching design performance objectives. Figure 1.2-2 shows a plot of the reactor total power as a function of the hottest parent core fuel plate temperatures. Figure 1.2-3 presents various parent core temperature data versus the calculated core discharge air temperature (T3.60 - see figure 1.2-4 and 1.2-5 for locations of stations). These data in general were as expected.

Figure 1.2-6 presents pressure drops between various system locations as a function of T3.60. Due to the fact that X 39-5 engines were used for this operation system pressure drops are slightly higher than those measured for the X 39-4 engines used in all previous HTRE-2 testing. Engine performance data are presented in Apendix I.



15. O REFERENCE MARKS ON ALL PARTS THIS ASSY TO BE ALIGNED LONGITUDINALLY
14. SAFETY WIRE PER MS 33540
13 PART NO 16 TO BE USED AT TUBE IDENT PATT LOCATIONS 1 THRU 61 & PART NO 17 TO BE USED AT TUBE IDENT PATT LOCATIONS 62 THRU 127
12 MINIMUM INSIDE DIMENSION ACROSS FLATS OF PARTS 1 & 2 WHEN ASSEMBLED TO BE 4.295
11 TUBE BUNDLES OF PART 14 & TUBE BUNDLES OF PART 13, 18 & 19 MAXIMUM DIMENSION ACROSS FLATS TO BE 4.295
10 TUBE BUNDLES OF PART 13 & TUBE BUNDLES OF PARTS 16 & 17 MAXIMUM DIMENSION ACROSS FLATS TO BE 4.244
9 SUR F & SUR G MUST BE SQ & TRUE WITH ℄ OF ASSEMBLY WITHIN .020 TIR
8 THIS ASSEMBLY TO SLIDE INTO INSERT ASSEMBLY 6430805 G1 OR EQUIV WITH A MAX OF 10LBS FORCE
7 CAMBER NOT TO EXCEED .070 FROM SUR F TO SUR G
6 TWIST OF PARTS 1, 2 & 5 NOT TO EXCEED .130 FOR ENTIRE LENGTH SUR F TO SUR G.
5 CENTERLINE OF PART NO 8 TO BE SQ & TRUE WITH SUR F WITHIN .030 TIR.
4 MAXIMUM EXTERNAL DISTANCE ACROSS FLATS NOT TO EXCEED 4.765
3 WELDING PER GE [illegible]
2 FILLER METAL AMS 5798
1 LECTRODETCH GE 655E414G1 REV___ PER P23A-YA1

NOTES

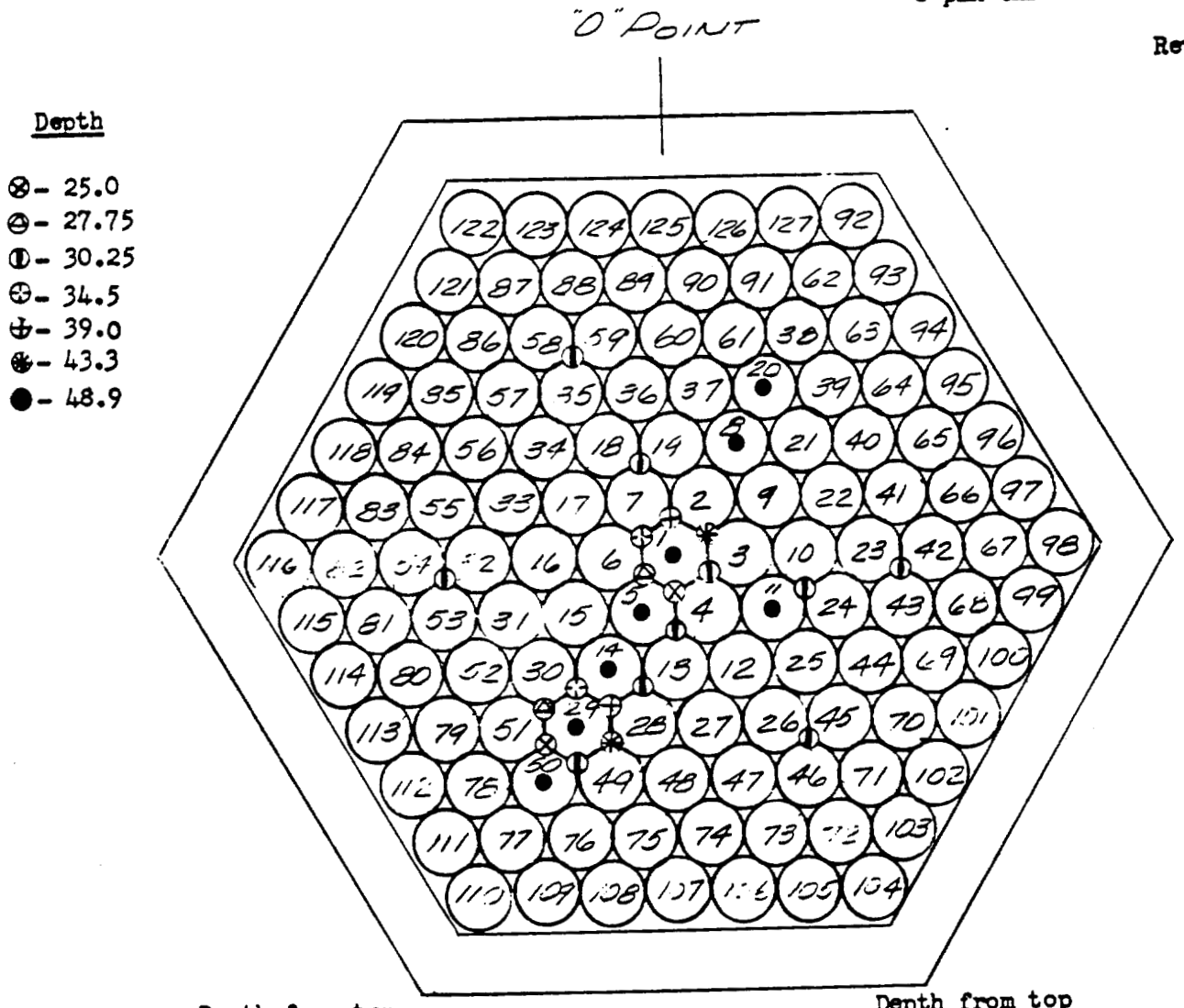
Fig. 1.1-1 - Cartridge Assembly L2E-1 (653E414)

[redacted]

[redacted]

Thermocouple Location Insert L2E1
48 pin Connector
8 pin Chromel Alumel Box

Rev. B



Idaho Code	Depth from top of front grid	Tier
1-2-25	25.0	6
50-1-25	25.0	6
5-1-28	27.75	7
30-2-28	27.75	7
35-1-30	30.25	8
7-1-30	30.25	8
53-1-30	30.25	8
10-2-30	30.25	8
43-1-30	30.25	8
13-1-30	30.25	8
28-1-30	30.25	8
46-1-30	30.25	8
4-1-30	30.25	8
29-2-30	30.25	8

Idaho Code	Depth from top of front grid	Tier
7-2-35	34.5	9
29-1-35	34.5	9
14-2-39	39.0	10
1-1-39	39.0	10
2-2-43	43.3	11
49-1-43	43.3	11
50-3-49	48.9	
29-3-49	48.9	
14-3-49	48.9	
5-3-49	48.9	
1-3-49	48.9	
8-3-49	48.9	
20-3-49	48.9	
11-3-49	48.9	

00-1-00 - Couple above tube
00-2-00 - Couple below tube
00-3-00 - Air couple

[redacted]

Figure 1.1-2

[redacted]

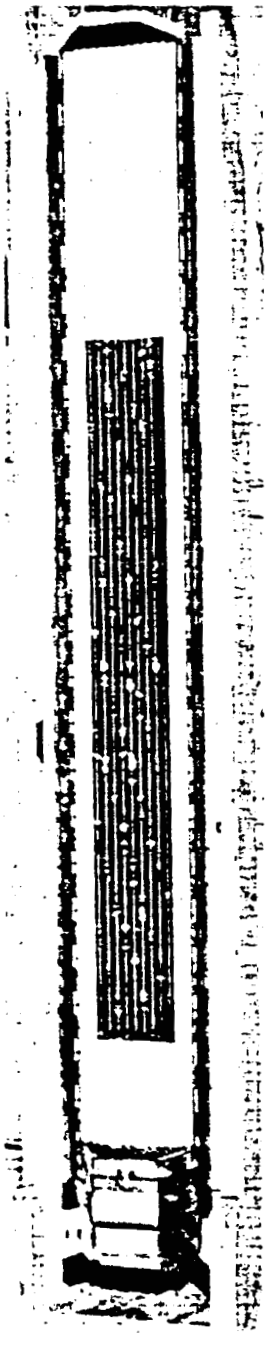
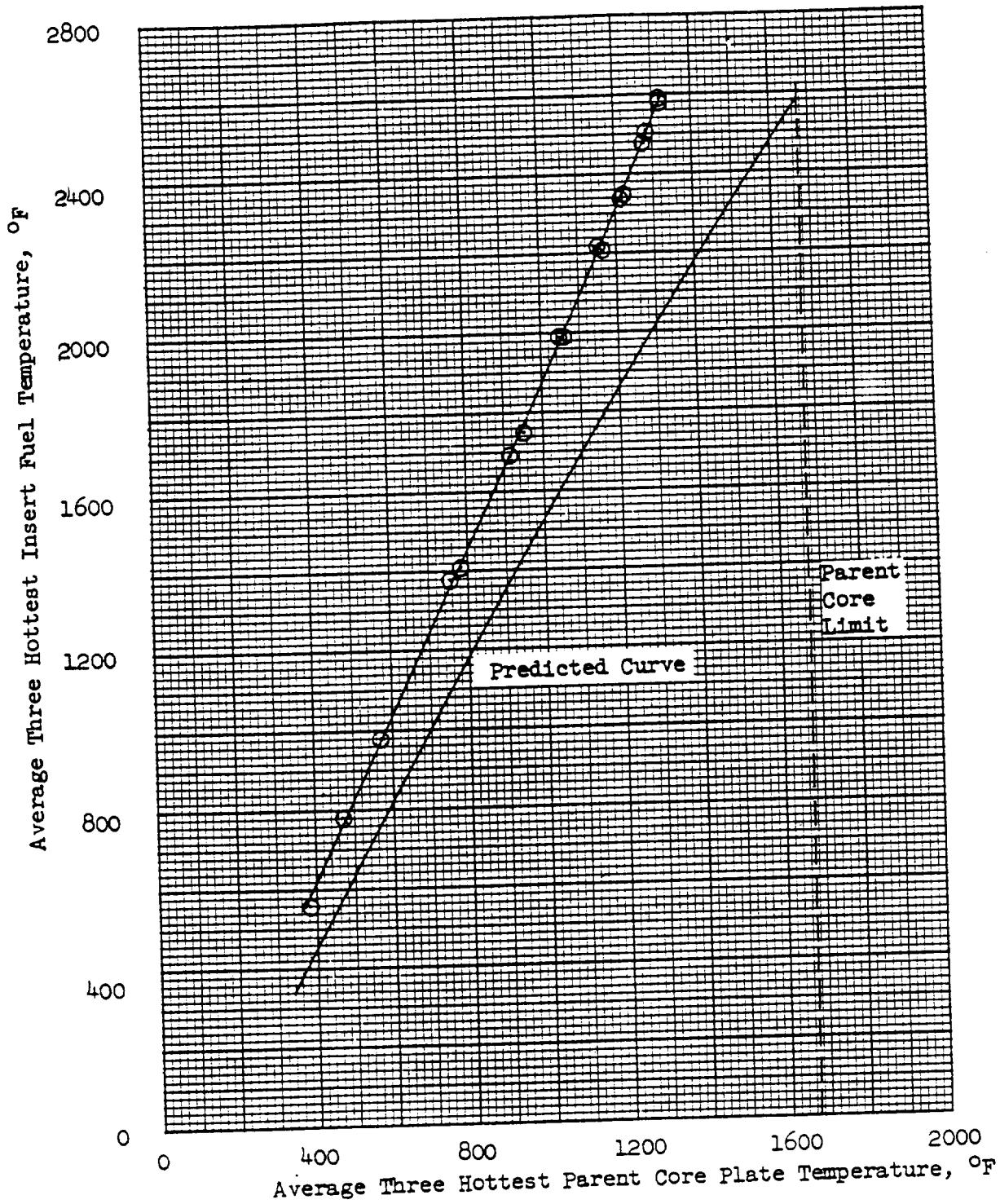


Fig. 1.1-3 - Partially assembled L2E-1 Cartridge (C-15377)

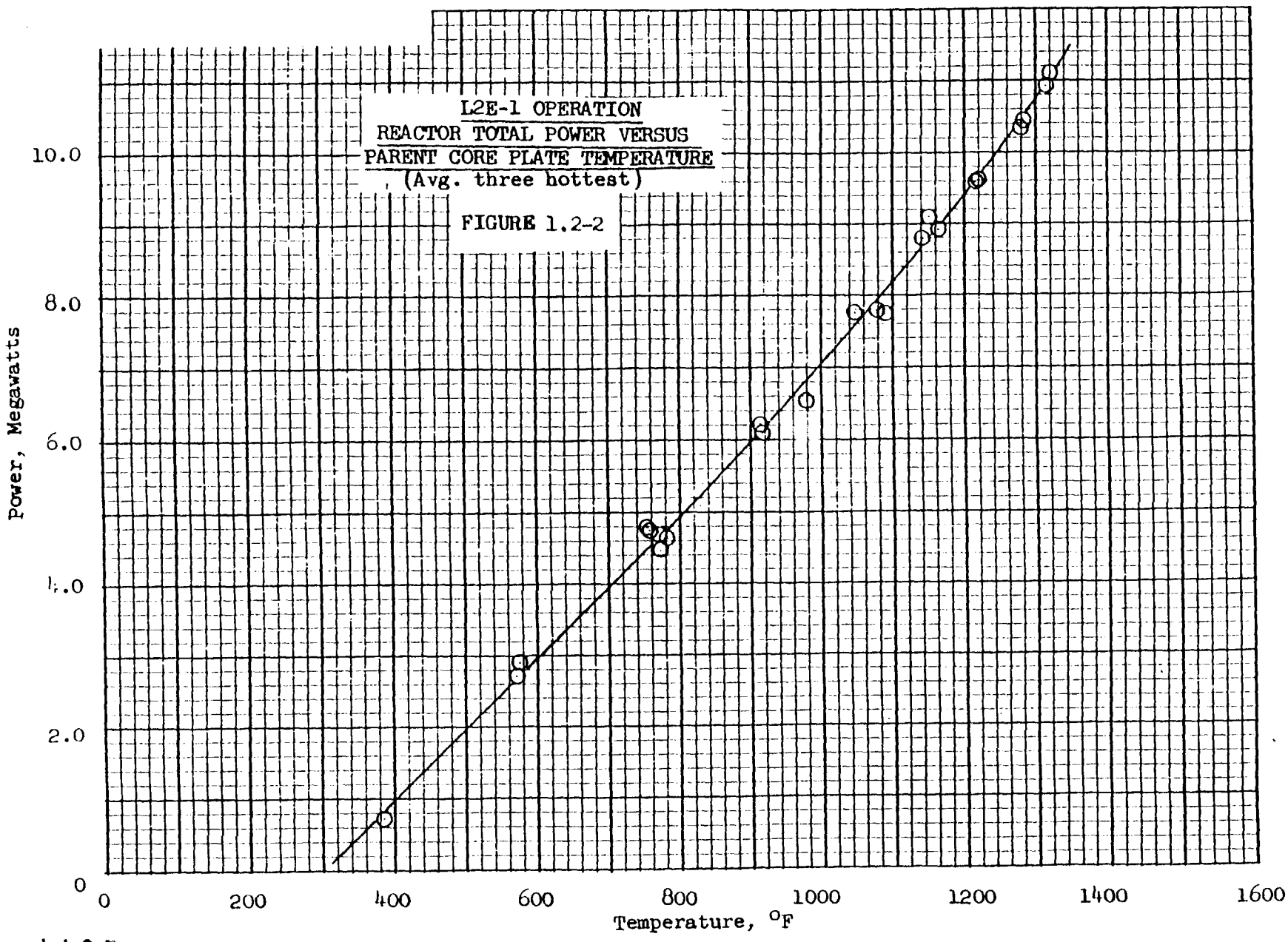
1187104



CARTRIDGE L2E-1
INITIAL POWER INCREASE
TO DESIGN TEMPERATURE

FIGURE 1.2-1

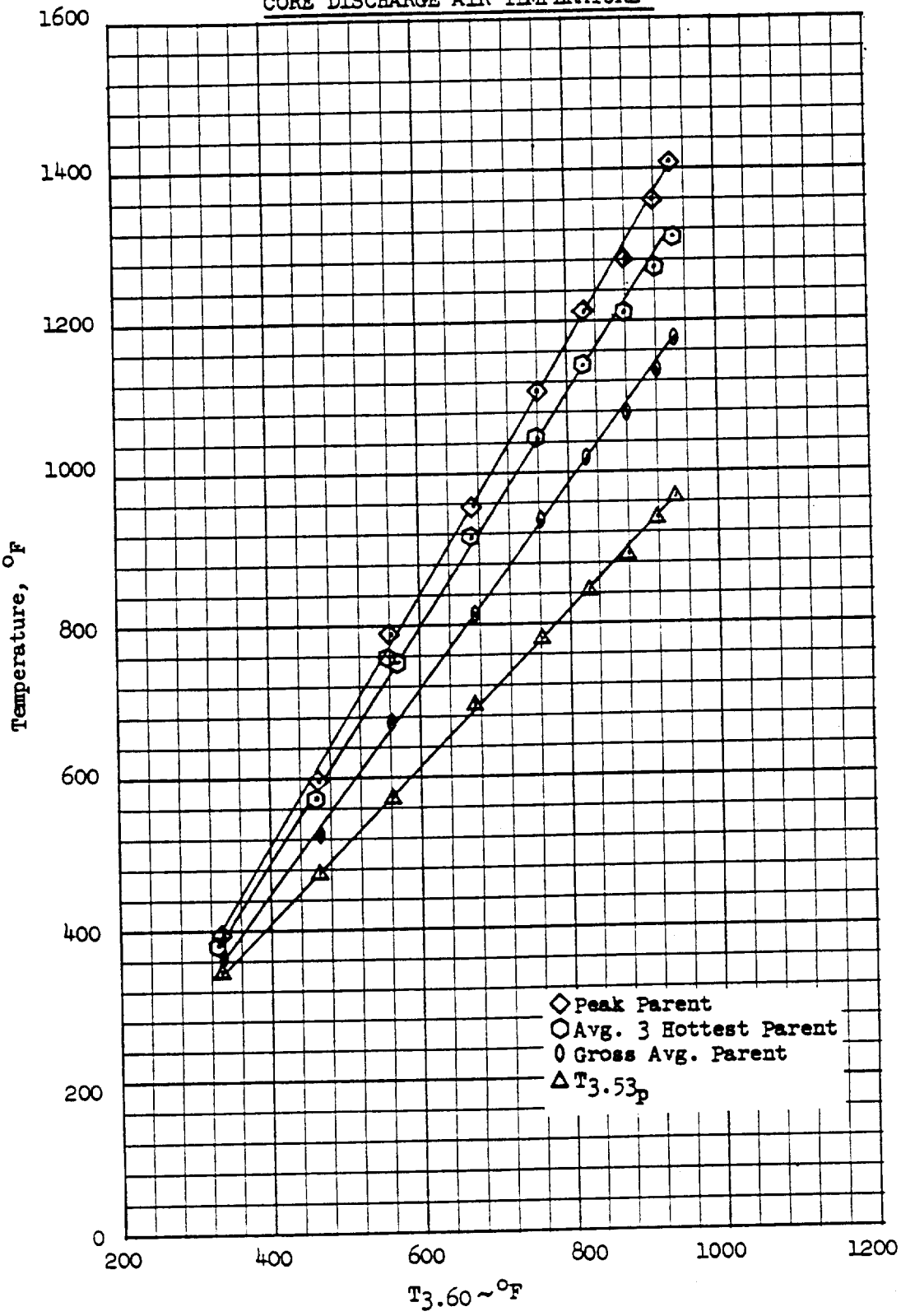
1187105


L2E-1 OPERATION
REACTOR TOTAL POWER VERSUS
PARENT CORE PLATE TEMPERATURE
(Avg. three hottest)
FIGURE 1.2-2
Power, Megawatts
10.0
8.0
6.0
4.0
2.0
0
0
200
400
600
800
1000
1200
1400
1600
Temperature, °F

1187106

FIGURE 1.2-3

L2E-1 CARTRIDGE
COMPOSITE PARENT TEMPERATURES
VERSUS
CORE DISCHARGE AIR TEMPERATURE



GENERAL INSTRUMENTATION AND NOMENCLATURE
OF AIR FLOW - C.T.F.

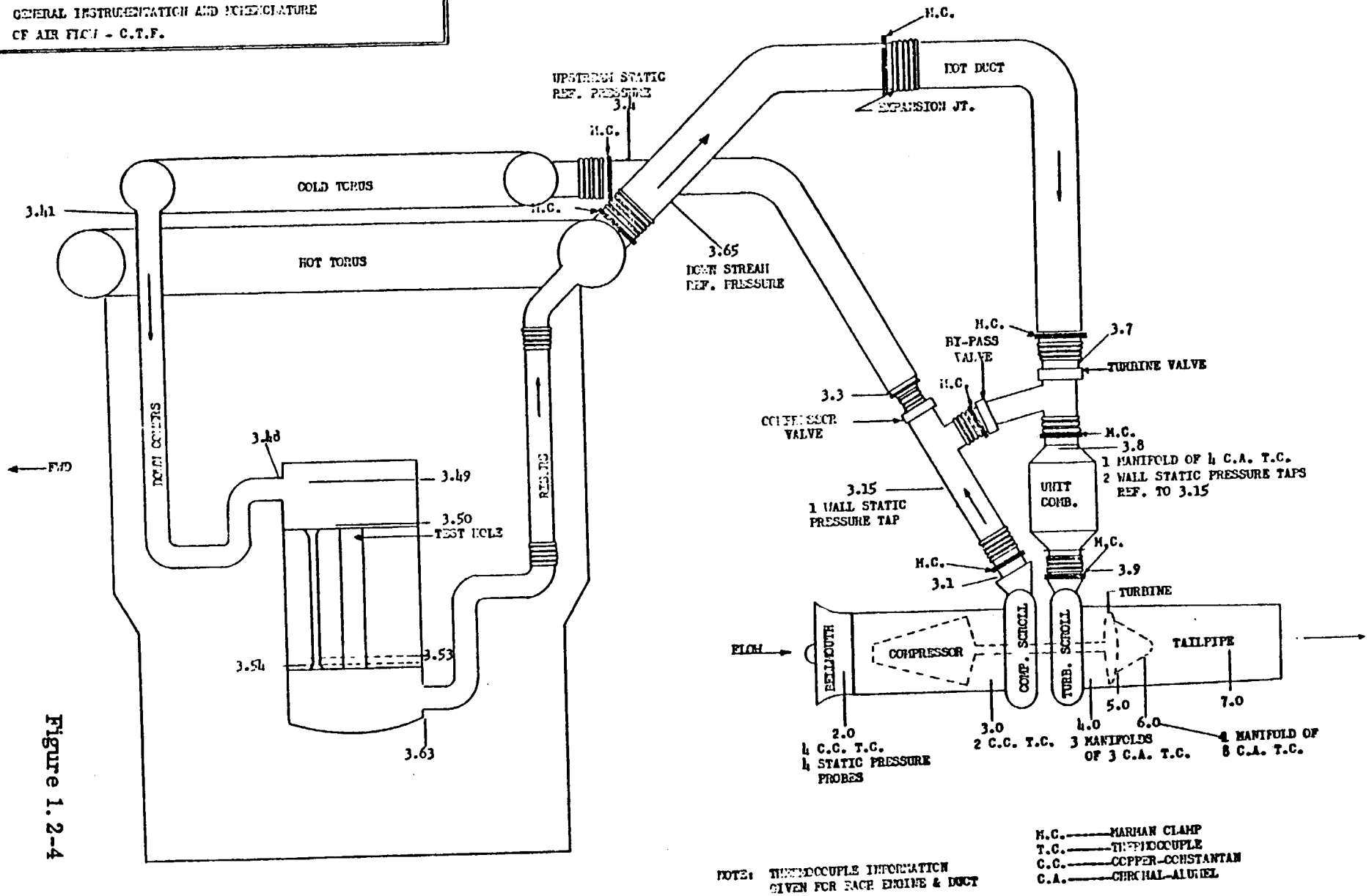


Figure 1.2-4

1187108

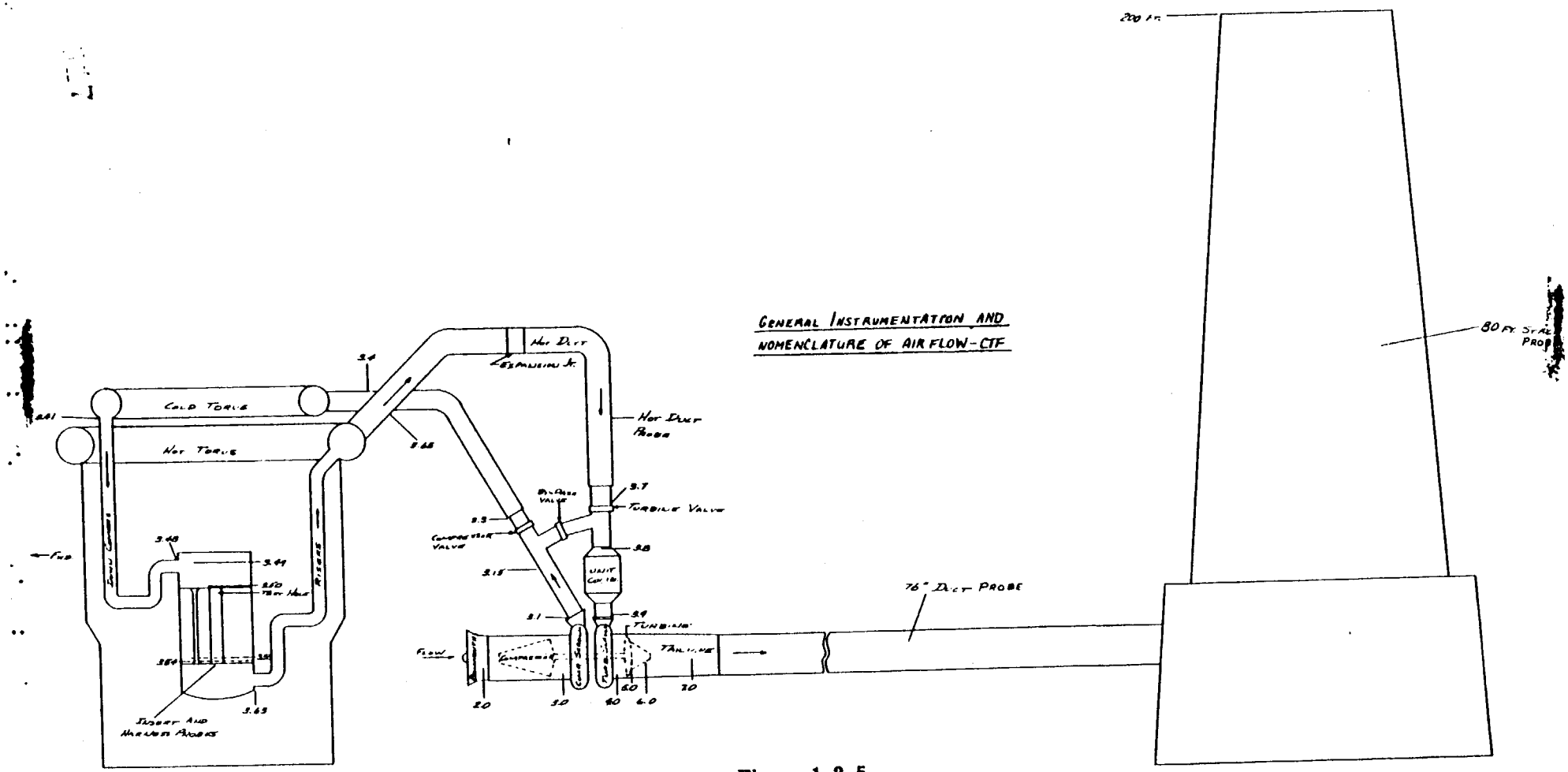


Figure 1.2-5

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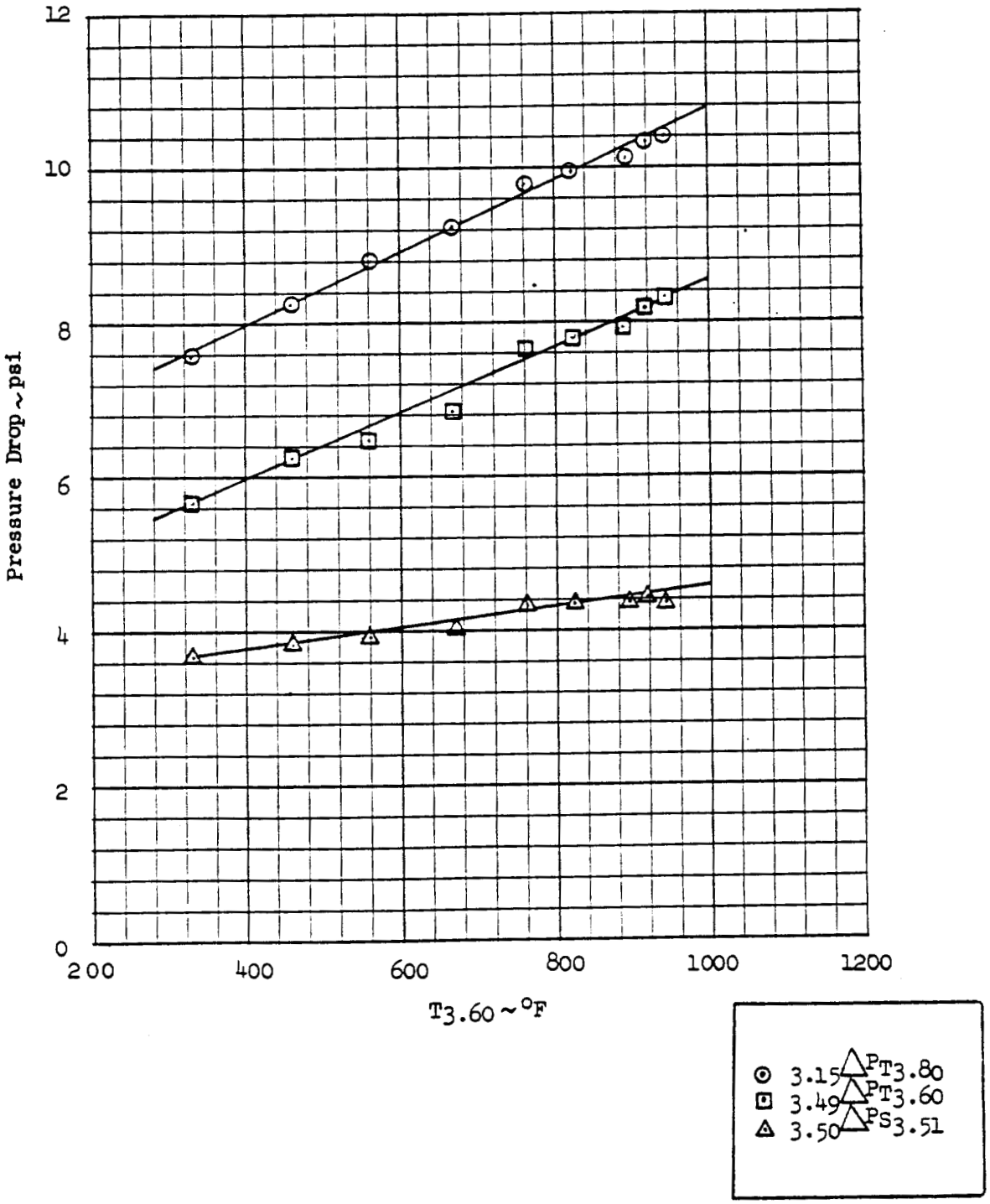
L2E-1 CARTRIDGE
SYSTEM PRESSURE DROP SURVEY
VERSUS
CORE DISCHARGE AIR TEMPERATURE

FIGURE 1.2-6

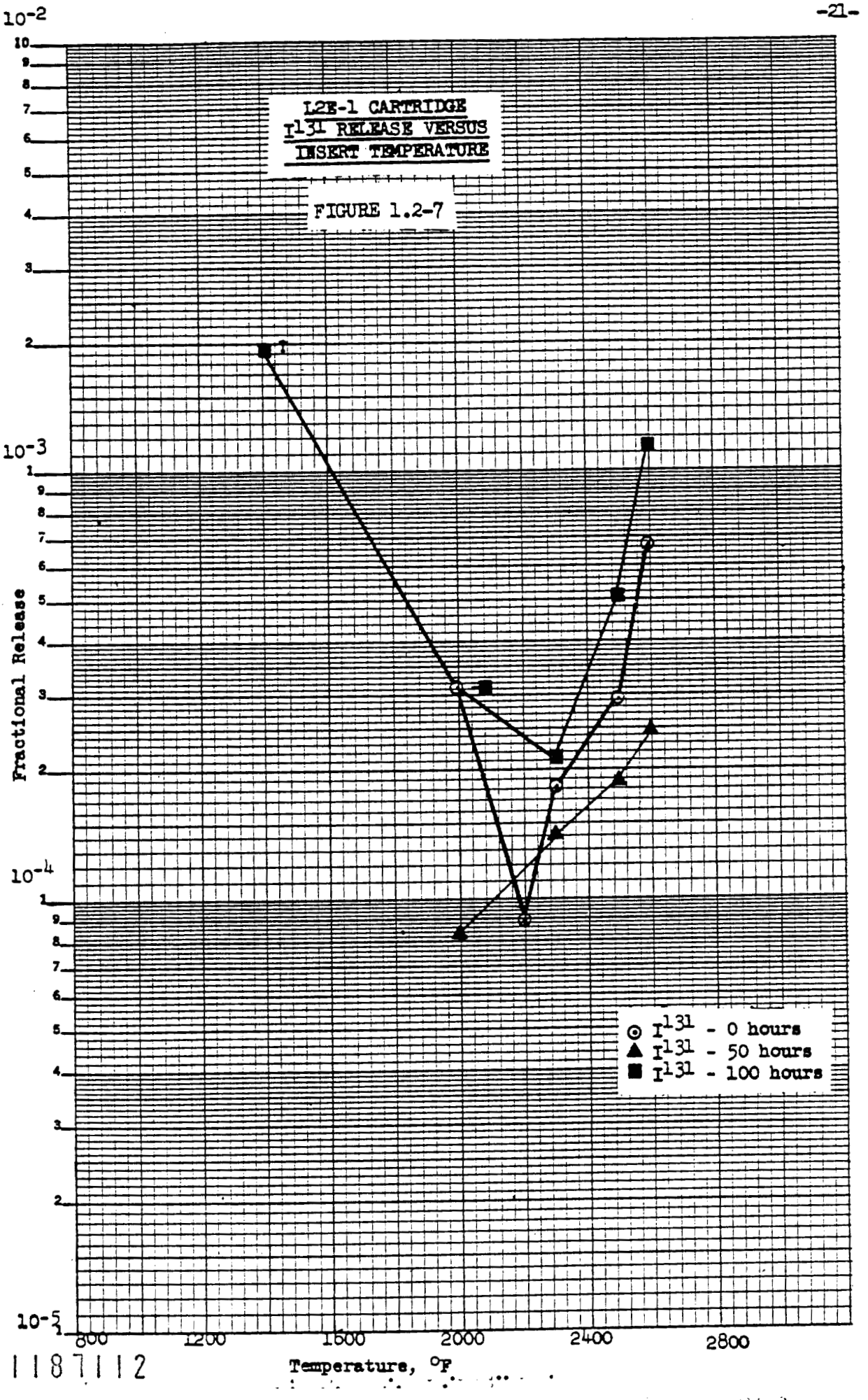


During the initial increase to full power and in subsequent increases to full power (at 50 hours and 100 hours) data were obtained from various stack fission product monitoring stations. These data were collected to determine the effect of temperature on the rate of fission product release. Figures 1.2-7 and 1.2-8 show fractional release data for Iodine 131 and 135 as a function of temperature. These data will receive further discussion in section 1.5. Figure 1.2-9 shows a plot of the gross fission product activity measured at the 80 ft. stack sampling location (see figure 1.2-5 for sampling locations) as a function of total reactor power. On the same graph for comparison purposes data from the L2A-1 and L2C-1 operations are presented. (The L2C-1 data are used as a background for fissions of residual Uranium lodged in the lower cocoon and are subtracted from L2A-1 or L2E-1 values to obtain the net release). It is seen that the net release from the L2E-1 operation is approximately a factor of 3 below that of the L2A-1 operation. This suggests that the (.0015 nominal) Al_2O_3 ID coating is to some extent effective in delaying the release of certain fission products.

In general the results of the increasing power steps were in agreement with predictions. The one exception being the fact that design temperatures were reached at 10.5 MW instead of the predicted 12 MW. This subject will be discussed in section 1.5.

1.3 ENDURANCE TESTING

After the performance characteristics of the insert had been established the operation proceeded to accumulate time on the reactor at the design maximum indicated (thermocouple) temperature of 2515°F. Figures 1.3-1, 2, 3 present the longitudinal temperature distribution, and the radial fuel and air temperature


L2E-1 CARTRIDGE
I131 RELEASE VERSUS
INSERT TEMPERATURE
FIGURE 1.2-7
Fractional Release
Temperature, °F
800
1200
1600
2000
2400
2800
10-2
10-3
10-4
10-5
I131 - 0 hours
I131 - 50 hours
I131 - 100 hours

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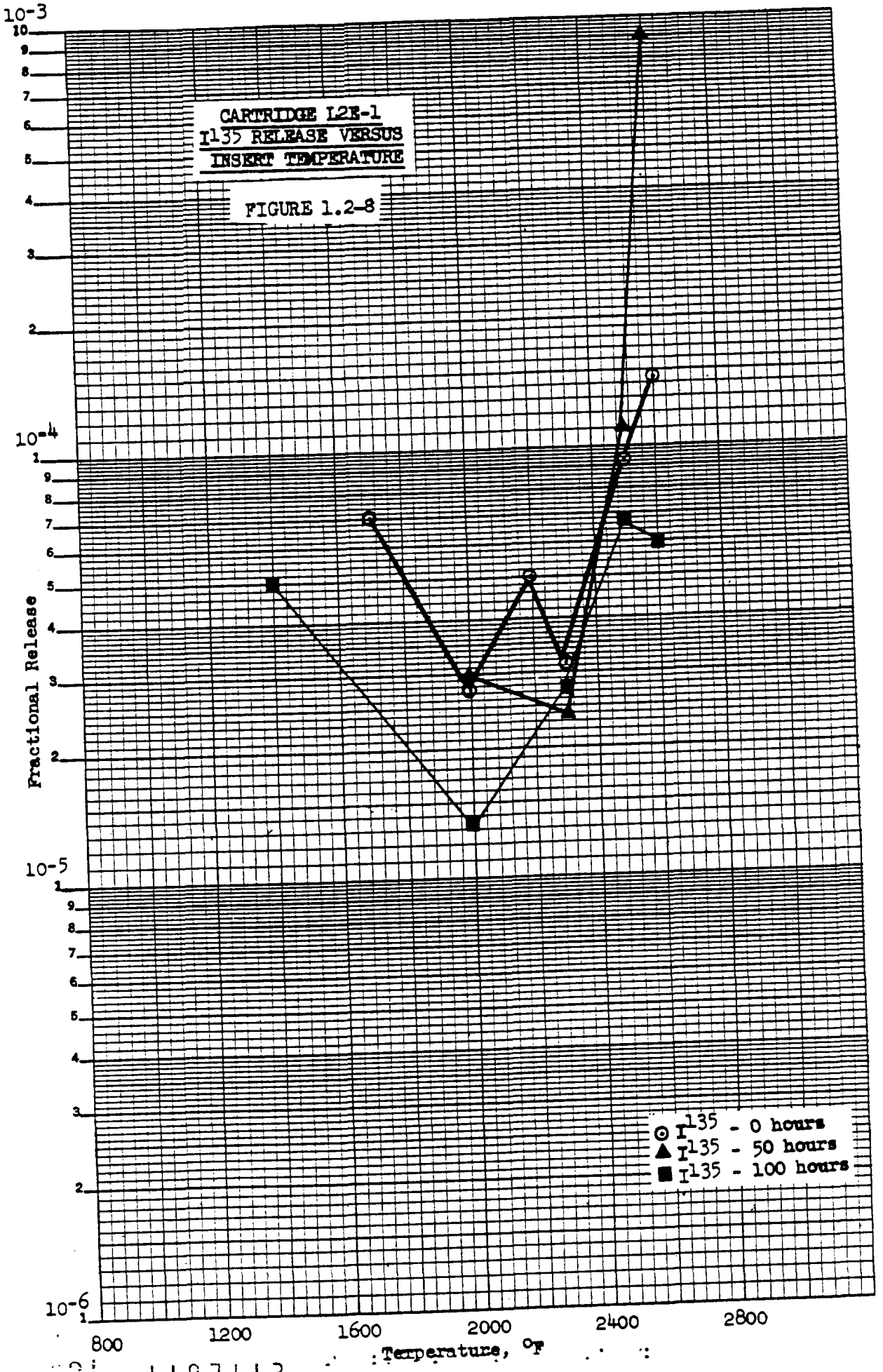
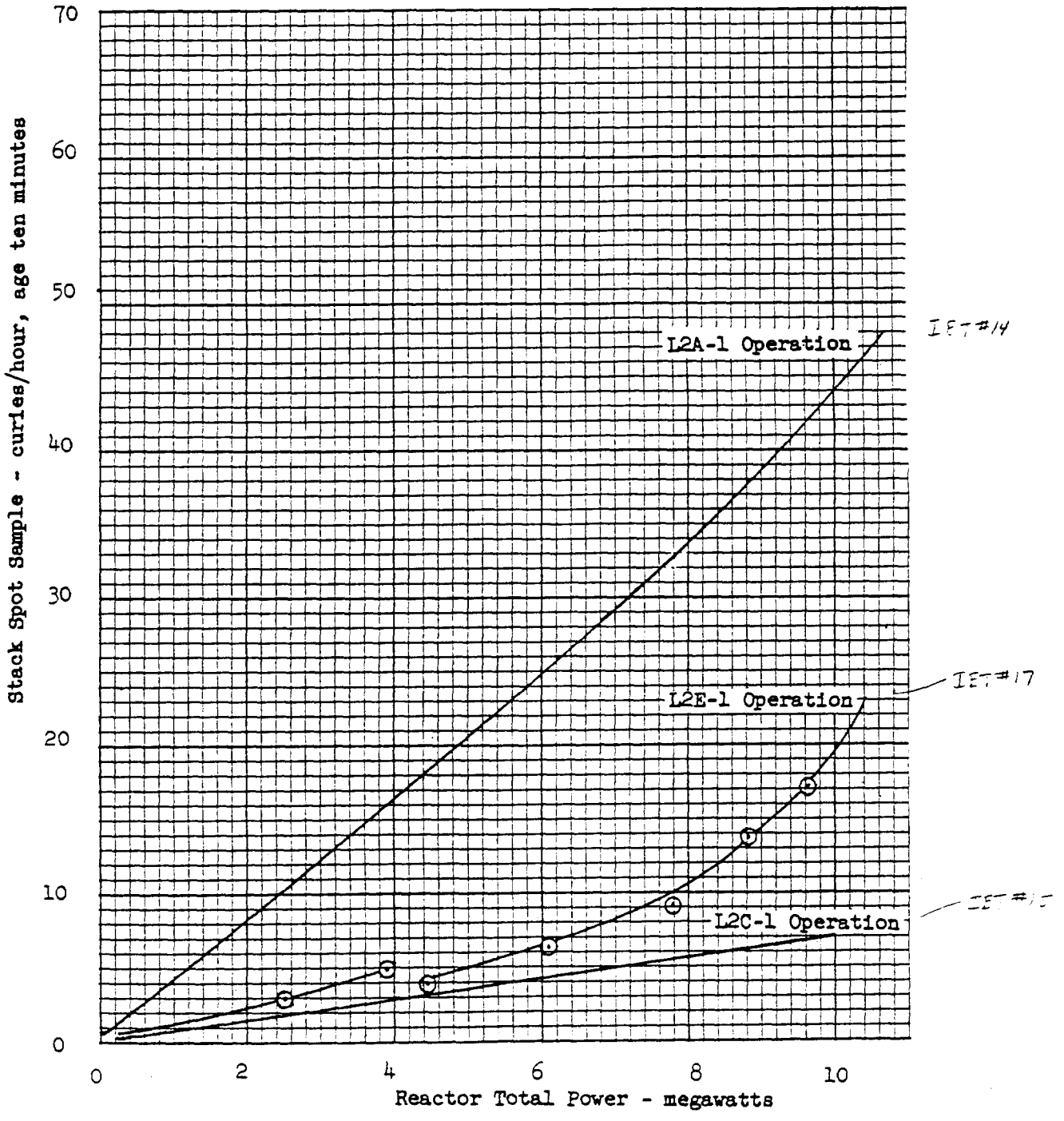

CARTRIDGE L2E-1
I135 RELEASE VERSUS
INSERT TEMPERATURE
FIGURE 1.2-8
Fractional Release
10-3
10-4
10-5
10-6
800
1200
1600
2000
2400
2800
Temperature, °F
I135 - 0 hours
I135 - 50 hours
I135 - 100 hours

FIGURE 1.2-9

STACK SPOT SAMPLE RELEASE VS.

REACTOR TOTAL POWER



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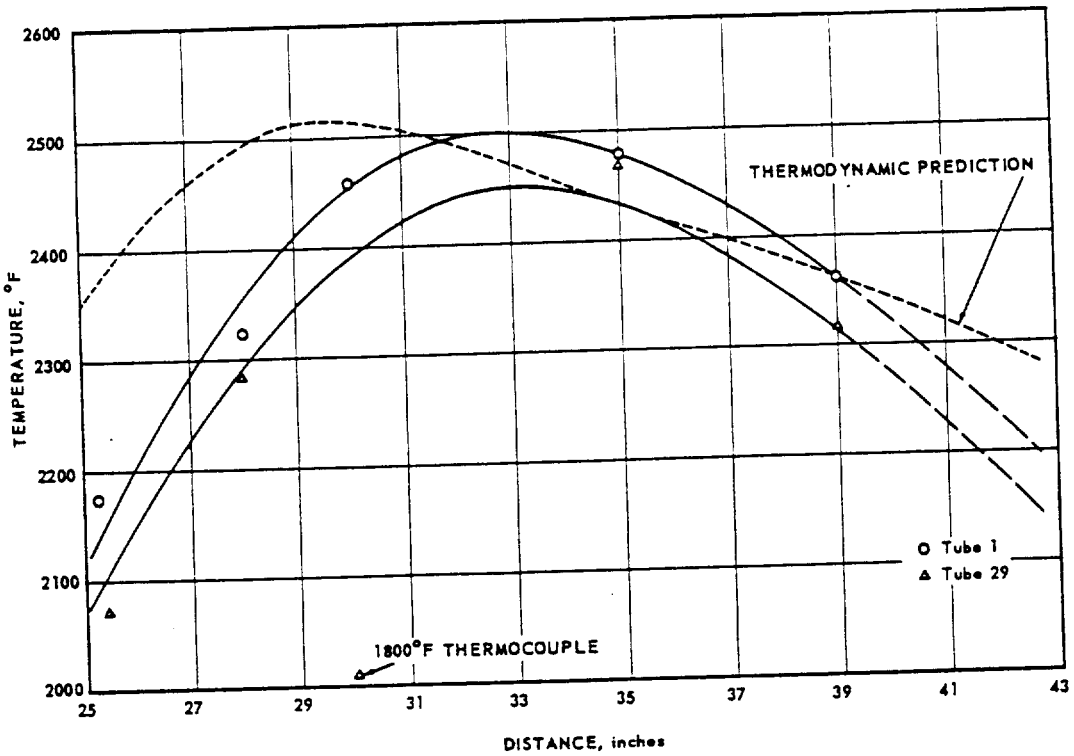


Figure 1.3-1 – Cartridge L2E-1 longitudinal temperature profile – 10.4 megawatts

[redacted]

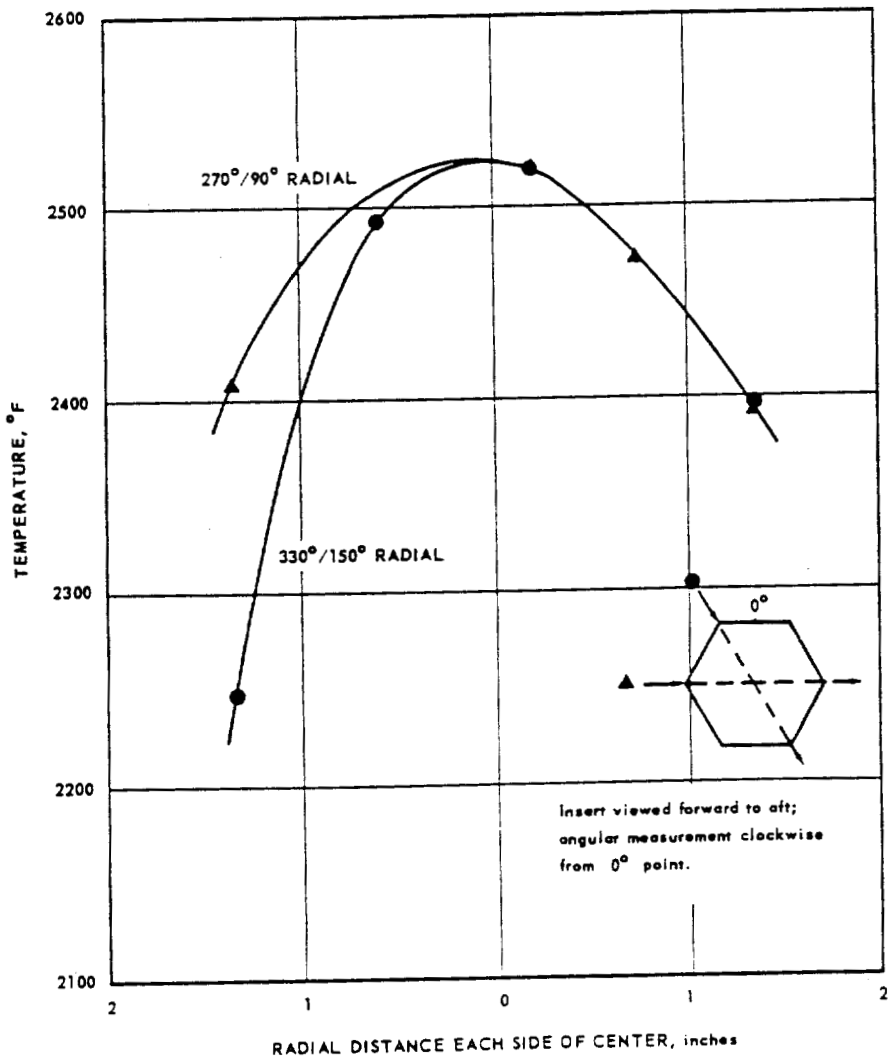
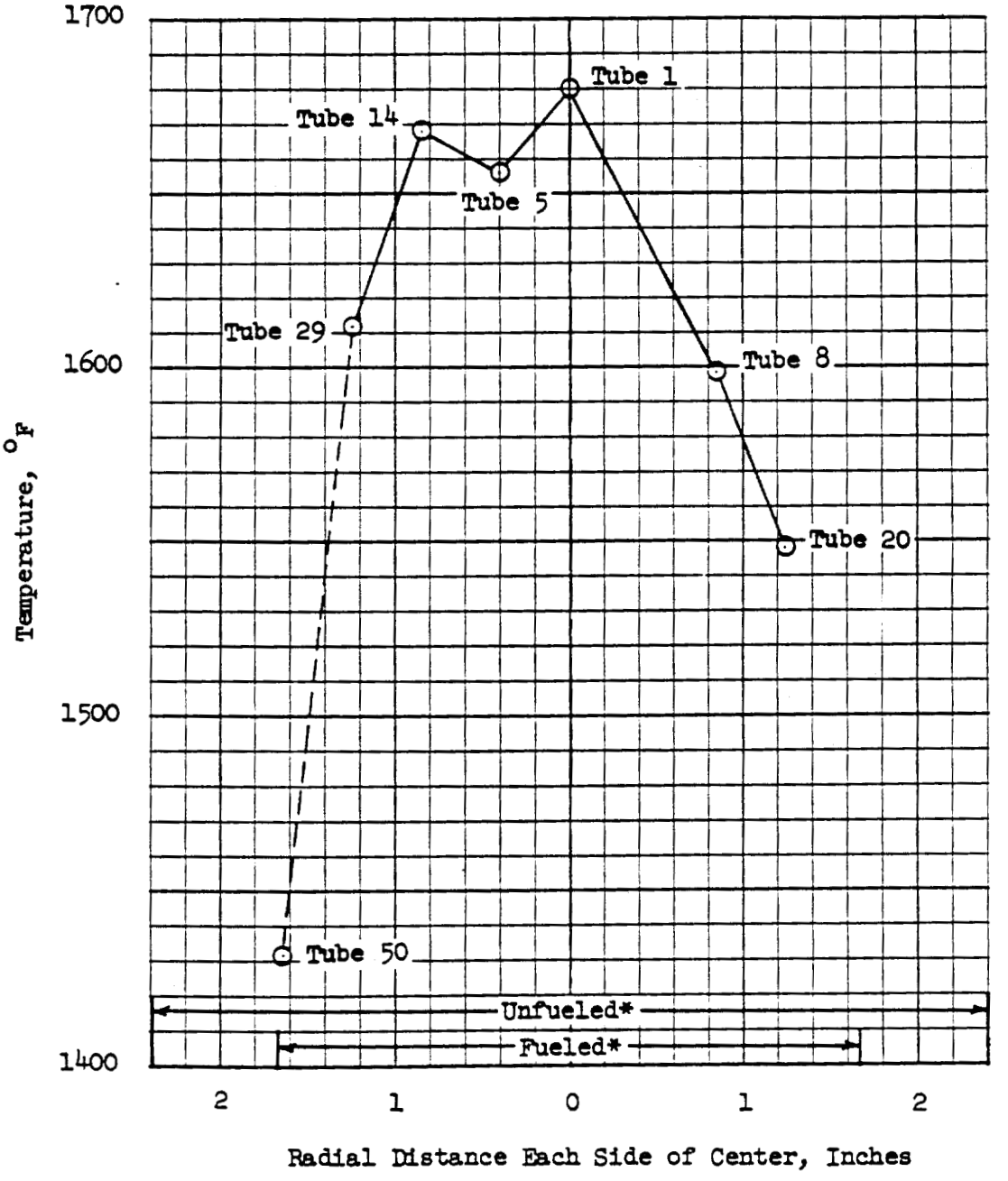


Figure 1.3-2 - Cartridge L2E-1 radial fuel temperature profile – 10.4 megawatts, 45.5 hours on test

FIGURE 1.3-3

CARTRIDGE L2E-1
RADIAL EXIT AIR TEMPERATURE PROFILE
10.4 MW (FULL POWER)



* Across corners dimension

distribution (on the ~~longitudinal~~ temperature graph is also plotted the predicted distribution). These distributions will receive further discussion in section 1.5.

The endurance testing proceeded without unusual incidents. Tables 1.3-1 and 2 present the operating history and a correlation of run numbers with dates.

Figures 1.3-4 shows a composit of total reactor power, insert maximum fuel tube temperatures, insert maximum air temperature and $T_{3.65}$ (reactor discharge air temperature) for the 106 hours of testing. Figure 1.3-5 shows a composit of total engine weight flow and insert weight flow. Figure 1.3-6 presents plots of performance check point parameters (points occuring throughout the endurance testing at which conditions were the same as or very near to those of the first on test data) as a function time. These data were recorded to determine if initially recorded parameters were varying as the test progressed.

Apendix II presents a complete thermocouple temperature history.

1.4 POST OPERATIONAL EXAMINATION

At the conclusion of 106 hours of endurance testing the reactor was returned to the hot shop where the insert was removed and examined. See figure 1.4-1 showing removal of this cartridge from the L2 insert "can". Visual examination of the cart ridge assembly immediately after removal showed the structure to be in excellent condition. Thermocolor paints and tapes applied to the outside of the insulation liner support tube were clearly visible (color changes will be discussed in sectior 1.5). See figure 1.4-2. The cartridge was then removed to the RML where half of the insulation liner was removed and the fuel tubes examined.

TABLE 1.3-1

IET ACCUMULATIVE POWER HOURS

TEST IET No. 17 — CORE D101-L2E-1 — DATE AND TIME BEGIN F.P. INVENTORY 7/24/57-000

Date 1959	Time End Day's Oper.	*Hrs. Above 1% This Date	*Hrs. Above 1% Accum.	Megawatt Hours This Date	Megawatt Hours Accum.	This Date Avg. Mw	This Date Max. Mw	Hrs. Full Nucl. This Date	Hrs. Full Nucl. Accum.	**Hrs on Test This Date	**Hrs on Test Accum.	Engine #5017 Hrs. This Date	Engine #5017 Accum.	Engine #5028 Hrs. This Date	Engine #5028 Accum.	Number of Days Above 1%
				--- 28 of the 30 parent fuel elements were also used for IET #8, 10, 11, 12, 14, and 15 and during these tests the reactor was above 1% ---												102
						Total accumulative hours since engine overhaul							34.68		20.27	
												0.43	35.11	0.48	20.75	
10-21		-						-		-		-		0.53	21.28	
10-23		-						-		-		-		1.90	23.18	
10-26		-						-		-		-		5.72	28.90	
10-27		-						-		-		4.83	39.94	-		
10-28		-						-		-		4.63	44.57	0.28	29.18	
10-29		-						-		-		3.63	48.20	-		
10-30		-						-		-		10.50	58.70	-		103
11-2	2006	0.60	0.60	0.06	0.06	0.10	0.10	-		-		9.55	68.25	-		104
11-3	2229	1.88	2.48	4.06	4.12	2.16	2.90	-		-		5.80	74.05	-		105
11-4	2010	1.25	3.73	5.91	10.03	4.73	5.00	-		-		6.01	80.06	-		106
11-5	2243	2.35	6.08	10.73	20.76	4.57	4.94	-		-		7.16	87.22	-		107
11-6	2318	2.65	8.73	11.37	32.13	4.29	4.77	-		-		6.83	94.05	-		108
11-9	2315	4.23	12.96	18.63	50.76	4.40	4.65	-		0.30	0.30	7.67	101.72	-		109
11-10	2159	2.92	15.88	20.99	71.75	7.19	10.46	-		-		10.23	111.95	-		110
11-11	[redacted]322	3.12	19.00	19.82	91.57	6.35	8.92	-		2.85	3.15	8.80	120.75	-		111
11-12	[redacted]243	4.52	23.52	42.68	134.25	9.44	11.10	-		2.70	5.85	10.15	130.90	-		112
11-13	[redacted]316	3.66	27.18	34.29	168.54	9.37	10.76	-		10.50	16.35	13.37	144.27	-		113
11-16	[redacted]313	11.40	38.58	116.97	285.51	10.26	10.58	-		8.18	24.53	-		13.78	42.96	114
11-17	2245	9.55	48.13	99.24	384.75	10.39	11.27	-		1.35	25.88	7.92	152.19	-		115
11-18	2312	2.47	50.60	21.41	406.16	8.68	10.38	-		7.20	33.08	11.58	163.77	-		116
11-19	2253	8.47	59.07	85.31	491.47	10.08	10.85	-		1.62	34.70	10.17	173.94	-		117
11-20	2123	2.23	61.30	18.35	509.82	8.23	10.55	-		1.12	35.82	6.83	180.77	-		118
11-23	2256	1.93	63.23	17.29	527.11	8.96	11.06	-		5.07	40.89	9.33	190.10	-		119
11-24	2259	6.03	69.26	60.10	587.21	9.97	10.78	-		9.17	50.06	12.78	202.88	-		120
11-25	2303	10.30	79.56	104.62	691.83	10.16	10.82	-		3.08	53.14	14.78	217.66	-		121
11-30	2259	9.73	89.29	83.35	775.18	8.57	11.26	-		6.37	59.51	12.68	230.34	-		122
12-1	2253	8.02	97.31	77.20	852.38	9.63	10.87	-		6.78	66.29	11.38	241.72	-		123
12-2	2159	8.08	105.39	81.09	933.47	10.04	10.99	-		9.95	76.24	13.90	255.62	-		124
12-3	2305	11.17	116.56	115.66	1049.13	10.35	11.02	-		4.37	80.61	10.32	265.94	-		125
12-4	2307	5.68	122.24	55.16	1104.29	9.71	10.88	-		5.15	85.76	12.75	278.69	-		126
12-7	2303	6.87	129.11	66.31	1170.60	9.65	10.86	-		3.63	89.39	11.72	290.41	-		127
12-8	2213	5.72	134.83	53.02	1223.62	9.27	10.79	-		5.15	94.54	10.93	301.34	-		128
12-9	2400	5.80	140.63	59.23	1282.85	10.21	10.82	-		8.40	102.94	20.40	321.74	-		129
12-10	1217	11.87	152.50	107.05	1389.90	9.02	11.21	-		1.87	104.81	21.65	343.39	-		130
12-11	1757	8.93	161.43	75.64	1465.54	8.47	11.84	-		1.18	105.99	17.77	361.16	-		131
12-12	2255	3.00	164.43	26.08	1491.62	8.69	11.26	-								

--- End IET #17 ---

*1% = 100 kilowatts **On-Test Conditions: 2515°F max indicated insert fuel element temperature with 58.0 ± 0.5 #/sec air flow.
Beginning 11/12 - 825°F ± 5°F #1 $T_{3.65}$ air with 58.0 ± 0.5 #/sec air flow.
Beginning 11/17 - 862°F ± 5°F #2 $T_{3.65}$ air with 58.0 ± 0.5 #/sec air flow.
On 11/19 held 2515°F ± 10°F max insert fuel element to plot $T_{3.65}$ vs T_2, with 58.0 ± 0.5 #/sec air flow.
Beginning 11/20 - $T_{3.65}$ determined by T_2 58.0 ± 0.5 #/sec air flow.

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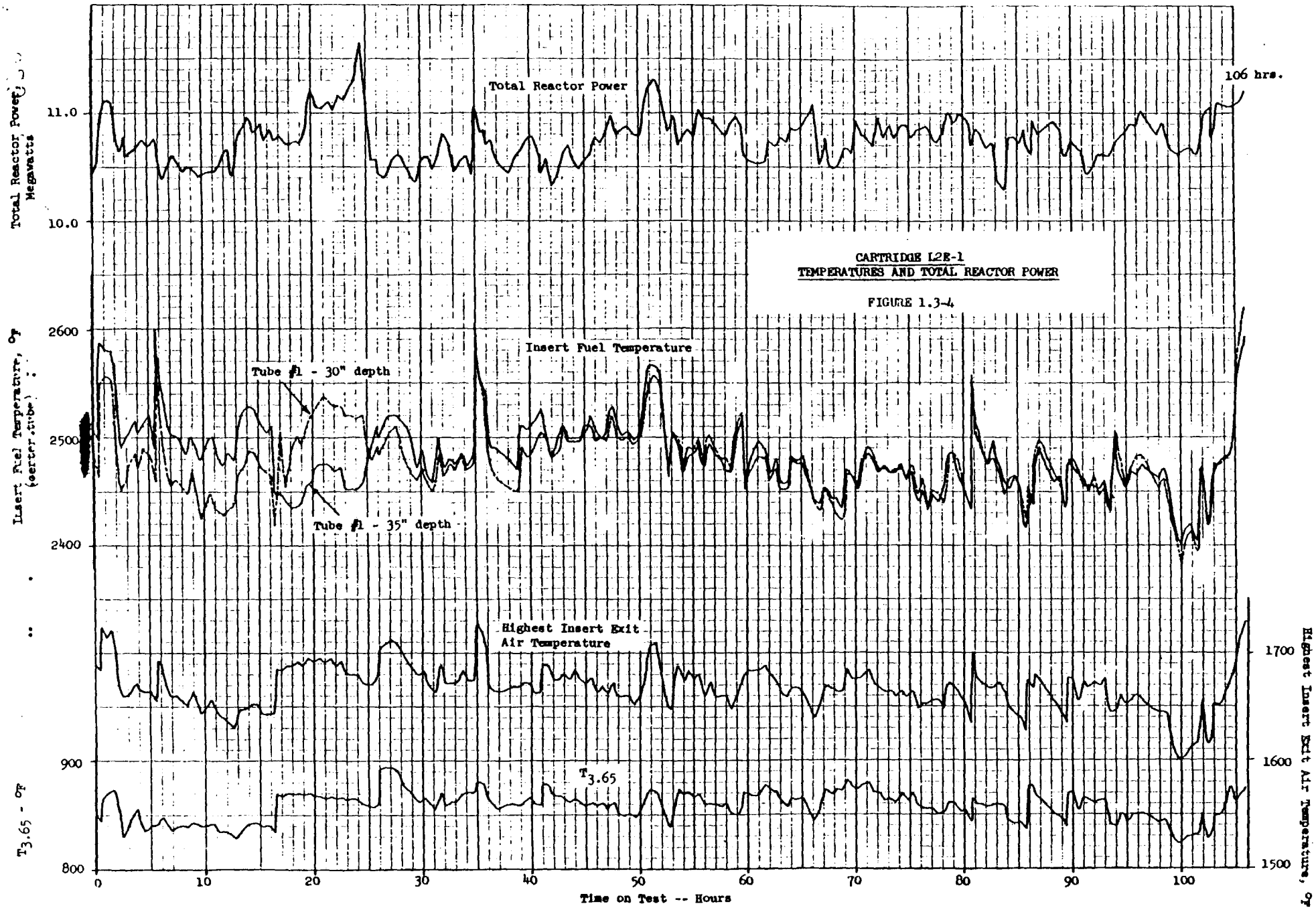
[redacted]

TABLE 1.3-2

LOG OF TIME ON TEST

RUN #	DATE	TIME ON TEST	ACCUMULATED TIME ON TEST
1-18	11-12	2.88	2.88
1-19	11-13	2.70	5.58
1-20	11-16	10.77	16.35
1-21	11-17	8.18	24.53
1-22	11-18	1.35	25.88
1-23	11-19	7.20	33.08
1-24	11-20	1.62	34.70
1-25	11-23	1.12	35.82
1-26	11-24	5.07	40.89
1-27	11-25	9.17	50.06
1-28	11-30	3.08	53.14
1-29	12-1	6.37	59.51
1-30	12-2	6.78	66.29
1-31	12-3	9.95	76.24
1-32	12-4	4.37	80.61
1-33	12-7	5.15	85.76
1-34	12-8	3.63	89.39
1-35	12-9	5.15	94.54
1-35	12-10	8.40	102.94
1-36	12-11	1.87	104.81
1-38	12-12	1.18	105.99



CARTRIDGE L2E-1
TEMPERATURES AND TOTAL REACTOR POWER

FIGURE 1.3-4

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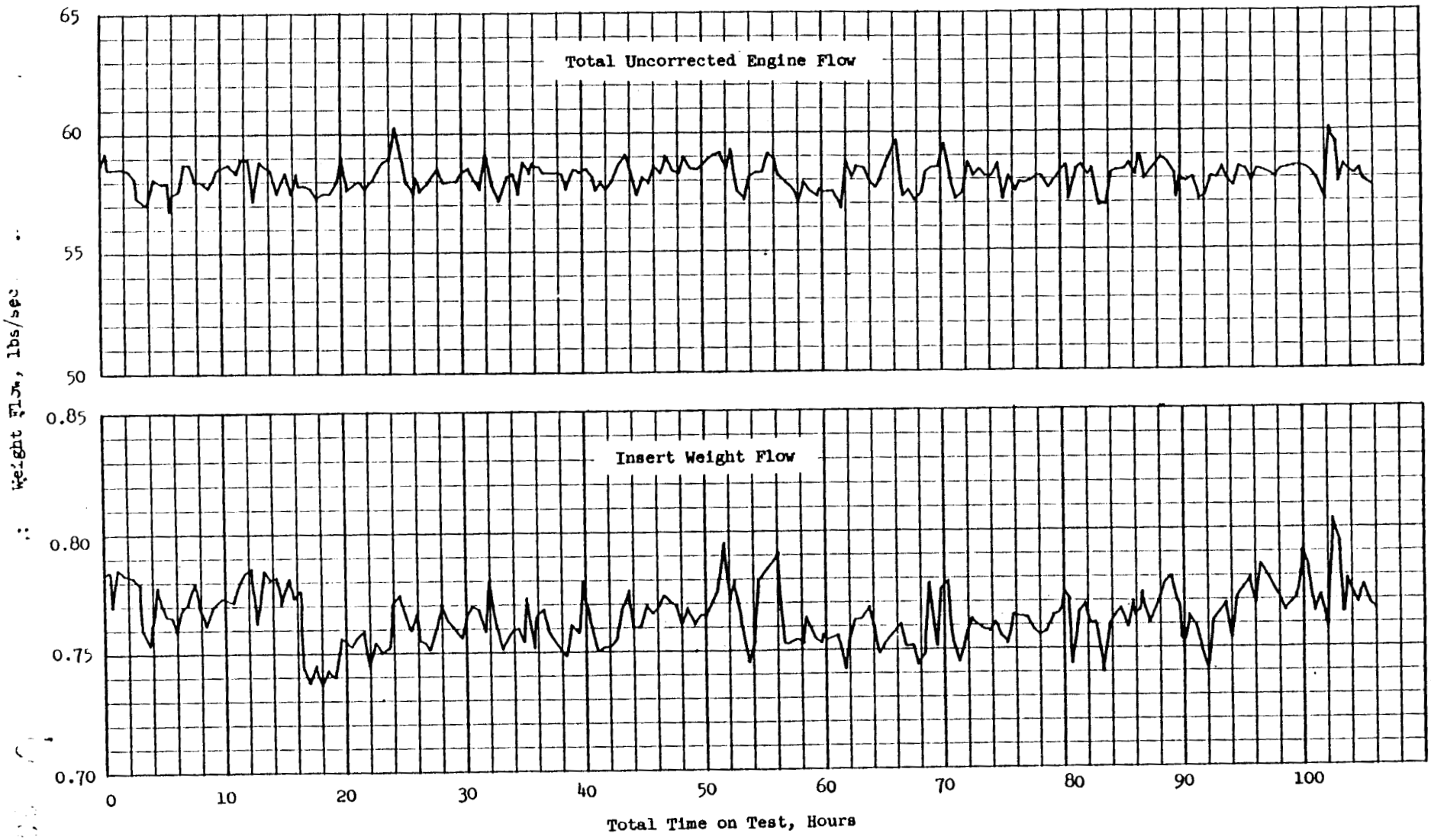


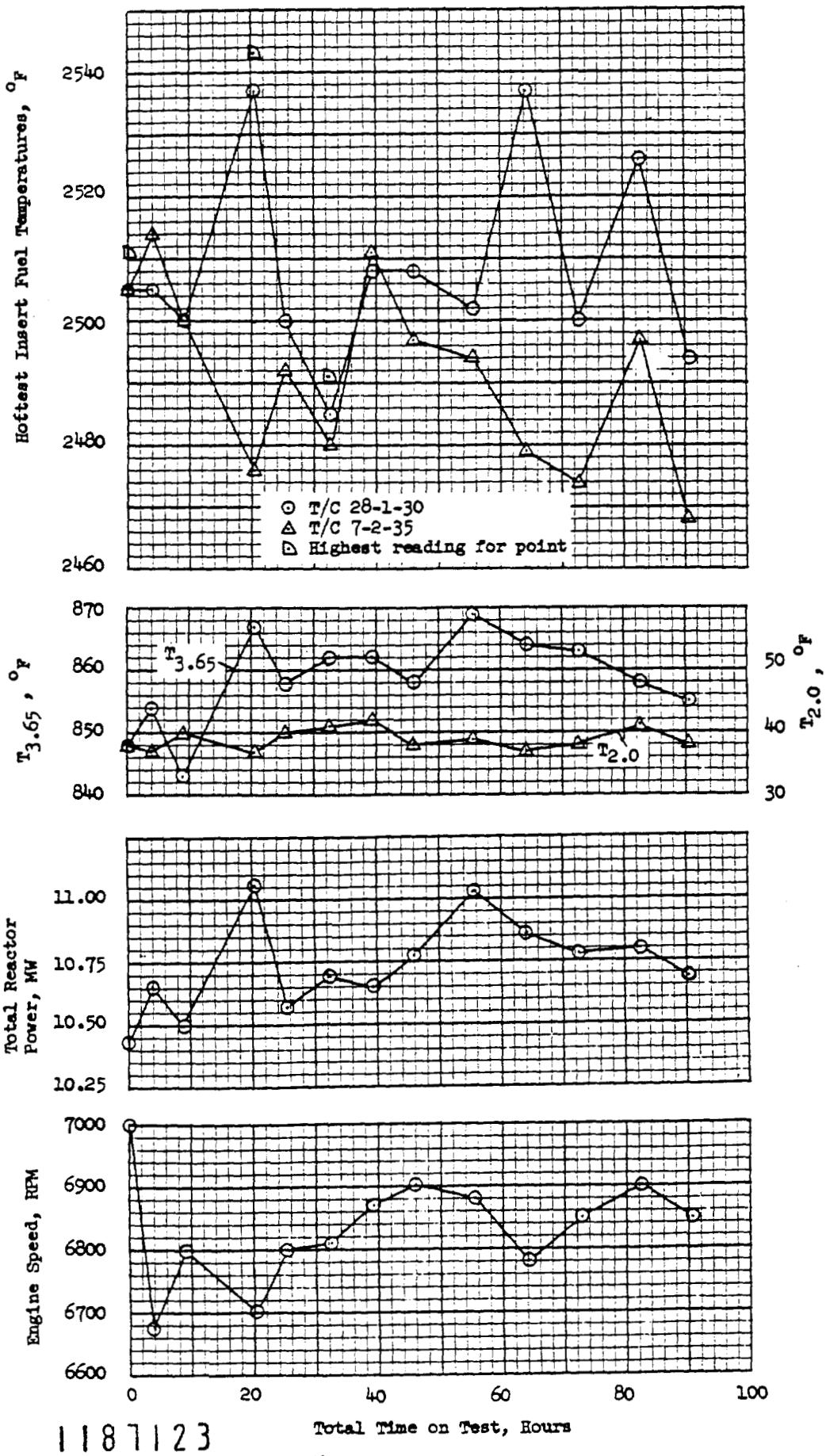
CARTRIDGE L2E-1
WEIGHT FLOWS
FIGURE 1.3-5

1187122

FIGURE 1.3-6

CARTRIDGE L2E-1

PERFORMANCE CHECK-POINT PARAMETERS



1187123

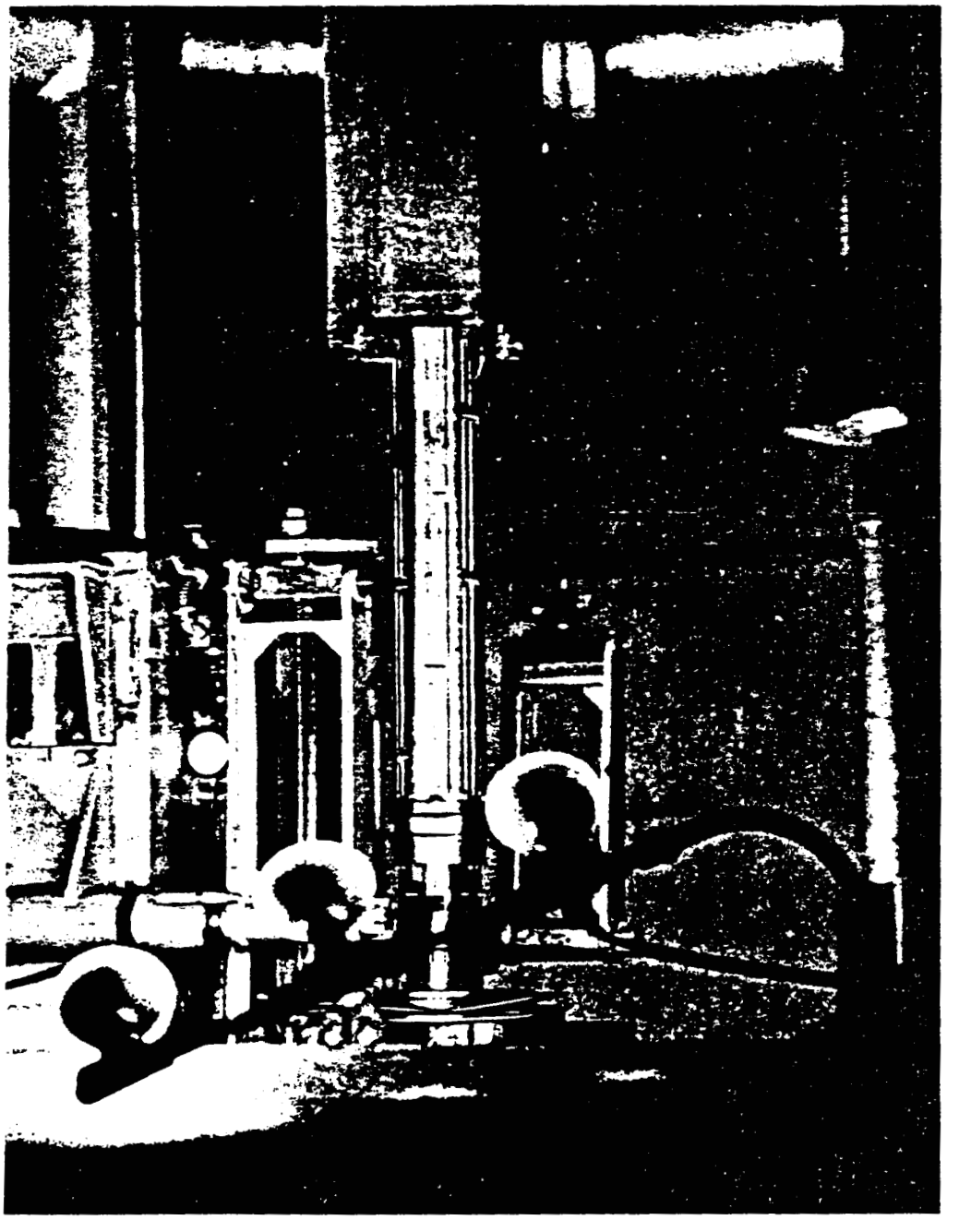


Fig. 1.4-1 - L2E-1 Insert Cartridge After Test (C-15540)

1187124

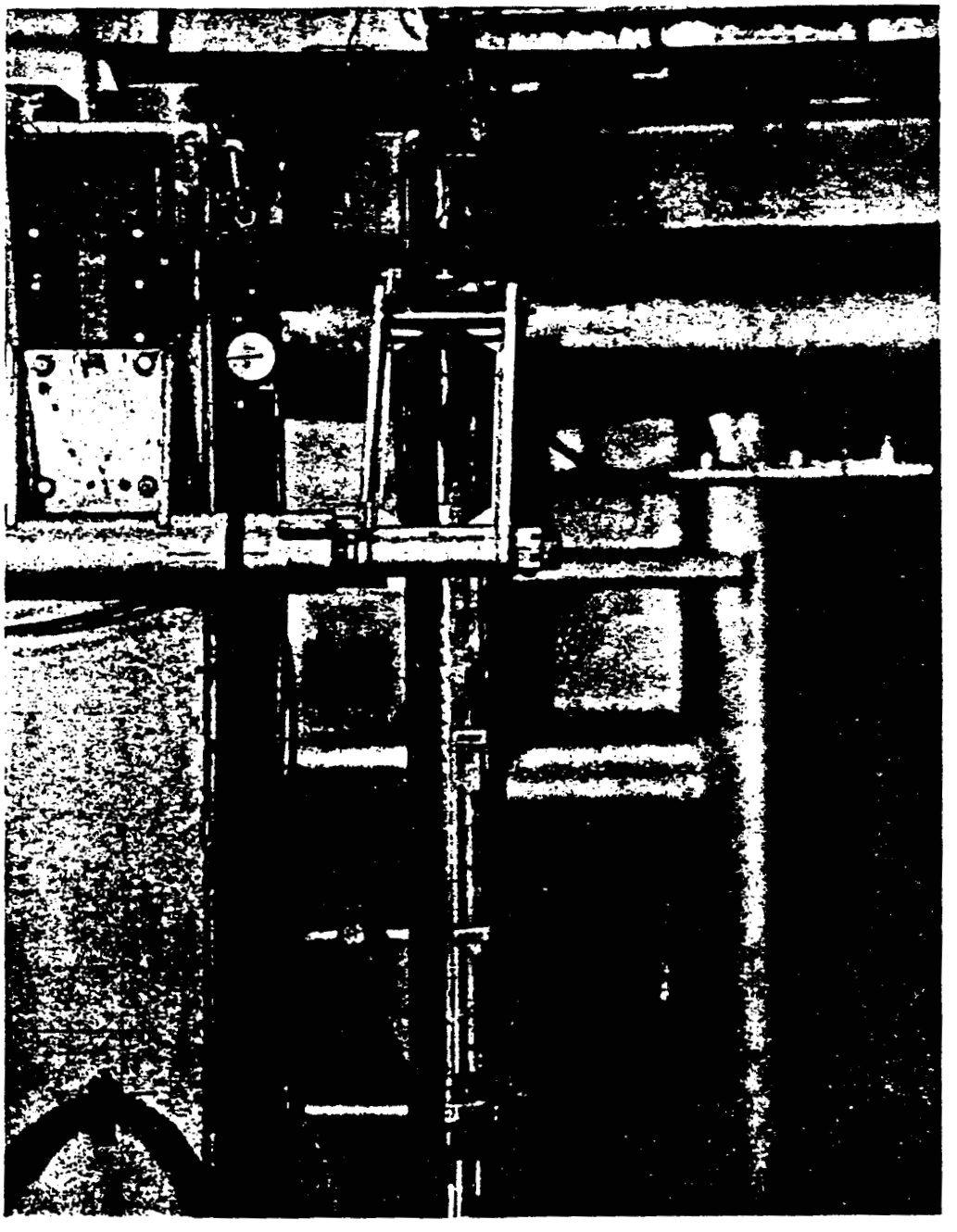


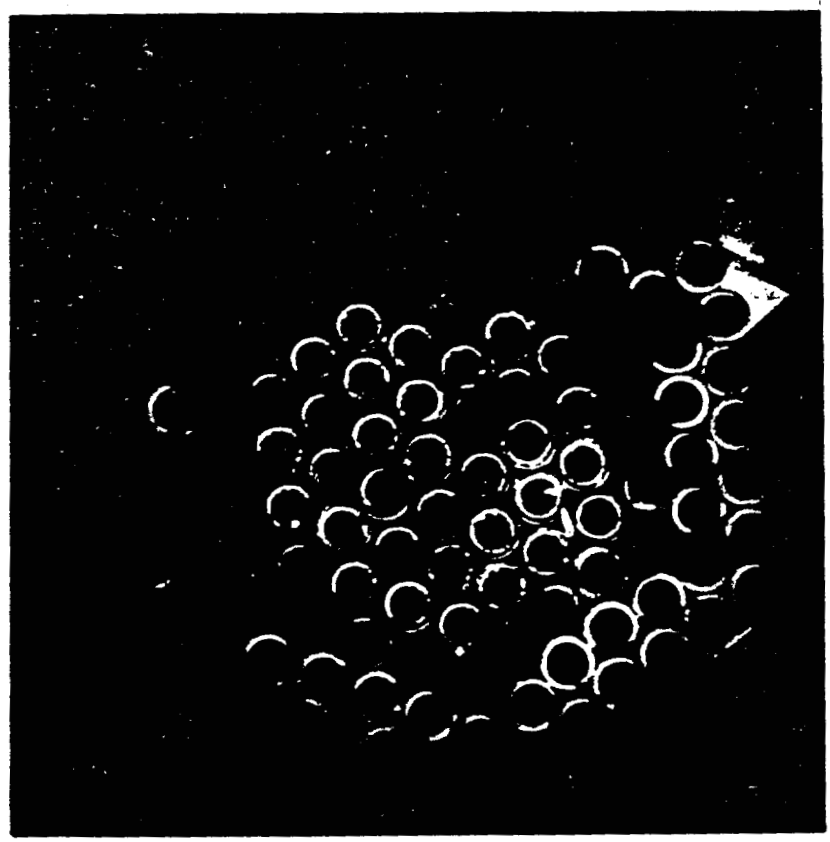
Fig. 1.4-2 - L2E-1 Insulation Liner Support Tube After Test (C-15542)

1187125

A general visual examination (through the RML periscope) of the fueled tubes showed no crystal growths or white powder (BeO) deposits. Some of the tube ends had a whitish appearance but this was attributed to the extrusion process. Figures 1.4-3 and 1.4-4 show photographs of the L2E-1 stages along side of which are placed photographs of the L2A-1 tubes for comparison. The inside diameter of some of the tubes appeared to be rougher than others with variations in the degree of blackness also being noted. The outside surface of some of the tubes was streaked with a substance having a tan color. The presence of these streaks suggests flow down the interstices and possibly across the edges. The occurance of the streaks will be investigated in more detail in particular as to orientation and location with respect to instrumentation. After the general visual examination had been completed and the tubes had been weighed selected fueled tubes were bisected and the inside surfaces observed under high magnification. This examination showed three types of deposit or formation on the tube ID's.

1. Crystal growths having a hairlike appearance ranging in height from 0.5 mils to 2.5 mils and occurring in a more or less random distribution in the tubes examined with no preference for hot region location or for tube ends. See figures 1.4-5 and 6.

   Figure 1.4-5 shows the relative size of one of the crystals (lower left hand corner) to the tube wall. Figure 1.4-6 shows typical hairlike crystals on ID of split tube. Figure 1.4-7 shows surface photograph of a tube in position 35 stage 5 which had relatively many crystal fibers. (Magnification is approximately 30 to 1).



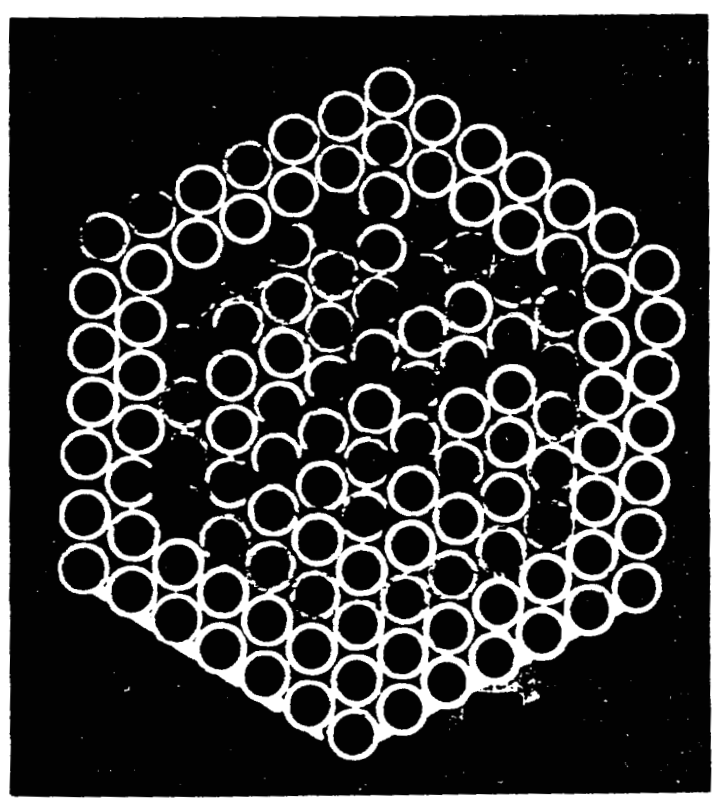
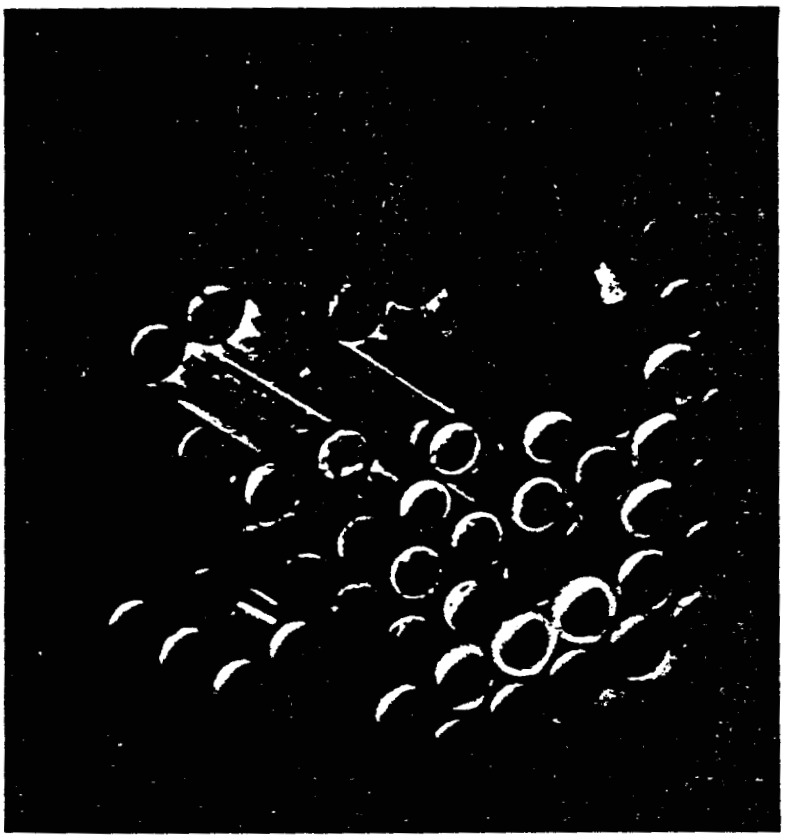


Fig. 1.4-3 - L2A-1 and L2E-1 Tubes Downstream Face - Stage 8
(C-15014 and C-15592)

1187127



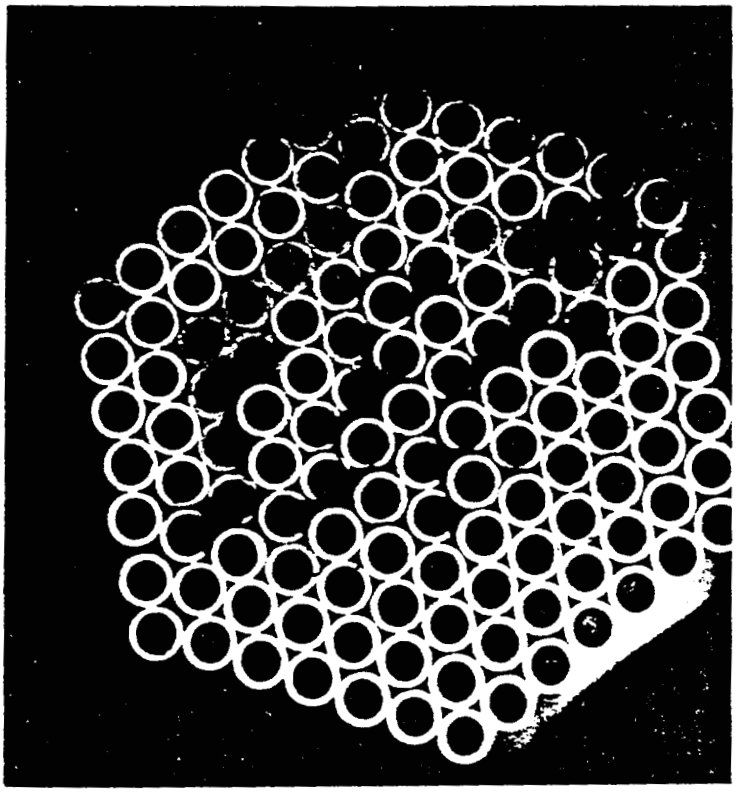


Fig. 1.4-4 - L2A-1 and L2E-1 Tubes Downstream Face - Stage 7
(C-15010 and C-15593)

1187128

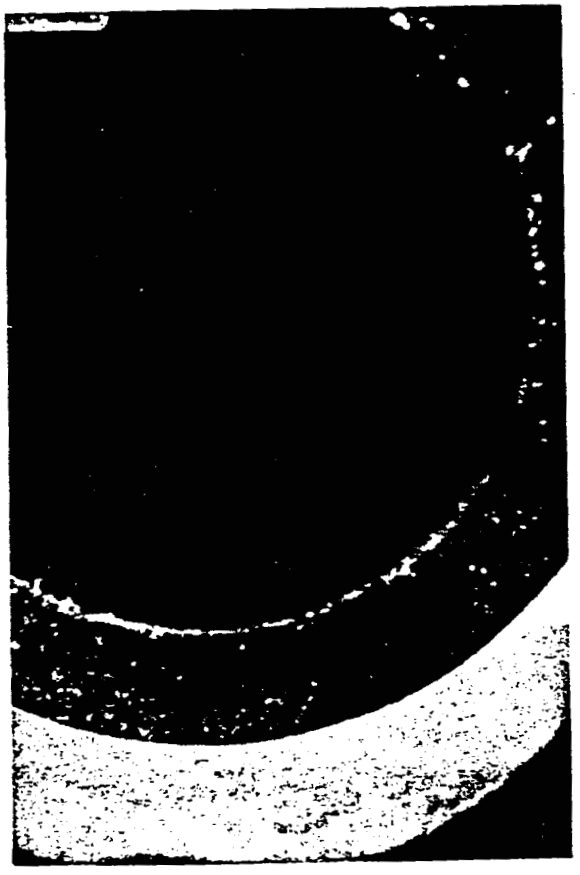


Fig. 1.4-5 - I.D. Upstream End of Tube 6 - Stage 10 (10X) (C-15600)

1187129

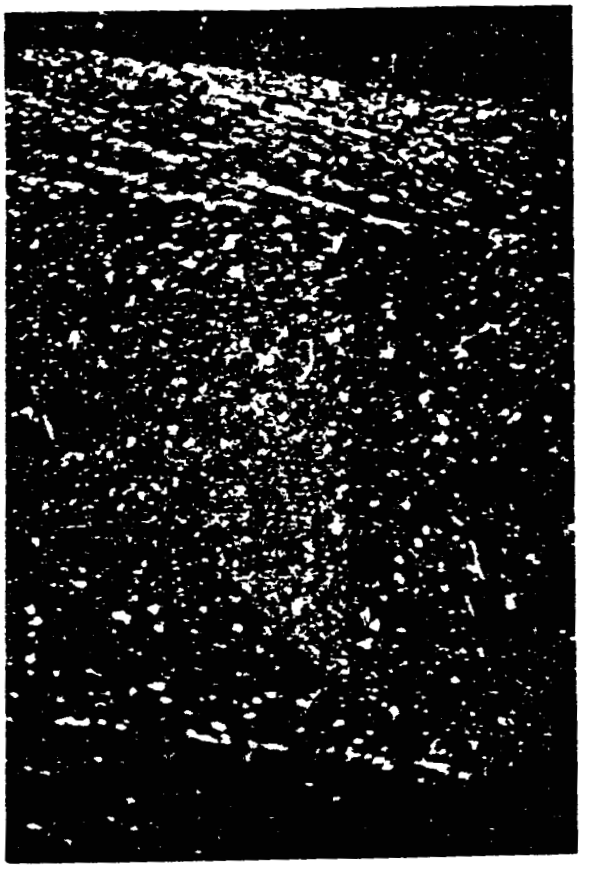


Fig. 1.4-6 - Tube Position 58-Stage 4 Split Longitudinally Showing I. D. Surface - Note Fine Hair-Like Crystals (10X) (C-15729)

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Fig. 1.4-7 - I. D. Surface of Tube Position 35 - Stage 5 (30X) (C-15733)

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2. A coarse globular deposit or growth having the appearance of sand and having a tan color. The deposit was heaviest near the longitudinal center of a particular tube and diminished towards the ends to deposits having a powdery appearance. This deposit also occurred at random throughout the hot regions of the insert. See figures 1.4-8 and 9.

3. A clinker type growth or deposit was also observed having an approximate 10 mil diameter but being relatively scarce. See figure 1.4-10 and 11. Figure 1.4-10 shows the tube end and indicates the relative size of the growth.

The investigation into the nature and causes of these deposits has just begun and as a consiquence, at the writing of this report, little information is available. It can however be speculated, that if such deposits or growths are a normal result of the operation of this type of tube then as far as testing is concerned, longer endurance cycles will be required to determine if the deposits increase with time. It is to be emphasized that for the 106 hours of test time accumulated no unusual changes in performance were observed.

The weighing of representative tubes indicated that approximately 8% of the tubes lost weight. Table 1.4-1 lists the results of the weighings. This subject will receive further discussion in section 1.5.

The aft grid plate was examined photographically, in some detail and showed the apparent elongation of the holes. See figure 1.4-12. This elongation is thought to be due to a temperature gradient in the plate produced by the cooler unfueled tube air. This subject will also receive further discussion in section 1.5.

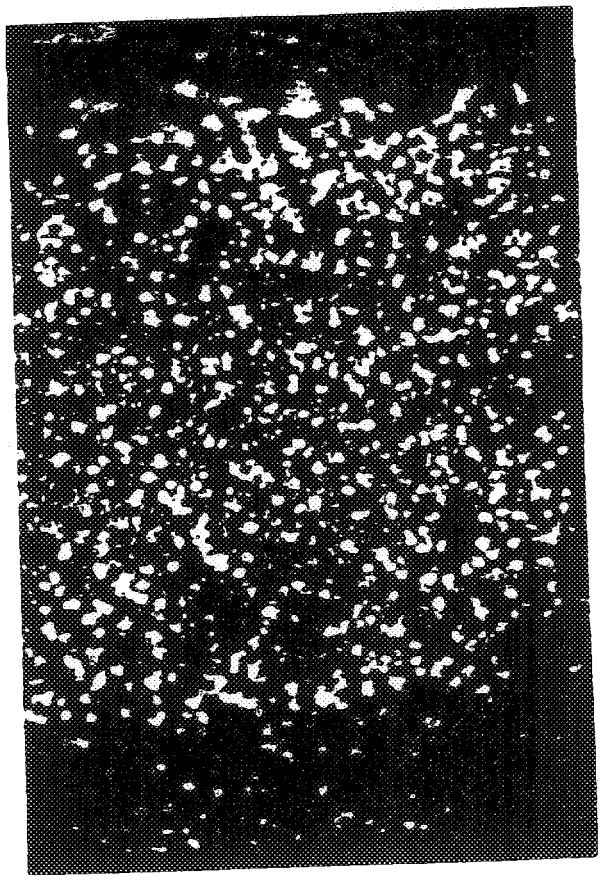

Fig. 1.4-8 - I.D. Surface of Tube Position 58 - Stage 10 (10X) (C-15727)

1187133

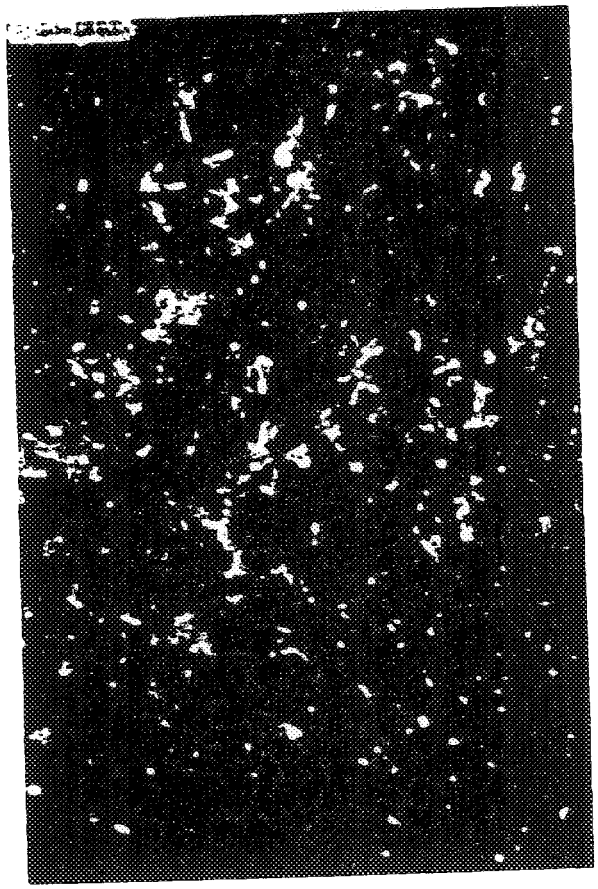

Fig. 1.4-9 - I.D. Surface of Tube Position 7 - Stage 4 (10X) (C-15732)

Fig. 1.4-10 - Upstream End of Tube Position 7 - Stage 9 (10X) (C-15599)

1187135

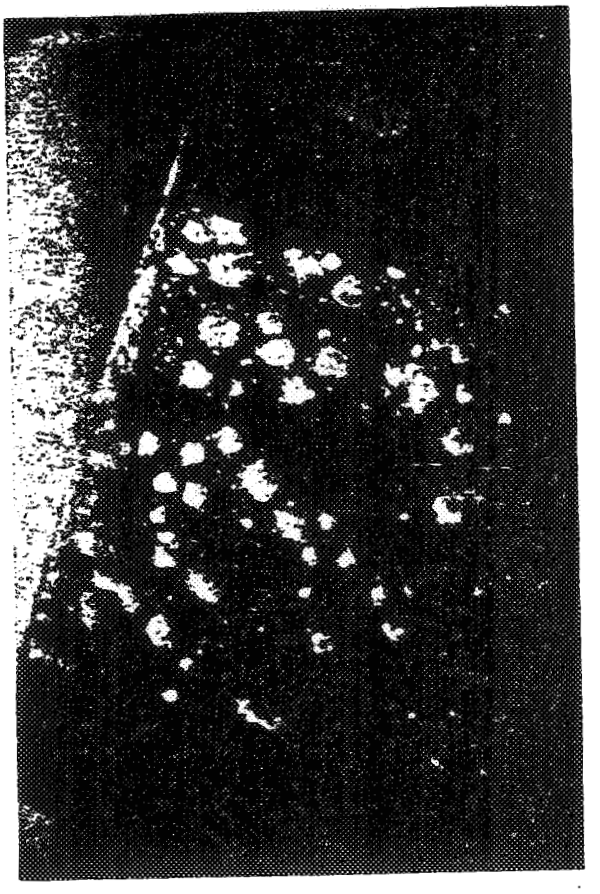

Fig. 1.4-11 - L.D. Surface of Tube 7 - Stage 6 (10X) (C-15734)

1187136

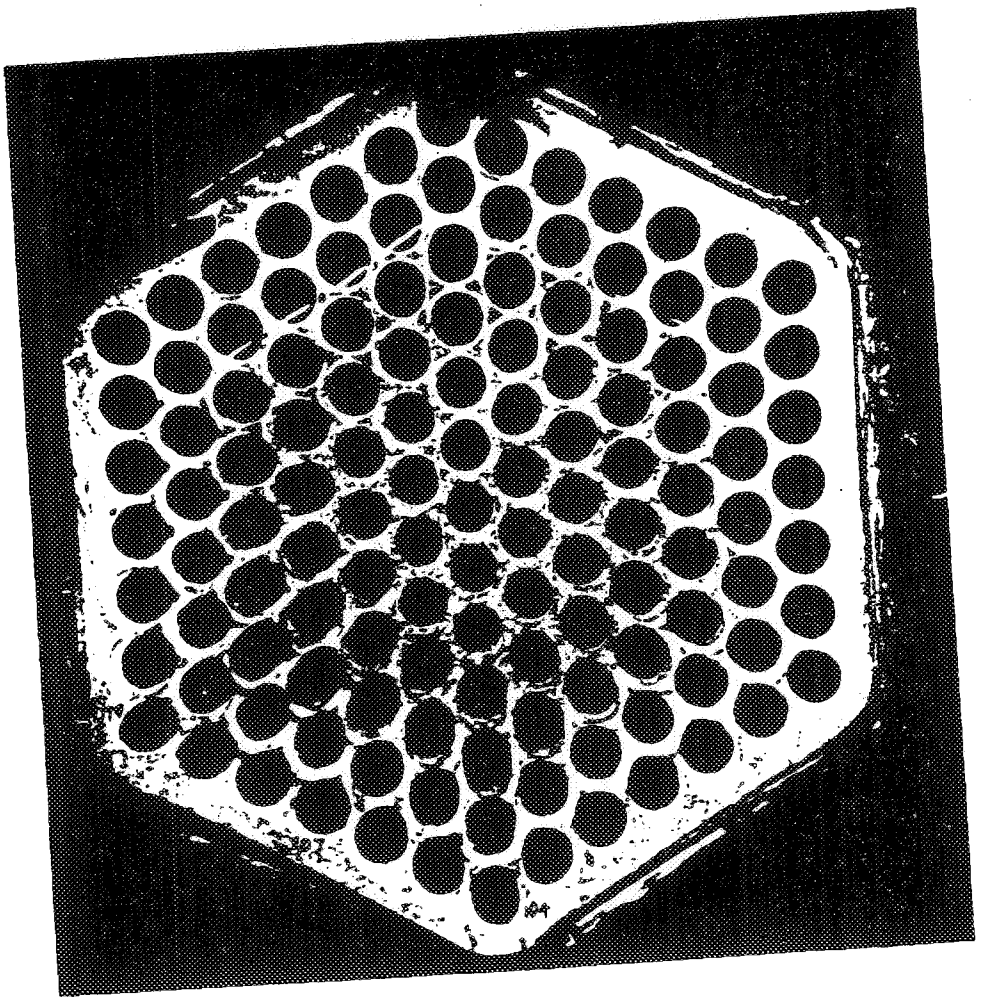

Fig. 1.4-12 - Photo (C-15562)

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[redacted]

TABLE 1.4-1

L2E-1 Weight Changes

Tube I.D.	Stage and Arrangement Numbers 4 A,B,C,	5 A,B,C,	6A,B,C	7A,B,C	8A,B,C	9A,B,C,	10A,B,C	11A,B,C	12 B,C
1-B	+.0079	+.0413	+.0279	+.0434	+.0234	+.0303	+.0374	+.0366	+.0819
3-A	+.0274	+.0224	+.0247	+.0390	+.0172	+.0315	+.0480	+.0198	
5-A	+.0265	+.0227	+.0257	+.0254	+.0356	+.0331	+.0356	+.0535	
7-A	-.0027	+.0264	+.0212	+.0411	+.0187	+.0387	+.0339	+.0431	
10-B	+.0036	+.0160	+.0242	+.0279	+.0186	+.0156	+.0370	+.0144	+.025
14-C	+.0086	+.0169	+.0200	+.0217	-.0152	-.0216	+.1608	+.0124	+.0911
18-C	+.0109	+.0174	+.0258	+.0081	-.0012	+.0013	+.0285	+.0116	+.0129
23-B	+.0046	+.0126	+.0162	+.0224	.0000	-.0031	+.0212	+.0154	+.0136
29-B	.0000	-.0157	+.0197	+.0091	+.0346	+.0215	+.0289	+.0145	
35-B	+.0050	+.0527	+.0191	+.1464	-.0163	-.0130	-.0150	+.0192	
42-A	+.0124	+.0173	+.0206	+.0172	+.0134	+.0253	+.0122		
50-A	+.0131	+.0121	+.0177	+.0224	+.0288	+.0256	+.0196		
58-A	+.0139	+.0180	+.0160	+.0316	+.0300	+.0248	+.0211		
6-C								+.0142	
17-B								+.0231	
33-C								+.0076	
32-B								+.0154	
54-C								+.0086	
16-A							+.0353		

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1.5 DATA ANALYSIS AND INTERPRETATION

The primary basis for the data analysis and interpretation is by comparison with the L2A-1 insert test data. Since the only significant difference between the L2A-1 and the L2E-1 is an ID coating of Al_2O_3 on the L2E-1 tubes the relationship of similar types of data will give a measure of the effectiveness of the design improvements.

Of primary interest is the hydrolysis problem. From the visual examination of the insert it is apparent, at least for the times and temperatures involved, that the Al_2O_3 coating is effective in reducing to essentially zero BeO hydrolysis, as detected through the deposition of BeO in the lower stages of the cartridge. This statement may be more significant than would at first appear since even through the L2E-1 was a round tube insert with no back side coating and with the possibility of interstice flow hydrolysizing the OD of the tubes, no BeO deposits were observed by direct visual examination. In other words the L2E-1 would represent a worst case type of hydrolysis test in comparison to a cartridge made of hex tubes.

The weighing of individual tubes shows that 8% of the L2E-1 tubes weighed lost weight compared to 45 percent of the L2A-1 tubes indicating the apparent effectiveness of the coating in reducing the evolution of BeO from the surfaces of the cartridge tubes.

Cartridge Performance Analysis

As stated previously the design temperature of 2500°F (2515°F indicated) was achieved at a lower power than predicted (10.5 instead of 13 total). The predicted and measured maximum average temperatures as a function of total reactor power are shown

on figure 1.5-1. The measured and predicted longitudinal temperature distributions are shown in figures 1.3-1 and 1.5-2. It is seen from this profile that the measured curve is displaced aft of the predicted curve.

It will be difficult to establish the exact reason for the failure to obtain the design conditions at the predicted power however several factors may have contributed. These are:

1. From table 1.5-1 it is seen that though these exist differences between measured and predicted $P_{T3.49}$ (reactor inlet total pressure) and RPM values, the total flow and core inlet temperature are essentially the same. Therefore, a heat balance standpoint only two factors could have caused the lower on test total core power these being power generation in the insert and insert flow leakage, (Assuming the orifice plate is accurately measuring the flow and assuming that the heat transfer characteristics are as calculated).

TABLE 1.5-1

	Values assumed in thermo analysis	Nominal Values Measured
Correct Eng. Speed	7375	6836
Corrected CDF	59.9 lbs/sec	59.348
$P_{T3.49}$	54.2	48.807
$T_{3.49}$	344°F	344°F

Table 1.5-2 lists the power generations derived from critical experiments and those derived and used in the thermodynamic analysis.

FIGURE 1.5-1
CARTRIDGE L2E-1
INSERT FUEL TUBE MAXIMUM AVERAGE TEMPERATURE
VERSUS TOTAL REACTOR POWER

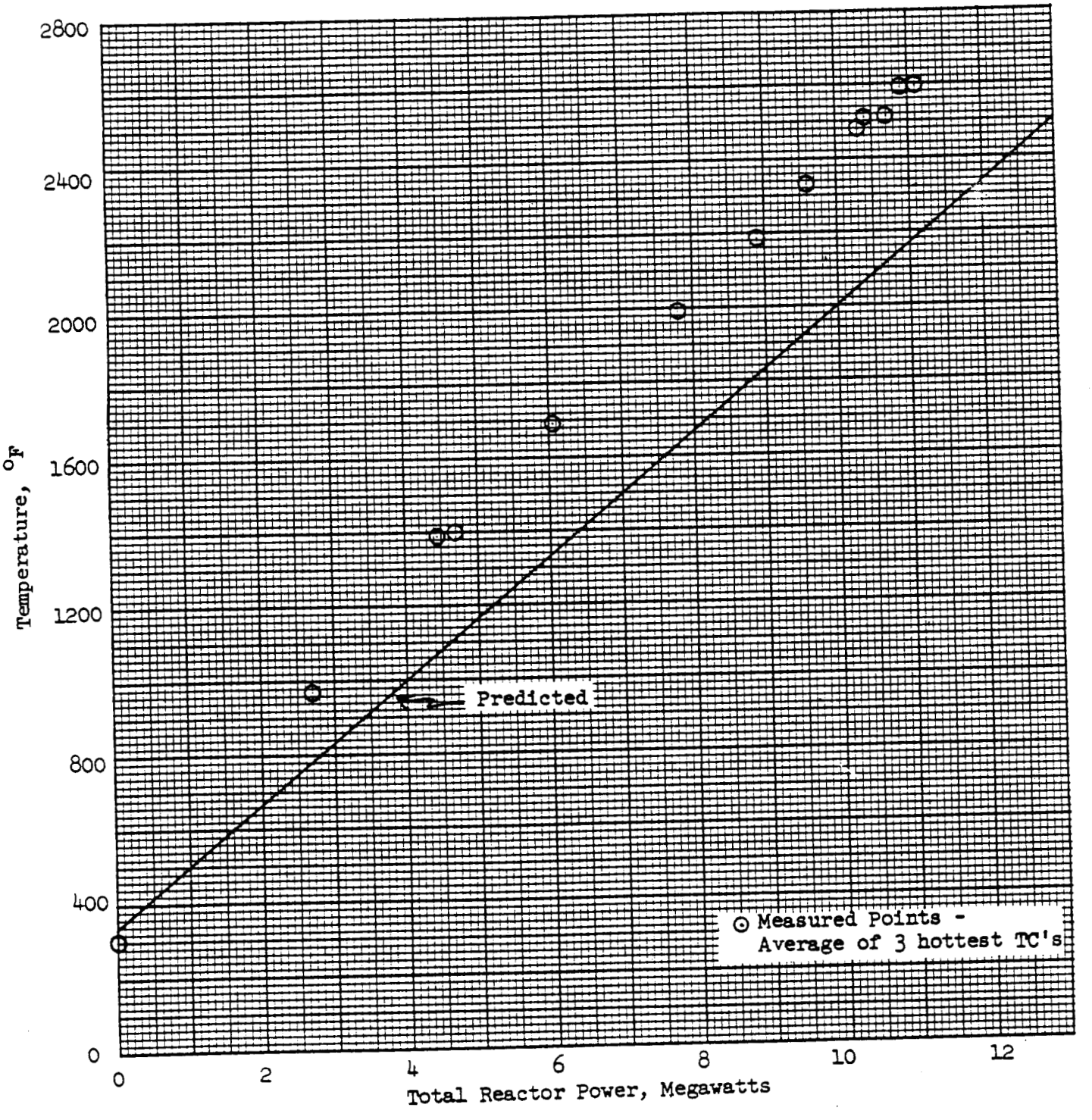
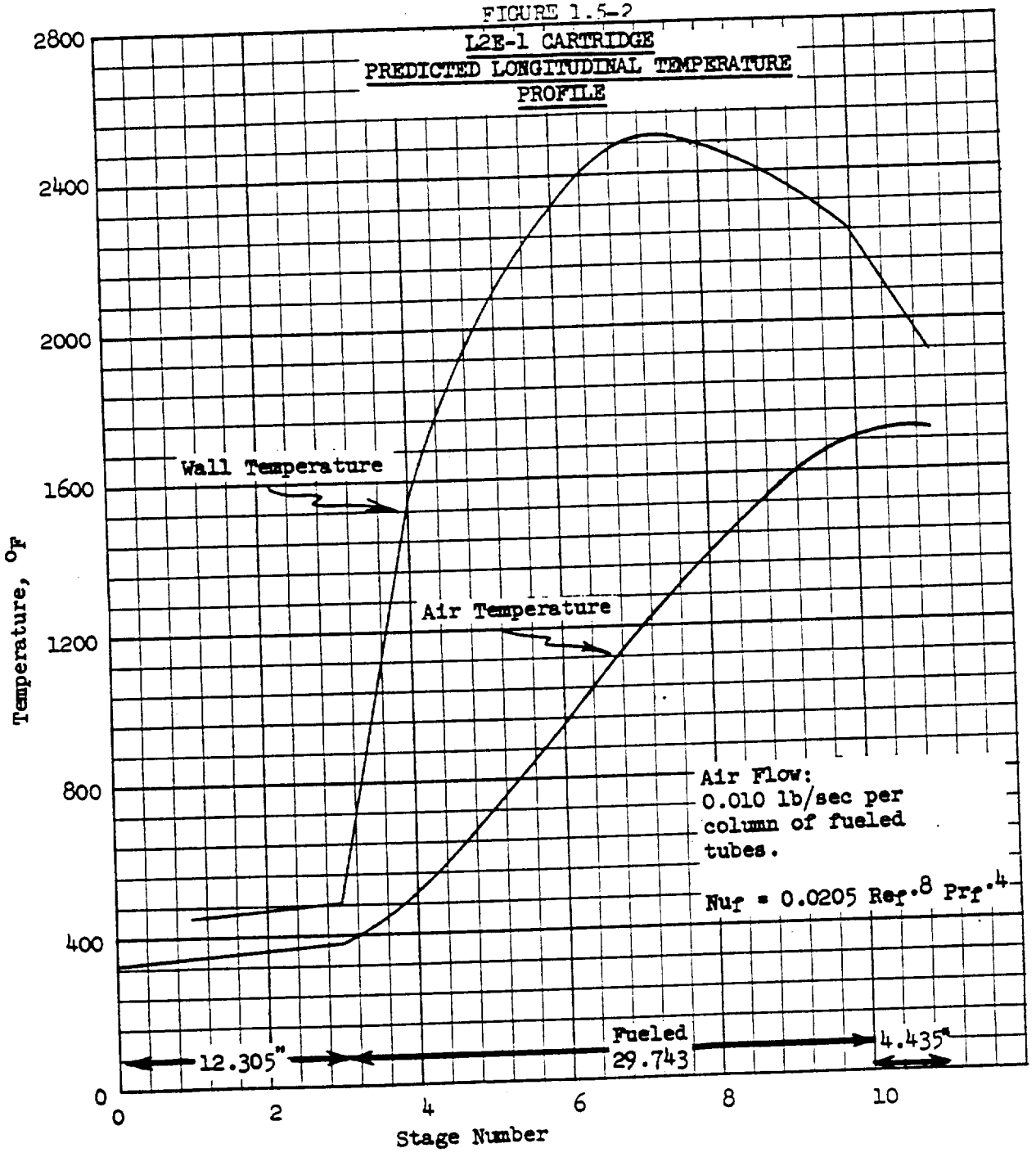


FIGURE 1.5-2

L2E-1 CARTRIDGE

PREDICTED LONGITUDINAL TEMPERATURE PROFILE



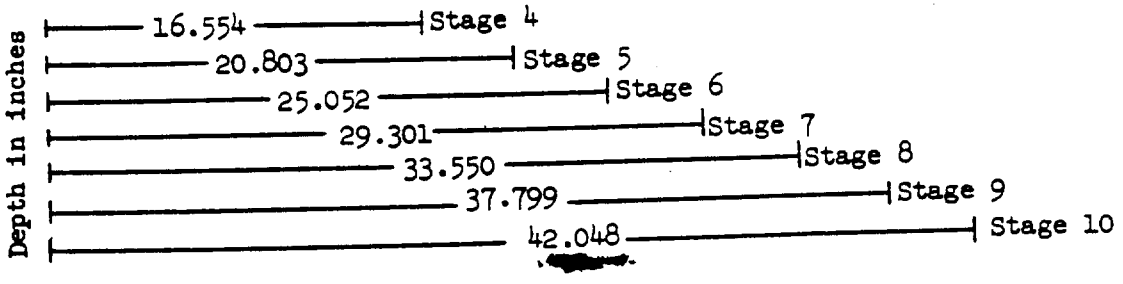


TABLE 1.5-2

TOTAL CORE POWER	CE POWER (INSERT)	THERMO POWER (Used in analysis of insert)	
at 10 MW	233 KW	216 KW	2.16
at 12 MW	280 KW	259 KW	2.16
at 10.75 MW	250 KW	232 KW	2.16

This table shows an 8% difference between CE data and values used in the thermo analysis. Based on the flow and temperature values observed during the test it is possible to compute power generations in the insert at 10.75 MW which range from 215 KW (assuming 10 percent leakage and a minimum temperature rise across the insert - 1265°F) to 250 KW (assuming no leakage and a maximum temperature rise across the insert - 1300°F). It is therefore seen that it is possible to use data in the heat balance analysis which represents a maximum error of approximately 15 percent. This coupled with a possible 8 percent difference in power generation values used in the analysis gives some indication as to why an 11 percent error in predicting the on test power level could exist.

From the longitudinal curves predicted and measured (figure 1.3-1) it is seen that longitudinal location of the peak temperatures differ. This would indicate that the actual power profile of the HTRE #2 is peaked a little aft of the assumed profile (a conclusion which seems to be supported by recent CE data). A discrepancy in power profile could also account for the lower (than predicted) exit air temperature (1600°F avg. instead of 1650°F).

Effluent Activity

During the L2E-1 operation samples of the effluent were taken from several locations along the duct and stack system, see figure 1.2-5. The most consistant

and consequently probably the most accurate complete set of data were obtained from the sampling probe located at the 80 ft. level of the stack. This sampling line terminates in a shielded vault at the base of the stack which is habitable during power operations making possible monitoring of the equipment and the taking of several samples at various times.

The results of the effluent sampling are presented in figures 1.2-9, 1.5-3*, 4 and 5 and shows the gross release as measured by paper filter samples and the fractional release of I^{131}, I^{135}, Ba 140 and Sr91 as measured by carbon filters. On figures 1.5-3 and 4 are also presented for comparison data from the L2A-1 operation. (The release fraction of a particular isotope is determined by ratioing the amount of isotope measured in the effluent to the amount produced in the insert cartridge during the sampling time.) In general the carbon trap Iodine 131 data indicate a reasonably flat release rate when all the points are averaged. By comparison the L2A-1 data shows an increasing trend towards the end of the operation. It was theorized in the L2A-1 Operations Report (XDC 59-10-61) that this increase might be due to corrosion of the BeO fuel tube surface, as a result of hydrolysis, which caused larger and larger amounts of the relatively longer half lived I^{131} to be carried away by the air stream as the operation progressed. The facts that the release was flat for the L2E-1 operation and that relatively little Be release occurred seem to indicate that the coating was effective in holding constant the fractional release of I^{131} with time, thereby tending to substantiate the theory on corrosion.

Though the Al_2O_3 coating apparently was effective in reducing or eliminating hydrolysis it was apparently ineffective in reducing the release of the iodines.

* All carbon trap release data obtained from the stack vault are multiplied by a factor of 1.56 to account for sampling line plate-out. The accuracy of this factor is now being investigated.

FIGURE 1.5-3

INSERT I2E-1 I^{131} FRACTIONAL RELEASE RATE - VAULT

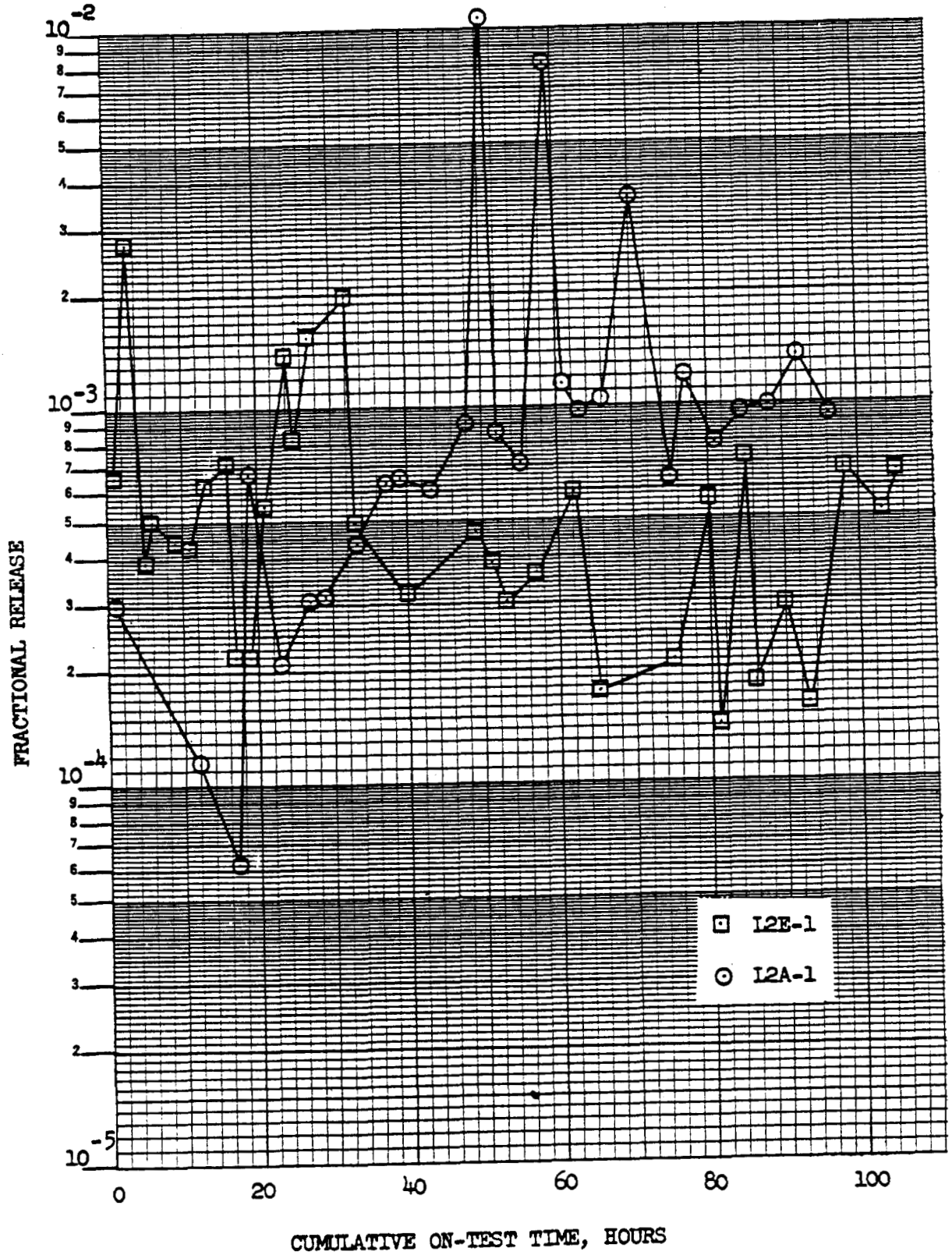


FIGURE 1.5-4

INSERT I2E-1 I^{135} FRACTIONAL RELEASE RATE - VAULT

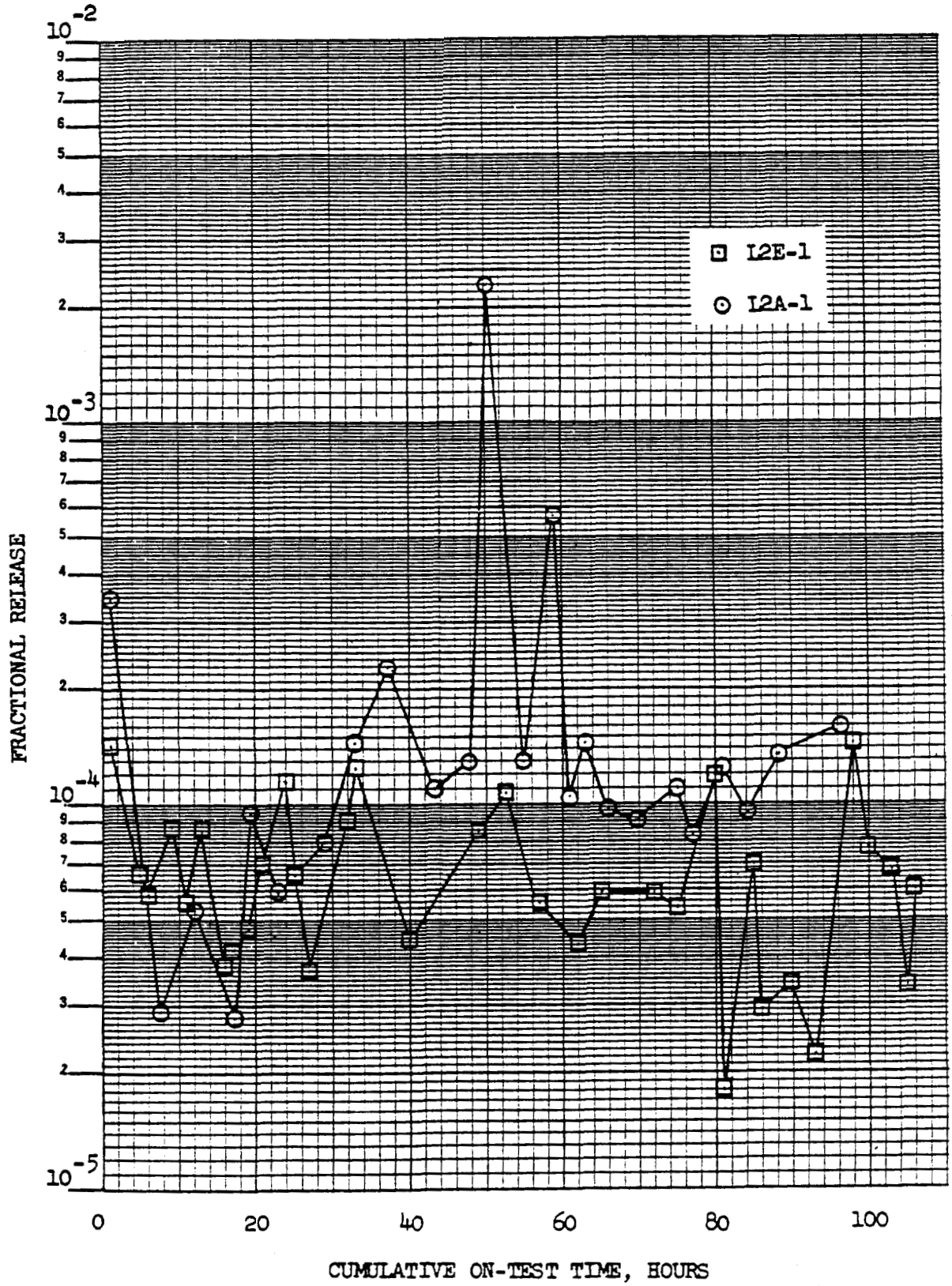


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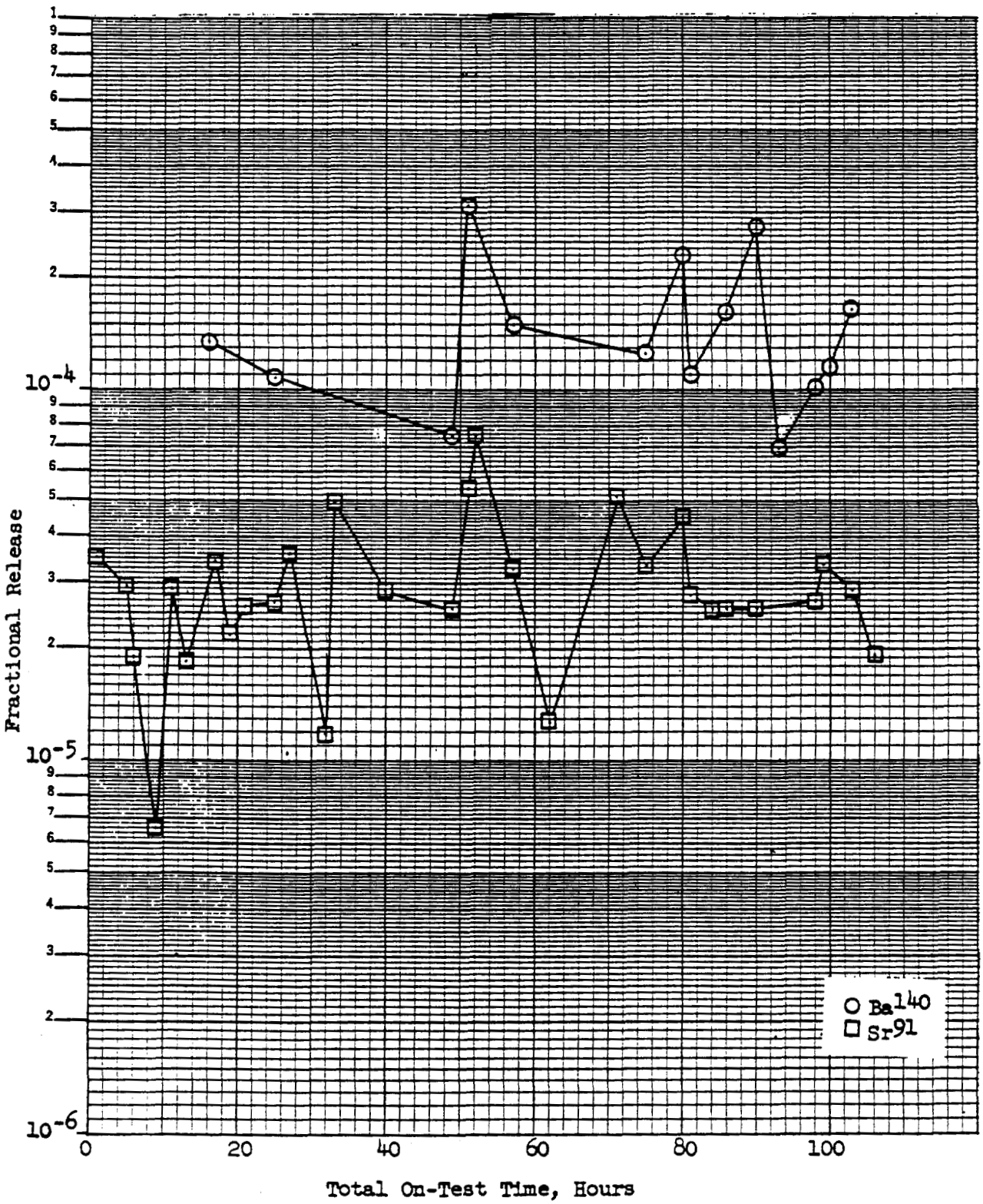
FIGURE 1.5-5
CARTRIDGE L2E-1
FRACTIONAL RELEASE OF Ba^{140} AND Sr^{91}
VAULT SAMPLES

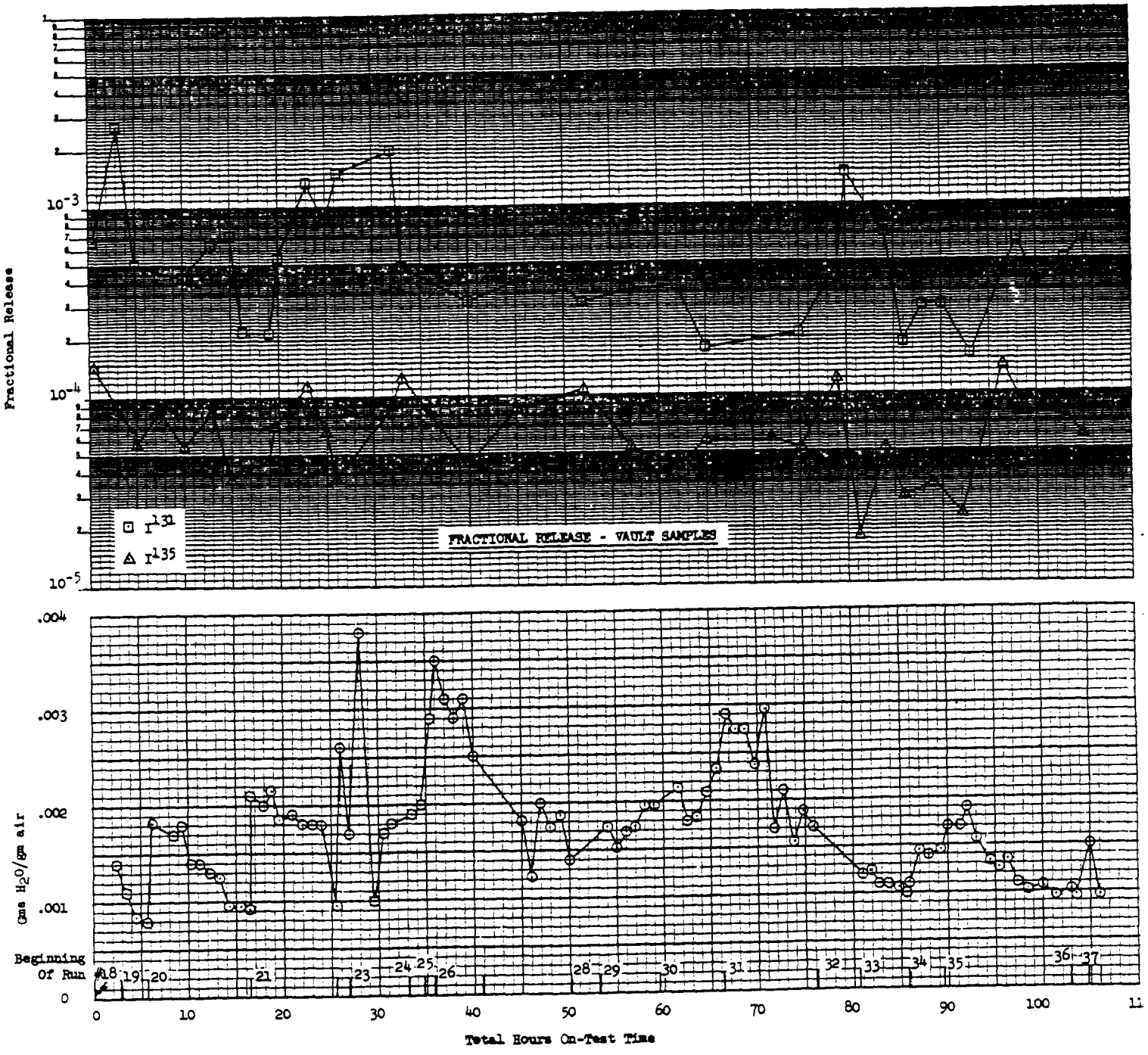


On the other hand the gross fission product release, compared to L2A-1 data was down by a factor of between 3 and 4. Refer to figure 1.2-5. It is therefore probable that the coating is effective in delaying the release of certain of the fission products.

Data from an analysis of the carbon traps for beryllium indicated an average release of 8.5 micrograms per second. This compares to an average release of 28 micrograms per second measured during the L2A-1 operation and represents a reduction by a factor of approximately 3. This can probably be attributed to the ID coating.

At three times during the test cycle increasing temperature - power tests were performed similar to the original sequence to obtain the on test conditions. At the various temperature levels release data were obtained in an effort to evaluate release as a function of temperature. Figures 1.2-7 and 8 show the results of these data for I 131 and I 135 taken at 0 hours and at 50 and 100 hours of operation. These data tend to indicate that between 2300°F and 2600°F the release rate increases by a factor of between 3 and 6. However these data must be considered as inconclusive due to the limit on accuracy of sampling which at present lies within a factor of 10.

Figure 1.5-6 shows a plot of the water content of the air at the Idaho Test Station as a function of the time on test. On the same page the fractional release of I 131 and I 135 is repeated. These data are presented to show that no general correlation between air moisture content and release fractions exist.



IET #17, CARTRIDGE L2E-1
AIR WATER CONTENT DURING FULL POWER OPERATION

FIGURE 1.5-6

[redacted]

1187149

Controls and Instrumentation

Investigation of thermocouple failures in the L2A-1 and L2C-1 insert cartridge operations led to the following design changes for the L2E-1 cartridge:

1. Addition of positive mechanical stops to cartridge connector to prevent ceramic insulator damage due to excessive mating forces.
2. Increase in length of stroke of upper support assembly to allow for uncertainties in upper plenums shrinkage when insert core seats in parent reactor core.
3. Redesign of connector sockets to insure self-alignment with mating pins during mating procedures.
4. Provision of protective sleeves to allow fastening of thermocouple wire to upper grid plate without causing damage to wire during welding of fastener straps.
5. Provision of adequate support for thermocouples measuring air temperature.
6. General improvement of quality control during fabrication.

This attention to detail and quality control in the manufacture of the thermocouples resulted in no failures during the L2E-1 operation in comparison to 11 failures (46% of total) for the L2A-1 operation.

During the operation one thermocouple continually read 300°F to 400°F lower than thermocouples at the same location in other sections of the insert. This was couple number 29-2-30. Figure 1.34 (the longitudinal temperature profile) shows a typical reading of this couple in relation to other readings. Assuming the couple is good (which seems to be a reasonable assumption based on resistance measurements), data points to the fact that the couple may have been influenced by some cooling phenomina. The fact that two thermocouples in similar environments

on the same tube (see figure 1.1-2 for thermocouple layout) at longitudinally cooler points recorded higher temperatures supports this conclusion. Figure 1.5-7 shows a plot of L2E-1 isotherms for the insert cross section at the 30 inch depth. The thermocouple in question is located at approximately at a 1-1/2 inch radius and at a 210° angle. One possible cause of thermocouple cooling could be the result of locating the thermocouple too near a tube junction. See figure 1.5-8. If cross flow at the tube junction existed it is probable that the junction would be cooler.

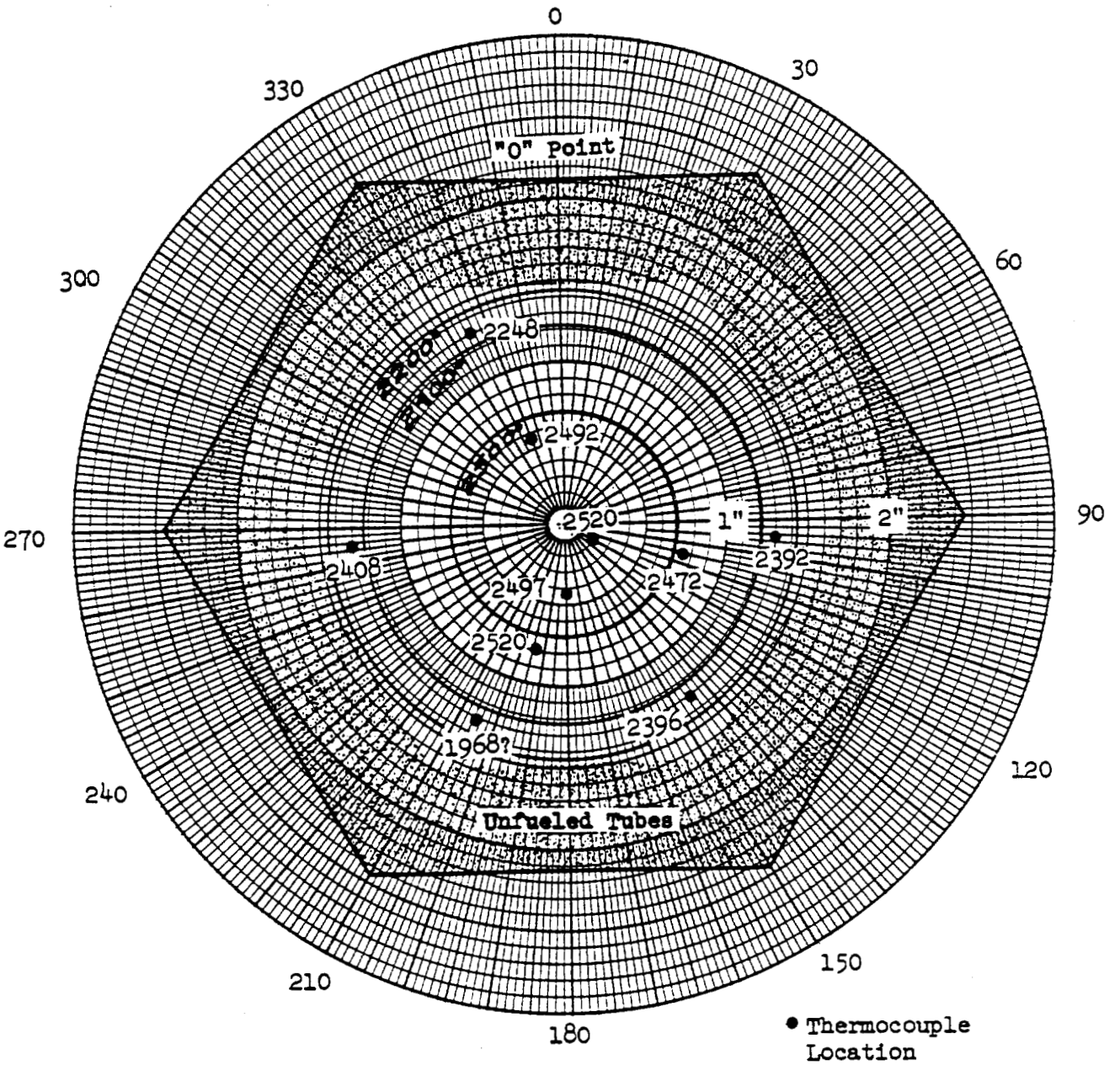
An examination of the radial air and fuel tube temperature profiles (see figures 1.3-2 and 3) shows a normal 100°F gradient across 4 inner rows of fuel tubes. Air temperature from tube 50 (outer most row of tubes - 5 row) gives indication that the outer row normal fuel temperature was between 2200°F and 2300°F representing a maximum temperature gradient across the tube bundle of 300°F. The L2A-1 temperature gradient was also approximately 300°F however across the inner 4 rows the gradient was higher than the L2E-1 being approximately 200°F. These data indicate that a higher percentage of the L2E-1 fuel tubes were at or near design temperatures (approximately 60%).

Throughout the test cycle the temperatures of the various thermocouples were compared with previously recorded data to determine if any changes were taking place in the distributions. Figure 1.5-9 shows plots of longitudinal temperature distributions recorded at the start of the test cycle and after 45.5 and 103.5 hours of power operation. It is seen that very little change in distribution occurred. This tends to indicate that original conditions effecting distributions remained essentially unchanged throughout the operation e.g. tube roughning, crystal growth, etc.

FIGURE 1.5-7

CARTRIDGE L2E-1
RADIAL FUEL ISOTHERMS

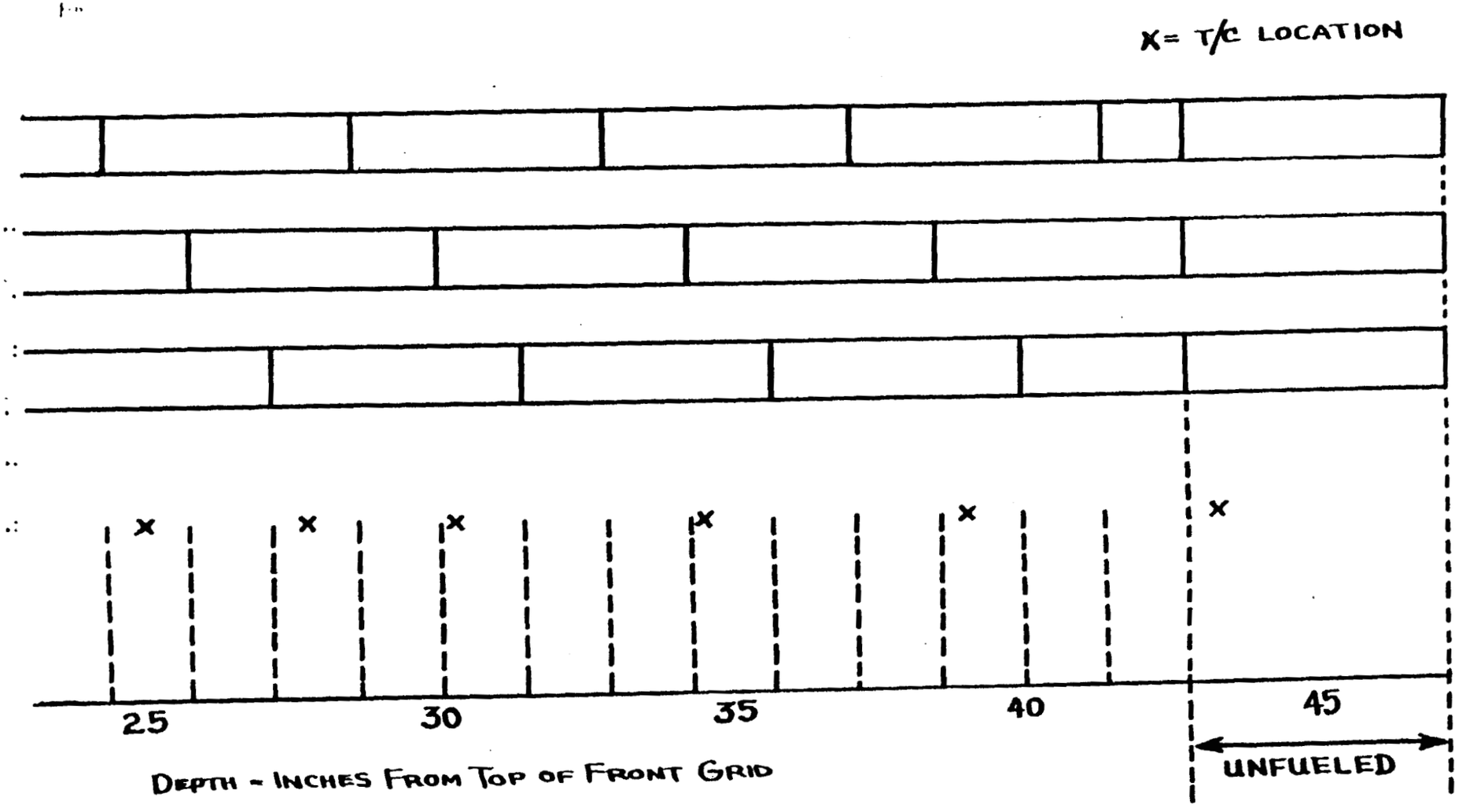
10.6 Megawatts
45.5 Hours on Test



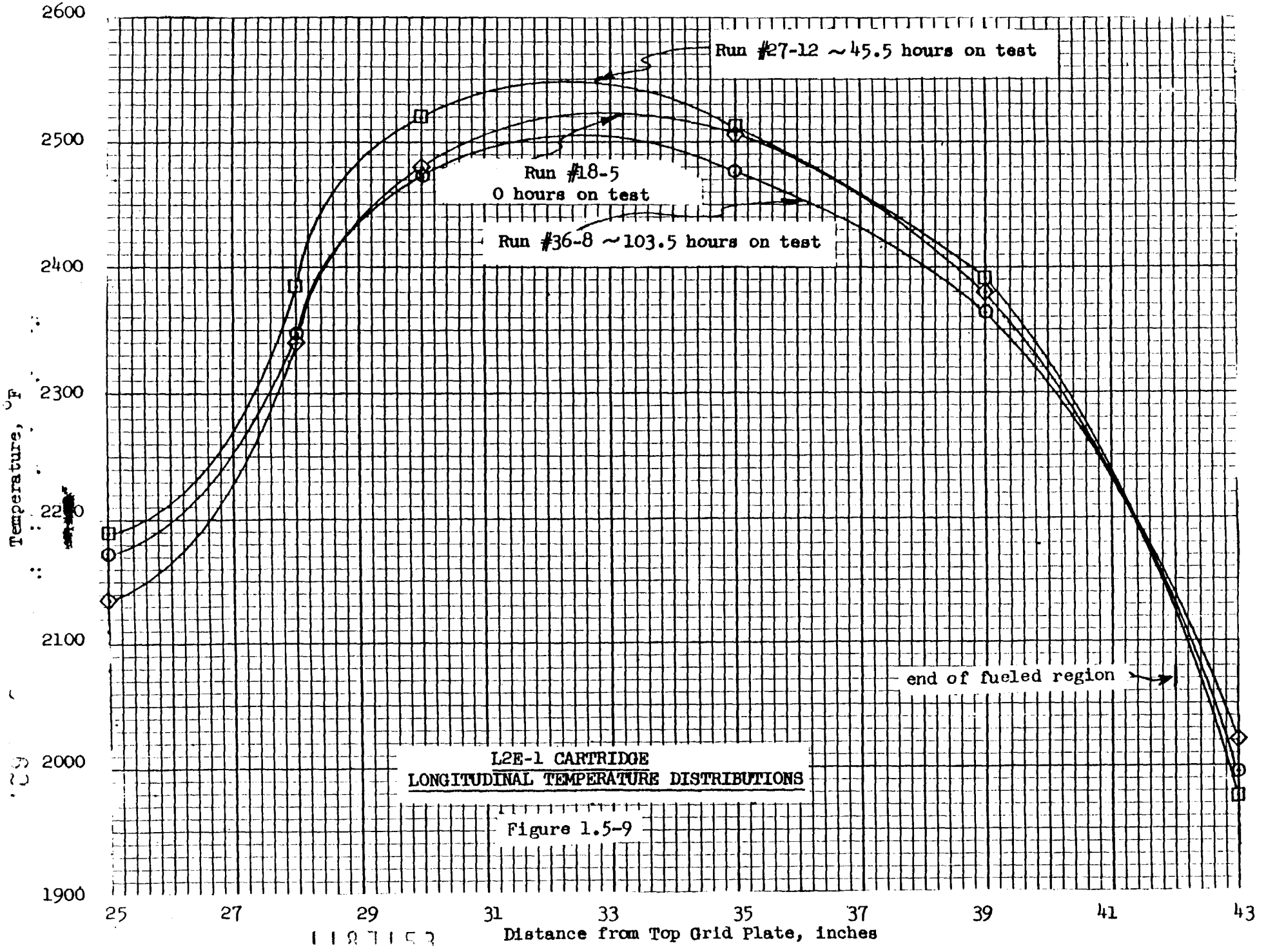
View of insert forward to aft.
All temperatures in °F.
Depth = 30" from top of front grid.

1187152

FIGURE 1.5-8



1187152A



L2E-1 CARTRIDGE
LONGITUDINAL TEMPERATURE DISTRIBUTIONS

Figure 1.5-9

Fuel to Air ΔT

Subsequent to the insert 2-B operations laboratory tests were setup to evaluate the effect on heat transfer and flow characteristics for fueled ceramic tubes, as a result of crystal growths and BeO deposits. Table 1.5-3 presents the measured results of these tests for comparable test conditions. From the table it is seen that the measured ΔP increases ranged from 12 to 37 percent and is presumably due to increased resistance to flow caused by the deposit. Translating a ΔP increase to ceramic fuel cartridge operations in HTRE-2 would result in a flow decrease and a tube temperature increase for a constant total core power. The ΔP increase would therefore be undesirable from an overall systems performance standpoint for the fuel scale ceramic reactor cores.

In opposition to the detramental effects of increases pressure drop is the possibility of the existance of increased heat transfer coefficient caused by roughning of the tube walls as a result of deposits. Increased heat transfer coefficient would reduce the fuel to air ΔT.

Test results from the L2A-1 and L2E-1 operations are inconclusive or are lacking, however it is possible to make some deductions from the data which are available. Figure 1.5-10 shows a plot of fuel tube to exit air ΔT as a function of time on test. As far as the L2E-1 operation was concerned there was essentially no change in ΔT, over the 106 hours of testing for approximately the same flow conditions (see figure 1.3-4). This suggests that no change in heat transfer coefficient occurred. The fact that flow conditions tended to remain constant suggests that an increase in insert pressure drop did not occur. The certainty of the deduction is dependant on insert air leakage fraction which could increase for increased fuel tube resistance with the measured total cartridge flow remaining constant.

FIGURE 1.5-3

REVISED (12-30-58) SUMMARY OF OPERATING CONDITIONS FOR WATER VAPOR CORROSION TESTS OF BEO TUBES

TUBE NO.	DATE TEST STARTED	TOTAL HOURS ON TEST	NO. OF HEATING ELEMENTS	APPROX. HEATED LENGTH (INCHES)	AIR FLOW (SCFM)	AIR TEMP. INLET (°F)	AIR TEMP. EXIT** (°F)	DEW POINT NOMINAL AIR (°F)	DEW POINT NOMINAL ROOM (°F)	MAXIMUM*** SPECIMEN TEMP. (°F)	INLET N_{Re}	% INCREASE IN ΔP	BeO CRYSTAL DEPOSITS
5A*	8-11-58	100	6	18	5.45	760	1550	25	50	2550	24,200	37	Outside-Slight Inside -Slight
7A*	9-9-58	100	1	12	5.45	1000	1620	25	50	2525	21,500	12	Outside-Slight Inside -Slight
11B*	10-20-58	100	1	18	7.65	1000	1650	25	50	2500	20,400	20	Outside-Slight Inside -Moderate

A - Insert 2-B Diameter Tube
B - HTRE-4 Diameter Tube
* - Fueled tube
** - Thermocouple located about 12" downstream from heated zone. Temperature out of heated zone 250° - 400°F higher
*** - Optical pyrometer reading at hottest region of outside wall ± 50°F

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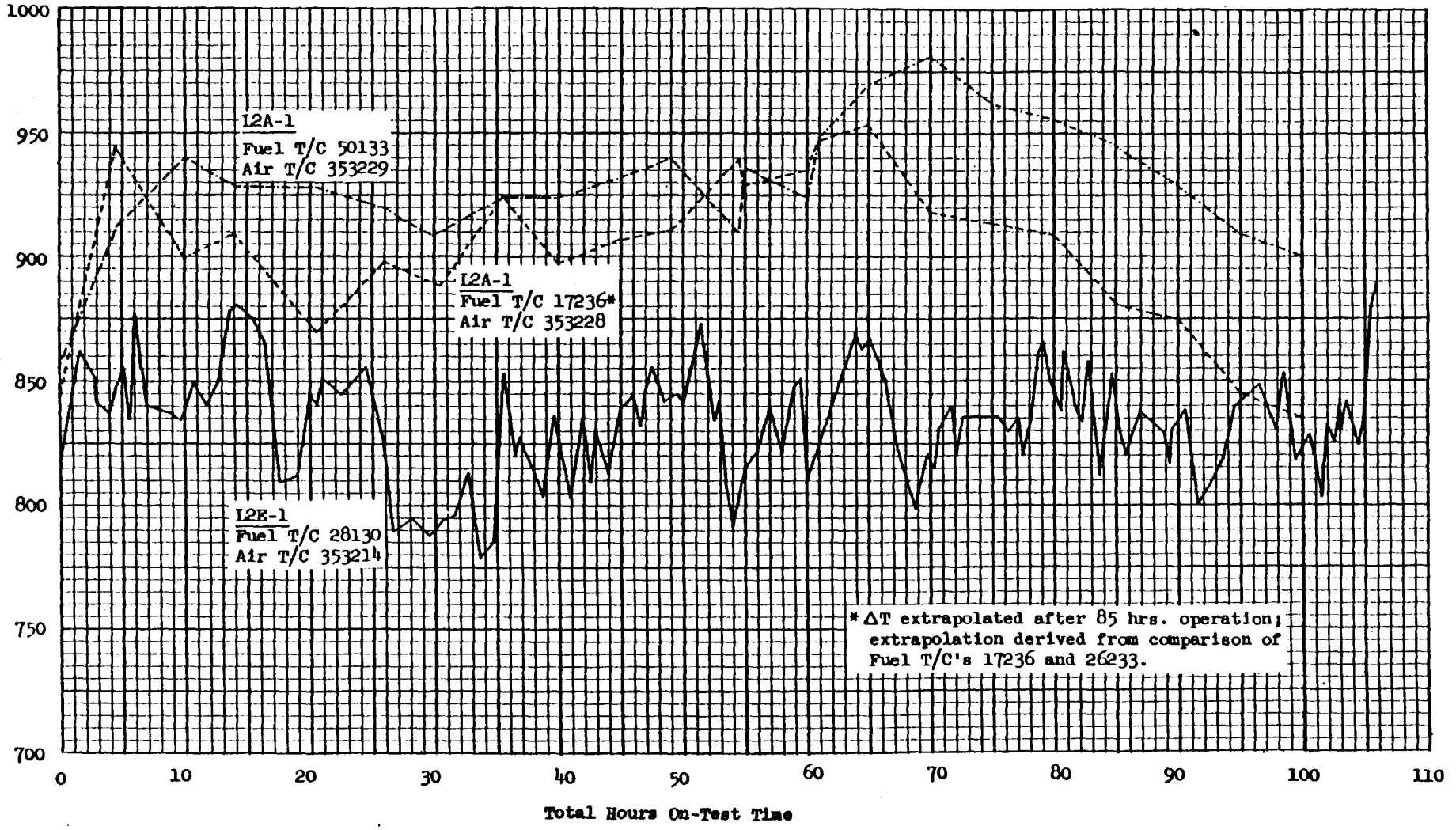
FIGURE 1.5-10

COMPARISON OF INSERT L2E-1 AND L2A-1

FUEL TUBE TO EXIT AIR ΔT



NOTE: Due to failure in the L2A-1 of thermocouples in longitudinal and radial positions similar to those of L2E-1 thermocouples, the L2A-1 data presented here is the best available for purposes of comparison.

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During the L2A-1 operation the ΔT change with time remained essentially constant for 60 to 70 hours at which time it gradually began to decrease. If it is assumed that an accurate interpretation of the data was made then it is possible to conclude that the crystal deposits and powder deposits caused a change in heat transfer coefficient to an extend sufficient to override the probable flow resistance effect (reduced weight flow) to produce improved performance.

The net result of these speculations is the conclusion that up to a point (defined by temperature, test time and magnitude of deposits) the formation of deposits in fueled ceramic tubes may tend to improve the performance of the system of which the ceramic fuel tube material is the power producing element.

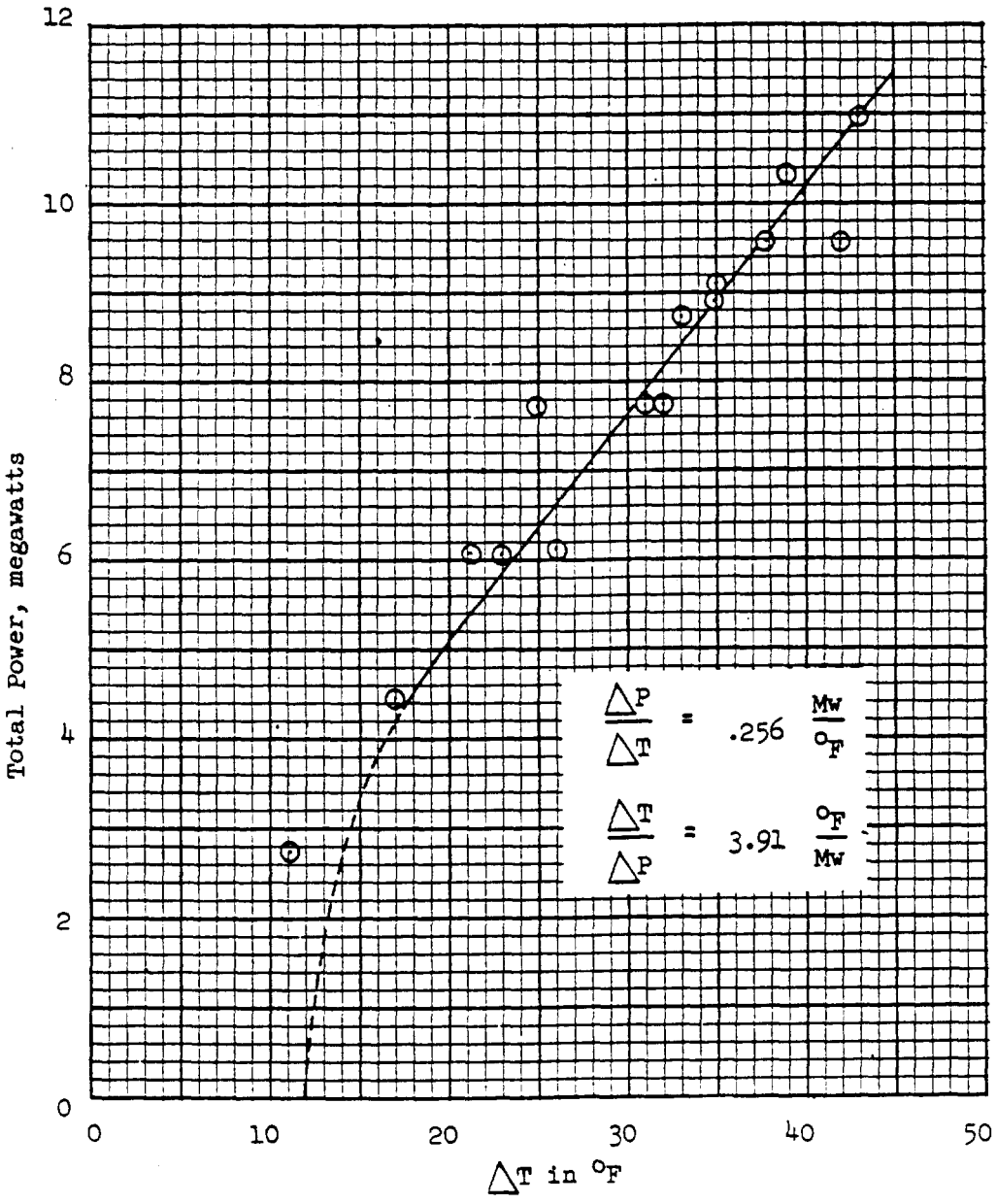
Water Temperature Rise in the L2 "Can"

The water temperature rise across the L2E-1 insert "can" was recorded during the L2E-1 operation to evaluate the secondary (gammas and neutrons) heat generation in the insert "can" materials. Figure 1.5-11 shows a plot of the total reactor power as a function of temperature rise across the "can". The data presented in figure 1.5-11 represents a more precise determination than data recorded during the L2A-1 operation. (This is due primarily to the relocation of the water temperature measuring thermocouples from the top of the insert plug to the insert "can"). From the slope of the linear portion of this curve the heat input to the water is calculated to be 7.06 KW/MW. From the fact that a 14°F temperature rise existed across the insert at cold flow conditions it will be assumed that 34% of the heat input was due to heat transferred from engine air (approximately the same magnitude of heat transfer was measured during the L2A-1 operation). Therefore the net heat due either to gamma ray protons or neutrons, or to transfer from the insert cartridge (calculated

FIGURE 1.5-11

L2E-1 CARTRIDGE

REACTOR TOTAL POWER VS. INSERT WATER ΔT



maximum of 4 percent) would be 4.66 KW/MW representing a heating rate of (based on an insert materials content of 11.43 x 10^4 gms) 0.041 W/gm MW. Assuming 4% is due to transfer from insert cartridge (at full power) the heating rate due to gammas and neutrons would be 0.039 W/gm MW. Since the prediction was 0.045 W/gm MW an over estimate of approximately 12% is indicated.

Fission Product Poison History

The history of the buildup and decay of fission products for the L2E-1 operation as a function of time is presented in figures 1.5-12 through 1.5-16 the first data point of figure 1.5-12 represents the poisoning effect of the long lived fission products remaining from previous operations and is seen to be 1.1 percent. (Predicted value 1.18 percent). The Kex predicted and measured was 1.30 percent at 150°F. (The Kex for the cold clean core at 150°F would then be 2.40 percent). Data taken from an 11 hour power run of 11/16/59 at a total reactor power of 10.7 MW was plotted and extrapolated per calculation to show the extent of fission product poisoning at equilibrium, see figure 1.5-17. It is seen from the curve that equilibrium is essentially reached after 40 hours at which time the poisoning effect is 1.9 percent.

Electrostatic Precipitator Results

As a result of the operation of the L2E-1 insert a suitable source of fission products in the effluent air stream became available for the evaluation of an electrostatic precipitator in removing air contamination. The effectiveness of the precipitator in removing contamination is measured by ratioing carbon trap and paper filter samples taken at the entrance and exit of the precipitator.

Preliminary analysis of data collected indicated 50 to 60 percent effectiveness

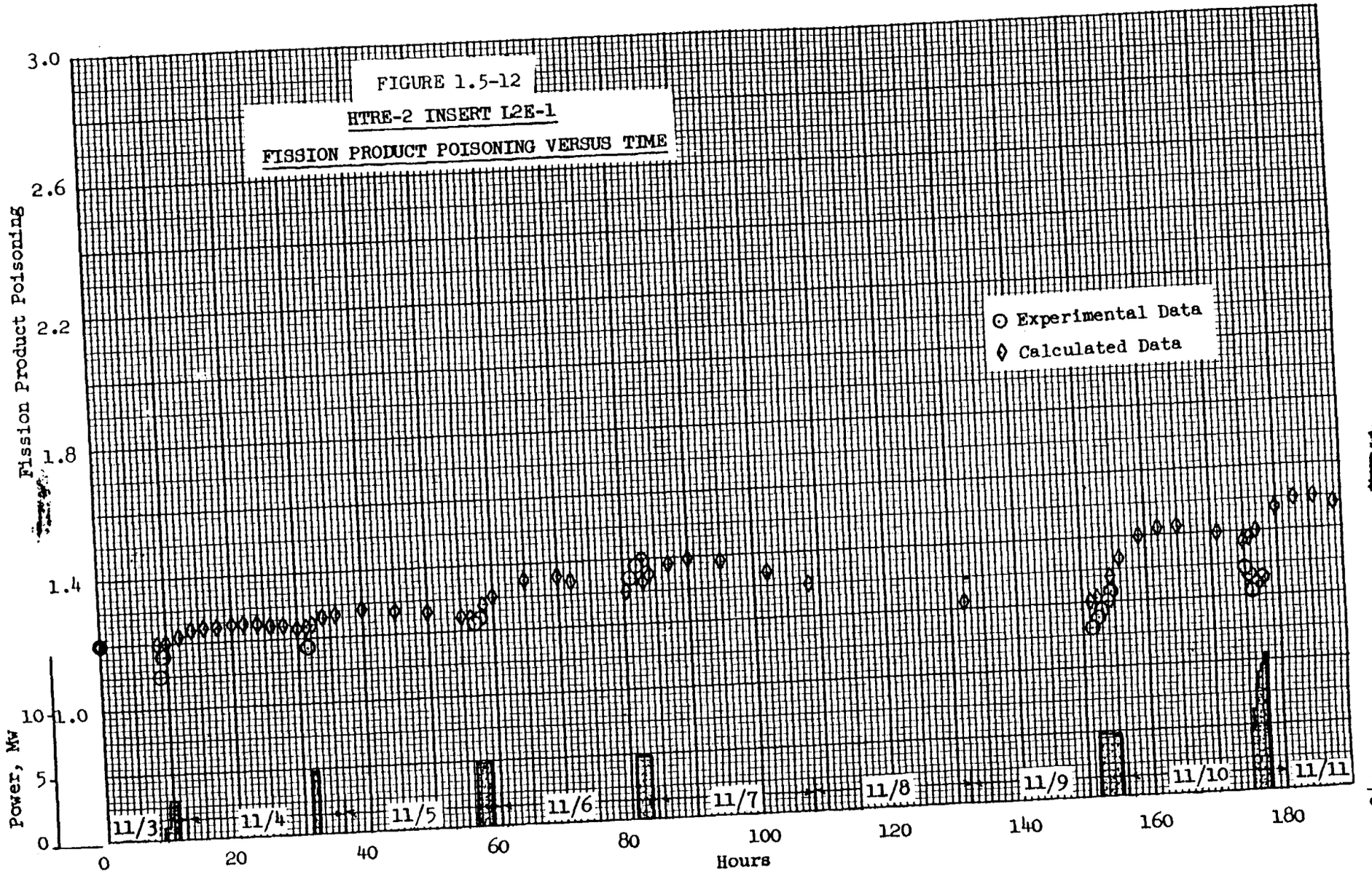


FIGURE 1.5-12

HTRE-2 INSERT L2E-1

FISSION PRODUCT POISONING VERSUS TIME

1187160

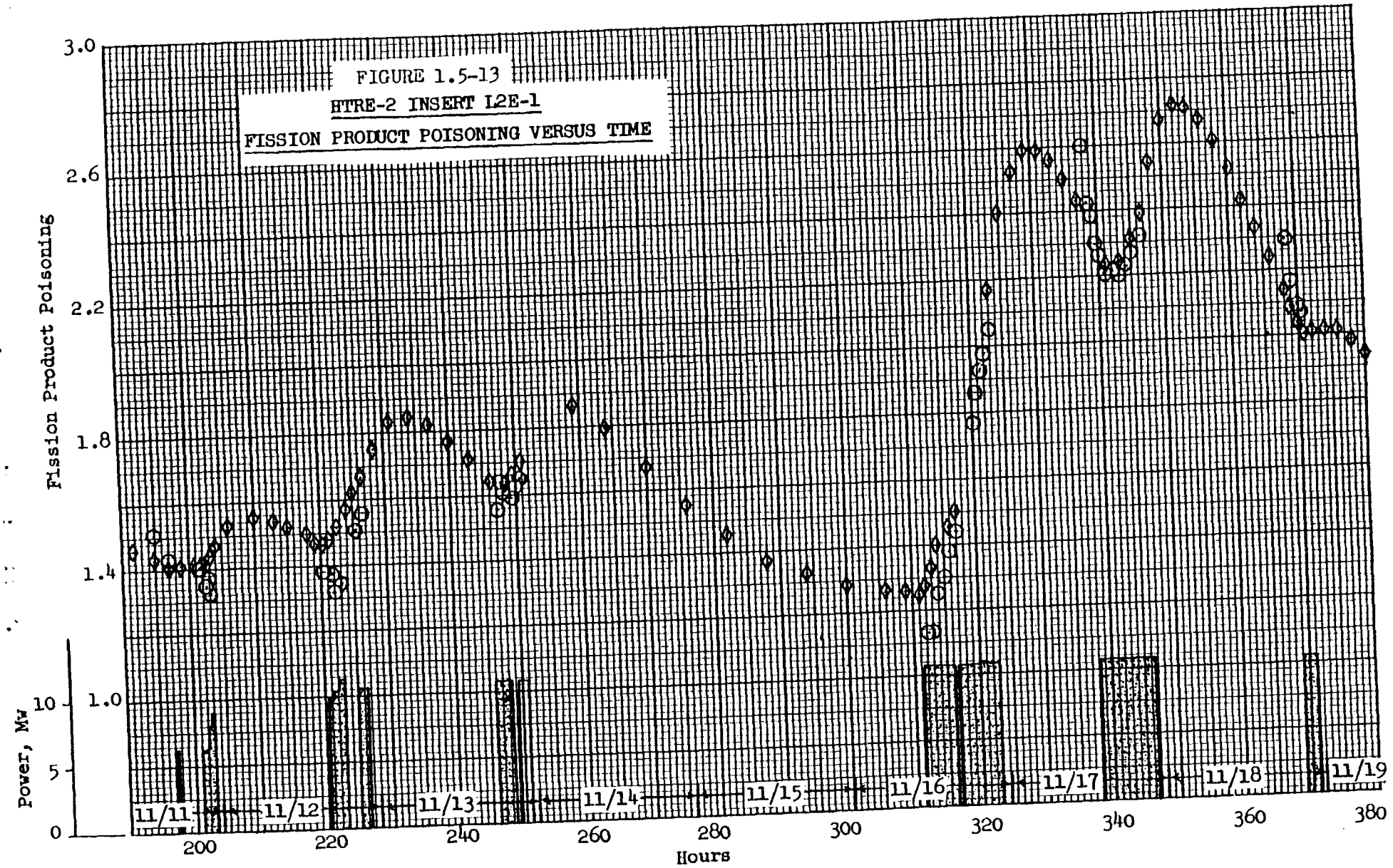


FIGURE 1.5-13
HTRE-2 INSERT L2E-1
FISSION PRODUCT POISONING VERSUS TIME

1187161

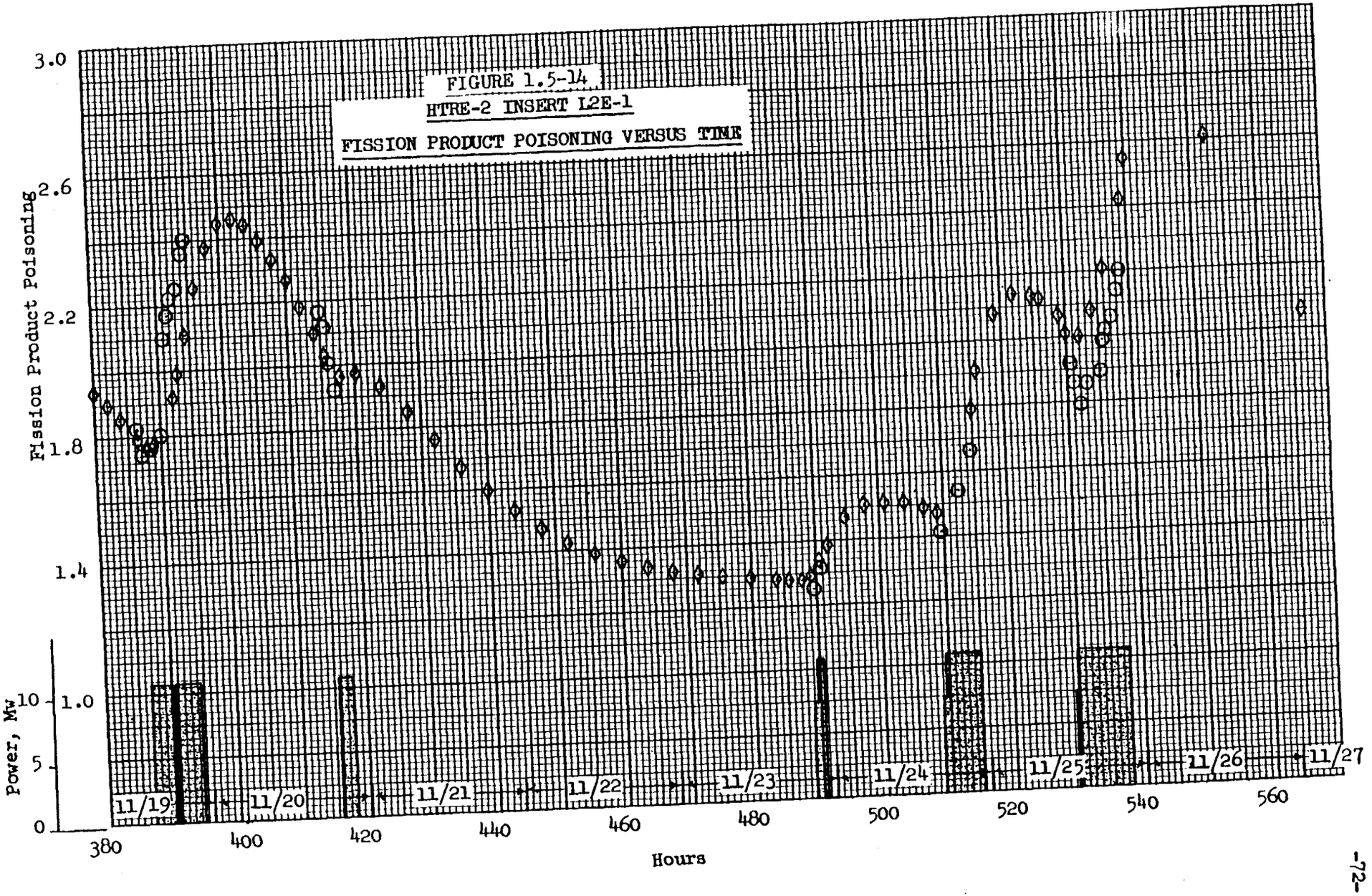


FIGURE 1.5-14
HTRE-2 INSERT L2E-1
FISSION PRODUCT POISONING VERSUS TIME

1187162

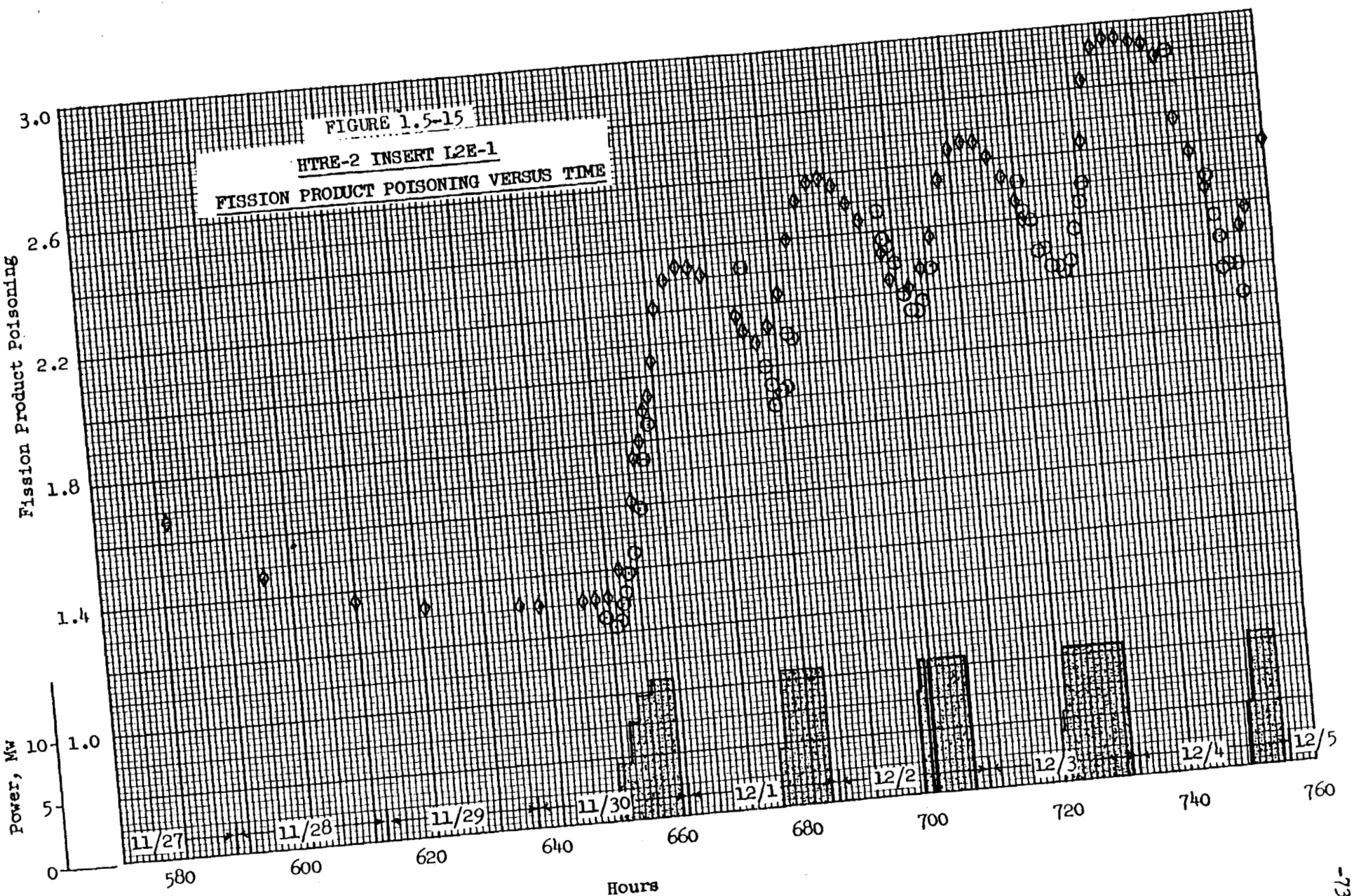


FIGURE 1.5-15

HTRE-2 INSERT L2E-1

FISSION PRODUCT POISONING VERSUS TIME

1187163

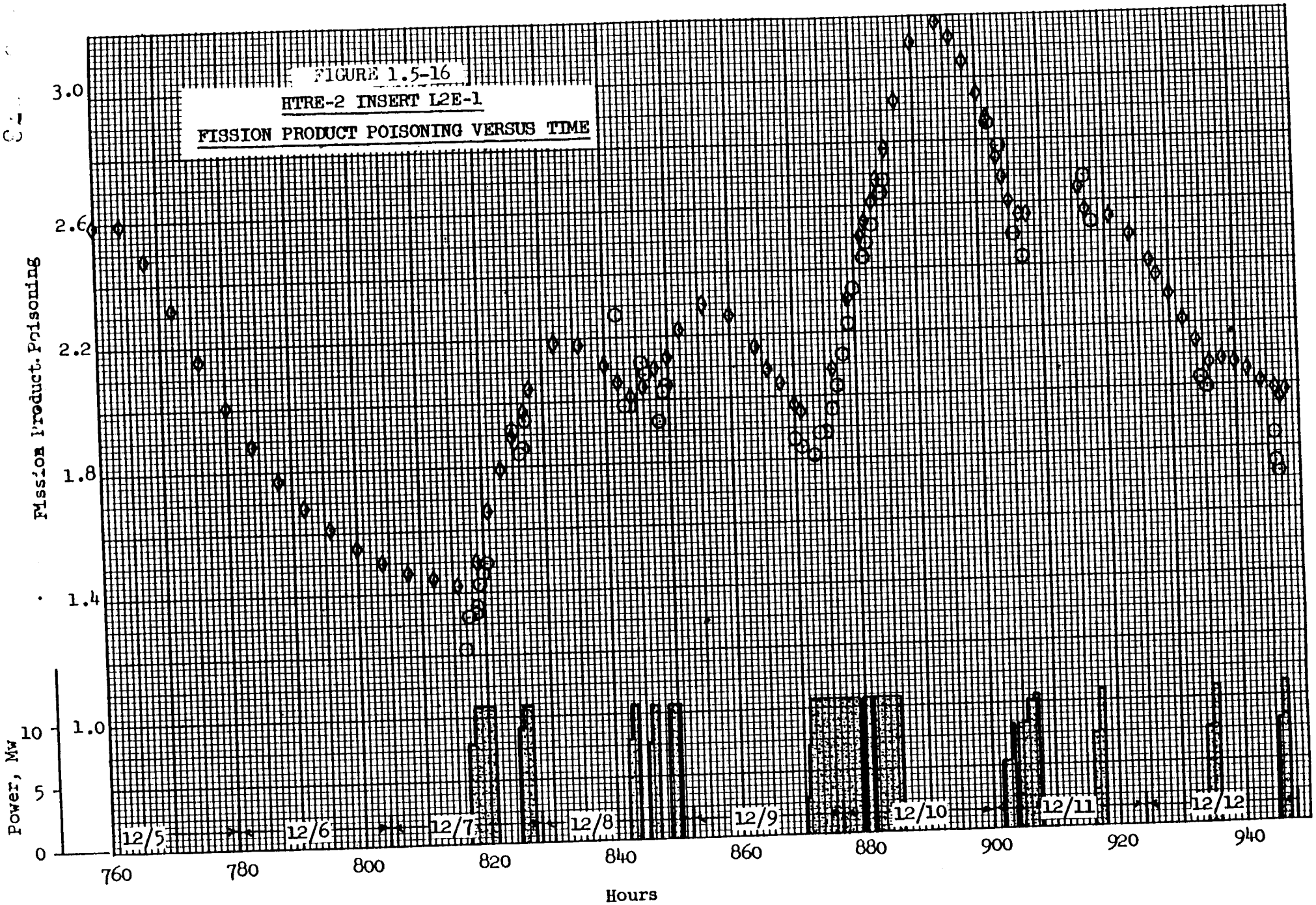


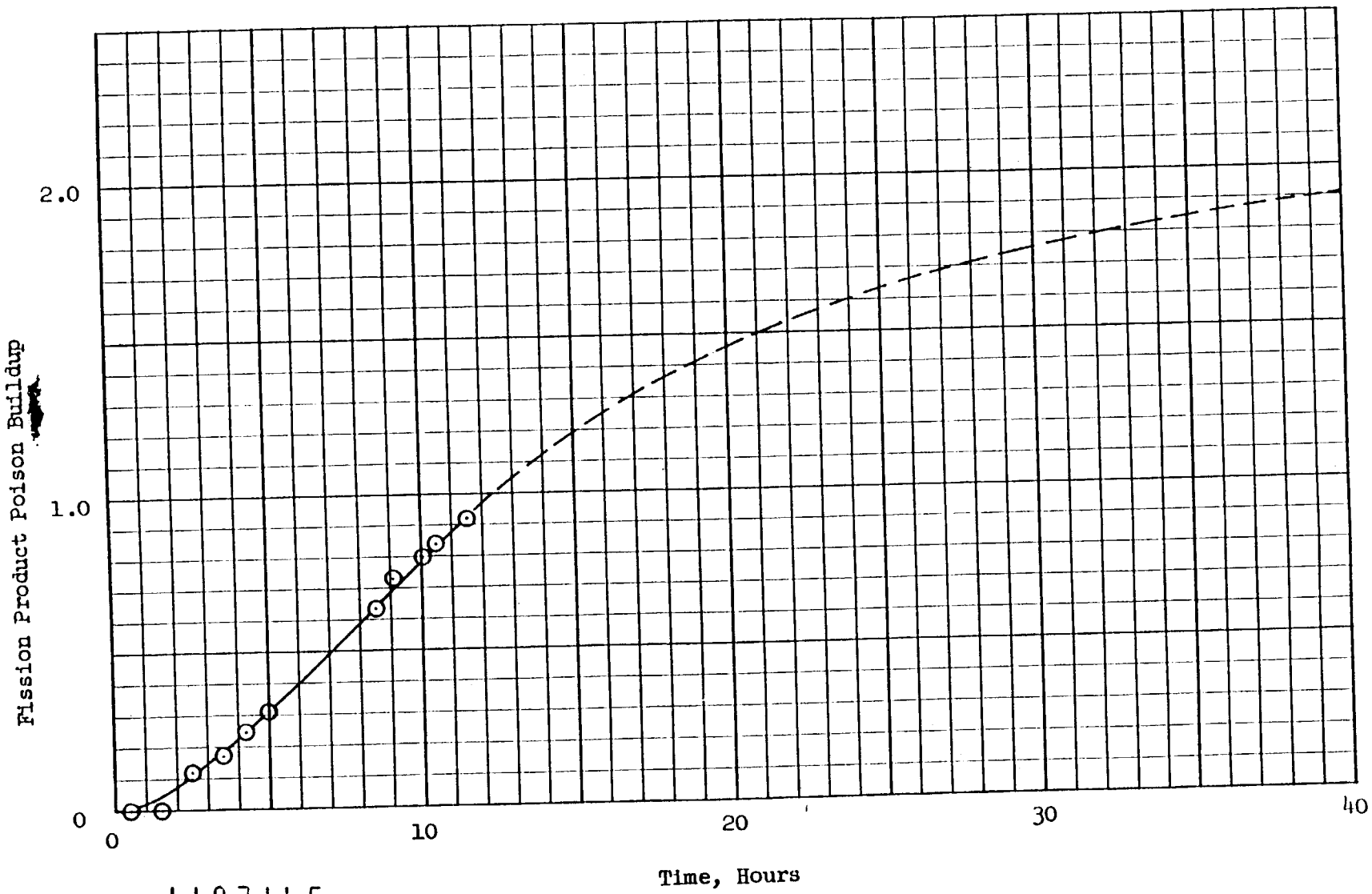
FIGURE 1.5-16
HTRE-2 INSERT L2E-1
FISSION PRODUCT POISONING VERSUS TIME
Fission Product Poisoning
3.0
2.6
2.2
1.8
1.4
1.0
Power, Mw
10
5
0
12/5
12/6
12/7
12/8
12/9
12/10
12/11
12/12
760
780
800
820
840
860
880
900
920
940
Hours

1187164

FIGURE 1.5-17

HTRE-2 INSERT L2E-1

FISSION PRODUCT POISON BUILDUP VERSUS TIME



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under normal operation conditions (no additives to air stream). Efficiencies up to 90 percent have been measured with additives in the effluent stream. The most promising of the additives seems to be carbon in the form of fine powder. Other additives are under investigation. Optimization of the additives and the injection techniques should make possible the realization of the 90 percent efficiencies.

More information on the operation of the precipitator will become available with the operation of the HTRE-2 L2E-3 insert cartridge scheduled to begin in February, 1960.

HTRE-2 - A-4 CORE

After the HTRE-2 core had been removed from the CTF at the ITS Hot Shop it was discovered that one of the 6 water flow risers had ruptured at a weld and was leaking water. As a result of this damage future HTRE-2 operations will be performed using the A-5 core which has previously not been operated at power. Attempts will be made to repair the A-4 core.

THERMOCOLOR PAINTS

As yet the complete evaluation of changes in paint color has not been made. It can be stated that paints remained bonded to the surfaces applied and some changed color. The complete results will be reported at a later date.

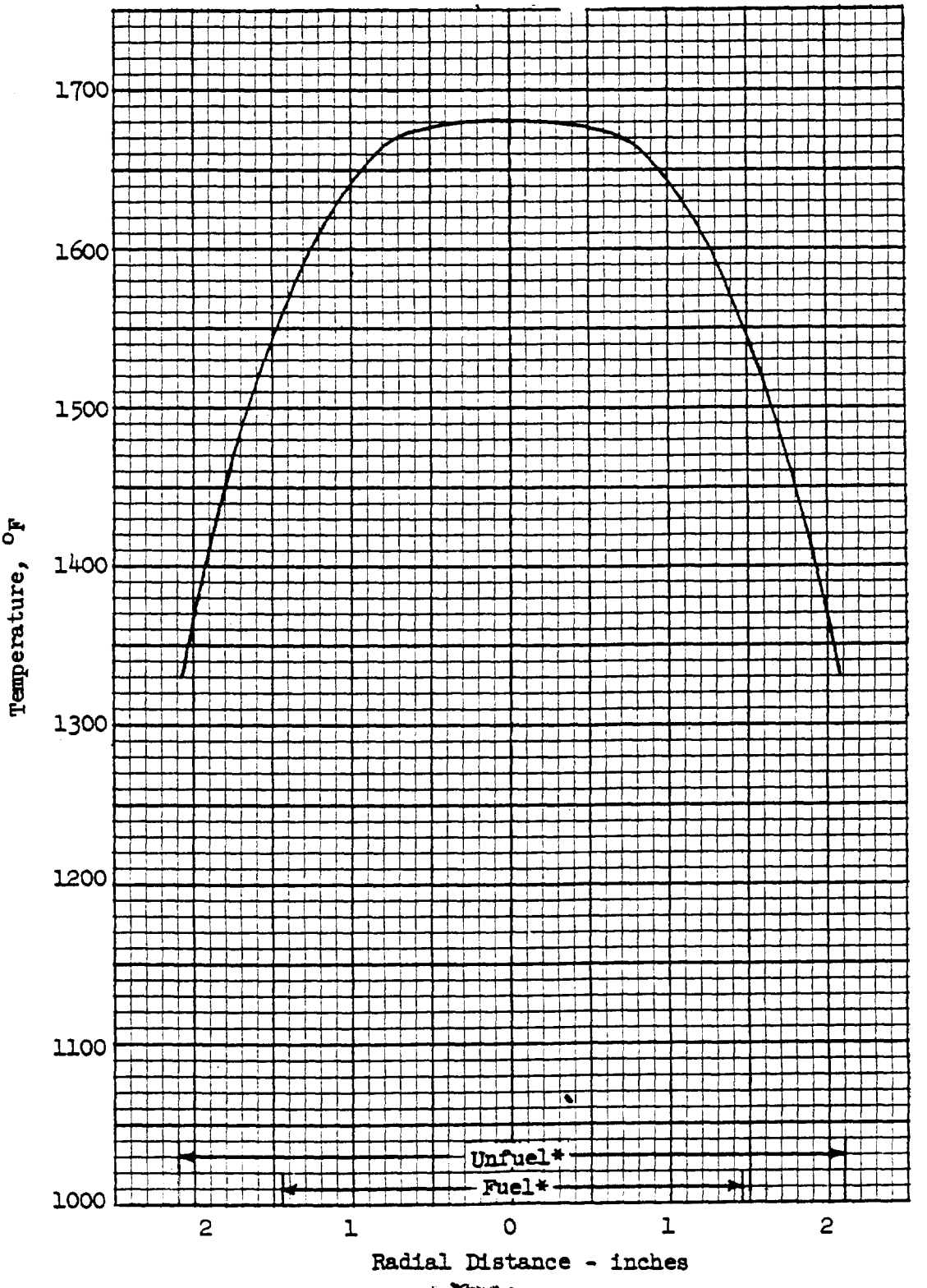
REAR GRID PLATE

Figure 1.4-12 pictures the rear grid plate of the L2E-1 after test and shows the symmetrical elongation of the plate holes. This elongation is undoubtedly the result of a radial temperature gradient established on the grid plate by cooling air

flowing down the outside unfueled tubes of the insert. A stress analysis is now being performed to determine temperatures and stresses required to produce a measured deformation. The results of this analysis will be reported at a later date. Figure 1.5-18 shows the estimated radial grid temperature profile.

FIGURE 1.5-18

CARTRIDGE L2E-1
ESTIMATED RADIAL TEMPERATURE
OF REAR GRID



*Across flats dimension

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APPENDIX I Data obtained from the operation of the X39-5 engines through the CTF system are presented in figures A I-1 through A I-7. Data from the two engines on the CTF during the L2E-1 operation (engine numbers 5017 and 5028) are shown.

APPENDIX II Figures A II-1 through A II-22 show the history of the insert cartridge thermocouples for the 106 hours of endurance testing. Sudden drops in temperature of three thermocouples in figures A II-3 and 4 are probably due to malfunction of the recording equipment. In figure A II-14 the readings on two thermocouples which remain constant for several points are also thought to be the result of recorder malfunction. Data shown in figures A-II-21 and 22 are the result of increasing temperature tests to evaluate fission product release as a function of temperature.

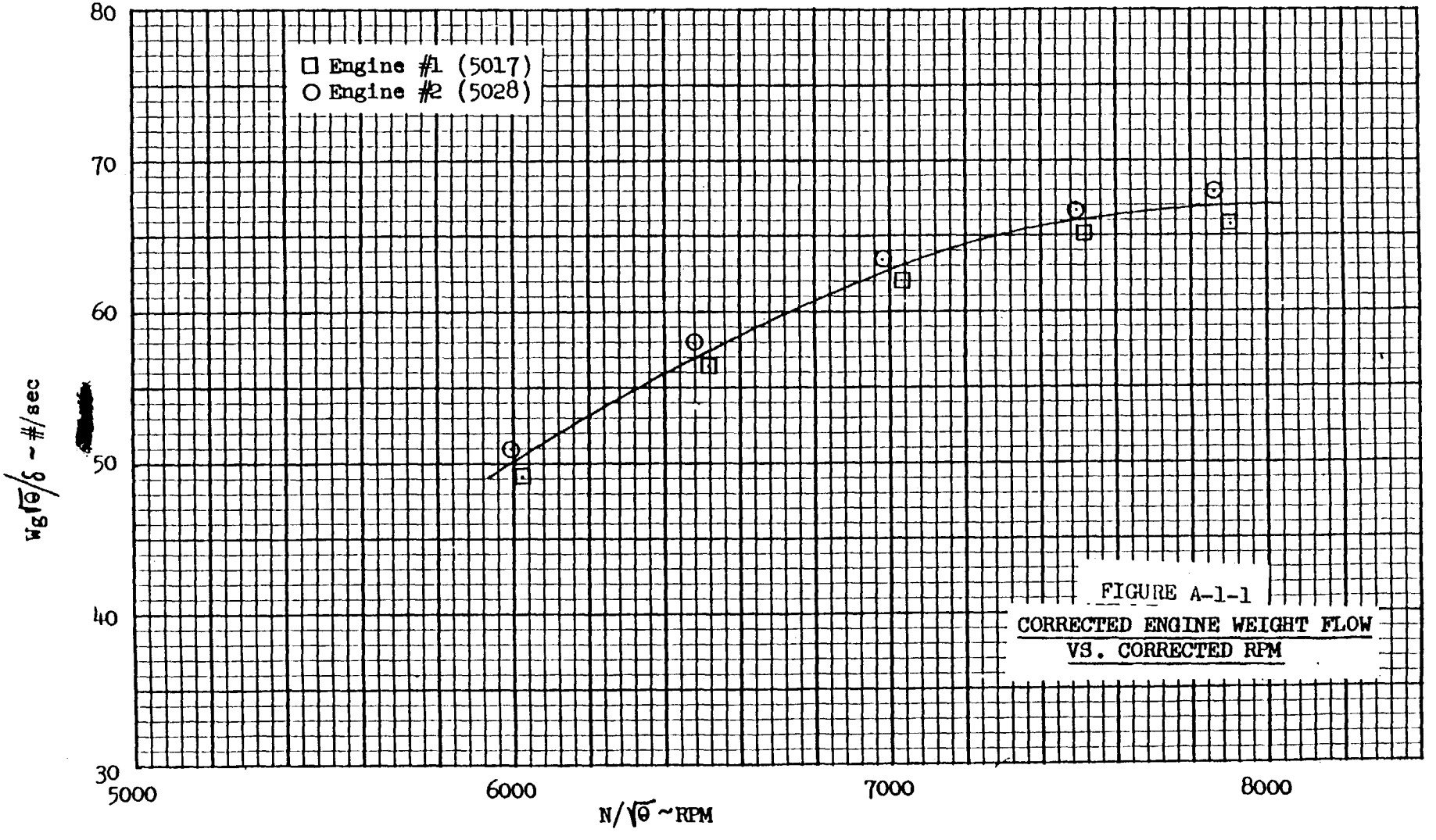

FIGURE A-1-1

CORRECTED ENGINE WEIGHT FLOW VS. CORRECTED RPM

1187170

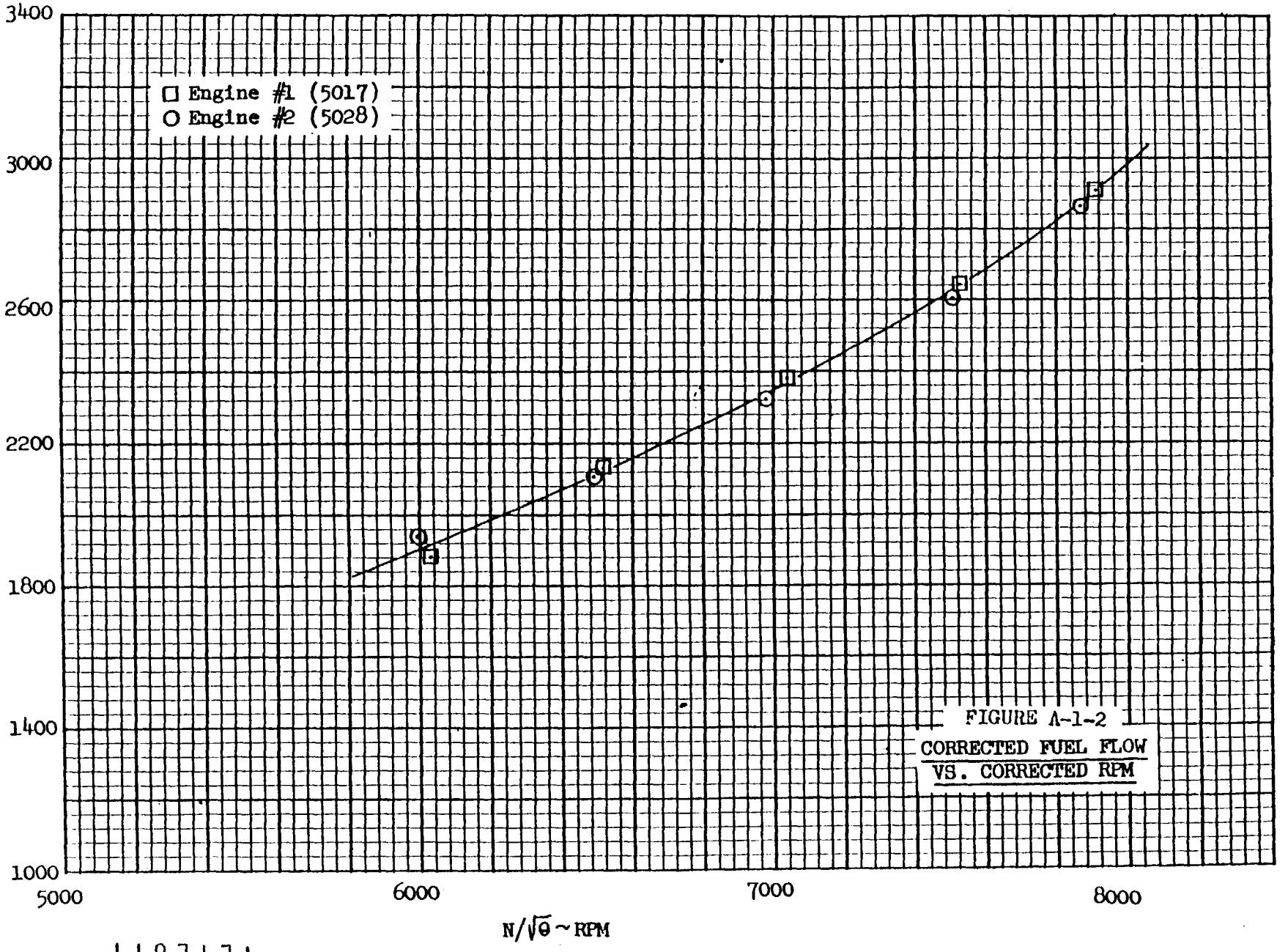

FIGURE A-1-2

CORRECTED FUEL FLOW VS. CORRECTED RPM

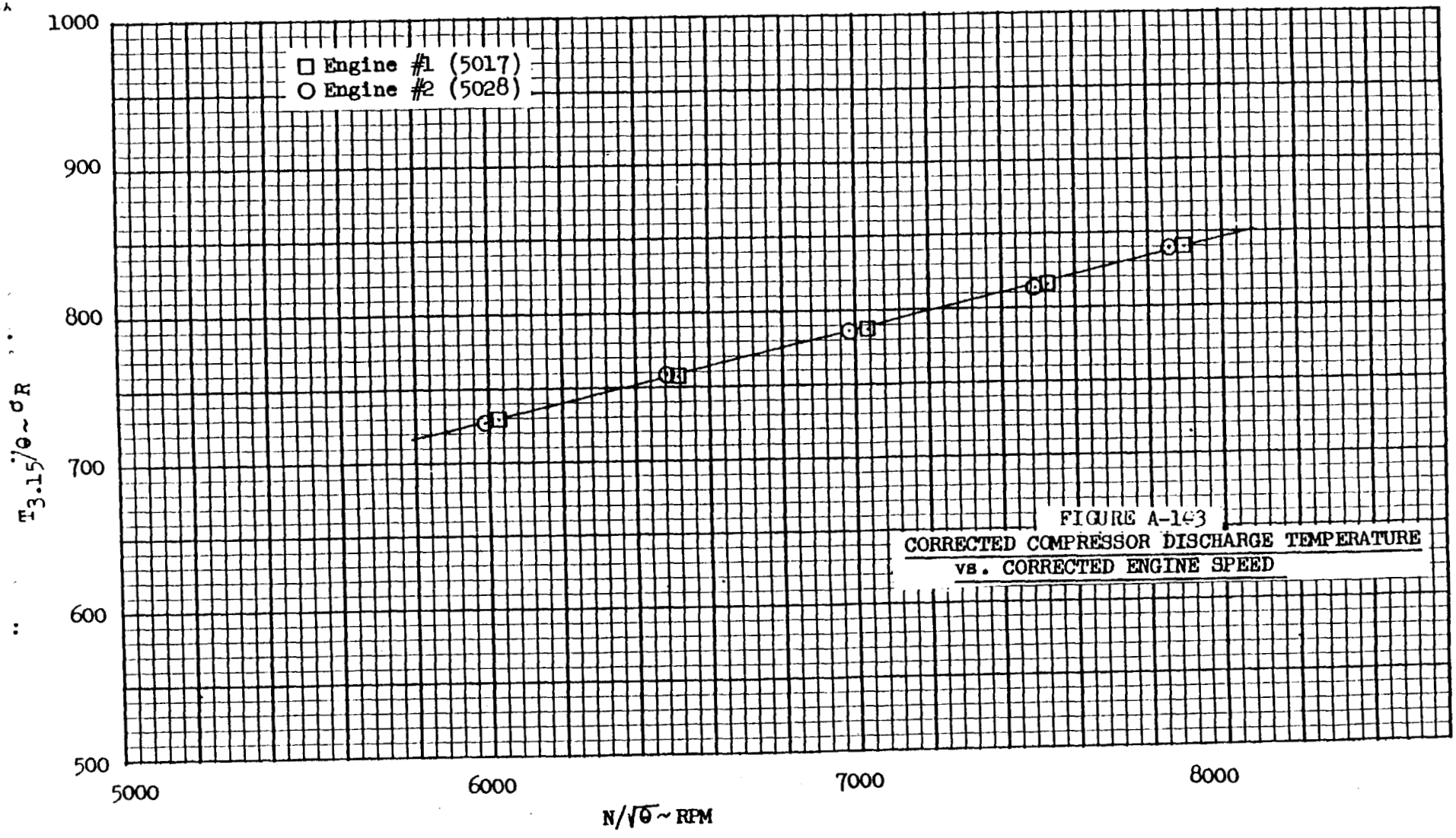

FIGURE A-103
CORRECTED COMPRESSOR DISCHARGE TEMPERATURE
vs. CORRECTED ENGINE SPEED

1187172

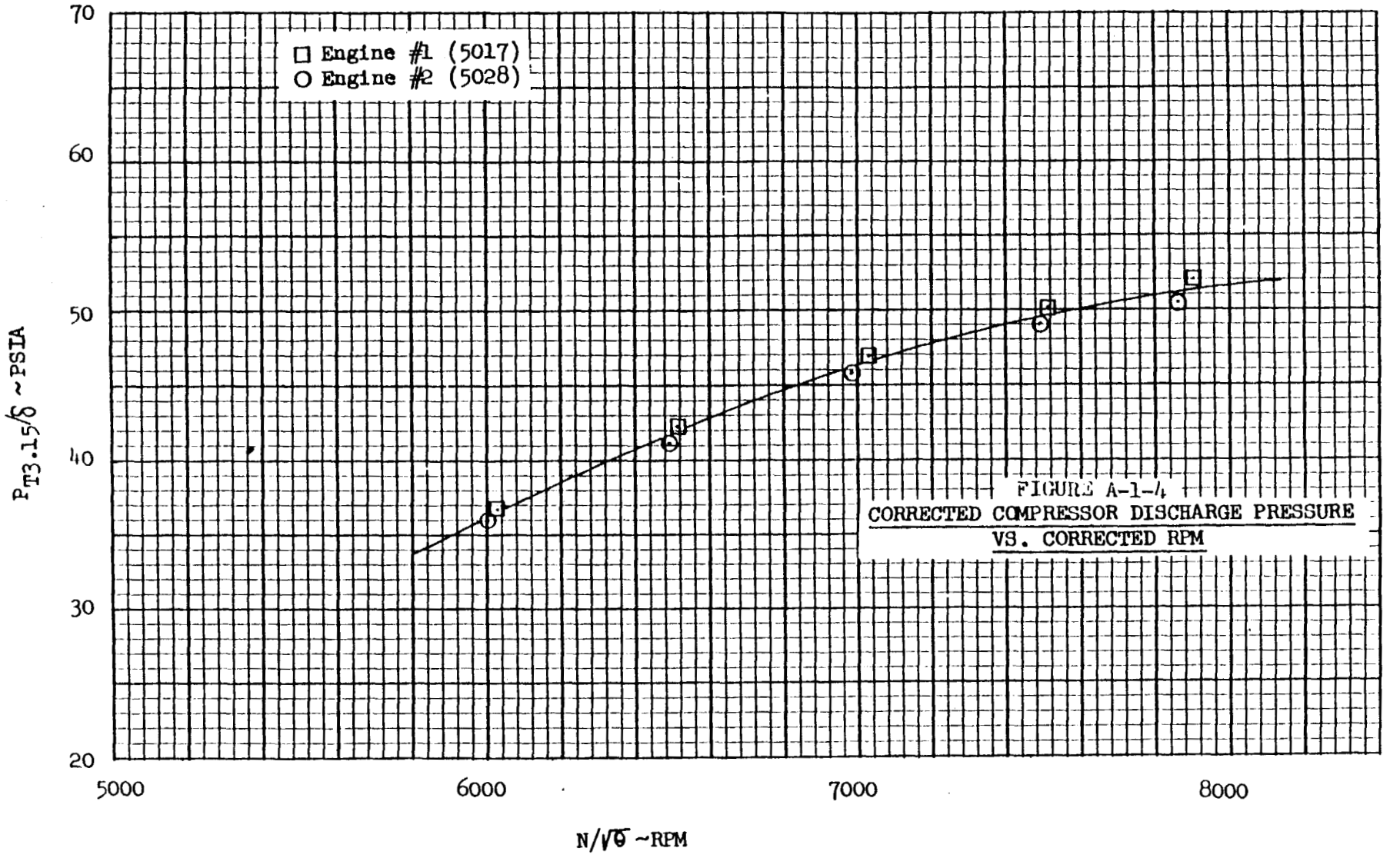

FIGURE A-1-4
CORRECTED COMPRESSOR DISCHARGE PRESSURE
VS. CORRECTED RPM

1187173

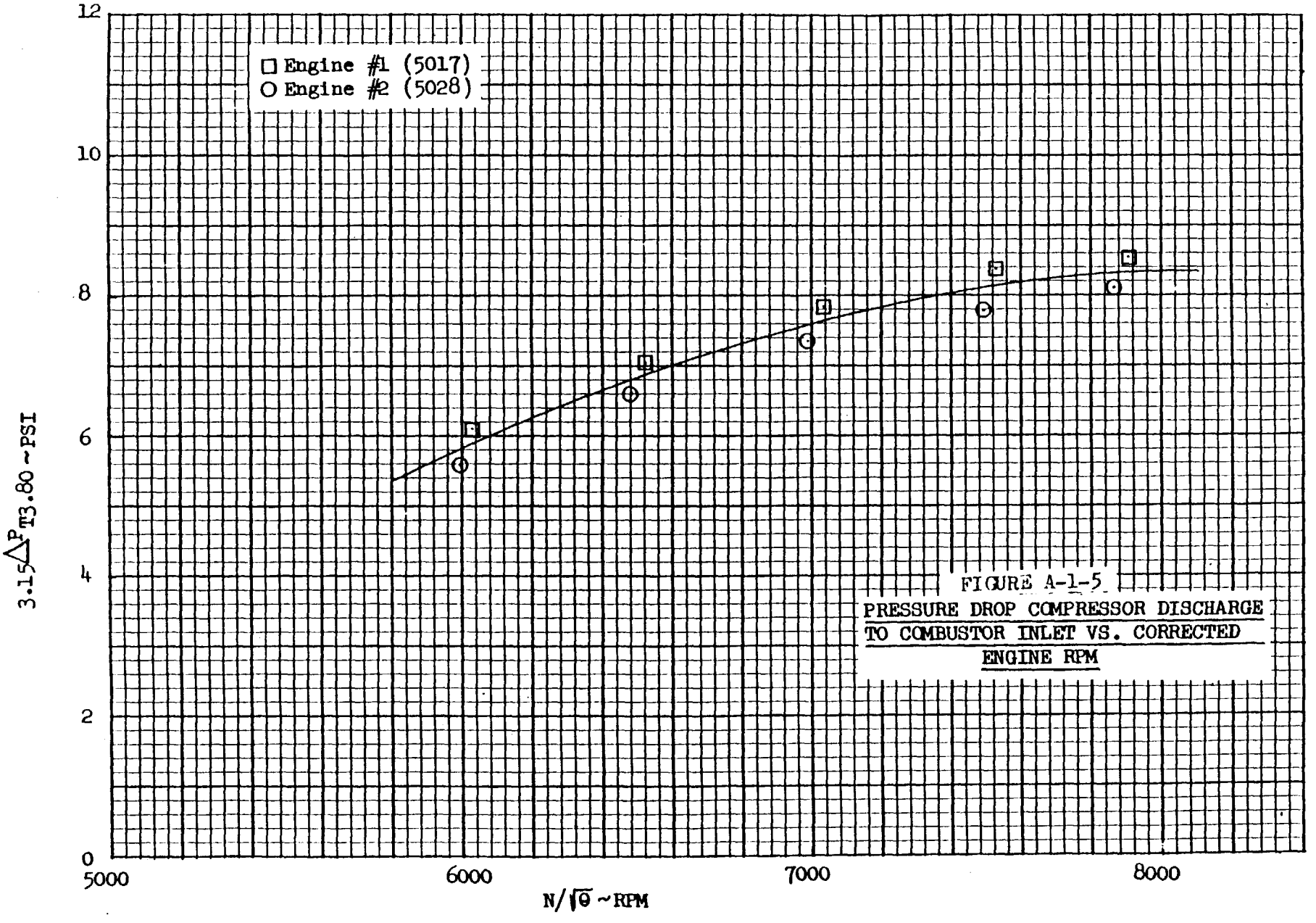

FIGURE A-1-5
PRESSURE DROP COMPRESSOR DISCHARGE TO COMBUSTOR INLET VS. CORRECTED ENGINE RPM

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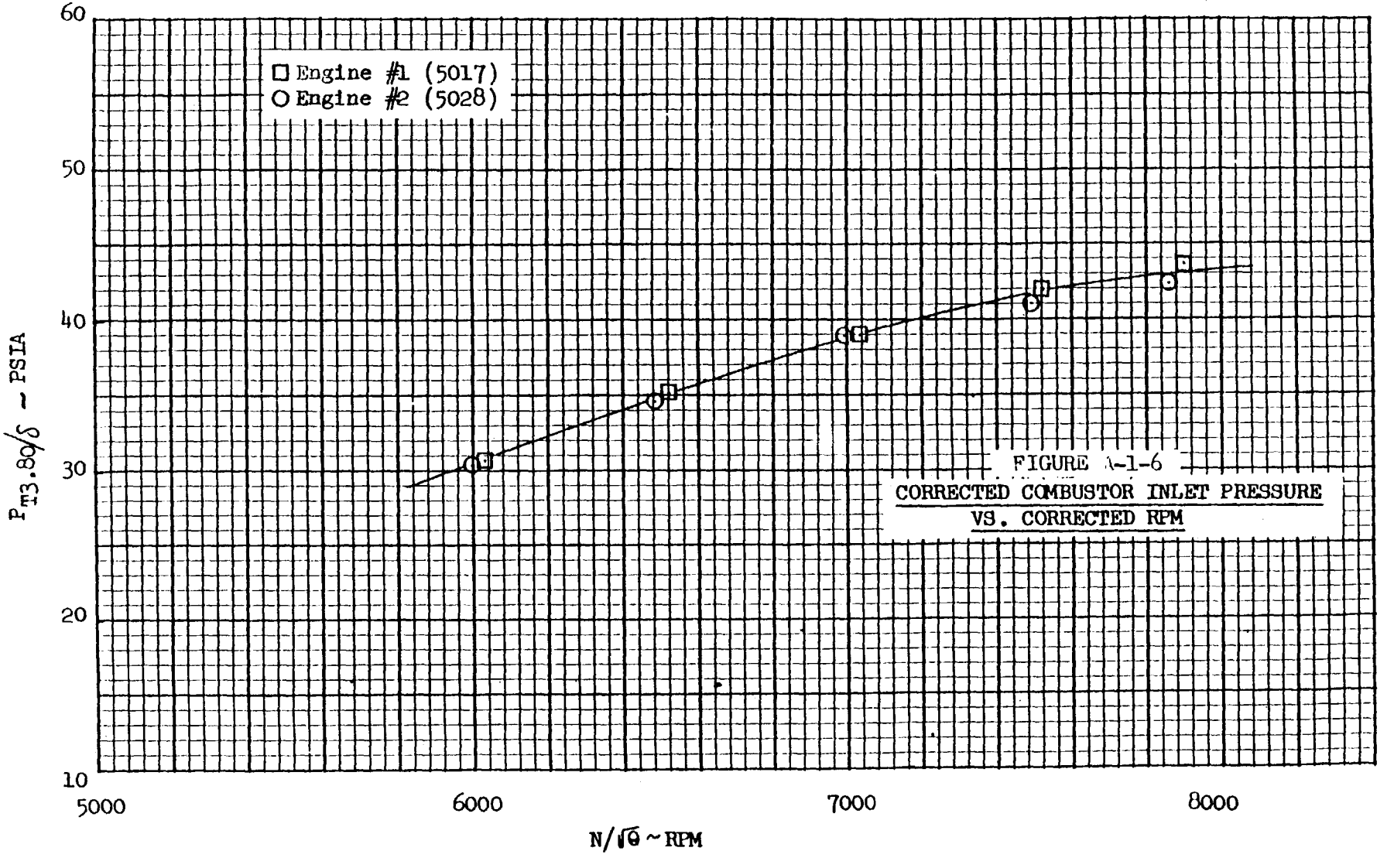

FIGURE A-1-6
CORRECTED COMBUSTOR INLET PRESSURE
VS. CORRECTED RPM

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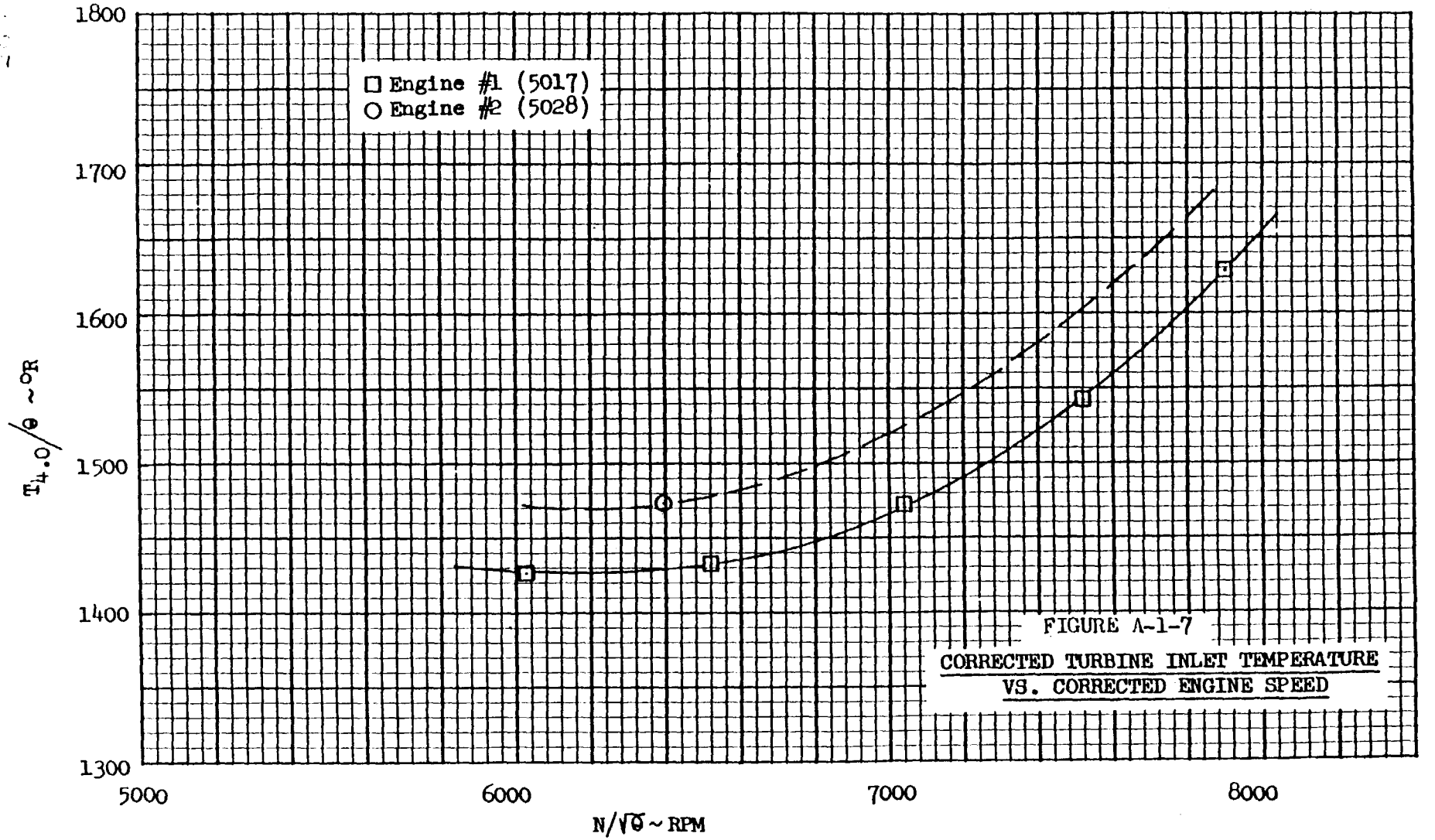

FIGURE A-1-7

CORRECTED TURBINE INLET TEMPERATURE VS. CORRECTED ENGINE SPEED

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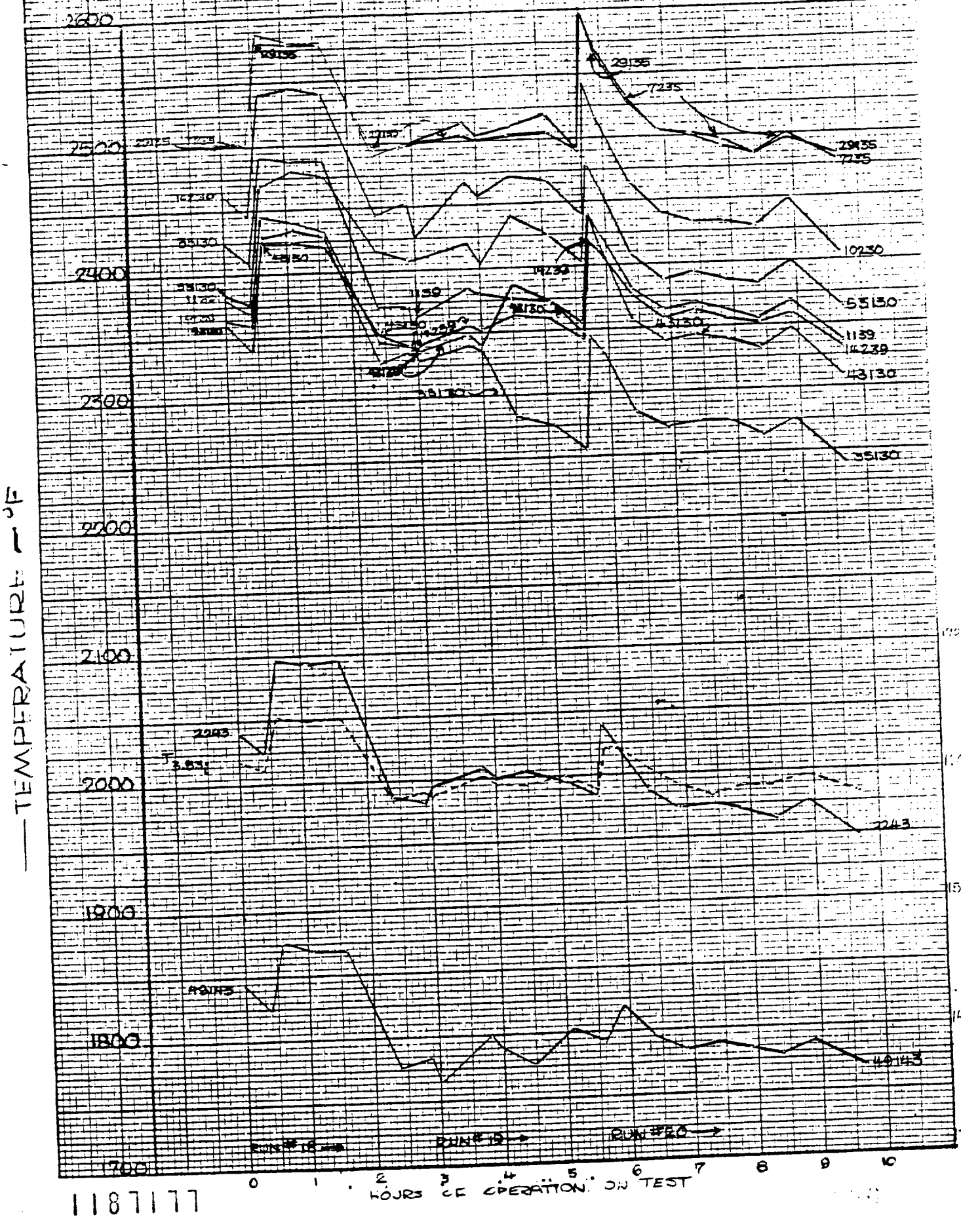
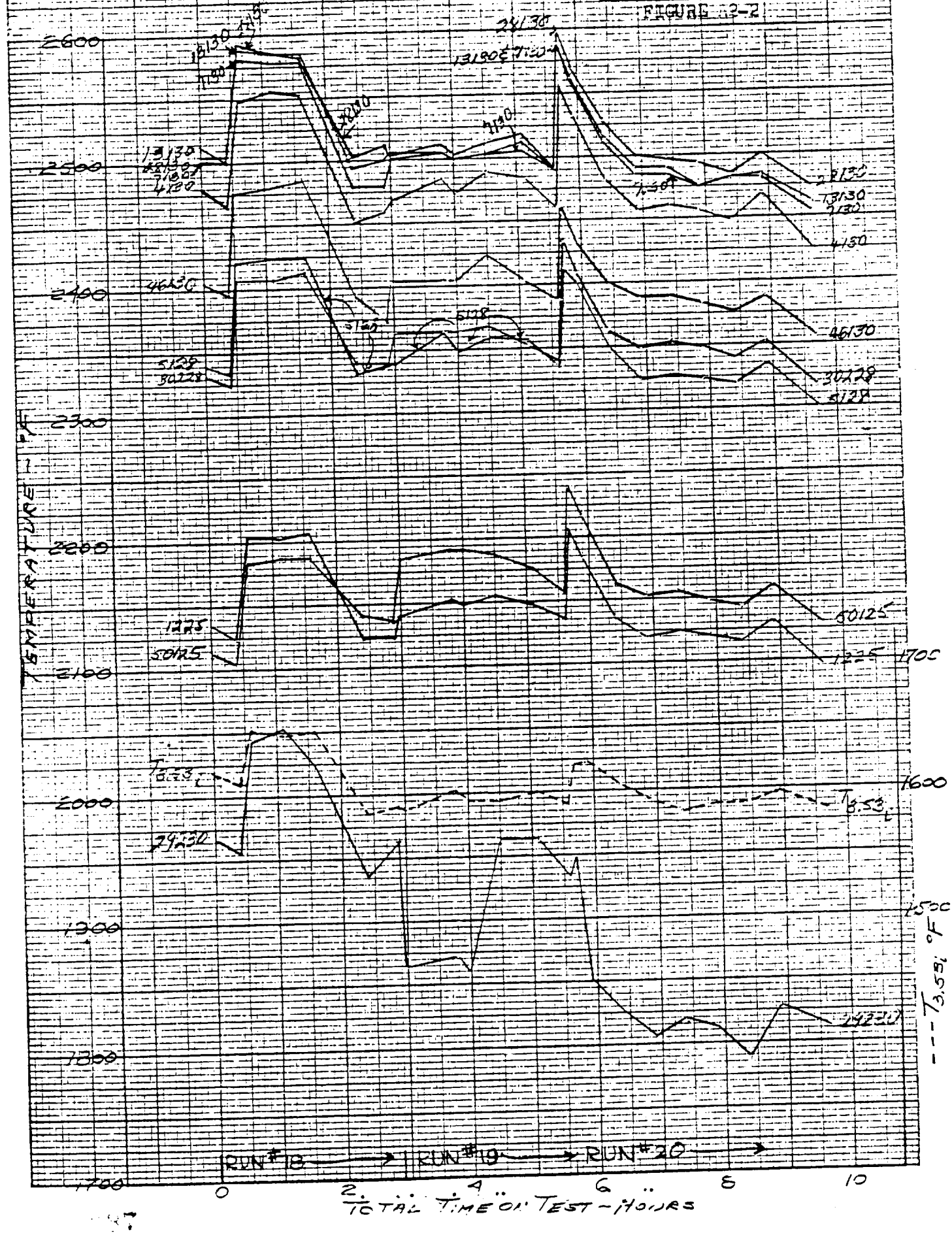
FIGURE A2-


TEMPERATURE - °F
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
0
1
2
3
4
5
6
7
8
9
10
HOURS OF OPERATION ON TEST
RUN #18
RUN #19
RUN #20
29135
7235
10230
55130
1159
14239
43130
35130
2243
49143


L.E.T. No. 17
INSERT L2E-1 FUEL
TEMPERATURES
FIGURE 2-2
TEMPERATURE - °F
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
13130
28130
7130
4130
46130
5128
30228
1225
50125
29230
1700
1600
1500
$T_{3.53_i}$
$T_{3.53_i}$ °F
RUN #18
RUN #19
RUN #20
0
2
4
6
8
10
TOTAL TIME ON TEST - HOURS

1187178

FIGURE A2-3

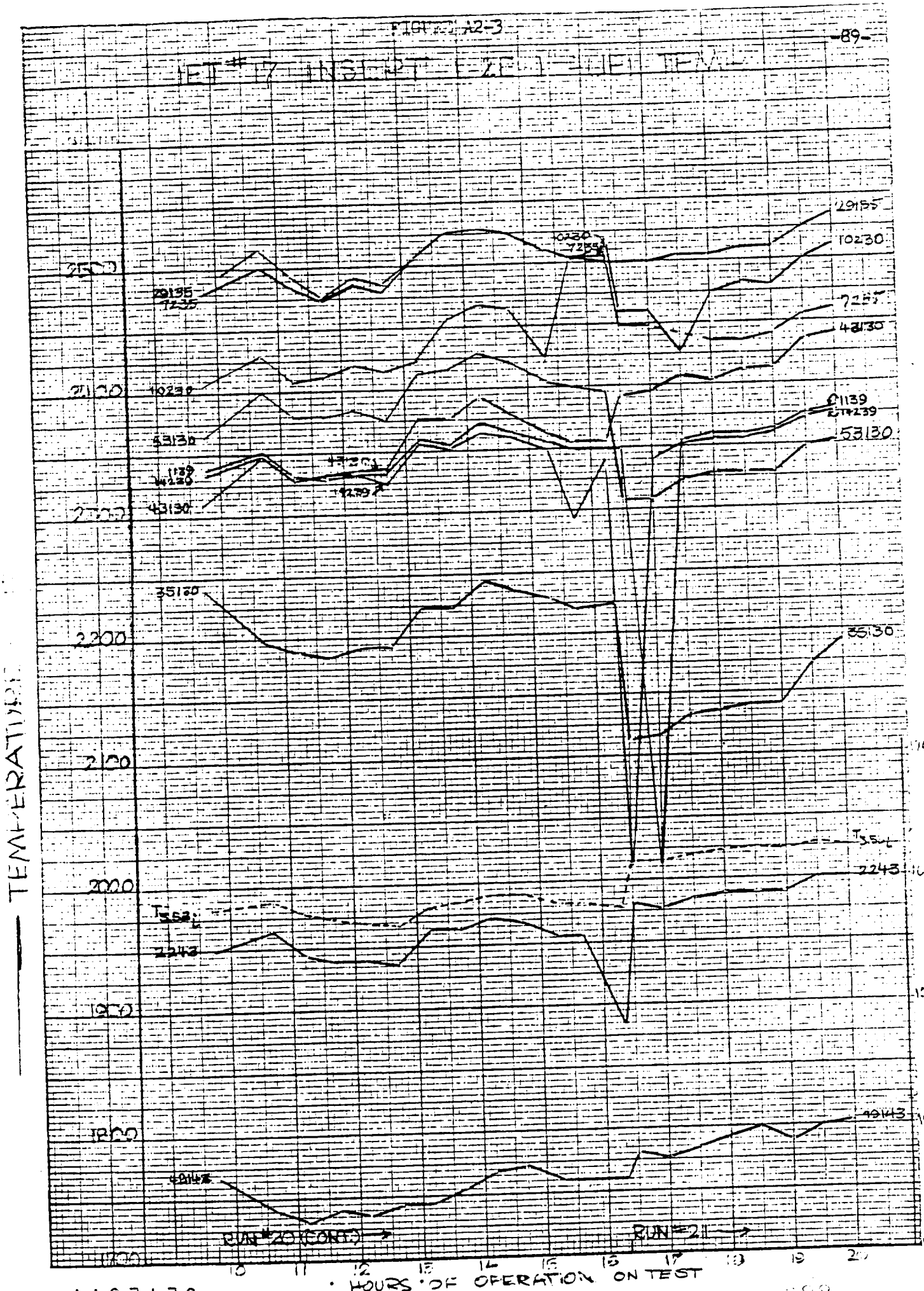


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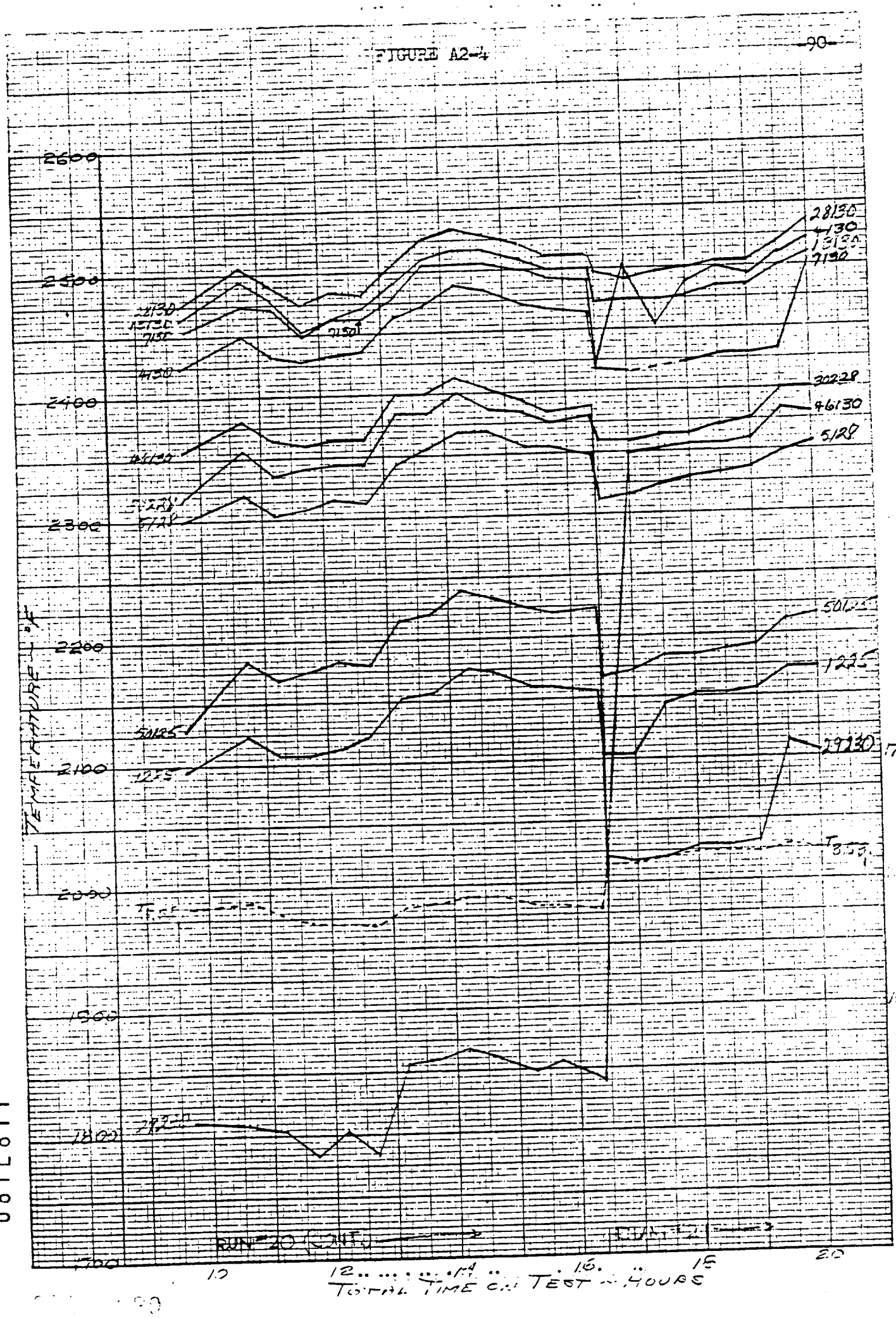
FIGURE A2-4



0811811

FIGURE A2-5

TEST NO. 17

INSERT K2E-1 FUEL

TEMPERATURES

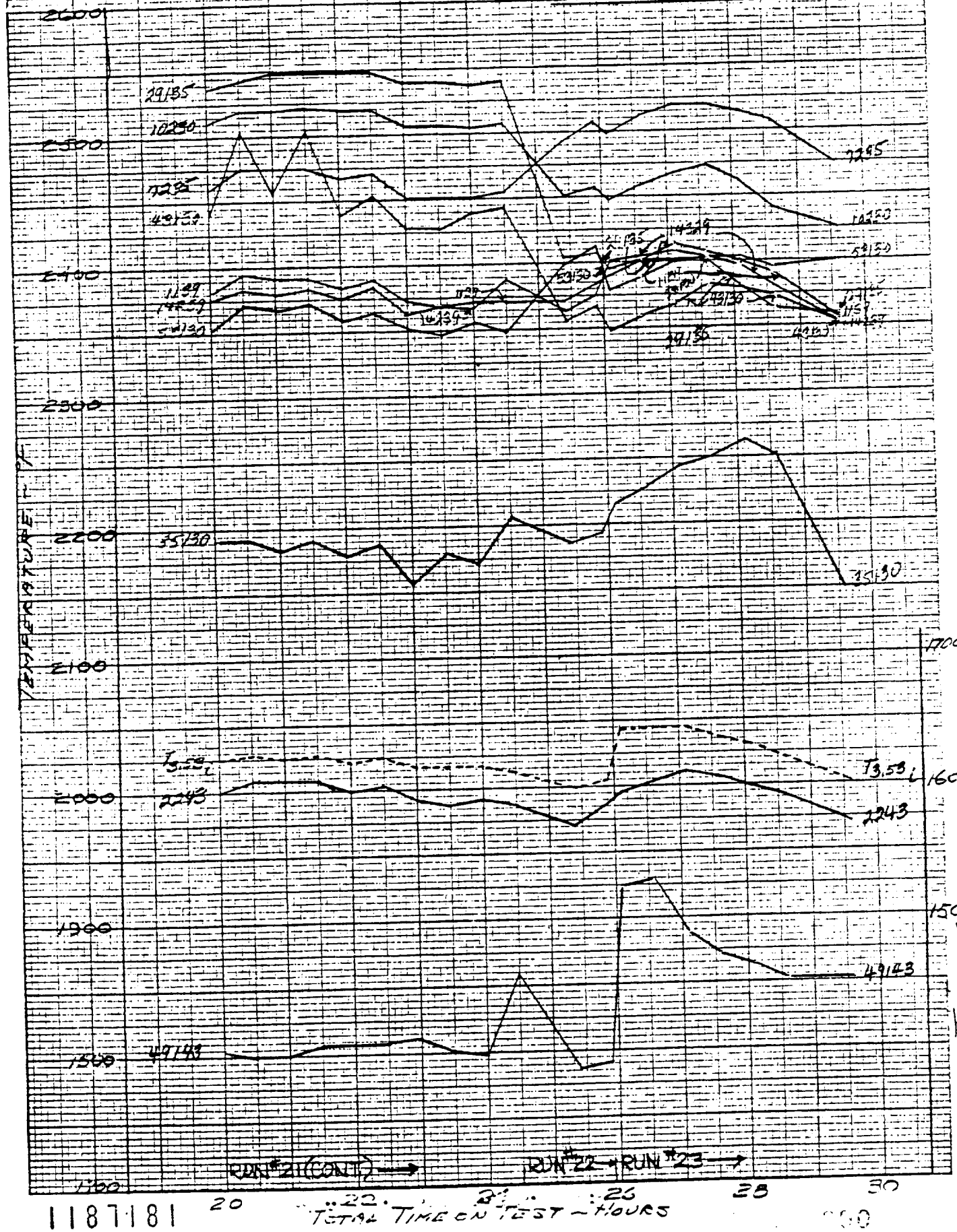
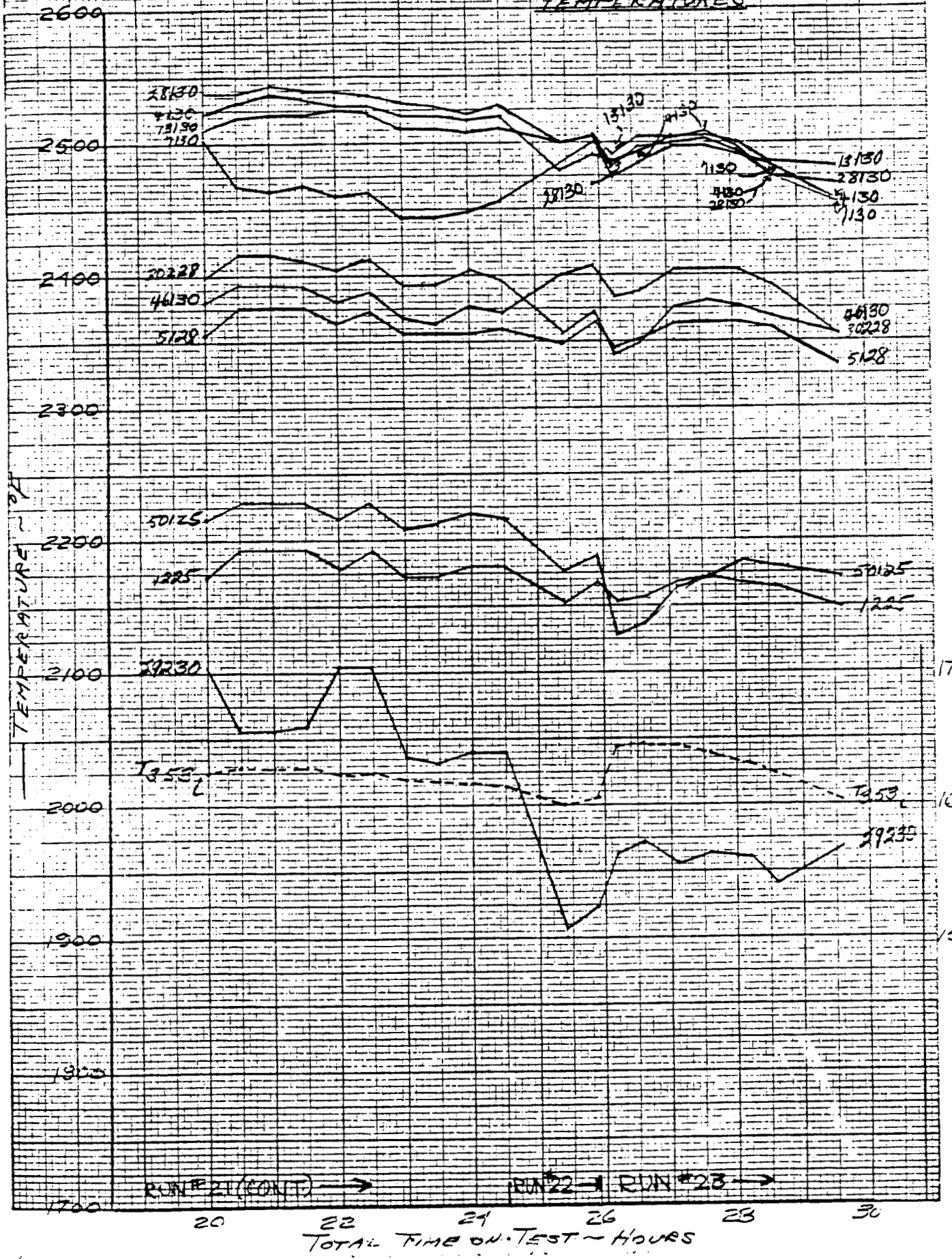


FIGURE A2-6

LET No. 17
INSERT L2E-1 FUEL TEMPERATURES

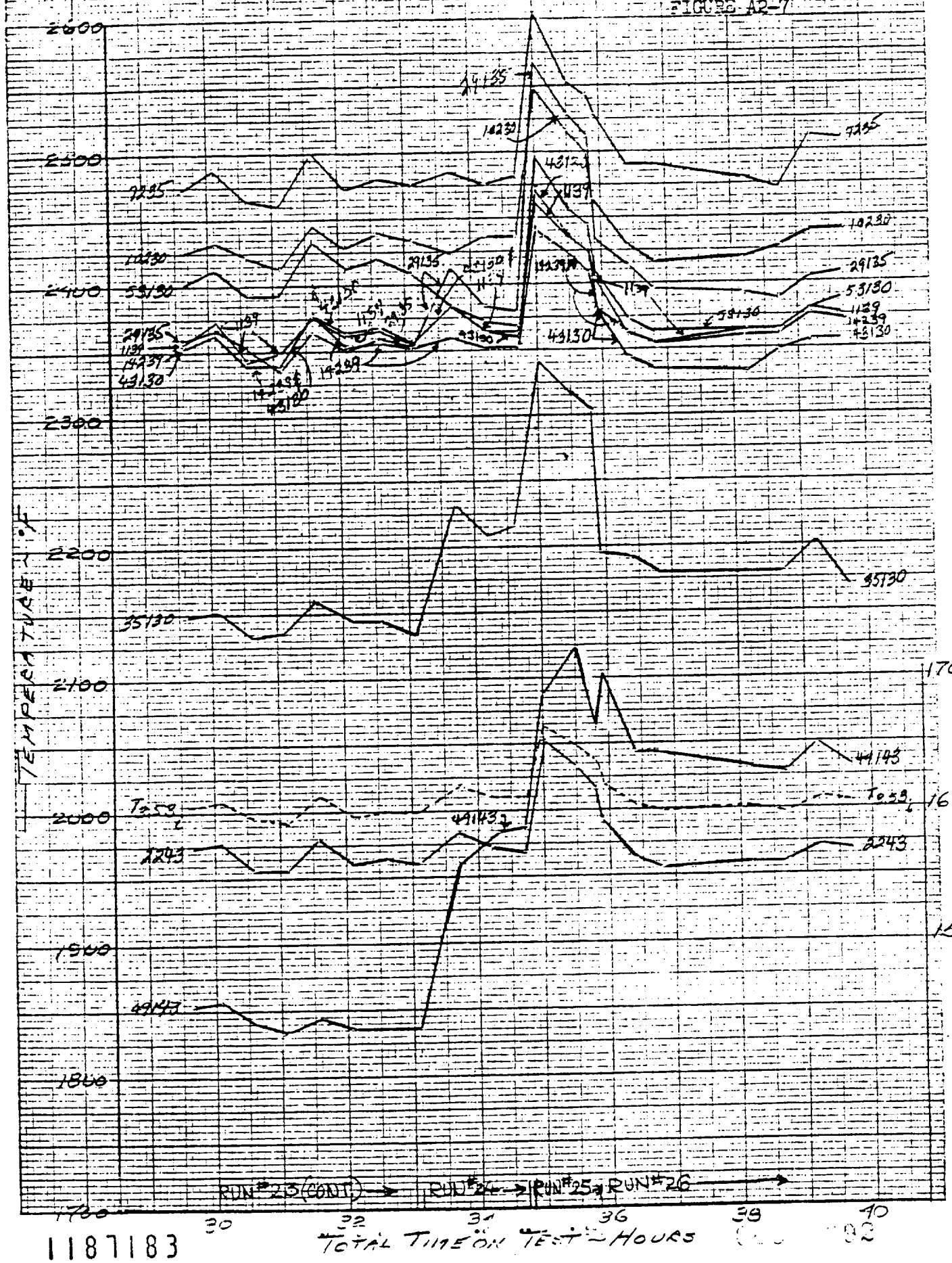


1181182

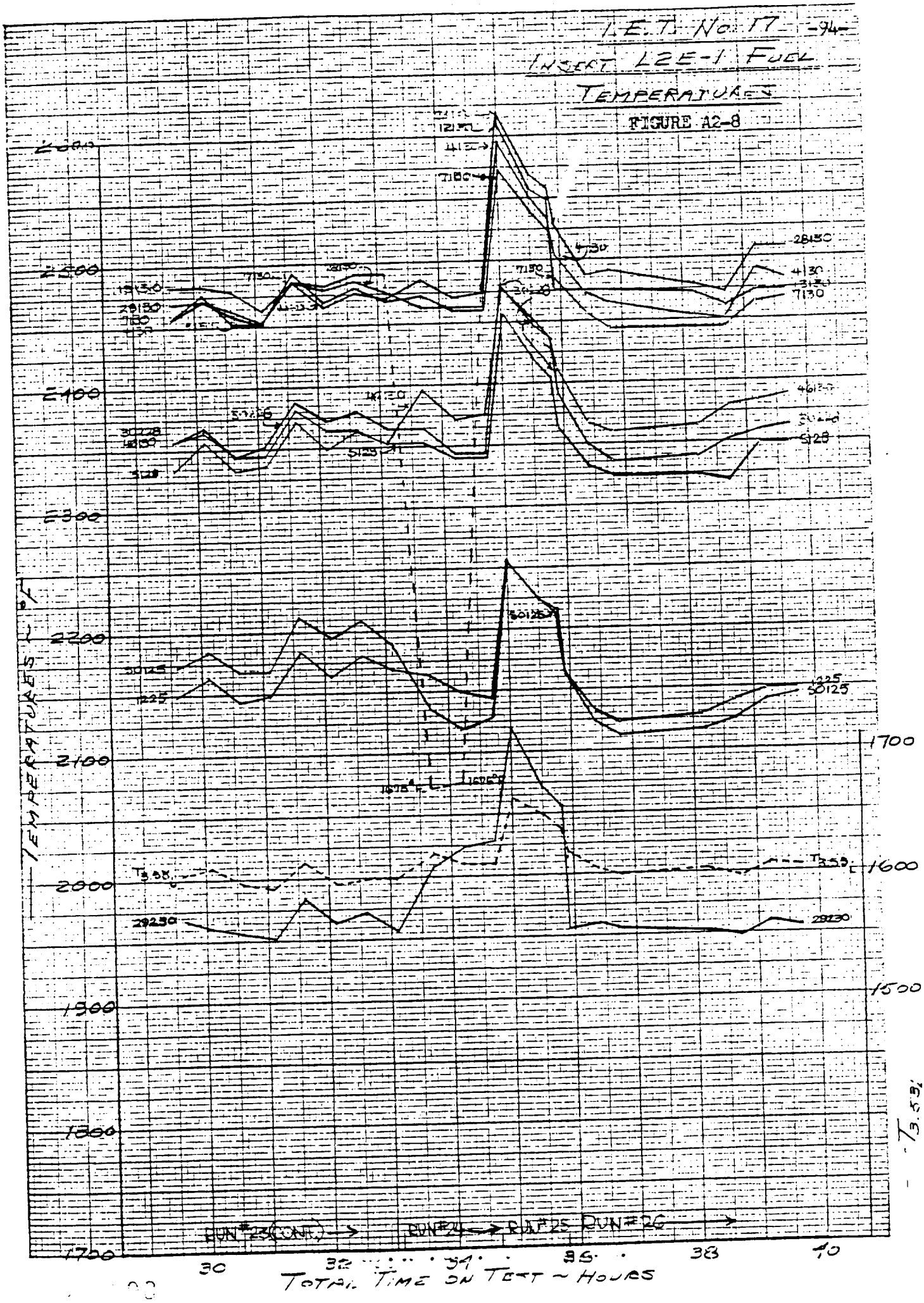
I.E.T. No. 17

INSERT LZE-1 FUEL TEMPERATURES

FIGURE AR-7



1187183

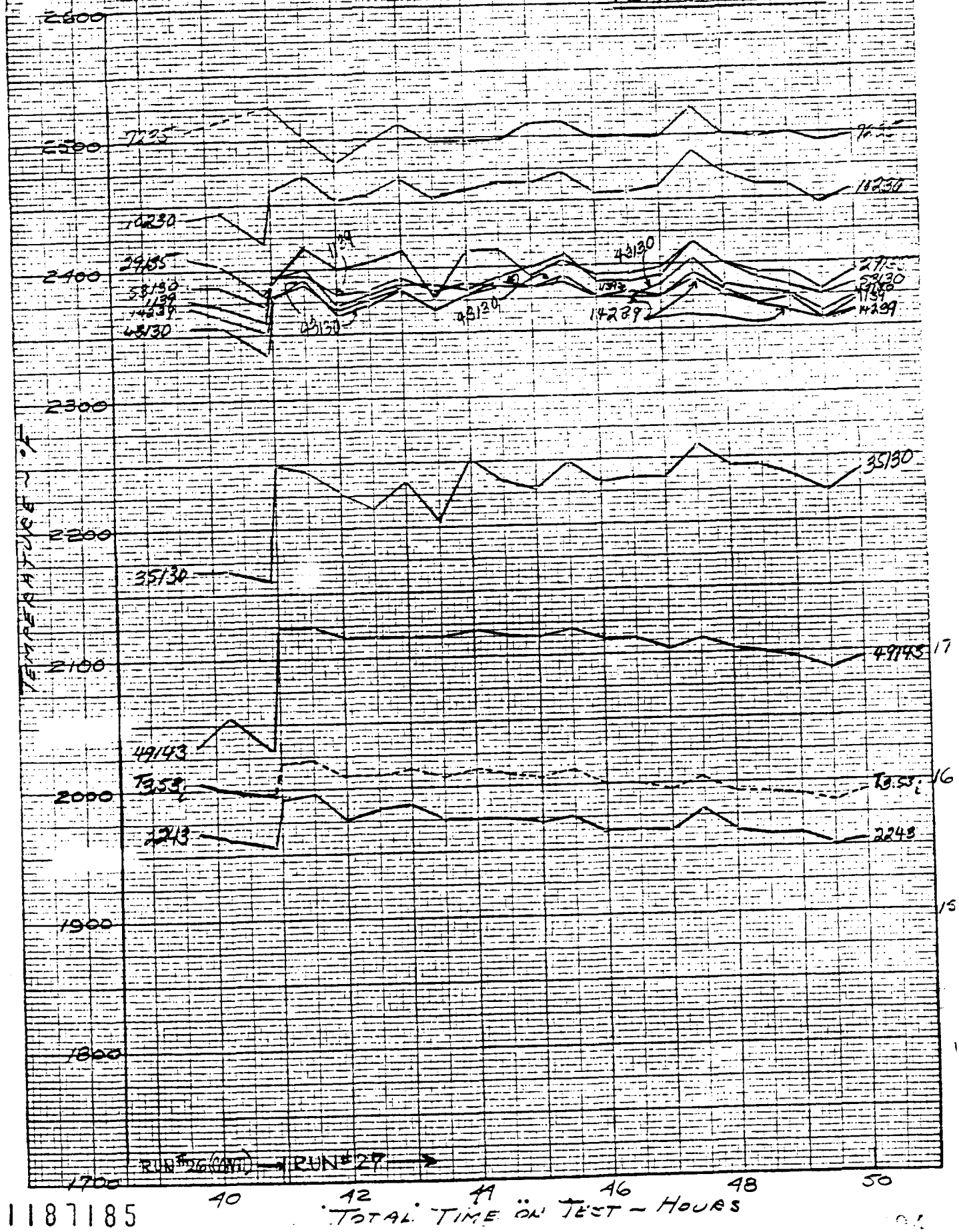

I.E.T. No. 17
-94-
INSERT L2E-1 FUEL
TEMPERATURES
FIGURE A2-8
TEMPERATURES ~ °F
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1700
1600
1500
RUN #23 (CONT.) →
RUN #24 → RUN #25 RUN #26 →
30
32
34
36
38
40
TOTAL TIME ON TEST ~ HOURS
28130
4130
7130
46130
5128
50125
1225
29230
T3.53

1187184

FIGURE A2-9

I.E.T. No. 17

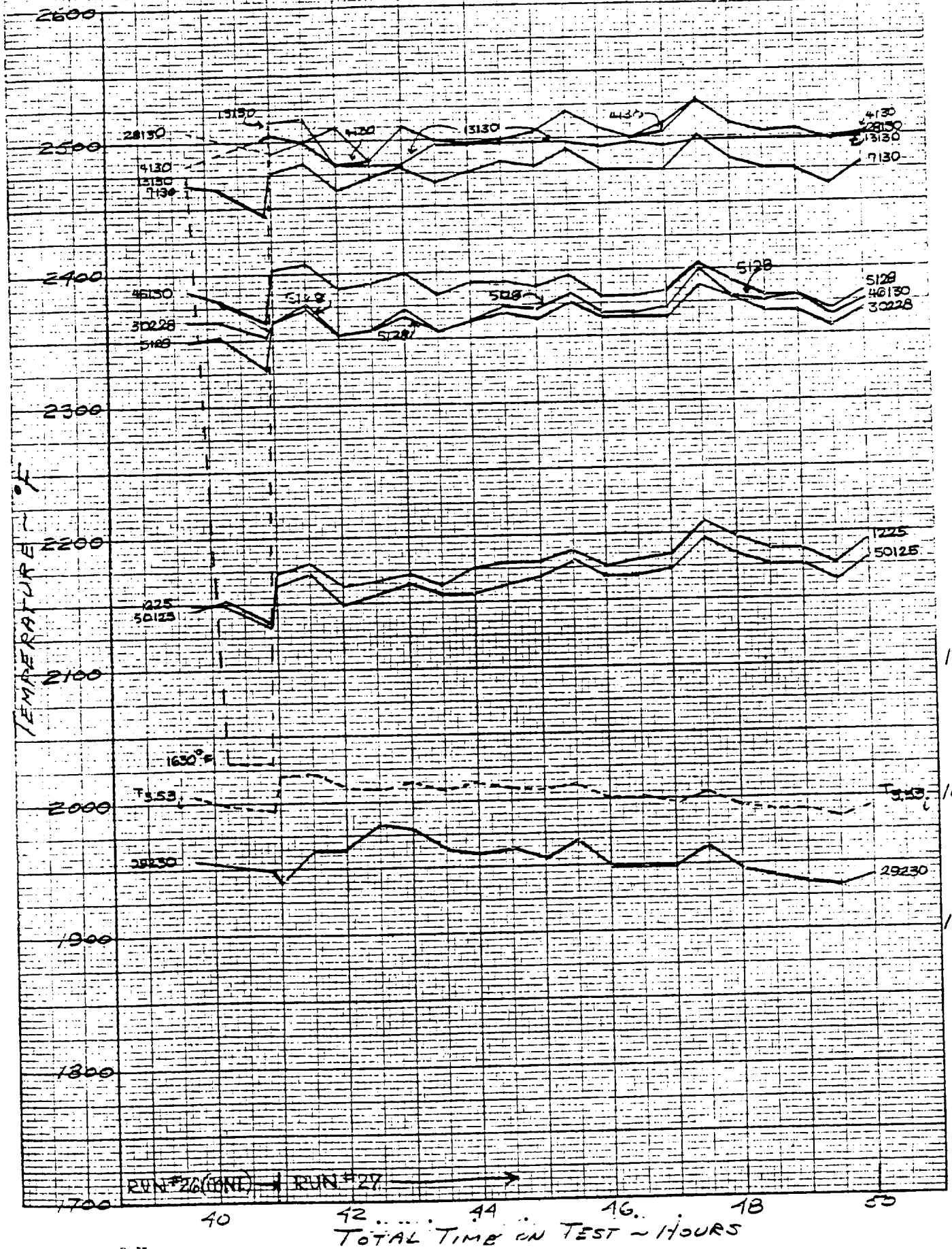
INSERT 12E-1 FUEL TEMPERATURES



I.E.T. No. 17

INSERT L2E-1 FUEL TEMPERATURES

FIGURE A2-10

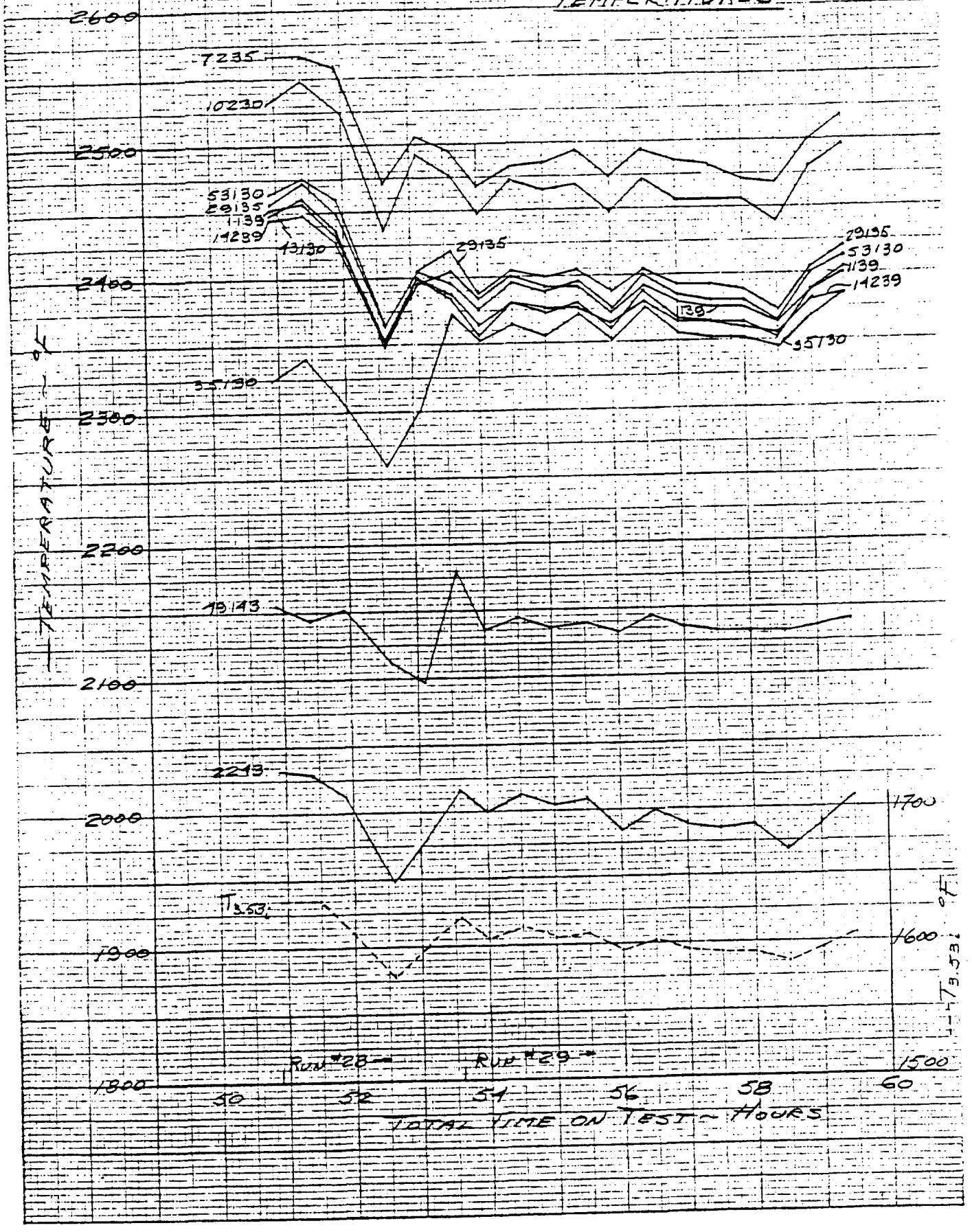


9811886

FIGURE A2-11

I.E.T. No. 17

INSERT LZE-1 FUEL TEMPERATURES



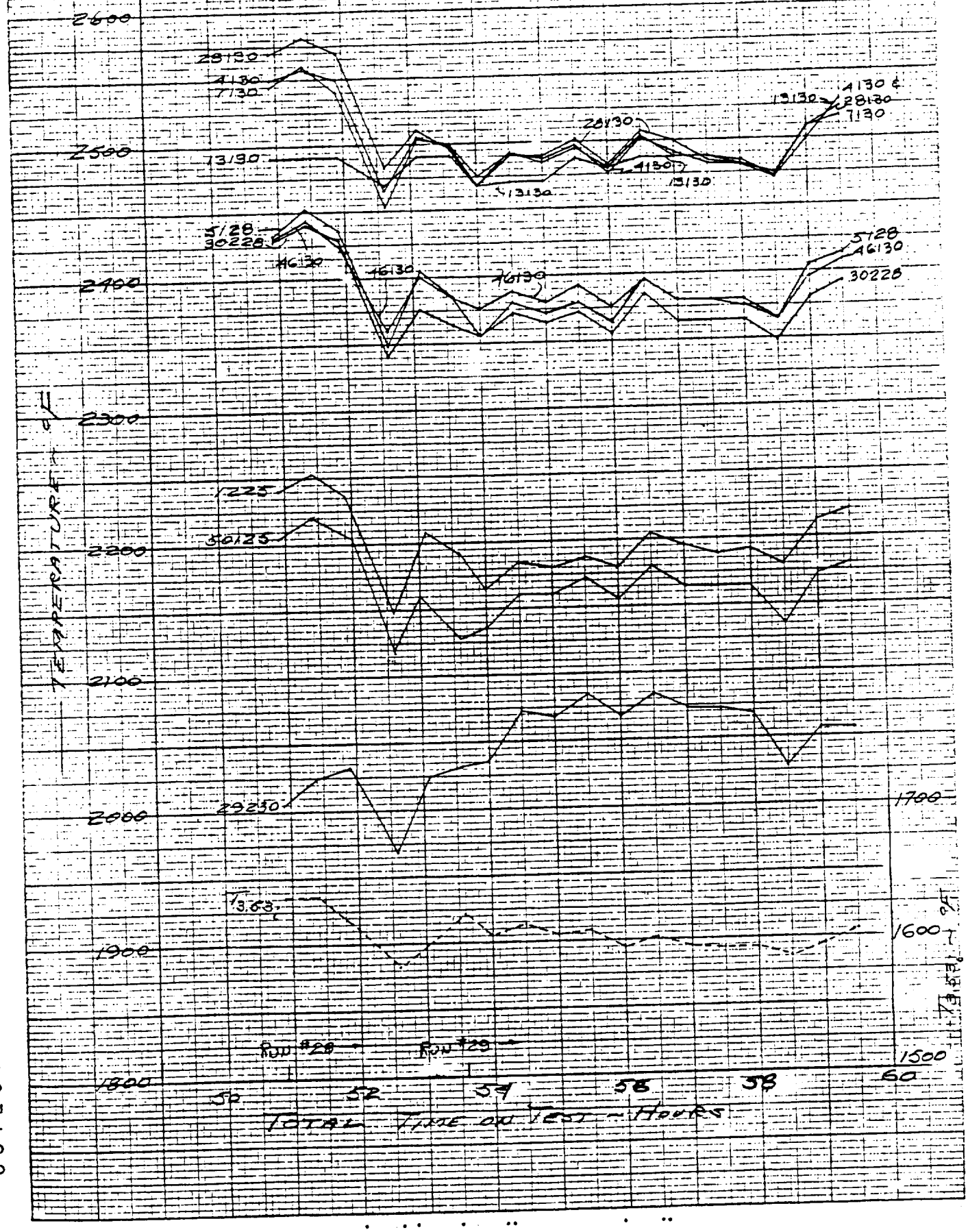
1187187

J-E.T. No. 17

JET-A 2-1 FUEL

TEMPERATURES

FIGURE A2-12

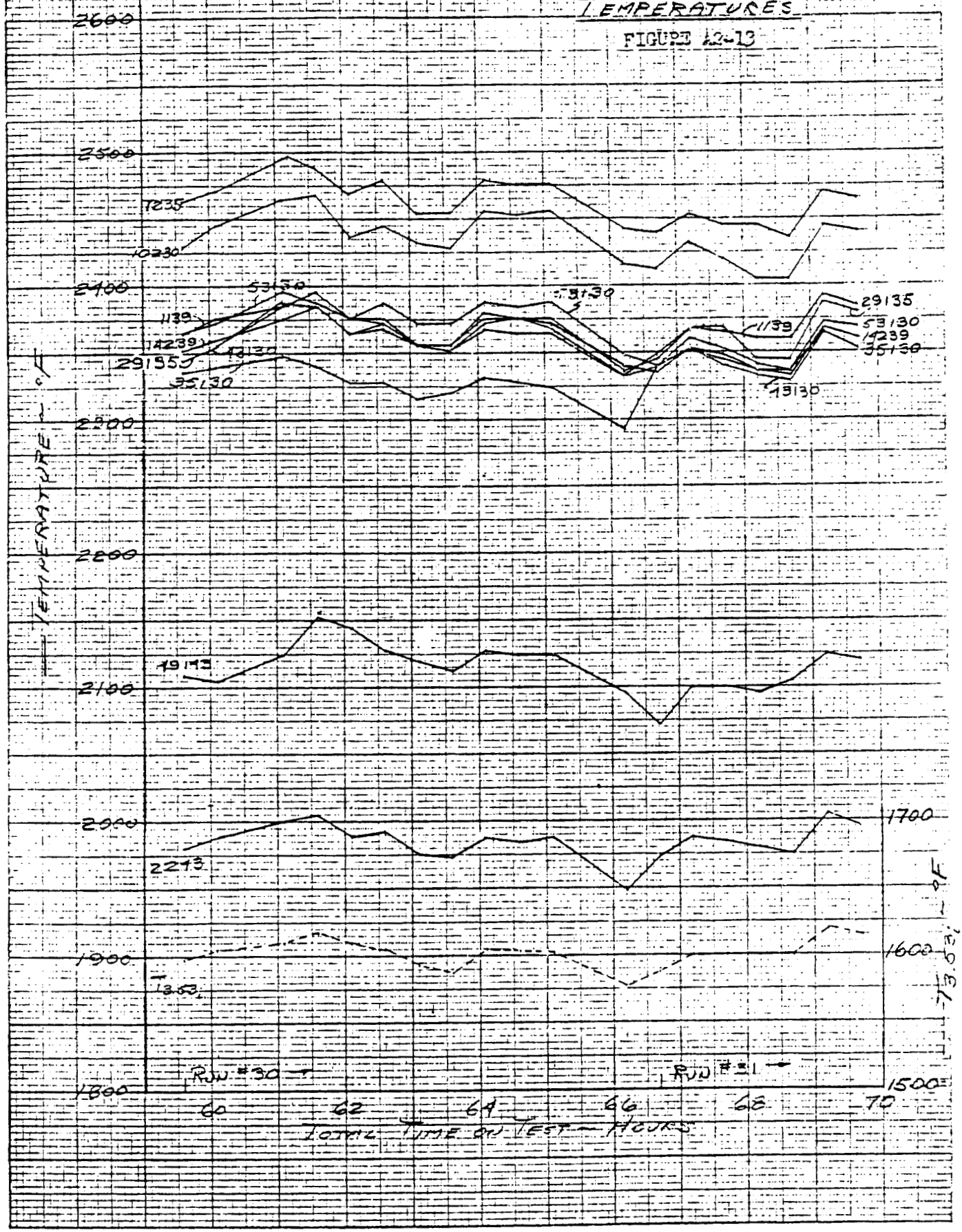


11871188

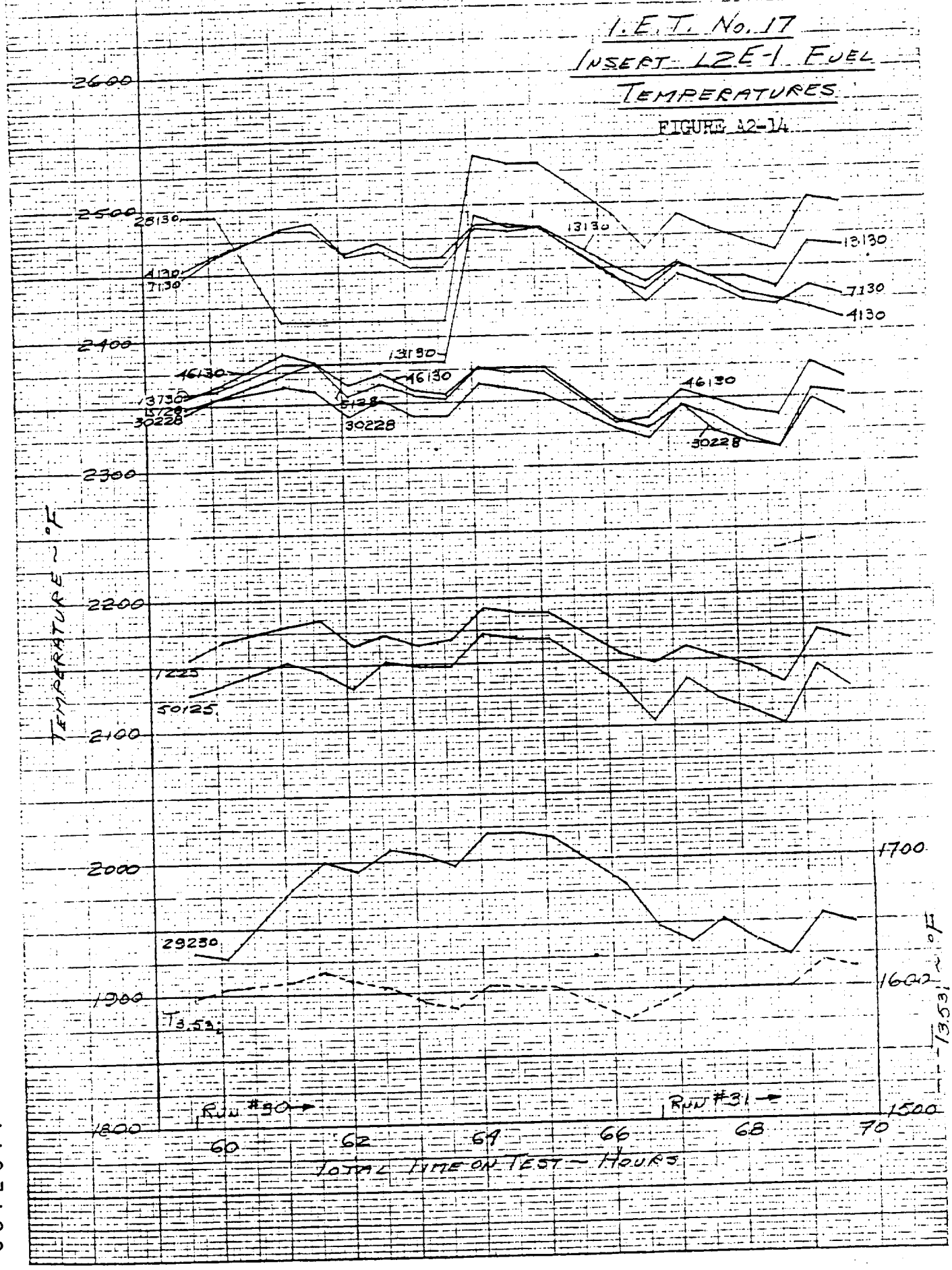
I.E.T. No. 17

INSERT L2E-1 FUEL TEMPERATURES

FIGURE L2-13



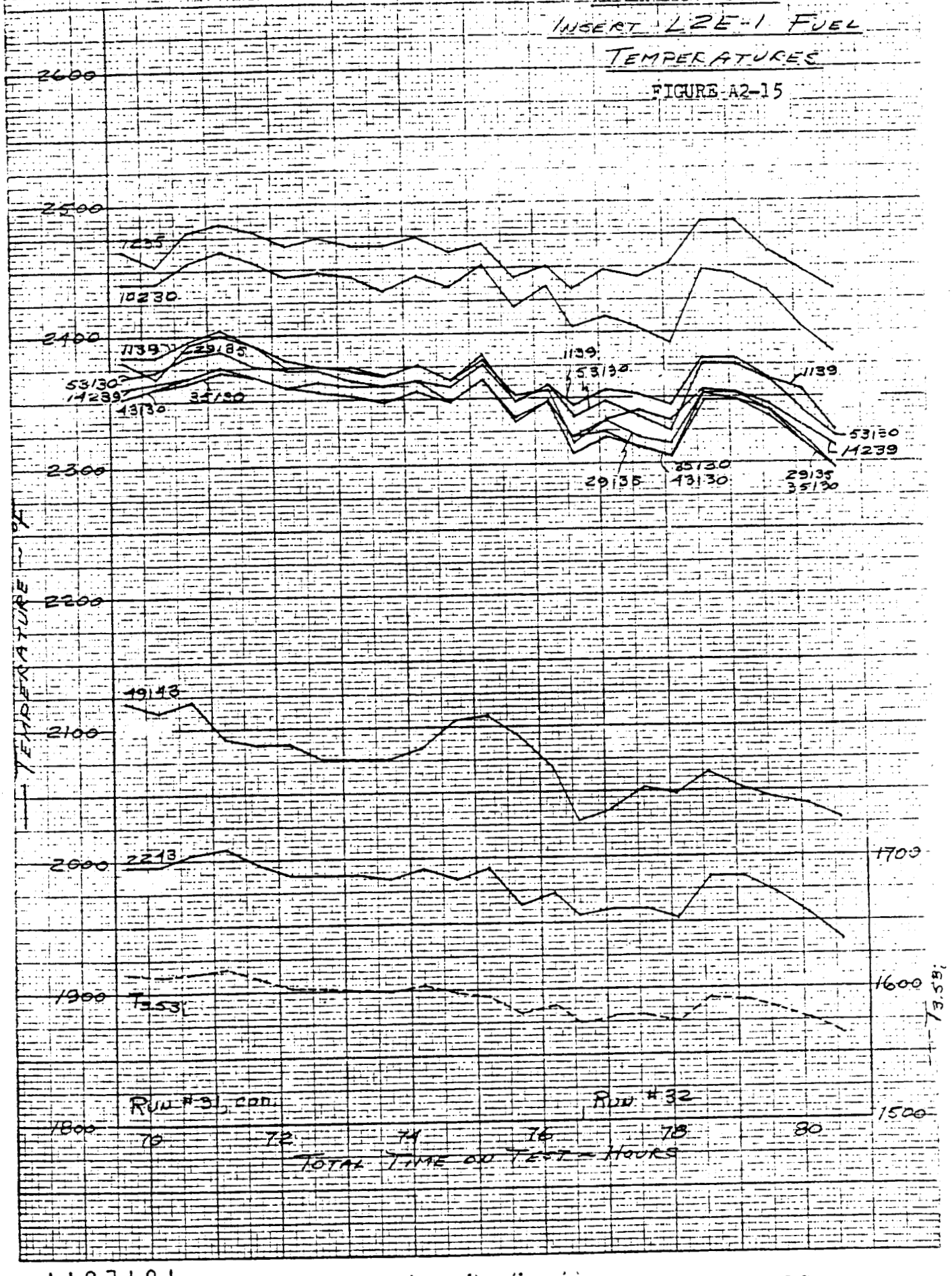
1187189


I.E.T. No. 17
INSERT L2E-1 FUEL
TEMPERATURES
FIGURE A2-14
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
28130
4130
7130
13130
13130
7130
4130
13130
46130
46130
46130
13730
15128
30228
5128
30228
30228
1225
50125
29230
$T_{3.53}$
$T_{3.53}$ ~ °F
TEMPERATURE ~ °F
RUN #30
RUN #31
60
62
64
66
68
70
TOTAL TIME ON TEST ~ HOURS

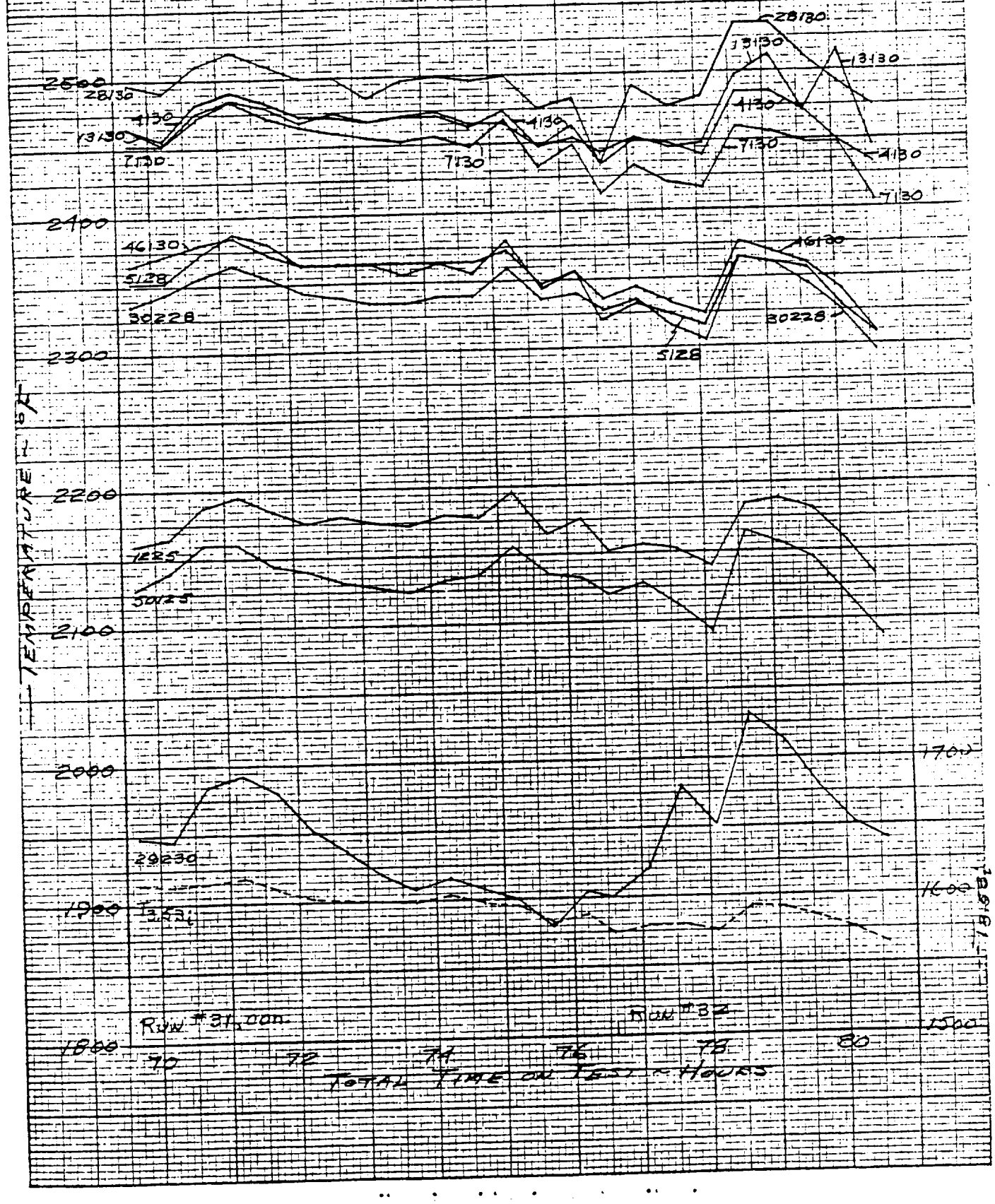
0611811

L.E.T. No. 17
INSERT L2E-1 FUEL
TEMPERATURES

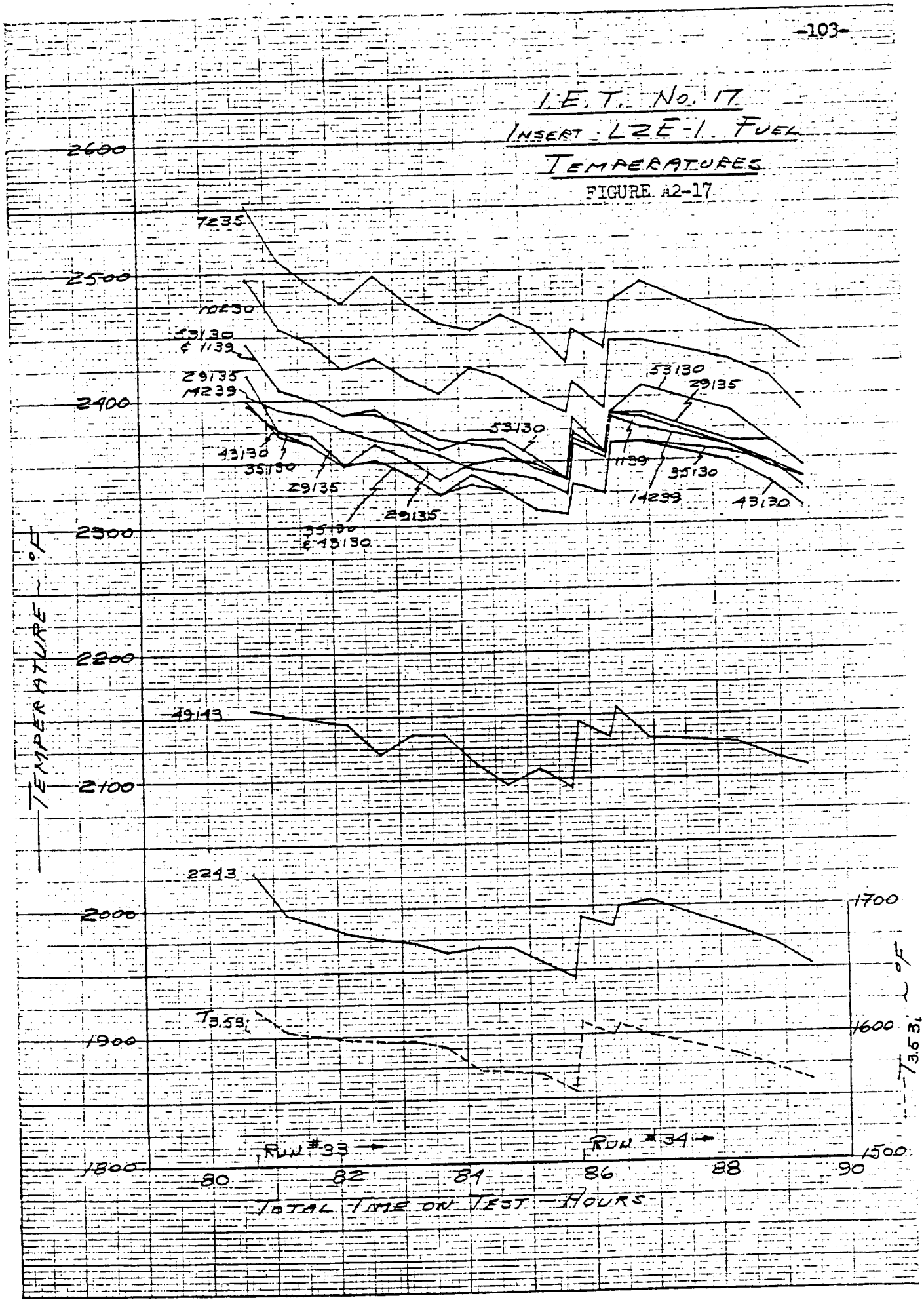
FIGURE A2-15



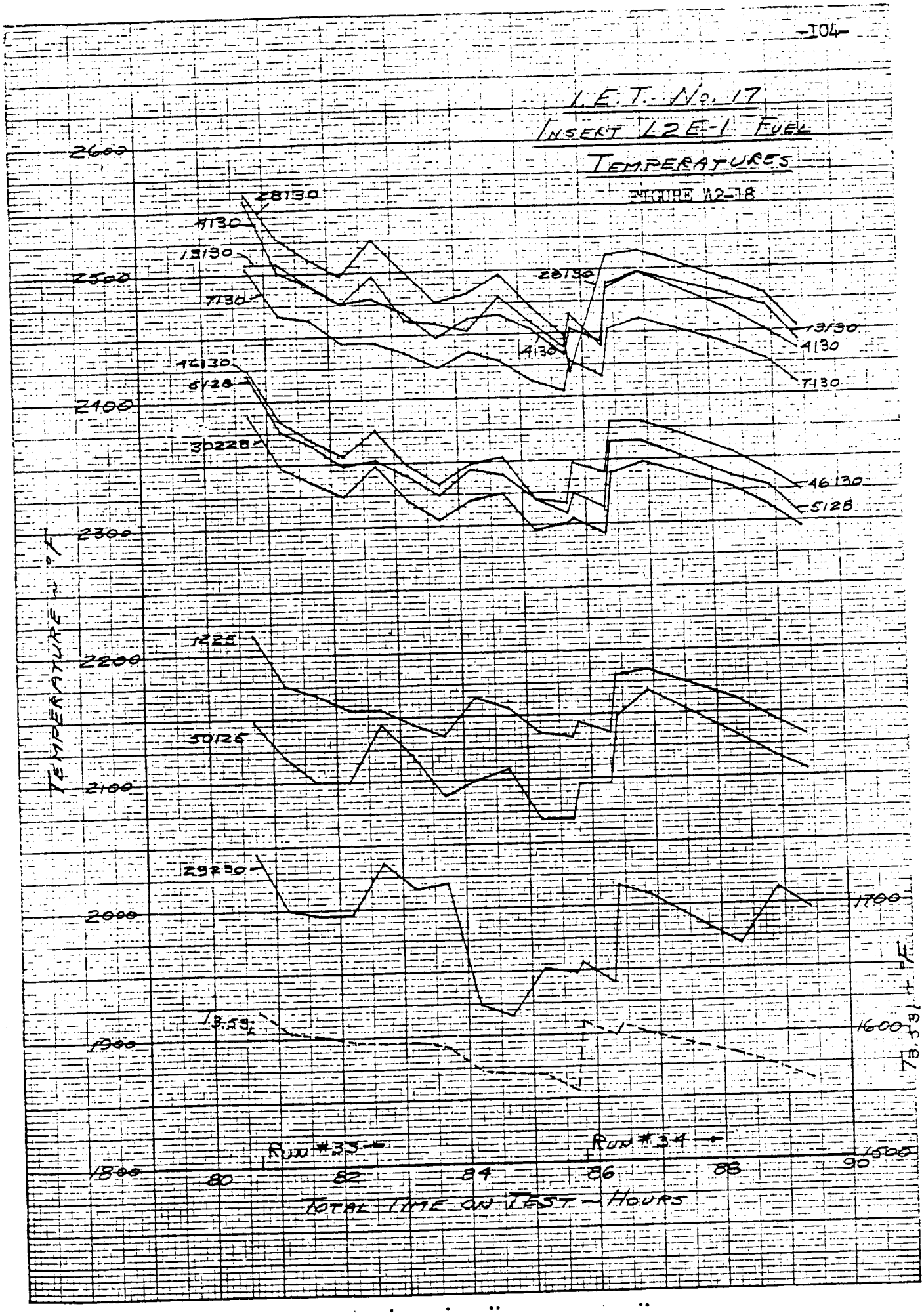
I.E.T. No. 17
INSERT L2E-1 FUEL
TEMPERATURES
FIGURE A2-16



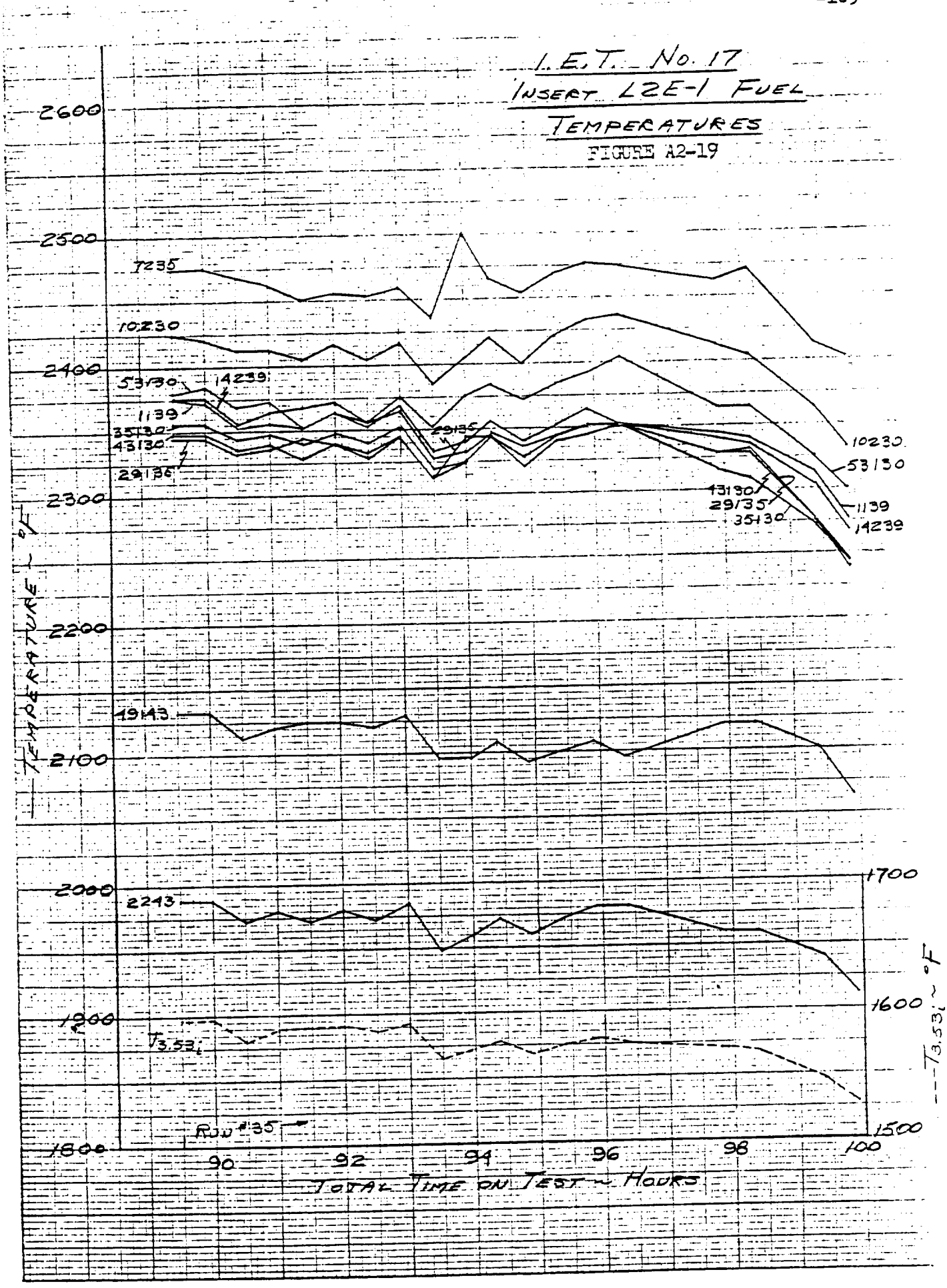
1187192

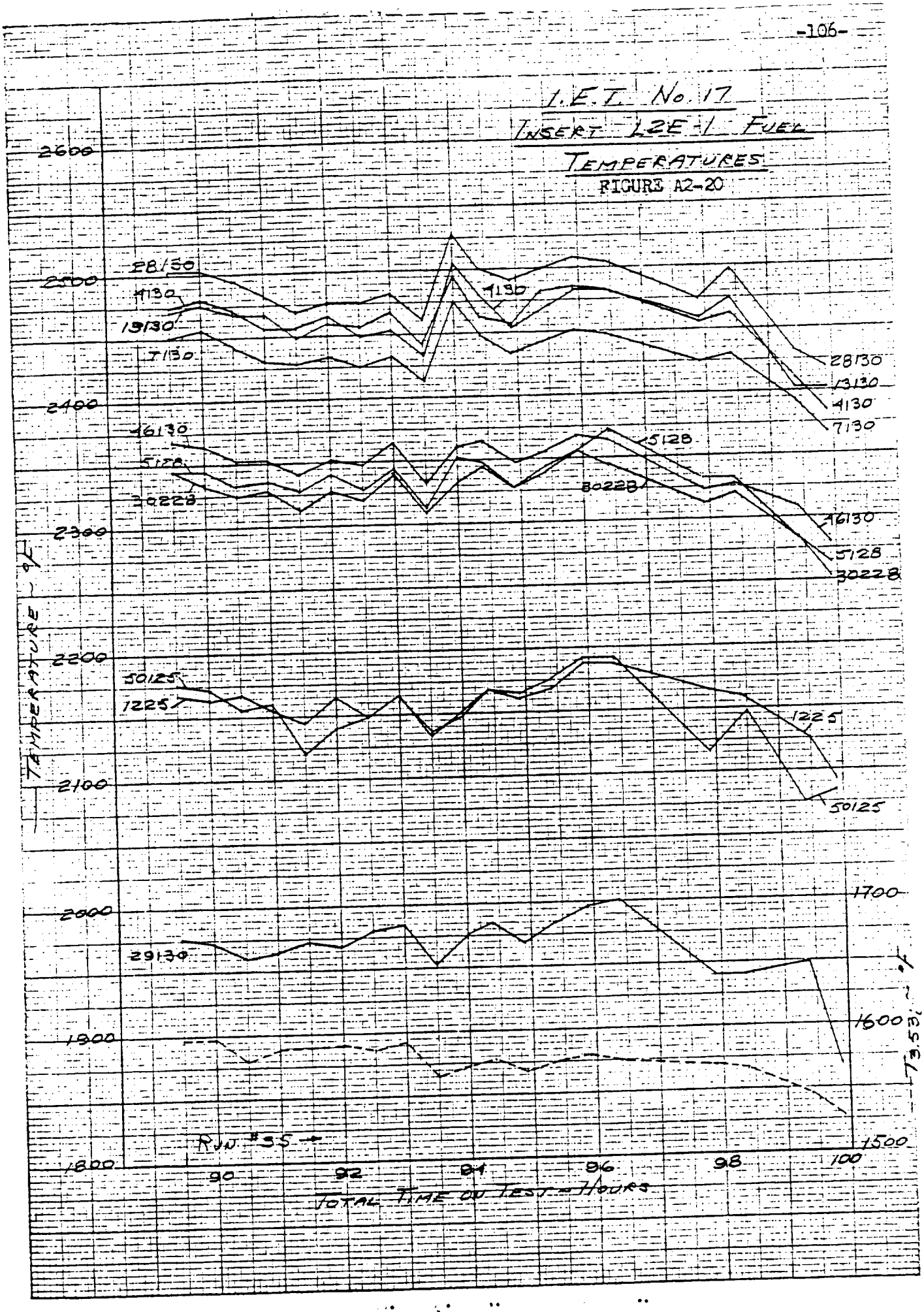

I.E.T. No. 17
INSERT L2E-1 FUEL
TEMPERATURES
FIGURE A2-17
2600
2500
2400
2300
2200
2100
2000
1900
1800
7235
10230
53130 & 1139
29135
14239
43130
35130
29135
35130 & 43130
29135
53130
53130
29135
1139
35130
14239
43130
49143
2243
T3.53i
1700
1600
1500
T3.53i ~ °F
TEMPERATURE ~ °F
RUN #33
RUN #34
80
82
84
86
88
90
TOTAL TIME ON TEST ~ HOURS

1187193


I.E.T. No. 17
INSERT L2E-1 FUEL
TEMPERATURES
FIGURE A2-18
TEMPERATURE ~ °F
2600
2500
2400
2300
2200
2100
2000
1900
1800
28130
4130
13130
7130
46130
5128
30228
1225
50125
29230
T3.53
1700
1600
1500
T3.531 ~ °F
RUN #33
RUN #34
80
82
84
86
88
90
TOTAL TIME ON TEST ~ HOURS

1187194


I.E.T. No. 17
INSERT L2E-1 FUEL
TEMPERATURES
FIGURE A2-19
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
TEMPERATURE ~ °F
7235
10230
53130
14239
1139
35130
43130
29135
19143
2243
T3.53i
RUN #35
10230
53130
1139
14239
43130
29135
35130
90
92
94
96
98
100
TOTAL TIME ON TEST ~ HOURS
T3.53i ~ °F


I.E.I. No. 17
INSERT L2E-1 FUEL
TEMPERATURES
FIGURE A2-20
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
TEMPERATURE ~ °F
28/50
4130
13130
7130
28130
13130
4130
7130
16130
5128
30228
5128
30228
16130
5128
30228
50125
1225
1225
50125
29130
RUN #55 →
90
92
94
96
98
100
TOTAL TIME ON TEST ~ HOURS

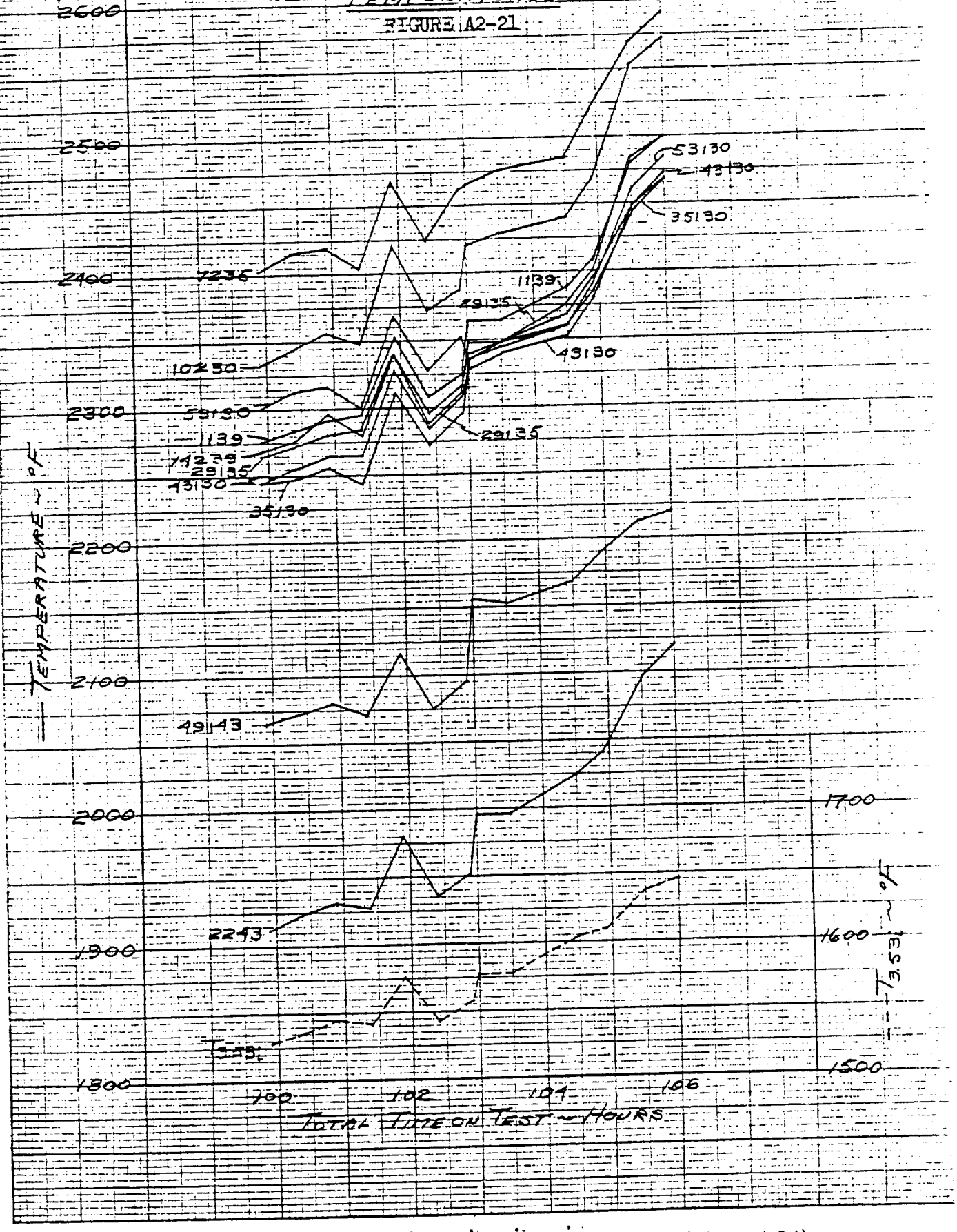
1118196

I.E.T. No. 17

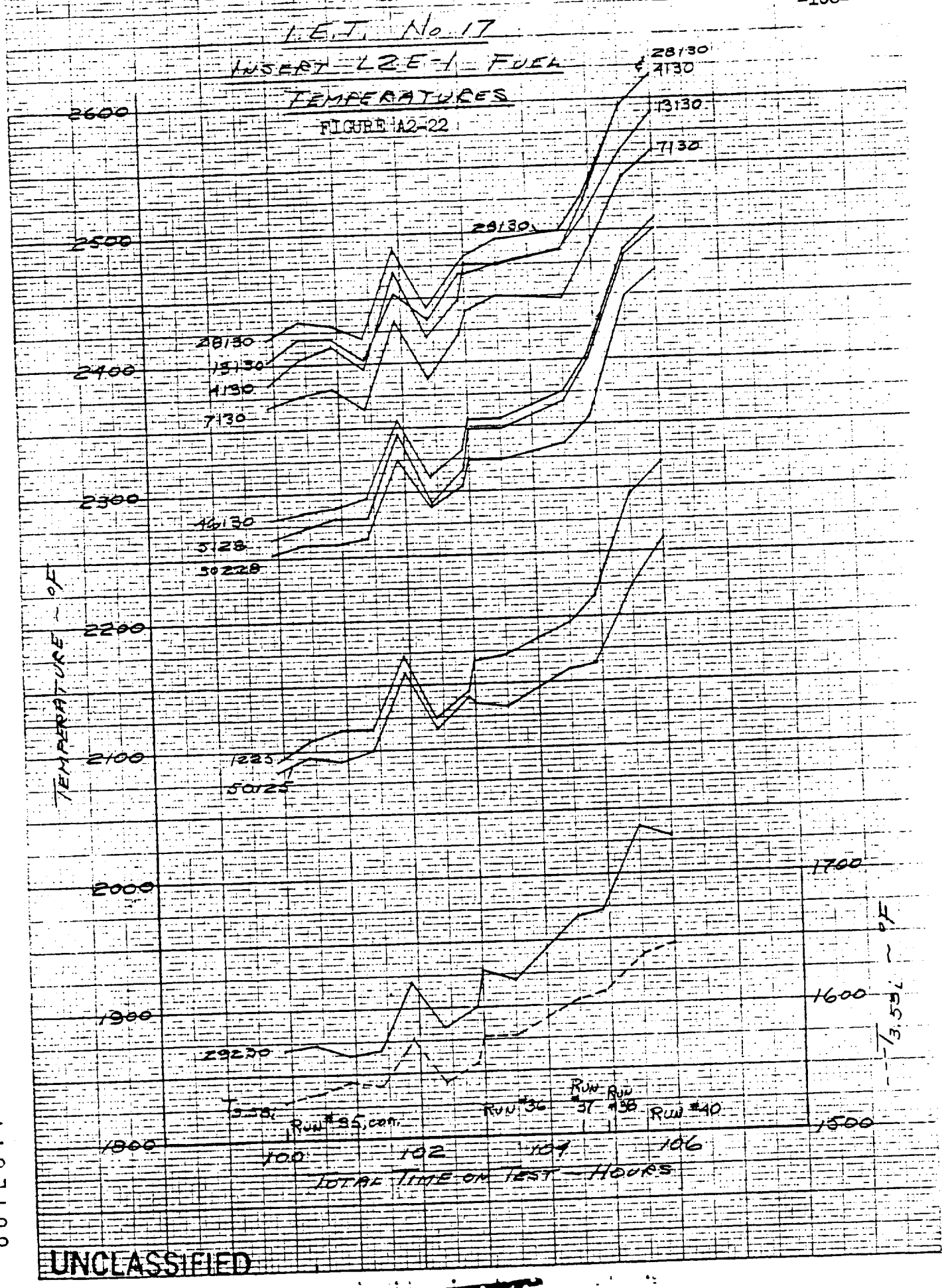
INSERT 12E-1 FUEL

TEMPERATURES

FIGURE A2-21



UNCLASSIFIED


I.E.T. No. 17
INSERT L2E-1 FUEL
TEMPERATURES
FIGURE A2-22
28130
4130
13130
7130
29130
28130
13130
4130
7130
46130
5128
50228
1225
50125
29230
$T_{3.58i}$
RUN #35, con.
RUN #36
RUN #37
RUN #38
RUN #40
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
TEMPERATURE ~ °F
$T_{3.58i}$ ~ °F
100
102
104
106
TOTAL TIME ON TEST ~ HOURS