DOE/ET/32043-T15

18 September 1979

GENERAL PURPOSE HEAT SOURCE

TASK GROUP

FINAL REPORT

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PREPARED FOR THE

DIVISION OF ADVANCED NUCLEAR SYSTEMS AND PROJECTS

OF THE

UNITED STATES DEPARTMENT OF ENERGY

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D. A. Galvin
Mound Facility

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Battelle Columbus Labs

Concurred: R. S. Weston for A. Schaffhauser 9/14/79
A. Schaffhauser
Oak Ridge National Lab.

Concurred:
M. B. Eck
Fairchild

Concurred: Richard H. Tait for D. T. Rankin 9/18/79
D. T. Rankin/R. A. Brownback for RAB 9/18/79
Savannah River

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GPHS TASK GROUP FINAL REPORT

INTRODUCTION

On July 10 and 11, 1979, the Low Mass, Revision B (LMRB) design of the General Purpose Heat Source (GPHS) was presented at DOE. The reentry thermal analysis of this design indicated temperatures during normal operation, reentry and impact that were unacceptable. DOE, therefore, appointed a Task Group to determine the viability and safety of the GPHS and to make recommendations regarding design modifications that would provide a viable heat source for the International Solar Polar Mission (ISPM). The following organizations were directed by DOE to appoint representatives to the Task Group:

General Electric - Chairman (R. Hemler)
Applied Physics Lab - (J. Hagan)
Battelle Columbus Lab - (I. Grinberg)
Fairchild Industries - (M. Eck)
Los Alamos Scientific Lab - (S. Bronisz)
Mound Facility - (D. Galvin)
Oak Ridge National Lab - (A. Schaffhauser)
Savannah River Lab - (D. T. Rankin)
Savannah River Plant - (R. Brownback)
Department of Energy, HQ - (R. Morrow)

TASK GROUP SUMMARY OF KEY EVENTS

On July 30, 1979, at DOE, a task group meeting was held and an interim report was made to DOE. The following are highlights of that meeting:

1) There was preliminary confirmation of the BCL thermal/reentry analysis although the procedure for handling hypersonic tumbling heat transfer was questionable.

2) It was confirmed that the LMRB design would not meet the temperature requirements.

3) It appeared that modifications could be made to the LMRB design which yield a viable heat source if side-on stable reentry could be avoided by slightly altering the aeroshell configuration.

4) Preliminary analytical results for a cube configuration were encouraging especially from peak and impact temperature viewpoints. However, impact tests were required to determine survivability at a higher impact velocity.

5) Impact tests at 800°C for fine and intermediate grain iridium were successful.

AC01-79ET32043

A meeting was held at Battelle on August 7, 1979, to obtain agreement among the task group on the following:

1) Boundary conditions to be used by BCL in their reentry analysis.

2) Refinements/modifications required in the BCL analytical approach.

3) Materials properties, especially emissivity and conductivity, to be used for pyrolytic graphite in future analyses pending confirmation by property measurements.

On August 21, 1979, the Task Group met at DOE to review the results of design studies, analyses and tests performed by the participating organizations. The results and conclusions from this meeting are as follows:

- Impact test representative of the terminal velocity and impact temperature for the cube resulted in a breached capsule.

- The peak reentry temperature could be lowered significantly by relocating the pyrolytic graphite from inside the GIS to outside the GIS.

- The impact temperature would be raised to an acceptable value by increasing the size of the gaps in the heat source from a nominal .005 inch to approximately 0.010 inch.

- Side-on stable reentry still results in higher than desired peak temperatures during reentry.

- Based on analyses by APL, it appears that the BCL analysis for tumbling reentry yields conservatively high peak reentry temperatures.

Based on the results of the above meeting, a recommended GPHS design was presented to DOE on August 22, 1979, which was projected to meet all temperature and safety requirements. This design which shall be called Low Mass Revision C (LMRC) has the following characteristics which are different from the LMRB version:

1) Corner modifications to preclude side-on stable reentry.

2) Relocation of the Pyrolytic Graphite insulator shells (2) from inside the Graphite Impact Shell (GIS) to outside the GIS.

3) Incorporation of larger (from $\sim$.005 to $\sim$.010 inch) gaps between adjacent components to raise the impact temperature.

In addition, it was recommended that CBCF-3 graphite insulation be characterized and pursued as an alternate to the pyrolytic graphite since it offers the potential of a lighter heat source with reduced complexity and additional temperature margin. Further, it was recommended that test programs be performed to:

1) Verify side-on reentry destabilization in wind tunnel tests.

2) Verify the heating rates for the rectangular parallelepiped heat source module shape in wind tunnel tests.

3) Verify the capsule impact capability with the insulator located outside the GIS with impact testing.

4) Verify drag coefficient and terminal velocity for the GPHS module with drop tests.

5) Verify physical properties (especially emissivity and thermal conductivity) of the Fine Weave Pierced Fabric (FWPF) aeroshell, the pyrolytic graphite, CBCF-3 and iridium via properties measurements.

It was also recommended that the ISPM converter should be sized to accept a heat source with a 5.5 inch diagonal maximum dimension. The length to be used shall be defined by LASL based on detailing of the recommended design.

These recommendations were accepted by DOE. Direction was given by DOE to maintain the Task Group intact until the viability of the recommended design was verified. DOE also directed that emphasis be placed on the measurement of physical properties of CBCF-3 and that CBCF-3 continued as a desirable substitute for pyrolytic graphite. The Task Group was requested to prepare a plan for: 1) the resolution of the final GPHS design, including the CBCF-3 option; 2) GPHS testing; and 3) final design freeze for module production.

This plan should be reviewed with DOE on September 5 or 6, 1979. Also, the Task Group was asked to present a status review of the GPHS design on September 18 or 19, 1979.

Included as attachments to this report are copies of the handouts from the presentation given to DOE at the August 22nd meeting.

GENERAL PURPOSE HEAT SOURCE
TASK GROUP
FINAL REPORT
22 AUGUST 1979

AGENDA

I.	INTRODUCTION	GE	0900 - 0910
II.	DESIGNS CONSIDERED	LASL	0910 - 0925
III.	REENTRY ANALYSIS RESULTS SUMMARY	BCL	0925 - 1000
IV.	ASSESSMENT OF VALIDITY OF BCL ANALYSIS	APL	1000 - 1020
V.	RESULTS OF 1D ANALYSES AND TRADEOFFS	FI	1020 - 1035
VI.	IMPACT TEST RESULTS SUMMARY	LASL	1035 - 1055
VII.	RECOMMENDED IRIDIUM TEMPERATURE LIMITS	ORNL	1055 - 1115
VIII.	CONCLUSIONS/RECOMMENDATIONS	GE	1115 - 1140
IX.	GE PROJECT STATEMENT		1140 - 1200
	LUNCH		1200 - 1300
	GOVERNMENT CAUCUS		1300 →

GPHS REVIEW

AUGUST 21 & 22, 1979

DOE/GERMANTOWN

MODULE DESIGN

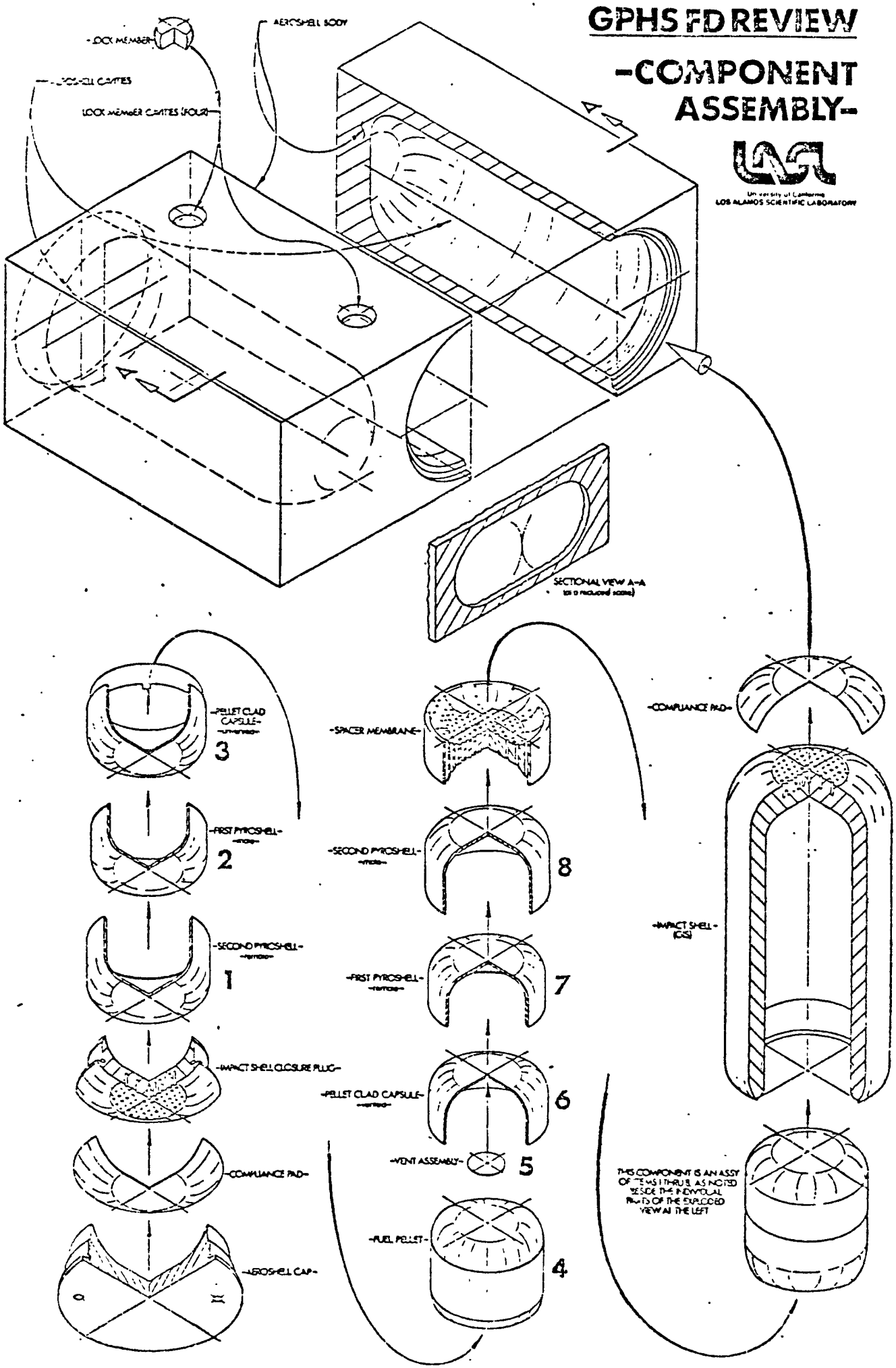
R. ZOCHER

University of California
LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545

GPHS FD REVIEW

-COMPONENT ASSEMBLY-

University of California
LOS ALAMOS SCIENTIFIC LABORATORY



GPHS DESIGNS

PG PLACEMENT MERITS

WORTH	POSITION INSIDE
±	PUNCH THROUGH PROTECTION (VELOCITY DEPENDENT)
+	MASS CONCENTRATED AT MINIMUM DIMENSION
±	ASSEMBLY MAY BE MORE DIFFICULT REMOTE
-	TEMPERATURE RESPONSE NOT AS GOOD
	POSITION OUTSIDE
-	PG NOT CONTAINED AS WELL IN IMPACT EVENT
±	MANUFACTURE AT HIGHER UNIT COST BUT FEWER PARTS
+	EASIER ASSEMBLY
+	BEST TEMPERATURE RESPONSE

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GPHS LMRB

PG PLACEMENT

MASS COMPARISON OF DESIGN UNITS

COMPONENT	INSIDE GIS	OUTSIDE GIS
PuO_2	608.96	608.96
CLAD	233.32	233.32
COMPLIANCE	1.60	1.60
GIS	205.22	183.46
AEROSHELL	410.94	439.61
*PG SETS	54.83	95.15
	1514.92	1567.10
	(3.340 #)	(3.455 #)
@ 250 W_T	74.85 W/#	72.36 W/#
#/FT^2 FACE ON	34.86	35.44
*WALL OF PG	0.0305	0.0350
WALLS OF GIS	0.152 x .230	0.167 x 0.255

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GPHS REVIEW

PG PLACEMENT

* RECOMMEND ACTIVE TESTING TO ESTABLISH OUTSIDE OF GIS PLACEMENT OF PG FOR USE IN GPHS DESIGN

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REENTRY THERMAL ANALYSES
AND
MATERIAL PROPERTY ANALYSES

AUGUST 21-22, 1979

Battelle
Columbus Laboratories

COMPARATIVE DESIGNS THERMAL RESPONSE

ORBIT DECAY FACE-ON STABLE/FLAT SPIN REVISED PG PPTYS.

DESIGN	TEMPERATURE, C OPERATING	PEAK	IMPACT
LMRB	1343	1534	~880
LMRB-10MILGAPS	1343	1534	1050
LMRB-2 PG SHIFT	1321	1478	885
2PG SHIFT-10MILGAPS	1321	1478	1055
TD4.1	1305	1473	905
CUBE-PLUG FORWARD	1347	1651	1113

3-D RESULTS - REVISED PYROLYTIC Є- PFIZER FLAT K

DESIGN	HYPERSONIC REENTRY CONFIGURATION	TRAJECTORY	RELEASE ALTITUDE KFT	CLAD TEMPERATURE C OPERATING	PEAK	IMPACT	RECESSION IN. STAG. PT.	CORNER
LMRB	FACE ON STABLE	ORBIT DECAY	270	1343	1534	832	.050	.058
LMRB	TUMBLING	MIN. GAMMA	330	1343	1967	940	.056	.051
LMRB	SIDE ON STABLE (plan fin)	MIN. GAMMA	330	1343	2222	924	.145	.198
PYRO SHIFTED	FACE ON STABLE	ORBIT DECAY	270	1321	1478	838	.048	.057
PYRO SHIFTED	TUMBLING	MIN. GAMMA	330	1321	1864	967	.054	.050

3-D RESULTS - REVISED PYROLYTIC ϵ - PFIZER FLAT K

DESIGN	HYPERSONIC REENTRY CONFIGURATION	TRAJECTORY	RELEASE ALTITUDE KFT	CLAD TEMPERATURE C OPERATING	PEAK	IMPACT	RECESSION IN. STAG. PT.	CORNER
TD 4.1	FACE ON STABLE	ORBIT DECAY	270	1305	1473	857	.053	.060
TD 4.1	TUMBLING	MIN. GAMMA	330	1305	1862	1008	.059	.053
LASL CUBE	FACE ON STABLE PLUG FORWARD	ORBIT DECAY	270	1347	1651	1065	.072	.071
LASL CUBE	FACE ON STABLE PLUG FORWARD	MIN. GAMMA	330	1347	1978	1131	.111	.128

SENSITIVITY RUNS - LMRB - REVISED PYROLYTIC ϵ
PFIZER FLAT PYROLYTIC K

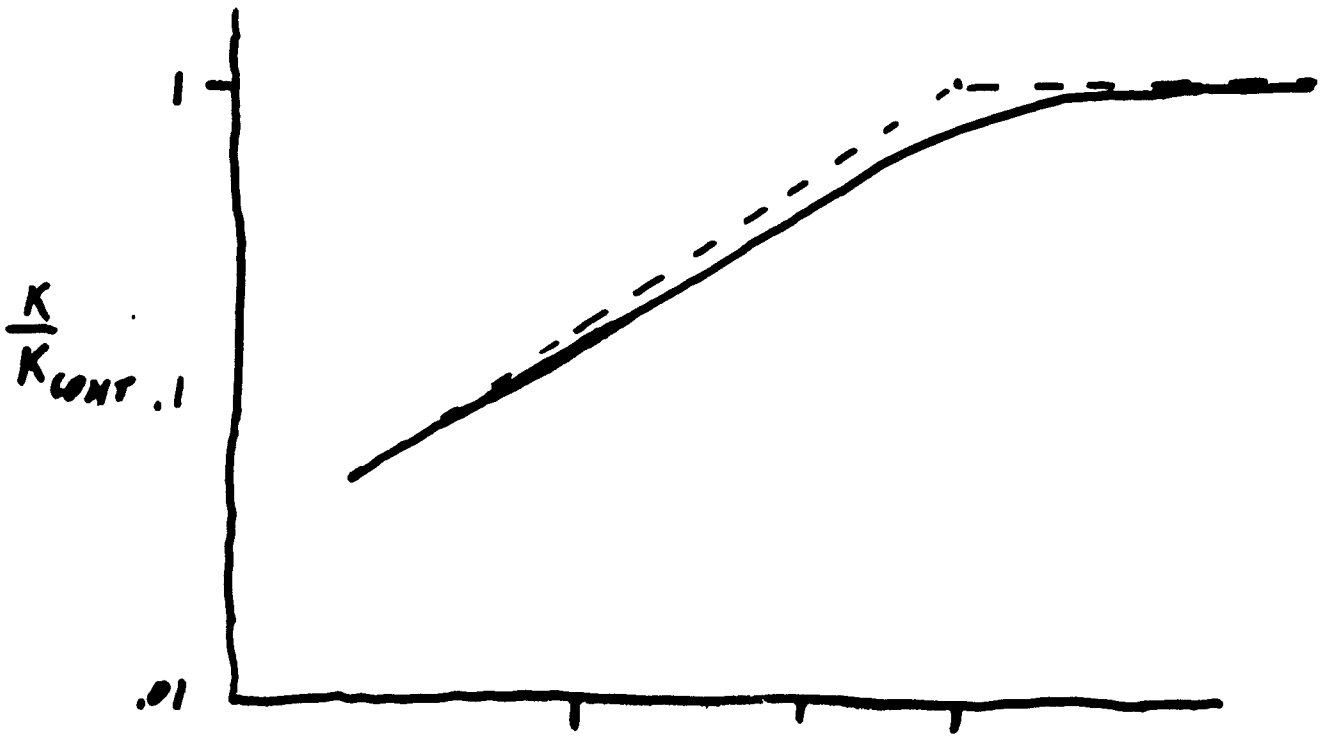
ORBIT DECAY - HYPERSONIC FACE ON STABLE - 270 KFT RELEASE
130 KFT CONTINUUM ALTITUDE 1343 C OPERATING TEMP.

SUBSONIC REENTRY CONFIGURATION	SUBSONIC COOLING CORRELATION	CLAD TEMPERATURE C PEAK	IMPACT	RECESSION IN STAG. PT.	CORNER	SPECIAL CONDITIONS
TUMBLING	AUGMENTED BY VPI DATA	1534	832	.050	.058	
FLAT SPIN	AUGMENTED BY VPI DATA	1534	848	.051	.058	
TUMBLING	ORIGINAL BCL	1534	864	.050	.058	
TUMBLING	ORIGINAL BCL	1534	1033	.049	.058	ALL GAPS INCREASED TO 10 MILS

SENSITIVITY RUNS - LMRB - ORIGINAL PYROLYTIC ϵ
PFIZER PYROLYTIC K

ORBIT DECAY - HYPERSONIC FACE ON STABLE - 270 KFT RELEASE 1375 C OPERATING TEMP.

SUBSONIC REENTRY CONFIGURATION	CONTINUUM ALTITUDE KFT	CLAD TEMPERATURE C PEAK	IMPACT	RECESSION IN STAG. PT.	CORNER	SPECIAL CONDITIONS
TUMBLING	130	1545	835	.050	.058	
TUMBLING	115	1546	838	.050	.058	
TUMBLING	100	1546	843	.050	.058	
TUMBLING	0	1546	1329	.048	.057	
	81	1546	850	.050	.058	
FLAT SPIN	130	1545	852	.051	.058	
TUMBLING	130	1545	834	.050	.058	G.E. TRANSONIC DRAG



MEAN FREE PATHS		1	4	10	40	
ALTITUDE	KFT	130	100	81	52	
PRESSURE	mm Hg	2.7	11	27	108	
TIME	SEC	1162	1194	1215	1268	1470
~ T_{GAS}	C	1500	1400	1300	1100	
$\frac{H_{RAD}}{H_{CONTINUUM}}$		.38	.33	.29	.22	

ASSESSMENT OF BCL ANALYSES

HYPERSONIC - (PEAK TEMPERATURES)

FACE STABLE - GOOD (GE- MAY BE CONSERVATIVE)

TUMBLING - MAY BE CONSERVATIVE - LACK OF ACCURATE HEATING RATE DATA

SUBSONIC - (IMPACT TEMPERATURES)

UNCERTAINTIES IN HEATING RATE, DISTRIBUTION AND OXIDATION MODEL - HOWEVER THE SURFACE RE-RADIATION APPEARS TO BE CONTROLLING FACTOR.

HIGH TEMPERATURE PROPERTIES OF PG NEED CONFIRMATION - ALSO ϵ OF FWPF

THERMAL MODEL — NO SIGNIFICANT DISCREPANCY (FI)

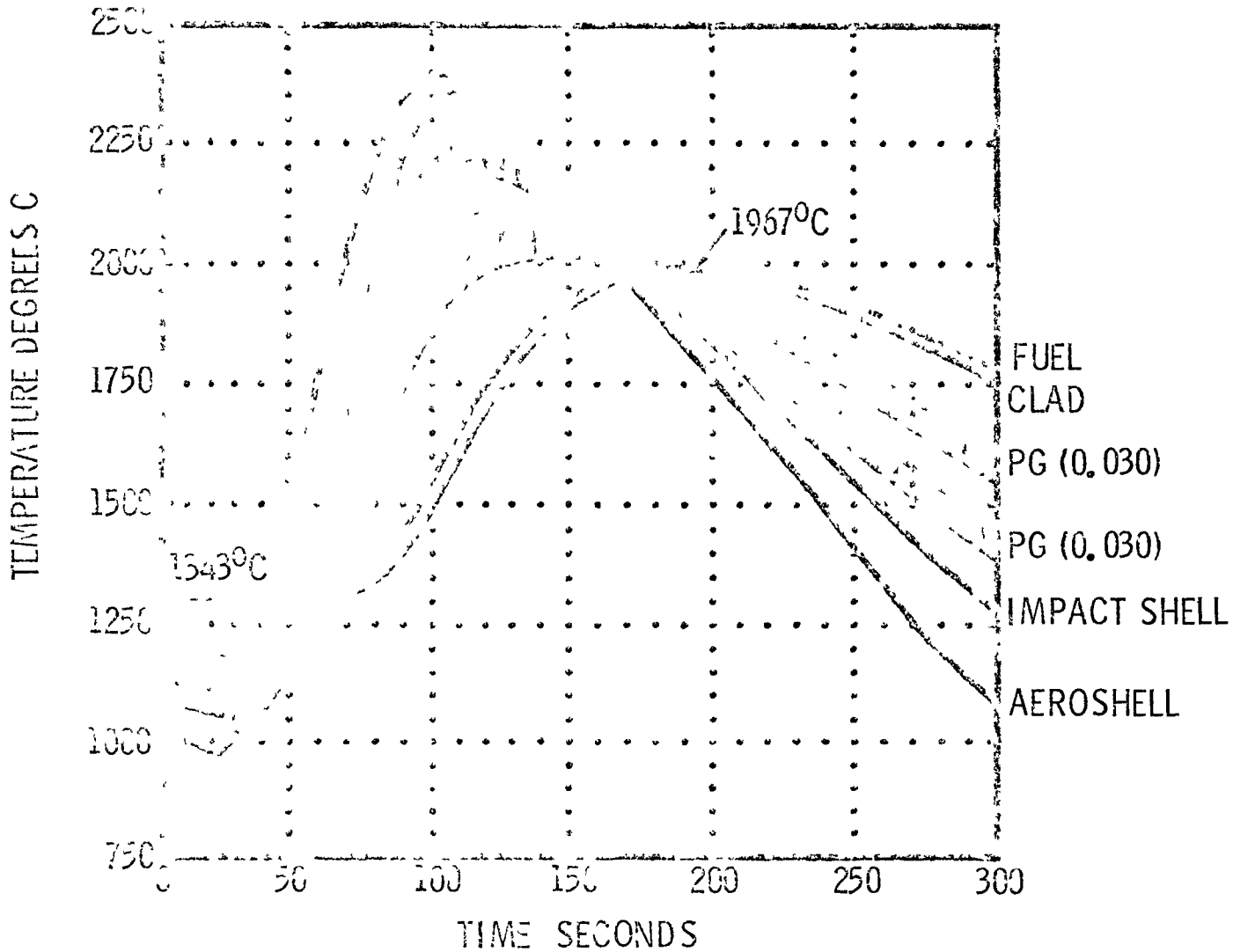
GPHS ALTERNATIVE DESIGN STUDY

A. Schock
Fairchild Industries

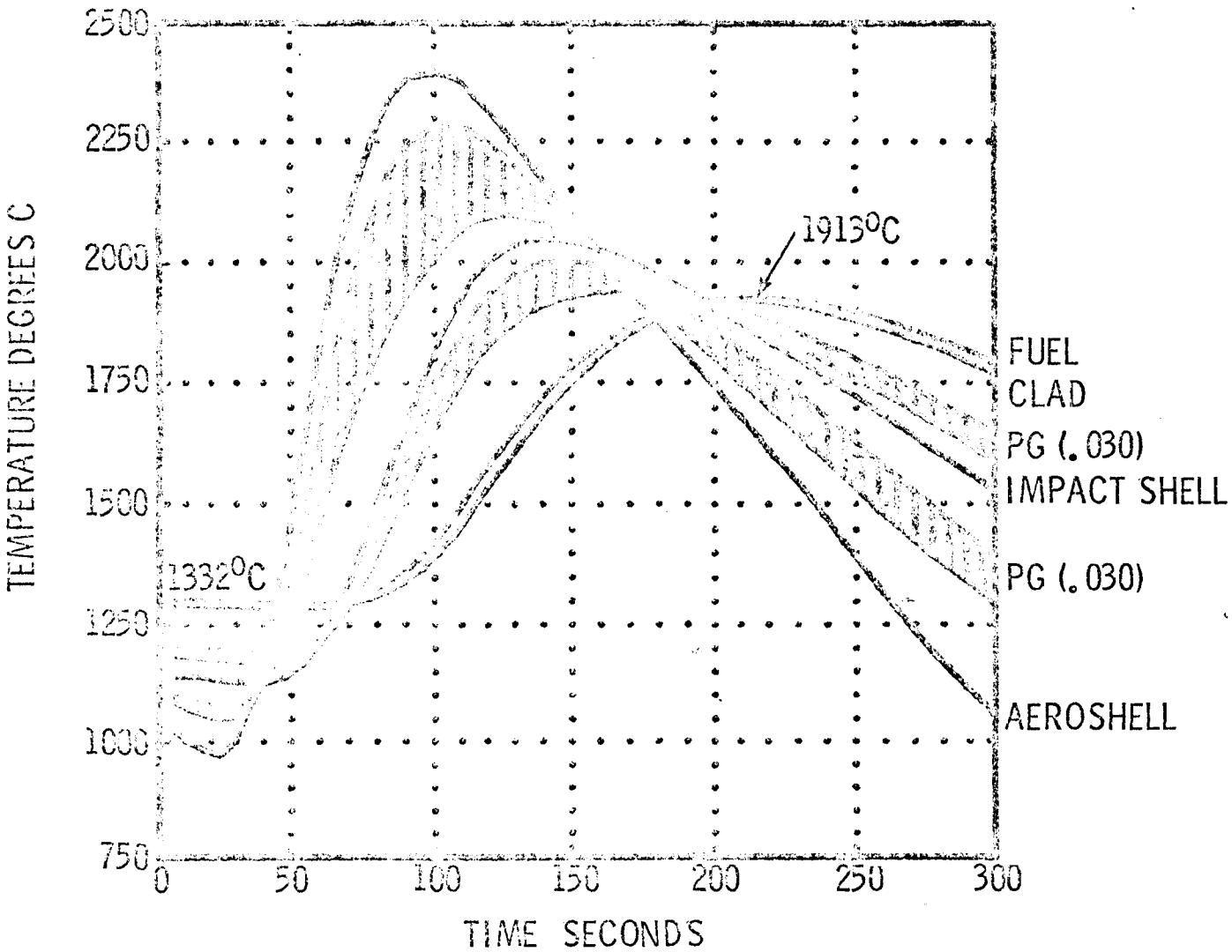
Presented at DOE Meeting
Germantown, Maryland

August 21-22, 1979

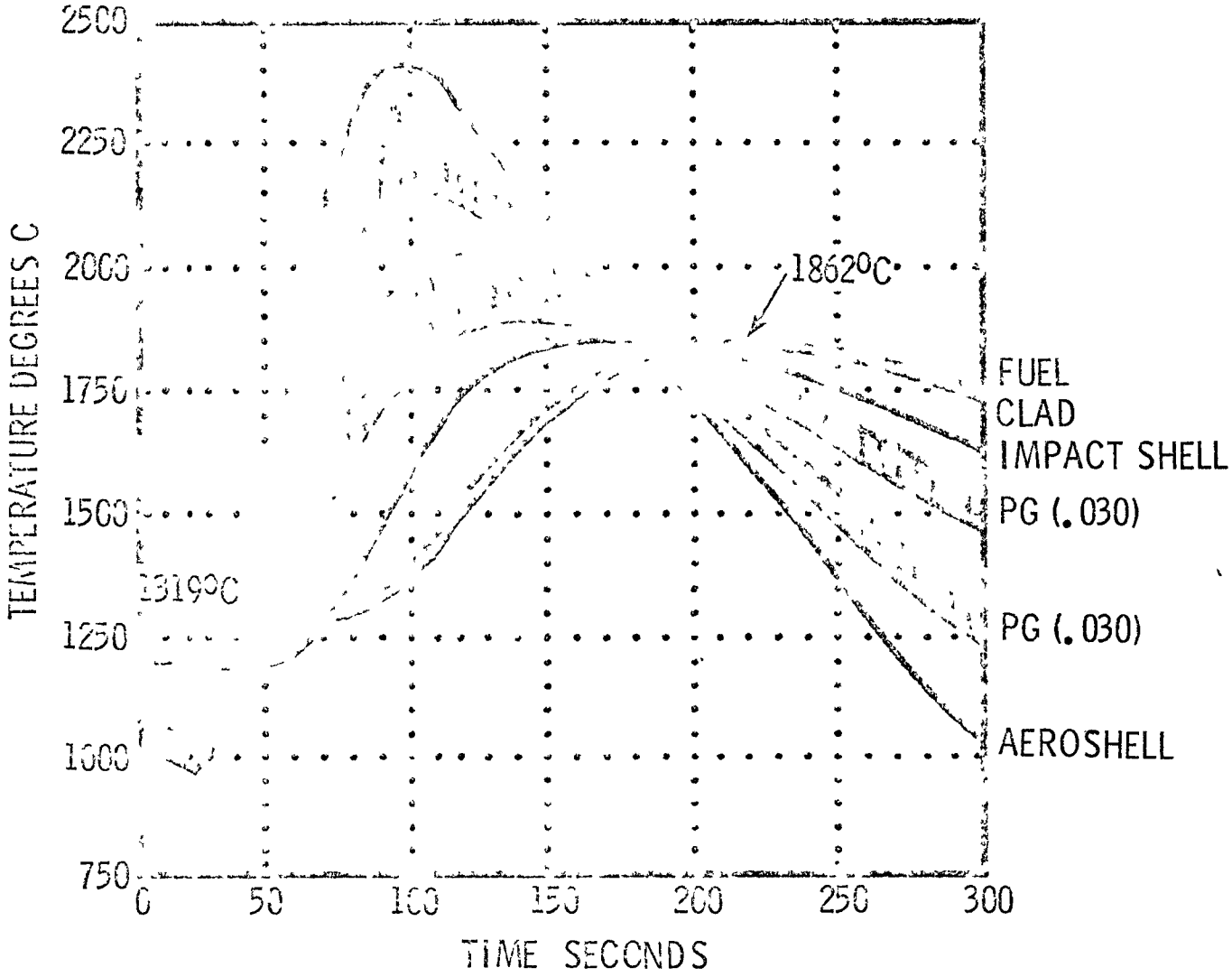
[illegible] TEMPERATURE PEAKS



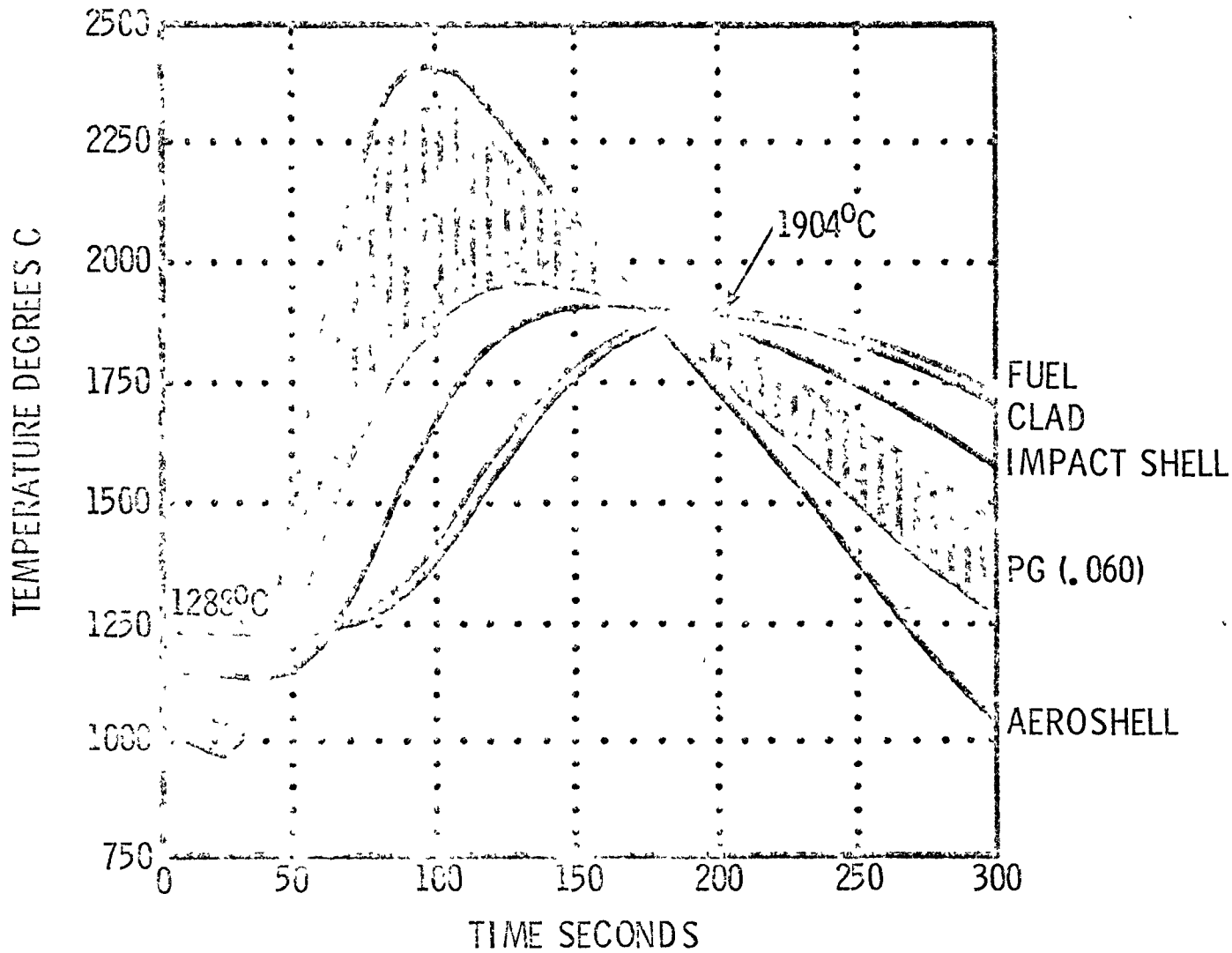
DESIGN 1 TEMPERATURE PEAKS



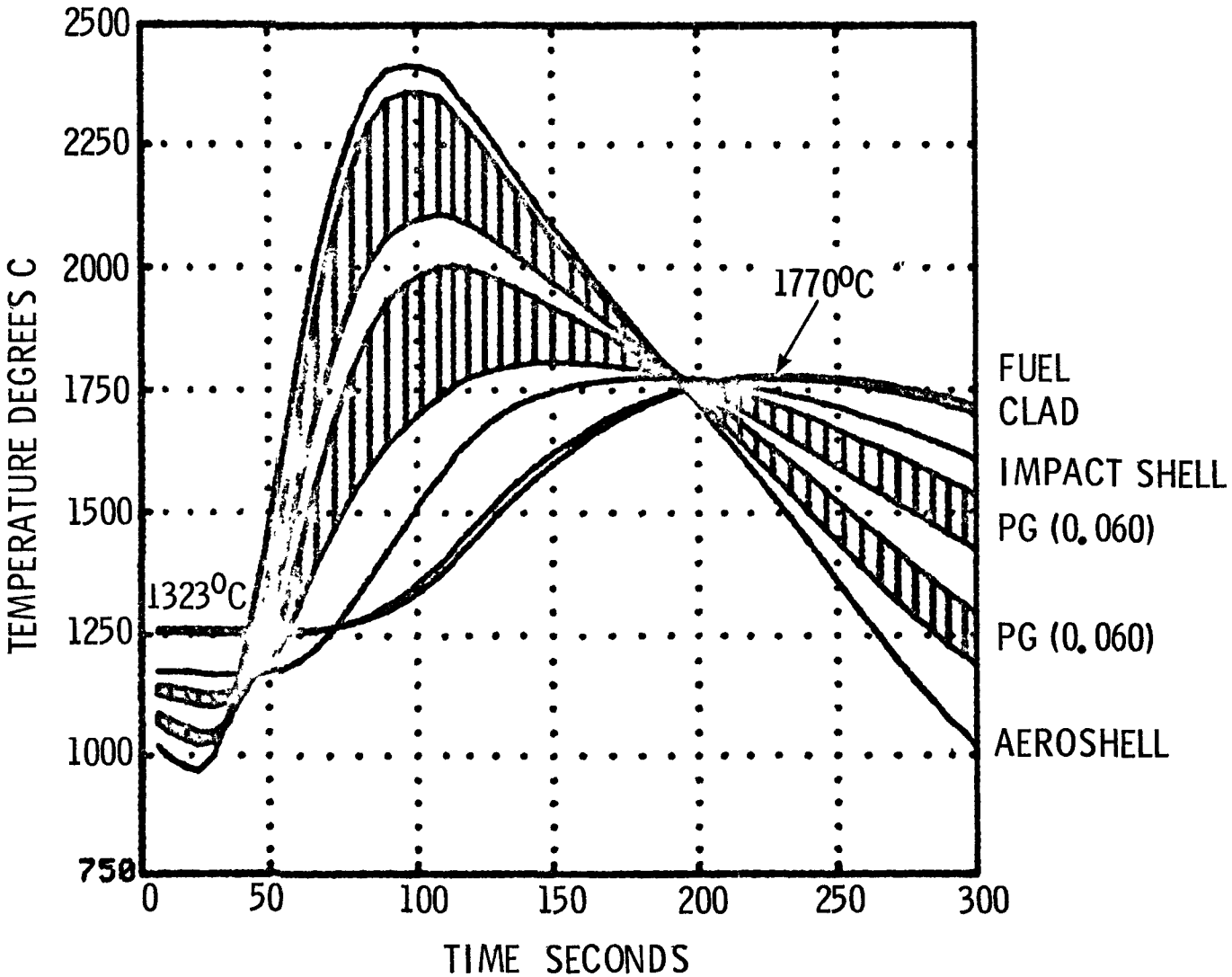
DESIGN TEMPERATURE PEAKS



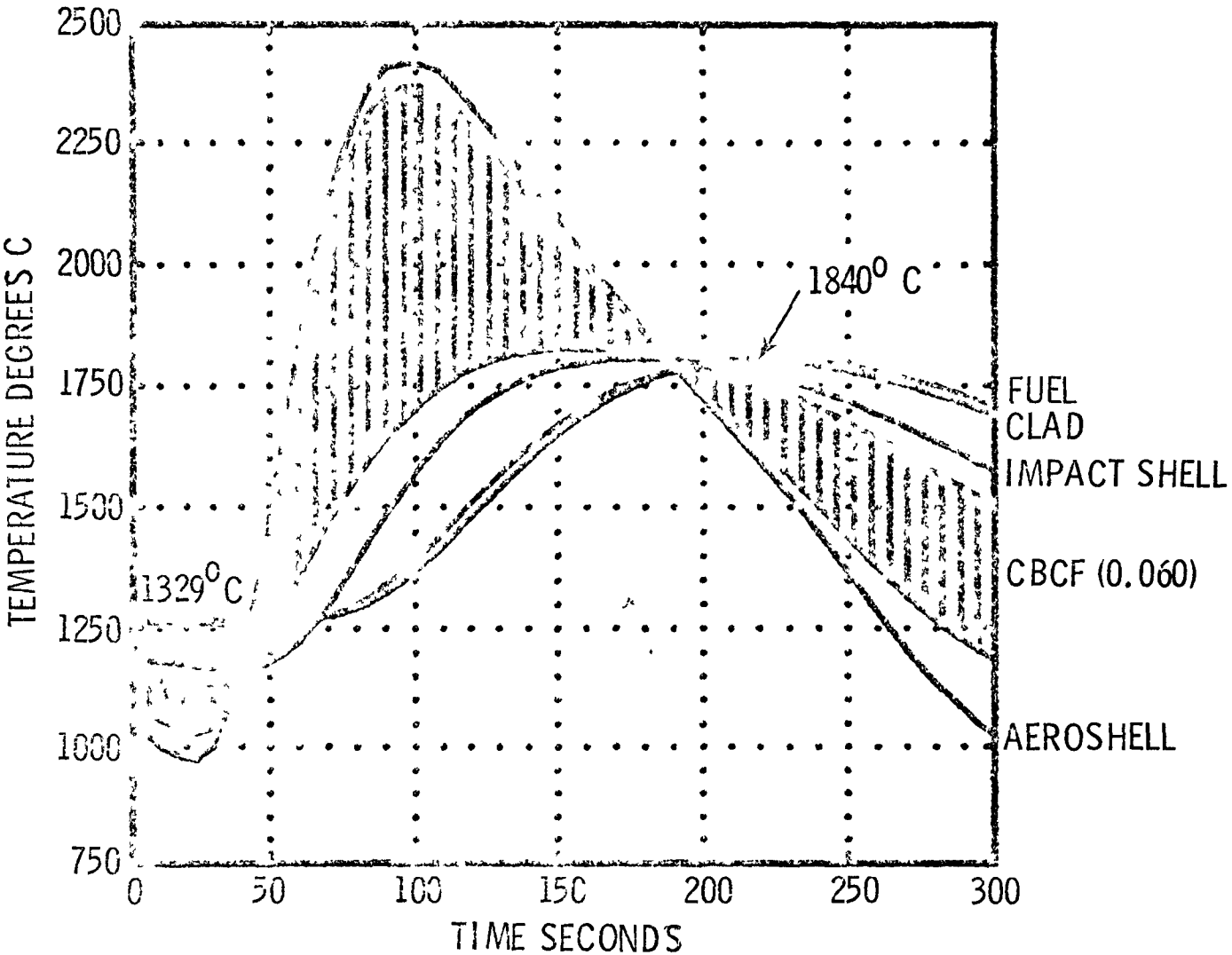
DESIGN 3 TEMPERATURE PEAKS



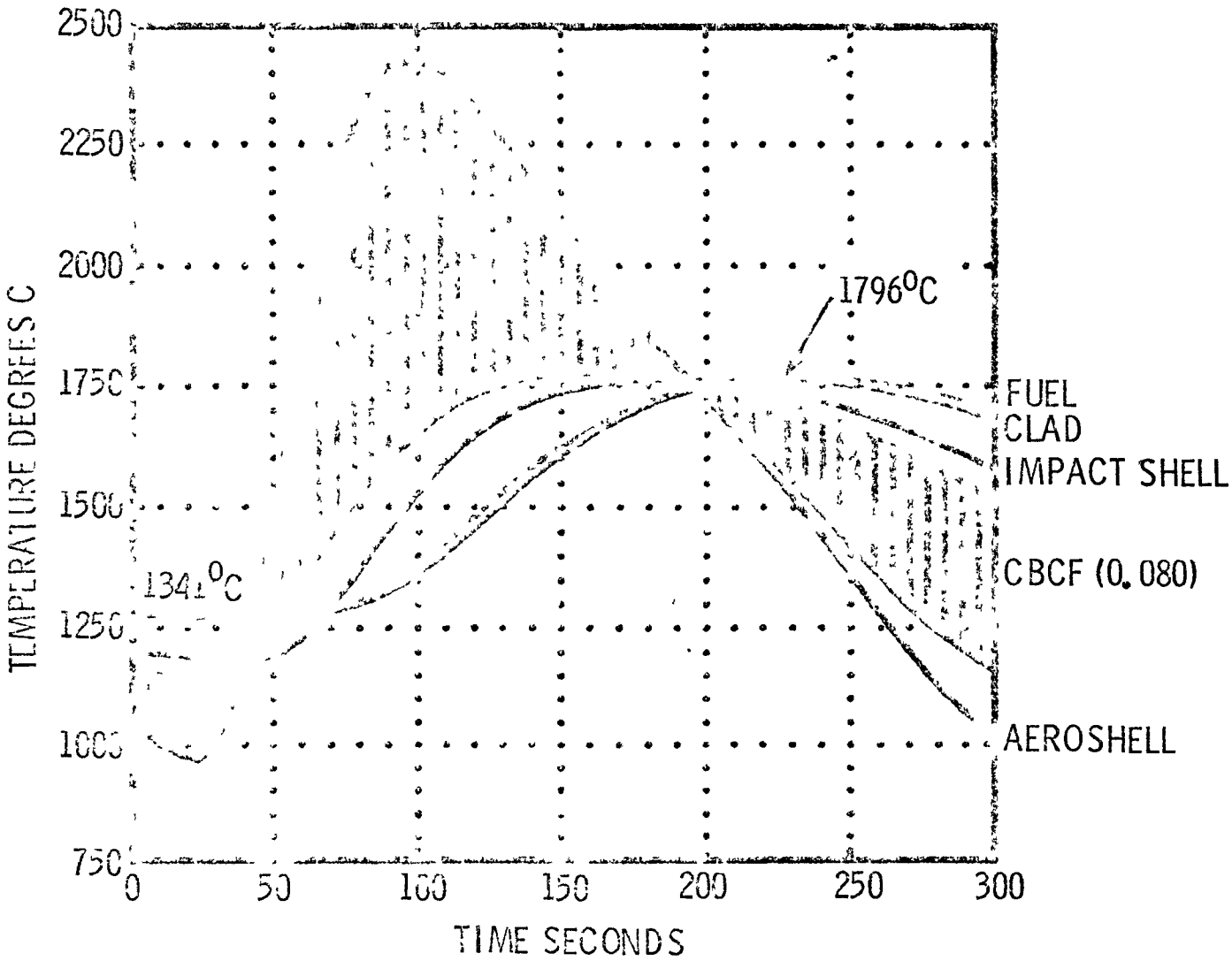
DESIGN 3A TEMPERATURE PEAKS



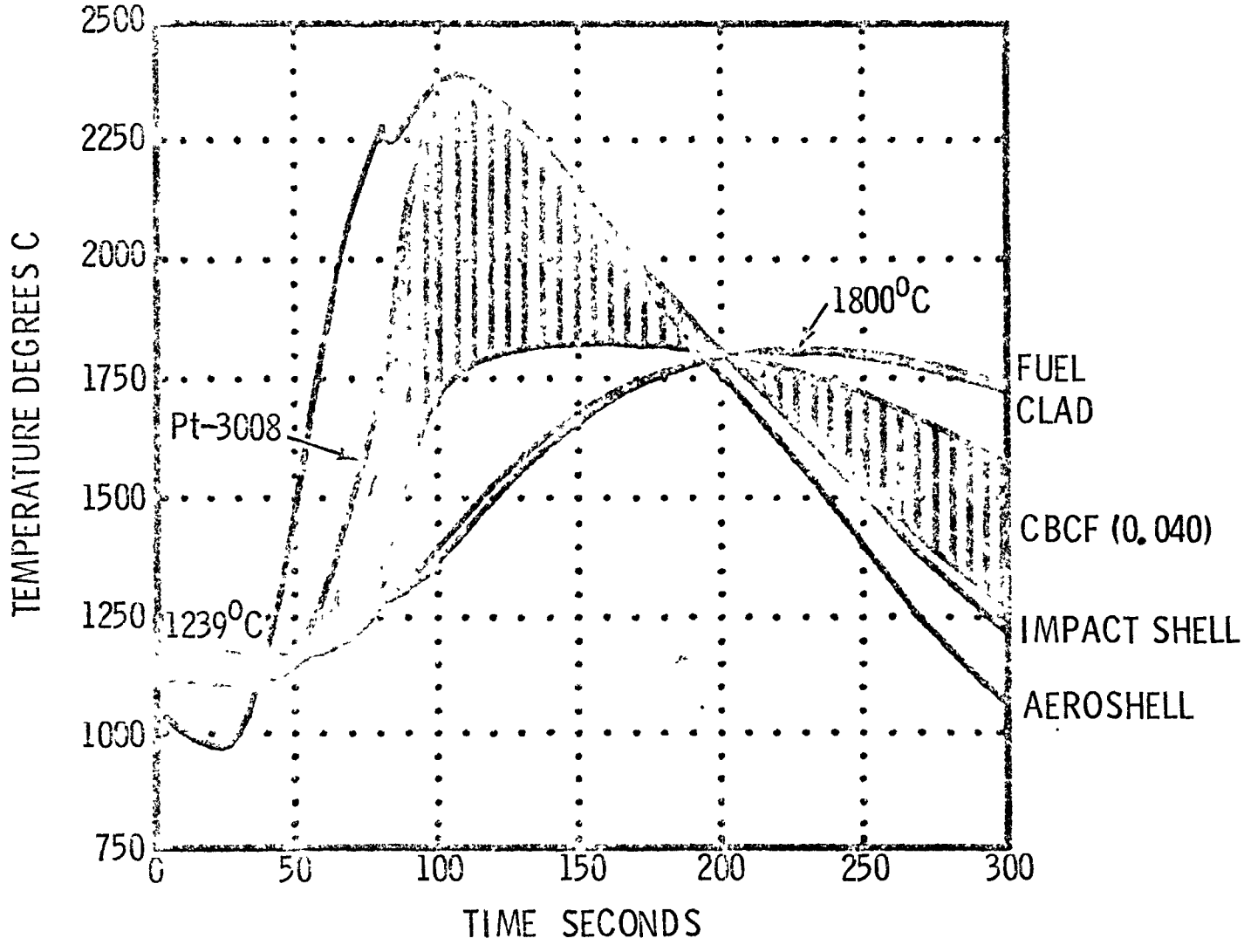
DESIGN 4A TEMPERATURE PEAKS



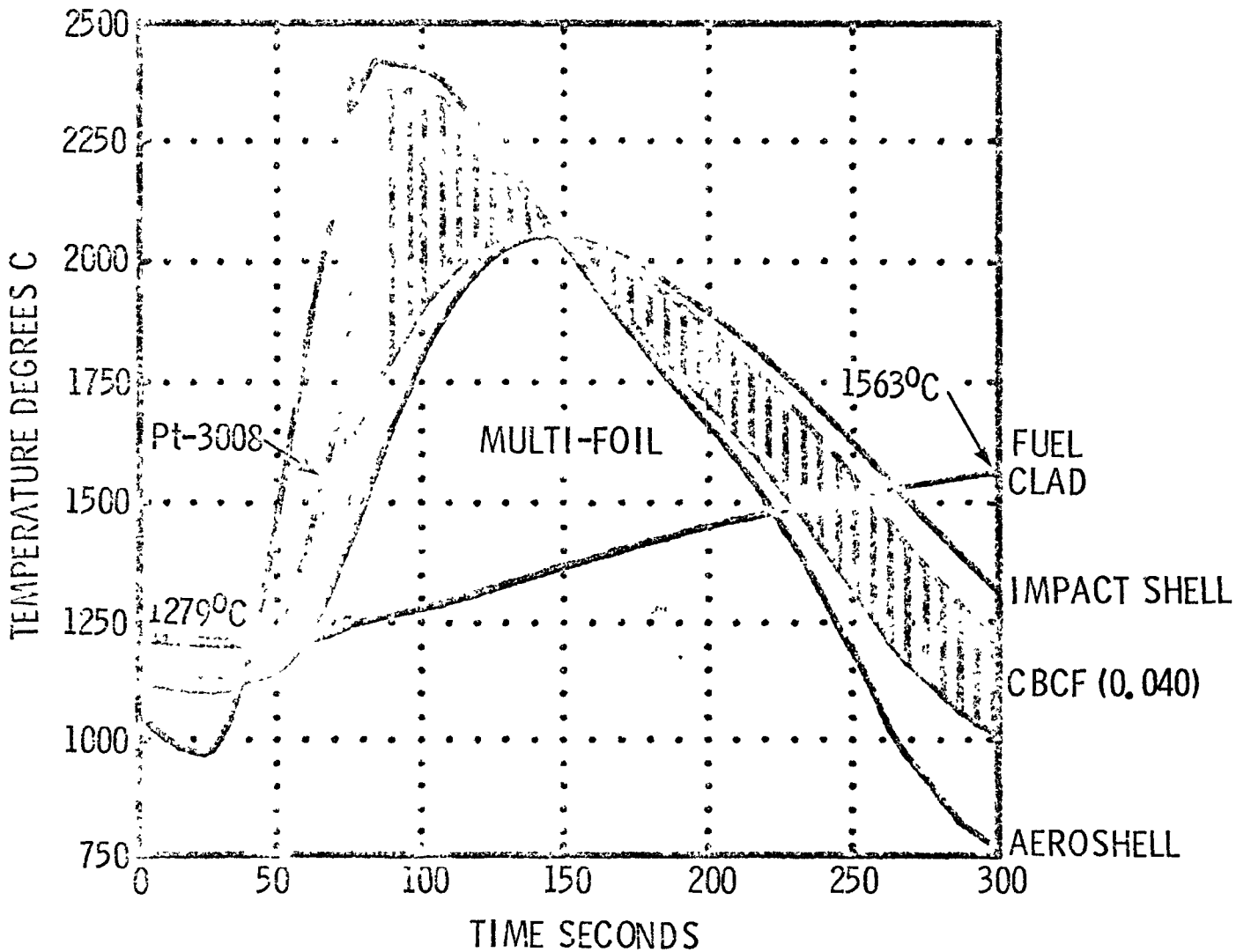
DESIGN TEMPERATURE PEAKS



DESIGN 9 TEMPERATURE PEAKS



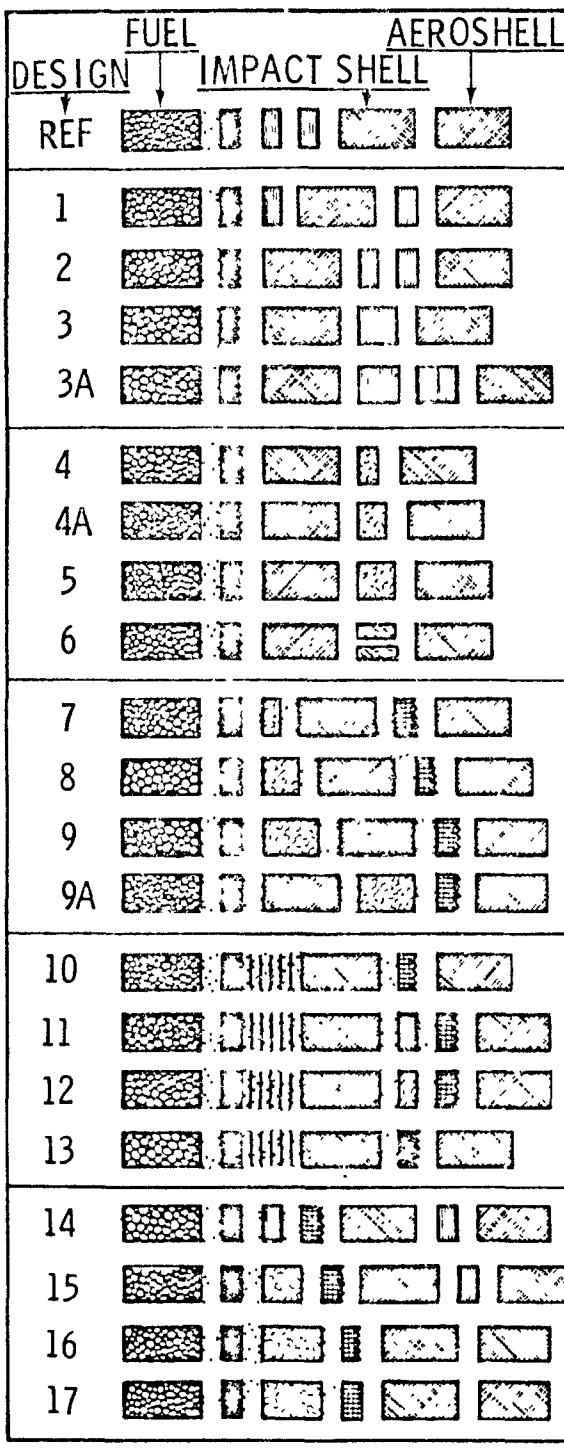
DESIGN 12 TEMPERATURE PEAKS



CRITICAL TEMPERATURES (°C)*

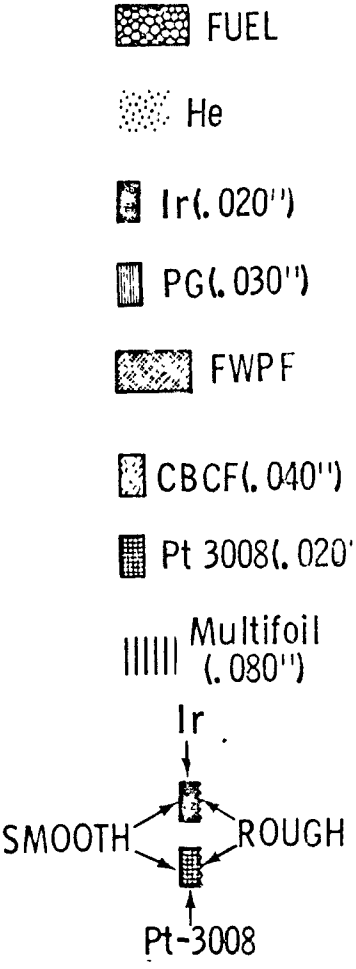
BEFORE NORMALIZATION

DESIGN	NORMAL	PEAK
CLAD TEMPERATURE →	NORMAL	PEAK
TENTATIVE GOALS →	<1330	<1800
REF	1350 1318	2030 2008
1	1307	1954
2	1294	1903
3	1258	1945
3A	1296	1811
4	1283	1942
4A	1302	1881
5	1320	1837
6	1271	
7	1201	1969
8	1205	1894
9	1209	1841
9A	1201	1736
10	1249	1660
11	1253	1620
12	1254	1604
13	1238	1649
14	1275	1944
15	1273	1908
16	1245	1879
17	1271	1883



← OLD ε, k
← NEW ε, k

KEY:



*MIN-GAMMA, TUMBLING

CRITICAL TEMPERATURES (°C)*

NORMALIZED TO MATCH BCL'S 3D RESULTS FOR NEW REF CASE

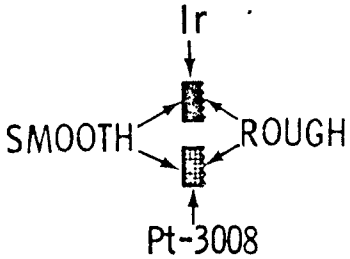
	NORMAL	PEAK
CLAD TEMPERATURE →	NORMAL	PEAK
TENTATIVE GOALS →	<1330	<1800
DESIGN (FUEL, IMPACT SHELL, AEROSHELL)		
REF	1375	1989
	1343	1967
1	1332	1913
2	1319	1862
3	1288	1904
3A	1323	1770
4	1308	1901
4A	1329	1840
5	1341	1796
6	1296	
7	1231	1928
8	1235	1853
9	1239	1800
9A	1234	1695
10	1274	1619
11	1278	1579
12	1279	1563
13	1262	1608
14	1300	1903
15	1298	1867
16	1270	1838
17	1296	1842

← OLD ε, k

← NEW ε, k

KEY:

- FUEL
- He
- Ir(.020")
- PG(.030")
- FWPF
- CBCF(.040")
- Pt 3008(.020")
- Multifoil (.080")



*MIN-GAMMA, TUMBLING

CRITICAL TEMPERATURE MARGINS*

AFTER NORMALIZATION

DESIGN	NORMAL 1330-T	PEAK 1800-T
REF	-45 / -13	-189 / -167
1	- 2	-113
2	+11	- 62
3	+42	-104
3A	+ 7	+ 30
4	+22	-101
4A	+ 1	- 40
5	-11	+ 4
6	+34	
7	+99	-128
8	+95	- 53
9	+91	0
9A	+96	+105
10	+56	+181
11	+52	+221
12	+51	+237
13	+68	+192
14	+30	-103
15	+32	- 67
16	+60	- 38
17	+34	- 42

CLAD TEMPERATURE → NORMAL 1330-T, PEAK 1800-T

MARGIN IN °C →

FUEL, AEROSHELL, IMPACT SHELL

← OLD ε, k

← NEW ε, k

KEY:

- FUEL
- He
- Ir(.020")
- PG(.030")
- FWPT
- CBCF(.040")
- Pt 3008(.020")
- Multifoil (.080")

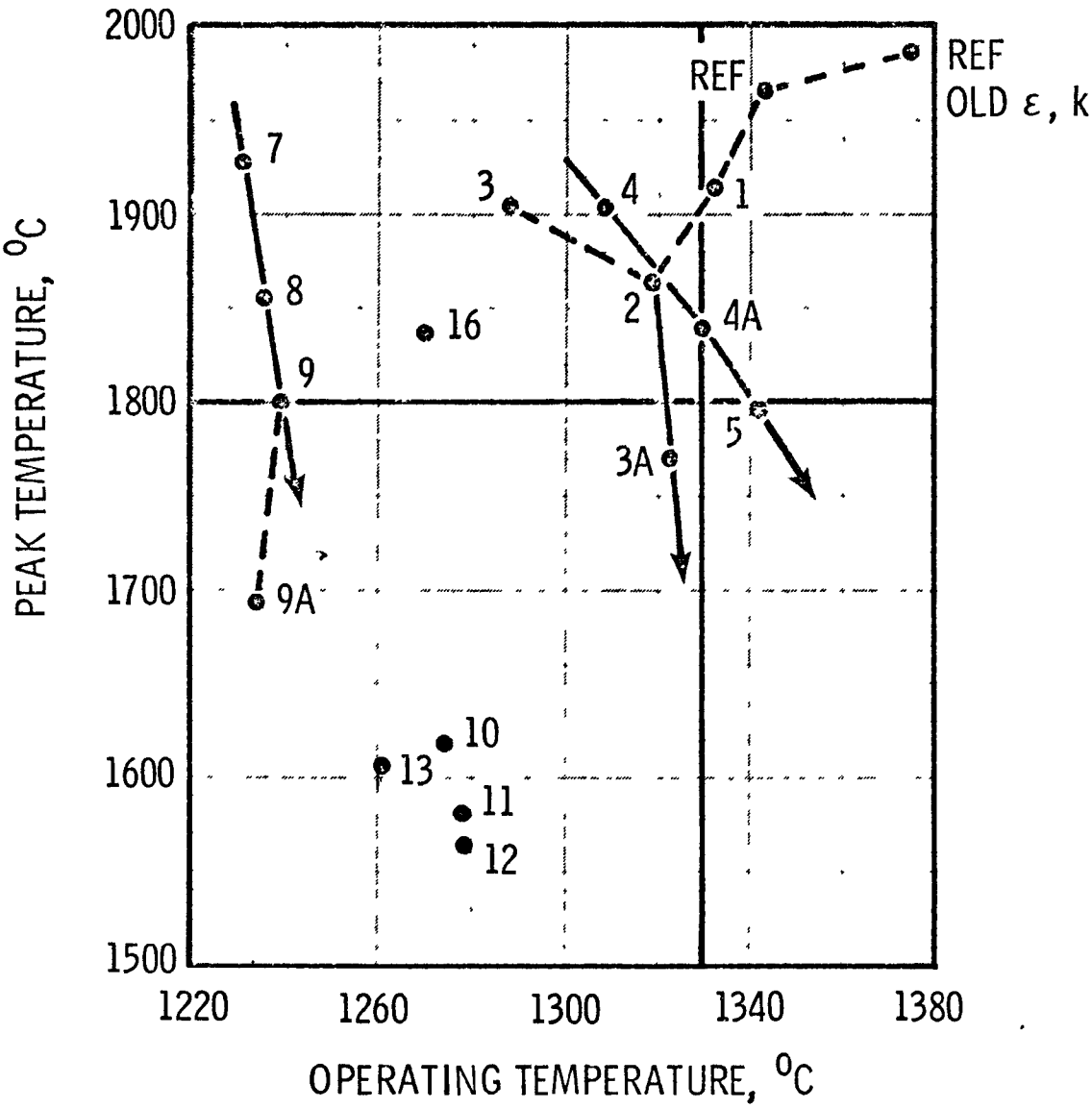
Ir

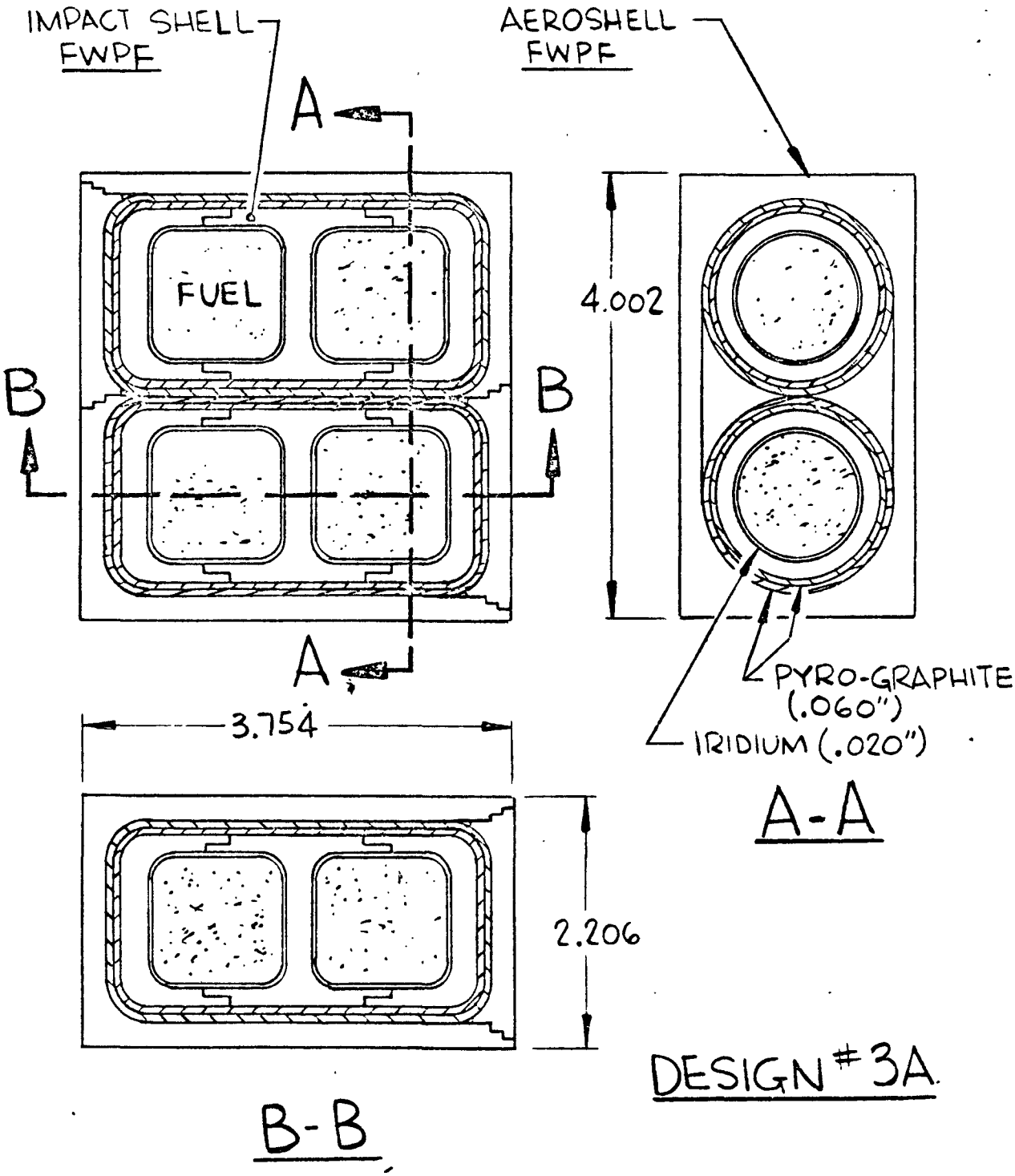
SMOOTH ROUGH

Pt-3008

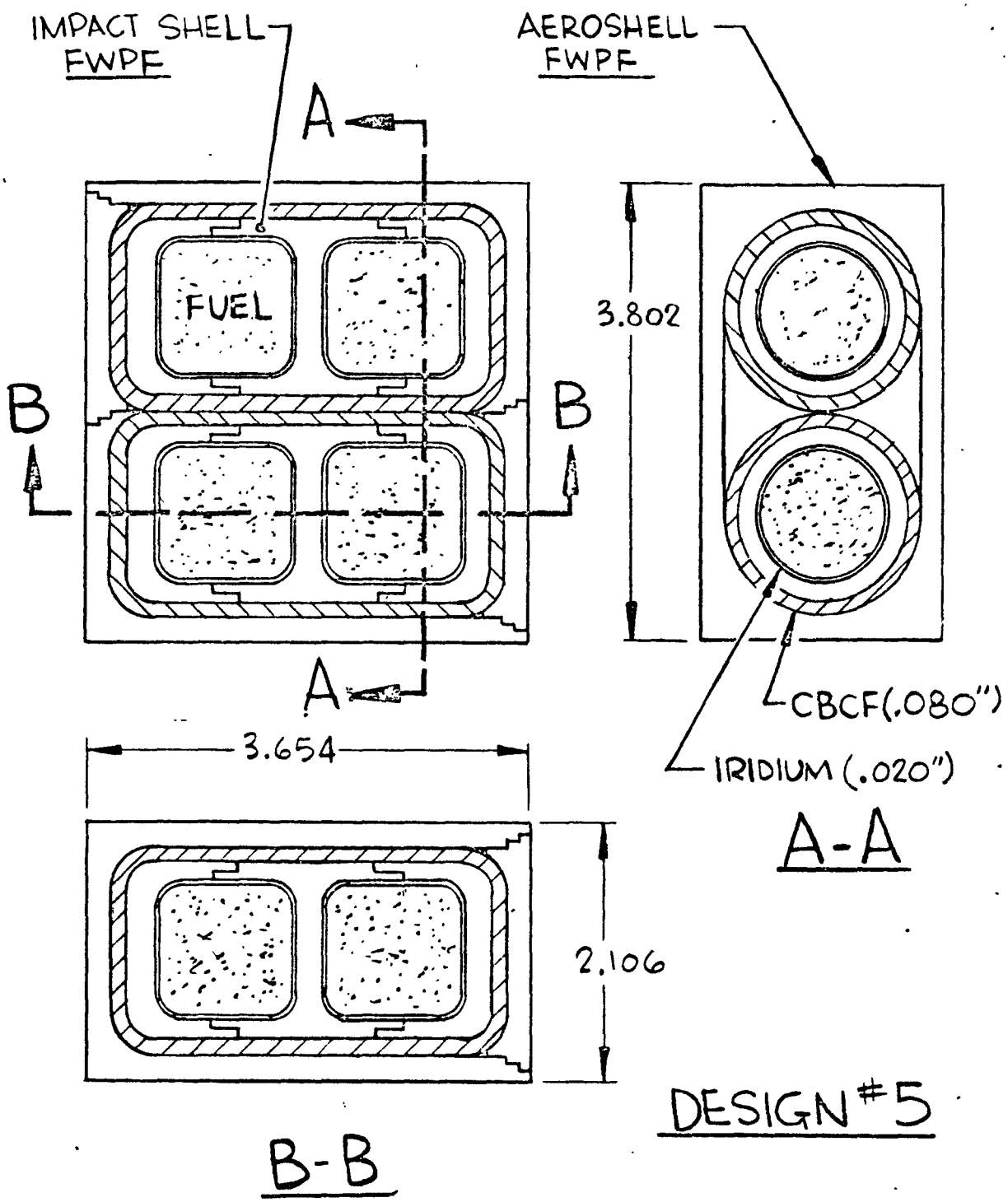
*MIN-GAMMA, TUMBLING

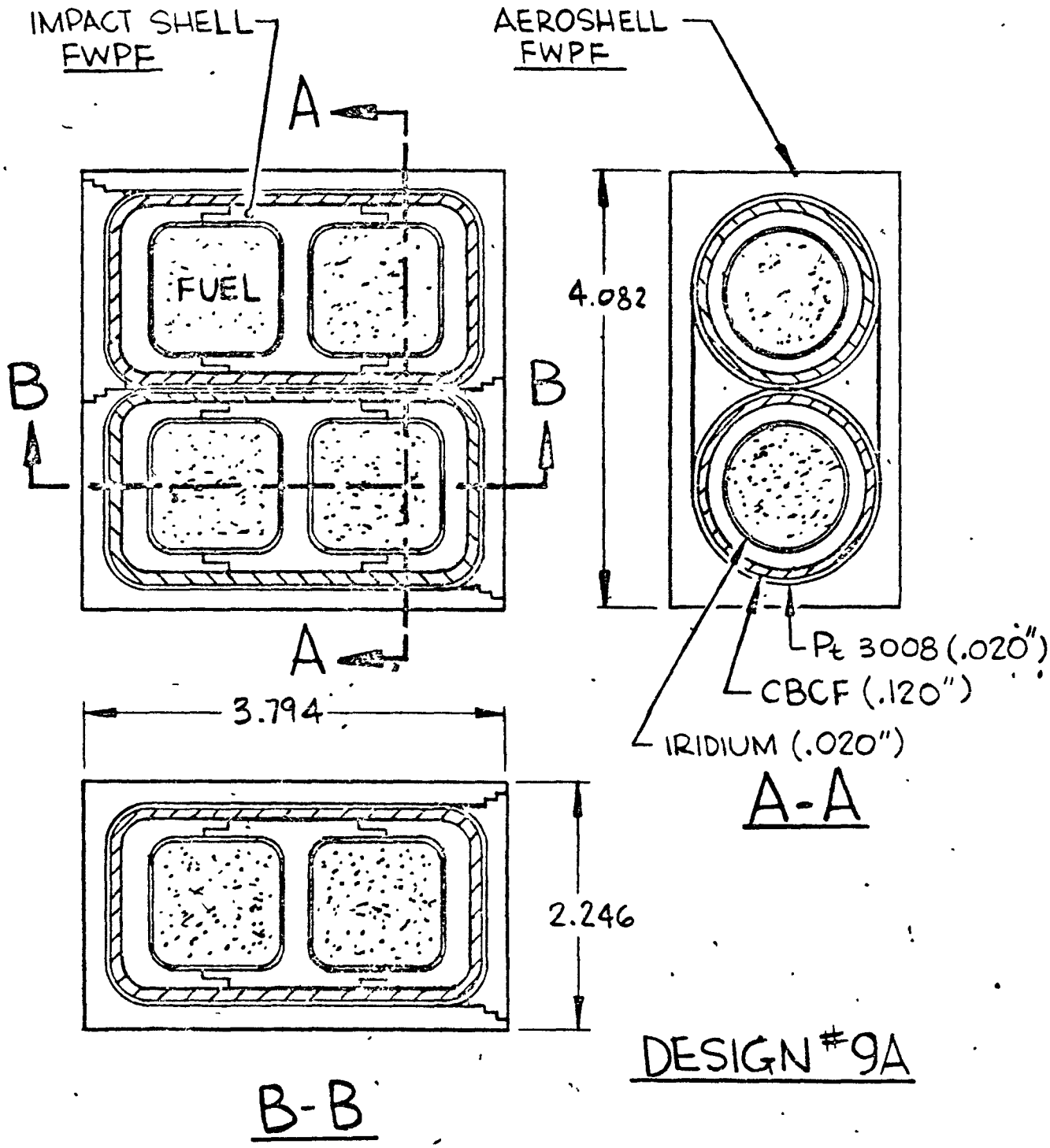
DESIGN COMPARISON
OPERATING AND PEAK TEMPERATURES FOR TUMBLING REENTRY




IMPACT SHELL
FWPF
AEROSHELL
FWPF
A
A
B
B
FUEL
4.002
3.754
2.206
PYRO-GRAPHITE
(.060")
IRIDIUM (.020")
A-A
B-B

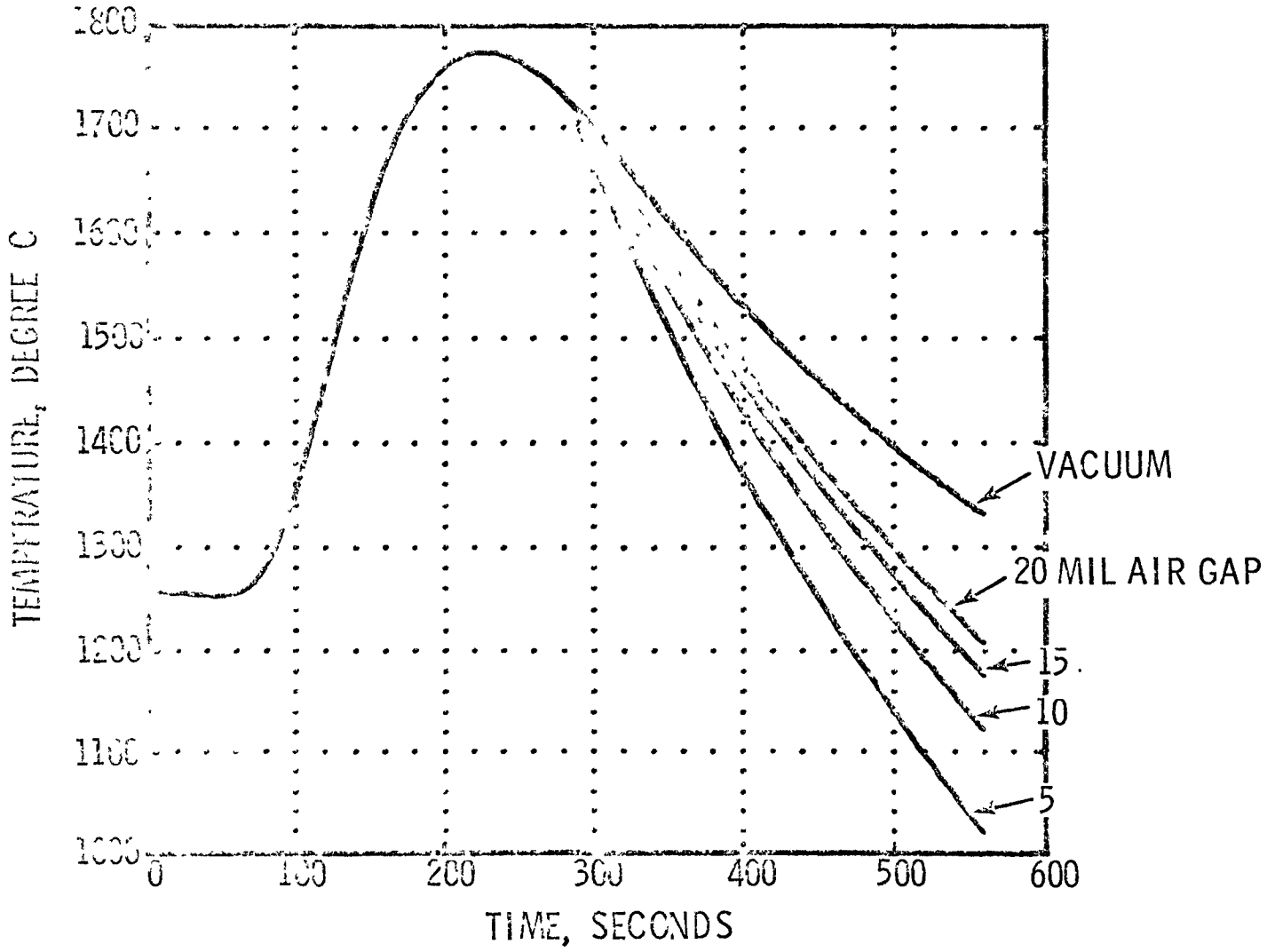
DESIGN # 3A


IMPACT SHELL
FWPF
AEROSHELL
FWPF
A
A
B
B
FUEL
3.802
3.654
2.106
CBCF(.080")
IRIDIUM (.020")
A-A
B-B
DESIGN #5


IMPACT SHELL
FWPF
AEROSHELL
FWPF
A
A
B
B
FUEL
4.082
3.794
2.246
Pt 3008 (.020")
CBCF (.120")
IRIDIUM (.020")
A-A
B-B

DESIGN #9A

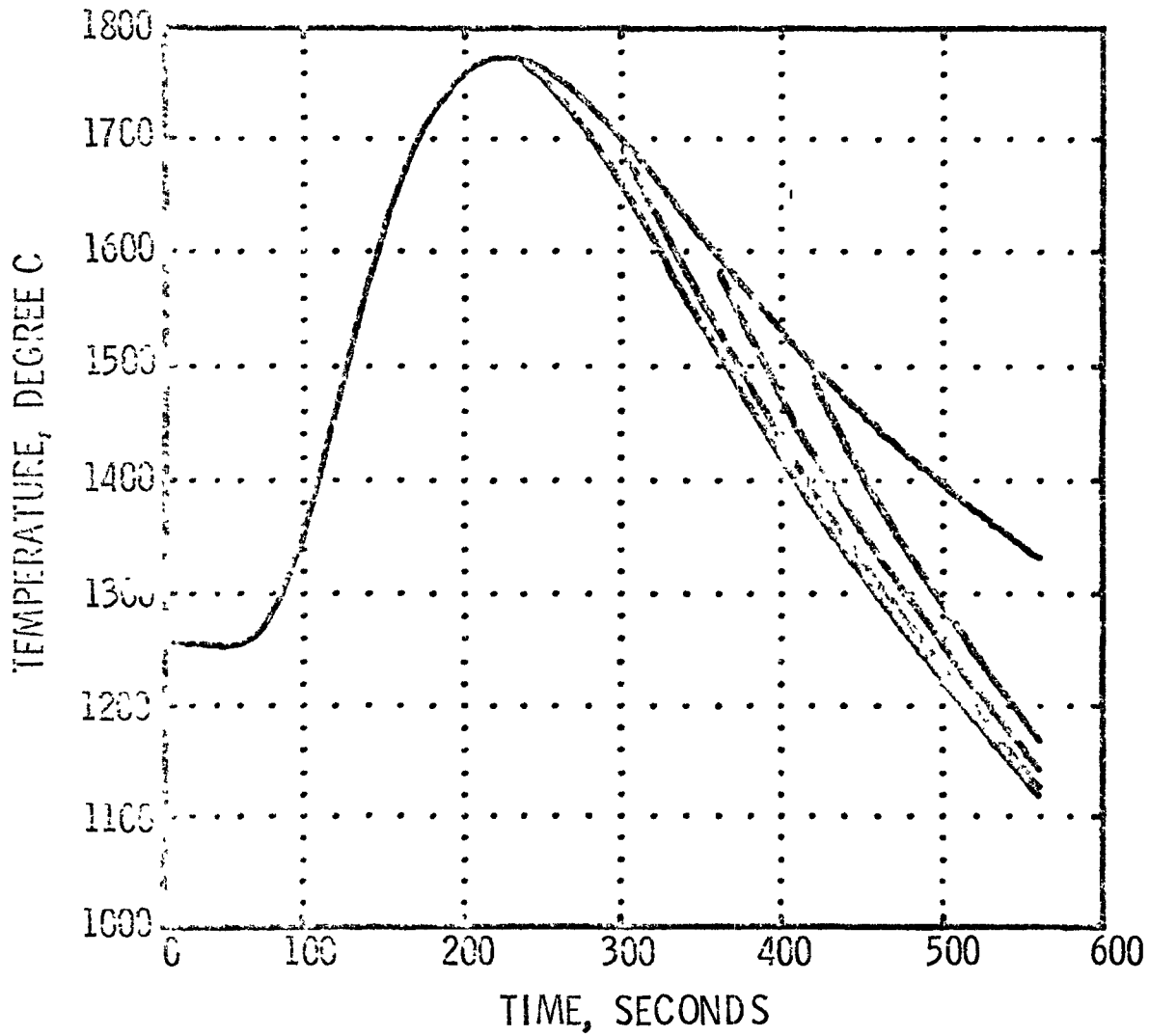
DESIGN GA EFFECT OF AIR GAP AT 290 SECONDS



EFFECT OF GAP WIDTHS ON IRIDIUM IMPACT TEMPERATURE

AFTER MIN-GAMMA REENTRY AIR INTRODUCED AT 290 SEC.	
GAP	Ir - IMPACT TEMP
5	981.0 ^{0}C
10	1102.0^{0}C
15	1163.0^{0}C
20	1198.0^{0}C

DESIGN 3A, 10 MIL AIR GAP
EFFECT OF AIR AT DIFFERENT TIMES



EFFECT OF AIR INTRODUCTION ON IRIDIUM IMPACT TEMPERATURE

AFTER ORBITAL DECAY AIR GAP 10 MIL REENTRY	
AIR ON AT	IMPACT-TEMPERATURE
240 SEC	1100.0°C
300 SEC	1103.0°C
360 SEC	1119.0°C
420 SEC	1144.0°C

CLAD TEMPERATURES (°C) FOR VARIOUS DESIGNS

CLAD TEMPERATURE →	NORMAL	PEAK		IMPACT				
TENTATIVE GOALS →	T < 1330	T < 1800		$T_{FO} > 900$, $T_T > 980$				
REENTRY →	-	MIN-GAMMA	ORBIT DECAY	MIN-GAMMA		ORBIT DECAY		
				.005"	.010"	.005"	.010"	← GAPS
DESIGN (FUEL, IMPACT SHELL, AEROSHELL)								
REF	1343 (1343)	(1870) 1967 (1967) (2320)	(1534) 1625 (1627) (1767)	(883) 950 (940) (929)	1095	(832) 921 (903) (897)	1061	← FACE-ON ← SIDE-ON ← TUMBLING
1	1352	1913	1588	970	1114	926	1066	
2	1319 (1320)	1862 (1864)	1564 (1478*)	971 (967)	1116	918 (838*)	1056	*FACE-ON
3	1288	1904	1588	890	1020	852	976	
3A	1323	1770	1535	1041	1169	981	1102	
4	1308	1901	1574	1074	1155	1004	1083	
4A	1329	1840	1555	1165	1230	1076	1141	
5	1341	1796	1544	1234	1288	1132	1187	
9	1259	1800	1589	1305	1377	841	936	
9A	1234	1695	1575	1320	1365	835	930	
12	1279	1563	1577	1486	1500	971	1018	

Ir — MULTI-FOIL; Pt-3008; CBCF-40; PG-30

THESE COLUMNS WERE NORMALIZED TO MATCH BCL 3D RESULTS FOR REFERENCE CASE

BCL 3D RESULTS ARE IN PARENTHESES

CATHODE TEMPERATURE MARGINS FOR VARIOUS DESIGNS

CLAD TEMPERATURE →	NORMAL		PEAK		IMPACT		
MARGIN IN °C →	1330-T		1800-T		T_{FO} - 900, T_T - 980		
REENTRY PATH →	-		MIN-GAMMA		ORBITAL DECAY		
					5 MIL	10 MIL	← GAPS
DESIGN (FUEL / AEROSHELL / IMPACT SHELL)							
REF	-13	(-13)	-167	(-70) (-520) (-167)	-59	(-68) (-80) (-77)	+ 81
1	- 2		-113		-54		+ 86
2	+11	(+9)	- 62	(-64)	-62	(-62*)	+76
3	+42		-104		-128		- 4
3A	+ 7		+ 30		+ 1		+122
4	+22		-101		+ 24		+103
4A	+ 1		- 40		+ 96		+161
5	-11		+ 4		+152		+207
9	+91		0		-139		-44
9A	+96		+105		-145		-50
12	+151		+237		-109		+38

← FACE-ON
← SIDE-ON
← TUMBLING
*FACE-ON

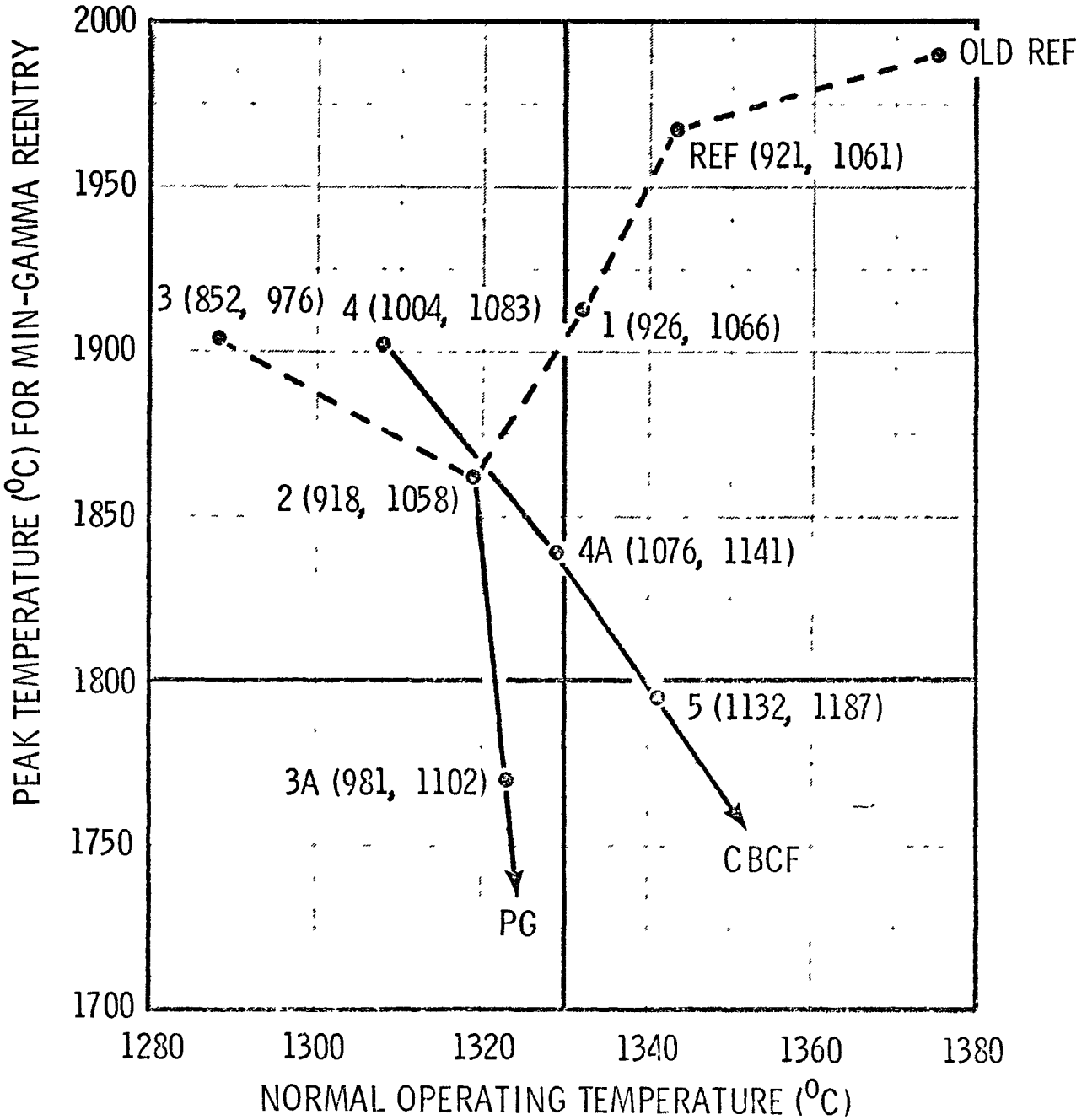
MULTI-FOIL
PG-30
CBCF-40
PI-3008

{THESE COLUMNS BASED ON TEMPERATURES NORMALIZED TO MATCH BCL 3D REF CASE

BCL MARGINS SHOWN IN PARENTHESES

CRITICAL TEMPERATURES FOR TUMBLING REENTRY

NUMBERS IN PARENTHESES ARE IMPACT TEMPERATURES (^{0}C)
AFTER ORBITAL DECAY, WITH 5 AND 10 MIL GAPS

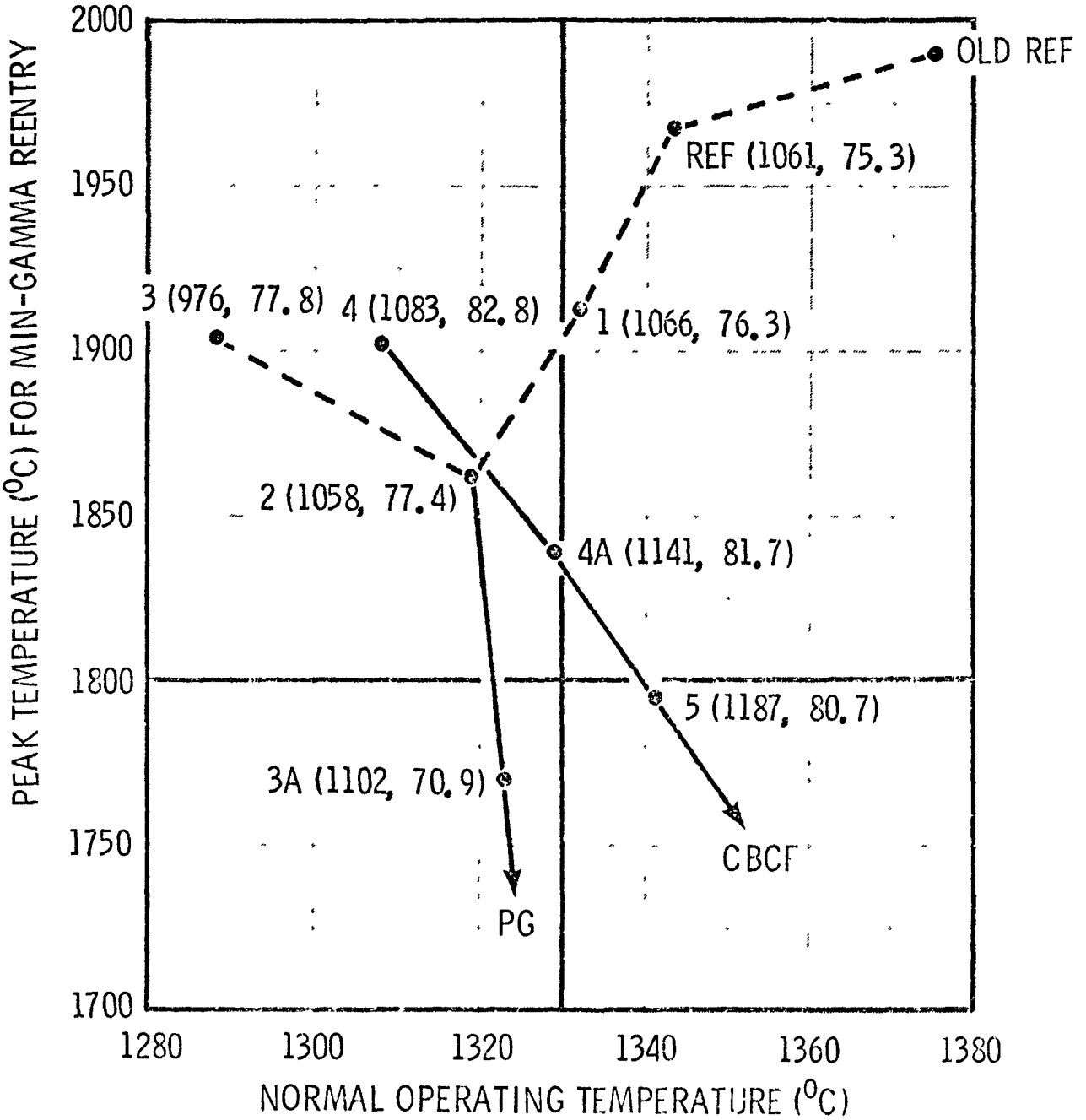


MODEL DESIGN CHARACTERISTICS

DESIGN	DIMENSIONS (IN.)		WEIGHT (LB)	SPECIFIC POWER (WATTS/LB)
ORIGINAL	3.65 x 3.76 x 2.03	0.0		
REF. DESIGN	3.73 x 3.82 x 2.08	0.90	3.32	75.3
DESIGN 1	3.73 x 3.74 x 2.08	0.90	3.28	76.3
DESIGN 2	3.73 x 3.66 x 2.08	0.90	3.23	77.4
DESIGN 3	3.69 x 3.64 x 2.06	0.54	3.21	77.8
DESIGN 3A	3.97 x 3.78 x 2.20	3.06	3.53	70.9
DESIGN 4	3.61 x 3.60 x 2.02	-0.18	3.02	82.8
DESIGN 4A	3.69 x 3.64 x 2.06	0.54	3.06	81.7
DESIGN 5	3.77 x 3.68 x 2.10	1.26	3.10	80.7
DESIGN 7	3.73 x 3.76 x 2.08	0.90	3.69	67.7
DESIGN 8	3.89 x 3.92 x 2.16	2.34	3.89	64.2
DESIGN 9	4.05 x 4.08 x 2.24	3.78	4.12	60.6
DESIGN 9A	4.05 x 3.82 x 2.24	3.78	3.83	65.2
DESIGN 10	3.89 x 3.92 x 2.16	2.34	3.97	63.0
DESIGN 11	4.05 x 4.00 x 2.24	3.78	3.87	64.6
DESIGN 12	4.09 x 4.02 x 2.26	4.14	4.46	56.0
DESIGN 13	3.89 x 3.92 x 2.16	2.34	4.10	61.0
DESIGN 14	3.85 x 3.86 x 2.14	1.98	3.76	66.5
DESIGN 15	4.05 x 4.06 x 2.24	3.78	3.97	62.9
DESIGN 16	4.05 x 4.14 x 2.24	3.78	4.00	62.5
DESIGN 17	4.05 x 4.14 x 2.24	3.78	4.00	62.5

CRITICAL TEMPERATURES FOR TUMBLING REENTRY

NUMBERS IN PARENTHESES ARE IMPACT TEMPERATURES (^{0}C) AFTER ORBITAL DECAY, WITH 10 MIL GAPS, AND SPECIFIC POWER (IN WATTS/LB)

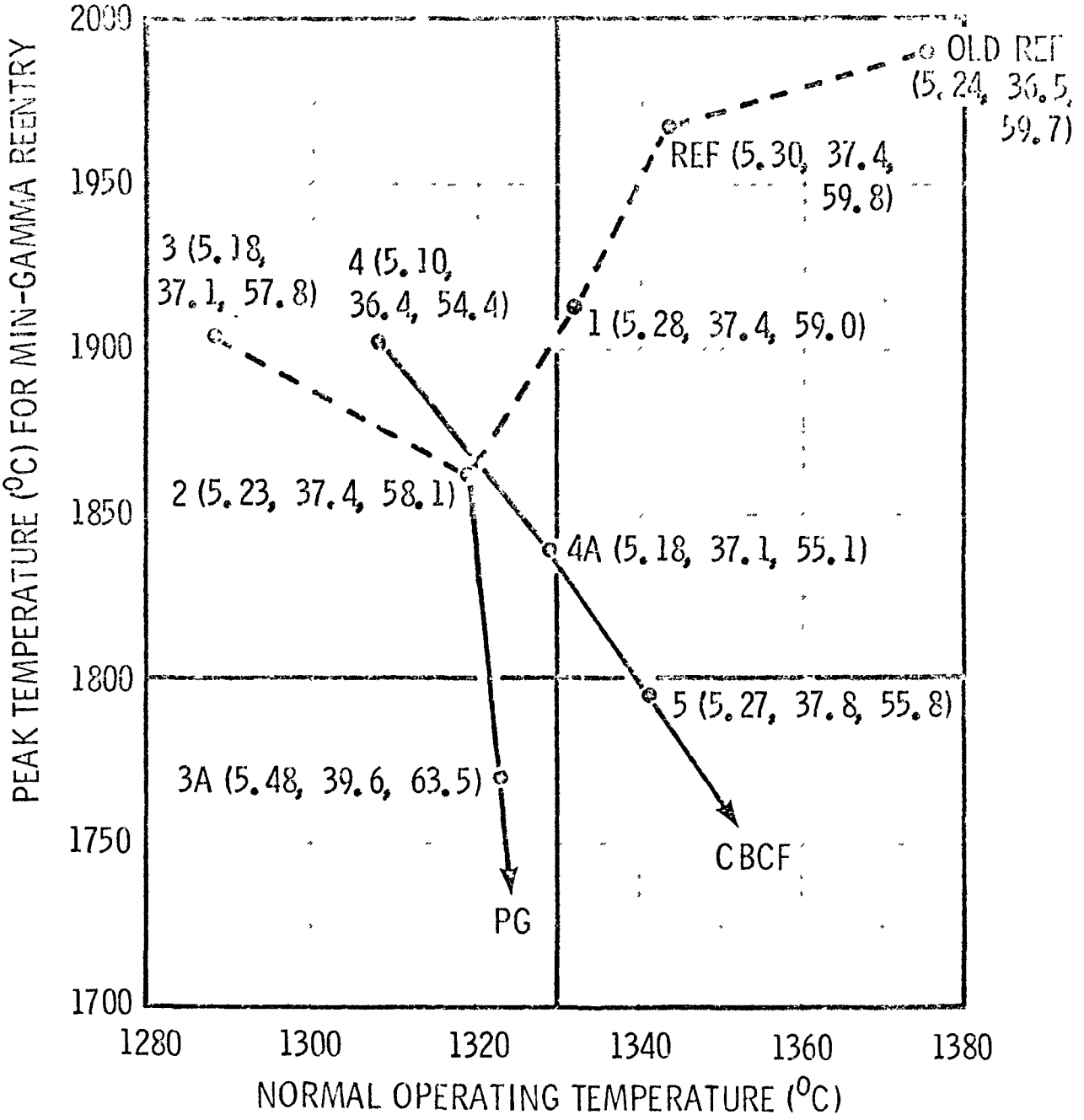


HEAT SOURCE SIZE AND WEIGHT

DESIGN	SINGLE MODULE DIAGONAL (IN.)	SINGLE MODULE HEIGHT (IN.)	SINGLE MODULE WT (LB)	18 MODULES TOTAL HT. (IN.)	18 MODULES TOTAL WT. (LB)
REF DESIGN	5.34	2.08	3.32	37.4	59.8
DESIGN 1	5.28	2.08	3.28	37.4	59.0
DESIGN 2	5.23	2.08	3.23	37.4	58.1
DESIGN 3	5.18	2.06	3.21	37.1	57.8
DESIGN 3A	5.48	2.20	3.53	40.0	63.5
DESIGN 4	5.10	2.02	3.02	36.4	54.4
DESIGN 4A	5.18	2.06	3.06	37.1	55.1
DESIGN 5	5.27	2.10	3.10	38.0	55.8
DESIGN 9	5.75	2.24	4.12	40.3	74.2
DESIGN 9A	5.57	2.24	3.83	40.3	68.9
DESIGN 12	5.73	2.26	4.46	40.7	80.3

GENERAL PARAMETERS OF VARIOUS DESIGNS (10 MIN GAMMA)

NUMBERS IN PARENTHESES ARE THE DIAGONAL DIMENSION, STACK HEIGHT, AND WEIGHT OF AN 18-MODULE HEAT SOURCE



EFFECT OF IRIDIUM EMISSIVITY

ε_{Ir}	OPERATING TEMP.	PEAK TEMP.
0.2	1341°C	1773°C
0.28	1315°C	1774°C
0.30	1310°C	1774°C
0.40	1294°C	1774°C

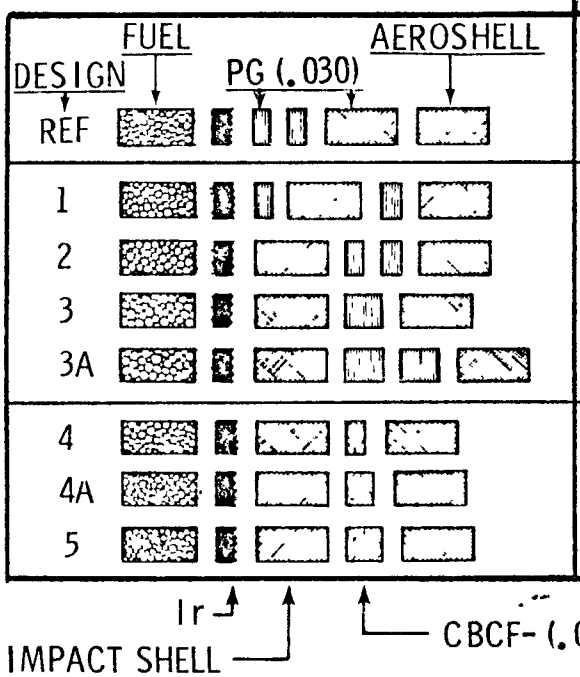
EFFECT OF FWPF EMISSIVITY

EMISSIVITY		TEMPERATURE	
1200°C	1800°C	OPERATING	PEAK
0.82	0.92	1315°C	1774°C
0.70	0.82	1320°C	1819°C

EFFECT OF HIGHER HEAT INPUT (QNET)

RELATIVE HEAT INPUT	PEAK CLAD TEMPERATURE
1.00	1824
1.20	1906
1.40	1981
1.60	2049

PRINCIPAL HEAT SOURCE (18-MODULE HEAT SOURCE)

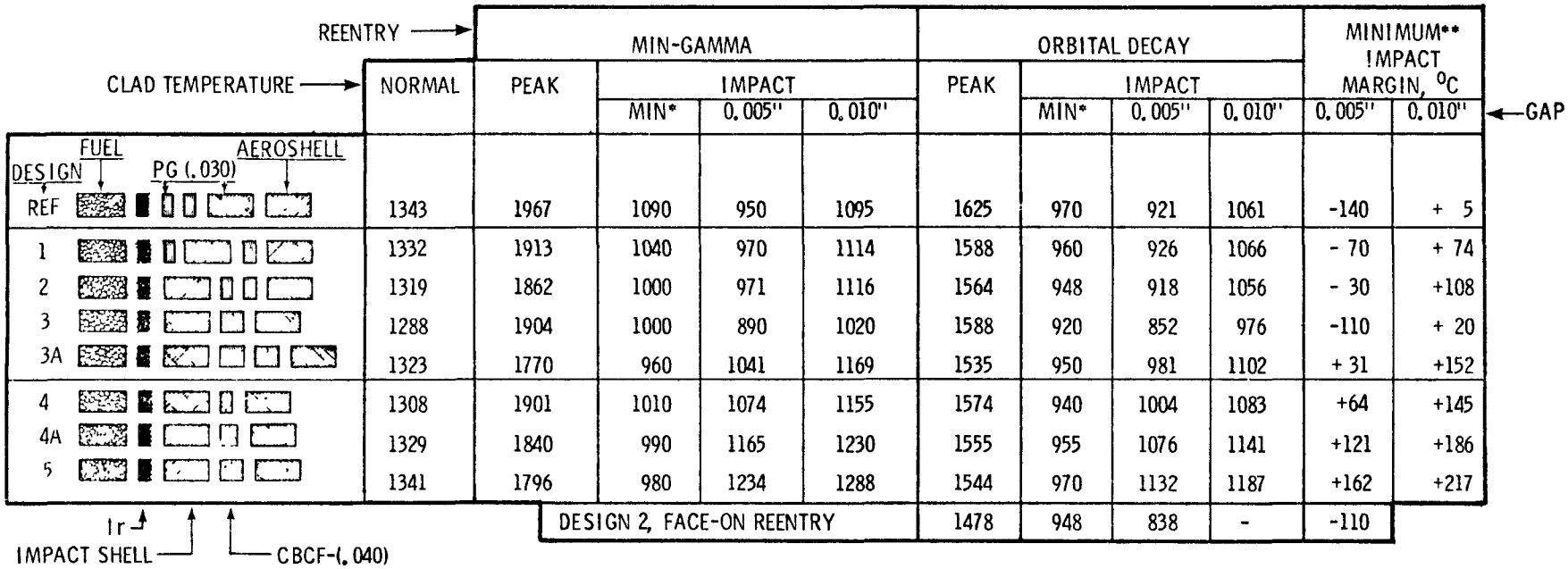


	IMPACT* TEMPERATURE MARGIN, °C		DIAGONAL DIMENSION	STACK HEIGHT	WEIGHT	SPECIFIC POWER
GAPS→	0.005"	0.010"	INCH	INCH	LB	W/LB
REF	-140	+ 5	5.34	374.	59.8	75.3
1	- 70	+ 74	5.28	37.4	59.0	76.3
2	- 30	+108	5.23	37.4	58.1	77.4
3	-110	+ 20	5.18	37.1	57.8	77.8
3A	+ 31	+152	5.48	39.6	63.5	70.9
4	+ 64	+145	5.10	36.4	54.4	82.8
4A	+121	+186	5.18	37.1	55.1	81.7
5	+162	+217	5.27	38.0	55.8	80.7

* MINIMUM IMPACT TEMPERATURE MARGIN FOR TUMBLING REENTRY (BASED ON SCHAFFHAUSER DATA FOR 20% LOCAL STRAIN) THIS MARGIN SHOULD BE GREATER THAN +100 TO COVER THE LOWER IMPACT TEMPERATURE OF FACE-ON CASE

IMPACT TEMPERATURE MARGINS

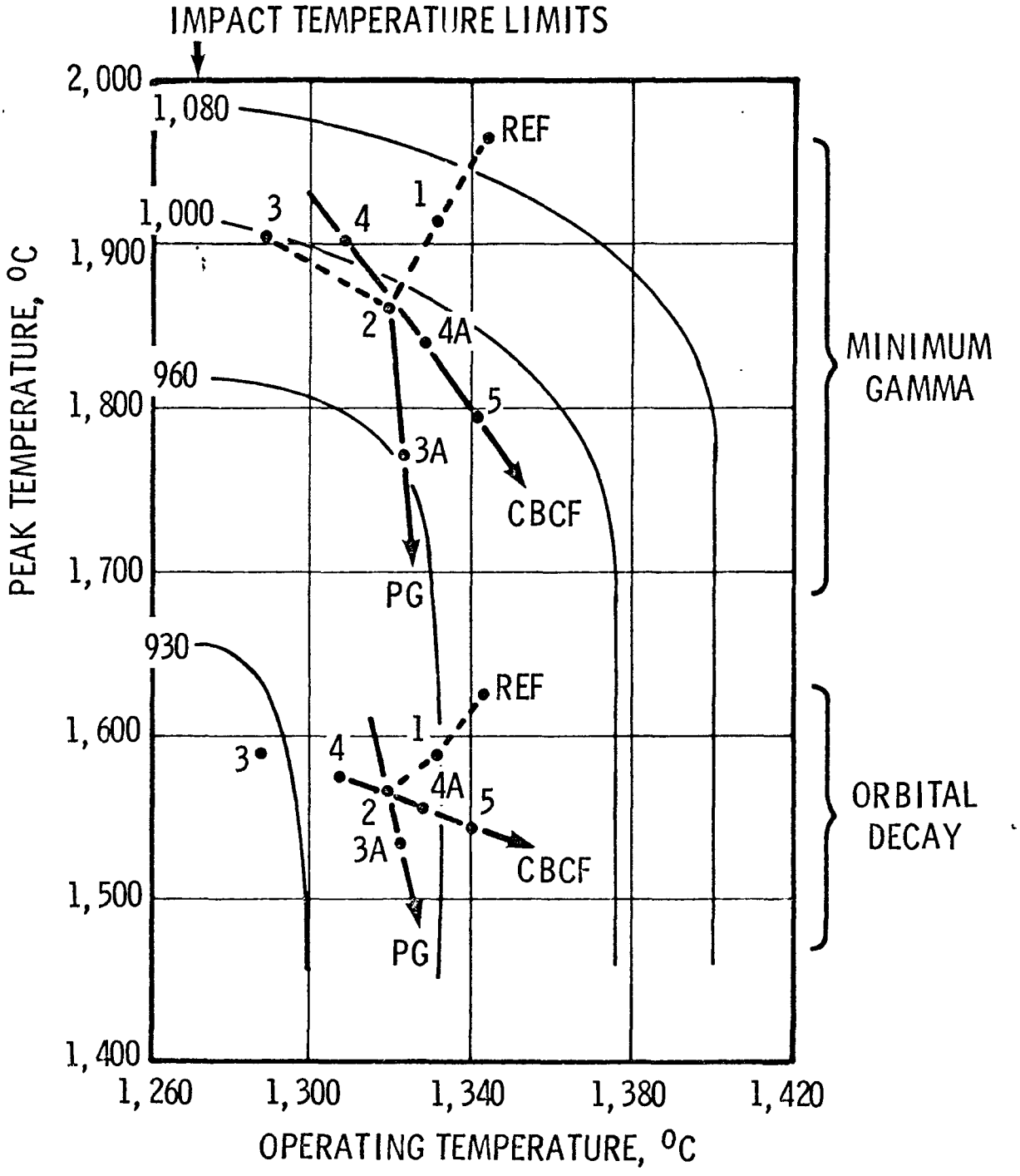
DESIGN	CLAD TEMPERATURE (NORMAL)	MIN-GAMMA PEAK	MIN-GAMMA IMPACT MIN*	MIN-GAMMA IMPACT 0.005"	MIN-GAMMA IMPACT 0.010"	ORBITAL DECAY PEAK	ORBITAL DECAY IMPACT MIN*	ORBITAL DECAY IMPACT 0.005"	ORBITAL DECAY IMPACT 0.010"	MINIMUM** IMPACT MARGIN, °C 0.005"	MINIMUM** IMPACT MARGIN, °C 0.010"
REF	1343	1967	1090	950	1095	1625	970	921	1061	-140	+ 5
1	1332	1913	1040	970	1114	1588	960	926	1066	- 70	+ 74
2	1319	1862	1000	971	1116	1564	948	918	1056	- 30	+108
3	1288	1904	1000	890	1020	1588	920	852	976	-110	+ 20
3A	1323	1770	960	1041	1169	1535	950	981	1102	+ 31	+152
4	1308	1901	1010	1074	1155	1574	940	1004	1083	+64	+145
4A	1329	1840	990	1165	1230	1555	955	1076	1141	+121	+186
5	1341	1796	980	1234	1288	1544	970	1132	1187	+162	+217
DESIGN 2, FACE-ON REENTRY						1478	948	838	-	-110	



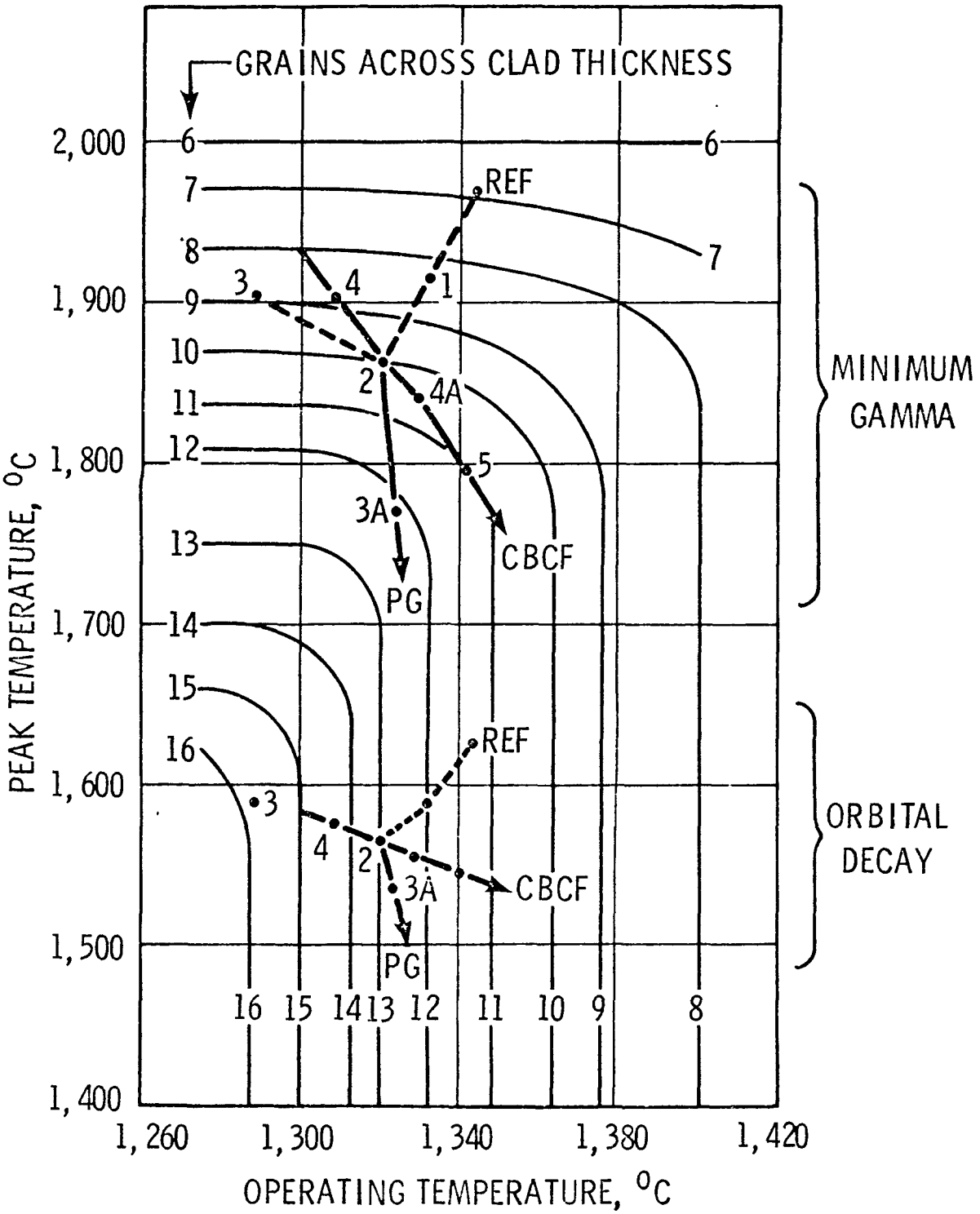
*MINIMUM ALLOWABLE IMPACT TEMPERATURE FOR GIVEN OPERATING AND PEAK TEMPERATURES (SCHAFFHAUSER DATA FOR 20% LOCAL STRAIN)

**MINIMUM IMPACT TEMPERATURE MARGIN FOR TUMBLING REENTRY THIS SHOULD BE GREATER THAN +100 TO COVER LOWER IMPACT TEMPERATURE OF FACE-ON CASE

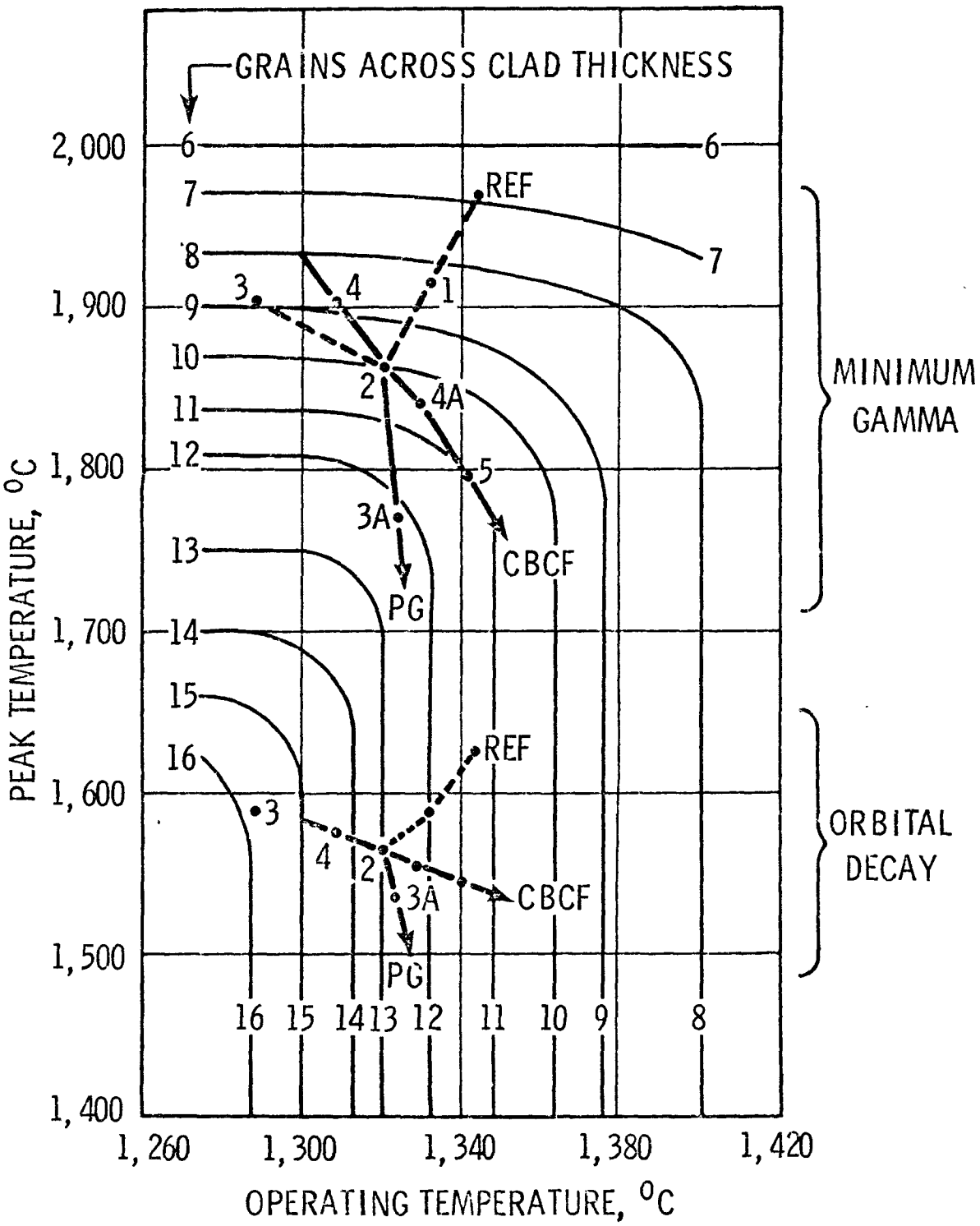
MINIMUM ALLOWABLE IMPACT TEMPERATURES



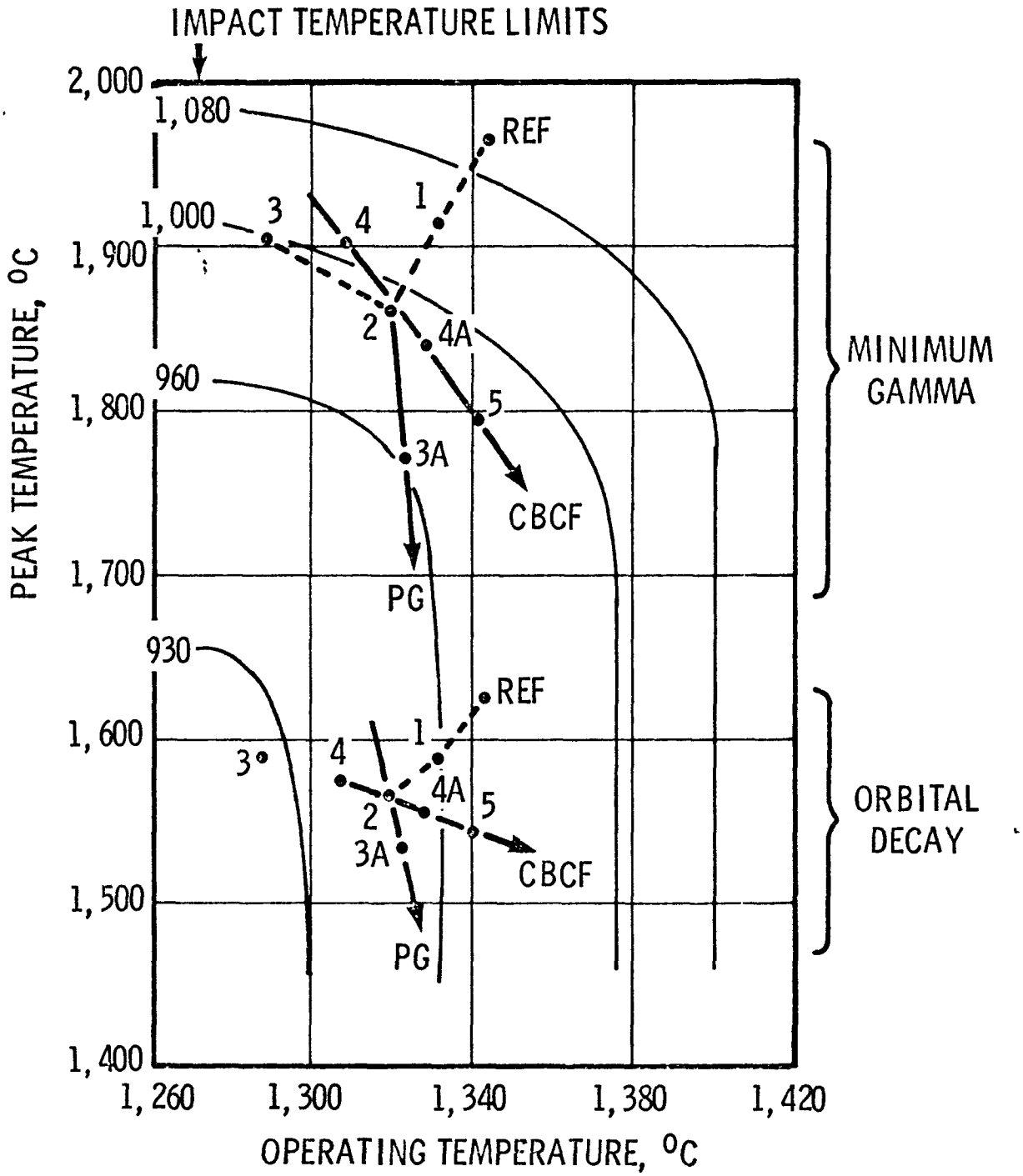
GRAIN GROWTH AFTER SIX-MONTH OPERATIONS AND TWO-MINUTE RE-ENTRY PEAK



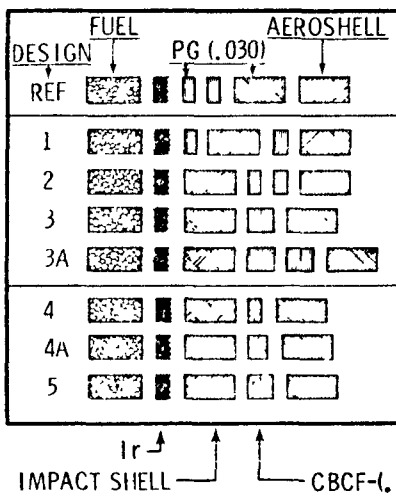
GRAIN GROWTH AFTER SIX-MONTH OPERATIONS AND TWO-MINUTE RE-ENTRY PEAK



MINIMUM ALLOWABLE IMPACT TEMPERATURES



IMPACT TEMPERATURE MARGINS

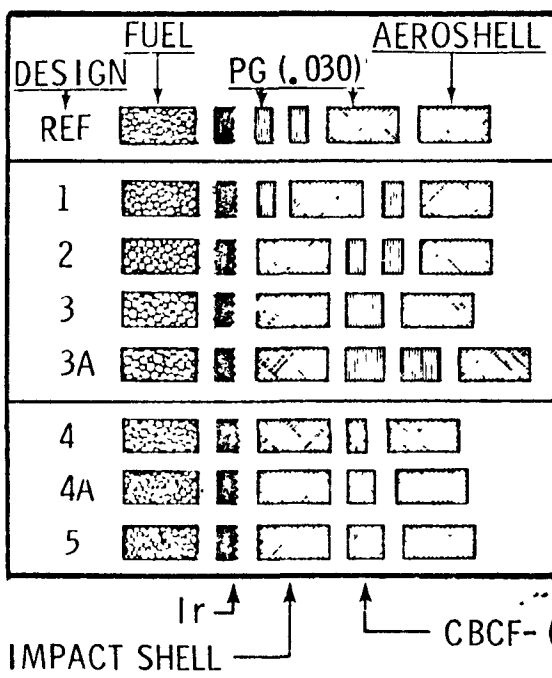


REENTRY → / CLAD TEMPERATURE →	MIN-GAMMA					ORBITAL DECAY				MINIMUM** IMPACT MARGIN, °C	
	NORMAL	PEAK	IMPACT			PEAK	IMPACT				
			MIN*	0.005"	0.010"		MIN*	0.005"	0.010"	0.005"	0.010" ← GAP
REF	1343	1967	1090	950	1095	1625	970	921	1061	-140	+ 5
1	1332	1913	1040	970	1114	1588	960	926	1066	- 70	+ 74
2	1319	1862	1000	971	1116	1564	948	918	1056	- 30	+108
3	1288	1904	1000	890	1020	1588	920	852	976	-110	+ 20
3A	1323	1770	960	1041	1169	1535	950	981	1102	+ 31	+152
4	1308	1901	1010	1074	1155	1574	940	1004	1083	+64	+145
4A	1329	1840	990	1165	1230	1555	955	1076	1141	+121	+186
5	1341	1796	980	1234	1288	1544	970	1132	1187	+162	+217
DESIGN 2, FACE-ON REENTRY						1478	948	838	-	-110	

*MINIMUM ALLOWABLE IMPACT TEMPERATURE FOR GIVEN OPERATING AND PEAK TEMPERATURES (SCHAFFHAUSER DATA FOR 20% LOCAL STRAIN)

**MINIMUM IMPACT TEMPERATURE MARGIN FOR TUMBLING REENTRY THIS SHOULD BE GREATER THAN +100 TO COVER LOWER IMPACT TEMPERATURE OF FACE-ON CASE

PRINCIPAL HEAT SOURCE (18-MODULE HEAT SOURCE)



	IMPACT* TEMPERATURE MARGIN, °C		DIAGONAL DIMENSION	STACK HEIGHT	WEIGHT	SPECIFIC POWER
GAPS→	0.005"	0.010"	INCH	INCH	LB	W/LB
REF	-140	+ 5	5.34	374.	59.8	75.3
1	- 70	+ 74	5.28	37.4	59.0	76.3
2	- 30	+108	5.23	37.4	58.1	77.4
3	-110	+ 20	5.18	37.1	57.8	77.8
3A	+ 31	+152	5.48	39.6	63.5	70.9
4	+ 64	+145	5.10	36.4	54.4	82.8
4A	+121	+186	5.18	37.1	55.1	81.7
5	+162	+217	5.27	38.0	55.8	80.7

* MINIMUM IMPACT TEMPERATURE MARGIN FOR TUMBLING REENTRY (BASED ON SCHAFFHAUSER DATA FOR 20% LOCAL STRAIN) THIS MARGIN SHOULD BE GREATER THAN +100 TO COVER THE LOWER IMPACT TEMPERATURE OF FACE-ON CASE

GPHS TASK-GROUP MEETING

AUGUST 21 & 22, 1979

DOE/GERMANTOWN

S. BRONISZ

University of California
LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos New Mexico 87545

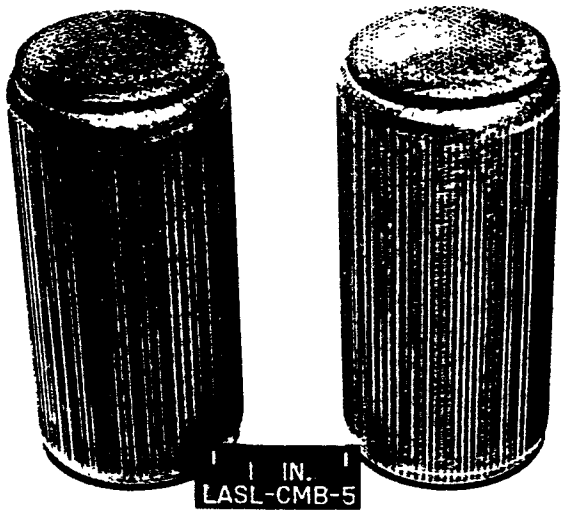
An affirmative action equal opportunity employer

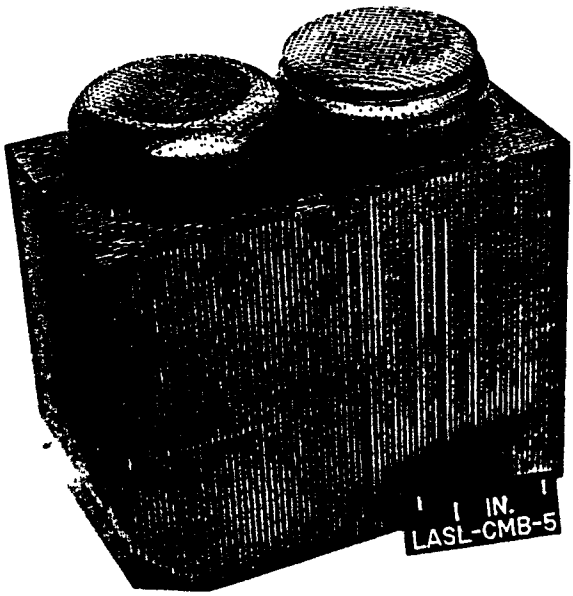
GPHS IMPACT TESTS

THE GPHS DESIGN IMPACT TESTS WERE CARRIED OUT AT 58 M/S AND 965°C AND RESULTED IN THE FINAL MODULE DESIGN.

THIS DESIGN WAS THEN TESTED AT 900°C AND 800°C.

A MORE SUBSTANTIAL GIS WAS TESTED AT 78M/S AND 1075°C (CUBE CONDITIONS).





MGCI-PUIR-110-23

Table: GPHS IMPACTS of 62.5 W IG-0.3% W / PuO_2 CAPSULES

CAPSULE No.	TYPE OF IMPACT	CAPSULE LOCATION	HEAT TREAT and grains/thick	IMPACT SHELL	IMPACT TEMP. °C	IMPACT VELOCITY m/s	Max. diam. strain %	Diagonal or diametral shrinkage %	Max. positive weld strain	Local Strains Shear or thickness	Local Strains Bending	Fracture
IRG-10	Double 90°	Leading Caps.	1 h at 1500°C 25-28	DGIS-2	965	58	2.5	-1.3	4 %	a	<5%	No
IRG-30	Double 0°	Leading Caps.	-"-	DGIS-6	965	58.1	5.5	-6.6 (HEIGHT)	4.3	46%	16	No
IRG-17	Mockup Module 45°	Leading GIS Leading Caps.	-"-	DGIS-2	965	58	9.0	-12.4	8.9	40	15	No
IRG-14	Double 27°	Leading Caps.	-"-	DGIS-2	965	57.2	3.5	-8.9	3.5	a	9	No
IRG-15	-"-	-"-	-"-	DGIS-2	965	~56	9.1	-7.4	8.1	75	20	No
IRG-23	-"-	-"-	-"-	DGIS-4	965	57.9	5.8	-7.9	5.8	a	15	No
IRG-24	-"-	-"-	-"-	DGIS-5	965	58	5.1	-8.3	5.1	a	8	No
IRG-27	-"-	-"-	-"-	DGIS-6	900	58	4.3	-7.7	4.3	14	9	No
IRG-43	-"-	-"-	-"-	DGIS-6	800	58	8.8	-9.2	8.8	b	b	No
IRG-42	-"-	-"-	1 h at 1650°C ~10-12	DGIS-6	800	58	4.1	-6.8	4.1	a	~<5	No
IRG-19	Module 45° Short Edge	Leading GIS Leading Caps.	1 h at 1500°C 25-28	DGIS-3	965	57.6	4.6	-9.3	4.1	a	13	2 possib Microcra
IRG-20	-"-	Trailing GIS Leading Caps.	-"-	DGIS-3	965	57.6	3.0	-2.4	2.8	a	<5	No
IRG-29	Module 45° Corner	Lead. GIS Trail. Caps.	-"-	DGIS-6	965	58	6.7	-7.1	5.0	a	16	No
IRG-28	-"-	Trail. GIS Lead. Caps.	-"-	DGIS-6	965	58	0.8	-1.7	0.8	a	<5	No
IRG-39	Double 27°	Lead	5-6	"	800	58	11.0					YES
	Double 27°	Lead	12-14	DGIS-7	1075	79						YES

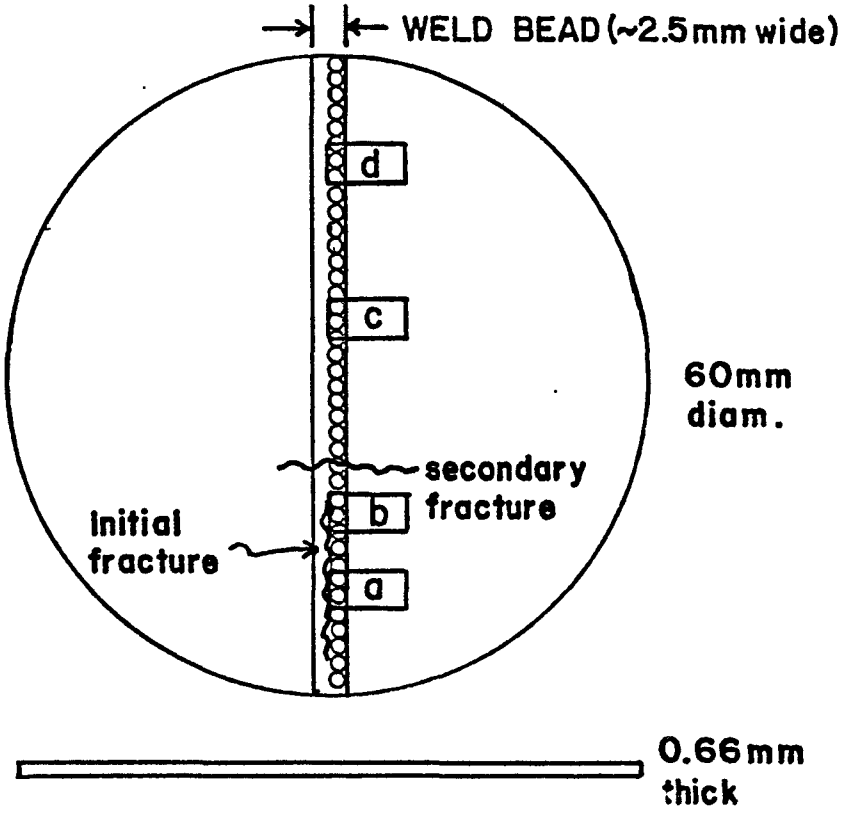
(a) Not significant
(b) Not measured to date

GPHS IMPACT RESULTS

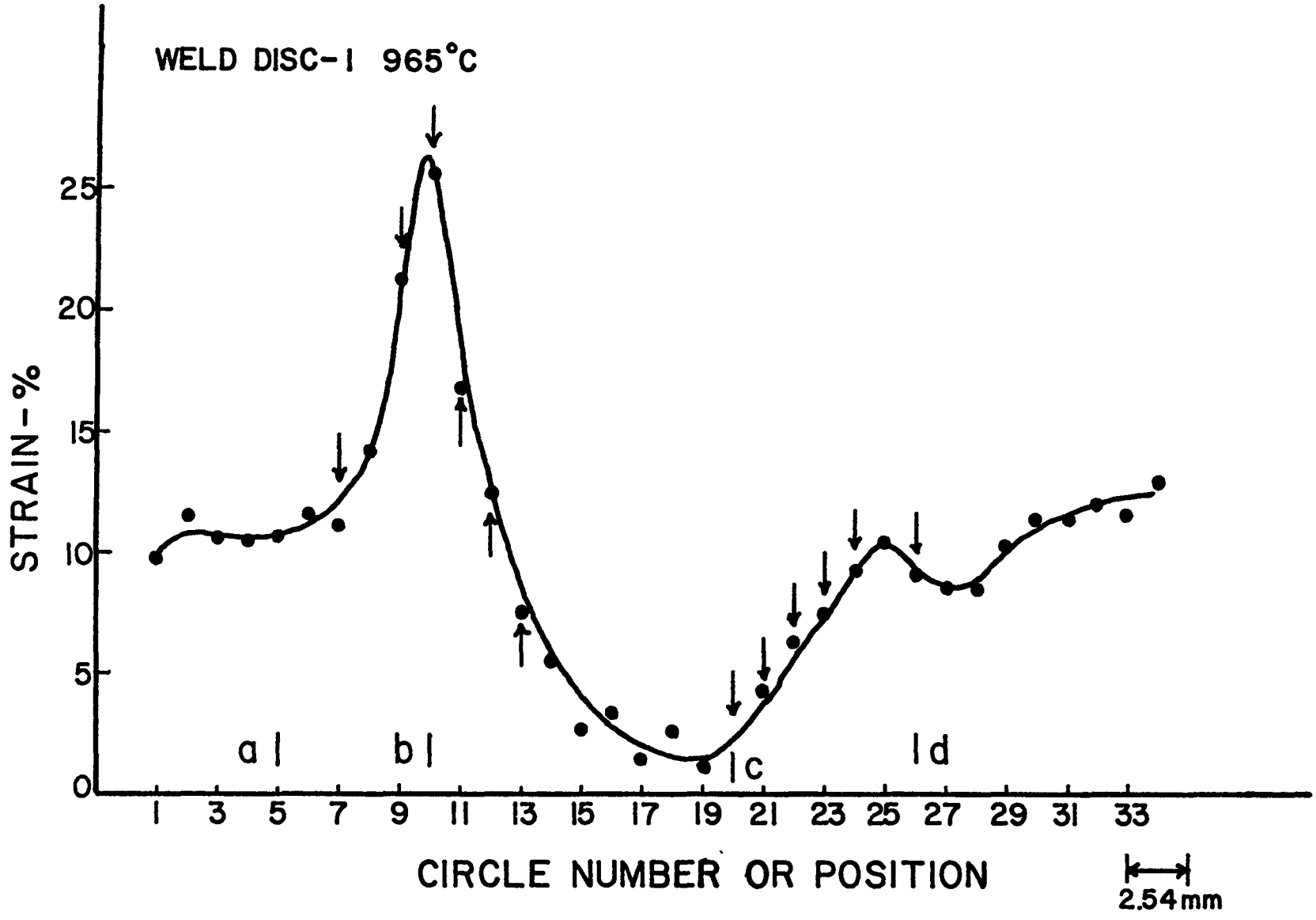
AT 965°C AND 900°C (58M/S) THE IRIDIUM CAPSULE WAS FINE-GRAINED AND DID NOT FAIL.

AT 800°C (58M/S) FINE-GRAINED IRIDIUM AND MODERATE-GRAINED IRIDIUM DID NOT FAIL, BUT COARSE-GRAINED IRIDIUM DID FAIL.

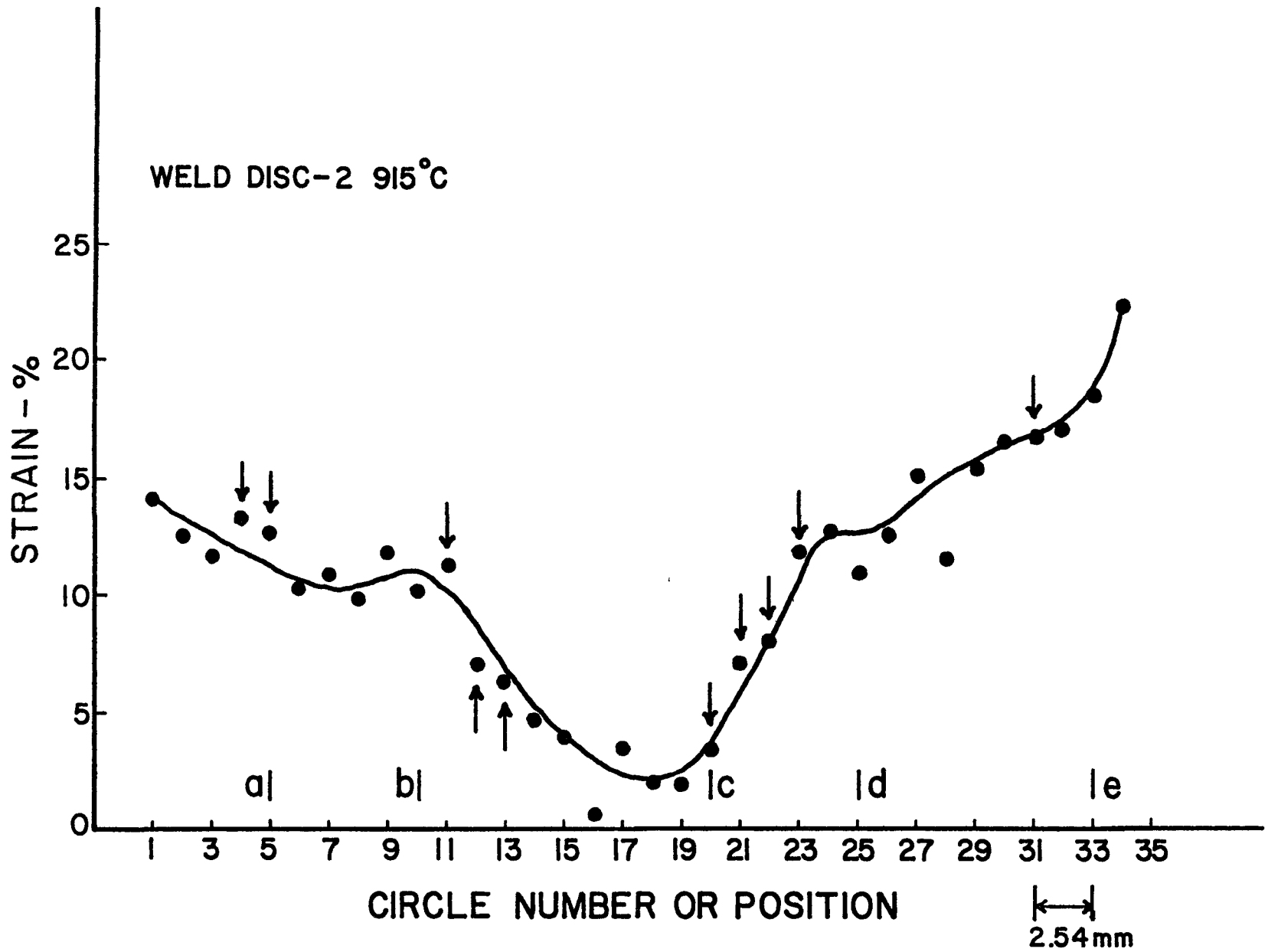
AT 1075°C (78M/S) MODERATE GRAINED IRIDIUM FAILED AS A RESULT OF FUEL PUNCH-THROUGH (HIGH LOCAL STRAINS).

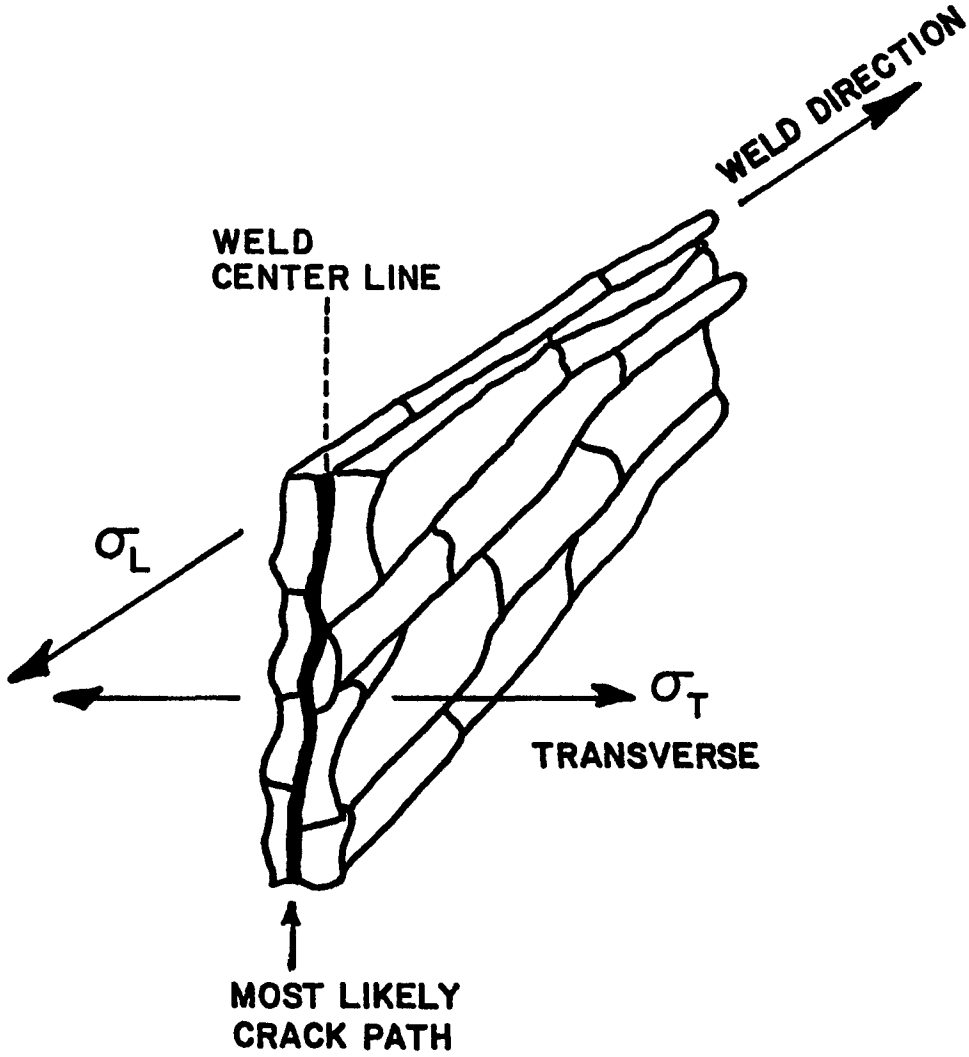


THE WELD DUCTILITY OF IRIDIUM (DOP-26) IS BEING EVALUATED WITH THE LASL BIAXIAL CUP TEST.


WELD DISC-1 965°C
STRAIN-%
0
5
10
15
20
25
a
b
c
d
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33
CIRCLE NUMBER OR POSITION
2.54mm

lower case letters ...

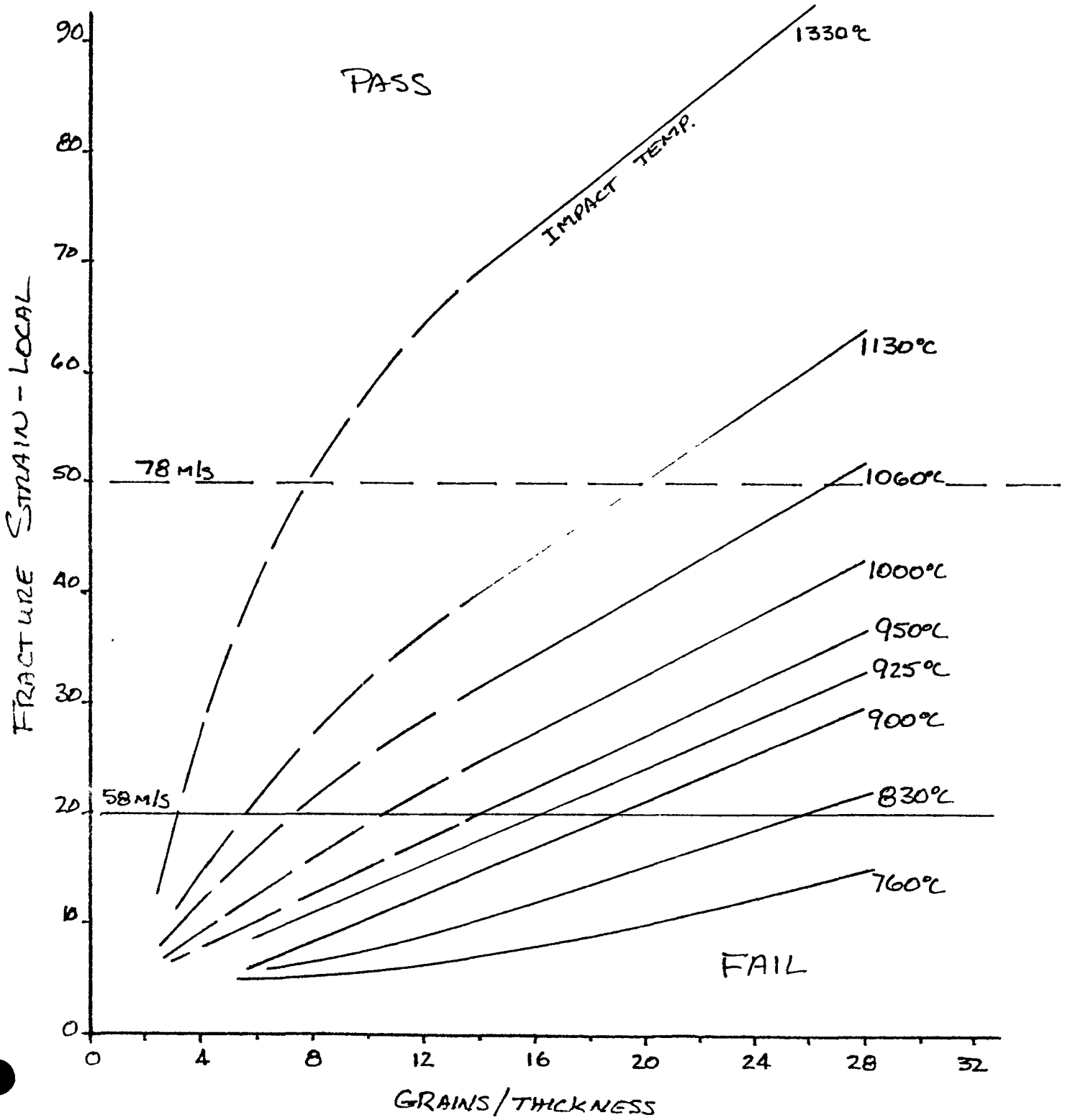


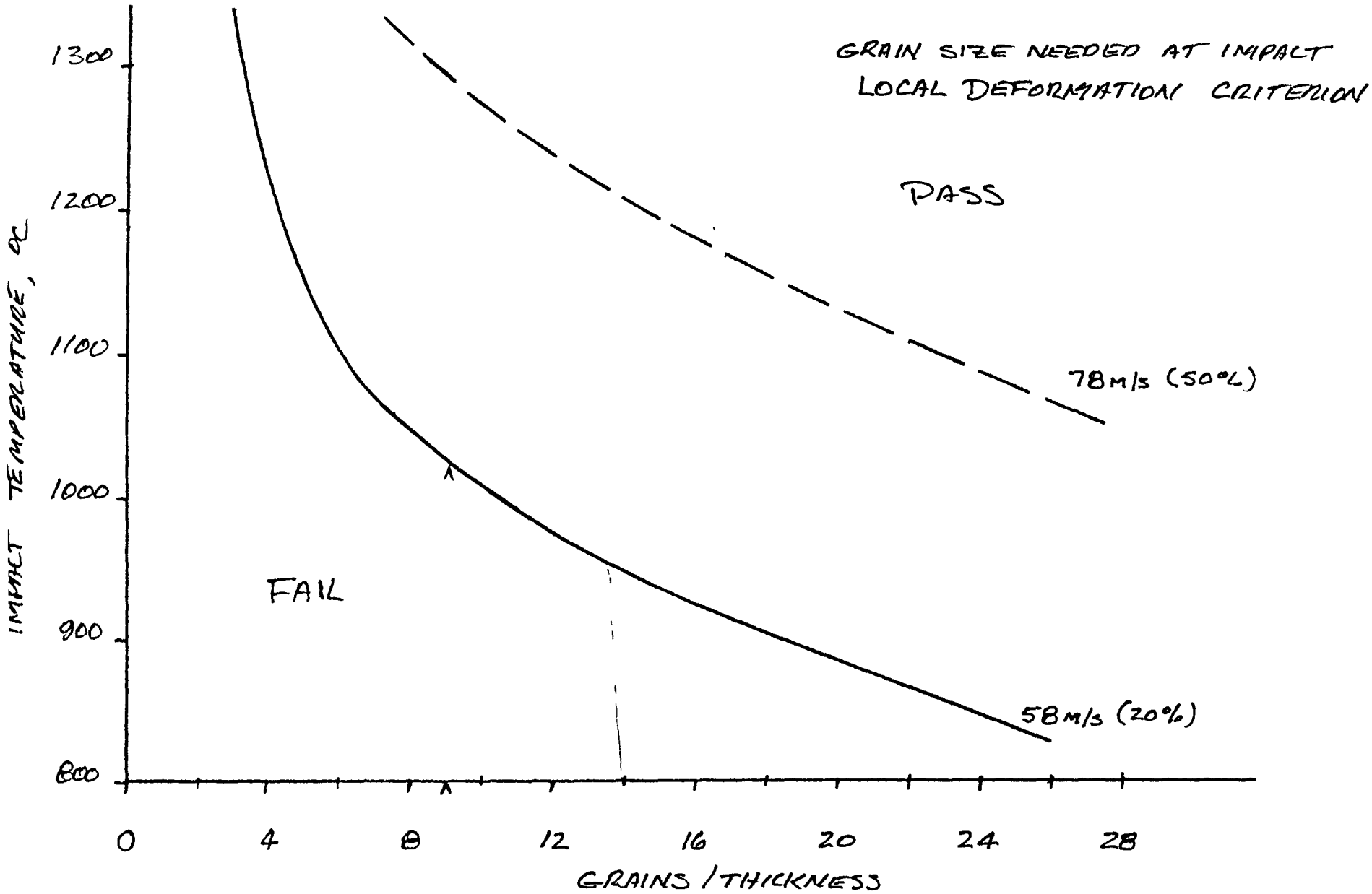

WELD DIRECTION
WELD
CENTER LINE
σ_L
σ_T
TRANSVERSE
MOST LIKELY
CRACK PATH

GPHS BIAXIAL IMPACT TESTS

THE BIAXIAL CUP TEST RESULTS AND THE UNIAXIAL TENSILE TEST RESULTS CAN BE COMBINED TO DETERMINE THE LOCAL-STRAIN IMPACT CAPABILITY OF DOP-26 IRIDIUM AS A FUNCTION OF TEMPERATURE AND GRAIN SIZE.

THE REQUIRED CAPABILITY DEPENDS ON THE IMPACT VELOCITY AND THE DEGREE OF PROTECTION.


PASS
FAIL
IMPACT TEMP.
1330°C
1130°C
1060°C
1000°C
950°C
925°C
900°C
830°C
760°C
78 m/s
58 m/s
FRACTURE STRAIN - LOCAL
GRAINS / THICKNESS
0
10
20
30
40
50
60
70
80
90
0
4
8
12
16
20
24
28
32


GRAIN SIZE NEEDED AT IMPACT
LOCAL DEFORMATION CRITERION
PASS
FAIL
78 m/s (50%)
58 m/s (20%)
IMPACT TEMPERATURE, °C
1300
1200
1100
1000
900
800
0
4
8
12
16
20
24
28
GRAINS / THICKNESS

PUNCH-THRU IMPACT EXPERIMENTS

- TO SIMULATE EFFECTS OF FUEL PUSH-THROUGH EVENTS ON Ir-0.3% W CLADDING RESPONSE
  1) LOCALIZED STRAINS FOR THE ORDER OF 10-15%
- IMPACTS AT 800^{0} AND 61 m/s
- Ir-0.3% W HEAT TREATMENT: 19 hrs/1500^{0}
  1) ~14 GRAINS/THICKNESS
  2) SURVIVED PUNCH-THRU TEST WITHOUT FAILURE
- Ir-0.3% W HEAT TREATMENT: 1 hr/1650^{0}
  1) ~10 GRAINS/THICKNESS
  2) FRACTURE PRODUCED BY PUNCH-THRU TEST

University of California
LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos New Mexico 87545
An affirmative action/equal opportunity employer

PYROLYTIC GRAPHITE LOCATION

A PAIR OF 900°C PUNCH-THROUGH TESTS ON FINE-GRAINED IRIDIUM(DOP-26) SHOWED THAT THERE WAS CHANGE IN STRAIN WITH OR WITHOUT PG BETWEEN THE IRIDIUM AND THE IMPACT GRAPHITE.

WITH PG	15.6%
WITHOUT PG	16.7%

HOWEVER, THE SAMPLE WITHOUT PG HAD SURFACE CRACKS, WHILE THE ONE WITH PG DID NOT CRACK.

PYROLYTIC GRAPHITE PROPERTIES

THE INITIAL MEASUREMENTS MADE AT LASL ON THE ACTUAL GPHS PG CUPS SHOW THAT THE MATERIAL HAS A LOW THERMAL CONDUCTIVITY.

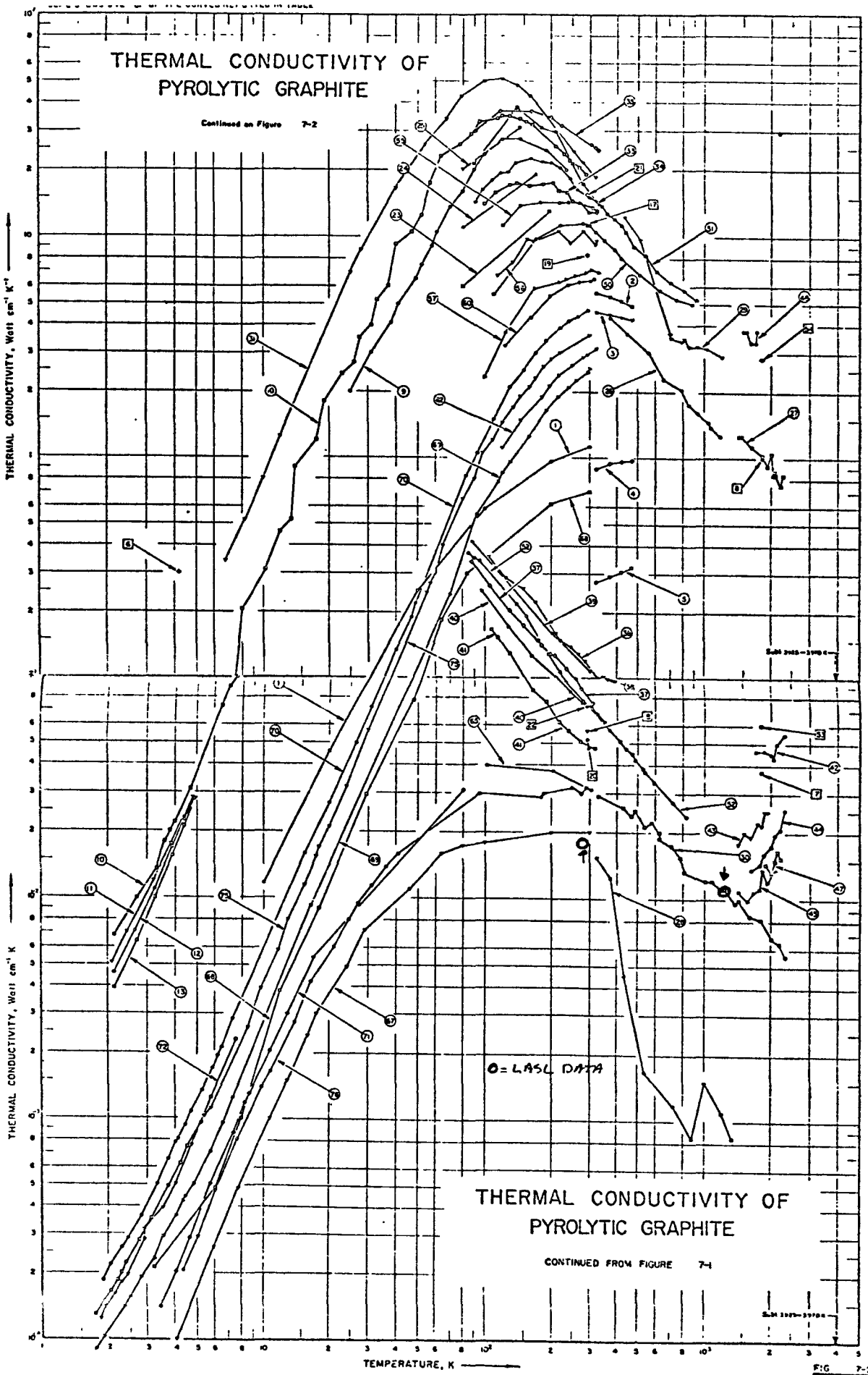
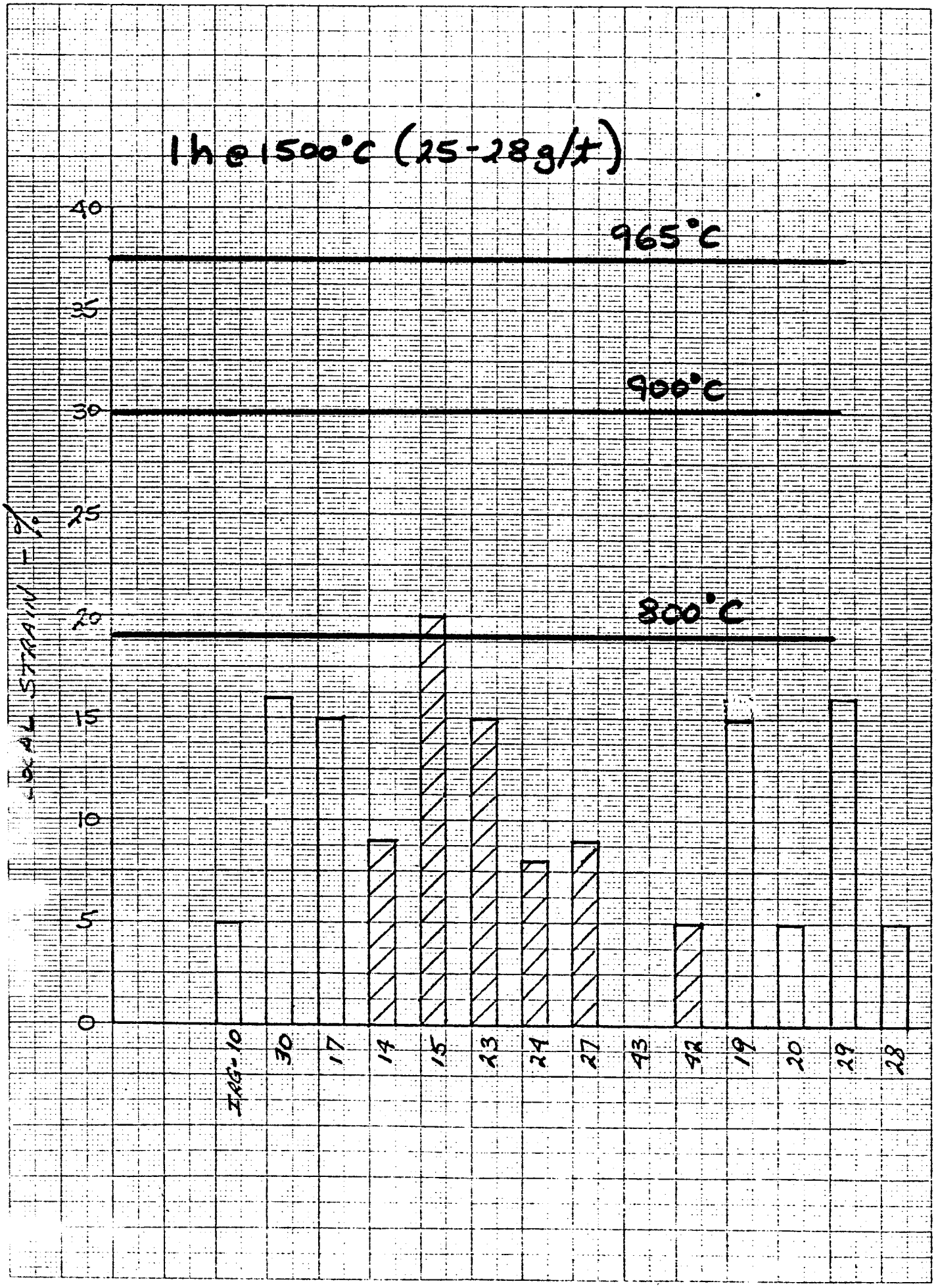
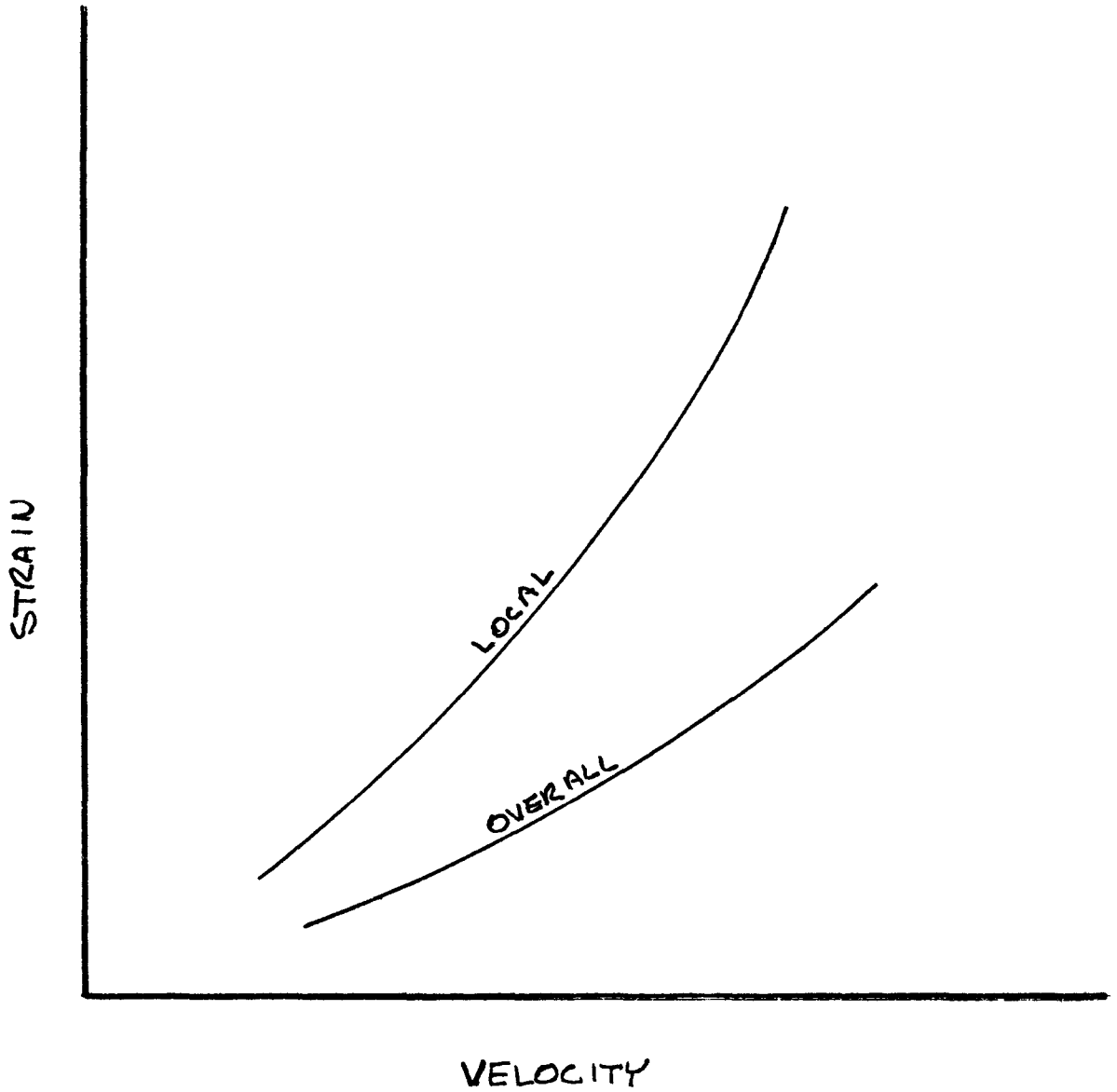

THERMAL CONDUCTIVITY OF
PYROLYTIC GRAPHITE
Continued on Figure 7-2
THERMAL CONDUCTIVITY, Watt cm⁻¹ K⁻¹
THERMAL CONDUCTIVITY, Watt cm⁻¹ K
O = LASL DATA
THERMAL CONDUCTIVITY OF
PYROLYTIC GRAPHITE
CONTINUED FROM FIGURE 7-1
TEMPERATURE, K

FIG 7-2



SQUARE 10 X 10 TO THE CENTIMETER AS-8014 GD



LOCAL STRAIN (FUEL PUSH THROUGH) IS AFFECTED MORE STRONGLY BY IMPACT VELOCITY.

DESIGN COMPARISON

CUBE MODULE -500W_T

ADVANTAGES:

- -NO STRONG EFFECTS OF HYPERSONIC ORIENTATION
- -LESS HEROIC EFFORTS NEEDED TO RAISE IMPACT TEMPERATURE
- -GREATER BASIC POWER DENSITY

DISADVANTAGE:

- -HIGHER IMPACT VELOCITY - REQUIRES ADDITIONAL DESIGN TESTS

HALF-CUBE MODULE -250W_T

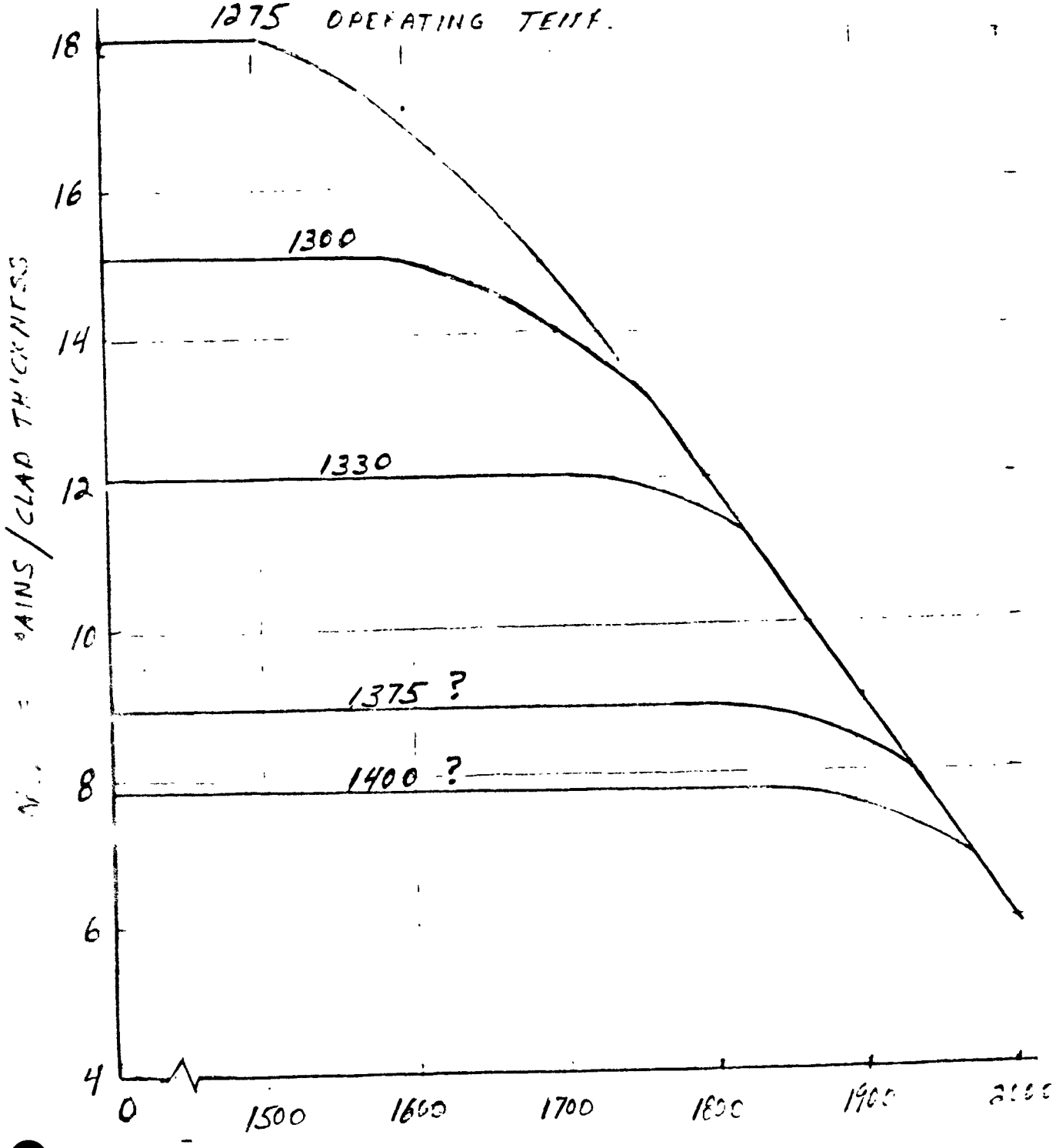
ADVANTAGES:

- -LOWER AVERAGE PEAK REENTRY TEMPERATURE
- -LOWER IMPACT VELOCITY

DISADVANTAGES:

- -LOW IMPACT TEMPERATURE - REQUIRES DESIGN MODIFICATIONS AND SOME TESTING
- -SENSITIVE TO HYPERSONIC ORIENTATION
- -REQUIRES SIDE-ON DESTABILIZATION
- -REQUIRES WIND TUNNEL TESTS (EXTENSIVE)

EFFECT OF REENTRY HEAT PULSE ON
SIZE AFTER 5000 HR AT VARIOUS OPERATING TEMPS.



REENTRY HEAT PULSE TEMPERATURE
2 MIN AT TEMPERATURE, °C

ACS

Prediction[a] of Minimum Impact Temperature Required to Survive GPHS Capsule Impact

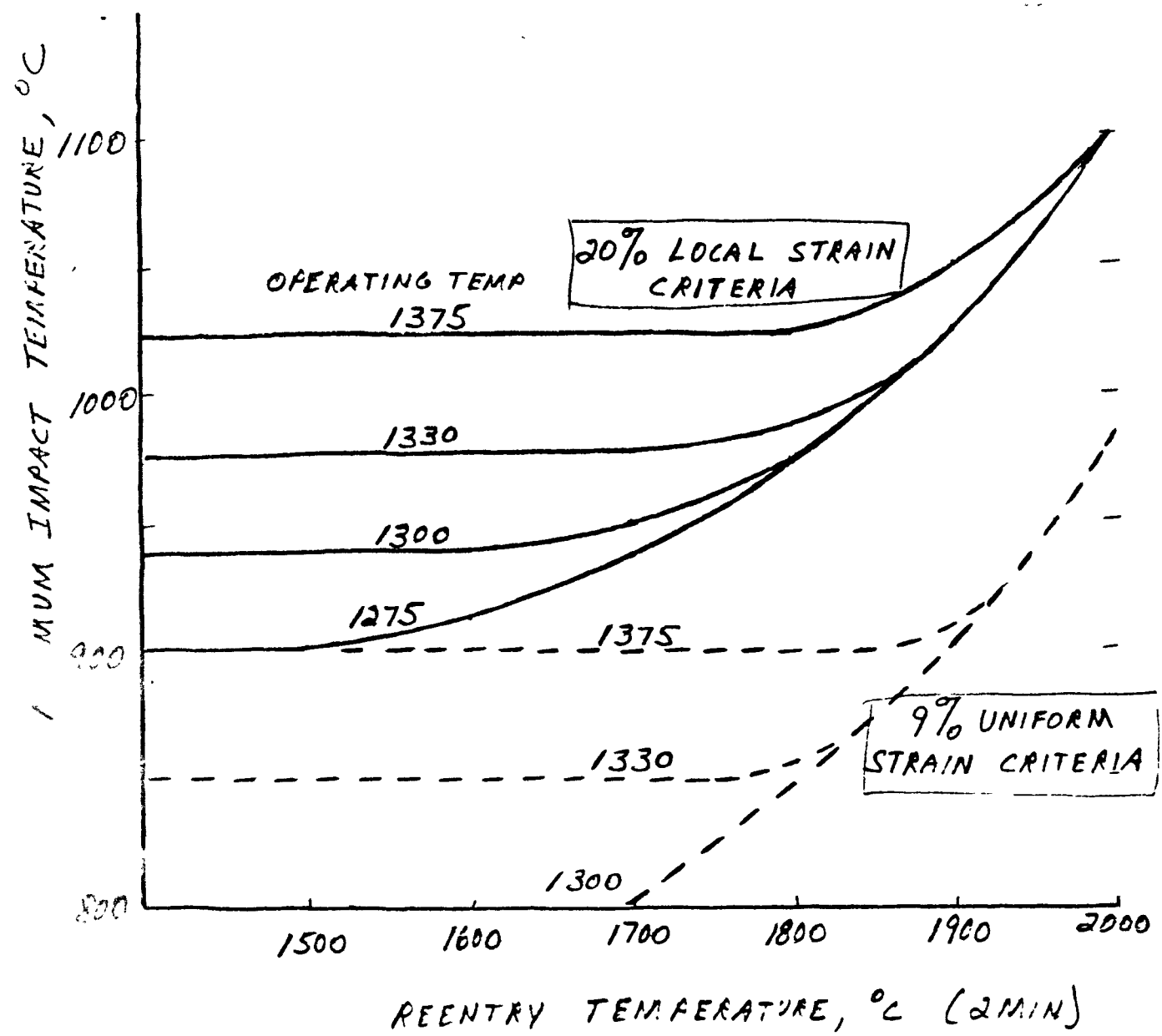
Operation Temperature[b] (6 month)	STRAIN ~~Impact Velocity (fps)~~ CRITERIA	Minimum Impact Temperature (°C) — Maximum Reentry Temperature (2 min) 1500	1600	1700	1800	1900	2000
1275	AVG. ~~200~~	800	800	800	850	900	980
	LOCAL ~~250~~	900	915	940	975	1025	1100
1300	AVG ~~200~~	800	800	800	850	900	980
	LOCAL ~~250~~	940	940	950	975	1025	1100
1330	AVG ~~200~~	850	850	850	850	900	980
	LOCAL ~~250~~	975	975	975	985	1050	1100
1375	AVG ~~200~~	900	900	900	900	900	980
?	LOCAL ~~250~~	1025	1025	1025	1025	1065	1100
1400	AVG ~~200~~	900	900	900	900	900	980
	LOCAL ~~250~~	1050	1050	1050	1050	1050	1100

[a]Prediction is based on:

1. Tensile impact and grain growth data of base metal IN VACUUM
2. Criteria of successful capsule impact
   AVG ~~200 fps~~: 9% minimum uniform elongation
   LOCAL ~~250 fps~~: 20% minimum local strain

[b]Assuming starting condition 1 h at 1500°C.

MINIMUM ALLOWABLE IMPACT TEMPERATURES AS A FUNCTION OF REENTRY TEMPERATURE AFTER OPERATION FOR 5000 HRS AT VARIOUS TEMPERATURES



RECOMMENDATIONS BASED ON
IMPACT AND GRAIN GROWTH DATA

1) USE 20% LOCAL STRAIN CRITERIA TO MINIMIZE POTENTIAL FOR FUEL PUNCH-THROUGH FAILURES — UNTIL CAPSULE IMPACT DATA BASE GREATER

2) LIMIT OPERATING TEMPERATURE TO 1330°C TO MINIMIZE POTENTIAL FUEL ENVIRONMENT/CLADDING GRAIN GROWTH INTERACTIONS

3) USING THESE CRITERIA, DESIGNS 3A, 4A and 2 PROVIDE THE MOST IMPACT MARGIN

4) DESIGNS 1, 3, 4, 5 WOULD BE ACCEPTABLE IF EMISSIVITY COATING IS QUALIFIED FOR IR OR GRAPHITES

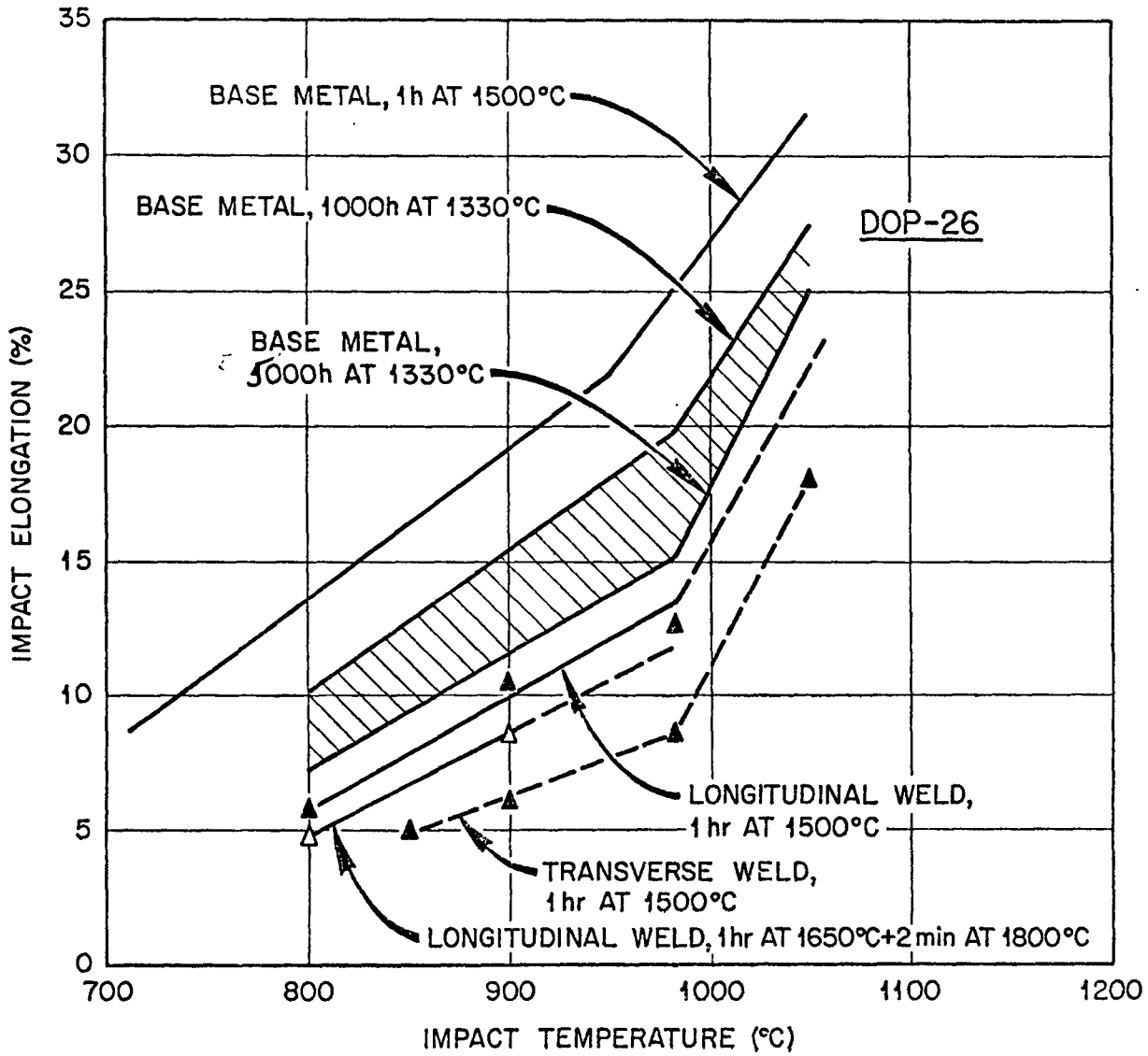
ORNL IS PROVIDING IMPACT DATA ON IRIDIUM AND PHYSICAL PROPERTIES DATA FOR GPHS MATERIALS

A. C. Schaffhauser
C. T. Liu
W. P. Eatherly
D. L. McElroy
G. C. Wei

GPHS TASK FORCE REVIEW
WASHINGTON, DC
AUGUST 21–22, 1979

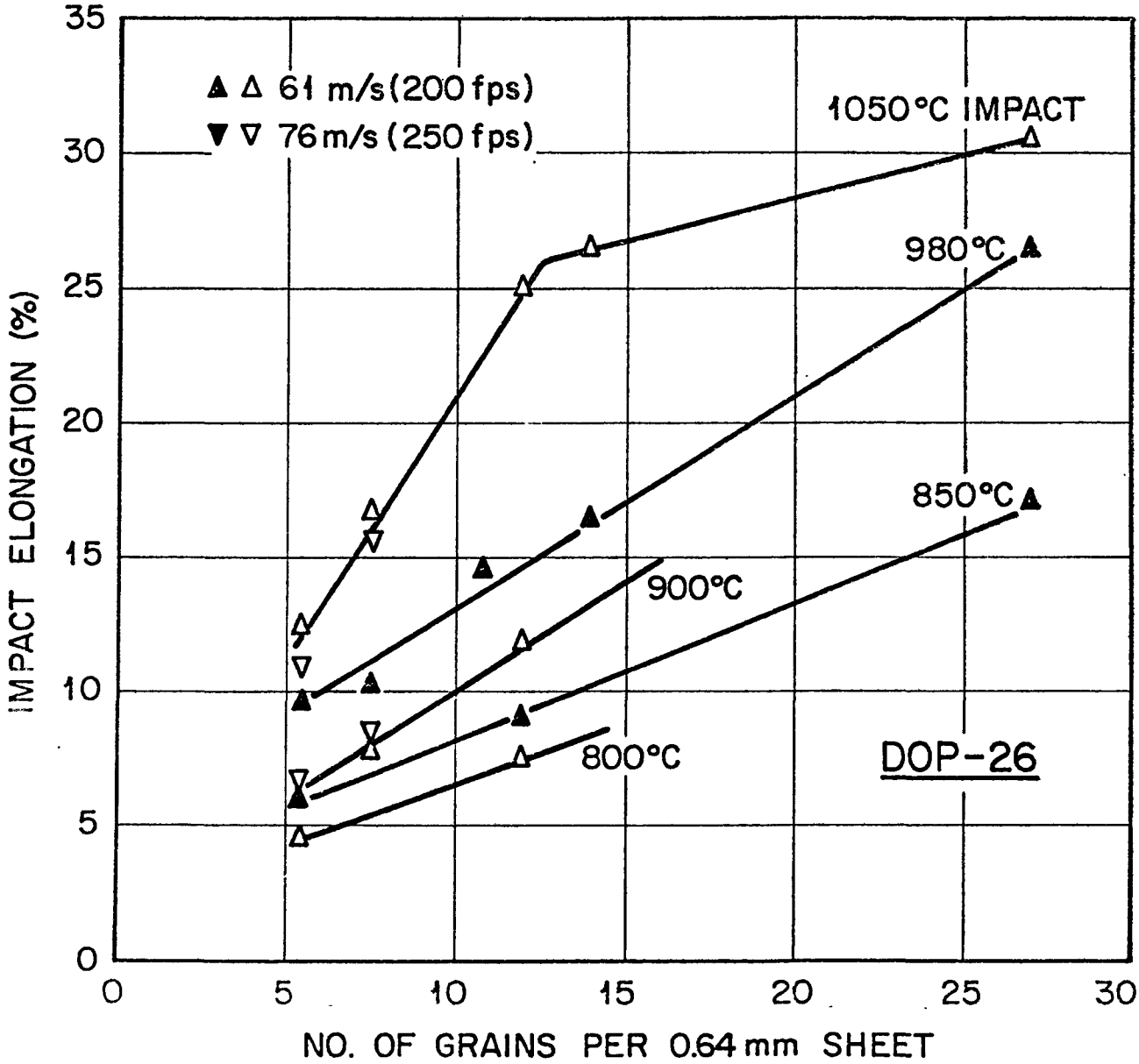
COMPARISON OF THE IMPACT DUCTILITY OF DOP-26 IRIDIUM BASE METAL AND WELDS

ORNL-DWG 79-15876

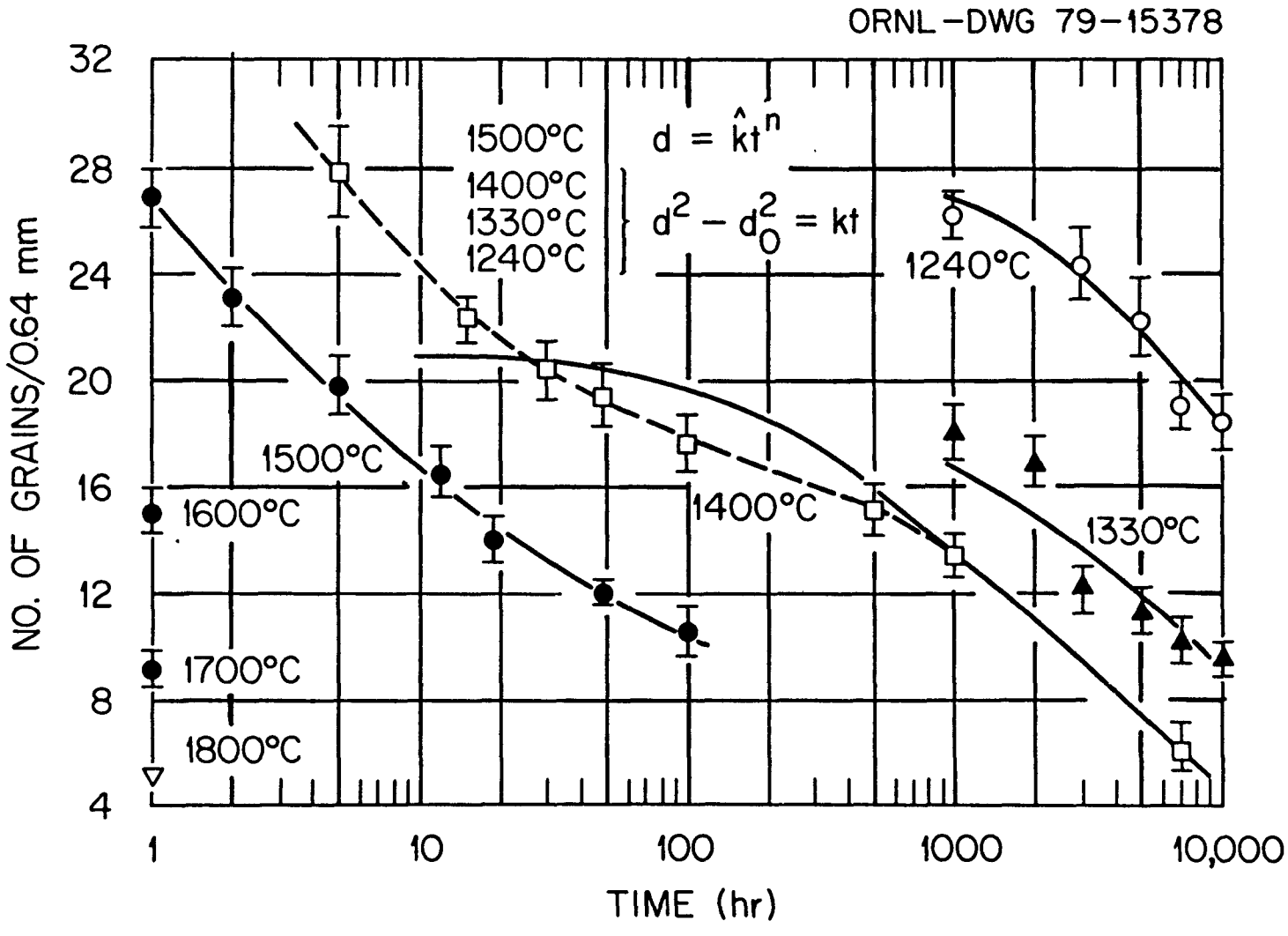


IMPACT DUCTILITY OF DOP-26 IRIDIUM AS A FUNCTION OF GRAIN SIZE AND IMPACT TEMPERATURE

ORNL-DWG 79-15875



GROWTH DATA ON DOP-26 IRIDIUM IN VACUUM



Effect of 6-Month Operation + 2 Minute Reentry Heating Pulse on Grain Size of DOP-26 Ir–0.3% W

Operation Temperature	Grain Size (Number of Grains per PICS Thickness)						
	6 months operation	Maximum Reentry Temperature (2 min)					
		1500°C	1600°C	1700°C	1800°C	1900°C	2000°C
1275	18	18	17	14	12	9	6
1300	15	15	15	14	12	9	6
1330	12	12	12	12	12	8	6
1375	9	9	9	9	9	8	6
1400	8	8	8	8	8	8	6

Prediction[a] of Minimum Impact Temperature Required to Survive GPHS Capsule Impact

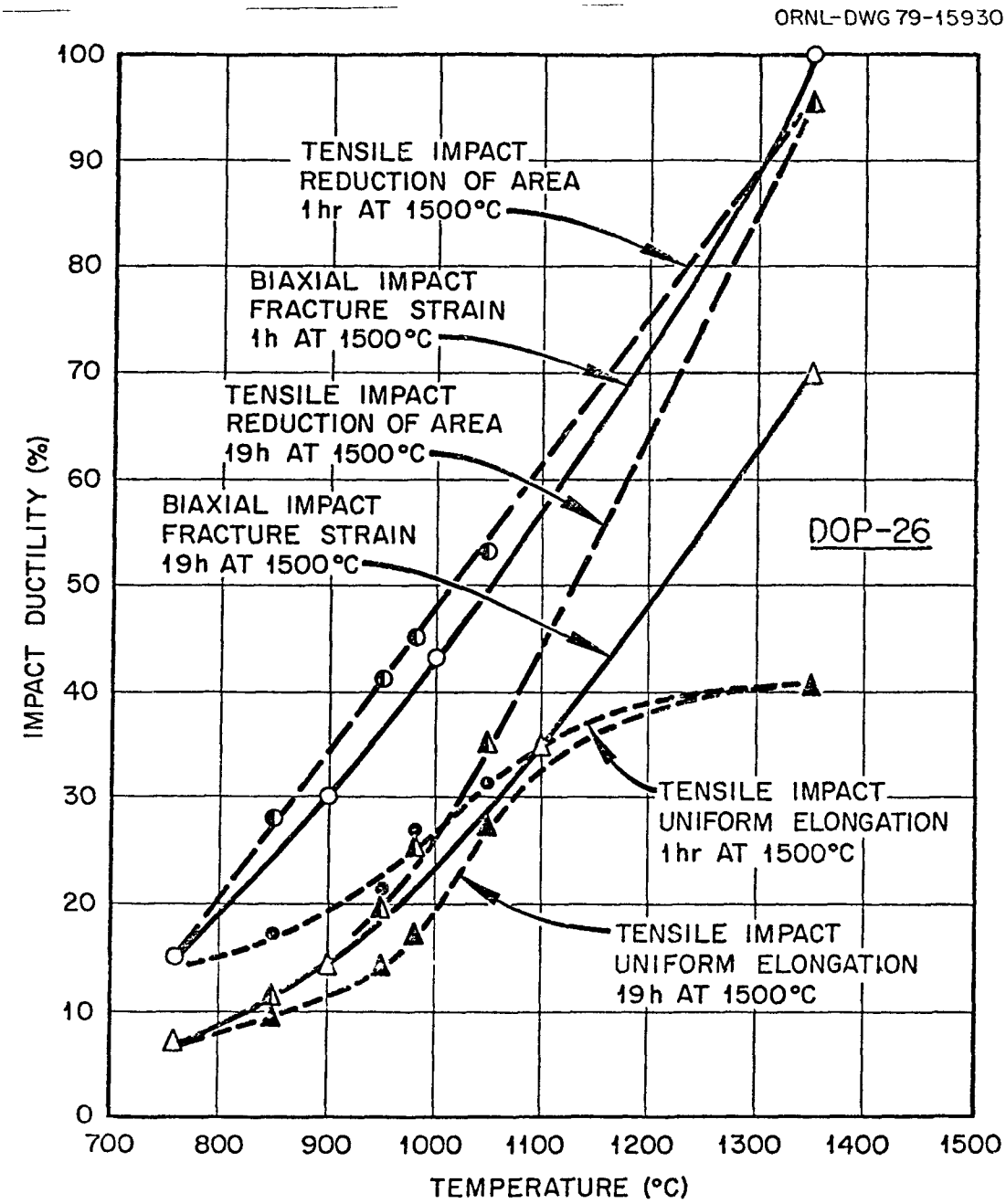
Operation Temperature[b] (6 month)	Impact Velocity (fps)	Minimum Impact Temperature (°C)					
		Maximum Reentry Temperature (2 min)					
		1500	1600	1700	1800	1900	2000
1275	AVG ~~200~~ LOCAL ~~250~~	800	800	800	850	900	980
1300	A ~~200~~ ~~250~~	800	800	800	850	900	980
1330	~~200~~ ~~250~~	850	850	850	850	900	980
1375	~~200~~ ~~250~~	900	900	900	900	900	980
1400	~~200~~ ~~250~~	900	900	900	900	900	980

[a]Prediction is based on:

1. Tensile impact and grain growth data of base metal.
2. Criteria of successful capsule impact
   200 fps: ~~8~~ 9% minimum <u>uniform</u> elongation;
   250 fps:

[b]Assuming starting condition 1 h at 1500°C.

CORRELATION OF TENSILE AND BIAXIAL IMPACT DATA



CORRELATION OF TENSILE AND BIAXIAL IMPACT DATA WITH GPHS CAPSULE IMPACTS

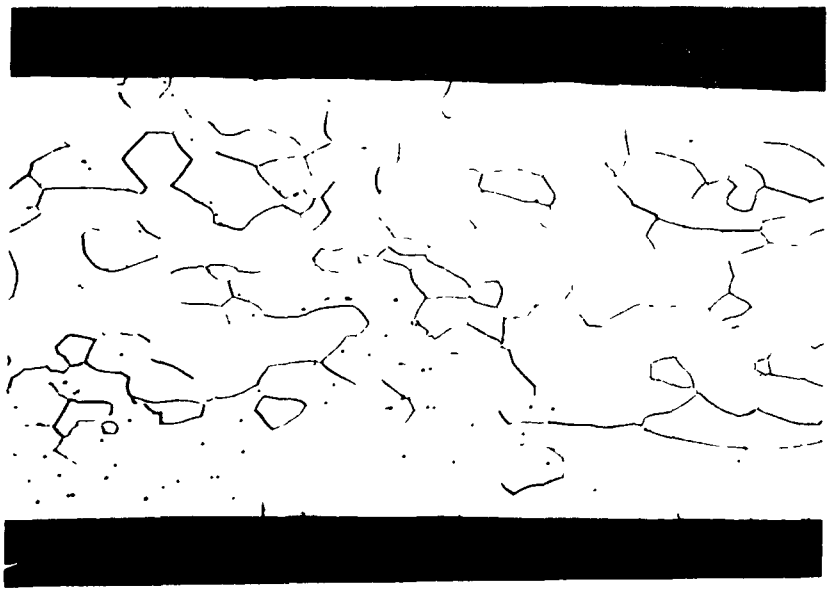
- UNIFORM ELONGATION IN TENSILE IMPACTS CORRELATES WITH THE DIAMETRIAL STRAIN OF GPHS IMPACTS.

- REDUCTION IN AREA OF TENSILE IMPACTS IS EQUIVALENT TO FRACTURE STRAIN IN BIAXIAL IMPACT TESTS. BOTH CAN BE CORRELATED WITH LOCAL STRAINS IN CAPSULE IMPACTS.

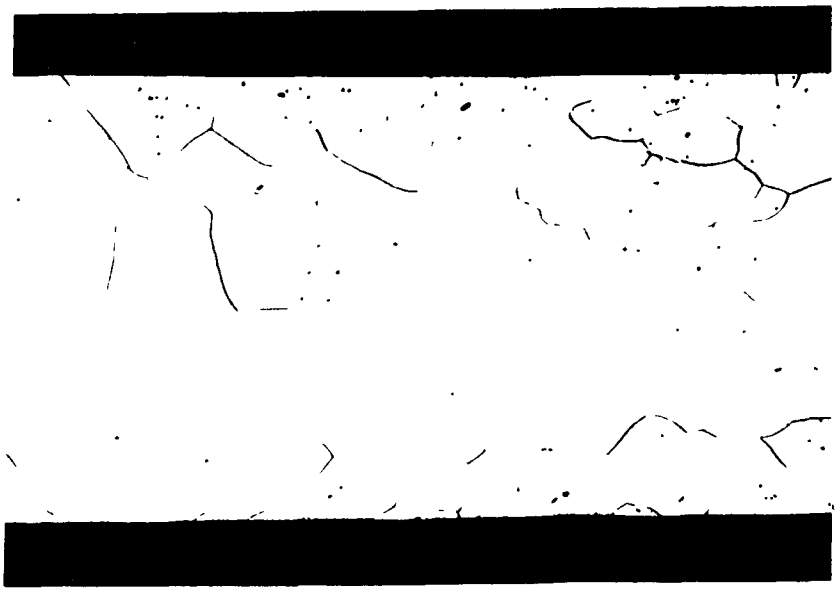
- MAJOR STRAIN IN CAPSULE WELDS CORRELATES WITH LONGITUDINAL TENSILE IMPACT AND BIAXIAL IMPACT TESTS.

- RESULTS OF TENSILE AND BIAXIAL IMPACTS AS FUNCTION OF IMPACT TEMPERATURE AND GRAIN SIZE WILL PREDICT THE OUTCOME OF GPHS CAPSULE IMPACTS.

PRELIMINARY RESULTS INDICATE PICS ENVIRONMENT
MAY EFFECT GRAIN GROWTH ON REENTRY



3000 h at 1330°C in VACUUM + 2 MIN AT 1900°C; 100x



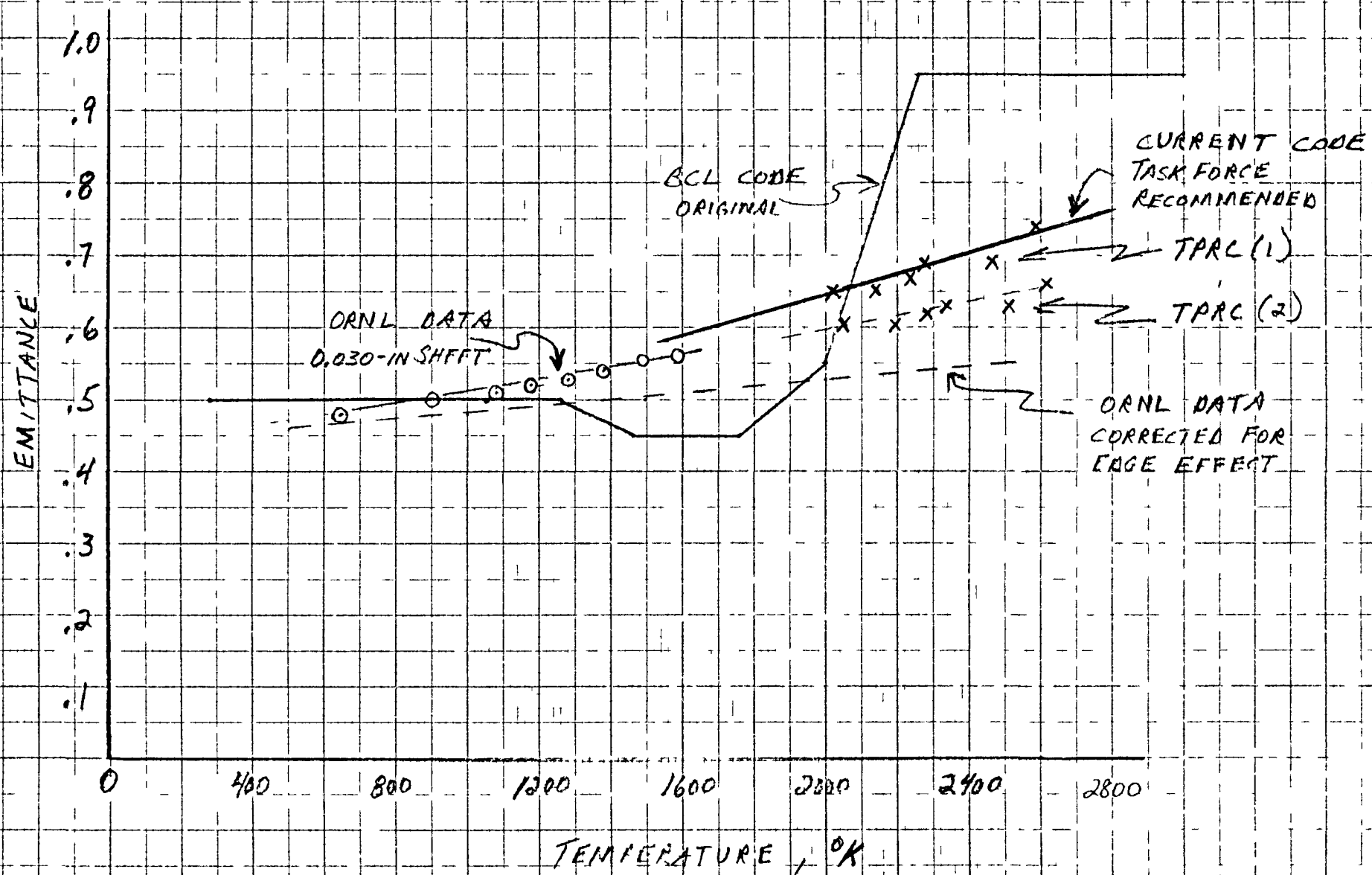
3000 h at 1330°C in 1 x 10^{-5} TORR OXYGEN + 2 MIN AT 1900°C; 100x

SPECIMEN CUT FROM SHOULDER OF TENSILE IMPACT SPECIMEN

A LARGE AMOUNT OF EMISSIVITY DATA IS REQUIRED
(TOTAL HEMISPHERICAL EMITTANCE, 800 to 2000°C)

- PYROLYTIC GRAPHITE
  1. NERVA SHEET: EARLY CONFIRMATION OF TASK FORCE RECOMMENDATIONS (ORNL)
  2. GPHS CUPS: GEOMETRY AND FABRICATION EFFECTS (ORNL or TECO)
- COATINGS FOR PYROLYTIC GRAPHITE
  1. CVD BN FROM PARMA (ORNL or PURDUE)
  2. CVD NbC FROM Y-12 (ORNL or PURDUE)
  3. PVD WC, ETC. FROM BCL (ORNL or PURDUE)
- IRIDIUM AND COATINGS
  1. GRIT BLASTED f(T,t) (ORNL)
  2. AQUA DAG ON GRIT BLAST SURFACE (ORNL)
  3. PVD WC FROM BCL (ORNL)
- OTHER GRAPHITES
  1. AVCO FWPF (ORNL or PURDUE)
  2. CBCF-3 (ORNL or PURDUE)

CURRENT CODE FOR PYROLYTIC GRAPHITE IS CLOSE TO ORNL MEASURED DATA ON SHEET



CONFIRMATORY THERMAL CONDUCTIVITY DATA IS REQUIRED

- PYROLYTIC GRAPHITE
  1. LASER DIFFUSIVITY (LASL and SORI)
  2. ARC IMAGE DIFFUSIVITY (PARMA)
  3. THERMAL CONDUCTIVITY, 60°C (ORNL)
  4. GPHS CUPS — COOLDOWN (ORNL)
- CBCF-3
  1. LASER DIFFUSIVITY (PURDUE and LASL)
  2. ARC IMAGE DIFFUSIVITY (PARMA)
  3. THERMAL CONDUCTIVITY (DYNATECK to 1000°C)
     (TECO to 1800°C) ~ 3 wks
- GPHS ASSEMBLY
  1. THERMAL MOCKUP — OPERATING (LASL)
  2. THERMAL MOCKUP — REENTRY (ORNL)

THE FOLLOWING MATERIALS ARE ON HAND AT ORNL FOR INVESTIGATION OF GPHS INSULATORS:

MATERIAL	MANUFACTURER	IDENTIFICATION/GEOMETRY	TYPE
PyC	UCC	GPHS/CUP	2100°C
PyC	PFIZER	GPHS/CUP	2100°C
PyC	UCC	MONOCHROMATOR/PLATE	2300°C
PyC	UCC	MONOCHROMATOR/PLATE	2300°C + 3200°C HT
PyC	PFIZER	NERVA/TUBE OR PLATE	2100°C
NbC on G	Y-12	NERVA/HEX TUBE	CVD NbC ON BULK GRAPHITE
BN-PyC	UCC	COMMERCIAL TUBE	CVD BN ON 2100°C PyC
CBCF-3	ORNL	EXPERIMENTAL/PLATE	LOW DENSITY FIBROUS MATTE INSULATOR

THE FOLLOWING THERMAL DIFFUSIVITY TESTS ARE EXPECTED TO BE PERFORMED AT THE PARMA RESEARCH CENTER:

MATERIALS:	GPHS CUPS, BOTH UCC AND PFIZER. CBCF-3 FIBER INSULATION, WITH AND AGAINST GRAIN.
TEMPERATURE RANGE:	1000°C to 2200°C MINIMUM, WITH FIVE DATA POINTS EACH ON REDUNDANT SAMPLES.
GEOMETRY:	FLAT DISCS. AN ATTEMPT WILL BE MADE TO DETERMINE DIFFUSIVITY AS A FUNCTION OF THICKNESS FOR CBCF-3.
TIME:	RESULTS ARE ANTICIPATED WITHIN THREE WEEKS OF CONTRACT INITIATION.

THE EQUIPMENT IS AN ARC IMAGE FURNACE WITH A SECTOR DISC, MEASURING PHASE CHANGE FROM FRONT TO REAR FORCE OF SAMPLE TEMPERATURE PULSE.

A NUMBER OF TECHNIQUES ARE AVAILABLE TO CHARACTERIZE AND SPECIFY PYROLYTIC GRAPHITE:

NON-DESTRUCTIVE

- APPARENT DENSITY IN HELIUM: ACCESSIBLE POROSITY
- EDDY CURRENT MAPPING: ELECTRICAL CONDUCTIVITY
- ACCOUSTIC REFLECTION: DELAMINATION
- BET SURFACE AREA: TOTAL ACCESSIBLE SURFACE AREA

DESTRUCTIVE

- LATTICE SPACINGS (X-RAY): STACKING ORDER AND X-RAY DENSITY
- BACON ANISOTROPY FACTOR (BAF): PREFERRED ORIENTATION
- SMALL ANGLE X-RAY SCATTERING (SAX): MICROPOROSITY DISTRIBUTION
- MERCURY POROSIMETRY: MACROPOROSITY DISTRIBUTION

ALL THESE FACTORS ARE STRUCTURAL SENSITIVE AND WILL AFFECT THERMAL CONDUCTIVITY AND EMISSIVITY.

CONCLUSIONS

- BATTELLE NET HEATING AND COMPUTATIONAL MECHANICS VERIFIED
- BATTELLE HYPERSONIC AND SUPERSONIC HEATING MODELS APPEAR CONSERVATIVE – ESPECIALLY FOR TUMBLING
- DATA BASE ON GPHS SHAPE IS SCANT
  - HEATING RATES FOR ALL REGIMES AND TRAJECTORIES
  - IMPACT CAPABILITY
  - TERMINAL VELOCITY/SUBSONIC DRAG
- SIDE-ON STABLE REENTRY CAN BE ELIMINATED
- VIABLE DESIGN VARIATIONS IDENTIFIED
- CONSIDERABLE VERIFICATION WORK REQUIRED
  - HEATING
  - IMPACT
  - TERMINAL VELOCITY
  - SIDE-ON DESTABILIZATION
- MINIMUM DESIRABLE IMPACT TEMPERATURE FOR VIABLE DESIGNS IN 950 – 1050 °C
- HEAT SOURCE CONFIGURATION MUST BE SELECTED BY 12/31/79

RECOMMENDATIONS

- RECOMMENDED DESIGN - MODIFIED LMRB
  - MOVE PG OUTSIDE GIS (2 LAYERS, 30 MILS EACH)
  - INCREASE GAPS FROM 5 MILS TO 10 MILS
  - VERIFY HEATING AND SIDE-ON DESTABILIZATION
  - CONTINUE INVESTIGATION OF DESIGN IMPROVEMENTS (THICKER PG, CBCF AND VARIABLE EMISSIVITY COATINGS)
- ADDITIONAL ANALYSIS AND TESTING TO VERIFY DESIGN AND POTENTIAL IMPROVEMENTS
- TEST PROGRAMS REQUIRED FOR VERIFICATION
  - MATERIALS PROPERTIES
  - WIND TUNNEL
  - IMPACT
  - DROP
- CONVERTER SIZED TO ACCEPT 5.6 INCH DIA. X 39.6 INCH LONG H.S.
  - DIAMETER SUBJECT TO CORNER LOADING VERIFICATION
  - LENGTH SUBJECT TO VERIFICATION BY LASL FOR PG THICKNESS, IMPACT PROTECTION AND DESIGN DETAILS