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ADDENDUM 'A'

TO LOC-B01787

THE FINAL REPORT ON A [U]
STUDY OF

AN ADVANCED MISSION PLANNING AND EVALUATION METHODOLOGY--SUPPORTING DATA [U]

JPL-CC0115

LOCKHEED
CALIFORNIA
COMPANY

BURBANK, CALIFORNIA

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~~SPECIFIC AUTHORIZATION FOR ACCESS REQUIRED~~

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ADDENDUM 'A'

TO

THE FINAL REPORT ON A

STUDY OF AN ADVANCED MISSION PLANNING

AND EVALUATION METHODOLOGY -- SUPPORTING DATA [U]

(CLASSIFIED VOLUME)

FOR

THE JET PROPULSION LABORATORY

~~JPL-C00145~~

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December 1964

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TABLE III

PAD LOADING SUMMARY

VEHICLE		CY1968	CY1969	CY1970	CY1971	CY1972	CY1973
ATLAS-AGENA	SCHED. FLIGHTS	17	14	14	10	11	9
	PADS AVAILABLE	6	6	6	6	6	6
ATLAS-CENTAUR	SCHED. FLIGHTS	9	9	9	7	6	5
	PADS AVAILABLE	1	1	1	1	1	1
TITAN II	SCHED. FLIGHTS	N/A	N/A	N/A	N/A	N/A	N/A
	PADS AVAILABLE						
TITAN III	SCHED. FLIGHTS	N/A	N/A	N/A	N/A	N/A	N/A
	PADS AVAILABLE						
SATURN I	SCHED. FLIGHTS						
	PADS AVAILABLE*						
SATURN IB	SCHED. FLIGHTS	10	9	9	5	4	5
	PADS AVAILABLE	3	3	3	3	3	3
SATURN V	SCHED. FLIGHTS	6	6	6	2	5	7
	PADS AVAILABLE	3	3	3	3	3	3

* PAD 34 INCLUDED BELOW, WITH SATURN IB "PADS AVAILABLE"

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COST ESTIMATES - LAUNCH VEHICLES

The costs of conventional launch vehicles are presented in Table IV. These data are for the 1968 - 1969 time period and are based on a ten-per-year launch rate for five years. The costs are for the basic vehicle hardware and for launch vehicle support.

TABLE IV

LAUNCH VEHICLE COSTS

Launch Vehicle	Cost - 10^6 dollars
Thor	2.0
Atlas	2.3
Thor Delta	2.5
Thor Agena B	5.3
Thorad D. Agena D	6.5
Centaur	7.5
Atlas - Agena D	7.8
Titan II	8.8
Atlas - Centaur	10.0
GLV - Gemimil.V	10.4
Titan III A	17.0
Saturn I	19.0
Saturn IB	20.5
Titan III C	26.6
Saturn V	63.0

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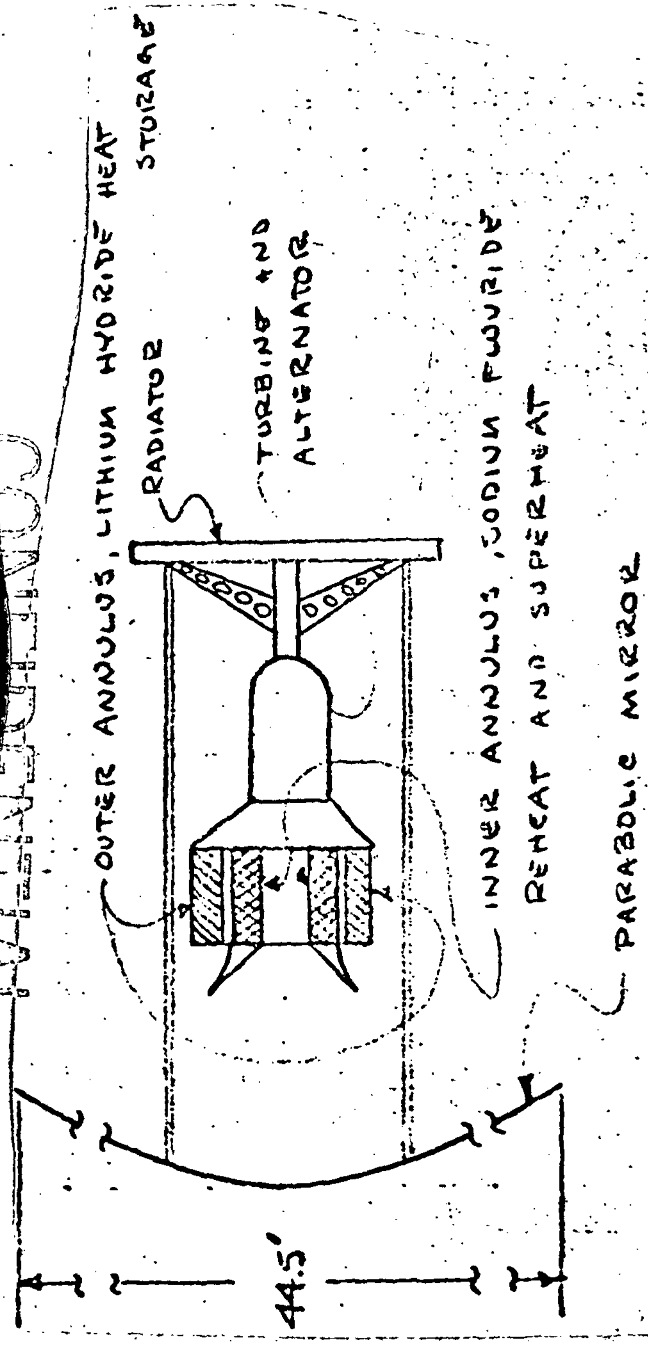

MANUFACTURER	SUNDSTRAND
AVAILABILITY	LATE 1967
BASIC SYSTEM DATA	
POWER LEVEL	15 KWe
SYSTEM WEIGHT	1000 - 1200 LB
USEFUL LIFE	1 YR CONTINUOUS
COST	NOT AVAILABLE
ENERGY SOURCE	SOLAR
POWER CONVERSION	TURBOELECTRIC (RUBIDIUM - RANKINE)
HEAT STORAGE	LITHIUM HYDRIDE
ORIENTATION	± .2°

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FIG. 19 ASTEC: ADVANCED SOLAR TURBO-ELECTRIC CONCEPT (REFERENCE 43)

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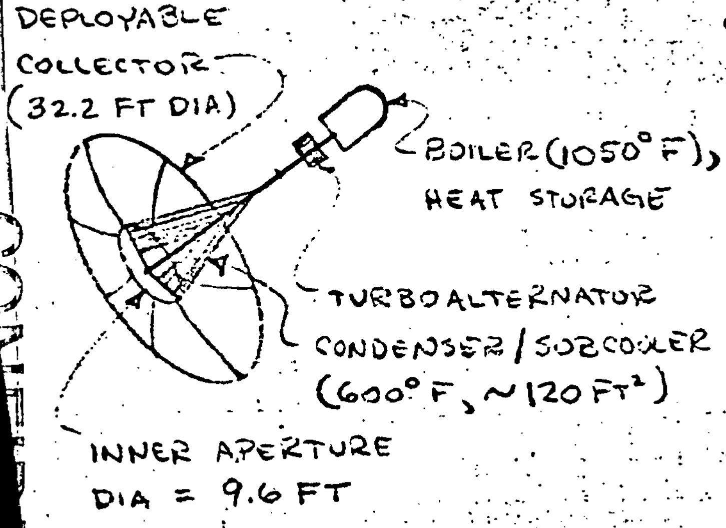

MANUFACTURER	TAPCO *
AVAILABILITY	3 YRS FROM GO-AHEAD
BASIC SYSTEM DATA	
POWER LEVEL	3 KWe
SYSTEM WEIGHT	700 LB
USEFUL LIFE	1 YR CONTINUOUS
COST	$150,000 **
ENERGY SOURCE	SOLAR
POWER CONVERSION	TURBOELECTRIC (HG - RANKINE)
HEAT STORAGE	LITHIUM HYDRIDE
ORIENTATION	±3/4°

NOTE: SYSTEM IS DESIGNED FOR 1 "G" (LATERAL OR LONGITUDINAL) WHEN DEPLOYED AND 7.5 "G" WHEN FOLDED

* A DIVISION OF THOMPSON RAMO WOOLDRIDGE

** AVERAGE OF 10 UNITS.

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FIG. 20 SUNFLOWER (REFERENCE 43)

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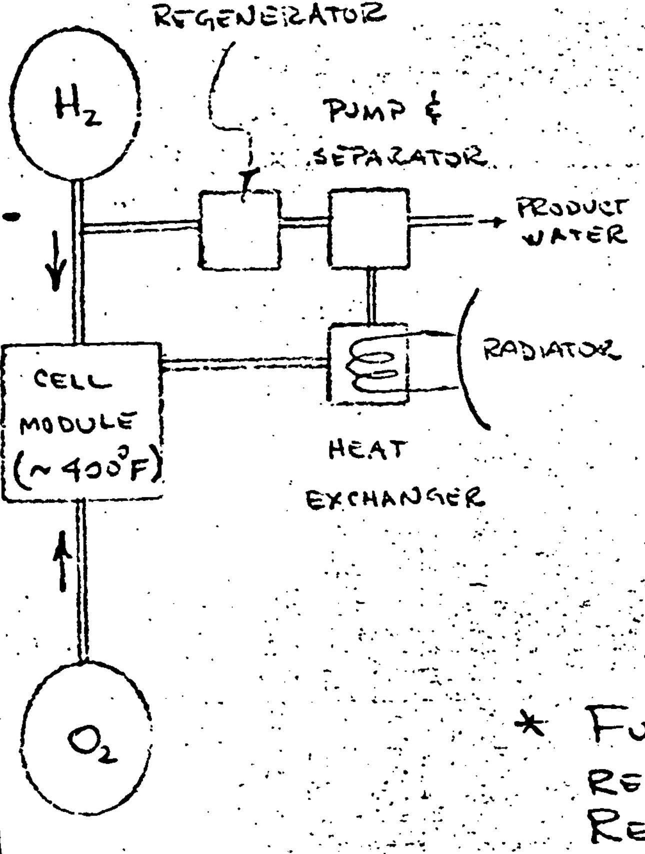

MANUFACTURER PRATT & WHITNEY

AVAILABILITY 1965

BASIC SYS DATA

POWER LEVEL 2 KW PEAK

SYSTEM WGT >155 LB* (~350 WH/LB)

USEFUL LIFE 7 DAY DUTY CYCLE

COST $18-36 M FOR R&D AND TESTING. 1ST UNIT COST NOT DEVELOPED.

* FUEL BATTERY ONLY - DOES NOT INCLUDE REACTANTS, CONTROL UNIT, COOLANT OR RADIATOR. REACTANT CONSUMPTION IS ~ 1 LB/KWH.

FIG. 32 PRATT & WHITNEY FUEL CELL - APOLLO (REFERENCE 43)

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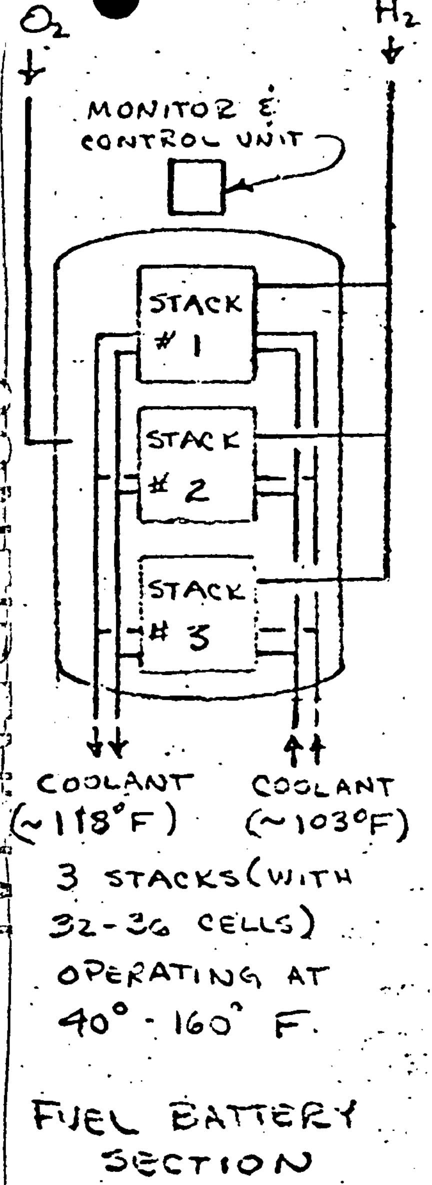

MANUFACTURER	GENERAL ELECTRIC CO.
AVAILABILITY	LATE 1963

BASIC SYSTEM DATA

POWER LEVEL	2 KW WITH 2 SECTIONS
SPECIFIC WGT*	155 LB
USEFUL LIFE**	2500 HOURS
COST	$1.4 M

* FUEL BATTERY ONLY. DOES NOT INCLUDE REACTANTS (H_2, O_2), TANKAGE OR RADIATOR. REACTANT CONSUMPTION IS ~ 1 LB/KWH. THE SPECIFIC WGT DECREASES FOR SHORTER DURATION.

** FOR DESIGN TESTING

*** 1ST UNIT

FIG. 33 SOLID ELECTROLYTE FUEL CELL - GEMINI (REFERENCE 13)

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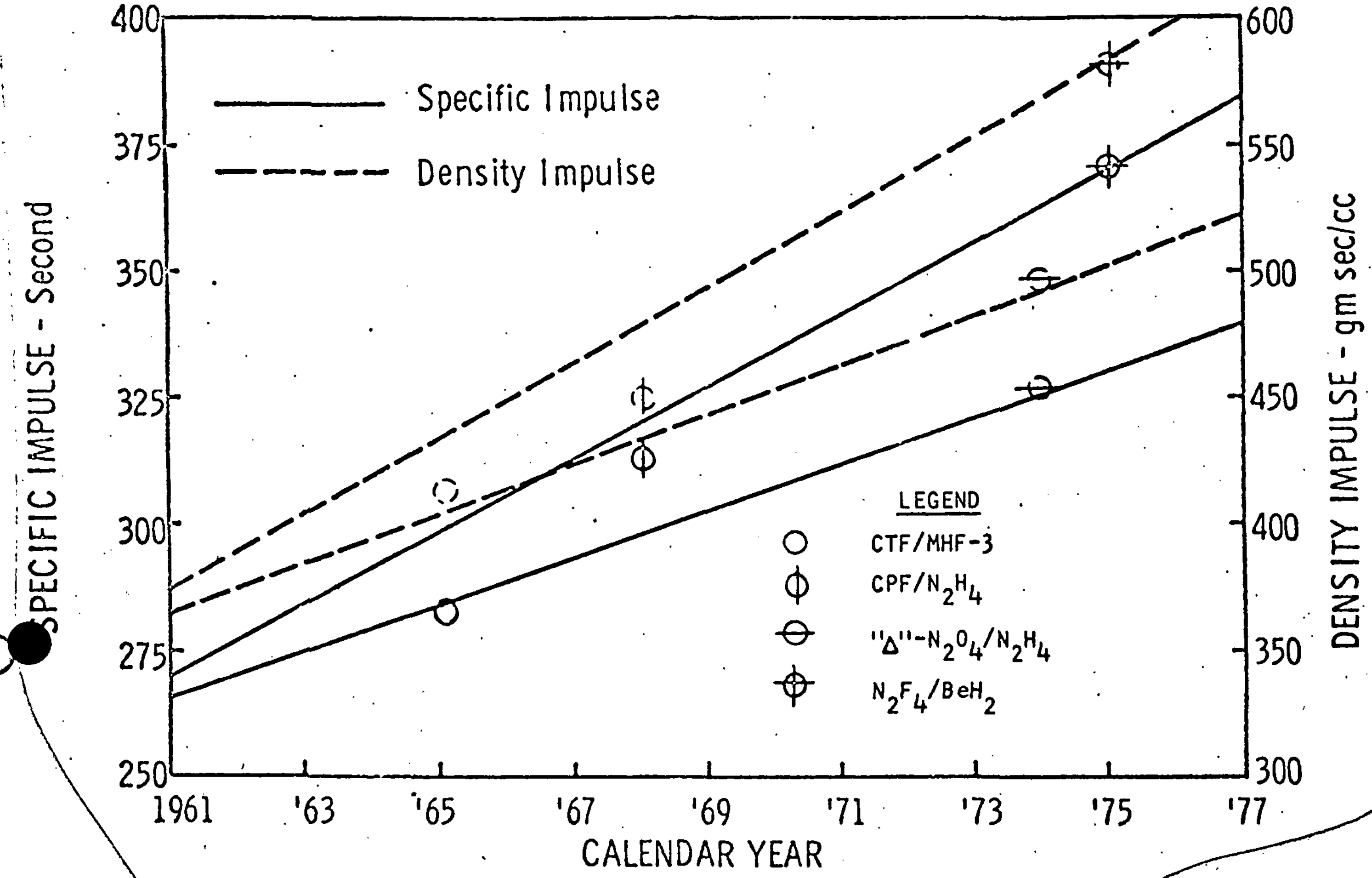

CTF - Chlorine Trifluoride
MHF - Mixed Hydrazine Fuels
CPF - Chlorine Pentafluoride
N_2H_4 - Hydrazine
N_2O_4 - Nitorgen Tetroxide
N_2F_4 - Hydrazine Fluoride
"Δ" - (Company Private)
BeH_2 - Beryllium Hydride

FIGURE 2

PERFORMANCE OF CANDIDATE PROPELLANT SYSTEMS VS TIME
(Packaged Liquid Systems)

Courtesy of Thiokol Corporation

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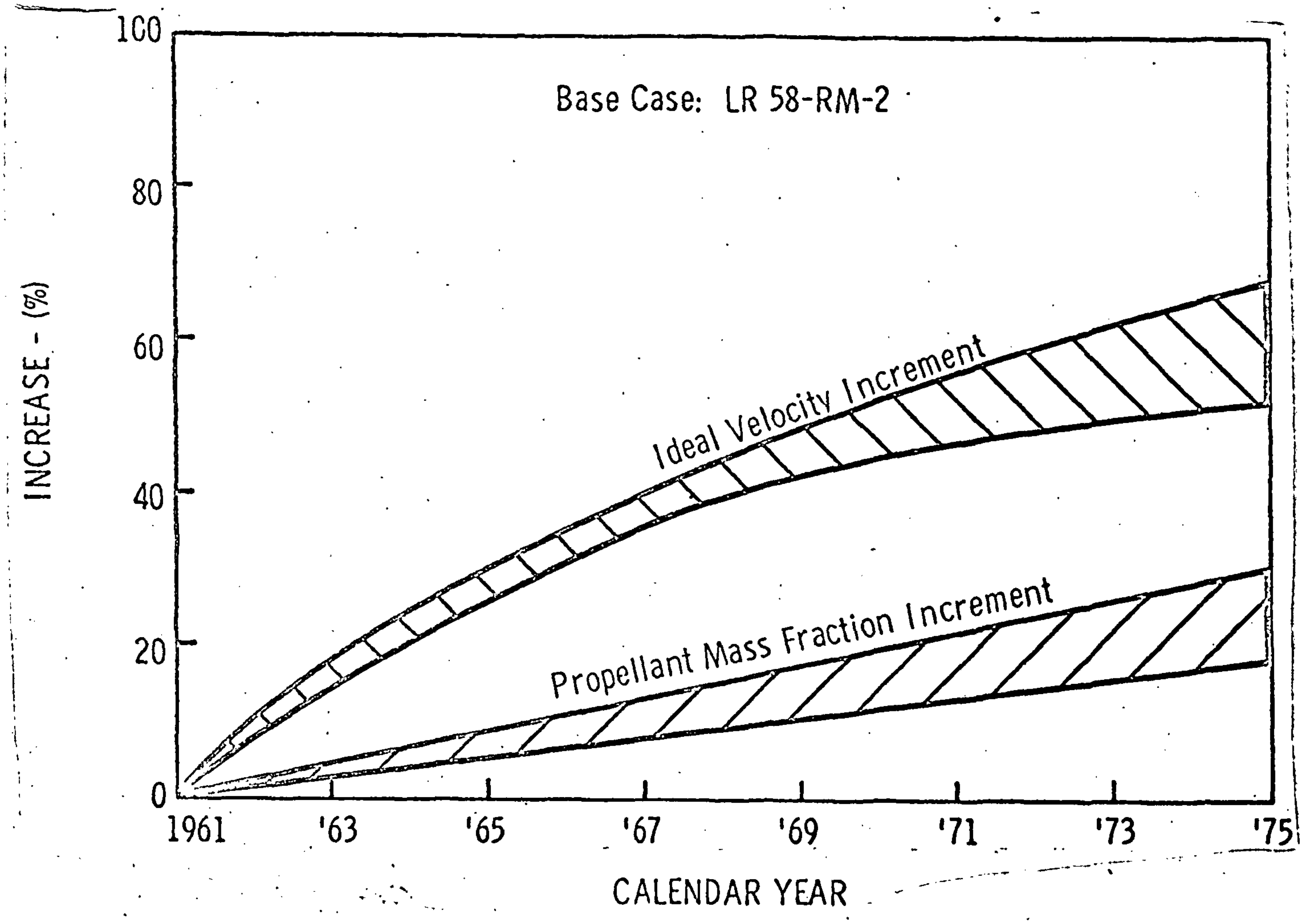

FIGURE 3

PREDICTED PERFORMANCE IMPROVEMENT
OF PACKAGED LIQUID MOTORS

Courtesy of Thiokol Corporation

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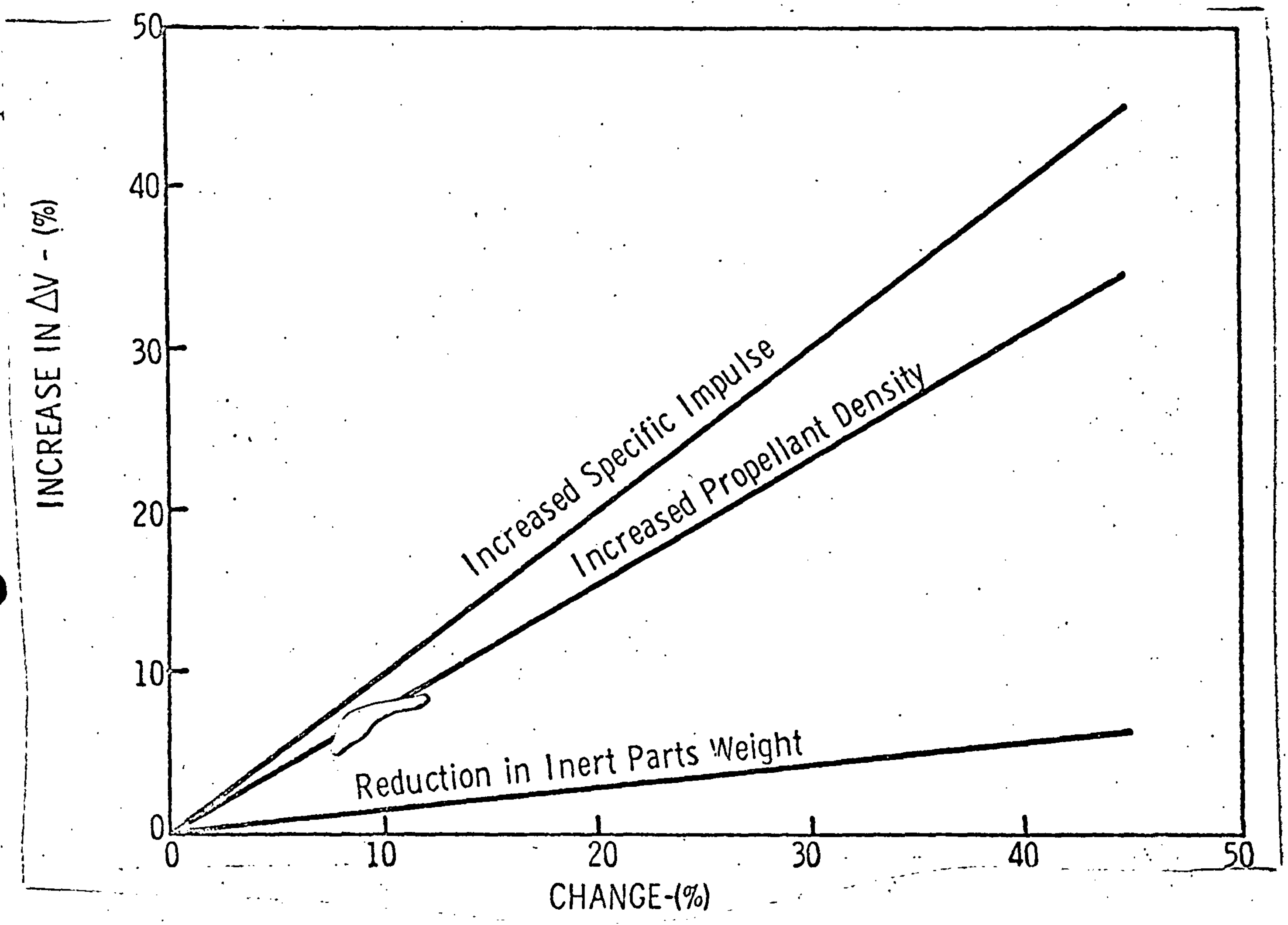

FIGURE 4

EFFECT OF DENSITY IMPULSE AND INERT
WEIGHT ON PACKAGED LIQUID ENGINE PERFORMANCE

Courtesy of Thiokol Corporation

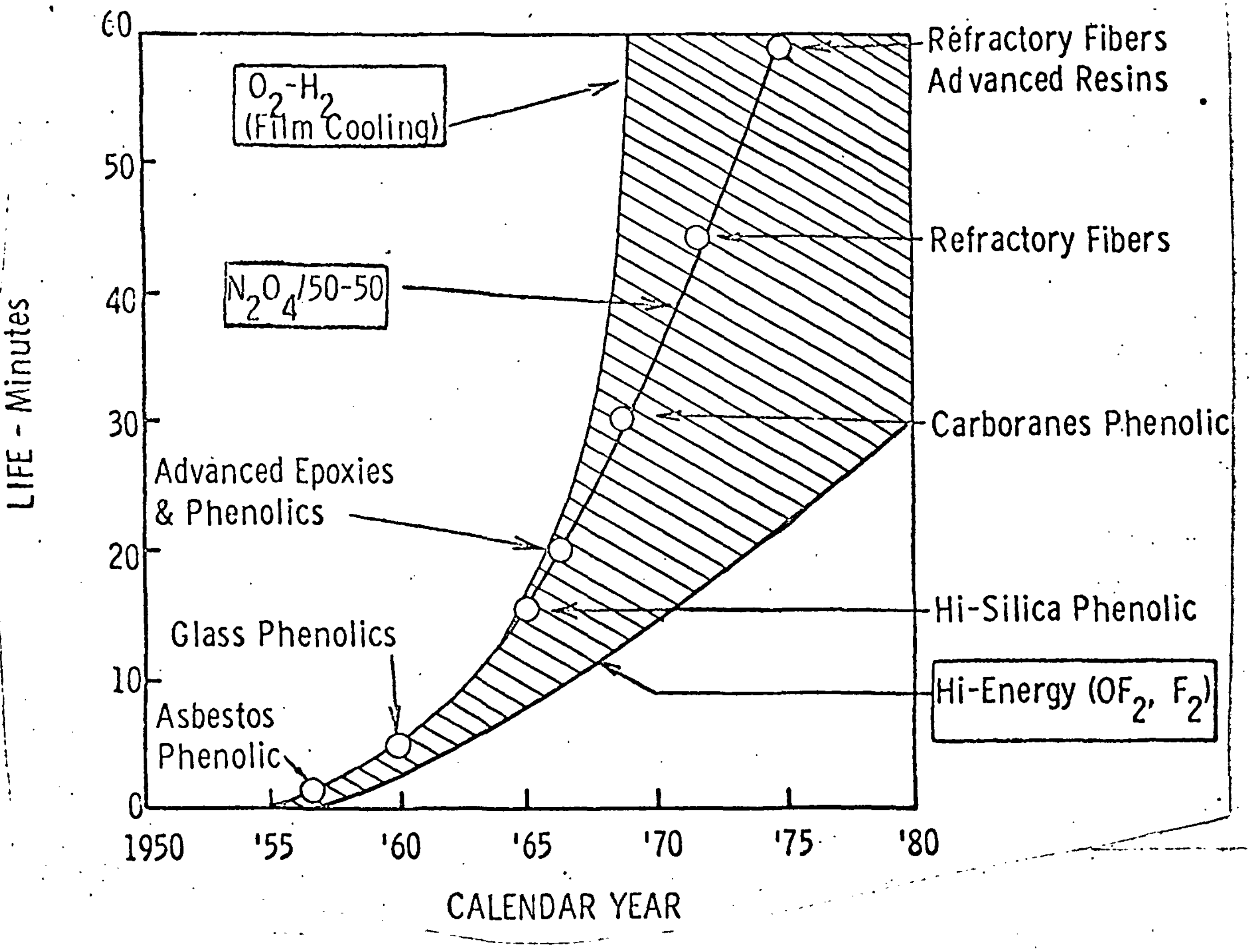

FIGURE 6

ABLATIVE CHAMBER LIFETIME

Courtesy of Thiokol . Corporation

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TABLE V

State-of-the-art Liquid Propellant Engines

REF.	MANUFACTURER	MODEL	THRUST LBS	WEIGHT LBS	PROPELLANTS O - F	I_{SP} SEC	P_c PSIA	e	COOLING METHOD	FEED SYS
1	BELL AEROSYSTEMS	8096	16,000	293	IRFNA-UDMH	292	508	45	REGEN.	PUMP
2	BELL AEROSYSTEMS	8133	16,000	278	N_2O_4-AERO 50	316	500	45	REGEN.	PUMP
3	ROCKETDYNE	NOMAD	12,000	*1,072	LF_2 - N_2H_4	357	150	20	REGEN.	PRES.
5	ROCKETDYNE	J-2	200,000	3,451	LOX - LH_2	426	686	27.5	REGEN.	PUMP
4	AEROJET	XLR-91-AJ-5	100,000	1,170	N_2O_4 - AERO 50	316	818	45	REGEN	PUMP
6	↕	M-1	1,500,000	20,000	LOX - LH_2	428	1,000	40	REGEN.	PUMP
↕	↕	AJ 10-138	8,000	180	N_2O_4 - AERO. 50	312	100	40	ABLATIVE	PRES.
↕	↕	AJ 10-137	21,900	690	N_2O_4 - AERO. 50	319	100	62.5	ABLATIVE	PRES.
↕	↕	AJ 10-131	2,200	95	N_2O_4 - AERO. 50	266	100	30	ABLATIVE	PRES.
6	AEROJET	AJ 10-118	7,575	207	IRFNA - UDMH	267	206	20	REGEN.	PRES.
7&8	PRATT & WHITNEY	RL10A-3	15,000	285	LOX - LH_2	429	300	40	REGEN.	PUMP
9	ROCKETDYNE	LEM-DESC.	10,500	355	N_2O_4 - AERO. 50	305	145	53	ABLATIVE	PRES.
	BELL	LEM-ASC.	3,500	140	N_2O_4 - AERO. 50	—	—	—	—	—

* INCL. TANKAGE

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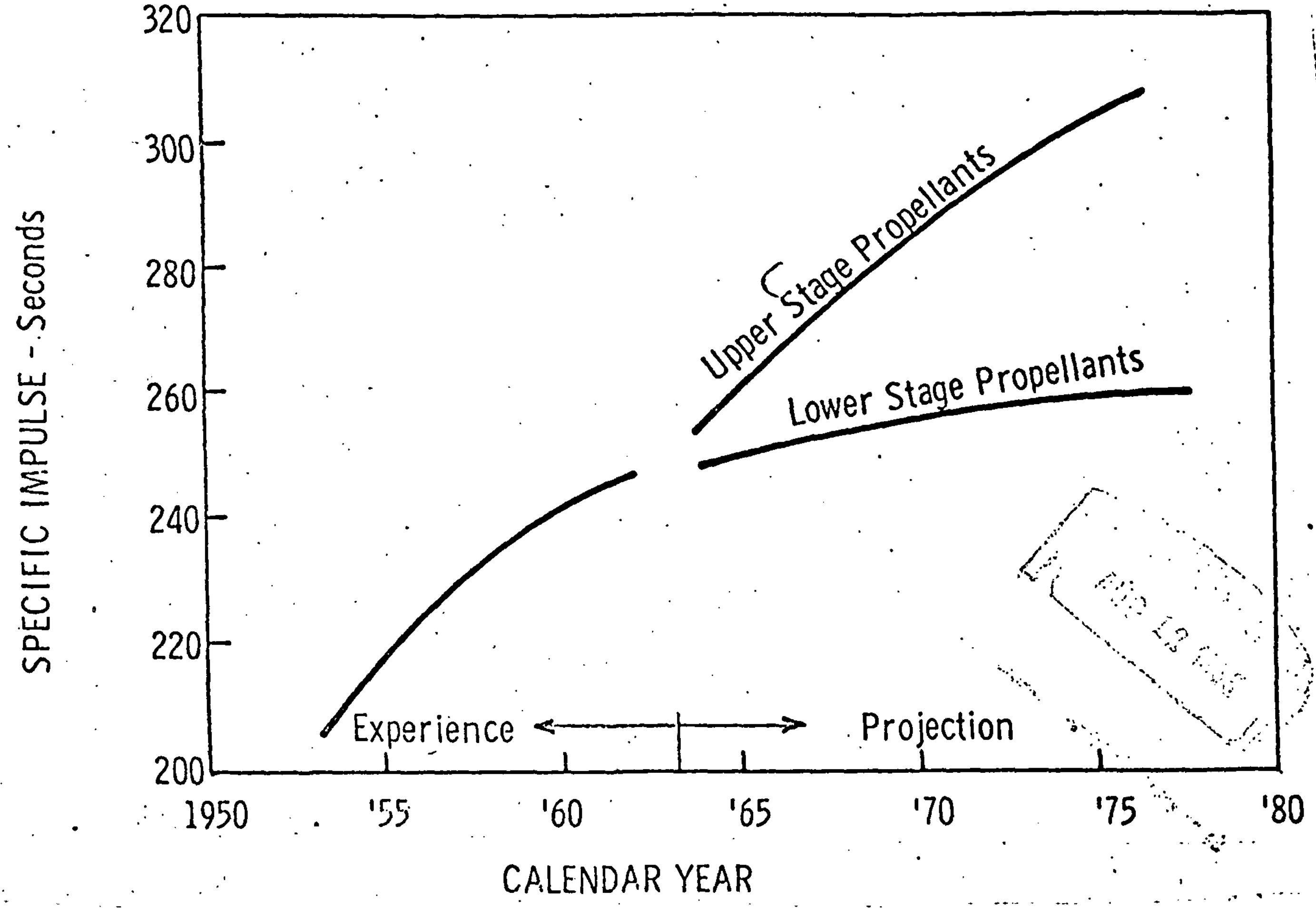

FIGURE 10

DELIVERED SPECIFIC IMPULSE TIME TABLE - SOLIDS

Courtesy of Thiokol Corporation

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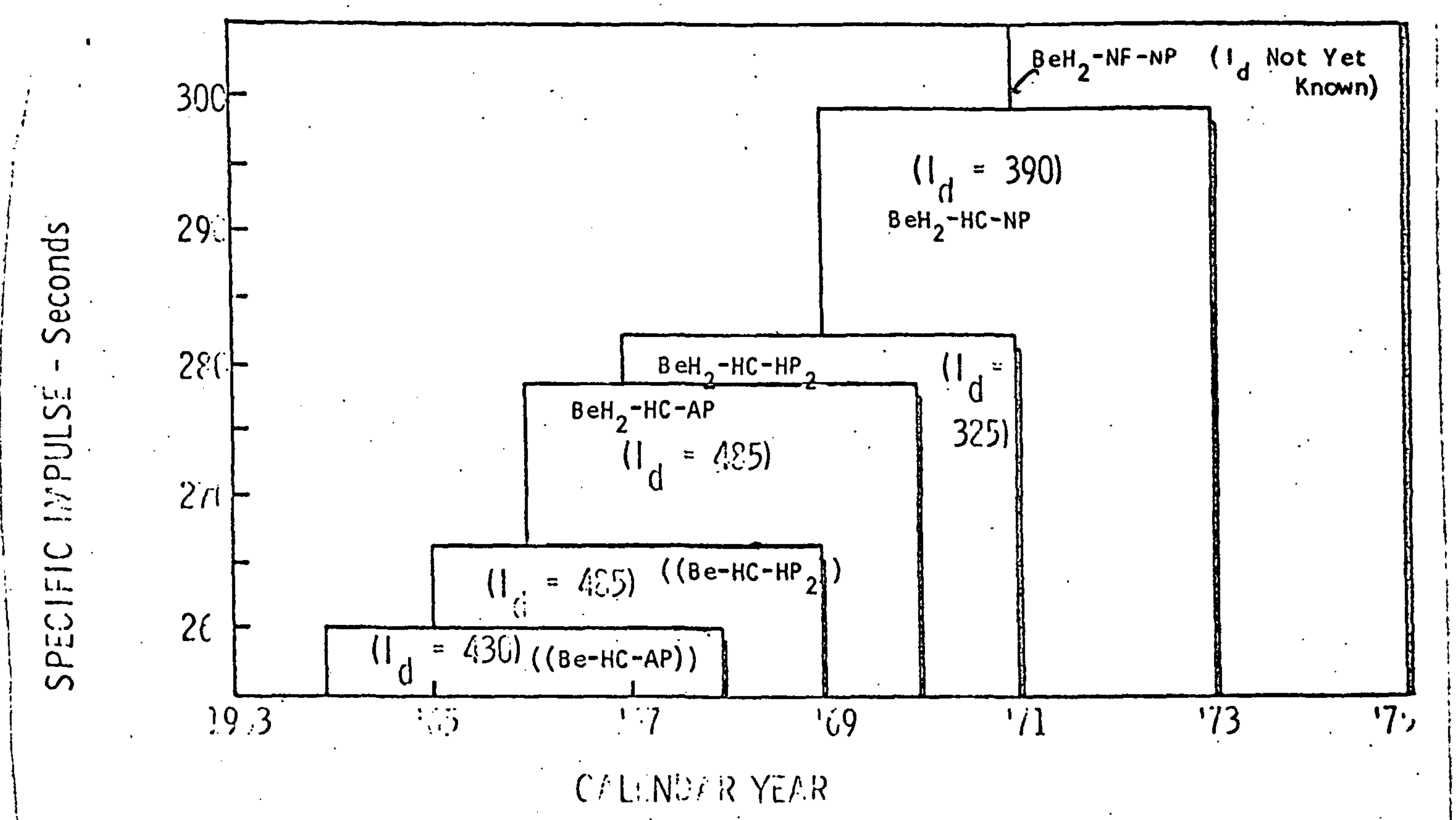

BeH_2 - Beryllium Hydride

AP - Ammonium Perchlorate

FIGURE 11

DELIVERED SPECIFIC IMPULSE VS TIME - SOLIDS
(Toxic Systems)

Courtesy of Thiokol Corporation

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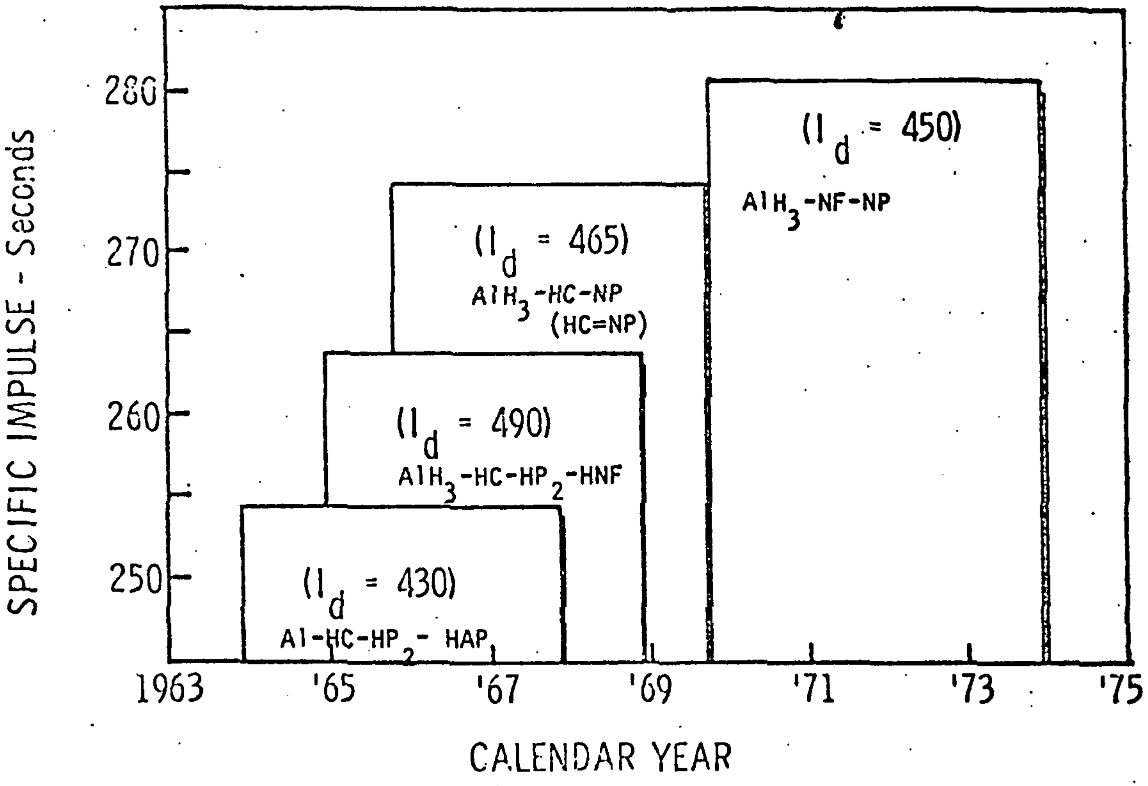

AlH_3 - Aluminum Hydride
NF - Nitrofluorine
NP - Nitronium Perchlorate
HC - Polymer (Binder)
HP_2 - Hydrazinium Diperchlorate
HNF - Hydrazine Nitroformate
HAP - Hydroxyl Ammonium Perchlorate

FIGURE 12

DELIVERED SPECIFIC IMPULSE VS TIME - SOLIDS
(Non-Toxic Systems)

Courtesy of Thiokol Corporation

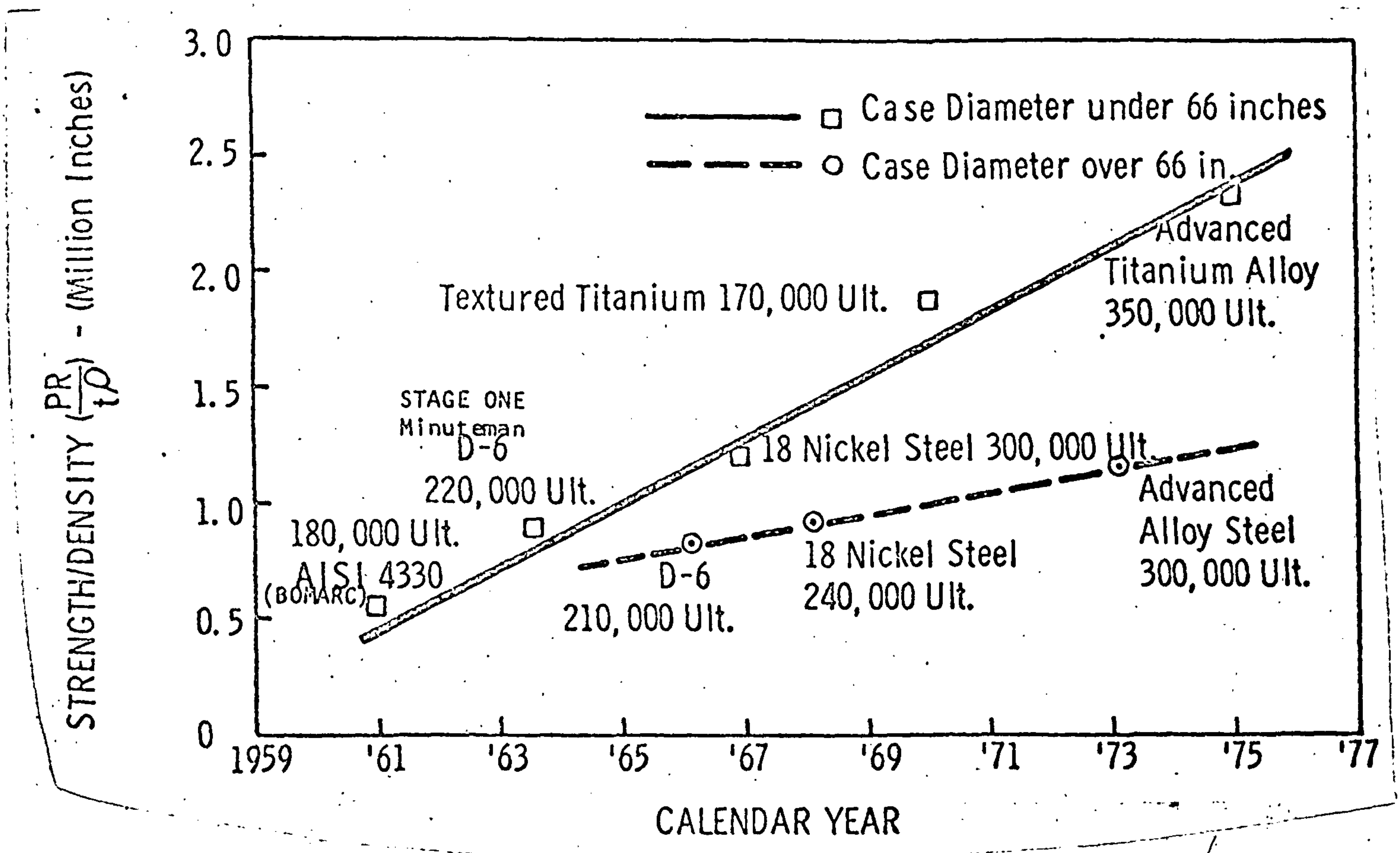

FIGURE 13

METAL CASE STRENGTH/DENSITY VS TIME

Courtesy of Thiokol Corporation

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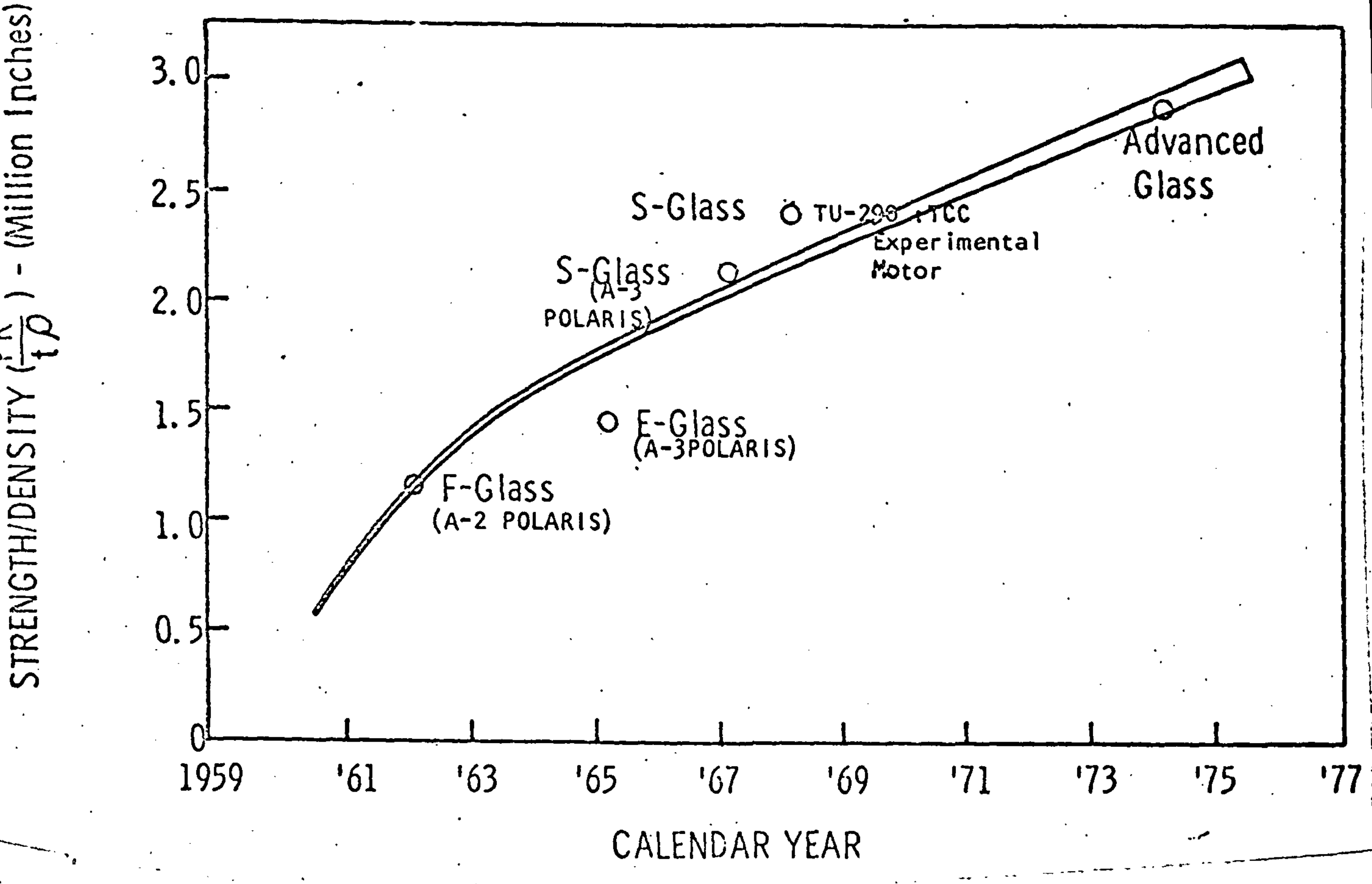

FIGURE 14

FIBERGLASS CASE STRENGTH/DENSITY VS TIME

Courtesy of Thiokol Corporation

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[redacted]

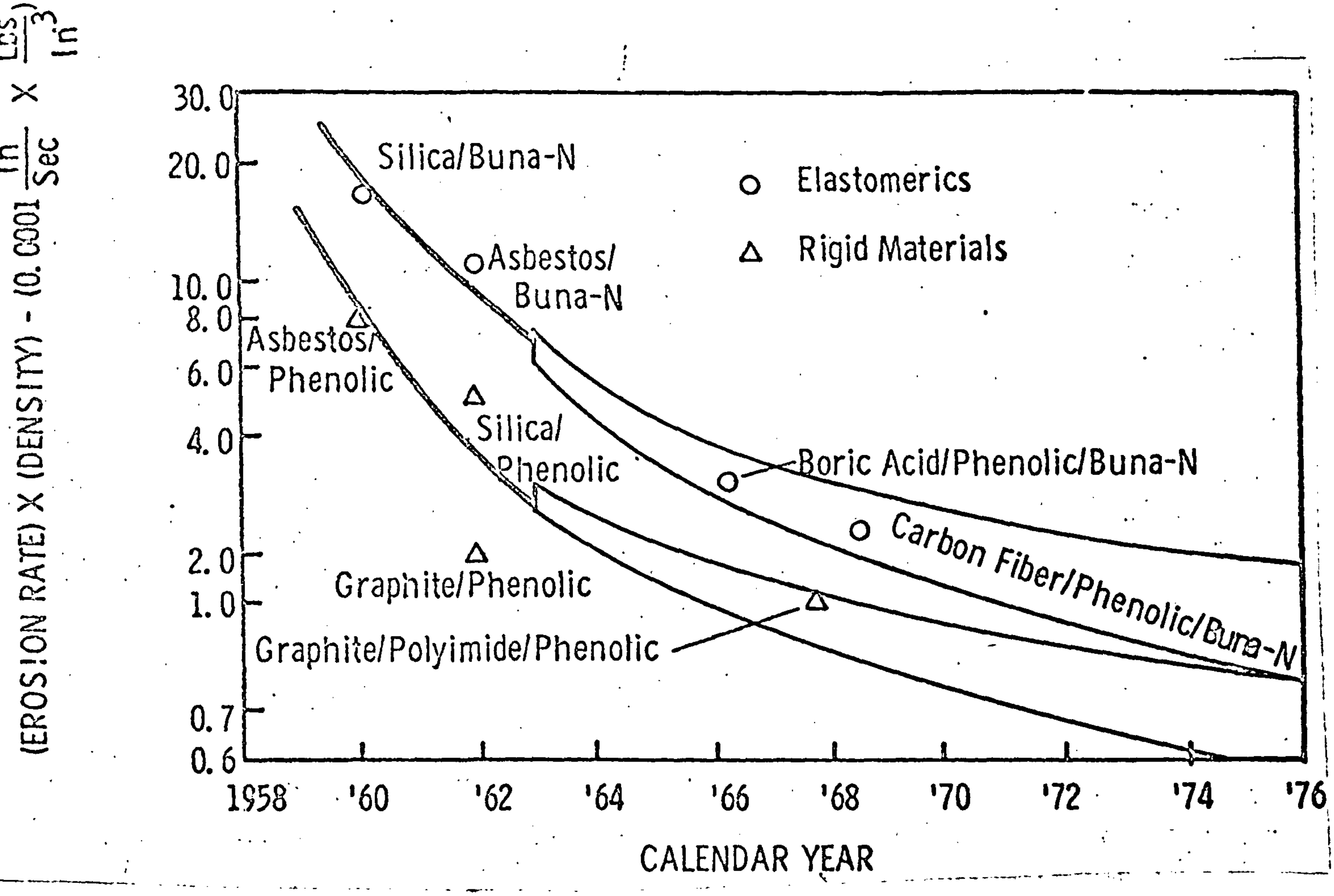

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FIGURE 15

INTERNAL INSULATION MATERIALS

Courtesy of Thiokol Corporation

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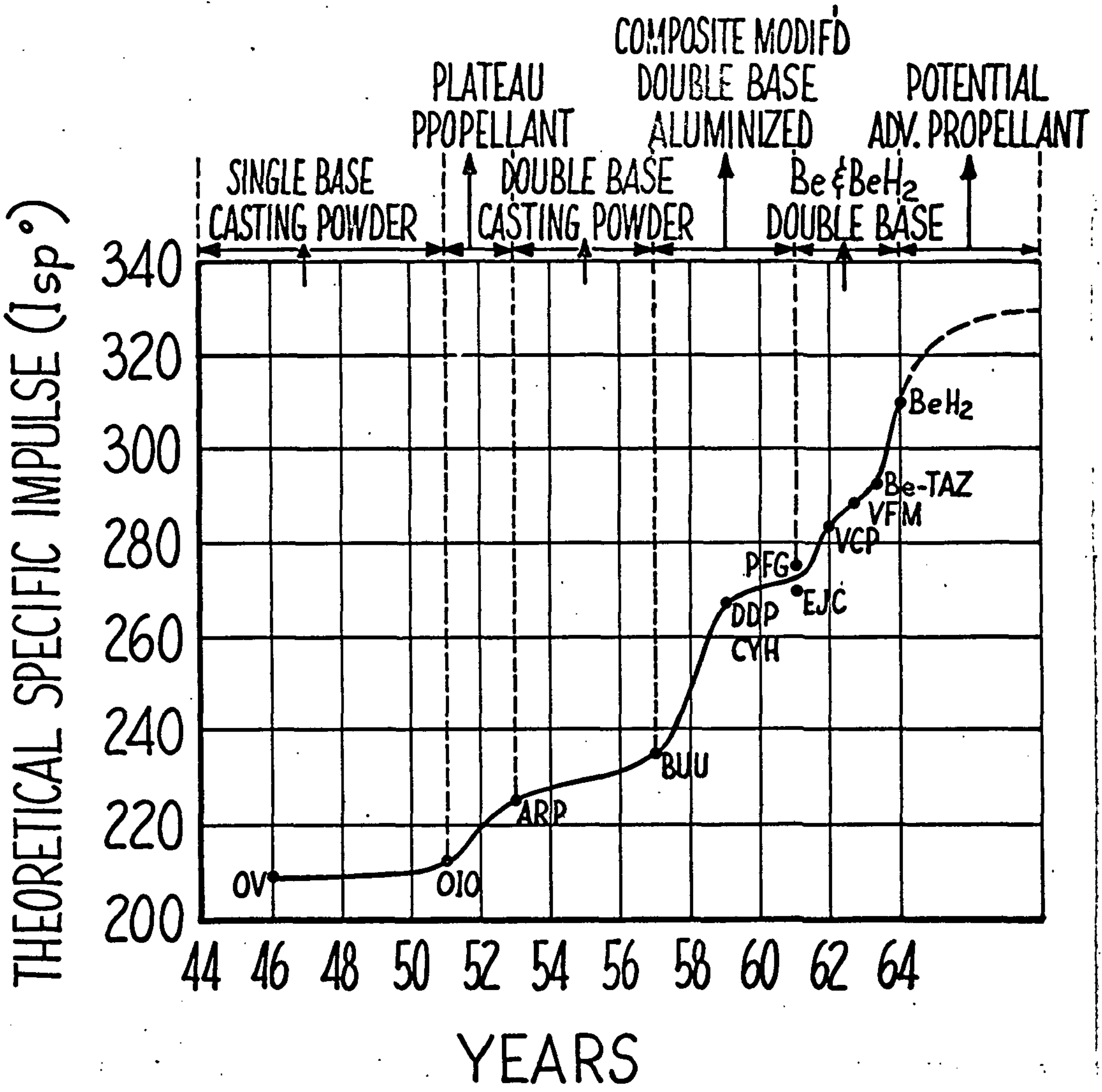

FIGURE 16

THEORETICAL SPECIFIC IMPULSE VS TIME - SOLIDS

Courtesy of Hercules Powder Company

Description of Operational NERVA

The presently defined operational NERVA will be liquid-propellant, turbopump-fed, nuclear rocket engine rated at nominal vacuum thrust of 56,100 pounds. The engine system consists of a liquid-hydrogen-propellant feed system, pressure shell, reactor and shield, regeneratively cooled nozzle, thrust structure, and additional components required for engine operation.

A summary of pertinent operational NERVA data as presently defined in the engine specifications is shown in Table VIII.

[redacted]

TABLE VIII

SUMMARY OF OPERATIONAL NERVA ENGINE DATA

(Reference 10)

Nominal Vacuum Thrust		56,100 lb
Reactor Power		1120 MW
Chamber Pressure		550 psia
Flowrate (total)		74.1 lb/sec
Specific Impulse (overall)		763 sec
Nozzle Area Ratio		40:1
Total Engine Dry Weight		13,684 lb
Unshielded Engine	11,434	
Shield	2,250 lb	
Length, Propellant Tank Bottom to Nozzle Exit		270 in.
Distance, Propellant Tank Bottom to Reactor Center		125 in.
Diameter (maximum)		143.5 in.
Number of Restarts (minimum)		3

[redacted]

Uprating of Operational NERVA

One approach to obtaining nuclear engines with better performance is through upgrading the performance of NERVA. Uprating the NERVA performance is governed by thermodynamic, mechanical, and structural design considerations.

Data for four NERVA uprating possibilities, described in Reference 10, are presented in Table IX. The first possibility is based on pump discharge flow of 93.0 lb/sec, which is 125 percent of rated heated-bleed cycle-pump-discharge flow.

The second case is also based on pump discharge flow of 93.0 lb/sec, but assumes a thrust chamber temperature of 4460°R. The basic assumptions were the same as stated for the first uprated system. The overall engine vacuum thrust of 74,140 lb and the overall engine specific impulse of 802 sec represent a probable upper limit for NERVA uprating without basic component changes. This limit occurs at a reactor power level of about 1580 MW.

The third uprating assumes that two NERVA turbopumps may be operated in parallel to flow about 148 lb/sec at a chamber pressure of 550 psia. Such an uprating requires extensive modification to the engine design, involving nearly every component except the basic turbopump and reactor core. Such an engine system, however, would produce about 119,000 lb of thrust at a power level of 2510 MW.

The fourth system is a conceptual design of an engine based on the maximum predicted power available from a NERVA B-4 type fuel-element core. The reactor core was redesigned to achieve its full heat-transfer capability, and limited only by the mechanical and thermal properties of the fueled graphite. The envelope dimensions of this engine are approximately those of the present NERVA; however, there are some size and weight increases due to the higher pressures and flows. (Reference 10)

[redacted]

TABLE IX

PERFORMANCE FOR DIFFERENT METHODS OF NERVA UPRATING

(Reference 10)

	NERVA	Method 1	Method 2	Method 3	New Design
Thrust (lb)	56,100	71,000	74,140	119,100	190,150
Specific Impulse (sec)	763	768	802	802	810
Chamber Pressure (psia)	550	704	704	550	1,000
Chamber Temperature (° R)	4,090	4,090	4,460	4,460	4,460
Total Propellant Flow (lb/sec)	74.1	93.0	93.0	148.6	235.3
Reactor Power (MW)	1,120	1,430	1,580	2,510	4,100

[redacted]

Phoebus Based Parametric Studies

Figures 20 and 21 illustrate thrust-to-weight ratio vs. thrust, and engine size vs. thrust, respectively. The specific impulse gains shown in Figure 20 are keyed as a function of time; that is, as larger engines are required, there should be sufficient state-of-the-art improvement to achieve the indicated performance. (Reference 10)

Heavy-Metal, Fast-Sepctrum Reactors

The fast-spectrum reactor utilized fission spectrum neutrons rather than those of intermediate or thermal energy levels to sustain the fission process. A reactor of this type contains only fuel-bearing material (i.e. no moderating material to slow down neutrons); however, neutron economy is inferior to moderated reactors, requiring a larger fuel inventory to sustain the chain reaction. Current concepts utilize refractory metals as a fuel-bearing matrix because fissionable compounds are poor structural materials, and because of good high-temperature properties of the refractory metals.

Present fuel-element design utilizes tungsten as the fuel-bearing material, since tungsten has the highest melting point and the lowest vapor pressure of all the refractory metals. However, the brittleness of presently available tungsten limits its use structurally; therefore, the fuel-bearing matrix is encapsulated in one of the other refractory metals. Tantalum is presently being used, since this material is the highest-melting refractory metal available commercially in the desired shapes and sizes.

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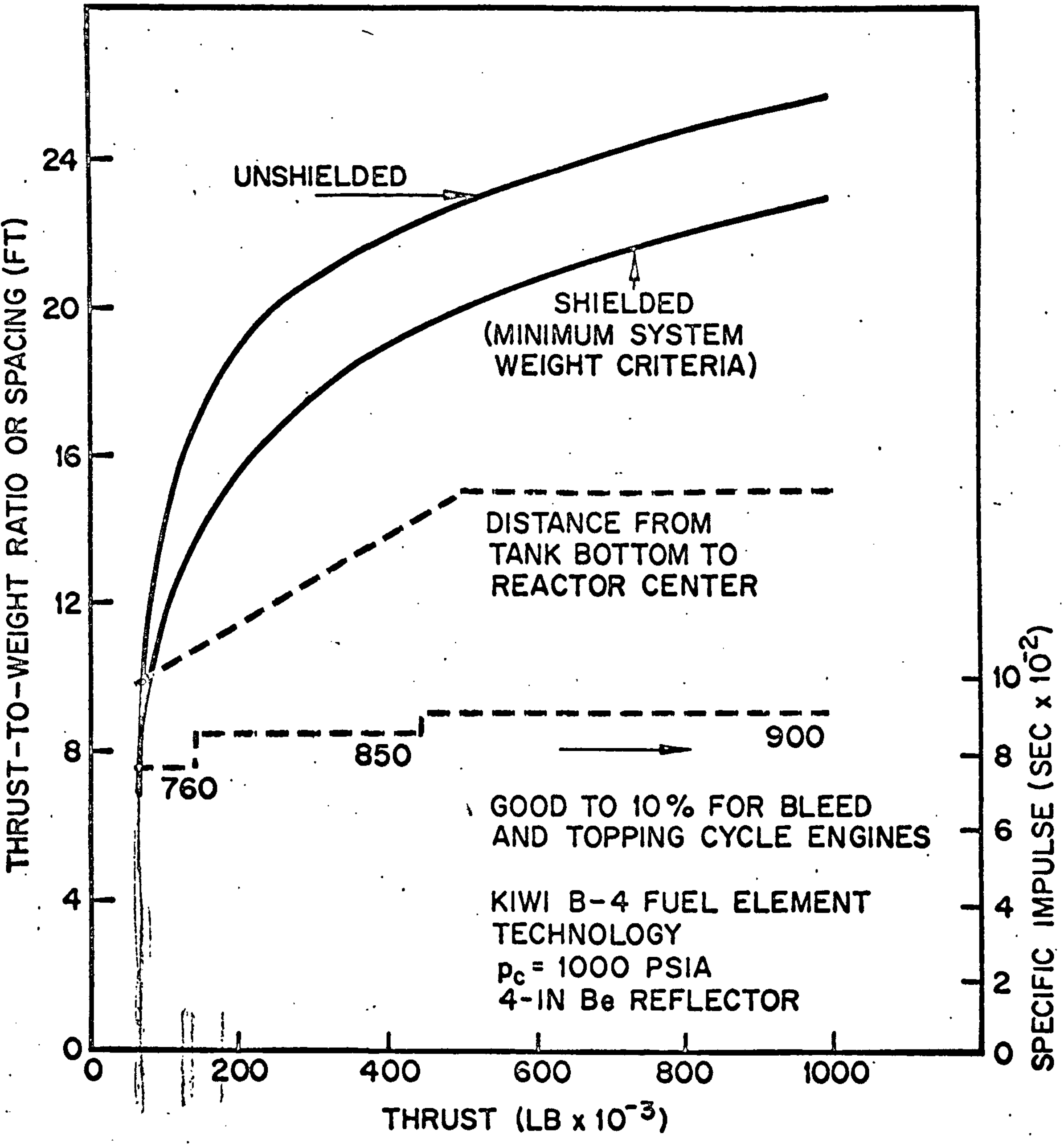

Fig. 20 Engine Data With Future Improvements Included

(Reference 10)

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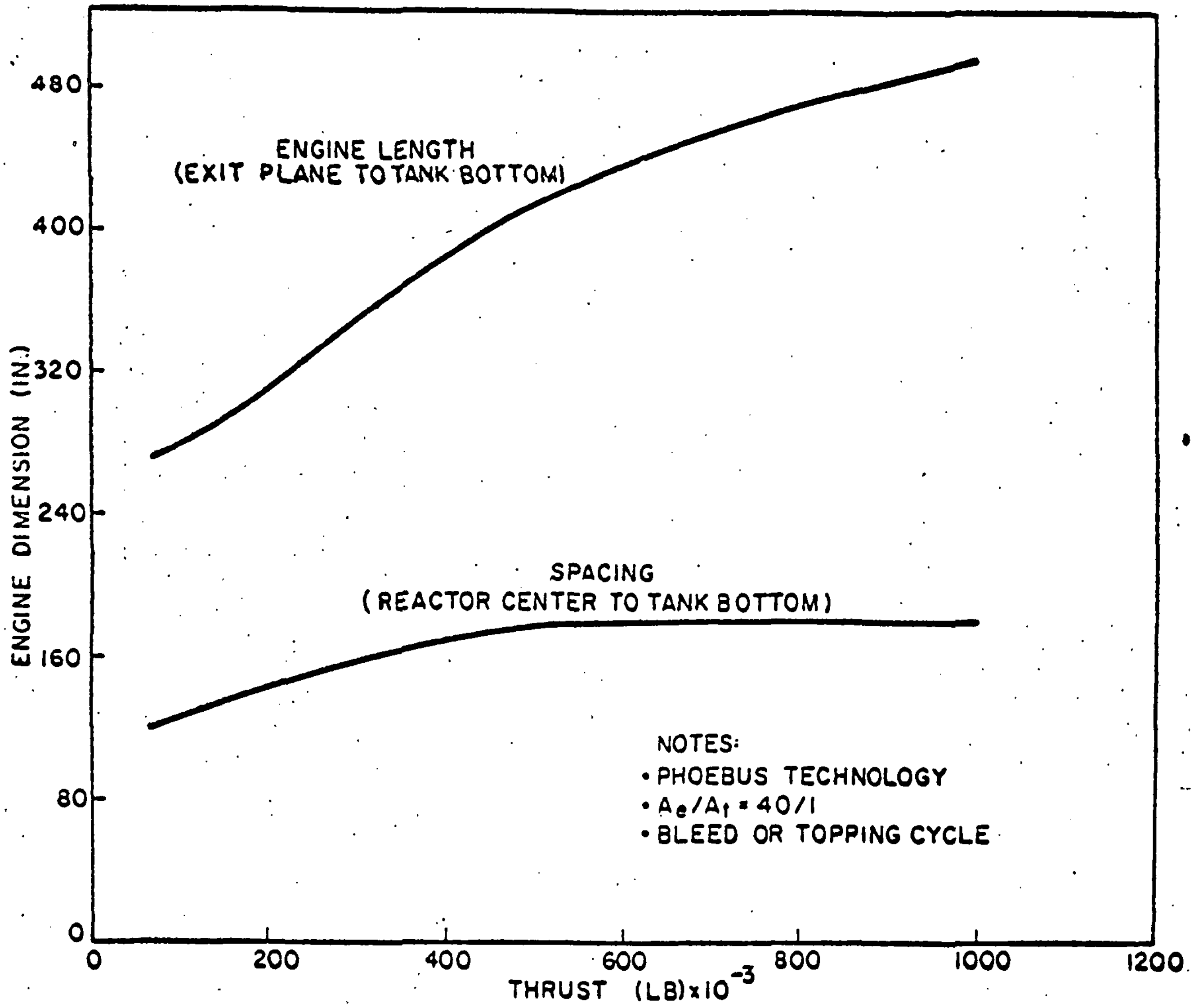

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Fig. 21 Nuclear Rocket Engine Dimensions

(Reference 10)

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The performance potential of these reactors is limited by the encapsulating material used. For example, the theoretical specific impulse obtainable using projected refractory metal liners is as follows:

Ta - 860 sec
W-Re - 890 sec
W - 920 sec

Adoption of the latter two materials is a function of improved commercial availability of material with the desired shapes, sizes, and characteristics.

Estimated operating life of these reactors, limited primarily by creep of metals, is 1 hr with 90 percent reliability and 90 percent confidence factor by 1969. A projected figure for 1975 is 100 hr based on 1 percent fuel burnup.

The fast-spectrum, heavy-metal reactor engine is superior in overall performance to graphite readtors up to approximately 275,000 lb thrust. Data for the weight vs. thrust comparison are shown in Figure 22. The comparison between these systems is made for a chamber gas temperature of 4500°R, though both are potentially capable of higher temperature operation.

At low-thrust values, the lighter weight of the fast-spectrum system is primarily due to the absence of moderating material permitting smaller, lighter reactors. This decrease in size leads to smaller, and therefore lighter, pressure shell, shield, and a portion of the nozzle. However,

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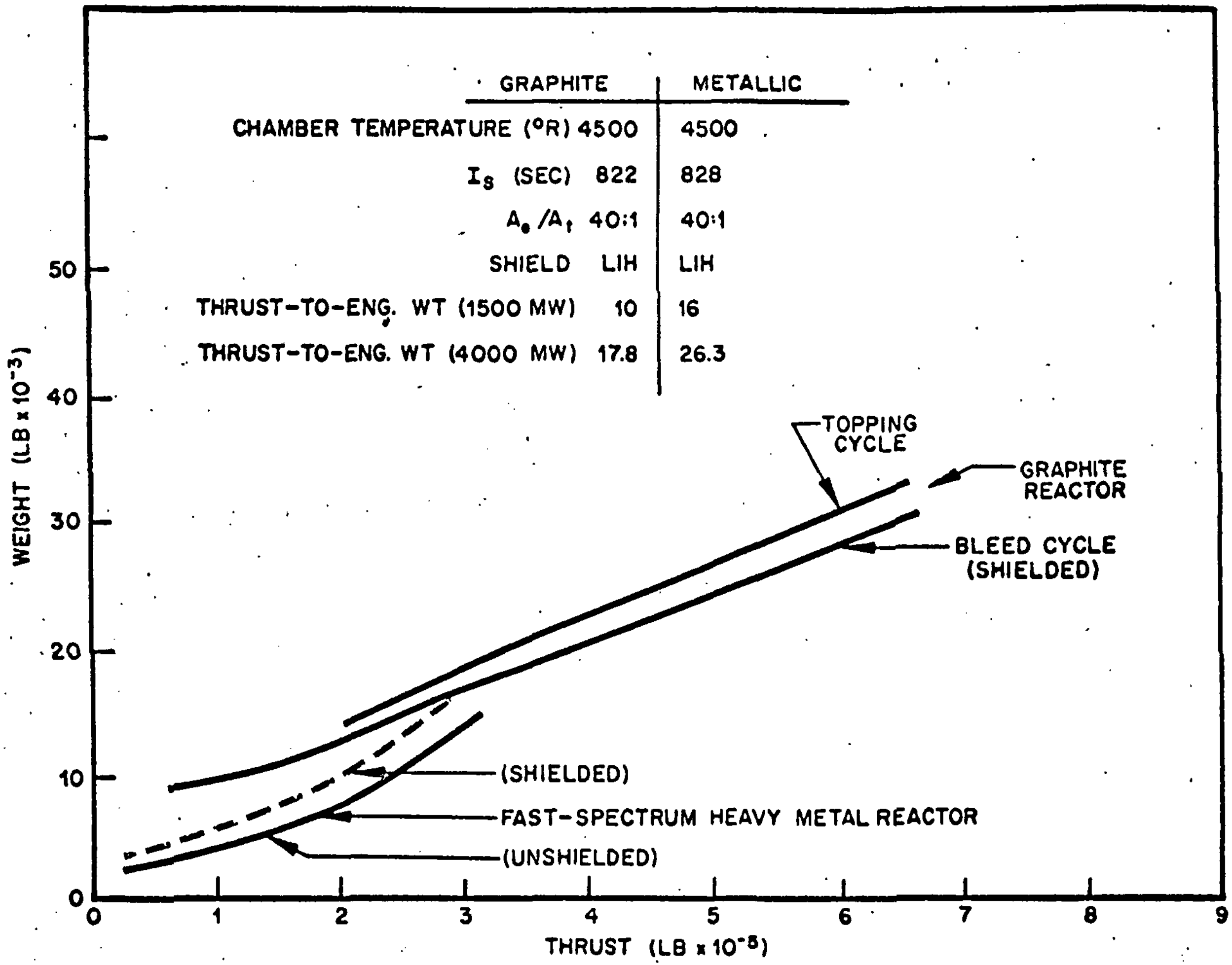

	GRAPHITE	METALLIC
CHAMBER TEMPERATURE (°R)	4500	4500
I_s (SEC)	822	828
A_e/A_t	40:1	40:1
SHIELD	LIH	LIH
THRUST-TO-ENG. WT (1500 MW)	10	16
THRUST-TO-ENG. WT (4000 MW)	17.8	26.3

Fig. 22 Metallic and Graphite Nuclear Engine Systems

(Reference 10)

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[redacted]

as the thrust level is increased, the fast-spectrum reactor becomes much heavier than the graphite reactor, since the higher fuel loading required and the fuel-bearing refractory metal are more dense than the graphite-fuel combination. The fast-spectrum engine, however, will always effect some saving in vehicle interstage structure weight, since the reactor is smaller than the graphite-moderated reactor. (Reference 10)

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