ENABLER I AND II ENGINE SYSTEM DESIGN MODELING AND COMPARISONS

23 OCTOBER 1992

PRESENTED BY:

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ALBUQUERQUE, NM 87123

PRESENTED AT:

1992 NUCLEAR PROPULSION - TECHNICAL INTERCHANGE MEETING
NASA LEWIS RESEARCH CENTER
SANDUSKY, OH

TOPICS

- OBJECTIVE/APPROACH
- ENGINE SYSTEM DESIGN/MODELING ASSUMPTIONS
- ENGINE SYSTEM SCALING/COMPARISONS
- CONCLUDING REMARKS

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OBJECTIVE/APPROACH

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OBJECTIVE / APPROACH

- **Objective:**
  - Define a Near-Term Solid-Core NTP Engine System Scaling Database
    - -- Identify/Document Unified Set of Performance, Weight and Size Scaling Data
    - -- Results Should Be Useful to Meet Initial Mission and Concept Design Study Requirements

- **Approach:**
  - Acquire/Review Past Rover/NERVA Engine Design Work
  - Assess Current Engine System Data
  - Conduct Preliminary NTP Engine System Design Trades Using the NESS Design Program
    - -- Establish Operating Range of Interest and Technology Design Approach
    - -- Design Analysis Responsibilities
      - SAIC - Engine System
      - Westinghouse - Reactor and Internal Shield (ENABLER Reactor)
  - Establish a Catalog of Enabler I and II Engine System Design for a Range Configurations and Operating Conditions

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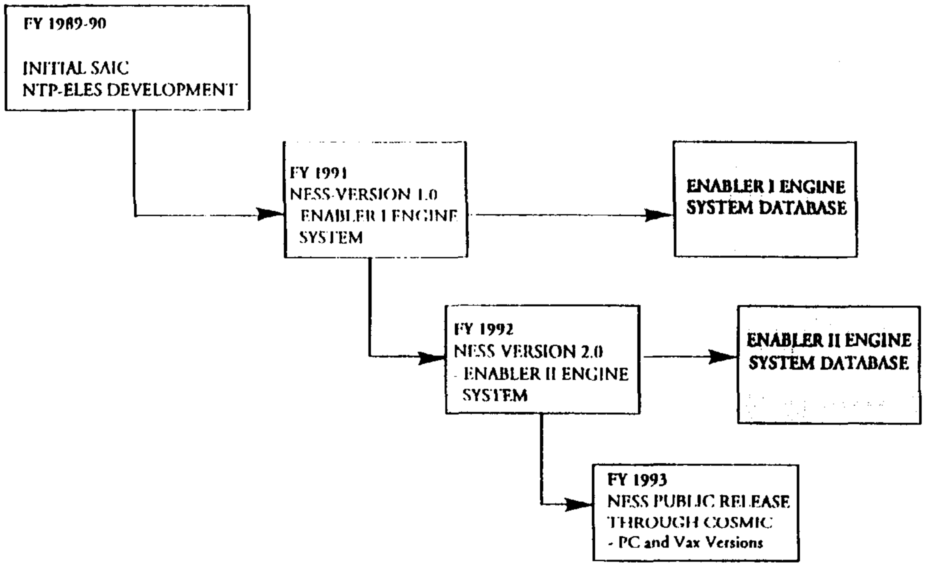
ENABLER I AND II ENGINE SYSTEM DESIGN DATABASE DEVELOPMENT CLOSELY PARALELLED NESS PROGRAM DEVELOPMENT



FY 1989-90

INITIAL SAIC
NTP-ELES DEVELOPMENT

FY 1991
NESS-VERSION 1.0
- ENABLER I ENGINE SYSTEM

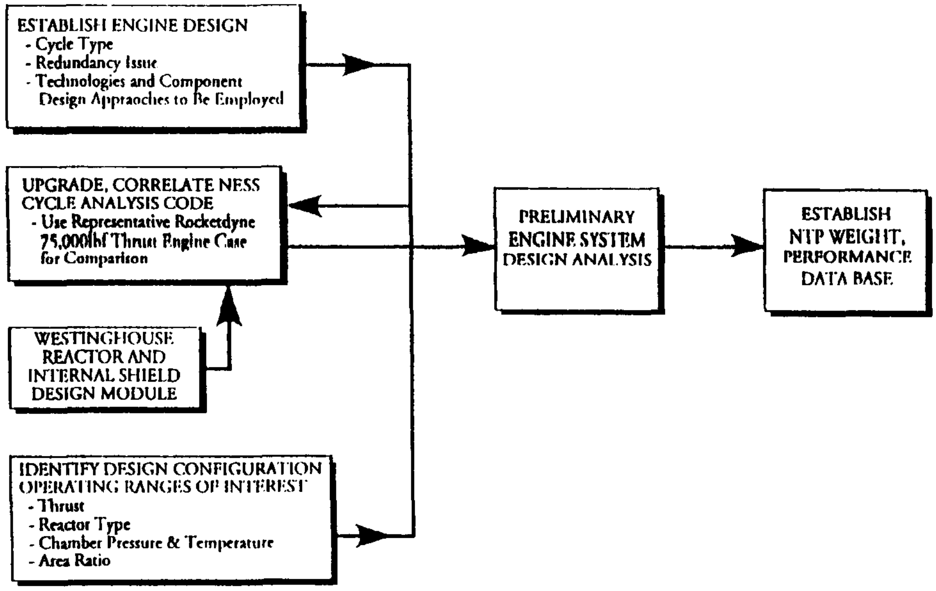
ENABLER I ENGINE SYSTEM DATABASE

FY 1992
NESS VERSION 2.0
- ENABLER II ENGINE SYSTEM

ENABLER II ENGINE SYSTEM DATABASE

FY 1993
NESS PUBLIC RELEASE THROUGH COSMIC
- PC and Vax Versions

OVERALL NTP ENGINE SYSTEM ASSESSMENT APPROACH



ESTABLISH ENGINE DESIGN
- Cycle Type
- Redundancy Issue
- Technologies and Component Design Approaches to Be Employed

UPGRADE, CORRELATE NESS CYCLE ANALYSIS CODE
- Use Representative Rocketdyne 75,000lbf Thrust Engine Case for Comparison

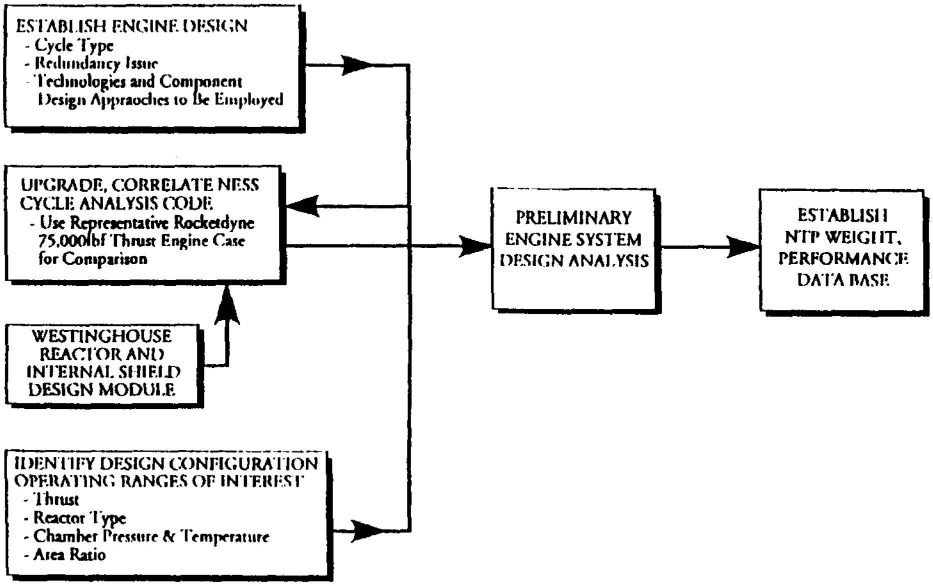
WESTINGHOUSE REACTOR AND INTERNAL SHIELD DESIGN MODULE

IDENTIFY DESIGN CONFIGURATION OPERATING RANGES OF INTEREST
- Thrust
- Reactor Type
- Chamber Pressure & Temperature
- Area Ratio

PRELIMINARY ENGINE SYSTEM DESIGN ANALYSIS

ESTABLISH NTP WEIGHT, PERFORMANCE DATA BASE

OVERALL NTP ENGINE SYSTEM ASSESSMENT APPROACH



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PRELIMINARY ENGINE SYSTEM DESIGN ANALYSIS

ESTABLISH NTP WEIGHT, PERFORMANCE DATA BASE

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KEY TECHNICAL DOCUMENTS REVIEWED

- XE-Prime Engine - Final Report
- Small Nuclear Engine Final Report
- Experience Gained From the Space Nuclear Rocket Program (ROVER)
- History Summary Report
- Safe, Compact, Nuclear Propulsion - Final Report
- NERVA Preliminary Design Safety Report
- Nuclear Rocket Engine Optimization Program
- NASA Lewis Nuclear Thermal Propulsion Workshop, 1990
- "Design of Second-Generation Nuclear Thermal Rocket Engines," AIAA Report
- On-Going NASA Lewis NTP System Studies

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ENABLER REACTOR DESIGN AND OPERATING PARAMETERS EXAMINED

- Full Element/Chamber Temperature Range
  - Graphite: 2,200 - 2,500K
  - Composite: 2,500 - 2,900K
  - Carbide: 2,900 - 3,300K
- Thrust Level: 15,000-250,000 lbf
- Chamber Pressure: 500 and 1000 psia

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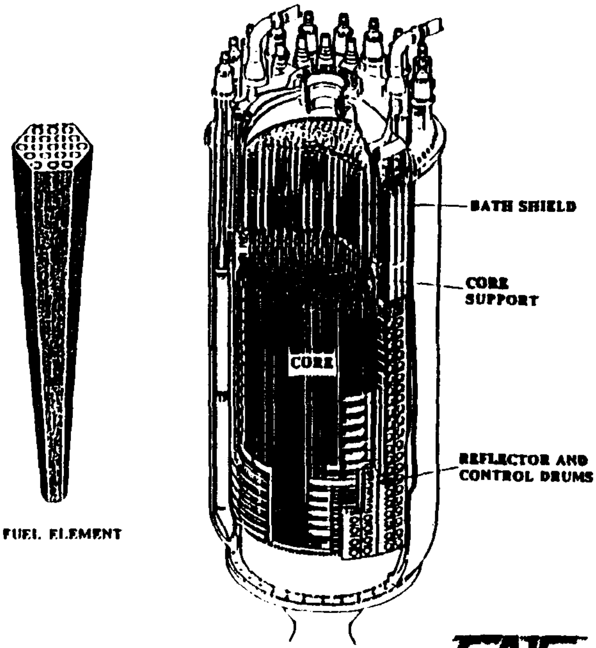
ENABLER (NERVA TYPE) NUCLEAR THERMAL ROCKET ENGINE



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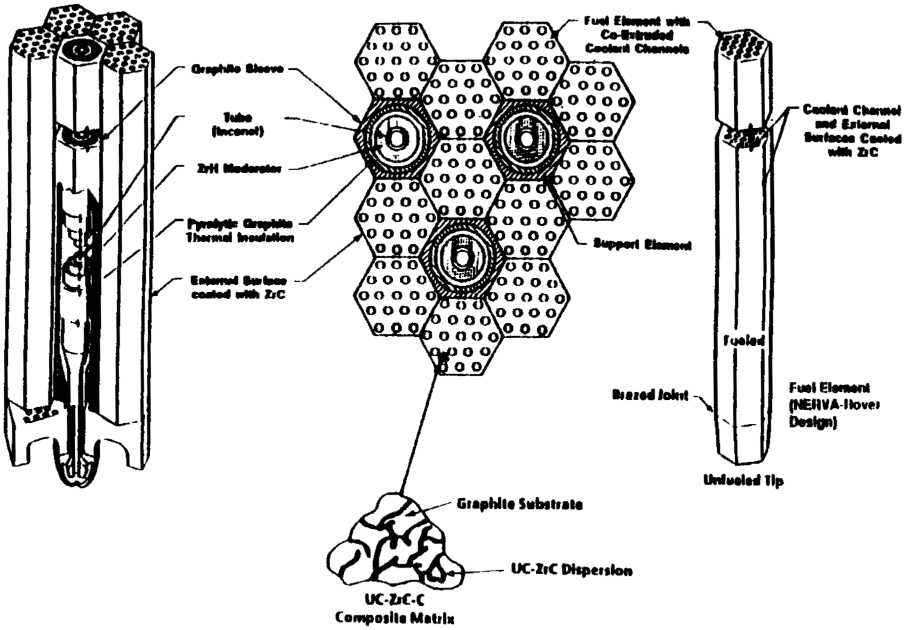
PRISMATIC FUEL ELEMENTS AND SUPPORTS



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FUEL AND SUPPORT ELEMENTS PARAMETERS

Fuel Element Composition	Graphite	Composite	Carbide
Temperature Range K	2200 - 2500	2500 - 2900	2900 - 3300
Fuel	Coated Particle	UC • ZrC Solid Solution and Carbon	(U, Zr) C Solid Solution
Coating	ZrC	ZrC	—
Unfueled Support Element Composition	Graphite	ZrC-Graphite Composite	ZrC
Unfueled Element Coating	ZrC	ZrC	—

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REACTOR PARAMETERS/CHARACTERISTICS AS A FUNCTION OF THRUST LEVEL

Thrust (1000 lbf)	15	25	>50
Reactor Power Range (MW)	275 - 400	460 - 670	920 - 6700
Fuel and Support Element Length [m (inch)]	0.89 (35)	0.89 (35)	1.32 (52)
Pressure Vessel Length [M(inch)]	2.10 (82.6)	2.13 (84)	2.58 (101.6)
Fuel Element Power (MW)	0.629	0.808	1.20
Relative Fuel Element Power Density	0.778	1.0	1.0
Ratio of Fuel Elements (N) to Support Elements	2:1	3:1	6:1
Pressure Vessel Material	Aluminum	Aluminum	Aluminum
Reflector Material	Beryllium	Beryllium	Beryllium
Internal Shield Material	BATH*/Lead	BATH/Lead	BATH/Lead

* BATH = Borated Aluminum Titanium Hydride

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RADIATION LEAKAGE LIMITS CRITERIA ASSUMED

- AT A PLANE 160 CM (63 INCHES) FORWARD OF THE CORE CENTER -

Type of Radiation	Radiation Leakage Limits Within Pressure Vessel Outside Radius
Gamma Carbon KERMA Rate	1.8×10^7 rad (c)/hr
Fast Neutron Flux	2.0×10^{12} n/cm^2 - sec, $E_n > 1.0$ MeV
Intermediate Neutron Flux	3.0×10^{12} n/cm^2 - sec, 0.4 eV $\leq E_n \leq 1.0$ MeV
Thermal Neutron Flux	6.0×10^{11} n/cm^2 - sec, $E_n < 0.4$ ev

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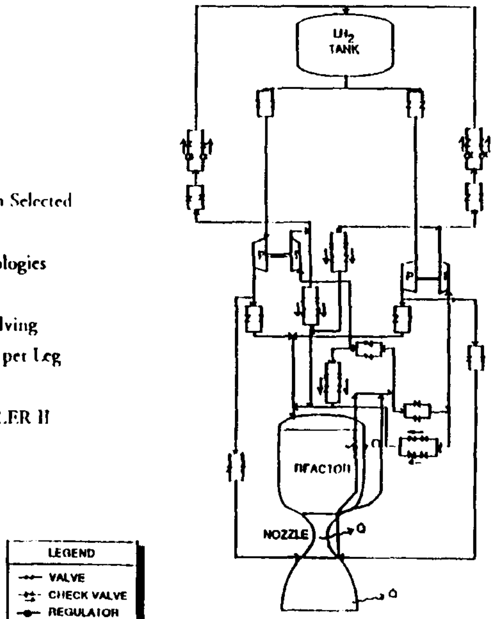
ENGINE SYSTEM ANALYSIS APPROACH/ASSUMPTIONS

- Use SAIC NESS Cycle Analysis Code
  - Check/Adjust Code to a Reasonable Test Case
    - Rocketdyne ENABLER I and ENABLER II 75,000 lbf, 1000 psia Engine System Design Selected
  - Model Engine as an Expander Cycle
  - Incorporate near-Term State-of-the-Art Technologies
  - Incorporate Dual Turbopump Feed system
    - Single Propellant turbopump With Dual Valving per Feed Leg - 80% Thrust Level Capability per Leg
    - Centrifugal Turbopumps Used
    - Boost Pumps Assumed Only for the ENABLER II Engine System
  - Use Westinghouse ENABLER Reactor System Design Model
    - Includes an Internal Shield Model
  - Examine Nozzle Ratios of 200 and 500:1



EXPANDER CYCLE

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KEY NTP ENGINE DESIGN AND TECHNOLOGY FEATURES

Design/Technology Feature(s)	Comment(s)
Gimbal Engine Mount	Based on the Space Shuttle Main Engine (SSME) Design Approach
Turbopump Assembly - Dual Feed System Legs with Dual Valving – 80% Pumping Capability per Feed Leg - Centrifugal Turbopumps – Pump Material: Inconnel – Turbine Material: MAR-M246	- Based on NERVA Design Approach (Redundancy Considerations) - Based on the SSME
Solid-Core NERVA Type Reactor Design - Internal Shield	- Uses State-of-the-Art Reactor System Fuels/Technologies/Materials (Westinghouse ENABLER Design) - Based on NERVA Design Approach and Requirements
Nozzle Assembly - 119% High Area Ratio RAO Contour – 200 and 500:1 - Three Section Assembly – Throat Region • 2:1 Upstream to 6:1 Downstream • Slotted Regen Wall Construction of Copper - Intermediate Region • 6:1 to 150:1 Downstream • Regen Cooled Inconnel Tube Bundles - Exit Nozzle Extension • 150:1 to Exit • Radiation Cooled Carbon-Carbon	- Conservative, High Performance Design, Common in the Propulsion Community - Based on the SSME and State-of-the-Art Rocket Propulsion Technology Base - Based on SSME - Based on SSME - Uses State-of-the-Art Rocket Propulsion Materials Technology Base
Miscellaneous Hardware - Propellant Lines - Valves - Electronics/Instrumentation/Processors	- State of the-Art Technologies Employed - Reduced Weight, Size, and Increased Capability

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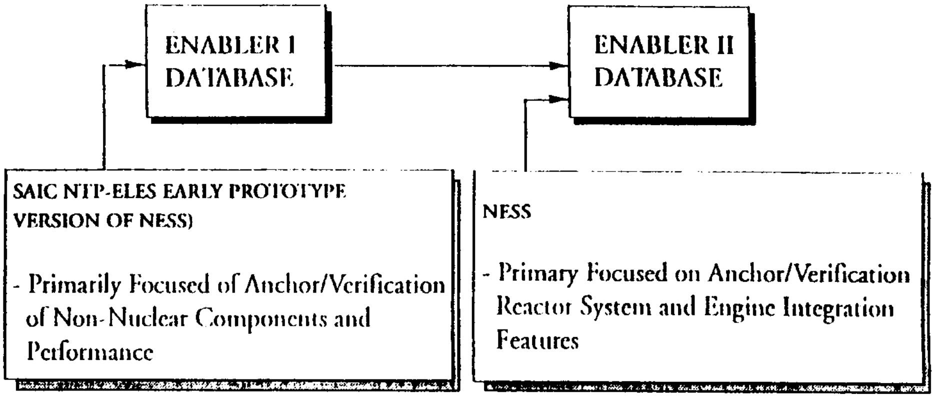
EXTENSIVE NESS PROGRAM VERIFICATION CONDUCTED IN PARALELL AS THE ENABLER NTP DATABASE DEVELOPED



ENABLER I DATABASE

ENABLER II DATABASE

SAIC NTP-ELES EARLY PROTOTYPE VERSION OF NESS)

- Primarily Focused of Anchor/Verification of Non-Nuclear Components and Performance

NESS

- Primary Focused on Anchor/Verification Reactor System and Engine Integration Features

INITIAL ENGINE COMPONENT WEIGHT COMPARISON*
- 75,000 lbf NTP ENGINE CASE -

Parameter	NERVA	Rocketdyne	SAIC ELES-NTP	Adjustments/Comments
Chamber Temperature (°K)	2500	2700	2700	—
Chamber Pressures (psia)	450	1000	1000	—
Area Ratio	100	500	500	—
Specific Impulse - Vac (sec)	850	923	922.8	—
Reactor (kg)	5890	5824	5823	—
Internal Shield (kg)	1583	—	1523	—
Nozzle Assembly (kg)	1051	440	421	• ELES NTP Value Increased by 5% - Rocketdyne Weight Considered a Good Baseline
Turbopump Assembly (kg)	243	304	104	• ELES NTP Value Increased by 30% - Rocketdyne Considered Conservative for SOA Designs
Nonnuclear Support Hardware (kg) - Lines, Values, Actuators, Instrumentation Thrust Structure	2425	1815	1264	• ELES NTP Value Increased by 40% - Rocketdyne Weight Considered a Good Baseline - Scaled From Previous Design Work

* Rocketdyne uses their Mark-25 type axial turbopump (4 stages); ELES-NTP used a single-stage centrifugal pump.

INITIAL ENGINE COMPONENT WIEGHT COMPARISON*

- 75,000 lbf NTP ENGINE CASE -

Parameter	NERVA	Rocketdyne	SAIC ELES-NTP	Adjustments/Comments
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INITIAL ENGINE CYCLE PARAMETER COMPARISON*

- 75,000 lbf NTP ENGINE CASE -

Parameter	Rocketdyne	SAIC - ELES NTP
Pump Flowrate (kg/s)	36.7	36.9
Pump Discharge Pres. (psia)	1544	1538.3
Turbine Flowrate, % Pump	50	50
Turbine Inlet Temp. (°K)	555.6	555.3
Turbine Inlet Pres. (psia)	1412	1416.8
Turbine Pressure Ratio	1.25	1.295
Reactor Inlet Pres. (psia)	1130	1255.4
Reactor Power, (MW)	1645	—
Reactor Core Flowrate (kg/s)	36.7	36.9
Nozzle Chamber Temp (°K)	2700	2700
Nozzle Chamber Pres. (psia)	1000	1000
Nozzle Exit Diameter (m)	4.15	4.15
Nozzle Expansion Ratio	500	500
Specific Impulse-Vac (sec)	923	922.8
Pump Speed (rpm)	37,500	34,913

* Rocketdyne uses their Mark 25-type axial turbopump (4 stages); ELES-NTP used a single-stage centrifugal pump.

INITIAL ENGINE CYCLE PARAMETER COMPARISON*
- 75,000 lbf NTP ENGINE CASE -

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Nozzle Chamber Pres. (psia)	1000	1000
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Nozzle Expansion Ratio	500	500
Specific Impulse-Vac (sec)	923	922.8
Pump Speed (rpm)	37,500	34,913

* Rocketdyne uses their Mark 25-type axial turbopump (4 stages); ELES-NTP used a single-stage centrifugal pump.

CYCLE PARAMETER COMPARISON*
- 75,000 lbf ENABLER I, EXPANDER CYCLE -

Parameter	Rocketdyne	SAIC - ELES NTP	SAIC NESS
Total Flowrate (kg/s)	36.7	36.9	37.27
Pump Discharge Pres. (psia)	1,544	1,538.3	2,298.3
Turbine Flowrate, % Pump	50	50	50
Turbine Inlet Temp. (°K)	555.6	555.3	622.3
Turbine Inlet Pres. (psia)	1,412	1,416.8	1,969.0
Turbine Pressure Ratio	1.25	1.295	1.739
Reactor Inlet Pres. (psia)	1,130	1,255.4	1,132.1
Reactor Power, (MW)	1,645	-	1,587
Reactor Core Flowrate (kg/s)	36.7	36.9	36.2
Nozzle Chamber Temp (°K)	2,700	2,700	2,700
Nozzle Chamber Pres. (psia)	1,000	1,000	1,000
Nozzle Exit Diameter (m)	4.15	4.15	4.22
Nozzle Expansion Ratio	500	500	500
Specific Impulse-Vac (sec)	923	922.8	912.9
Pump Speed (rpm)	37,500	34,913	40,583

* Rockctdyne uses their Mark 25 type axial turbopump (4 stages); SAIC ELES-NTP used a single-stage centrifugal pump; SAIC NESS, Sample Case No. 8, uses a 5-stage axial pump.

CYCLE PARAMETER COMPARISON*
- 75,000 lbf ENABLER I, EXPANDER CYCLE -

Parameter	Rocketdyne	SAIC ELES-NTP	SAIC NESS
Specific Impulse - Vac (sec)	923	922.8	912.9
Reactor (kg)	5,824	5,823	4,783
Internal Shield (kg)	—	1,523	1,108
Nozzle Assembly (kg)	440	421	535
Turbopump Assembly (kg)	304	104	221
Nonnuclear Support Hardware (kg) - Lines, Values, Actuators, Instrumentation Thrust Structure	1,815	1,264	1,493

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CYCLE PARAMETER COMPARISON*
- 75,000 lbf ENABLER I, EXPANDER CYCLE -

Wall Temperature (°R)	Barrier Temperature (°R)	Isp (Sec.)	Fuel Film Cooling Fraction
1460	1630	912.9	0.03
1800	2106	915.9	0.03
2000	2429	917.5	0.02
2400	2892	919.4	0.02
2800	3418	921.2	0.02
3000	3651	921.9	0.02
3200	3864	922.4	0.02

* Core Temperature = 4000°R (2700°K)

DESIGN CASE COMPARISION OBSERVATIONS

- **NESS Design Exhibits 1% Lower Peformance Than Other Designs**
  - NESS Model More Accurately Predicts Nozzle Cooling Losses-Upstream Film Cooling Required to Meet Maximum Wall Temperature Requirements
- **Integrated Reactor/Engine System Design Effects Accounted for in the NESS Design**
  - Sized to Take Into Account Heat Captured by the Coolant Before It Enters the Reactor
  - Corresponds to Some Difference in Cycle Pressures, Temperatures, and Turbopump Operating Parameters
- **Other Weight Differences From Improvements in NESS Weight Correlations**
  - 3-Section Nozzle Design
  - Non-Nuclear Auxiliary Components
  - Update H_2 Properties

ENGINE SYSTEM SCALING/COMPARISONS

EXTENSIVE ENABLER I AND II ENGINE SYSTEM DESIGN DATABASE HAS BEEN DEVELOPED

- Database Covers A Large Engine Design/ Operating Paramenters
  - Fuel Type/Chamber Temperature
  - Thrust level
  - Chamber Pressure
  - Nozzle Area Ratio
- Top-level Design Scaling Trends Produced for the ENABLER I Engine System
  - Little Design Trend Analysis Conducted to Date on the Eanbler II Database
- All Engine Summary Design Data is Cataloged and is Available Through NASA Lewis

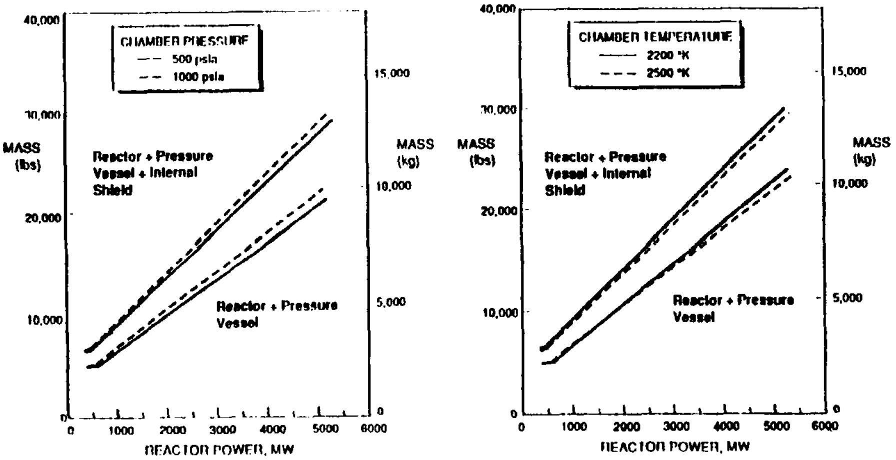
ENABLER ENGINE SYSTEM DESIGN TRADE SPACE ANALYZED

Fuel Type/Chamber Temperature (oK)	Thrust (lbf)	Chamber Pressure (psia)	Nozzle Area Ratio
Graphite/2500	15,000	500	200:1
Composite/2700	40,000	750	500:1
Carbide/3100	75,000	1,000	
	125,000	1,500	
	200,000	2,000	
	250,000		

ENABLER I DESIGN SCALING TRENDS

REACTOR AND INTERNAL SHIELD MASS SCALING

- Graphite Fuel -

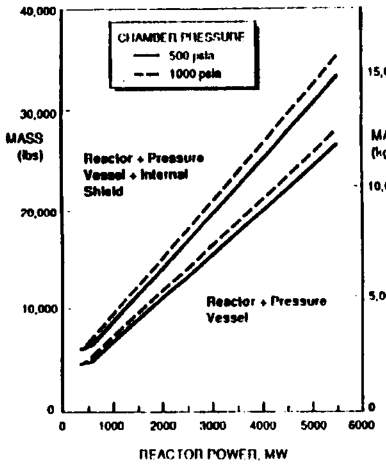


CHAMBER TEMPERATURE = 2500 °K

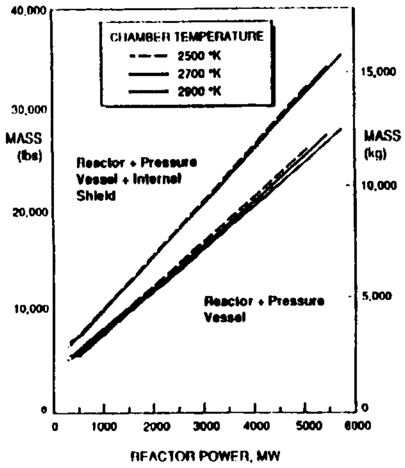
CHAMBER PRESSURE = 1000 psia

REACTOR AND INTERNAL SHIELD MASS SCALING

- Composite Fuel -



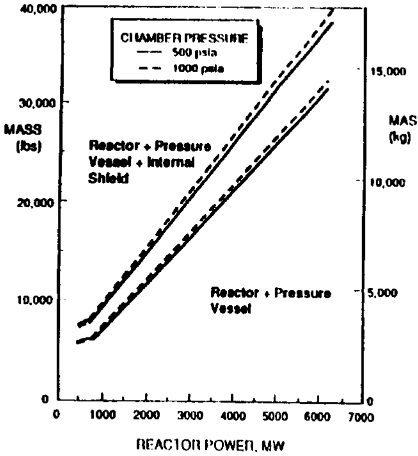
CHAMBER TEMPERATURE = 2700 °K



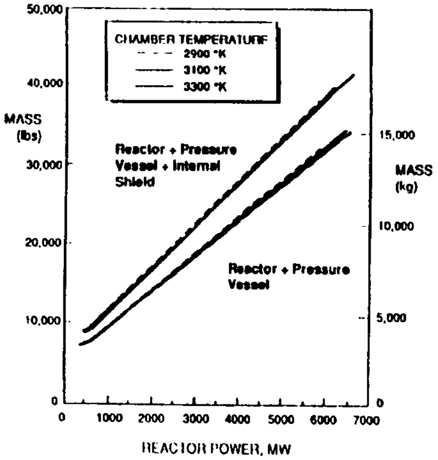
CHAMBER PRESSURE = 1000 psia

REACTOR AND INTERNAL SHIELD MASS SCALING

- Carbide Fuel -

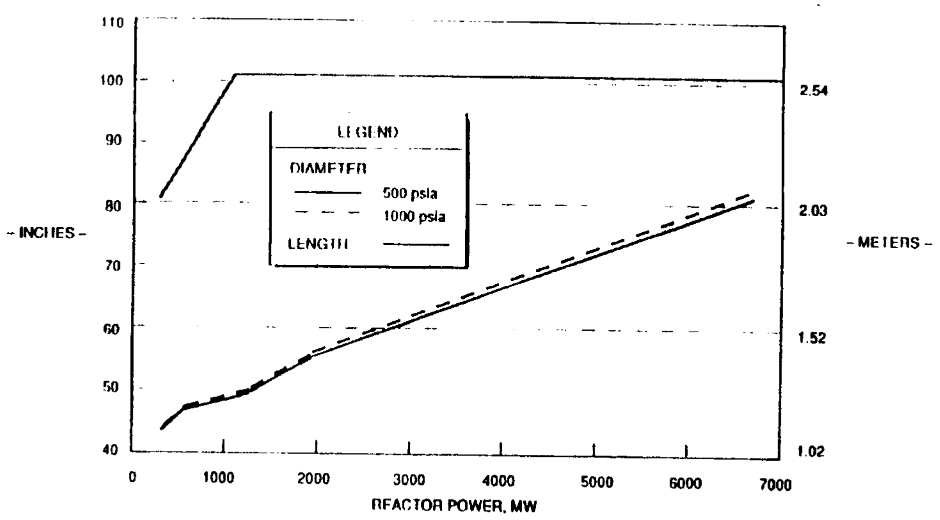


CHAMBER TEMPERATURE = 3100 °K



CHAMBER PRESSURE = 1000 psia

REACTOR PRESSURE VESSEL DIMENSIONS AS A FUNCTION OF POWER AND CHAMBER PRESSURE



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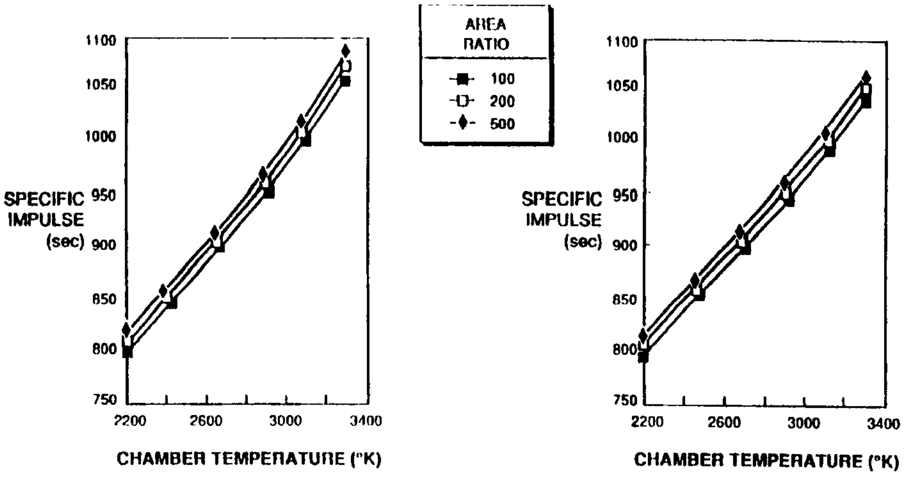
TYPICAL NTP ENGINE PERFORMANCE AS A FUNCTION OF CHAMBER PRESSURE, TEMPERATURE AND AREA RATIO

- 75,000 lbf Thrust -



CHAMBER PRESSURE = 500 psia

CHAMBER PRESSURE = 1000 psia

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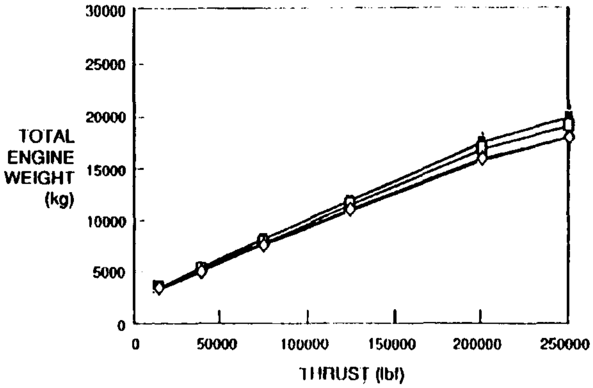
NTP ENGINE WEIGHT AS A FUNCTION OF THRUST, CHAMBER PRESSURE, AND AREA RATIO

- Graphite Fuel, Chamber Temperature - 2500 K -



KEY		
SYMBOL	CHAMBER PRESSURE (psia)	AREA RATIO
-■-	500	500
-□-	1000	500
-◆-	500	200
-◇-	1000	200

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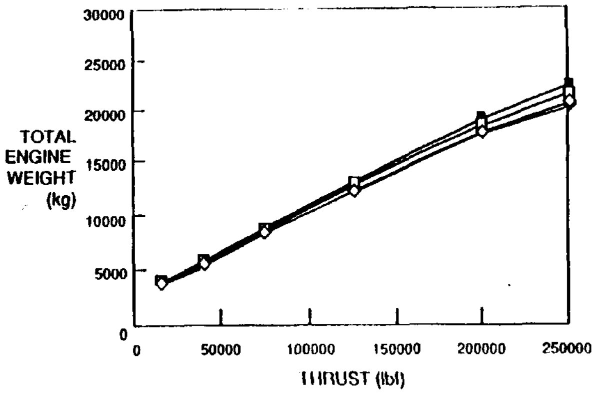
NTP ENGINE WEIGHT AS A FUNCTION OF THRUST, CHAMBER PRESSURE, AND AREA RATIO

- Composite Fuel, Chamber Temperature - 2700 K -



KEY		
SYMBOL	CHAMBER PRESSURE (psia)	AREA RATIO
-■-	500	500
-□-	1000	500
-◆-	500	200
-◇-	1000	200

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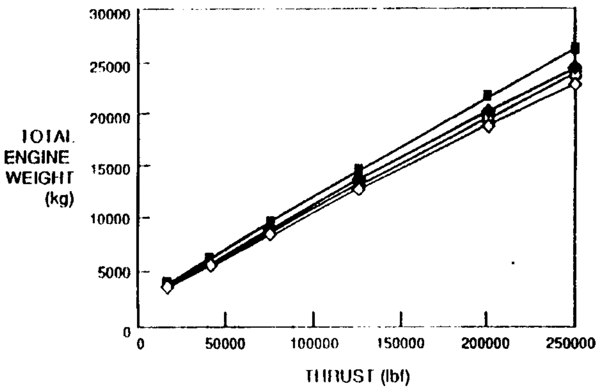
NTP ENGINE WEIGHT AS A FUNCTION OF THRUST, CHAMBER PRESSURE, AND AREA RATIO

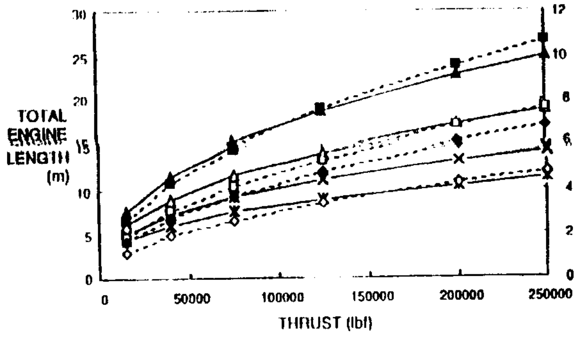
- Carbide Fuel, Chamber Temperature - 3100 K -



KEY		
SYMBOL	CHAMBER PRESSURE (psia)	AREA RATIO
-■-	500	500
-□-	1000	500
-◆-	500	200
-◇-	1000	200

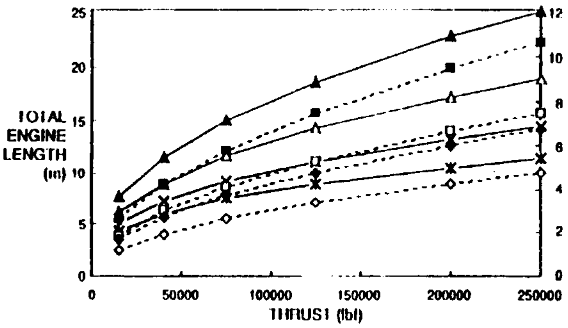
NTP ENGINE SYSTEM AS A FUNCTION OF THRUST,

- Graphite and Composite Fuel Engines -



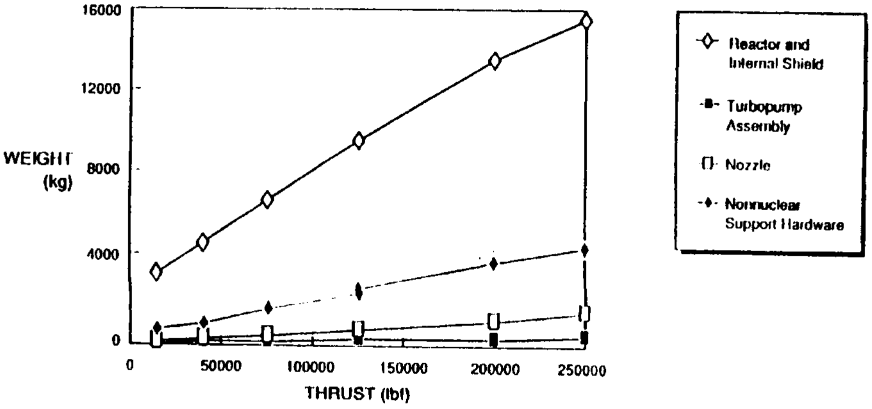
KEY			
DIMENSION	SYMBOL	CHAMBER PRESSURE (psia)	AREA RATIO
Length	★	500	500
	☆	1,000	
	✕	500	200
	✖	1,000	
Diameter	■	500	500
	□	1,000	
	◆	500	200
	◇	1,000	

NTP ENGINE SYSTEM AS A FUNCTION OF THRUST,
- Carbide Fuel Engines -



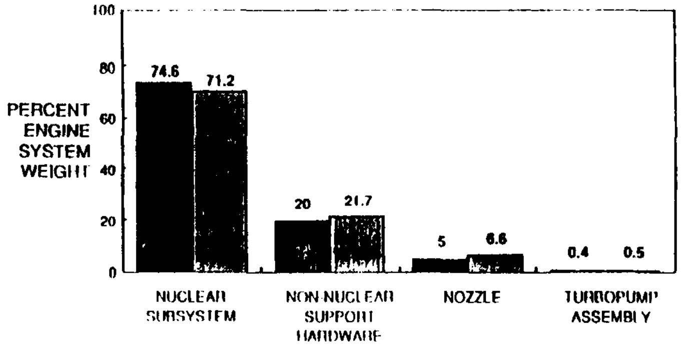
KEY			
DIMENSION	SYMBOL	CHAMBER PRESSURE (psia)	AREA RATIO
Length	▲	500	500
	△	1,000	
	✕	500	200
	✖	1,000	
Diameter	■	500	500
	□	1,000	
	◆	500	200
	◇	1,000	

NTP ENGINE SUBSYSTEM WEIGHT BREAKDOWN AS A FUNCTION OF THRUST,
- Composite Fuel, T_c = 2700 K, P_c - 1000psia, ε = 500:1 -



NTP ENGINE SUBSYSTEM PERCENT WEIGHT DISTRIBUTION FOR TWO THRUST LEVELS

- Composite Fuel, T_c = 2700 K, P_c = 1000 psia, ε = 500:1



KEY		
SYMBOL	ENGINE THRUST (lbf)	ENGINE WEIGHT (kg)
■	75,000	8,816
▣	250,000	22,410

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BASELINE NTP ENGINE DESCRIPTION*

- 75,000 LBF THRUST, EXPANDER CYCLE, COMPOSITE FUEL, T_c = 2700 K, P_c = 1000psia, ε = 500:1 -

Component	Features		Number
Reactor	• Reactor + Internal Shield Weight	6576 kg (14,500 lbm)*	1
	• Fuel Type - Composite		
	• Case Material - Aluminum	√	
	• Reactor Diameter	1 32 m (52 in)	
	• Reactor Length	2.59 m (102 in)	
	• Fuel Mass Flow Rate	36 9 kg/s (81 3 lbm/s)	
	• Reactor Exit/Nozzle Entrance		
	- Exit Chamber Pressure	6895 kPa (1000 psia)	
	- Temperature	2,700 K (4,860°R)	
Nozzle	• Nozzle Weight	442 kg (975 lbm)	1
	• Nozzle Material	√	
	- Slotted Regen Wall Construction of Copper to Area Ratio of 6:1		
	- Inconel Tube Bundles to Area Ratio of 150:1		
	• Extension Material - Carbon	√	
	• Regeneratively Cooled by Propellant to an Area Ratio of 150:1	√	
	• Nozzle Length	823 cm (324 in)	
	• Throat Diameter	18.8 cm (7.4 in)	
	• Exit Diameter	415 8 cm (163.7 in)	
	• Area Ratio	500:1	
	• Delivered Vacuum Isp	9043 N x sec/kg (923 sec)	
	• Delivered Thrust	333.6 kN (75,000 lbf)	
Main Pump Turbine	• Turbine Weight	15.9 kg (35 lbm)	2
	• Material MAR - M246	√	
	• No of Full Admission Turbine Stages	2	
	• Efficiency	0 70	
	• Pressure Ratio	1.995	
	• Diameter	16.0 cm (6.3 in)	
	• Turbine Speed	39,028 rpm	

* Total Component Weight - Typical

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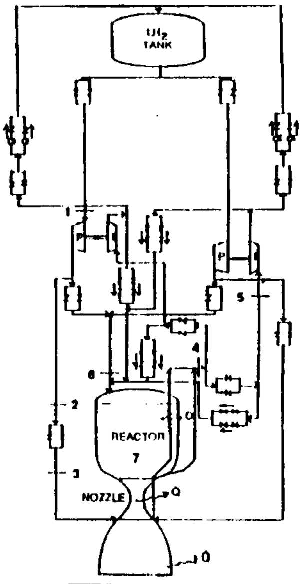
BASELINE NTP ENGINE DESCRIPTION*
- 75,000 LBF THRUST, EXPANDER CYCLE, COMPOSITE FUEL,
T_c = 2700 K, P_c = 1000psia, ε = 500:1 -
(CONT.)

Component	Features		Number
Main Fuel Pump	• Main Pump Weight • Material - Inconnel • Single-Stage Centrifugal Pump • Pressure Rise • Pump Speed • Pump Diameter • Pump Efficiency • Pump Horsepower	44.6 kg (98.4 lbm) √ √ 10,260 kPa (1488 psia) 39,028 rpm 25.7 cm (10.1 in) 0.715 8143 HP	2
Misc. Hardware Weights	• Thrust Mount • Thrust Support Hardware • Engine Lines • Main Valve • TPA Ignition • Gimbal System	737 kg (1624 lbm) 573 kg (1263 lbm) 91.9 kg (202.7 lbm) 182.6 kg (402.6 lbm) 15.7 kg (34.7 lbm) 34.9 kg (76.9 lbm)	1 1 2 4 2 1
Subtotal	• Total Nonnuclear Weight (TPA + Misc. Hardware + Nozzle) • Margin (2%)	2198 kg (4843 lbm) 44 kg (98.9 lbm)	
Total Engine System		8816 kg (19,440 lbm)	

* Total Component Weight - Typical

BASELINE NTP ENGINE CYCLE, OPERATING PARAMETERS
- 75,000 lbf Thrust, Composite Fuel,
T_c = 2700 K, P_c = 1000psia, ε = 500:1 -

STATION	PRESSURE (psia)	TEMP (°K)	$\dot{m}$ (kg/s)
1	50	22.2	18.4
2	1538	40.3	18.4
3	1487	40.3	18.4
4	1417	555.3	36.9
5	1404	555.3	18.4
6	1255	533.6	36.9
7	1000	2700.0	36.9



BASELINE NTP ENGINE CYCLE, OPERATING PARAMETERS
- 75,000 lbf Thrust, Expander Cycle, Composite Fuel, T_c = 2700 K, P_c = 1000psia, ε = 500:1 -

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ENGINE SUMMARY

EXPANDER CYCLE
ENABLER II
CENTRIFUGAL PUMPS
THRUST LEVEL -                   75000.0  lbf        333600.0  N
CHAMBER PRESSURE -                1000.0  psia         6890.0  kPa
CHAMBER TEMPERATURE -             4860.0  deg R        2700.0  deg K
NOZZLE EXIT AREA RATIO -           500.0                500.0
NUMBER OF FEED LEGS -                  2                    2
TOTAL PROPELLANT FLOWRATE -         83.1  lbm/s          37.7  kg/s

REACTOR
  COMPOSITE FUEL
  FUEL SCALING FACTOR               0.87                 0.87
  REACTOR WEIGHT                  6151.1  lbm          2790.0  kg
  SHIELD WEIGHT                   2424.3  lbm          1099.5  kg
  PRESSURE VESSEL DIA.              45.2  in            114.7  cm
  PRESSURE VESSEL LENGTH            87.0  in            221.0  cm
  CORE PROPELLANT MASS FLOW         80.7  lbm/sec        36.6  kg/sec

NOZZLE
  CONVERGING NOZZLE WEIGHT         167.5  lbm            76.0  kg
  NOZZLE EXTENSION WEIGHT           59.5  lbm            27.0  kg
  SECOND NOZZLE EXTENSION WEIGHT   228.1  lbm           103.5  kg
  TOTAL NOZZLE WEIGHT              455.2  lbm           206.4  kg
  AREA RATIO                       500.0                500.0
  THROAT DIAMETER                    7.5  in             19.0  cm
  EXIT DIAMETER                    153.0  in            388.3  cm
  NOZZLE LENGTH                    163.0  in            414.1  cm
  DELIVERED VACUUM ISP             902.0  sec          8844.4  N-sec/kg
  DELIVERED THRUST               75000.0  lbf        333600.0  N

TURBOPUMP ASSEMBLY (TOTAL FOR ALL FEED LEGS)
  MAIN PROP. TURBOPUMP WT          400.0  lbm           181.5  kg
  PROPELLANT BOOST PUMP WT          64.4  lbm            29.2  kg
  MAIN OX PUMP WEIGHT                0.0  lbm             0.0  kg
  TPA IGNITION WEIGHT               32.2  lbm            14.6  kg
  BLEED LINE/VALVE WEIGHT            0.0  lbm             0.0  kg

MISC. HARDWARE WEIGHTS
  THRUST MOUNT                    1562.0  lbm           708.5  kg
  SUPPORT HARDWARE                 610.1  lbm           276.4  kg
  ENGINE LINES                     215.0  lbm            97.5  kg
  MAIN VALVE                       382.0  lbm           173.3  kg
  GIMBAL + POWER SUPPLY            302.6  lbm           137.3  kg

  MARGIN ( 2.0%)                    83.1  lbm            37.7  kg
  TOTAL NONNUCLEAR WEIGHT         4236.1  lbm          1921.1  kg

TOTAL ENGINE SYSTEM
  TOTAL ENGINE WEIGHT            12811.0  lbm          5810.2  kg
  TOTAL ENGINE WEIGHT WITHOUT SHIELD  10387.2  lbm     4710.0  kg
  THRUST/WEIGHT RATIO WITH SHIELD    5.9  lbf/lbm        57.4  N/kg
  THRUST/WEIGHT RATIO WITHOUT SHIELD  7.2  lbf/lbm       70.8  N/kg
  REACTOR SAFETY ROD WT.-LAUNCH ONLY  310.9  lbm        141.0  kg
  TOTAL ENGINE LAUNCH WEIGHT     13122.4  lbm          5951.2  kg
  TOTAL ENGINE LAUNCH WT  W/O SHIELD  10698.1  lbm     4851.8  kg

PUMP-OUT CONDITIONS

  PUMP-OUT THRUST                60000.0  lbf        266880.0  N
  PUMP-OUT CHAMBER PRESSURE        800.0  psia         5516.0  kPa
  PUMP-OUT ISP                     903.5  sec          8864.8  N-sec/kg
  PUMP OUT CHAMBER TEMPERATURE    4860.0  deg R        2700.0  deg K

OVERALL DIMENSIONS
  OVERALL ENGINE LENGTH -          349.0  in            886.7  cm
  OVERALL ENGINE DIAMETER -        105.0  in            266.3  cm
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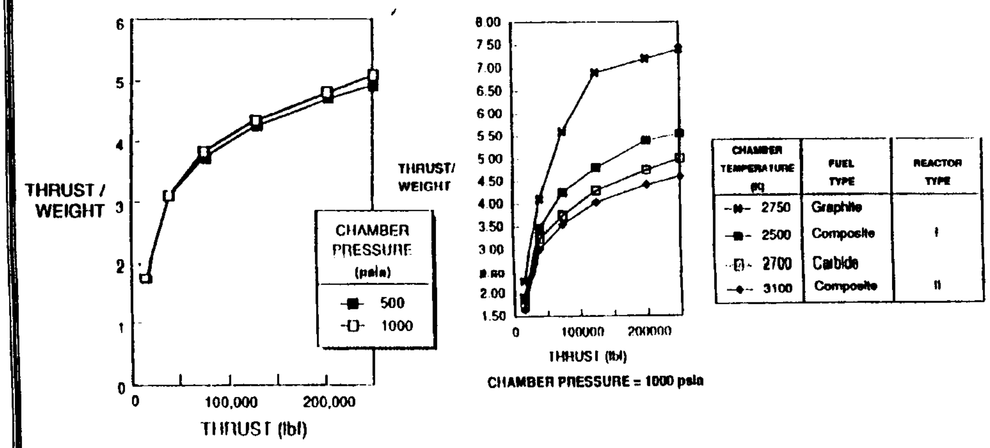
NTP ENGINE THRUST-TO-WEIGHT RATIO AS A FUNCTION OF THRUST
- ε = 500:1 -



COMPOSITE FUEL
CHAMBER TEMPERATURE = 2700° K

CHAMBER PRESSURE = 1000 psia

CONCLUDING REMARKS

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CONCLUDING REMARKS

- A Near-Term (ENABLER I and II) NTP Solid-Core System Database has Been Established
  - Based on the Well Documented/Anchored SAIC NESS Design Program
  - Incorporates Westinghouse's SOA Reactor System Design Correlations
  - Database is Organized, Documented and is Available Through NASA Lewis
- **Future Recommendations**
  - Perform a Comparative Assessment of the Database
    - -- Past Engineering Data Generated
    - -- Technology Sensitivity Studies
  - Initiate a Similar Study Activity With Engine Systems Using Different Reactor Types

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