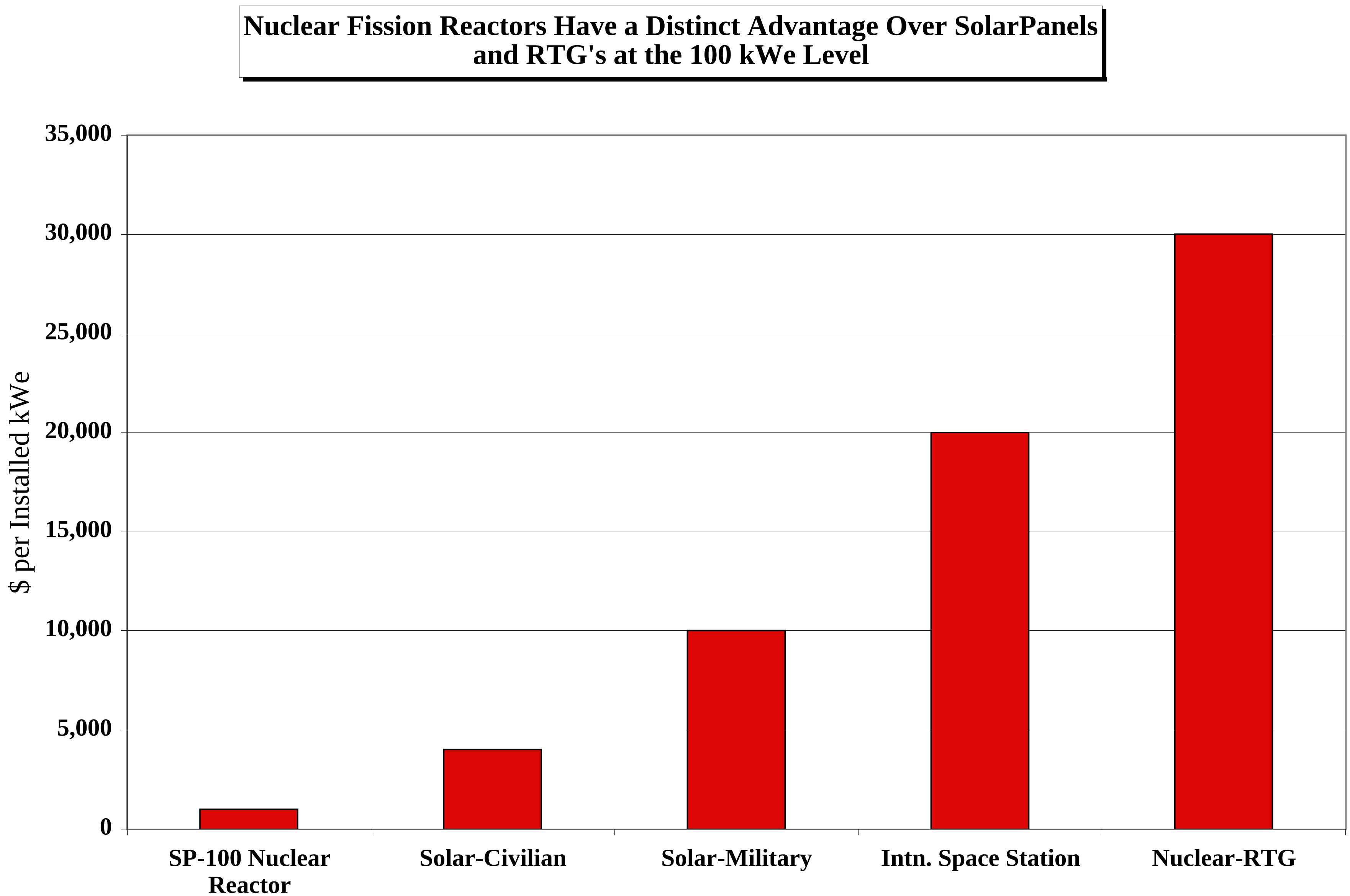
CLASSIFICATION OF NUCLEAR POWER SYSTEM TYPES BEING CONSIDERED FOR SPACE APPLICATION

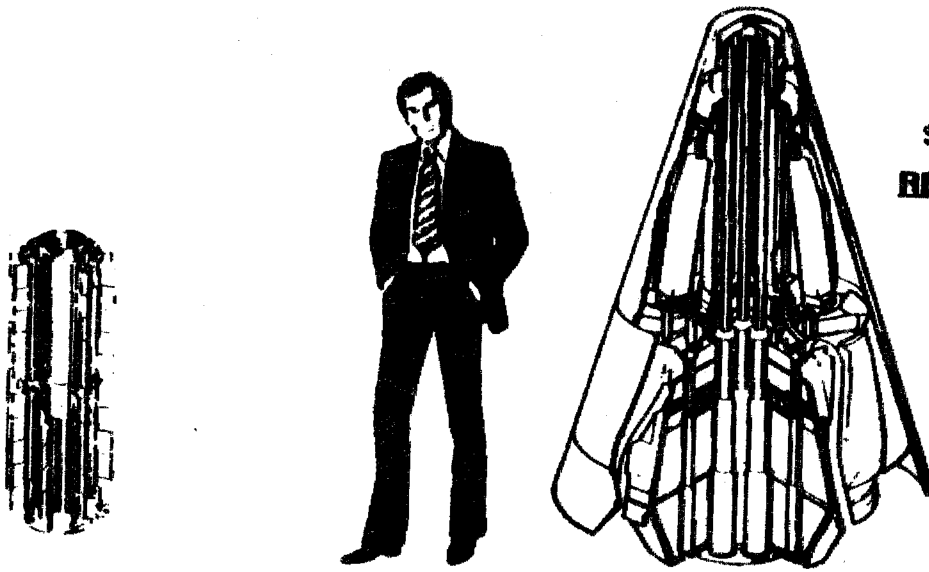
NUCLEAR POWER SYSTEM TYPE	ELECTRIC POWER RANGE (MODULE SIZE)	POWER CONVERSION
RADIOISOTOPE THERMOELECTRIC GENERATOR (RTG)	UP TO 500 We	STATIC: THERMOELECTRIC
RADIOISOTOPE DYNAMIC CONVERSION GENERATOR	0.5 kWe – 10 kWe	DYNAMIC; BRAYTON OR ORGANIC RANKINE CYCLES
REACTOR SYSTEMS HEAT PIPE SOLID CORE THERMIONICS	10 kWe – 1000 kWe	STATIC: THERMOELECTRIC, THERMIONICS DYNAMICS: BRAYTON, RANKINE, OR STIRLING
REACTOR SYSTEM HEAT PIPE SOLID CORE	1 – 10 MWe	BRAYTON CYCLE RANKINE CYCLE STIRLING CYCLE
REACTOR SOLID CORE PELLET BED FLUIDIZED BED GASEOUS CORE	10 – 100 MWe	BRAYTON CYCLE (OPEN LOOP) STIRLING MHD

ig. I.4 Classification of nuclear power system types being considered for space application.. *Courtesy of Los Alamos National Labo.*


Nuclear Fission Reactors Have a Distinct Advantage Over SolarPanels and RTG's at the 100 kWe Level
$ per Installed kWe
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
SP-100 Nuclear Reactor
Solar-Civilian
Solar-Military
Intn. Space Station
Nuclear-RTG

NUCLEAR POWER SYSTEMS FOR SPACE

RTG



SP-100
REACTOR

RADIOISOTOPE THERMOELECTRIC GENERATOR - RTG
• POWERED WITH A RADIOISOTOPE (PU-238) A BY-PRODUCT OF OPERATING REACTORS
• 0.1 TO 1 kWe
• THE RADIOISOTOPE IS ALWAYS PRODUCING THERMAL ENERGY AND CANNOT BE STOPPED. ELECTRICAL OUTPUT IS REGULATED BY SHUNT
• THE RADIOISOTOPE IS A POTENTIAL HAZARD IF IT ESCAPES FROM ITS CONTAINMENT
• 1.3×10^5 CURIES OF Pu-238 (TYP)

SPACE REACTOR POWER SYSTEM
• POWERED WITH A FISSIONABLE MATERIAL (U-235)
• 10 TO 1,000 kWe
• NUCLEAR FISSION PRODUCES THERMAL ENERGY. FISSION PROCESS CAN BE STOPPED BY INSERTING NEUTRON ABSORBERS
• GENERATED FISSION PRODUCTS ARE A POTENTIAL HAZARD IF THEY ESCAPE FROM THE SYSTEM
• 12×10^6 CURIES OF MIXED FISSION PRODUCTS AFTER 7 YEARS POWER OPERATION

BOTH RTG'S AND REACTORS CAN SAFELY PROVIDE POWER IN SPACE

<u>SP -100 SPACE NUCLEAR REACTOR</u>

- **Joint DOD/ DOE / NASA program to demonstrate that a nuclear reactor can be built and operated in the 10-1000 kW_e range for space application in the 1990’s**

- **Initial work started in 1978 and a down selection to the present SP -100 configuration occurred in 1985.**

    See SP-100 History

- **Ground Evaluation Studies (GES) in a National Assembly Test (NAT) was scheduled for the early 1990's but funding problems required a restructuring of the program to demonstrate a complete technology and lifetime test by 1998. The program was terminated in FY95.**

    SP-100 Project Phases
    Funding Bar Chart
    SP-100 fact Sheet
    SP-100 A national Effort

SP-100 HISTORY

FY 83

- TRIAGENCY DOD, DOE & NASA INITIATED SP-100 PROGRAM

10'S-100'S KWE SURVIELLANCE, PROPULSION, ZERO "G" LAB POWER

FY 83, 84 & 85

- EXPERIMENTALLY & ANALYTICALLY STUDIED ALL SPACE REACTOR POWER SYSTEMS

AUGUST 1985 SELECTED

- LI COOLED UN FUELED FAST REACTOR/SiGe TE CONVERTER

FY 86 TO FY 94

- SIGNIFICANTLY IMPROVED TECHN FOR SPACE REACTOR POWER

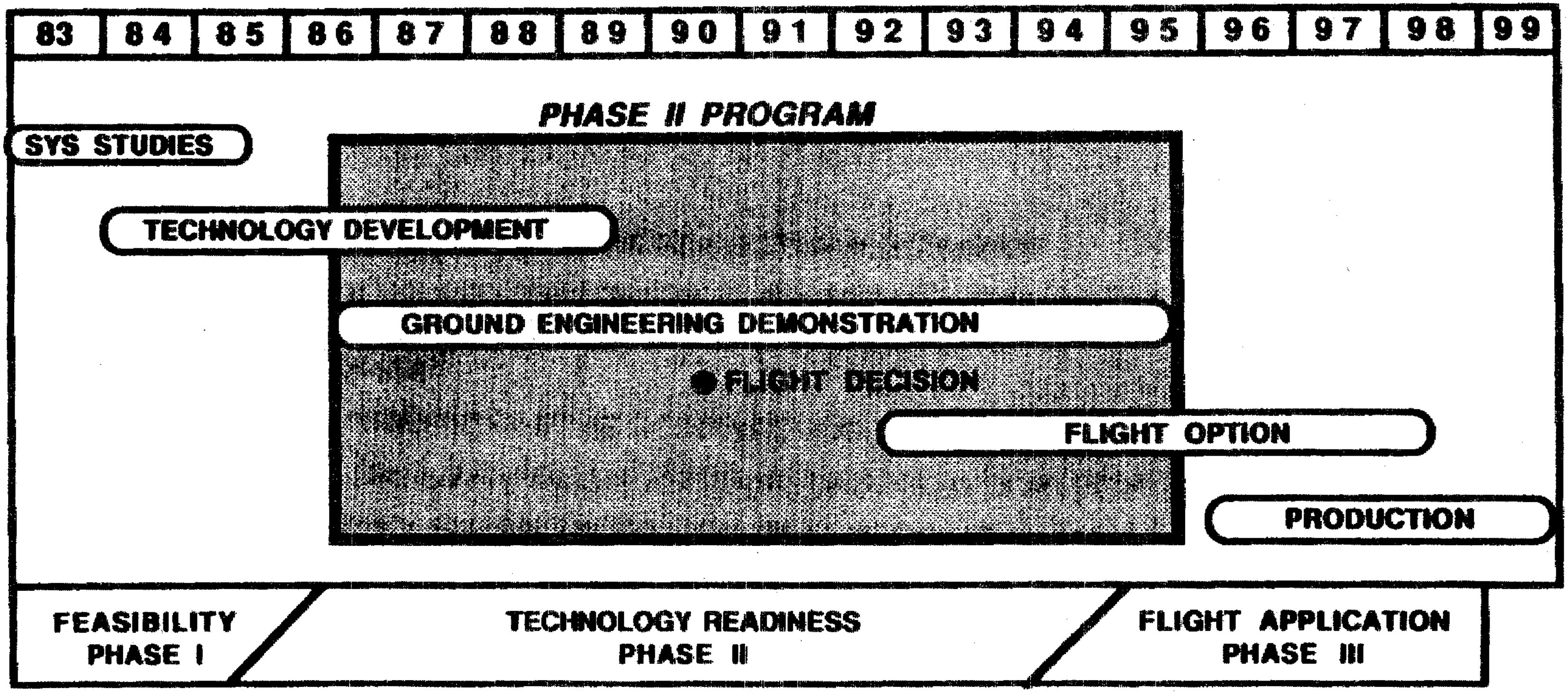
SP-100 PROJECT PHASES

GES PROGRAM OBJECTIVES

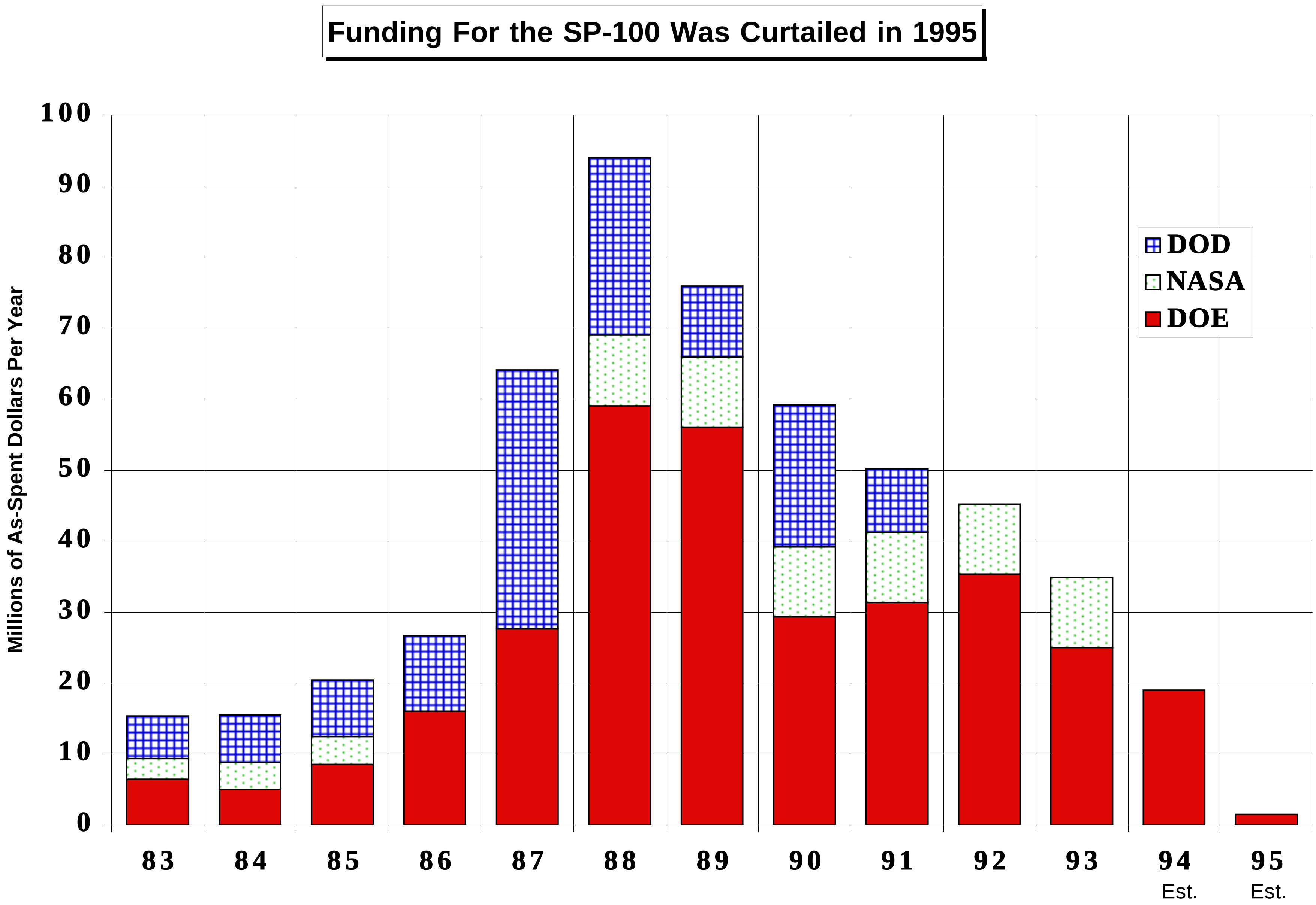
- O RESOLUTION OF OPEN FEASIBILITY ISSUES
- O DEVELOPMENT OF SYSTEM LIFETIME
- O DEVELOP MANUFACTURING CABABILITIES
- O SYSTEM QUALIFICATION ANALYSIS AND TESTING

GES PROGRAM RESULTS

- O VALIDATED DESIGN TECHNOLOGY
- O PERFORMANCE DATA BASE
- O VALIDATE DESIGN MARGINS
- O DEMONSTRATED FABRICATION TECHNIQUES



JIM 7- OVERVIEW



Funding For the SP-100 Was Curtailed in 1995
Millions of As-Spent Dollars Per Year
100
90
80
70
60
50
40
30
20
10
0
83
84
85
86
87
88
89
90
91
92
93
94
Est.
95
Est.
DOD
NASA
DOE

SP-100 Fact Sheet

System Developer -- Department of Energy

Funding Agencies -- Department of Energy, NASA, (DOD prior to 1992)

Participating National Laboratories & NASA Centers
(approximately 80 people on the program)

- Los Alamos N.L. (New Mexico)
- Oak Ridge N.L. (Tennessee)
- Hanford N.L. (Washington)
- Sandia N.L. (New Mexico)
- Argonne N.L. (Idaho)
- Jet Propulsion Lab. (California)
- NASA Lewis Research Center (Ohio)

Industrial Members (approximate number of employees on the program)

- Industrial (220 people) - Pennsylvania, California, Florida
- 300 vendors nationwide

Program Funding History ($)

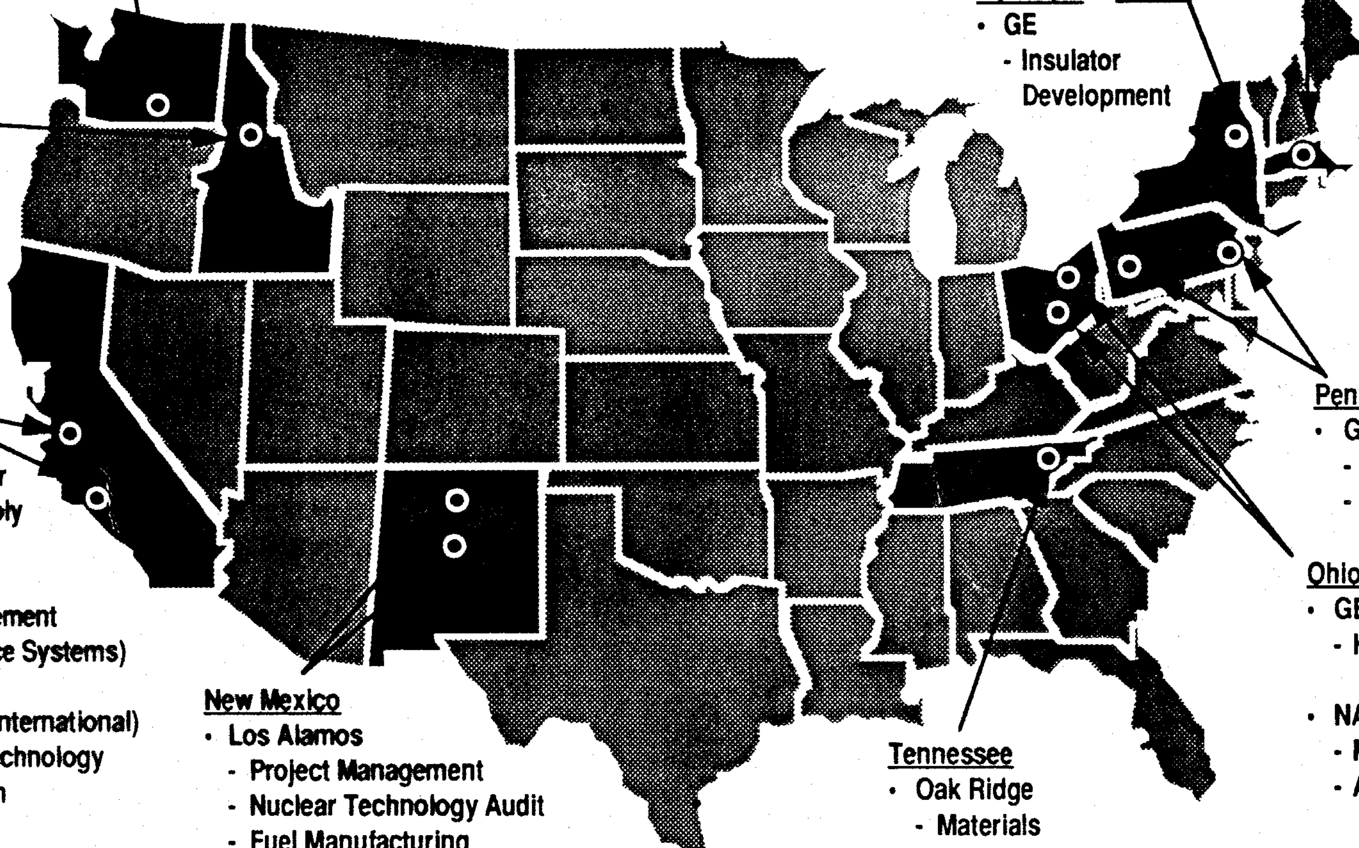
FY	Incremental Funding	Cumulative Funding
1986	26,700,000	26,700,000
1987	64,100,000	90,800,000
1988	94,000,000	184,800,000
1989	75,875,000	260,675,000
1990	59,175,000	319,850,000
1991	50,175,000	370,025,000
1992	45,175,000	415,200,000
1993	36,000,000	451,200,000

System Features

- Modular Design - scalable from 10 kilowatts to 1 megawatt
- Long Life - ten year mission life, 7 year full power life
- Performance - 2 hour to self sustenance, restart capability
- High Reliability - solid state throughout, minimal moving parts
- Safe - meets stringent U.S. safety requirements

SP-100 - A National Effort
Primary Participants

SP-100 HAS OVER 500 VENDORS IN 27 STATES



__Washington__
- HEDL (Westinghouse)
  - Nuclear Assembly Test
  - Fuel & Materials Test

__Idaho__
- ANL
  - Core Criticals
  - Fuel Tests

__California__
- GE
  - Nuclear Reactor Design/Assembly
- JPL
  - Project Management (Overall & Space Systems)
- ETEC (Rockwell International)
  - Liquid Metal Technology
  - Instrumentation

__New Mexico__
- Los Alamos
  - Project Management
  - Nuclear Technology Audit
  - Fuel Manufacturing
- Sandia National Lab
  - Rad Hard Electronics

__New York__
- GE
  - Insulator Development

__Massachusetts__
- Thermo Electron Corp
  - Thermoelectrics
  - Materials

__Pennsylvania__
- GE
  - Program Management
  - Space Subsystems

__Ohio__
- GE
  - Heat Pipe Welding
- NASA Lewis
  - Materials
  - Adv. Conver.

__Tennessee__
- Oak Ridge
  - Materials
  - Instrumentation

INFRASTRUCTURE BUILT

- **Overall Design**

  Design Driving Criteria
  Performance and Interface Requirements
  Selection Parameters
  Flight System Design
  Key Features of Updated GFS Design
  SRPS Launch Requirements
  Deployment Scenario
  Design Flexibility

DESIGN DRIVING CRITERIA

OW MASS, COMPACT SIZE

FAVORS HIGH TEMPERATURE SYSTEMS (HIGH WASTE HEAT REJECTION TEMPERATURES).

LONG LIFETIME

FAVORS LOW TEMPERATURE, FAMILIAR TECHNOLOGY, REDUNDANCY, AVOIDANCE OF COMPLEXITY, HIGH FUEL INVENTORY.

RELIABILITY

FAVORS AVOIDANCE OF MISSION ENDING SINGLE POINT FAILURE MECHANISMS.

FREEDOM FROM VIBRATION

FAVORS STATIC CONVERSION SYSTEMS

SURVIVABILITY

FAVORS LOW MASS, STRUCTURAL RIGIDITY, SMALL HIGH TEMPERATURE RADIATORS.

HIGH POWER WITH LONG LIFETIME

FAVORS HIGHER EFFICIENCY CONVERSION SYSTEMS.

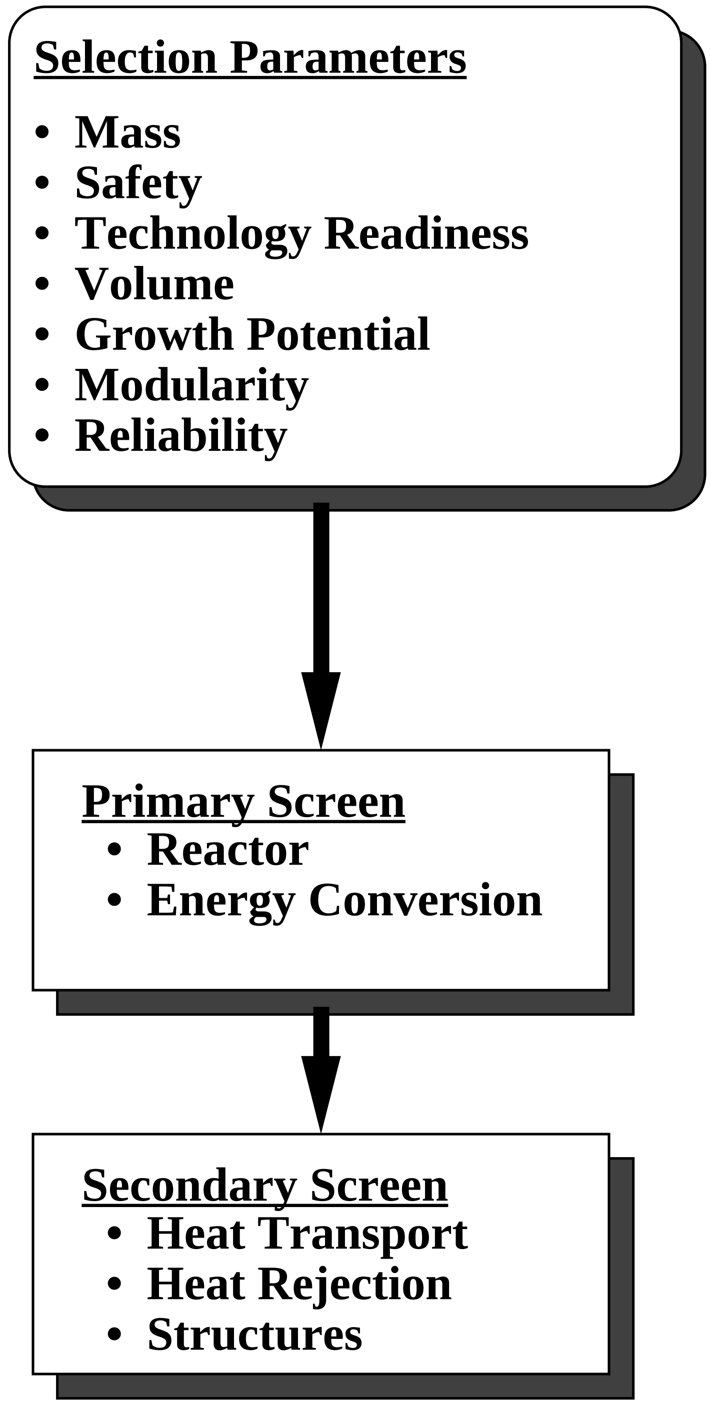
SAFETY CONSTRAINTS

SUBCRITICAL WATER IMMERSION

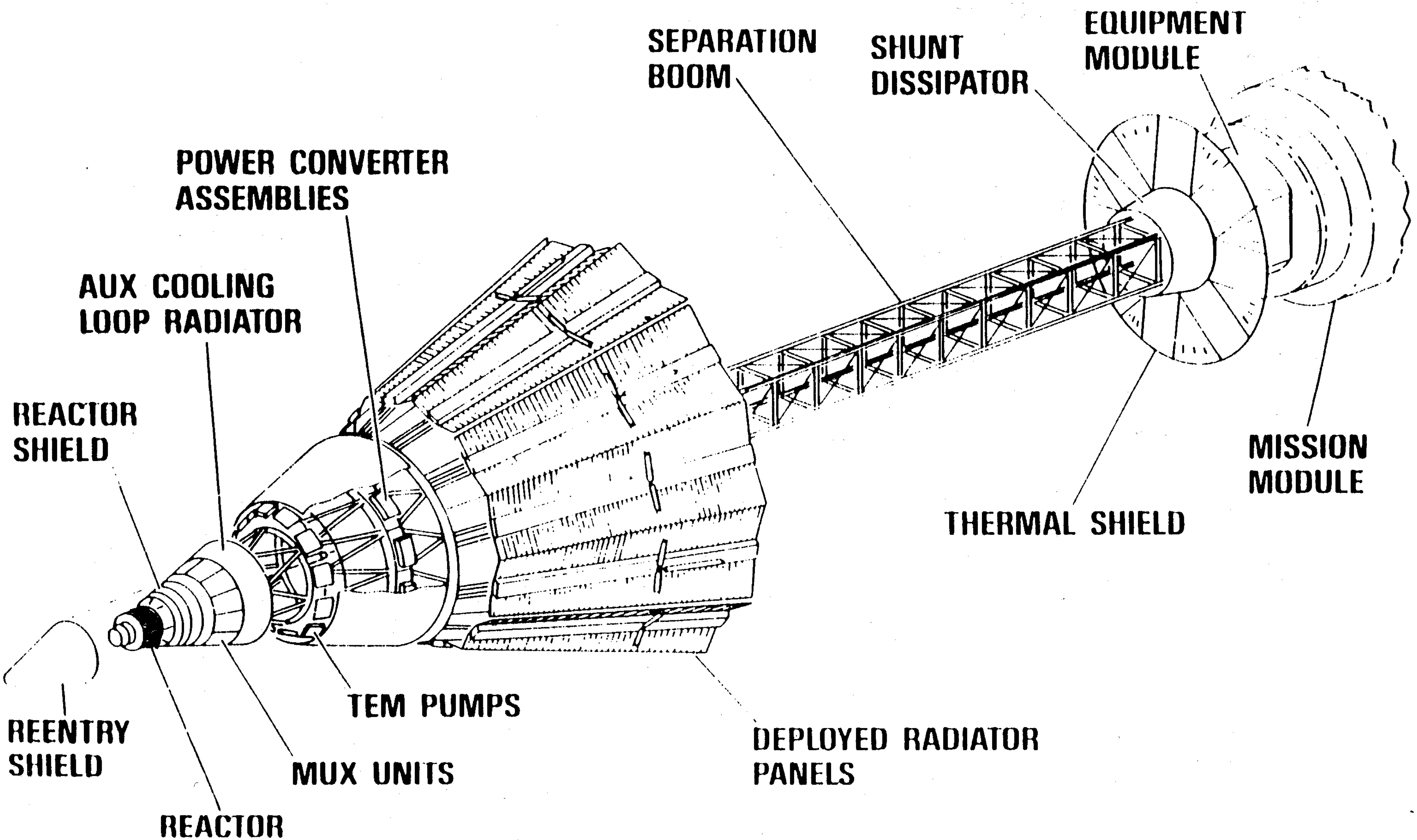
RE-ENTRY STABILITY

DECAY HEAT REMOVAL

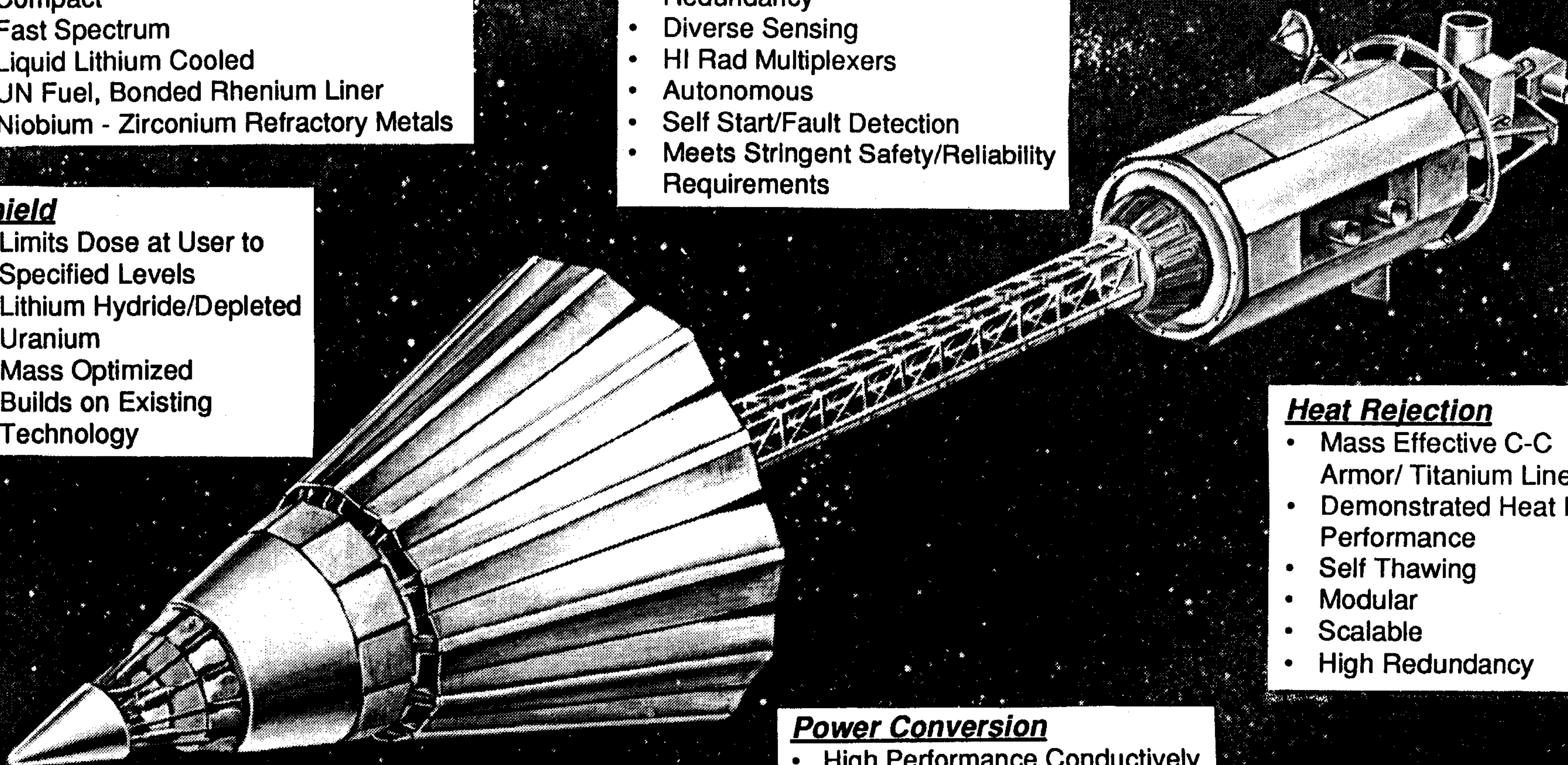
SUBCRITICAL IN LAUNCH ACCIDENTS


Selection Parameters
• Mass
• Safety
• Technology Readiness
• Volume
• Growth Potential
• Modularity
• Reliability
Primary Screen
• Reactor
• Energy Conversion
Secondary Screen
• Heat Transport
• Heat Rejection
• Structures

FLIGHT SYSTEM DESIGN



Key Features of Updated GFS Design



Reactor
- 2.4 Megawatt Thermal
- Compact
- Fast Spectrum
- Liquid Lithium Cooled
- UN Fuel, Bonded Rhenium Liner
- Niobium - Zirconium Refractory Metals

RI&C
- Multiple Control and Shut Down Redundancy
- Diverse Sensing
- HI Rad Multiplexers
- Autonomous
- Self Start/Fault Detection
- Meets Stringent Safety/Reliability Requirements

Shield
- Limits Dose at User to Specified Levels
- Lithium Hydride/Depleted Uranium
- Mass Optimized
- Builds on Existing Technology

Heat Rejection
- Mass Effective C-C Armor/ Titanium Liner
- Demonstrated Heat Pipe Performance
- Self Thawing
- Modular
- Scalable
- High Redundancy

Power Conversion
- High Performance Conductively Coupled T/E Conversion
- Long Life
- Compact Size
- Modular Design -1.5 kWe Units (TCAs)

Primary Heat Transport
- TEM Pumps - No Moving Parts
- Passive Gas Separation
- Passive Accumulator Function
- Combined Thaw and Aux Cooling
- Hydraulic Arrangement Assures Stability

JPL

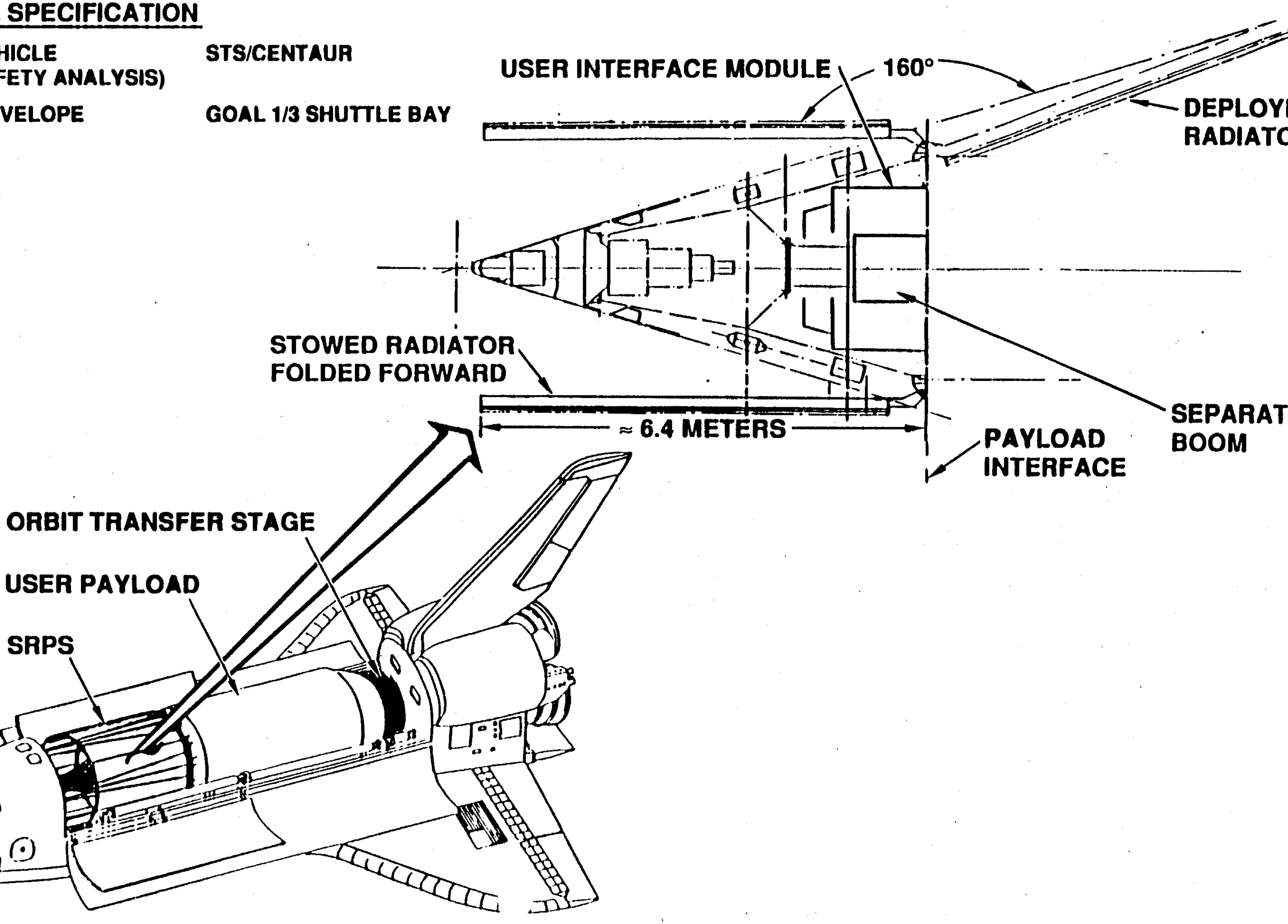
Los Alamos

SRPS LAUNCH REQUIREMENTS

NASA DOE DOD SP 100

TECHNICAL SPECIFICATION

- LAUNCH VEHICLE (LOADS, SAFETY ANALYSIS) — STS/CENTAUR
- STOWED ENVELOPE — GOAL 1/3 SHUTTLE BAY



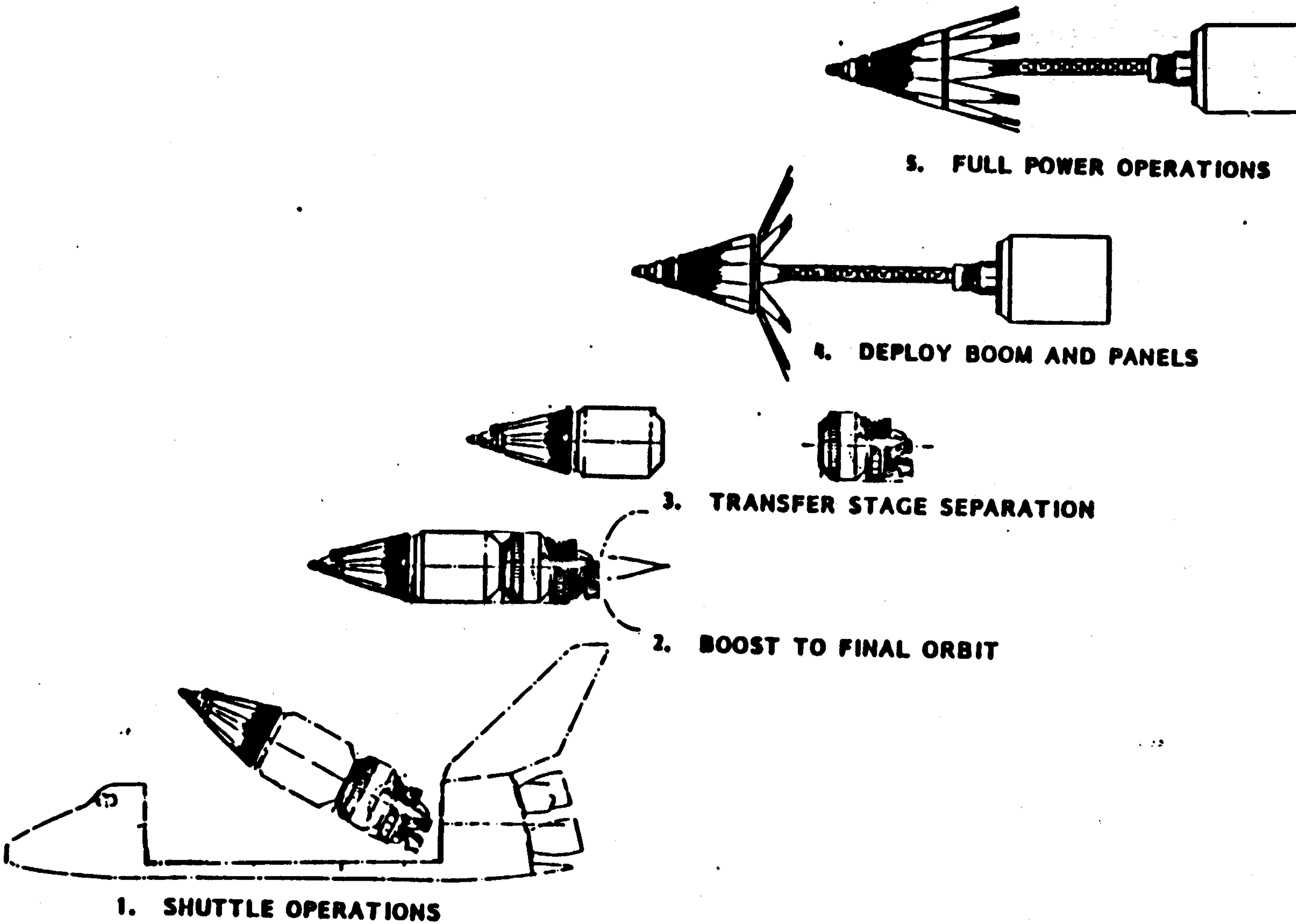


Figure 2.7-1. Launch Through Deployment

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DESIGN FLEXIBILITY

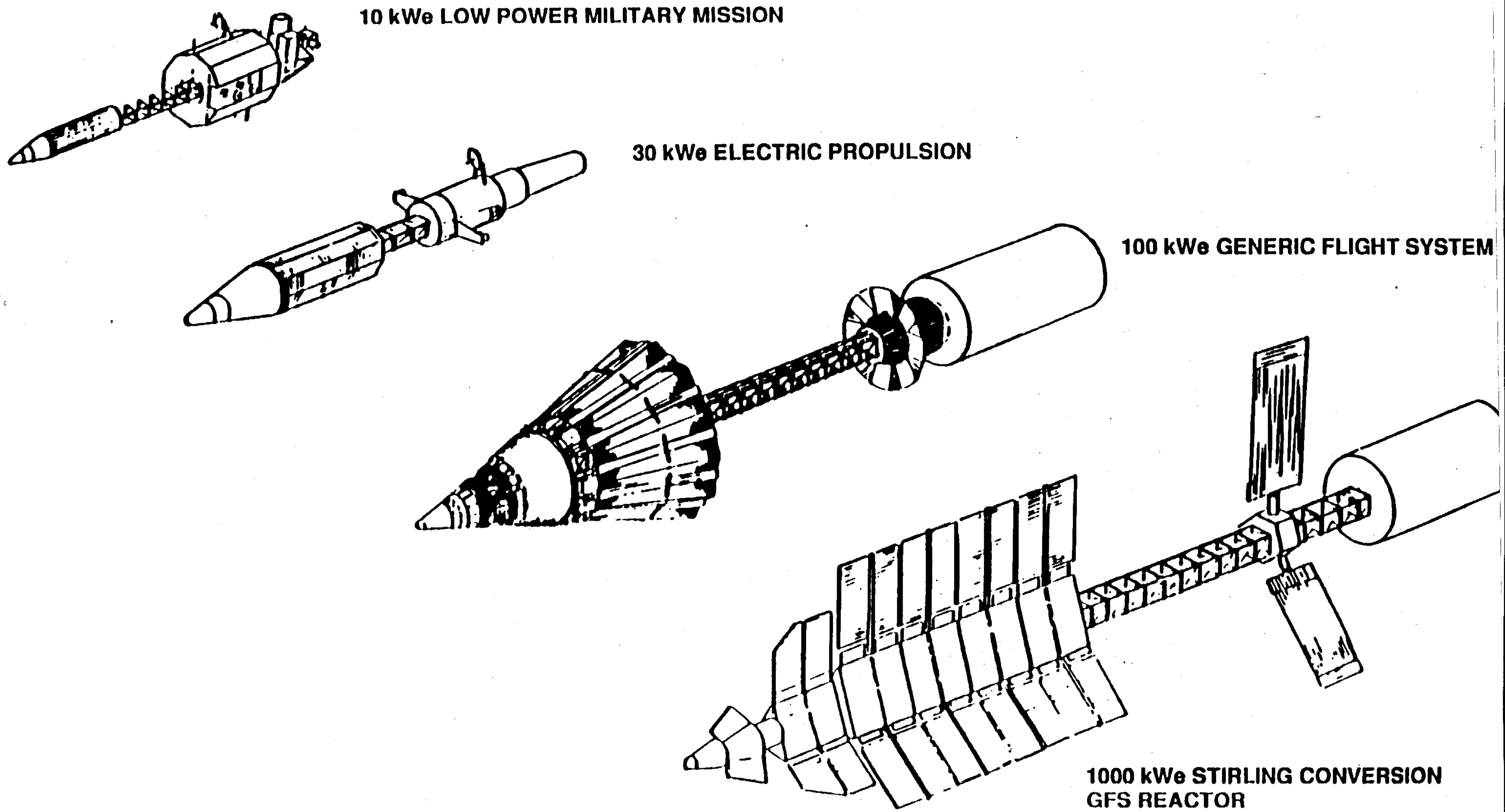

TABLE 2.1-1. Performance and Interface Requirements

	PARAMETER	REQUIREMENT	DESIGN FEATURE(S)
o	DESIGN LIFETIME	7 YEARS	FUEL INVENTORY FISSION GAS ACCOMMODATION
o	RELIABIITY	0.95	T/E CONVERSION FLIGHT-PROVEN ESTABLISHED REACTOR DATA BASE
o	MAIN BUS POWER	100 KWe	MODULAR DESIGN PROVIDES SCALEABILITY
o	MAIN BUS VOLTAGE	200 VDC	OPTION RANGE (28-400) READILY PROVIDED
o	LOAD FOLLOWING	RAPID, CONTINUOUS	FULL SHUNT
o	SHIELDED DIAMETER AT USER INTERFACE	15.5 METERS (50 FEET)	LARGER AREAS PROVIDED AT MINIMUM PENALTY
o	RADIATION AT USER I/F	10^{13} NEUTRON/CM^2 5×10^5 RADS(λ)	REACTOR SHIELD
o	THERMAL FLUX AT USER I/F	0.07W/CM^2	MEETS SPECIFIED REQ'T (0.14W/CM^2) EASILY MODERATED BY BOOM LENGTH
o	SOLAR ORIENTATION	NO RESTRICTIONS	FULL SUN DESIGN
o	NATURAL RADIATION & METEOROIDS/DEBRIS	MASS ALLOWANCE IN BASELINE FOR WORST CASE ENVELOPE	METEOROID ARMOR RADIATION SHIELDS