<table>
<thead>
<tr>
<th>Nuclear Power System Type</th>
<th>Electric Power Range (Module Size)</th>
<th>Power Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radioisotope Thermoelectric Generator (RTG)</td>
<td>Up to 500 We</td>
<td>Static: Thermoelectric</td>
</tr>
<tr>
<td>Radioisotope Dynamic Conversion Generator</td>
<td>0.5 kWe - 10 kWe</td>
<td>Dynamic; Brayton or Organic Rankine Cycles</td>
</tr>
<tr>
<td>Reactor Systems Heat Pipe Solid Core Thermionics</td>
<td>10 kWe - 1000 kWe</td>
<td>Static: Thermoelectric, Thermionics Dynamics: Brayton, Rankine, or Stirling</td>
</tr>
<tr>
<td>Reactor System Heat Pipe Solid Core</td>
<td>1 - 10 MWe</td>
<td>Brayton Cycle Rankine Cycle Stirling Cycle</td>
</tr>
<tr>
<td>Reactor Solid Core Pellet Bed Fluidized Bed Gaseous Core</td>
<td>10 - 100 MWe</td>
<td>Brayton Cycle (Open Loop) Stirling MHD</td>
</tr>
</tbody>
</table>

Image 1.4: 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 Solar Panels and RTG's at the 100 kWe Level
NUCLEAR POWER SYSTEMS FOR SPACE

**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
- $1.3 \times 10^5$ 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
- $12 \times 10^6$ Curies of mixed fission products after 7 years power operation

Both RTG's and reactors can safely provide power in space.
SP -100 SPACE NUCLEAR REACTOR

• Joint DOD/DOE/NASA program to demonstrate that a nuclear reactor can be built and operated in the 10-1000 kWe 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

- Resolution of open feasibility issues
- Development of system lifetime
- Develop manufacturing capabilities
- System qualification analysis and testing

GES PROGRAM RESULTS

- Validated design technology
- Performance data base
- Validate design margins
- Demonstrated fabrication techniques

PHASE II PROGRAM

- System Studies
- Technology Development
- Ground Engineering Demonstration
- Flight Decision
- Flight Option
- Production

FEASIBILITY PHASE I

TECHNOLOGY READINESS PHASE II

FLIGHT APPLICATION PHASE III

JIM 7 - OVERVIEW
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)
- Sandia N.L. (New Mexico)
- Oak Ridge N.L. (Tennessee)
- Argonne N.L. (Idaho)
- Hanford N.L. (Washington)
- 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 ($)

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

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

Massachusetts
- Thermo Electron Corp
  - Thermoelectrics
  - Materials

New York
- GE
  - Insulator Development

Pennsylvania
- GE
  - Program Management
  - Space Subsystems

Ohio
- GE
  - Heat Pipe Welding

Tennessee
- Oak Ridge
  - Materials
  - Instrumentation

- NASA Lewis
  - Materials

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

LIGHTWEIGHT, 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

- Power Converter Assemblies
- Aux Cooling Loop Radiator
- Reactor Shield
- Reentry Shield
- Reactor
- TEM Pumps
- MUX Units
- Deployed Radiator Panels
- Separation Boom
- Shunt Dissipator
- Equipment Module
- Mission Module
- Thermal Shield
**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

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

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

**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
TECHNICAL SPECIFICATION

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

USER INTERFACE MODULE
- 160°
- DEPLOY RADIATOR
- STOWED RADIATOR FOLDED FORWARD
- PAYLOAD INTERFACE
- SEPARATE BOOM

ORBIT TRANSFER STAGE
USER PAYLOAD
SRPS

- ≈ 6.4 METERS
1. SHUTTLE OPERATIONS

2. BOOST TO FINAL ORBIT

3. TRANSFER STAGE SEPARATION

4. DEPLOY BOOM AND PANELS

5. FULL POWER OPERATIONS

Figure 2.7-1. Launch Through Deployment
10 kWe LOW POWER MILITARY MISSION

30 kWe ELECTRIC PROPULSION

100 kWe GENERIC FLIGHT SYSTEM

1000 kWe STIRLING CONVERSION
GFS REACTOR
<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>REQUIREMENT</th>
<th>DESIGN FEATURE(S)</th>
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<tbody>
<tr>
<td>DESIGN LIFETIME</td>
<td>7 YEARS</td>
<td>FUEL INVENTORY</td>
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<td>FISSION GAS ACCOMMODATION</td>
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<td>RELIABILITY</td>
<td>0.95</td>
<td>T/E CONVERSION FLIGHT-PROVEN</td>
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<td>ESTABLISHED REACTOR DATA BASE</td>
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<tr>
<td>MAIN BUS POWER</td>
<td>100 KWe</td>
<td>MODULAR DESIGN</td>
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<tr>
<td></td>
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<td>PROVIDES SCALEABILITY</td>
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<tr>
<td>MAIN BUS VOLTAGE</td>
<td>200 VDC</td>
<td>OPTION RANGE (28-400)</td>
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<td>READILY PROVIDED</td>
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<tr>
<td>LOAD FOLLOWING</td>
<td>RAPID, CONTINUOUS</td>
<td>FULL SHUNT</td>
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<tr>
<td>SHIELDED DIAMETER AT USER INTERFACE</td>
<td>15.5 METERS (50 FEET)</td>
<td>LARGER AREAS PROVIDED AT MINIMUM PENALTY</td>
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<tr>
<td>RADIATION AT USER I/F</td>
<td>$10^{13}$ NEUTRON/CM$^2$</td>
<td>REACTOR SHIELD</td>
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<tr>
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<td>$5 \times 10^5$ RADS($\lambda$)</td>
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<tr>
<td>THERMAL FLUX AT USER I/F</td>
<td>0.07W/CM$^2$</td>
<td>MEETS SPECIFIED REQ'T ($0.14W/CM^2$)</td>
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<tr>
<td></td>
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<td>EASILY MODERATED BY BOOM LENGTH</td>
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<tr>
<td>SOLAR ORIENTATION</td>
<td>NO RESTRICTIONS</td>
<td>FULL SUN DESIGN</td>
</tr>
<tr>
<td>NATURAL RADIATION &amp; METEOROIDS/DEBRIS</td>
<td>MASS ALLOWANCE IN</td>
<td>METEOROID ARMOR</td>
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<td>BASELINE FOR WORST</td>
<td>RADIATION SHIELDS</td>
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<td>CASE ENVELOPE</td>
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