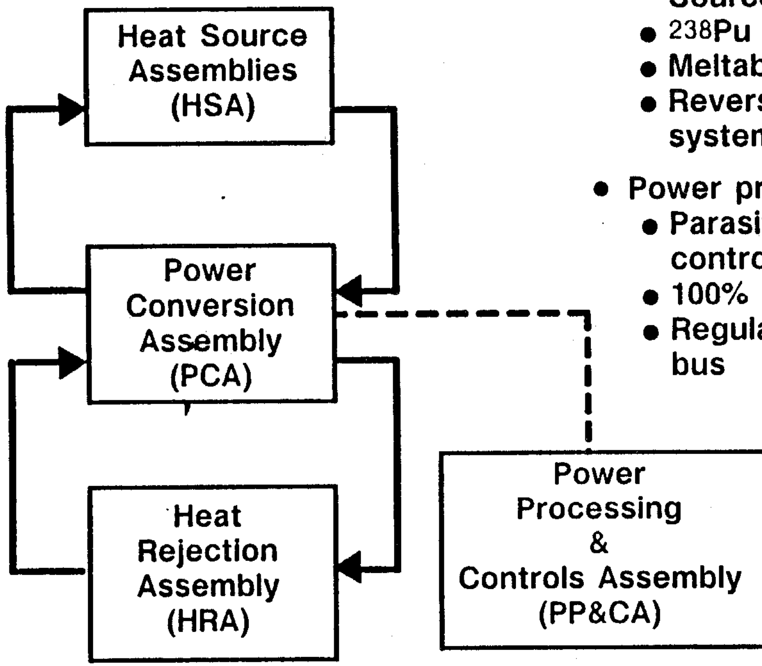
DIPS Features

- Power conversion
  - Closed Brayton Cycle (CBC)
  - Helium-xenon working gas

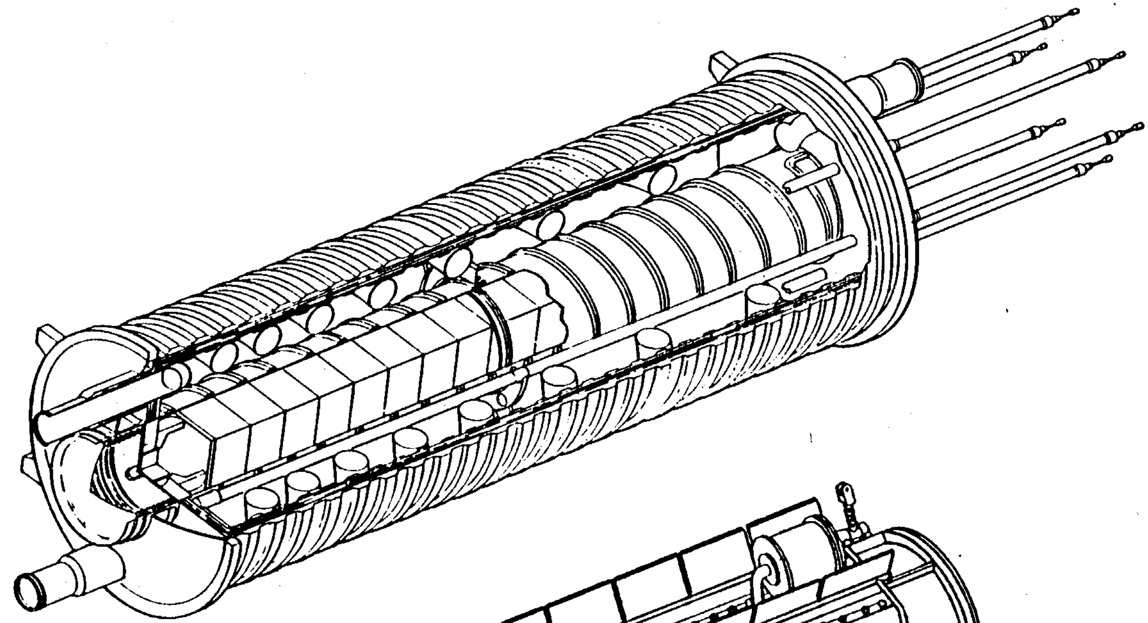


- Isotope heat source
  - General Purpose Heat Sources (GPHS)
  - ^{238}Pu fuel
  - Meltable multifoil insulation
  - Reversible heat removal system
- Power processing & controls
  - Parasitic load for power control
  - 100% redundant
  - Regulated output to user bus

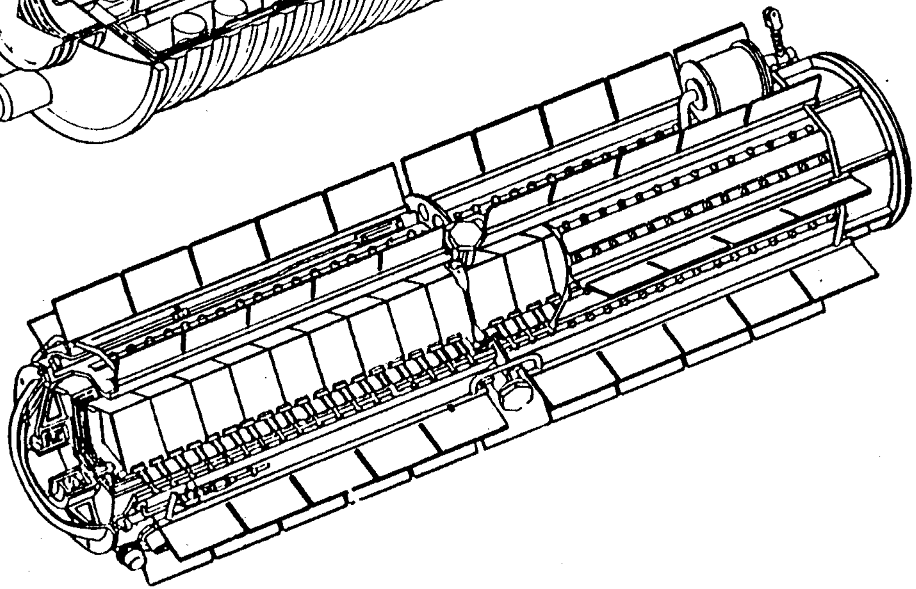
- Heat Rejection
  - Redundant H_2O/ammonia heat pipes
  - Optical solar reflector (OSR) tiles for enhanced emissivity

DIPS HSU Similar in Concept to Galileo RTG

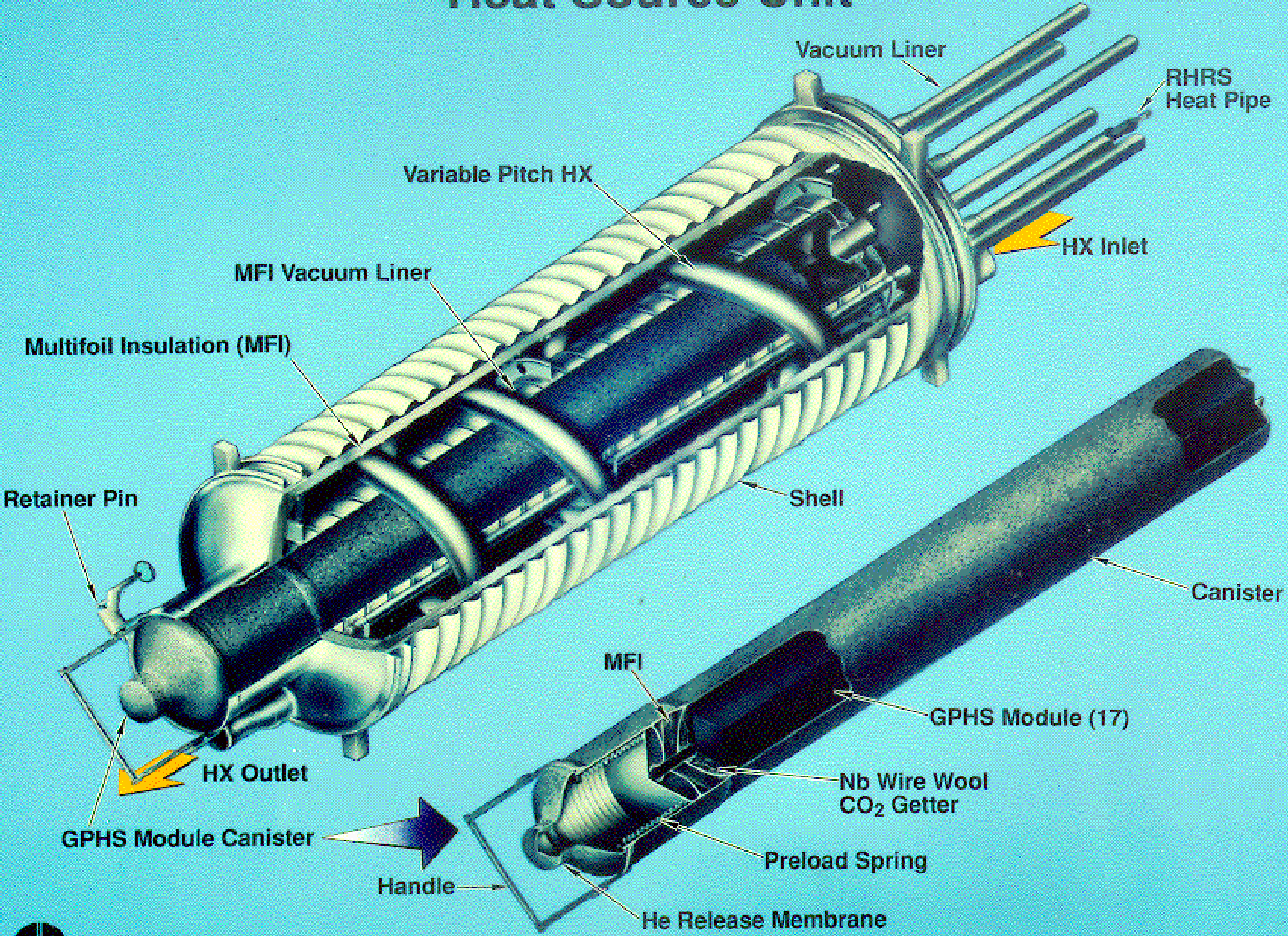
DIPS
HSU



Galileo
RTG



2.5 kWe DIPS Power Module Heat Source Unit



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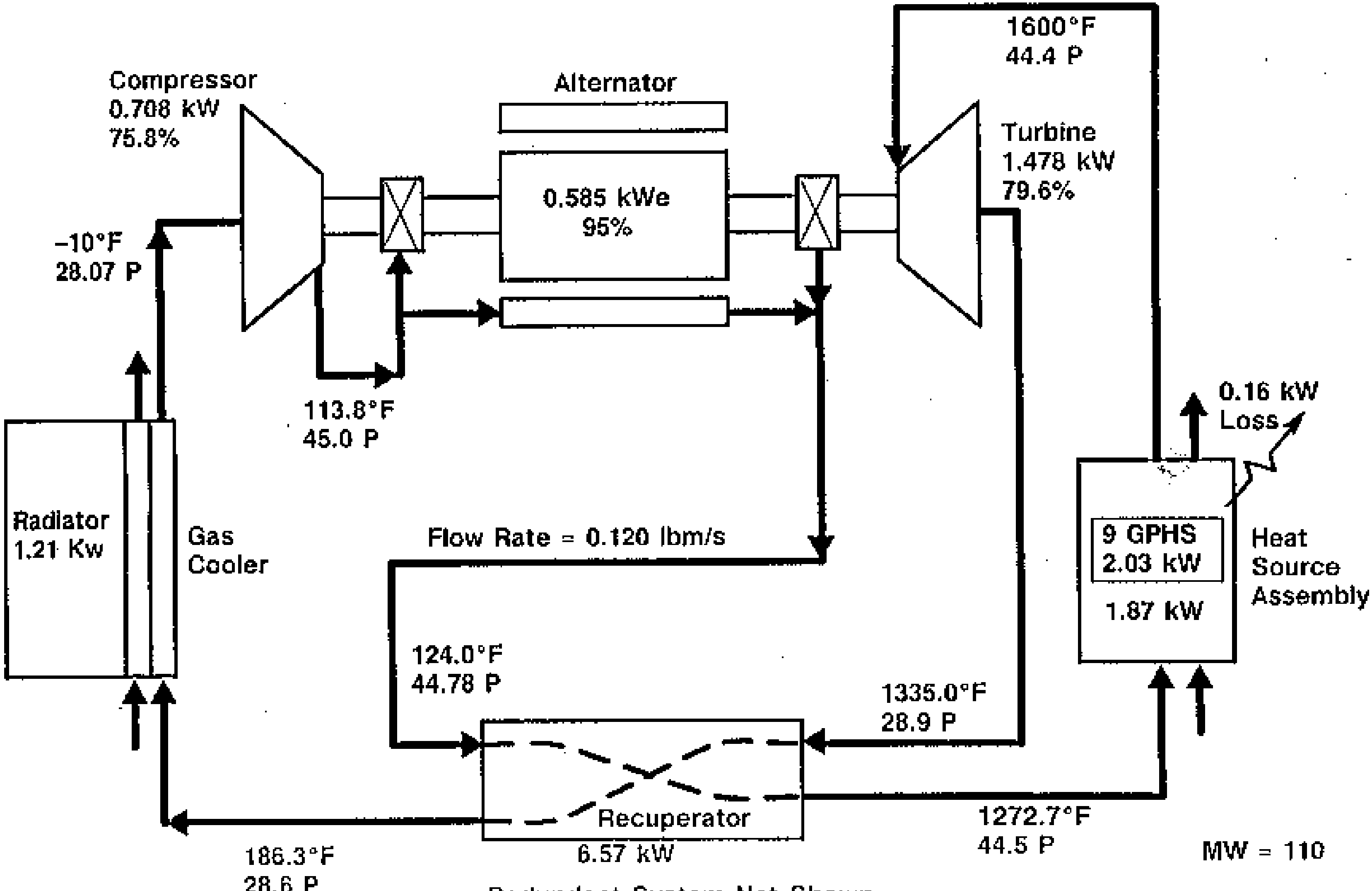
Flow Diagram of 0.5-kWe DIPS System



Redundant System Not Shown
P = psia

Radioisotope Generator Characteristics

	SNAP-3B	SNAP-9A	SNAP-19	SNAP-27	Transit-RTG	MHW	GPHS-RTG	DIPS-CBC
Mission	Transit	Transit	Nimbus Pioneer Viking	Apollo	Transit	LES 8/9 Voyager	Galileo	TBD
Fuel form	PU metal	Pu metal	PuO_2-Mo cermet	PuO_2 micro-spheres	PuO_2-Mo cermet	Pressed PuO_2	Pressed PuO_2	Pressed PuO_2
Thermoelectric material	PbTe	PbTe	PbTe–TAGS	PbSnTe	PbTe	SiGe	SiGe	NA
Beginning-of-life output power (kWe)	0.0027	0.0268	0.028–0.043	0.0635	0.0356	0.150	0.580	0.5–10.0
Mass (kg)	1.8	12.2	13.3–14.3	27.6	13.7	38.5	114	110–1,360
Specific power (W_e/kg)	1.5	2.2	2.1–3.0	2.3	2.6	3.9	5.1	4.5–7.3
Conversion efficiency (%)	5.0	5.1	4.5–6.3	5.0	4.2	6.3	6.6	22–26
Beginning-of-life fuel inventory (W_{th})	52	565	620–685	1,480	850	2,400	8,800	2,400–42,000
Fuel quantity (curies)	1,800	17,000	34,400 –80,000	44,500	25,500	7.7×10^4	2.6×10^5	$7.1 (10^4) – 1.2 (10^6)$

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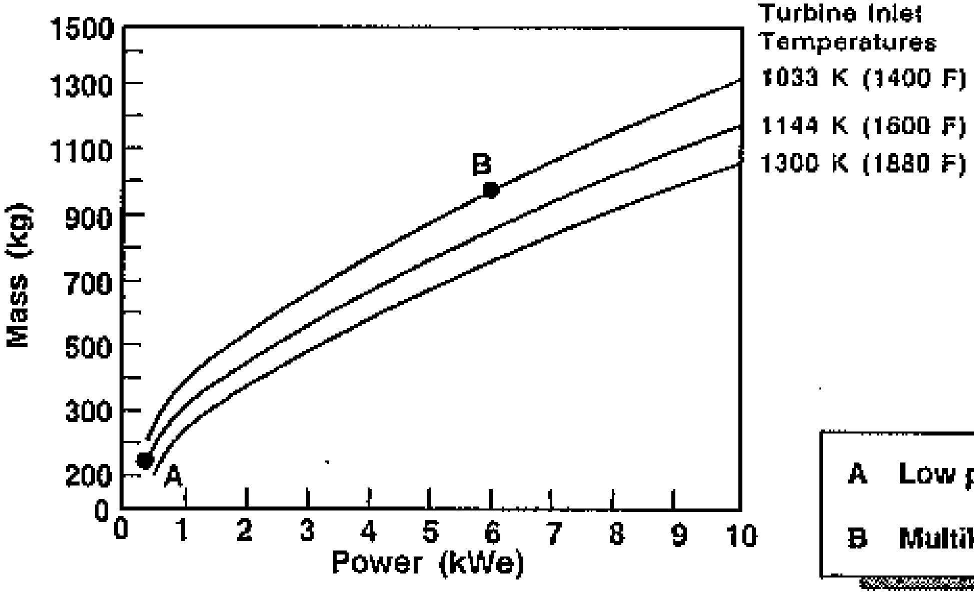
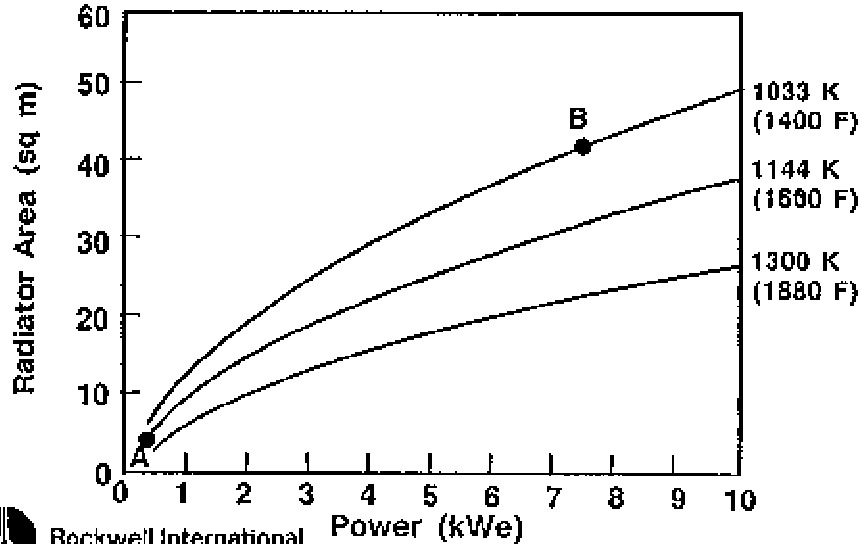
DIPS System Performance Characteristics
Unmanned Missions

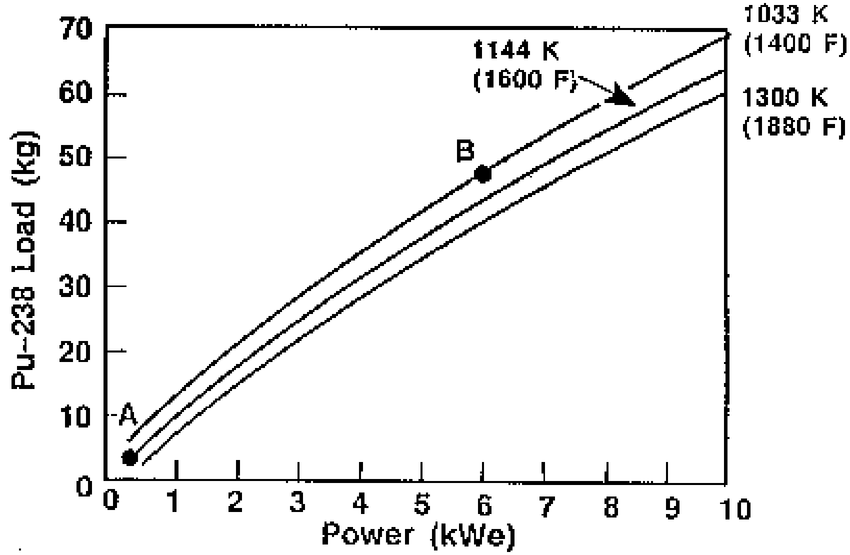


General Features

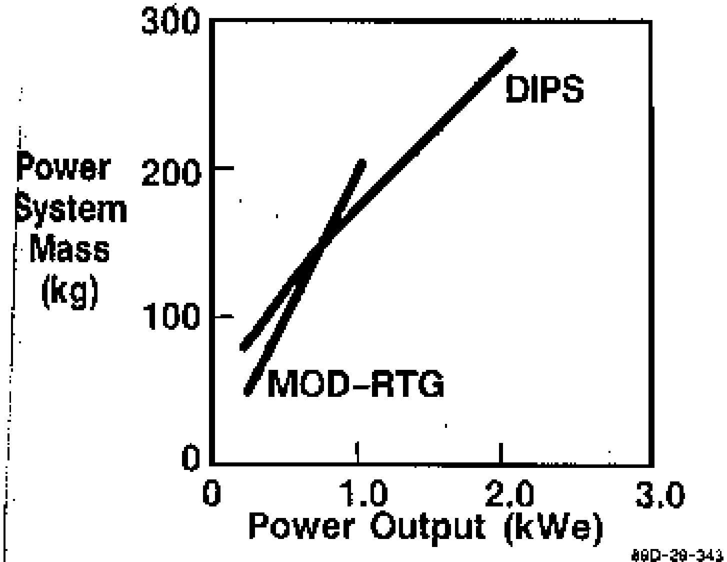
- Redundant power conversion system
- No single point failures
- Fuel canisters permanently installed
- Moderate sink temperature =190 K

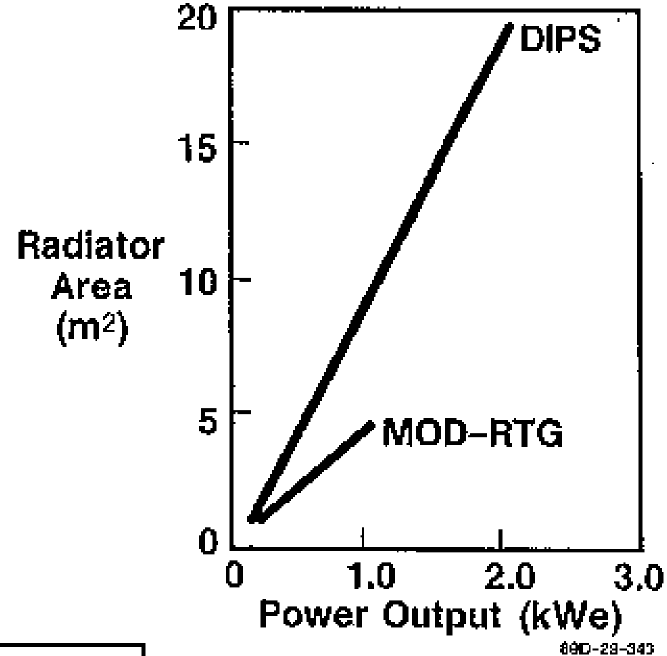
A	Low power DIPS for robotic rovers or science probes
B	Multikilowatt DIPS for planetary observation satellite

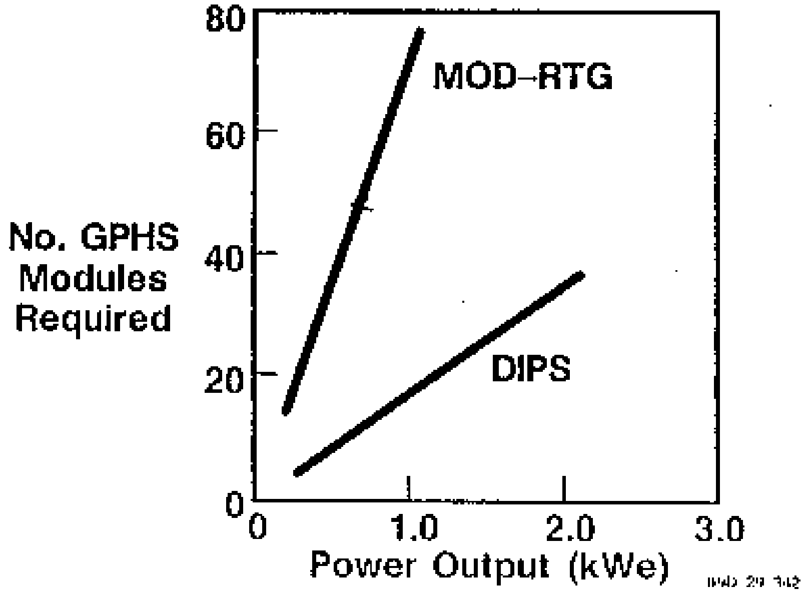




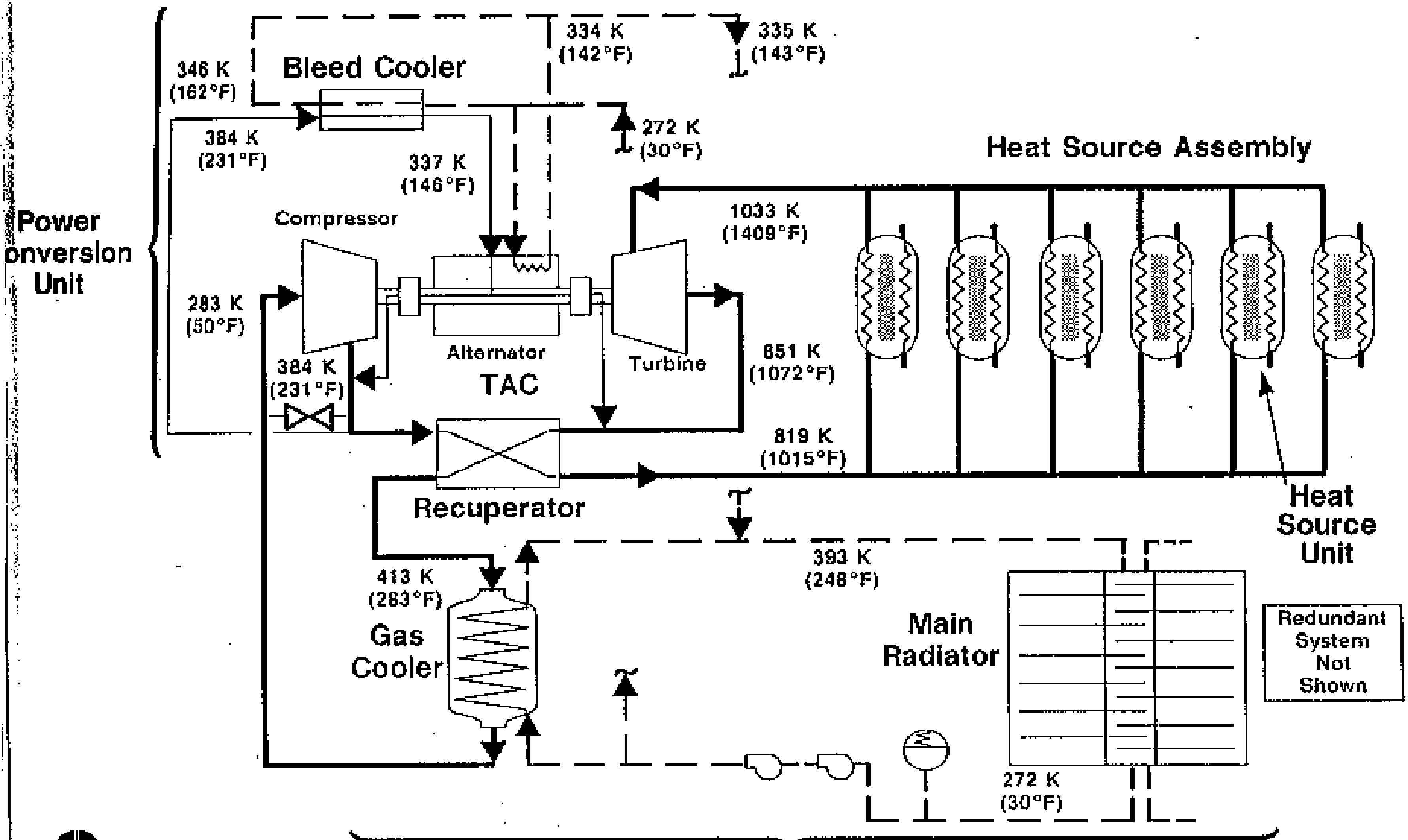
ow Power DIPS System Mass and Area Characteristics and Fuel Requirements Compared to Advanced MOD-RTG







DIPS System Schematic



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DIPS 6 kWe Design Point Summary

	BOM	EOM
Net power level (kWe)	6.0	6.0
Alternator gross power output (kWe)	6.90	6.90
Isotope thermal power (kWt)	25.0	22.9
Net cycle efficiency (%)	24.0	26.2
Operating lifetime (yr)	10	
Molecular weight	67.3	
Temperatures (K)		
Turbine inlet	1,008	1,033
Compressor inlet	289	283
Radiator inlet	413	402
Compressor discharge pressure (KPa)	375	359
Compressor pressure ratio	1.98	1.86
Turbine pressure ratio	1.86	1.76
Pressure loss factor	0.94	0.95
TAC speed (rpm)	47,860	44,520
Compressor flow rate (kg/s)	0.348	0.323
Radiator area (both sides) (m^2)	39.6	35.6*
Number of GPHS blocks per HSU	17	
Number of HSUs	6	

*Assumes 10% of heat pipes are lost

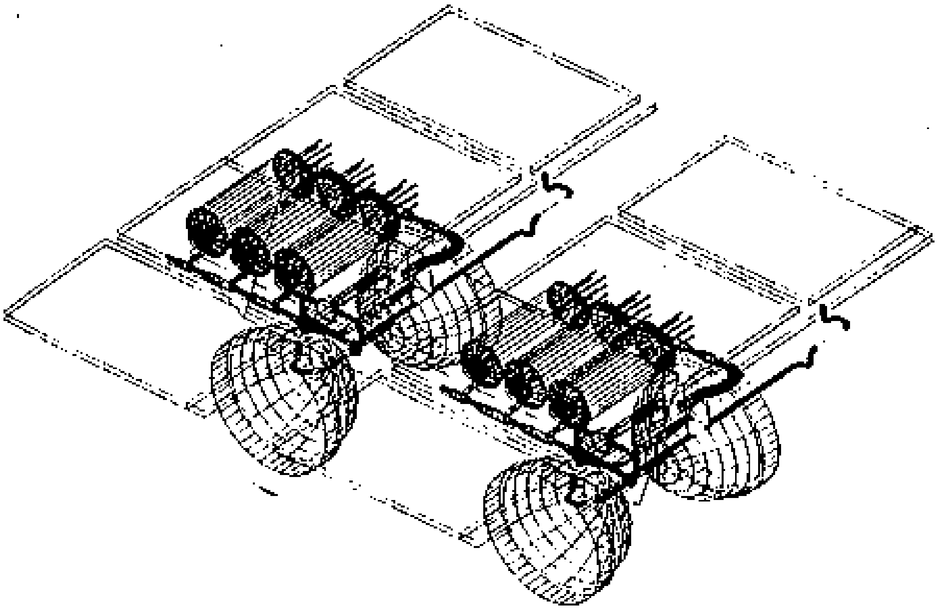
DIPS Weight Breakdown

6 kWe System (1050K Peak Temperature)

	Weight (kg)
Heat source assembly	307
Power conversion assembly	195
Heat rejection assembly	216
Power processing & control assembly	99
Miscellaneous components	79
System armor & structure	54
Total	950

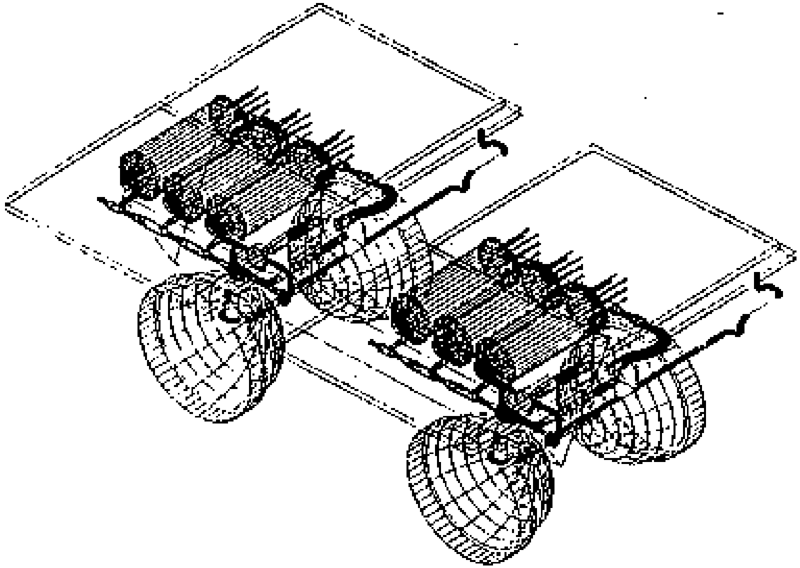
Typical DIPS Power Carts

Optimum Design



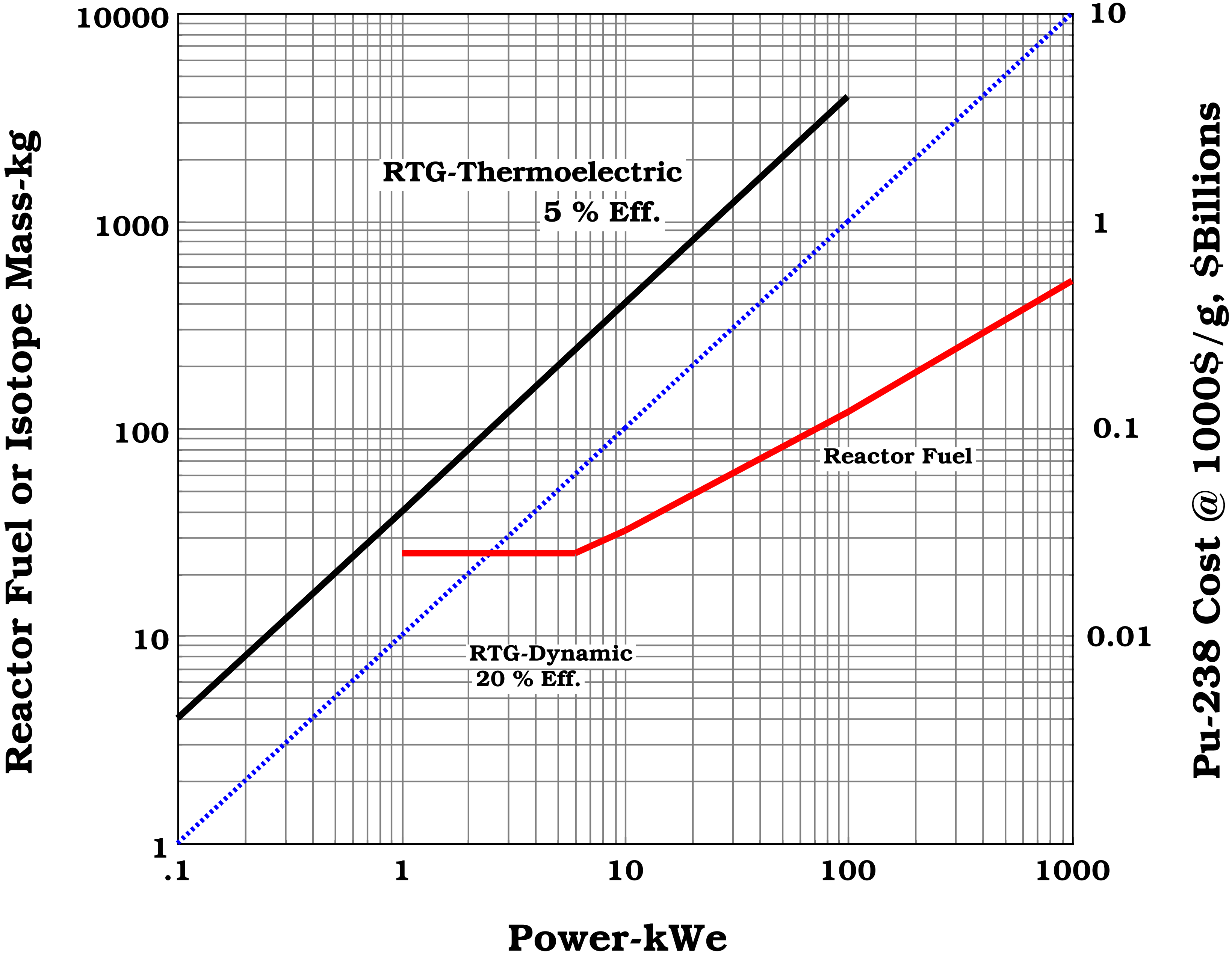
- Mass = 339 kg
- Area = 7.8 m^2
- Efficiency = 24.6%

Alternate Design



- Mass = 357 kg
- Area = 5.6 m^2
- Efficiency = 23.0%

Fuel Cost/Power Relationships For Space Power



U.S. Spacecraft Launches Involving Radioisotope Systems

Power Source	# of RTGs	Spacecraft	Mission Type	Launch Date	Status	Inventory* (Curies)**	Pu-238 kg	Fuel Form
SNAP-3	1	Transit 4A	Navigational	6/29/61	Currently in orbit.	1,500-1,600	0.09	Metal
SNAP-3	1	Transit 4B	Navigational	11/15/61	Currently in orbit.	1,500-1,600	0.09	Metal
SNAP-9A	1	Transit 5BN-1	Navigational	9/28/63	Currently in orbit.	17,000	0.99	Metal
SNAP-9A	1	Transit 5BN-2	Navigational	12/5/63	Currently in orbit.	17,000	0.99	Metal
SNAP-9A	1	Transit 5BN-3	Navigational	4/12/64	Mission aborted. Heat source burned up on reentry as designed.	17,000	0.99	Metal
SNAP-10A	Reactor	Snapshot	Experimental	4/3/65	Successfully achieved orbit and was shut down after 43 days.	n/a	10^{-5}	
SNAP-19	2	Nimbus B-1	Meteorological	5/18/68	Mission aborted and heat source retrieved.	34,400	2.01	µsphere
SNAP-19	2	Nimbus III	Meteorological	4/14/69	Currently in orbit.	37,000	2.16	µsphere
ALRHU	Heater	Apollo 11	Lunar	7/16/69	On lunar surface.	920	0.05	µsphere
SNAP-27	1	Apollo 12	Lunar/ALSEP	11/14/69	On lunar surface. Station shut down.	44,500	2.60	µsphere
SNAP-27	1	Apollo 13	Lunar/ALSEP	4/11/70	Mission aborted. Heat source jettisoned into the Pacific Ocean.	44,500	2.60	µsphere
SNAP-27	1	Apollo 14	Lunar/ALSEP	1/31/71	On lunar surface. Station shut down.	44,500	2.60	µsphere
SNAP-27	1	Apollo 15	Lunar/ALSEP	7/26/71	On lunar surface. Station shut down.	44,500	2.60	µsphere
SNAP-19	4	Pioneer 10	Planetary	3/2/72	Successfully operated to Jupiter and beyond the solar system.	80,000	4.68	PMC
SNAP-27	1	Apollo 16	Lunar/ALSEP	4/16/72	On lunar surface. Station shut down.	44,500	2.60	µsphere
Transit-RTG	1	Triad-01-1X	Navigational	9/2/72	Currently in orbit.	24,000	1.40	PMC
SNAP-27	1	Apollo 17	Lunar/ALSEP	12/7/72	On lunar surface. Station shut down.	44,500	2.60	µsphere
SNAP-19	4	Pioneer 11	Planetary	4/5/73	Successfully operated to Jupiter, Saturn and beyond the solar system.	80,000	4.68	PMC
SNAP-19	2	Viking 1	Mars Lander	8/20/75	On Martian surface. Lander shut down.	~40,980	2.40	PMC
SNAP-19	2	Viking 2	Mars Lander	9/9/75	On Martian surface. Lander shut down.	~40,980	2.40	PMC
MHW-RTG	2, 2	LES 8, LES 9	Communications	3/14/76	Currently in orbit.	318,000	18.60	PPO
MHW-RTG	3	Voyager 2	Planetary	8/20/77	Successfully operated to Neptune and beyond the solar system.	240,000	14.03	PPO
MHW-RTG	3	Voyager 1	Planetary	9/5/77	Successfully operated to Saturn and beyond the solar system.	240,000	14.03	PPO
GPHS-RTG	2	Galileo	Planetary	10/18/89	Successfully operating, orbiting Jupiter.	264,400	15.46	PPO
GPHS-RTG	1	Ulysses	Planetary	10/6/90	Successfully operated to the Sun's polar regions, mission continuing.	132,500	7.75	PPO
LWRHU	Heater	Mars Pathfinder	Mars Lander	12/4/96	Successfully operated on Mars.	93	0.006	PPO
GPHS-RTG	3	Cassini	Planetary	10/15/97	Successfully operating, on route to Saturn.	406,000	23.74	PPO

ALRHU - Apollo Lunar Radioisotope Heater Unit
ALSEP - Apollo Lunar Surface Experiment Package
GPHS - General Purpose Heat Source
LES - Lincoln Experimental Satellite

LWRHU - Light Weight Radioisotope Heater Unit
MHW - Multi-Hundred Watt
RTG - Radioisotope Thermoelectric Generator
SNAP - Systems for Nuclear Auxiliary Power

* Inventory at launch
** One curie is equal to 3.7×10^{10} Becquerel (Bq)

Fuel Form:
- µsphere - Plutonium Oxide Microspheres
- PMC - Plutonia Molybdenum Cermet
- PPO - Pressed Plutonium Oxide

1/26/98

Advanced Radioisotope Power Source Top Level Requirements for Near-Future Missions

Power (W_e)	Mass (kg)	Lifetime (y)	Efficiency (%)	Voltage (dc)	Number	Potential Mission
0.04 to 0.10	0.25	20	4-5	5	1	Mars Weather/Seismic Stations
1 to 2	0.5	5-10	5-10	5	1	Europa Lander Surface Laboratory
10 to 20	2	15-20	15	5	2	Surface In-Situ Lab Aerobots or Aero-rover
50 to 100	7 to 10	4 to 5	18 to 20	28	2 or 3	Rover and Sample Retriever
100 to 200	8 to 20	10	18 to 21	28	1	Europa Lander
100 to 200	8 to 20	15	18 to 21	28	2	Titan Explorer
100 to 200	8 to 20	15	18 to 21	28	1	Neptune Orbiter
100 to 200	8 to 20	15	18 to 21	28	1	Saturn Ring Observer
100 to 200	8 to 20	15 to 30	18 to 21	28	1	Interstellar Probe

After J. F. Mondt and B. J. Nesmith, Space Technology and Applications International Forum-2000, edited by M. S. El-Genk, American Institute of Physics, 2000.