Some Observations On the Use of Space Nuclear Power

Gary L. Bennett
Consultant
[NASA, DOE, etc., (ret.)]

Metaspace

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The designs, concepts, technologies, and missions discussed in this presentation should be viewed as pre-decisional and speculative only. This presentation should be viewed as a draft subject to revision. Trade names or manufacturers' names are used in this presentation for identification only. This usage does not constitute an official endorsement, either expressed on implied.

Disclaimer

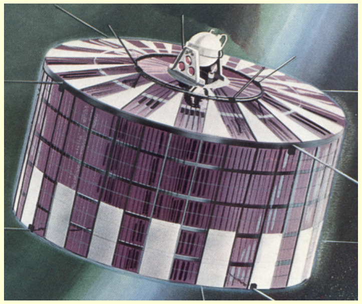
Some Observations on Space Nuclear Power

NRC Statement of Work

- Solicit inputs to and evaluate roadmaps
- Provide recommendations that identify and prioritize key technologies
  (NASA's exploration systems, Earth and space science, and space operations mission areas as well as those that contribute to critical national and commercial needs in space)

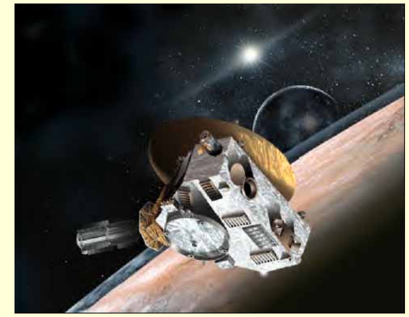
Purpose of this Presentation

- Provide input on space nuclear power with a focus on radioisotope power sources (RPSs)
- Provide some general recommendations and list some priorities.


Transit 4A

Uses of Space Nuclear Power By the United States

42 NPS on 24 Space Systems


New Horizons at Pluto

TRANSIT NAVY NAVIGATIONAL SATELLITES

Transit 4A and Transit 4B (1961) SNAP-3B (2.7 We)
Transit 5BN-1 and Transit 5BN-2 (1963) SNAP-9A (>25 We)
Transit TRIAD (1972) Transit-RTG (35 We)

SNAPSHOT SPACE REACTOR EXPERIMENT

SNAP-10A Reactor (1965) (>500 We)

NIMBUS III METEOROLOGICAL SATELLITE

SNAP-19B RTGs (1969) (2 @ 28 We each)

APOLLO LUNAR SURFACE EXPERIMENTS PACKAGES

Apollos 12 (1969), 14 (1971), 15 (1971), 16 (1972), 17 (1972) SNAP-27 (>70 We)

LINCOLN EXPERIMENTAL SATELLITES (COMMUNICATIONS)

LES 8 and LES 9 (1976) MHW-RTG (2 @ ~154 We each)

INTERPLANETARY MISSIONS

Pioneer 10 (1972) and Pioneer 11 (1973) SNAP-19 (4 @ ~40We each)
Viking Mars Landers 1 and 2 (1975) SNAP-19 (2 @ ~42 We each)
Voyager 1 and Voyager 2 (1977) MHW-RTG (3 @ >156 We each)
Galileo (1989) GPHS-RTG (2 @ 287 We each)
Ulysses (1990) GPHS-RTG (282 We)
Cassini (1997) GPHS-RTG (3 @ >290 We each)
Pluto-New Horizons (2006) GPHS-RTG (245.7 We)

Where we're going …

Medium Class Missions* - New Frontiers 4 (in alphabetical order)

- Comet Surface Sample Return
- Lunar South Pole -Aitken Basin Sample Return
- Saturn Probe
- Trojan Tour and Rendezvous
- Venus In Situ Explorer

Medium Class Missions* - New Frontiers 5 (in alphabetical order)

- Comet Surface Sample Return
- Io Observer
- Lunar Geophysical Network
- Lunar South Pole - Aitken Basin Sample Return
- Saturn Probe
- Trojan Tour and Rendezvous
- Venus In Situ Explorer

Large Class Missions (in priority order)

- Mars Astrobiology Explorer-Cacher Descope
- Jupiter Europa Orbiter Descope
- Uranus Orbiter and Probe (no Solar Electric Propulsion stage)

Two others in alphabetical order

- Enceladus Orbiter
- Venus Climate Mission

The committee's highest priority for near-term multi-mission technology investment is for the completion and validation of the Advanced Stirling Radioisotope Generator.

The committee is alarmed at the status of plutonium-238 availability for planetary exploration. Without a restart of plutonium-238 production, it will be impossible for the United States, or any other country, to conduct certain important types of planetary missions after this decade.

***Medium Class: $1 B (FY2015 $), excluding launch vehicle**
Potential RPS-powered mission

Source: *Vision and Voyages for Planetary Science in the Decade 2013-2022* (2011)

Source: Ralph McNutt, 7th IECEC, 2009

THE NATIONAL ACADEMIES

HIGH-PRIORITY RECOMMENDATION
^{238}Pu Production

The FY 2010 federal budget should fund the DOE to reestablish production of ^{238}Pu.

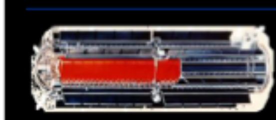
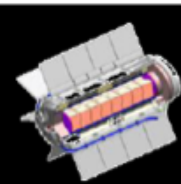
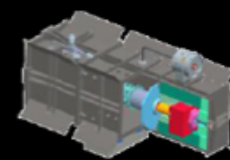
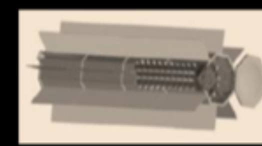
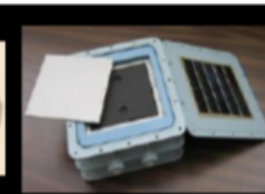
- As soon as possible, the DOE and the OMB should request–and Congress should provide–adequate funds to produce 5 kg of ^{238}Pu per year.

INL Materials and Fuels Complex

- NASA should issue annual letters to the DOE defining future demand for ^{238}Pu.

Source: Ralph McNutt, 7th IECEC, 2009

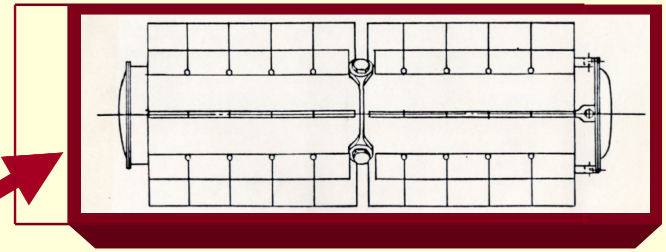
Performance of Past, Present, and Future Radioisotope Power Systems

					
	GPHS-RTG Past	MMRTG Present	ASRG In Development	ARTG Future	TPV Future
Electric Output, BOM, W_e	~~285~~ 300	125	~140-150	~280 to 420	~38-50
Heat Input, BOM, W_e	4500	2000	500	3000	250
RPS System Efficiency, BOM, %	6.3	6.3	~28-30	~9-14	~15-20
Total System Weight, kg	56	44.2	~19-21	~40	~7
Specific Power, W_e/kg	~~5.1~~ 5.3	2.8	~7-8	~7-10	~6-7
Number of GPHS Modules	18	8	2	12	1
GPHS Module Weight, kg	25.7	12.9	3.2	19.3	1.6
^{238}Pu Weight, kg	7.6	3.5	0.88	5.3	0.44

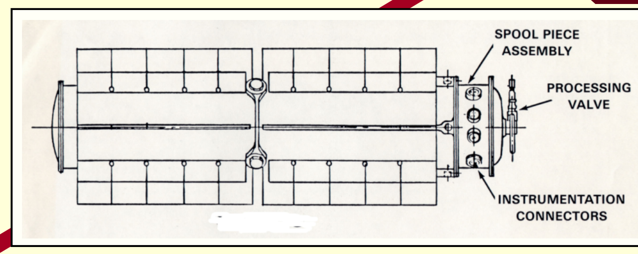
Source: *Radioisotope Power Systems: An Imperative for Maintaining U.S. Leadership in Space Exploration* (2009) (modified from S. Surampudi presentation, 18 Nov 2008)

Testing Philosophy

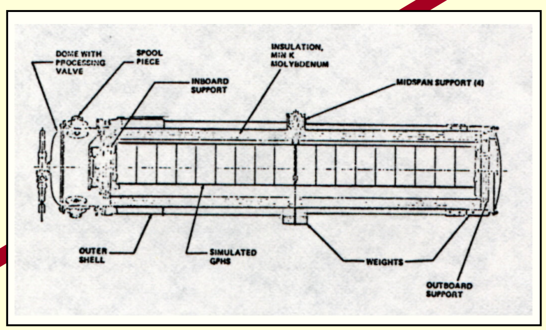
Testing at each step in the program was a key factor in the success of the General-Purpose Heat Source Radioisotope Thermoelectric Generator program



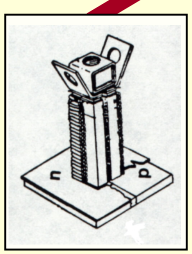
Flight Units



Engineering Unit Tests
Qualification Unit Tests

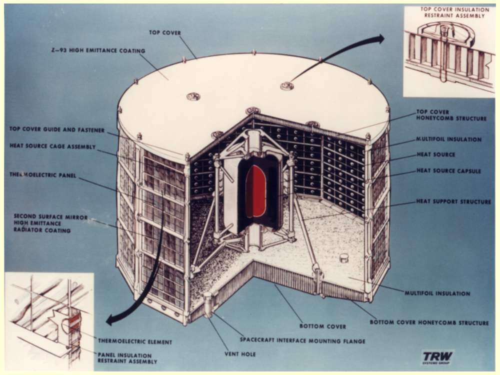


Component Engineering Testing

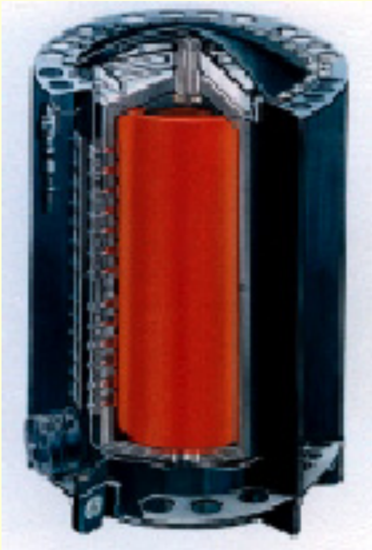


GPHS-RTG Converter Engineering Development Testing
• Materials Characterization • Component Testing • Converter Assembly Testing

"Multi-Mission" RTGs

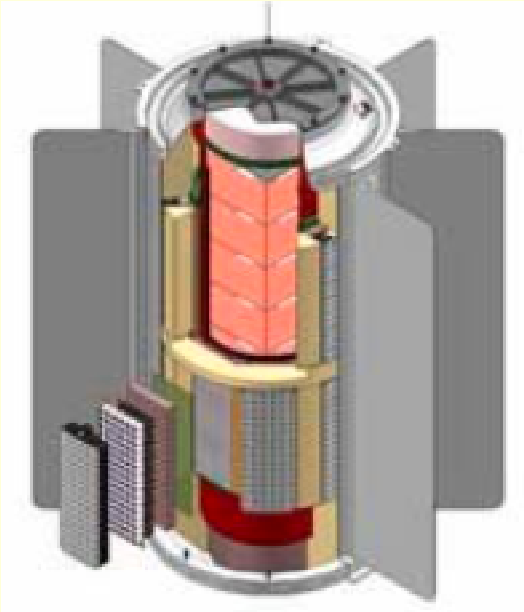


Transit-RTG

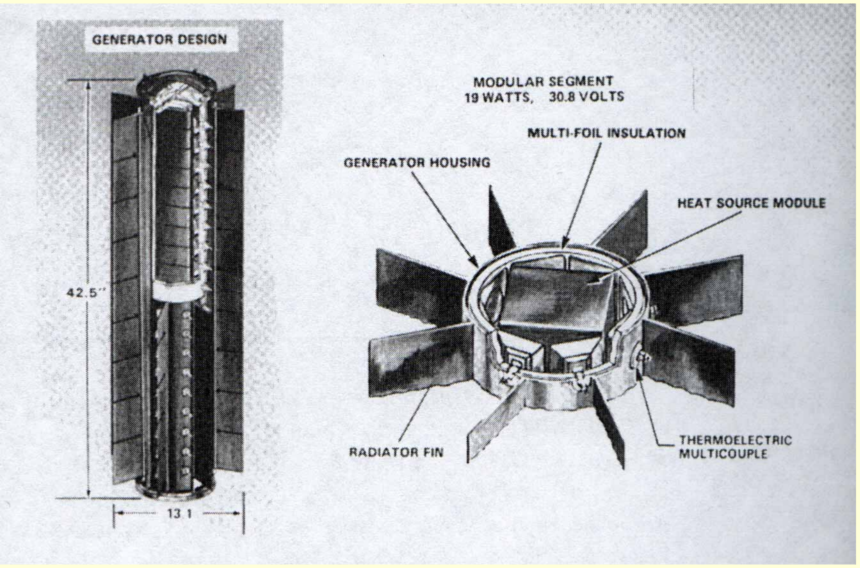


MHW-RTG

GPHS-RTG



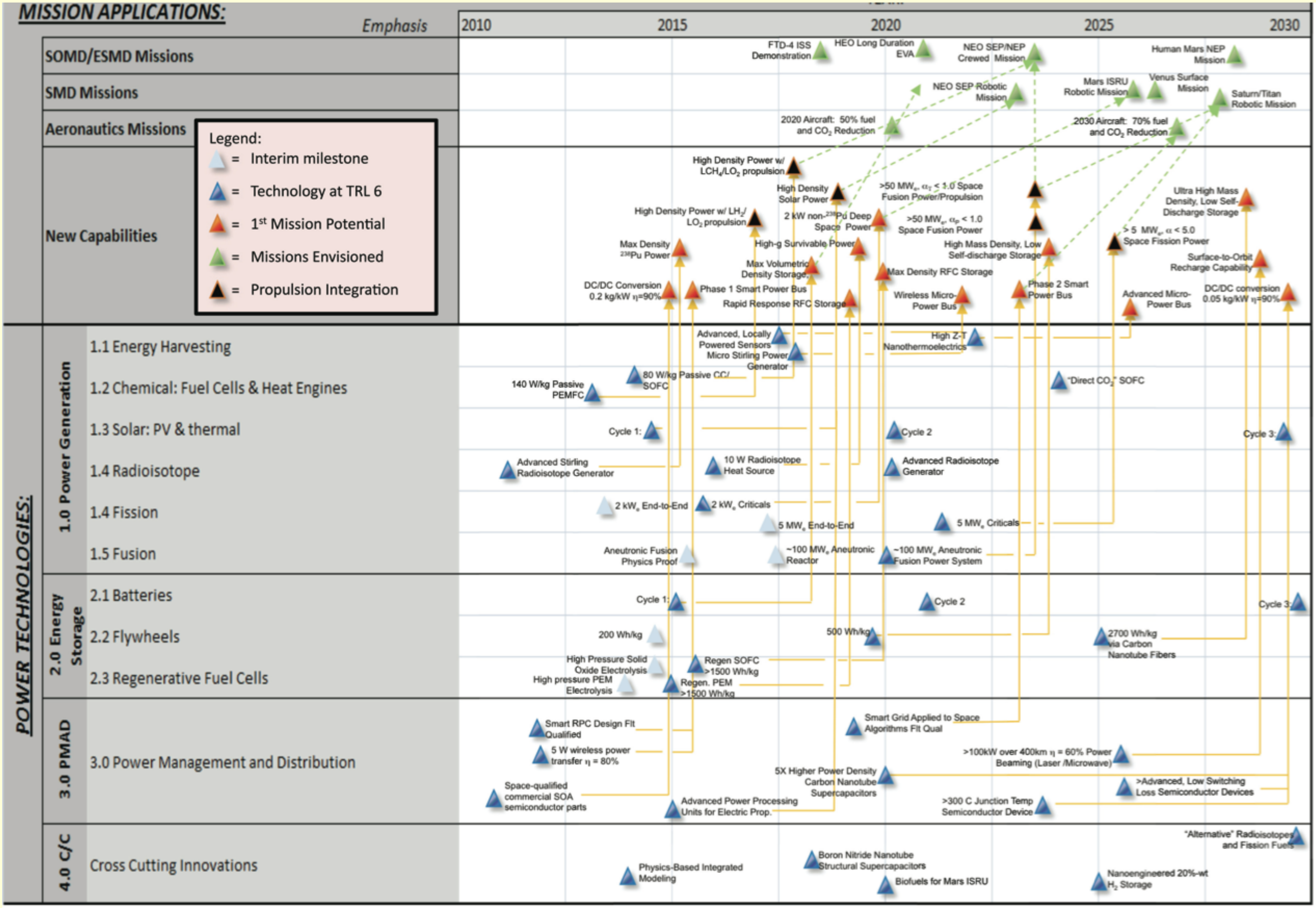
MMRTG



MOD-RTG

History suggests RTGs are mission specific

Space Power and Energy Storage Roadmap



Source: *Draft Space Power and Energy Storage Roadmap, Technology Area 03* (November 2010)

Some Suggestions for Improving Radioisotope Power Sources

- **Focus the Stirling resources on developing and validating the ASRG**

- **Spin off ATEC thermoelectric improvements (e.g., improved insulation, improved coatings, etc.) to**

  - MMRTG for surface applications
  - GPHS-RTG for space applications

NOTE: This is "near-term" backup to ASRG and ARTG and for those missions committed to RTGs

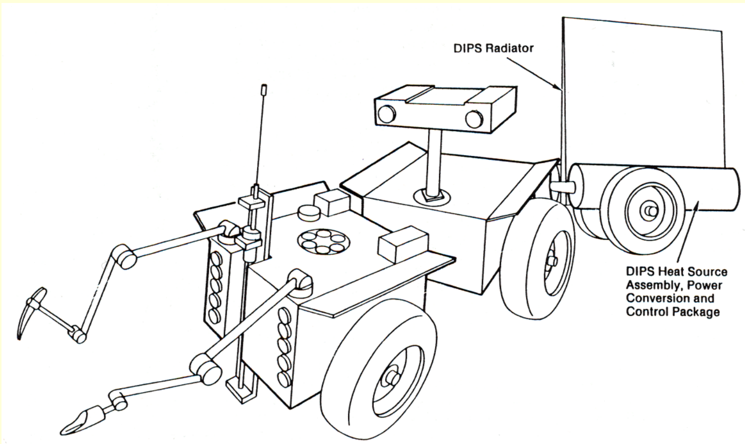
- **Develop in-house capability to manufacture thermoelectric elements**

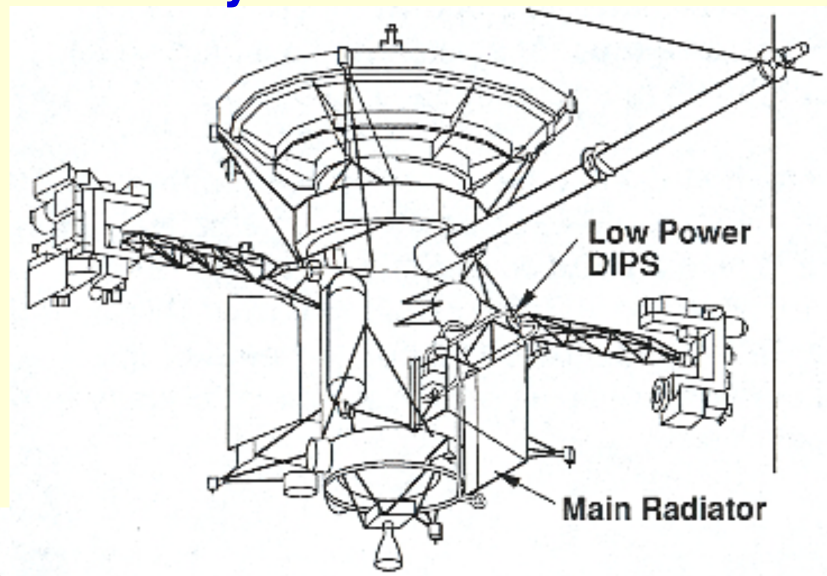
- **Fund DOE for technology, infrastructure and Pu-238**

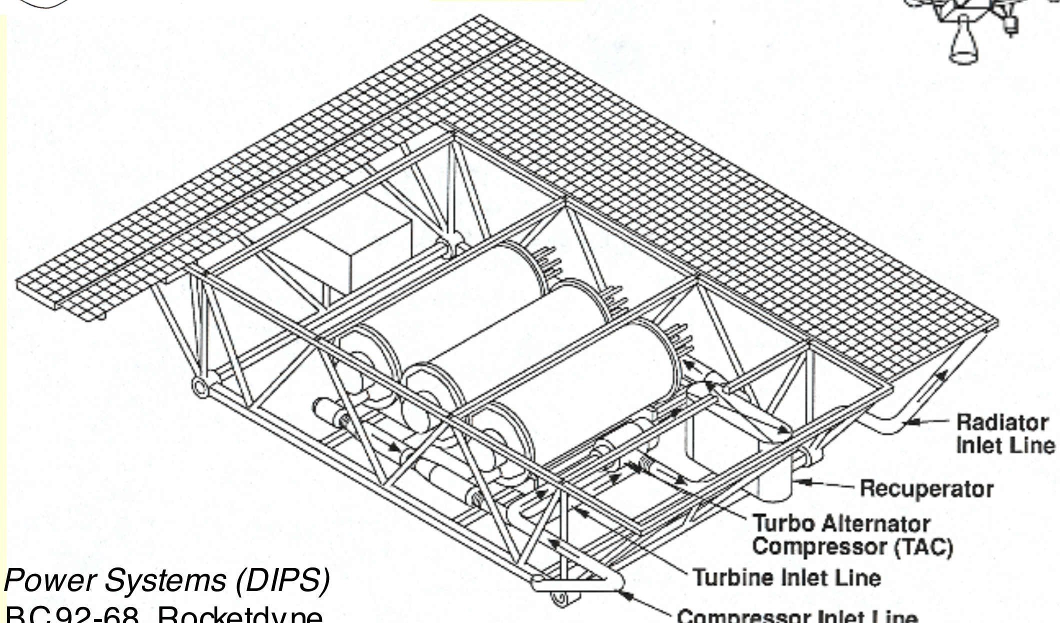
ASRG = Advanced Stirling Radioisotope Generator
ATEC = Advanced Thermoelectric Converter
MMRTG = Multi-Mission Radioisotope Thermoelectric Generator
GPHS-RTG = General-Purpose Radioisotope Thermoelectric Generator

And for future higher power requirements for RPS don’t forget the “other” RPS technology - DIPS

Dynamic Isotope Power System

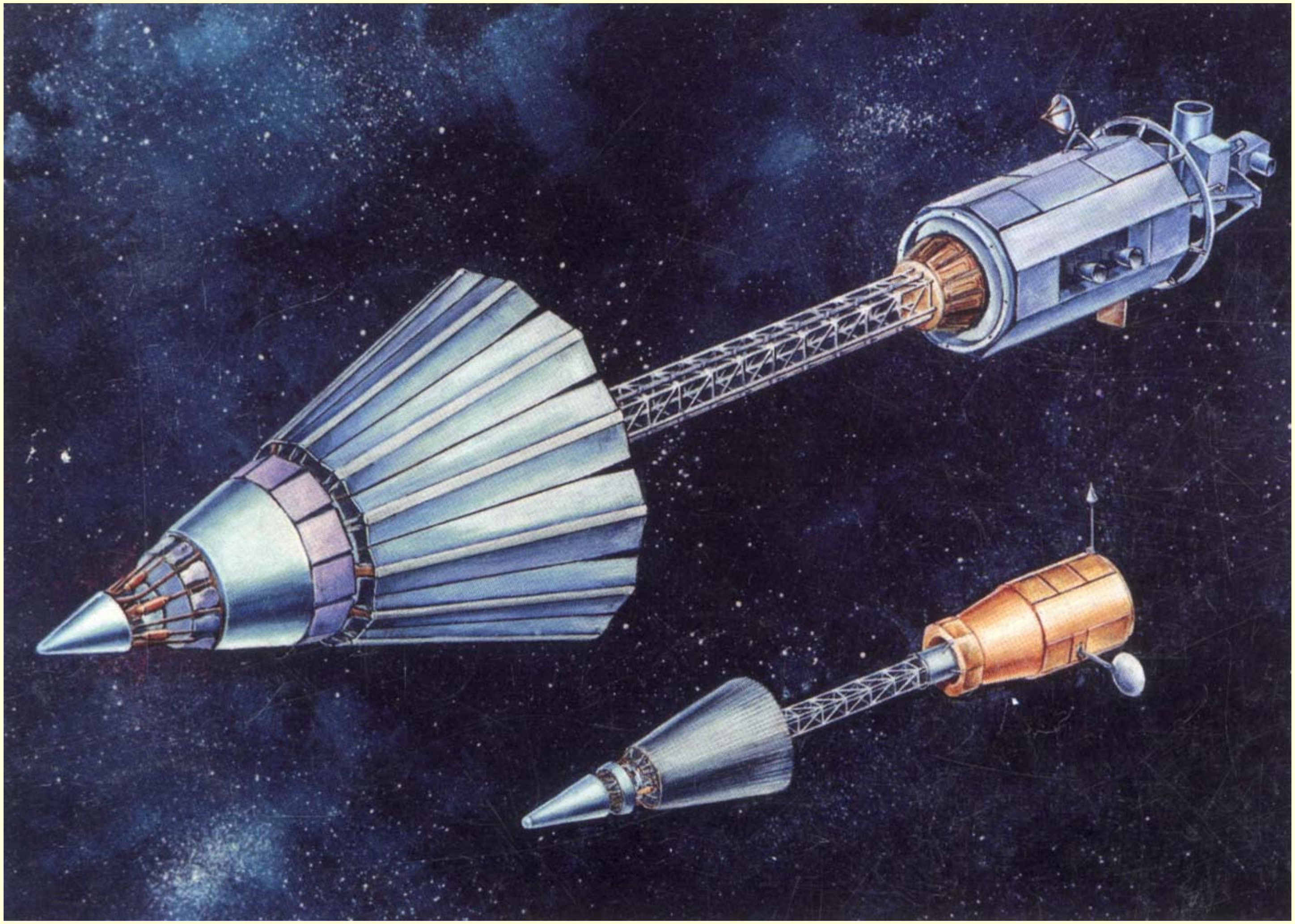




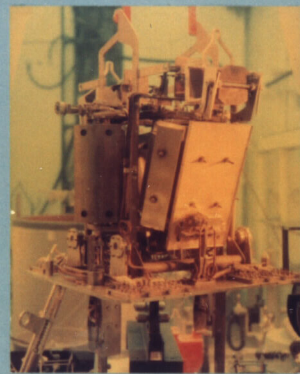


Source: *Dynamic Isotope Power Systems (DIPS) for Space Exploration*, BC92-68, Rocketdyne (August 1992)

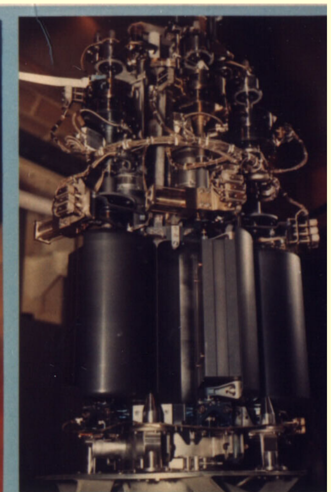
And on to fission power …



Source: SP-100 Space Reactor Power System Project



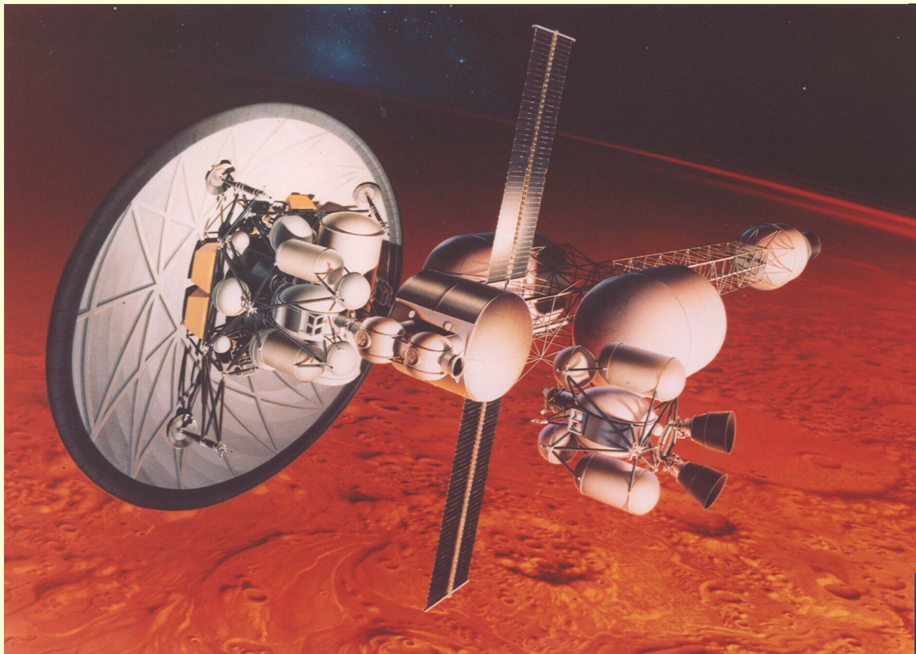
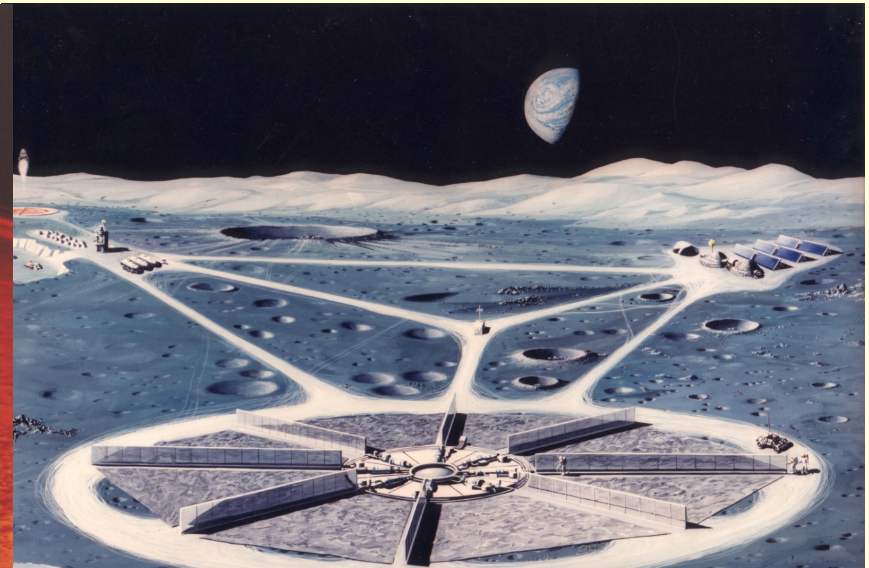


SNAP EXPERIMENTAL REACTOR (SER)	SNAP DEVELOPMENTAL REACTOR (SDR)	SNAP 8 EXPERIMENTAL REACTOR (S8ER)	SNAP 10A FLIGHT SYSTEM		SNAP 8 DEVELOPMENTAL REACTOR (S8DR)
			(FS-3)	(FS-4)	
SEPTEMBER 1959	APRIL 1961	MAY 1963	JANUARY 1965	APRIL 1965	JUNE 1968
DECEMBER 1960	DECEMBER 1962	APRIL 1965	MARCH 1966	MAY 1965	DECEMBER 1969
50 kwt	65 kwt	600 kwt	38 kwt	43 kwt	600-1000 kwt
225,000 kwt-hr	273,000 kwt-hr	5.1 x 10^6 kwt-hr	382,944 kwt-hr	41,000 kwt-hr	4.3 x 10^6 kwt-hr
-	-	-	402 watts	560 watts	-
-	-	-	4028 kw-hr	574 kw-hr	-
1800 hr AT 1200°F 3500 hr ABOVE 900°F	2800 hr AT 1200°F 7700 hr ABOVE 900°F	1 yr AT 1300°F 400 TO 600 kwt	10,005 hr (417 days)	1000 hr	7023 hr 1100-1300°F

9(704)-006-6C

Source: Rocketdyne

What do we want a fission power source to do?

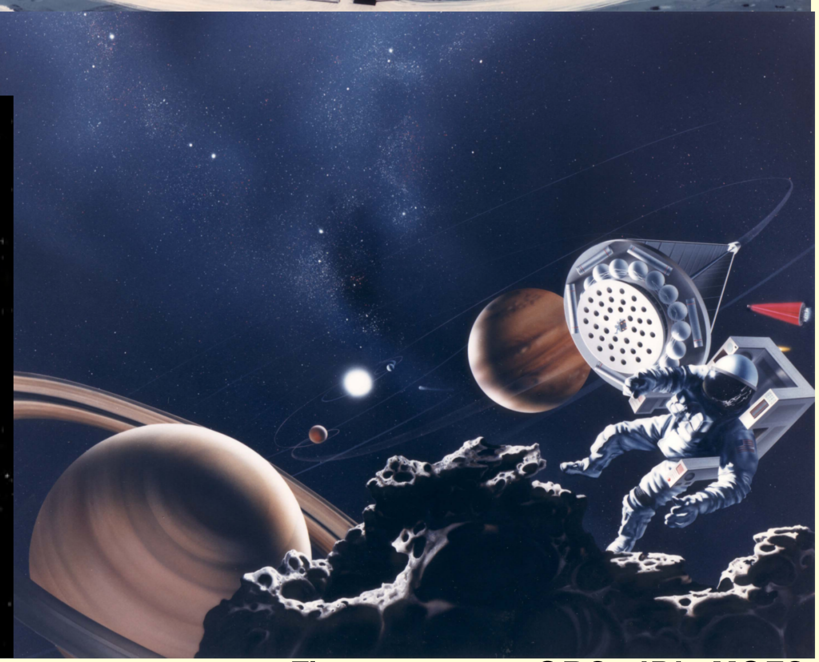


Figure sources: GRC, JPL, MSFC

*"Fission provides 'game-changing' solutions for powering advanced NASA missions."**

Some Philosophy

- Put safety first (including end-of-mission)

- Build in reliability at every level
  (e.g., no maintainability, no refueling)

- Start small and evolve

- Test materials and fuels at an early stage

- Design and build a reactor that is testable on Earth

- Avoid "paper reactors" -- start with what is known,
  what has been shown to work

- Manage through a joint NASA-DOE program office
  (like NERVA)

- Build support for the "long haul" (decade plus)

* *DRAFT Space Power and Energy Storage Roadmap*, NASA, November 2010

Paper Reactors v. Real Reactors
(or avoiding crises and deception)

Paper Reactor

- ***It is simple.***
- ***It is small.***
- ***It is cheap.***
- ***It is light.***
- ***It can be built very quickly.***
- ***It is very flexible in purpose.***
- ***Very little development is required. It will use mostly off-the-shelf components***
- ***The reactor is in the study phase. It is not being built now.***

Practical Reactor

- ***It is being built now.***
- ***It is behind schedule.***
- ***It is requiring an immense amount of development on apparently trivial items.***
- ***It is very expensive.***
- ***It takes a long time to build because of the engineering development problems.***
- ***It is large.***
- ***It is heavy.***
- ***It is complicated.***

Source: **Admiral Hyman G. Rickover (1953)**

Some thoughts on fission power technology

- Safety first and always!
- Launch vehicle constraints ⇒ compactness
- Compactness ⇒ epithermal/fast reactor
- Compactness ⇒ smaller shield (lower mass)
- Capable of evolving to a full-power lifetime of 10 - 20 years
- Materials should be compatible with the environment
- Reactor should be tested on Earth before the mission
  (NOTE: this could be the equivalent of the RTG program's "Qual Unit")
- Conversion system should be external to the reactor
  (shortens development and qualification schedules; provides more options for different applications; and reduces the size, complexity, and cost of test facilities)
- "No assembly required"
- Will need test facilities and knowledgeable people

For almost 50 years space nuclear power sources have proved to be safe, reliable, sturdy, long-live sources of electrical power.

- Since 1961, the U.S. has successfully launched 42 nuclear power sources (41 RTGs and one nuclear reactor) on 24 space missions.

- The SNAP-10A space nuclear reactor power system demonstrated the viability of automatically controlled, liquid-metal-cooled reactors for space applications.

- The RTGs have enabled some of the most challenging and scientifically exciting missions in human history.

  (Including Apollo Lunar Surface Experiments Packages; Pioneer flybys of Jupiter and Saturn; Viking Mars Landers; Voyager flybys of Jupiter, Saturn, Uranus and Neptune; Galileo orbital exploration of Jupiter; Ulysses solar polar explorer; Cassini orbital exploration of Saturn; New Horizons mission to Pluto)

- In general, the RTGs, from the first SNAP-3Bs to the GPHS-RTGs, have exceeded their mission requirements by providing power at or above the required and beyond the planned mission lifetime.