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Title: $^{238}PuO_2$ HEAT SOURCES: AN ENABLING TECHNOLOGY FOR SPACE EXPLORATION

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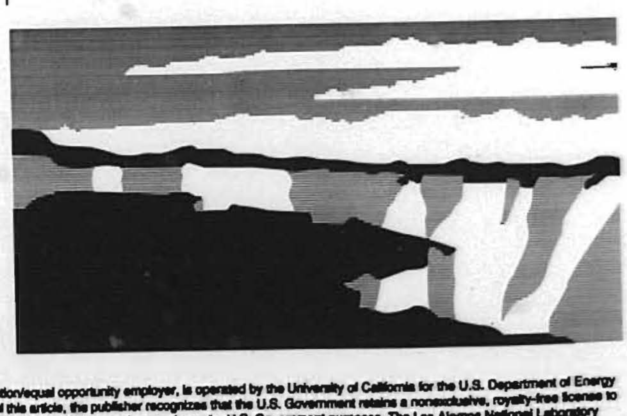

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$^{238}PuO_2$ HEAT SOURCES: AN ENABLING TECHNOLOGY FOR SPACE EXPLORATION

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ɔduction

:e the launch of Transit 4A, America's first radioisotope-powered navigational ·llite, in 1961, $^{238}PuO_2$ heat sources have been an integral and enabling ponent of the U.S. space exploration program. Radioisotope heat sources ɘd with various types and configurations of $^{238}PuO_2$ fuels have been ɔessfully used to provide electrical and thermal power to 23 U.S. space sions launched over a period of more than 35 years (Table I). Of these 23 sions, 15 were planetary exploration initiatives made possible only by the ilability of long-lived, robust power supplies.

ɜt Recently, the Cassini spacecraft was launched with three General-Purpose ·t Source (GPHS) radioisotope thermoelectric generators (RTGs) and 117 ıt-Weight Radioisotope Heater Units (LWRHUs). Each of the GPHS RTGs ıched on Cassini contained 72 GPHS capsules. All of these heat sources e fabricated at Los Alamos National Laboratory's (LANL's) plutonium ɔessing facility between 1994 and 1996.[1] Each Cassini RTG contained 72 vidual GPHS heat sources, each of which was fueled with a 151-g $^{238}PuO_2$ et. Each of the Cassini LWRHUs was fueled with a 2.7-g $^{238}PuO_2$ pellet.

prisingly, during the three and one half decades that $^{238}PuO_2$-fueled ıoisotope power systems have been demonstrated and continuously roved in terms of safety, reliability, and efficiency, U.S. capabilities to duce $^{238}PuO_2$ have significantly decreased. At the same time, progress in the ɔiency and longevity of chemical and solar power systems have reduced the e of potential applications for radioisotope power. However, $^{238}PuO_2$–fueled ıt sources and radioisotope power systems remain a viable option for deep .ce exploration and planetary missions that must survive hostile operating ·ironments.

ɘ Cassini Mission: A Comparative Analysis Of Power Supply Options

ɘ enabling aspect of radioisotope power supplies for deep space exploration .sions can best be illustrated by a comparative analysis of power supply ions available for NASA's most recent planetary explorer, the Cassini mission Saturn. The Cassini spacecraft, which had a gross weight at launch of over)0 kg, required an electrical power supply of between six and seven hundred s for the duration of the 12 year mission. The Cassini spacecraft was ched with three General-Purpose Heat Source (GPHS) radioisotope noelectric generators (RTGs) that provided an approximate thermal output inning of mission) of 13.3 kilowatts. With a thermoelectric conversion iency of approximately 6%, this equated to an electrical output of roughly

le I. U.S. Space Missions Successfully Launched With Radioisotope 'er Systems Or Heater Units

ion	Launch Date	Purpose	Power Source(s) and Types
sit 4A	1961	Navigation Satellite	SNAP-3B RTG[a]
sit 4B	1961	Navigation Satellite	SNAP-3B RTG
sit 5BN-1	1963	Navigation Satellite	SNAP-9A RTG
sit 5BN-2	1963	Navigation Satellite	SNAP-9A RTG
ɔus III	1969	Meteorological Obser.	SNAP-19B3 RTG
lo 12	1969	Lunar Exploration	SNAP-27 RTG
lo 14	1971	Lunar Exploration	SNAP-27 RTG
lo 15	1971	Lunar Exploration	SNAP-27 RTG
eer 10	1972	Planetary Exploration	SNAP-19 RTG
lo 16	1972	Lunar Exploration	SNAP-27 RTG
sit	1972	Navigation Satellite	Transit RTG
lo 17	1972	Lunar Exploration	SNAP-27 RTG
eer 11	1973	Planetary Exploration	SNAP-19 RTG
g 1	1975	Mars Exploration	SNAP-19 RTG
g 2	1975	Mars Exploration	SNAP-19 RTG
'8/9	1976	Communications Sat.	MHW[b] RTG
ger 2	1977	Planetary Exploration	MHW RTG
ger 1	1977	Planetary Exploration	MHW RTG
eo	1989	Planetary Exploration	2 GPHS[c] RTGs, 120 LWRHU[d] Heater Units
ses	1990	Solar Exploration	1 GPHS RTG
; Pathfinder	1997	Mars Exploration	3 LWRHUs
sini	1997	Planetary Exploration	3 GPHS RTGs, 117 LWRHUs

lioisotope Thermoelectric Generator
ti-Hundred Watt
neral-Purpose Heat Source
nt-weight Radioisotope Heater Unit

800 watts. However, as a result of radioactive decay of the ^{238}Pu and high-temperature degradation of the thermoelectric conversion elements, over the course of the 12 year mission the electrical output of the Cassini RTGs was expected to drop by approximately 25% to slightly more than 600 watts.

In addition to the three RTGs, the Cassini spacecraft carried 117 Light-Weight Radioisotope Heater Units (LWRHUs), each of which had a thermal output of 1 watt. The LWRHUs were mounted at specific locations on the spacecraft where delicate electronic hardware, valves, and other components required supplemental heating to maintain operability. Including the LWRHUs, radioisotope power supplies on the Cassini spacecraft represented a total thermal inventory at launch of 13.4 kW.

A comparative evaluation of currently-available power supply options for the Cassini mission, shown in Table II, demonstrates the significant mass and maneuverability penalties that would result from the use of chemical or solar[2] energy sources in place of the RTGs and heater units. Absent additional nuclear power options, such as a spacecraft reactor, radioisotope power sources were clearly the only viable option for providing electrical and thermal power to the Cassini spacecraft.

Table II. Power Supply Options For The Cassini Spacecraft[a]

Fuel Or Power Source	Quantity Or Size	Additional Requirements
Coal	201 tons[b]	747 tons O_2; tankage, combustion chamber(s) & controls.
Oil	113.4 tons	324 tons O_2; tankage, combustion chamber(s) & controls.
Hydrogen	42 tons	672 tons O_2; tankage, combustion chamber(s) & controls.
Solar Array[c]	500 m^2	Deployment scheme; support structure; enhanced spacecraft flight controls.

[a] Based on a 12 year mission and a thermal power requirement of 13.4 kW
[b] 1000 kg
[c] Solar array attributes are based on spacecraft electrical requirements only, component heating requirements are not considered.

Conclusion

At present, and for the foreseeable future, radioisotope power supplies remain an enabling technology for deep space and planetary exploration missions beyond the orbit of Mars, and in hostile environments that preclude the use of large solar arrays. In comparison to chemical fuels and processes, nuclear space power offers an increase in the energy that may be derived from an equivalent mass of fuel of up to one million times.[3]

References

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