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RTG OPTIONS FOR JPL'S PLUTO FAST FLYBY MISSION USING AMERICAN AND RUSSIAN FUEL

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Summary

Previous publications by the author described detailed design studies of a number of radioisotope power systems for the Pluto Fast Flyby (PFF) mission. The systems studied employed General Purpose Heat Source (GPHS) modules and a variety of conversion systems (thermoelectric, Stirling, and thermophotovoltaic) for transforming the isotope heat into electricity. The present paper confines its attention to the relatively conservative option employing standard thermoelectric unicouples, since that may be the only one flight-ready for the projected PFF launch in 2000.

Instead of the previously studied parametric assumptions of thermal power, the present study examines three specific fuel options: The first option, with the lowest thermal power, is to use the heat source modules from the F5 RTG, which was a spare flight unit for the 1989-launched Galileo mission and also for the upcoming Cassini mission. Its fuel was fabricated in 1982 and will have undergone radioactive decay for at least 18 years at the time of the PFF launch. Nevertheless, there is great interest in the possibility of using these existing heat source modules, because they would enable very substantial cost savings. The second fuel option is to use newly reprocessed fuel made at the end of DOE's current production run for NASA's Cassini mission. That production run is scheduled to be completed by the end of 1994. This option would yield an intermediate thermal power density, and would be the option yielding the lowest gamma emission rate. The third fuel option would be to use the Pu-238 obtained from Russia under the recently signed purchase agreement. This option could yield the highest thermal power, even higher than the maximum levels analyzed in our previous parametric studies.

The previous RTG design studies were based on the use of five standard GPHS modules per generator and two rings of 16 unicouples per module. In response to a request from JPL, the present study derives EOM power predictions for RTGs with five, six, and seven heat source modules, for each of the three fuel options described above, and compares the results with JPL's latest power demand goals (as revised on 2/18/94).

Our results show that an RTG with five heat source modules would fall far short of meeting JPL's goals with U.S. fuel. With the Russian fuel, it could meet the power demand plus 20% contingency reserve, but without the additional 10% margin stipulated by JPL.

For an RTG with six heat source modules (which increases the RTG mass by about 3 kg), the use of Russian fuel would provide plenty of margin, the use of new U.S. fuel would fall

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somewhat short of meeting JPL's stipulated 10% margin, and the use of the aged, depleted F5 fuel modules would provide no margin at all.

NASA, of course, would much prefer to use the F5 GPHS modules, because they already exist and have been paid for. But our results showed that the use of those aged and depleted modules would greatly reduce the RTG's power output. Even with six GPHS modules, they could have met JPL's 1992 baseline EOM goal, but not their 1994 goal which is ~10% higher. The depleted fuel modules reduce the power output not only because of their reduced thermal power but also because of the resultant drop in hot-junction temperature and conversion efficiency.

Clearly, much of the efficiency reduction could be recovered by restoring the hot-junction temperature to the proven values (~1000°C) used in previous flight RTGs. Our analyses showed that this can be accomplished by a simple design modification, namely the omission of two uncouple rings without any other design changes. This modification forces the heat to flow through fewer thermoelectric legs, increasing their heat flux and temperature drop. Our analysis showed that this raises the BOM and EOM output power by 19% and 10%, respectively, without exceeding the proven hot-junction temperature limit. It makes it possible to meet JPL's current EOM goal (with 20% contingency reserve plus 10% margin) with six GPHS modules, but not with five. We plan to explore additional design modifications that might enable us to meet JPL's EOM goals with an RTG employing five depleted GPHS modules.

EFFECT OF NUMBER OF HEAT SOURCE MODULES ON SIZE AND MASS OF PFF RTG

5
10 x 16
15.1"
15.8 kg

6
12 x 16
17.2"
18.1 kg

7
14 x 16
19.3"
20.4 kg

Heat Source Modu
Unicouples
RTG Height
RTG Mass

EFFECT OF FUEL OPTION AND NUMBER OF HEAT SOURCE MODULES ON POWER PROFILE AND MASS OF RTG FOR PLUTO MISSION

Two Unicouple Rings per Heat Source Module

EFFECT OF FUEL OPTION AND NUMBER OF HEAT SOURCE MODULES ON RTG PERFORMANCE (2 Unicouple Rings per H.S. Module)

	BOM (1-2000) Pu-238 Enrichment	BOM Thermal Power	Heat Source Modules	Mass of RTG	Optimum RTG Voltage	BOM Hot-Junction Temperature	Power Output		
							Launch	Flyby	EOM
	%	W/module	#	kg	V	°C	W	W	W
Russian Fuel	87.7	254							
	7-1-95*		5	15.8	19	992	90	73	71
			6	18.1	23	1003	109	88	86
			7	20.4	27	1012	129	102	100
Available U.S. Fuel	79.7	231							
	7-1-95*		5	15.8	17	916	75	64	62
			6	18.1	21	930	91	77	75
			7	20.4	25	940	108	90	88
Galileo Spare (F-5)	82.6	220							
	9-2-82*		5	15.8	16	878	68	59	58
			6	18.1	20	893	83	71	70

* Effective Separation Date

JPL's 1994 Baseline Power Demand Schedule for PFF (2-18-94)

Mission Phase	Pre-Encounter			Encounter		Post-Encounter
Duration	8 years			30 days		6 weeks
Mode #	1	2	3	6	6'	7
Activity Time	164 hr/wk	4 hr/wk	20x30 min	16 hr/day	8 hr/day	24 hr/day
Activity	Cruise	Downlink	PrePropulsive Maneuvers	Data Gathering	Data Transmission	
Power (Watts):						
Telecommunication	9.0	24.0	9.0	8.0	24.0	
Power Conditioning	12.2	14.7	15.1	13.5	14.4	
Attitude Control	9.7	9.7	9.9	16.0	9.7	
Data Processing	13.6	8.6	8.6	8.6	13.6	
Propulsion	0.4	0.4	16.9	0.4	0.4	
Thermal Control	1.0	1.0	1.0	1.0	1.0	
Science	1.0	1.0	1.0	6.0	0.0	
Total Power Demand	46.8	59.3	61.4	53.4	58.1	
incl. 20% contingency	56.2	71.2	73.7	64.1	69.7	
incl. 10% margin	61.8	8.3	81.1	70.5	76.7	
Energy Demand, kW hr	4216	130	1	34	96	

COMPARISON OF RTG* POWER OUTPUT WITH PFF POWER DEMAND** FOR THREE FUEL OPTIONS

* 5 Heat Source Modules, 10 Unicouple Rings

** 2-18-94

COMPARISON OF RTG* POWER OUTPUT WITH PFF POWER DEMAND** FOR THREE FUEL OPTIONS

* 6 Heat Source Modules, 12 Unicouple Rings

** 2-18-94

EFFECT OF NUMBER OF STANDARD UNICOUPLS ON PFF RTG WITH 5 GPHS MODULES FROM GLL SPARE (F5)

BOM 0	EOM 8.2	RTG PERFORMANCE YEARS FROM LAUNCH	BOM 0	EOM 8.2
1100	1031	THERMAL POWER, W(t)	1100	1031
878	839	HOT-JUNCTION, °C	1009	968
233	224	COLD-JUNCTION, °C	230	222
6.2	5.4	RTG EFFICIENCY, %	7.4	6.3
68	58	OUTPUT POWER, W(e)	81	65

EFFECT OF NUMBER OF 16-UNICOUPLER RINGS ON PFF RTG WITH 5 GLL-SPARE GPHS MODULES

Thermal Power = 1100 W at Launch, 1031 W at Flyby, Opt. Voltage = 16 V

EFFECT OF NUMBER OF 16-UNICOUPLE RINGS ON PFF RTG WITH 6 GLL-SPARE GPHS MODULES

Thermal Power = 1320 W at Launch, 1237 W at Flyby, Opt. Voltage = 19 V

EFFECT OF NUMBER OF F5 HEAT SOURCE MODULES ON PFF RTG WITH OPTIMUM NUMBER OF STANDARD UNICOUPLS

5
8 x 16
15.5
16

GPHS MODULES
UNICOUPLS
RTG MASS, kg
RTG VOLTAGE, V

6
10 x 16
17.8
19

BOM 0	EOM 8.2	RTG PERFORMANCE YEARS FROM LAUNCH	BOM 0	EOM 8.2
1100	1031	THERMAL POWER, W(t)	1320	1237
1009	968	HOT-JUNCTION, °C	994	953
230	222	COLD-JUNCTION, °C	238	230
7.4	6.3	RTG EFFICIENCY, %	7.2	6.3
81	65	OUTPUT POWER, W(e)	95	78

POWER OUTPUT OF RTGs* WITH 5 AND 6 GPHS MODULES VERSUS POWER DEMAND FOR PLUTO FAST FLYBY MISSION

*Using Aged (F5) H.S. Modules and Optimum Number of Unicouple Rings

REVISED DESIGN OF PFF RTG (Smaller, Lighter, More Efficient)

Cross-Sectional Views Showing Pyrolytic Support Studs at Eight Heat Source Corners

A-A

B-B

COMPARISON OF PREVIOUS AND REVISED PFF RTGs

6 Depleted (F-5) Heat Source Modules, 10 Standard Unicouple Rings

17.2"
8.4"

2.5%

17.8 kg

Height
Diameter

Thermal Loss
Through H.S.
Supports

Mass

14.6"
8.4"

2.0%

15.4 kg

EXPLORATORY ANALYSES (Incomplete)

To determine whether the power degradation rate can be significantly reduced during periods when the power demand is less than the RTG's maximum capability, by:

- Reducing its output voltage**
- Increasing its output current**
- Increasing the Peltier cooling rate**
- Reducing the hot-junction temperature**
- Reducing the thermoelectric degradation rate**

This strategy, if feasible, would eliminate the need for a shunt dissipator

EFFECT OF RTG* VOLTAGE AND THERMAL POWER ON ELECTRICAL OUTPUT

* 6 Heat Source Modules, 10 Unicouple Rings

EFFECT OF RTG* VOLTAGE AND THERMAL POWER ON HOT-JUNCTION TEMPERATURE

* 6 Heat Source Modules, 10 Unicouple Rings

HOT-JUNCTION TEMPERATURE VERSUS RTG* POWER FOR VARIOUS THERMAL POWERS

* 6 Heat Source Modules, 10 Unicouple Rings

EFFECT OF HOT-JUNCTION TEMPERATURE ON POWER LOSS DUE TO THERMOELECTRIC DEGRADATION (Without Fuel Decay)

OFF-OPTIMUM RTG VOLTAGE TO MATCH PFF POWER DEMAND PROFILE

HOT-JUNCTION TEMPERATURE

THERMOELECTRIC DEGRADATION

EFFECT OF OFF-OPTIMUM RTG VOLTAGE SCHEME ON POST-ENCOUNTER POWER OUTPUT VERSUS DEMAND