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RTG'S FOR SPACE EXPLORATION AT THE END OF THE 20th CENTURY

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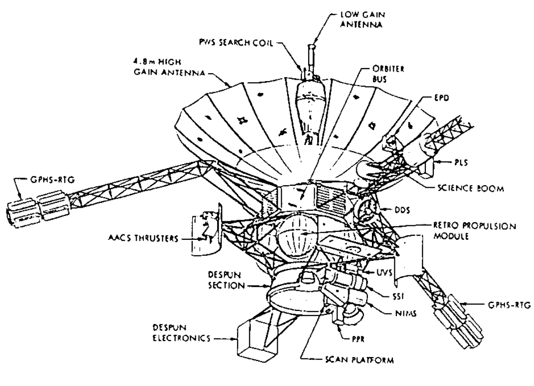
Abstract

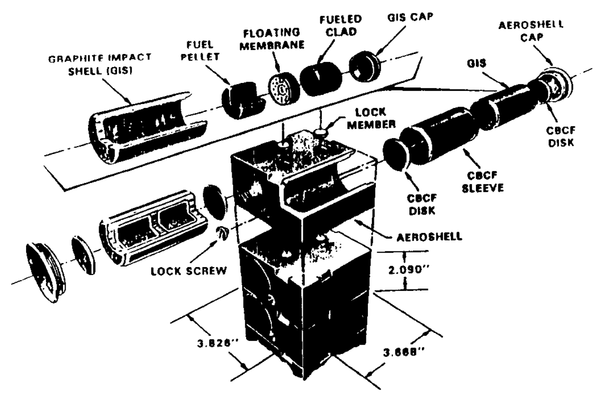
The radioisotope thermoelectric generators (RTG's) are the only type of energy conversion devices that are available for spacecraft designed for environments where sunlight is weak. The two upcoming missions Galileo and Ulysses will both use General Purpose Heat Source (GPHS) RTG's. Two other missions that are planned for mid nineties and will carry RTG's on board are: Comet Rendezvous Astroid Flyby (CRAF) and Cassini. Another mission that might become a program start in the last decade of the 20th century is Solarprobe. Solarprobe is most likely to use Modular RTG's. Several other missions that are in different planning stages are in need of RTG's to meet their power requirements: Mars Rover Sample Return, planetary penetrators, microspacecraft and Mars Egg. The paper briefly describes all of these missions stressing their RTG requirements.



Galileo spacecraft
Figure 1

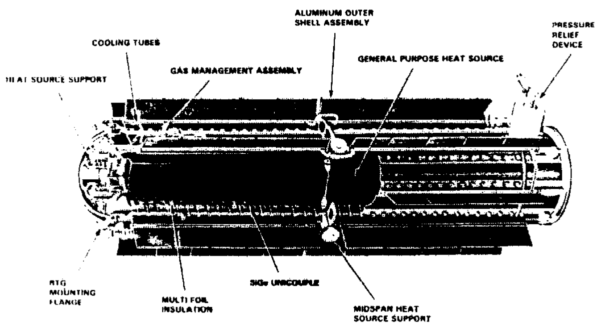
Galileo

Galileo is a mission to explore Jupiter and its moons. The spacecraft shown in figure 1 will be launched in October 1989 on a VEEGA (Venus Earth Earth Gravity Assist) trajectory. This trajectory takes the spacecraft first towards Venus. After receiving a gravity assist from Venus the spacecraft will make two close passes of Earth before gaining enough energy to direct itself to Jupiter. This first phase of the mission will take almost 6 years while Jupiter satellite tour will last only 22 months. Approximately 150 days before the spacecraft reaches Jupiter, a probe will be separated from the orbiter and inserted into the atmosphere. As the probe drifts down it will transmit scientific measurements to the orbiter. The orbiter will conduct various particle, plasma and magnetic field measurements as well as solid-state imaging. The Galilean satellites will be mapped at a roughly 1 km resolution.



General Purpose Heat Source
Figure 2

CH2781-3/89/0000-0715 $1.00



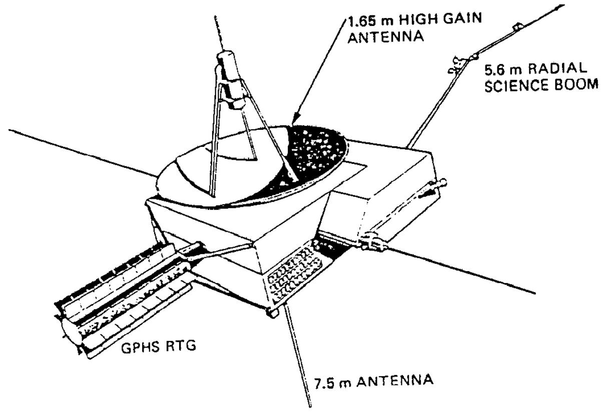
GPHS RTG
Figure 3

All power to the Galileo spacecraft is supplied by two GPHS RTG's. Figure 2 shows an expanded view of the GPHS. In October 1989, the time Galileo will launch, the fuel is expected to deliver about 4,294 thermal Watts per RTG. The total power produced by both RTG's at the Beginning of Mission (BOM) is 572 electrical Watts. The power decreases to 483 electrical Watts at the End of Mission (EOM). The working material in the Galileo RTG's is Si-Ge configured as unicouples shown in figure 3. Each one of Galileo RTG's has 572 unicouples. The unicouples operate at 1000°C on the hot side and 300°C on the cold side.

Ulysses

The Ulysses mission objectives are to explore the heliosphere and view the sun over a full range of heliographic latitudes. The chief study areas are: the solar corona, solar wind, structure of the sun-wind interface, heliosphere magnetic field, solar and non solar cosmic rays and interstellar and interplanetary neutral gas and dust. The Ulysses spacecraft shown in figure 4 will be launched in October 1990. Initially the spacecraft will travel to Jupiter and use the planet's gravity to bend its trajectory out of the ecliptic plane. The benefit of out of the ecliptic observations is that the properties of the solar corona are less complicated in polar directions.

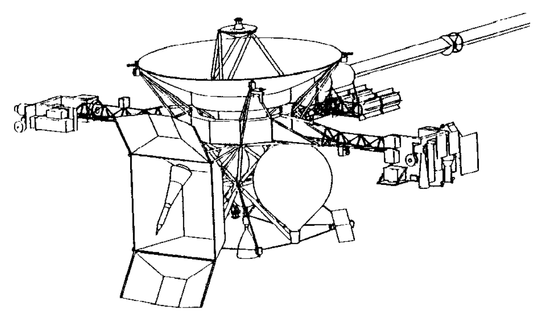
The Ulysses spacecraft will use only 1 RTG to satisfy the power requirements. The RTG used by the Ulysses program is the same kind GPHS RTG as slated for the Galileo project. The Ulysses RTG is expected to deliver 282 electrical Watts at BOM and 254 electrical Watts after 5 years at EOM. The BOM fuel loading is 4,302 thermal Watts.



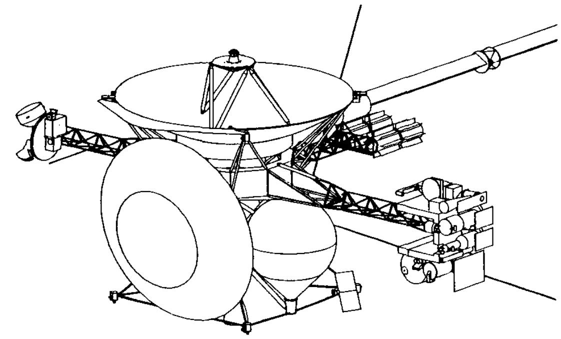
Ulysses spacecraft
Figure 4

CRAF

The Comet Rendezvous Asteroid Flyby (CRAF) has general objectives to obtain fundamental new information about the origin and evolution of the solar system, prebiotic chemical evolution and the origin of life, and astrophysical plasma dynamics and processes. The spacecraft depicted in figure 5 will conduct scientific observations of a selected comet and asteroid. The comet and asteroid selected depends on the launch date. It is currently slated for August 1995. The CRAF mission power needs will be met by 2 RTG's. The RTG's will be of the GPHS type or the Modular type depending on the availability at the project start. A spare Ulysses RTG might be used if there is one left over after launching the Ulysses spacecraft. CRAF might also use the spare Galileo converter and fuel from the Qualification unit. Ulysses' spare RTG and a refueled converter would produce for CRAF 543 electrical Watts at BOM and 461 electrical Watts at EOM some 7.5 years later.



CRAF spacecraft
Figure 5



Cassini spacecraft
Figure 6

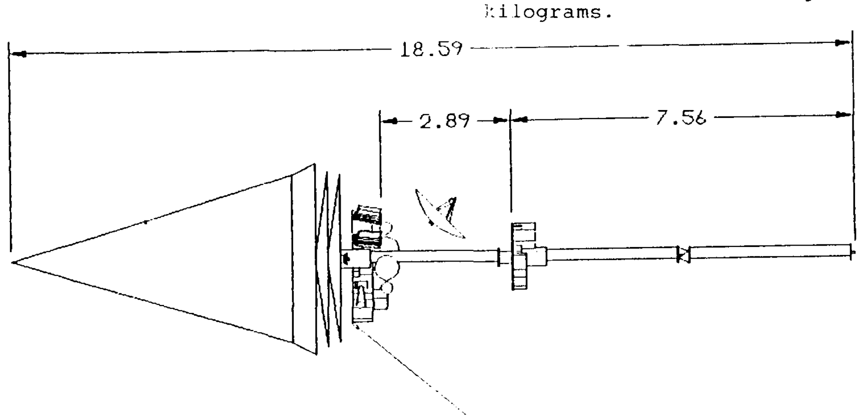
CASSINI

The Cassini project is to be a mission to Saturn that would orbit the planet and drop a probe into the atmosphere of Titan, Saturn's largest satellite. The spacecraft would use an Earth and Jupiter gravity assist to get to Saturn. Several asteroids are candidates for flybys en route to Saturn. The probe would enter Titan's atmosphere and the spacecraft would continue to orbit the planet for another 30-40 revolutions. Cassini spacecraft will be powered by two RTG's shown in figure 6. Just like in case of CRAF they might be of GPHS or MOD type. If the spacecraft were to use new RTG's with new fuel, they would deliver 308 electrical Watts at BOM and about 244 electrical Watts at EOM for 94,000 hour long mission.

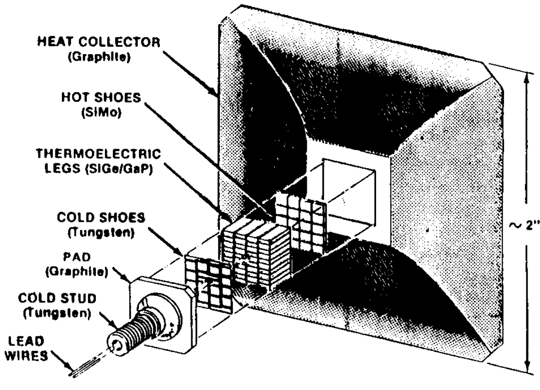
Solarprobe

The Solarprobe spacecraft depicted in figure 7 will investigate an extensive region of the solar system beginning extremely close to the sun (perihelion of 4 solar radii) and stretching all the way to the orbit of Jupiter. The spacecraft will carry out scientific investigations in three areas: solar internal dynamics and relativity, solar plasma and particle dynamics, and solar atmospheric structure. Space plasma scientists will have the opportunity to directly sample in situ that portion of the sun's outermost atmosphere where the corona is heated and the solar wind is formed and accelerated.

Because the spacecraft will travel first towards Jupiter, it must rely on RTG power. It will take 3 years for Solarprobe to complete a single pass of the sun. The power requirement at EOM is 416 electrical Watts. Solarprobe might require 3 Modular RTG's each containing 10 GPHS modules. Modular technology enables sizing the RTG's as smaller units and thus increasing the distance from the RTG's to the science platform. Maintaining a large distance is important to reduce the radiation doses received by the spacecraft electronics. Similar to the aforementioned missions Modular RTG's use GPHS modules for fuel, however, the conversion technology is different. The working material is still Si-Ge but it is arranged in groups of 8 multicouples like the one shown in figure 8. Each group of 8 multicouples receives heat from 1 GPHS module and produces 30 volts forming a basic building segment of a modular RTG. A Modular RTG is shown in figure 9. Solarprobe's 3 RTG's employing 10 segments each would produce about 520 electrical Watts at BOM. Each RTG would be 80 centimeters long and weigh 22 kilograms.



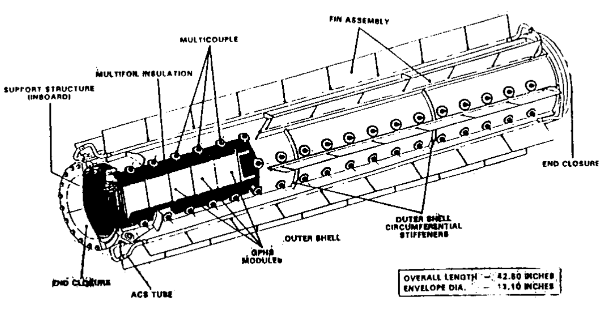
Solarprobe spacecraft
Figure 7



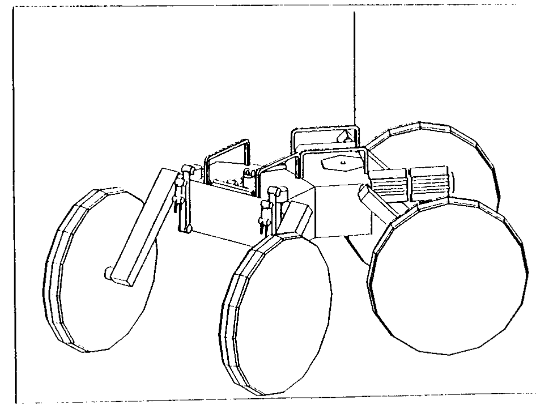
Multicouple
Figure 8

MARS ROVER SAMPLE RETURN (MRSR)

MRSR is a precursor to piloted Mars exploration. The mission would include a vehicle to collect the soil samples. The study is examining designs for a rover that could travel up to 1000 km. The lander and rover (shown in figure 10) would evaluate samples for transport to Earth and conduct on-site investigations. The electrical needs of the rover could be met by an RTG. Such an RTG would deliver from 500-1000 Watts electrical at the end of 5 years of operation. The major difference between the MRSR RTG and other space RTG's is that it is designed for operation in nonvacuum conditions. The Mars atmosphere includes mostly CO_2 but also minor amounts of N_2, Ar, O_2, CO, H_2O and H_2. An RTG operating in such an environment would have to be sealed to prevent oxidation of the hot internal components. A one way valve might have to be incorporated to relieve the helium that builds up inside. If the helium were not vented, the power produced by an RTG would reduce drastically. The power drop is due to the helium convectively shunting the heat away from the thermoelectric modules.



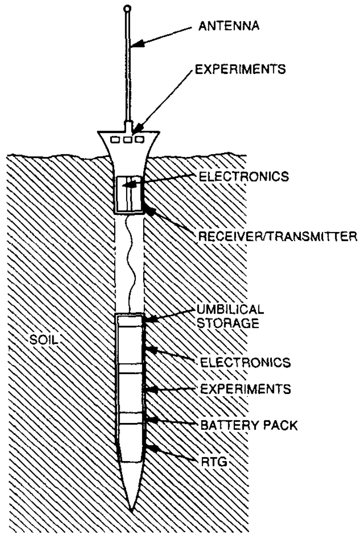
MOD RTG
Figure 9



Mars Rover
Figure 10

Planetary (Mars) Penetrators

There are four principal reasons for using penetrators to deploy experiments on planets. First, a number of penetrators can be deployed at widely separated places on the planet during a single mission therefore establishing a network of stations to measure geophysical, meteorological, geochemical and morphological phenomena. Second, penetrators can place experiments beneath the surface to obtain measurements at greater depths than possible by either soft or hard landers. Third, penetrators can provide important information on site selection for a possible sample return mission. Finally, penetrators can reach areas that cannot be reached by larger, more sophisticated soft landers due to mission safety constraints.
A basic design of a penetrator is shown in figure 11. The power to the penetrator is supplied by a small RTG. Such an RTG would produce between 0.5 and 2 watts of electrical power depending on the mission requirements. Si-Ge would most likely be used in such an application as the working material. Because of the limitations on temperature differential the efficiency of the RTG is not expected to exceed 4%. The thermal input of the RTG would be between 10-50 thermal Watts. This dissipated heat would be beneficial for maintaining the penetrator at proper temperature. Designs of Si-Ge thermopiles that meet requirements of the penetrators currently exist but there are no space qualified small heat sources. Most likely, the RTG heat source would have to be exclusively designed for the penetrator to ensure fuel containment under different abort scenarios at launch. Another option, depending on allowable size, weight and G-loading, might be to use a GPHS module with only as many PuO_2 pellets as needed to produce the correct fuel loading.

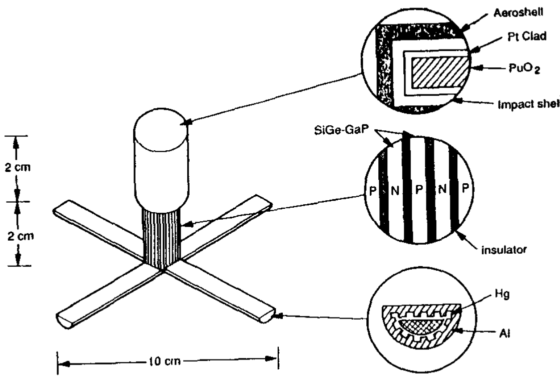


Planetary penetrator
Figure 11

<u>Microspacecraft</u>

Microspacecraft represents a new approach to conducting space science. The concept is to build small spacecraft that weigh less than 5 kg and are launched conventionally or by electromagnetic launchers. Meeting mission goals would be assured through multiple, frequent launches as opposed to the current approach of highly reliable, component redundant, single spacecraft. The microspacecraft could be involved in particle and fields, imaging, radio science, atmospheric science or surface science. The power needs of a microspacecraft would be met by a mini-RTG. A concept of such an RTG is depicted in figure 12.

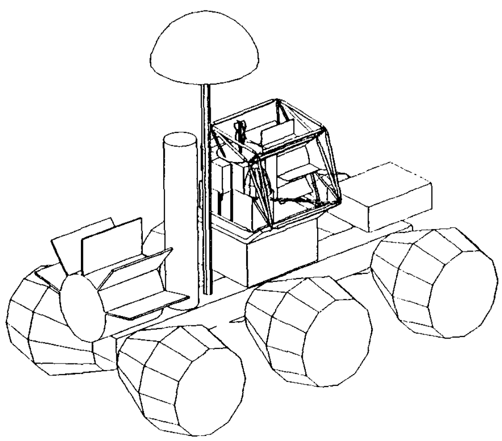
The RTG would rely on a heat source supplying 25 thermal Watts. After 5 years this RTG would deliver about 2 Watts of electrical power. The total weight of the RTG would be under 200 grams with 75% of it concentrated in the heat source. The thermoelectrics are expected to weigh only 11 grams. Advanced SiGe/GaP could be used as thermoelectric material arranged in form of 46 couples producing 0.2 Volts. The thermoelectrics would operate between 1273 K and 530 K. An Hg-Al heat pipe radiator would provide 72 cm^2 of surface area to assure low cold junction temperature.



Mini RTG
Figure 12

<u>Mars Egg</u>

Mars Egg is an autonomous package of science instruments that would be dropped by a Russian Mars Rover on the surface of Mars. Such package would include a seismometer, microwave atmospheric sounder, IR laser spectrometer, and a camera. All the instruments would be powered by a Modular RTG. Such an RTG pictured on the top of the Rover in figure 13 would supply about 50 electrical Watts. The RTG would consist of 3 GPHS segments weighing a total of 9 kilograms.



Mars Egg
Figure 13

Summary

There is a wealth of missions reaching into the 21st century that need RTG power to satisfy their electrical needs. Besides the RTG's of standard size similar to the 300 watt units built for Galileo and Ulysses spacecraft, there is a need for smaller RTG's supplying 2-50 watts. Modular RTG's might be able to satisfy the upper part of this range, therefore it is very valuable to have Modular RTG technology flight ready. However, there are still many applications where the Mod RTG's would be too bulky and heavy. Missions that utilize penetrators, microrovers, microspacecraft or autonomous experiments are in dire need of much smaller RTG's.

References

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Surface Penetrators for Planetary Exploration: Science Rationale and Development Program, James P. Murphy et al, NASA report TM-81251

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