RADIOISOTOPE THERMOELECTRIC GENERATORS (RTGS) FOR LUNAR EXPLORATION.

D. F. Woerner[1], [1]Jet Propulsion Laboratory/Caltech, 4800 Oak Grove Drive, MS 321-520, Pasadena, CA 91109, david.f.woerner@jpl.nasa.gov

Introduction: RTGs have been used for deep space exploration for decades, including powering lunar surface instruments during NASA's Apollo missions. RTGs have proved to be highly reliable. NASA and the Department Of Energy (DOE) are working on future generator designs in addition to producing the currently available Multi-Mission Radioisotope Thermoelectric Generator or MMRTG. An MMRTG is currently powering the Curiosity rover on Mars and was designed as a compact, rugged power source capable of landing on other bodies. This specific generator is now more than six years old and performing as predicted.

This presentation will provide the latest information on MMRTGs and other RTGs being engineered and studied.

Body: An MMRTG is on Mars powering the Curiosity rover[1], an enhanced or eMMRTG is being engineered with an industrial partner, and a study of an Advanced RTG, or ARTG, recently concluded with a briefing on the parametric analysis. Each of these generators relies upon several decades of RTG flight experience. The MMRTG is a derivative of the generators used for the Viking and Pioneer missions. The eMMRTG[2] uses almost the exact design of the MMRTG. The ARTG draws on the platform flown on the Cassini and Galileo missions. Similarly the enhancement to the MMRTG thermoelectric couples (unsegmented) is a stepping-stone for the couples needed for the ARTG (segmented).

The MMRTG development was started to satisfy the requirements of multiple missions including the Mars Science Laboratory (MSL) mission. The generator development began in late-2002 to support the 2009 launch of the MSL mission. The DOE completed the generator on time and fueled it; shortly thereafter the mission chose to slip the launch date. This left the MMRTG fueled and in storage for more than two years before it was launched and still following the 2011 launch, the MMRTG produced 114W, more than required. As it now operates on Mars it is providing more energy than the mission routinely requires, and power output degrades at approximately 4.8% per year, close to the degradation rate predicted months before launch and more than three years ago.

The MMRTG is a heat source for MSL[3] as well as a power source. The rover design includes heat exchangers that pick up waste heat from the MMRTG and transfer the heat to a circulating fluid. The fluid is routed throughout the rover to keep the avionics operating in a temperature band favorable to prolonging their lifetime.

The MMRTG was conceived as a multi-mission generator and as such operates in both vacuum and planetary atmospheres of Earth and Mars; it could power spacecraft in orbit around distant planets or be landed on them. It was also designed to multi-mission requirements that were not relevant to the MSL mission including the atmosphere of Titan. Further examples incude that the MMRTG was qualified to worst case Atlas V launch vehicle environments and was designed to minimize magnetic field emissions to meet the needs of science missions requiring the most powerful launch vehicles and/or measuring planetary magnetic fields.

There are two MMRTGs in NASA's inventory and both are allocated to the proposed Mars 2020 mission. In time, the mission will down select to one MMRTG and have it fueled for flight.

As part of a plan to enhance the MMRTG, JPL has begun to transfer thermoelectric couple (TEC) technology to the MMRTG TEC manufacturer that will enhance power output and reduce degradation, and JPL has begun performing systems engineering for the eMMRTG system using these new TECs.

eMMRTG engineering has identified a single, simple change to the MMRTG's design to support the new TECs; an emissivity coating added to a thin metal surface inside the generator will lower the temperatures that would be problematic if left unchanged. The new TECs and the change to the liner result in approximately a 24% enhancement to conversion efficiency. Further, the Beginning Of Life (BOL, the time of fueling) power boost is estimated to be approximately 166 W in a 4k thermal sink and under a 32V load. That is a 36% increase over the MMRTG in the same conditions. The eMMRTG is estimated to also degrade more slowly than the MMRTG. The eMMRTG is estimated to produce 109W, 101% more than the MMRTG's 54W, at EODL, or after 17 years of operation.

The eMMRTG technology transfer from JPL to industry is scheduled to be complete by the end of the 2018 fiscal year. NASA will then have the option to build and qualify an eMMRTG, if the transfer was completed successfully. The first eMMRTG could be ready for fueling as early as late 2020 or early 2021.

NASA will also have the chance to enhance the unsegmented TEC technology if the technology transfer was successful. Power output can again be increased significantly by adding a small segment to each of the two TEC legs, thereby creating segmented TECs. Generator concepts using these segmented TECs have been named Advanced RTGs or ARTGs.

Thermoelectric couples in general, due their design, allow for a great deal of flexibility, and this enabled the ARTG trade space to be studied parametrically and focusing on three unique designs: a single-point design, a modular design, and a multi-mission design. The single-point design looks very similar to the RTGs used on the Galileo and Cassini missions. This design would likely be large relative to the MMRTG, over twice the length but capable of producing ~500W at BOL and be designed to operate in vacuum only. Had this generator been available when Cassini launched, the mission would have needed only two generators rather than the three that were launched.

The modular ARTG design is significantly different from the single-point design. This generator would consist of modules that could be stacked to produce more powerful generators. The "base" module would produce approximately 45W. Power output would reach approximately 425W by stacking eight of these modules together. The TECs for this modular design would be made of the same materials as the TECs for the other ARTGs, but rather than use standalone TECs, the TECs would be packaged in a higher-density matrix, sometimes called a close-packed array. The modular ARTG would be rated for vacuum operation only.

A multi-mission ARTG would draw heavily upon the eMMRTG and enhance it further. The generator would be longer and weigh more but would produce approximately 200W of power at BOL as compared with the eMMRTG's 166W at BOL. The multi-mission ARTG would preserve the multi-mission requirements of the eMMRTG to the maximum extent practicable.

Conclusion: RTGs to support a variety of lunar missions are available or in detailed engineering development. Some designs could be available in less than eight years and could offer significant benefits over the current generation RTG.

References:

[1] NASA/JPL, *Mars Curiosity Rover - Mars Science Laboratory MMRTG Power System 2011,* video, http://www.youtube.com/watch?v=VsYC3Yz2kZM.
[2] Woerner, D., Cairns-Gallimore, D., Zakrajsek, J., O'Malley, T. (2014) NETS 2014, *Getting to an enhanced MMRTG*. [3] Bhandari, P. et al. (June 2011) SAE International Journal of Aerospace, vol. 4 no. 1 299-310.