ADVANCED STIRLING RADIOISOTOPE GENERATOR DESIGN OVERVIEW AND FUTURE PLANS.

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Introduction: The purpose of this paper is to provide a summary of the Advanced Stirling Radioisotope Generator (ASRG) history, a summary of the current flight ASRG design, the latest flight ASRG predicted performance, a status of the ASRG program and a layout for future Stirling based Radioisotope Power System plans.

Background: Radioisotope power conversion provides enabling technology for National Aeronautical Space Administration (NASA) missions that are constrained for electrical power due to inadequate available solar energy. In 2000 a Stirling Radioisotope Generator (SRG110) program was awarded to Lockheed Martin (LM), sponsored by the Department of Energy (DOE) and funded by NASA, to develop a significantly more efficient radioisotope power generator than the existing thermoelectric generator technology and to preserve a limited ^{238}Pu supply. In 2006, the SRG110 contract was replaced by the ASRG contract. This new contract, also sponsored by DOE and funded by NASA, implemented a more advanced Stirling convertor design to achieve even greater performance and higher specific power than the SRG110 design. In August 2008, an Engineering Unit (EU) ASRG was delivered to NASA Glenn Research Center (GRC) for extended operation testing. After the July 2012 Final Design Review (FDR), procurement of parts for the qualification unit ASRG proceeded.

Description: The ASRG is comprised of two physical units: the Generator Housing Assembly (GHA) and the Advanced Stirling Convertor Controller Unit (ACU) connected via three harnesses. The GHA is a modular, self-contained unit designed to be cantilever-mounted at one end to a host spacecraft, rover, or lander. The GHA consists of a housing with four radiator fins enclosing two Advanced Stirling Convertors (ASCs) mounted back to back, each with a dedicated heat source, heat source support and bulk thermal insulation. The flight GHA heat source is the plutonium fueled General Purpose Heat Source (GPHS). The GHA also has a Shunt Dissipator Unit (SDU) attached to the outboard end of the GHA. The SDU is electrically connected to the ACU and provides a direct, self-contained means to dissipate excess electrical power from the ACU to heaters where the heat is radiated to space. Each ASC converts the heat from one heat source into reciprocating motion, driving a linear alternator to produce AC power. The approach of dual opposed ASCs allows the cyclical force produced by each operating ASC to be reacted one against the other, thereby canceling the majority of the force from a single ASC. The ACU is an active-power-factor design, synchronizing the ASCs and maintaining a fixed-frequency operating point. The ACU is single-fault tolerant and uses high-frequency pulse-width modulation to create a sinusoidal voltage waveform to control the piston motion. The ACU rectifies the AC power to DC for use by the host mission. The DC power is compatible with battery or capacitor dominated spacecraft bus with a voltage range of 22 to 34 volts. The ACU also provides state of health telemetry and status.

Performance: The design life of a fueled ASRG is 17 years, 3 years in storage and 14 years in mission operations. The ASRG design meets NASA Planetary Protection cleanliness requirements specified in NPR 8020.12C, Mission Category IVc. The fueled ASRG is predicted to produce, at the beginning of life (BOL), 135 Watts DC power at 28 Volts and at the end of life (EOL) produce 120 Watts DC power at 28 Volts. This corresponds to a BOL specific power of 4.9 W_e/kg. The ASRG efficiency is summarized in Table 1.

Table 1: ASRG Conversion Efficiency

Description		Conversion Efficiency	
		BOL	EOL
GPHS to ASC		0.84	0.84
ASC	Stirling Convertor	0.44	0.43
	Alternator	0.90	0.91
ACU		0.88	0.84
Overall		0.293	0.276

The flight ASRG mass is approximately 29 kg. The GHA occupies a volume of approximately 0.11 cubic meter (roughly 79 by 38 by 38 cm) and the ACU occupies a volume of approximately 0.01 cubic meter (roughly 30 by 13 by 25 cm). The final ASRG design provides a five-fold thermal to electric efficiency improvement, a near two-fold specific power improvement and twenty percent higher power output when compared to the current RTG design, thereby preserving the limited ^{238}Pu supply and enabling more science payloads per mission.

Program Status: The ASRG program received notice of termination for convenience in November 2013. When the cancellation notice was received, the ASRG program was in the middle of parts procurement and assembly for the qualification unit ASRG. Approximately 70 percent of the GHA qualification unit hardware parts were completed. The two qualification unit ASCs were assembled with over 90% of its final flight parts and the unit had completed a few hours of early checkout run time. The remaining six flight ASCs were in various levels of parts procurement. The ACU Engineering Development Unit 4 Open Frame Assembly (EDU4-OFA), a flight controller design manufactured with commercial parts, was completed and testing was in process. Testing has currently verified greater than 90% of the ACU requirements. Over 99 percent of the qualification unit ACU parts were procured. At the time of termination, all major ASRG program technical challenges were resolved.

Future Plans: Despite the termination of the ASRG program, development of Stirling technology is continuing. NASA GRC continues its long term "ASC-E3" development contract with Sunpower, manufacturing ASC-E3 convertors based on the flight ASC design to prove the performance, long term operation and reliability of the ASC technology. Under this contract, Sunpower is delivering a total of four ASC-E3 pairs to NASA GRC for extended continuous operations and for demonstration tests. The first two pairs of ASC-E3 are pathfinders of the flight ASC. These two ASC-E3 pairs have been delivered to NASA GRC. The first pair completed GRC performance verification testing and is currently supporting ACU testing at LM Coherent Technologies (LMCT). The second ASC-E3 pair is under extended continuous operations testing at NASA GRC. The remaining two ASC-E3 pairs are identical to the flight ASCs and are scheduled for delivery in 2014. The extended continuous operations testing time for the four ASC-E3 pairs is expected to reach 25.5 years in 2018 which represents 1.5 times the life of the flight ASCs. NASA GRC is establishing a new contract with LMCT to deliver an ACU EDU4-OFA in May 2014 with an option to build, test and deliver a second identical EDU4-OFA. The unit(s) will be used at NASA GRC for system-level integration and test with the ASC-E3 units starting in 2014. To demonstrate the readiness of ASRG for future mission applications there is a proposed concept to build and deliver an ASRG for system test as a hosted payload on either a Geosynchronous Orbiting Satellite or International Space Station operating in the electrically heated configuration. This hardware could be built using existing ASRG qualification unit hardware. The ease of scaling the Stirling convertor to higher power also enhances the potential of designing a 300 to 500 Watt ASRG that will provide higher specific power and reduce mission integration complexity.

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