DESIGN OF THE SECOND ADVANCED STIRLING RADIOISOTOPE GENERATOR ENGINEERING UNIT. S. M. Oriti, E. J. Lewandowski, NASA Glenn Research Center, 21000 Brookpark Rd, Cleveland, OH.

Introduction: The Thermal Energy Conversion Branch at NASA Glenn Research Center (GRC) has been supporting the development of the Advanced Stirling Radioisotope Generator (ASRG). The ASRG was identified for use on two of the three candidate Discovery 12 missions [1]. A key element of the ASRG project is providing life, reliability, and performance data for the Advanced Stirling Convertor (ASC) as well as the ASRG. For this purpose, NASA GRC has established a laboratory that is conducting extended operation of Stirling radioisotope system hardware. One goal of this effort is to generate performance data over a sufficiently long period of time (tens of thousands of hours) to support probabalistic reliability analyses. NASA GRC has operated several ASCs in continuous unattended mode. This set of convertors represent several generations in the Sunpower ASC design spanning the history of the ASC development. Included are early developmental units (ASC-0s), the hermetically-sealed units developed for the ASRG engineering unit (ASC-Es), and the first hermetically sealed, 850 °C-capable units (ASC-E2s). As of December 2013, GRC has accumulated over 288,000 hours of operation on these ASCs.

The latest engineering model called ASC-E3 are also hermetically sealed and capable of 850 °C hot-end temperature operation. The convertors are being produced by Sunpower to the flight ASC-F design documentation and production practices, and as such exercise the fabrication process planned for the ASRG flight unit convertors. However, the ASC-E3 are not intended to be installed in any qualification or flight level generator. Instead, they will be used for extended operation and system testing. In the past, the configuation of the GRC extended operation test articles have not accurately emulated the flight unit hardware. For the ASC-E3s, the decision was made to tailor the extended operation hardware such that it emulates the ASRG flight design. This provides the opportunity for executing system-level tests that would normally not be possible until the production of the ASRG qualification unit. This flightlike support hardware has been given the test article name Engineering Unit 2 (EU2).

Design Guidelines: The test hardware designed previously for ASC-E2s differed from a flight generator in several ways. While the housing was made to aesthetically resemble the flight generator, the housing was not used as the heat rejection device for the Stirling cycle. Instead, a coolant collar was attached directly to the inner portion of the convertor's heat rejection flange. This was done to permit easiest control of the convertor's rejection temperature to achieve several different operating scenarios expected during a mission. Also, the ASC-E2 support hardware was not designed to provide a sealed inert argon environment around the convertors, which is achieved in the ASRG flight design. For the design of GRC's ASC-E3 extended operation hardware, the guiding principle was to duplicate all the design features of the flight unit where possible. However, some design features were sacrificed to reduce cost and complexity. These deviations include the use of aluminum for the housing instead of beryllium and a different electric heat source to emulate the radioisotope fuel. The design concept for GRC's flight-like housing is shown in Fig. 1.

Other features have been duplicated with the following exceptions. There will be no pressure relief device since this hardware will not experience ascent through the atmosphere. A remotely-located shunt dissipator unit will be utilized in lieu of one that attaches to the housing. The housing will make use of the same electrical feedthroughs and connectors for power, telemetry, and connection to the controller. The preliminary design effort was previously described in [3].

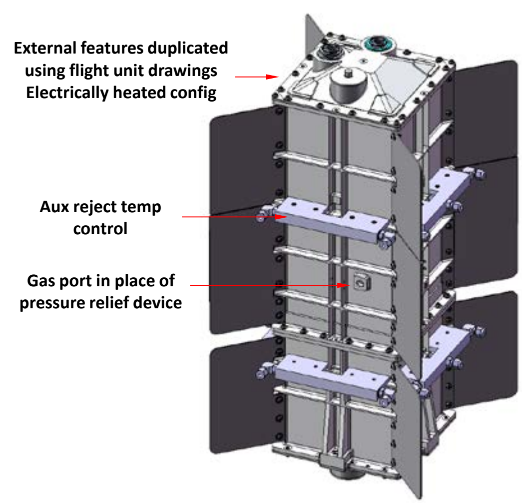

Figure 1. Concept for extended operation of ASC-E3s in a flight-like configuration. The convertors will be installed in a housing that provides cooling via conduction.

Convertors: The first pair of ASC-E3s, serial no. 1 and 2, have been identified for use in the EU2. These convertors were delivered to GRC in November of 2012. They underwent all planned tests, which included thermal insulation loss characterization, independent performance mapping [2], and a period of extended operation. These convertors have each accumulated over 3,000 hours of operation. The convertors were then assembled into a dual-opposed horzitonal configuration for controller checkout testing at Lockheed Martin. Flightlike connectors were installed on the ASCs to mimic those on the ASRG flight design (Fig 2). It is anticipated that the ASC-E3 pair will be returned to GRC Spring 2014.

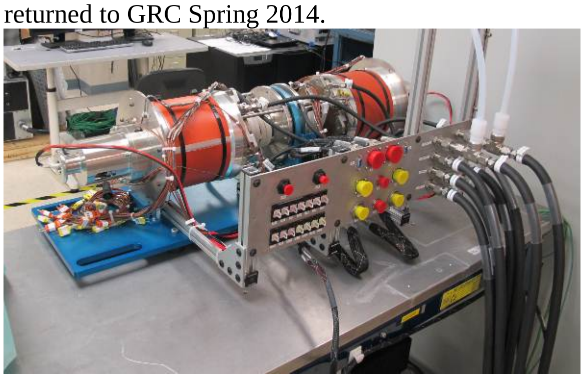

Figure 2. ASC-E3 #1 and #2 prepared for controller checkout testing at Lockheed Martin.

Electric Heat Source: The decision has been made to deviate from the flight unit's ground testing electric heat source. This was done to reduce cost and improve life of the heat source for in-air extended operation. Building on past experience with high-temperature convertor operation, GRC devised two heat source concepts. Both consist of an array of cartridge heaters inserted into a metal block, either nickel 201 or elemental molybdenum. Both designs duplicate the outer geometry of a radioisotope heat source, but only the molybdenum option has an equivalent heat capacity. To achieve the correct thermal mass, the molybdenum block design had the majority of its inner mass removed.

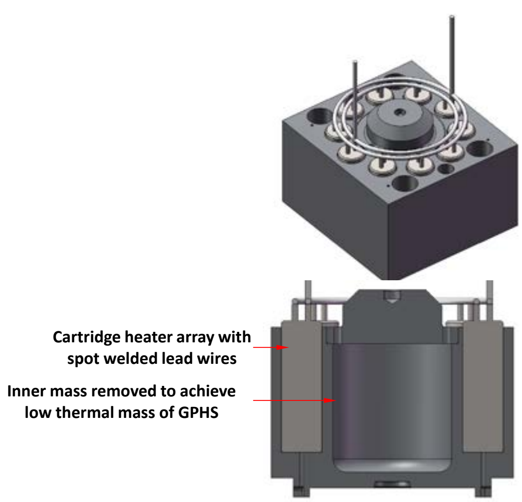

Figure 3. Design of a long-life electric heat source that emulates a radioisotope heat source.

Environmental Condition Control: The EU2 design allows for three methods of rejection temperature control: convection, radiation, and local conduction. The housing was design to have the same thermal properties as the ASRG flight design, so forced convection during ground testing is sufficient to achieve the needed heat rejection. Similarly, the radiation heat transfer properties have been duplicated so the EU2 is capable of being tested in thermal vacuum environment and performing similarly to the flight ASRG design. To enable tests encompassing the full range of heat rejection environment temperatures, auxiliary cooling blocks were designed that optionally attach to the housing ribs. These blocks contain a fluid passageway that will also local control of the housing ribs that coincide with the convertor rejection zones. These blocks also serve to increase the aluminum housing's thermal mass such that it matches that of the beryllium housing design. The housing is capable of containing an internal vacuum, allowing the EU2 to be used to test the insulation and convertors in a simulated space vacuum environment, with the associated changes in efficiency and dynamic performance, without putting the entire generator in a thermal vacuum chamber.

Controller: The EU2 assembly consists of the convertor pair in the housing (generator housing assembly, or GHA), and a controller. Lockheed Martin's engineering development unit (EDU) version 4 controller has been chosen for use in the EU2. This is the same controller that will be used for checkout testing with ASC-E3 #1 and #2 at Lockheed Martin Coherent Technology.

Instrumentation: The EU2 will incorporate much of the instrumentation that was planned for the ASRG qualification unit. Of particular note is the specially-designed sensor for monitoring the convertor hot-end temperature. This resistance temperature device (RTD)measurement system was selected by Lockheed Martin to meet the unique challenge of long-term high-temperature measurement with accuracy and stability. An RTD will be installed on each convertor and be utilized during planned testing.

Conclusion: GRC is preparing facilities for extended operation of a high-fidelity electrically-heated Stirling radioisotope generator incorporating ASC-E3 convertors and an EDU 4 controller. A housing has been designed that emulates the ASRG flight design thermal characteristics, but is made of aluminum instead of beryllium. Buildup will be completed and testing will start by September 2014.

References:

[1]Oriti, S.M. (2011). Extended Operation of Stirling Convertors at NASA Glenn Research Center. *AIAA-2011-5726*.

[2]Oriti, S.M (2013). Performance Measurement of ASC-E3s. *AIAA-2013-3813*
[3]Oriti, S.M (2012). Test Hardware Design for for Flightlike Operation of ASC-E3s. *AIAA-2012-4254*