NASA GRC SUPPORT OF THE FLIGHT ASRG PROJECT. S.D. Wilson[1] and W.A. Wong[1], [1]NASA Glenn Research Center, 21000 Brookpark Rd, 301-2, Cleveland, Ohio, 44135.

Introduction: The U.S. Department of Energy (DOE) and Lockheed Martin Space Systems Company (LMSSC) have been developing the Advanced Stirling Radioisotope Generator (ASRG) for NASA's space science missions. The generator uses two high-efficiency Advanced Stirling Convertors (ASCs), developed by Sunpower Inc. and NASA Glenn Research Center (GRC). GRC provides materials, equipment, testing and inspection services, and related data products to DOE/Lockheed Martin and Sunpower under a Government Furnished service agreement, called "GFX". These services carry out material evaluations, component tests, convertor characterization, and technology transfer.

The majority of GFX tasks have been completed with only some long-term organics evaluation, durability tests, and hardware transfers remaining. The Organics tasks are planned to complete in 2014 while durability tests are being re-evaluated based on current project goals. Sunpower, Inc. is on contract to deliver four additional ASC-E3s in 2014. To support ongoing E3 production, in-process workmanship vibration testing is planned at GRC. Plans also include providing ground support equipment that allows autonomous continuous operation of convertors at Sunpower.

Material and Component Evaluation: Material evaluations have been performed on various components in the ASC in order to predict potential life-limiting mechanisms or provide reliability models with more accurate inputs. The heater head is one such key component in the ASC. This thin-walled machined component has had numerous evaluations and analyses performed, including uniaxial creep testing of thick and thin specimens of the high temperature super alloy. GRC materials and structures personnel have developed an approach to characterize the long-term durability of the heater head, including both deterministic and probabilistic methods. Other evaluations performed include giga-cycle planar spring material tests, fasteners ductility testing, and evaluation of the multiple organic materials used in the cold-end of the convertor. Organics accelerated testing characterizes material limits or functionality based on moderately higher temperatures over time in different environments. In-situ outgassing assessment under gamma radiation, compatibility of off-gassed organics, thermal stability, and mechanical integrity of epoxies were performed. Some organics include Viton, ETFE, Kapton, Tra-Cast, and Loctite secondary thread locker.

Evaluations have also been performed on the power feedthrough, a component used to route electrical power out of the hermetic convertor. The welded feedthrough, shown in Figure 1, use an Inconel body, Alloy 20 pin, and a proprietary joint sealer. Testing included transient thermal cycling and long duration exposure to varying temperature magnitudes and hermeticity tests after each exposure. Also destructive testing was performed at varying temperatures to provide assembly integrity have provided data that verify sufficient margin to meet the 17 year life requirement.

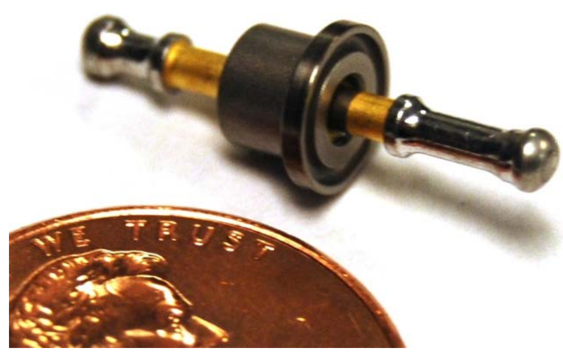

Figure 1. ASC Flight Power Feedthrough.

Convertor Characterization: Convertor level tests are used to characterize performance using operating conditions that simulate various environments anticipated during a mission. External random vibration testing has been used on earlier versions of the ASC engineering units to simulate launch and qualification conditions. Preparations are being made to subject ASC-E3 #4 to external random vibration at launch acceptance levels before extended operation, which simulates the life cycle of a flight convertor. Also, to verify convertors do not contain latent defects or manufacturing flaws, workmanship vibration testing is performed at GRC on all ASC's as part of the normal production process.

Durability Testing: Other tests, called durability tests are intended to stress convertors by operating outside limits imposed by the ASC Specification and experimentally demonstrate the existing margins in the design. The goal of these tests is to verify that the convertor can survive over-test conditions and perform as expected after returning to nominal conditions. These tests subject a convertor to the possibility of lateral contact between the moving components and running surfaces and/or axial contact of the moving components to hard limits. Four durability tests were originally planned, including: 1) repeated starting and stopping of the convertor, 2) exposing the convertor to a large static g-load, 3) random vibration testing at higher piston amplitudes to incite a number of piston and/or displacer contact events, and 4) a controller switch over or other event that would temporarily disable control and allow a limited number of contact events. Test 1 was completed successfully after ASC-E2 #8 was subjected to twice the flight anticipated start/stop cycles without any significant wear on running surfaces or change in performance. Test 2 exposed ASC-E2 #2 to static acceleration applied in the axial and lateral directions, conditions expected to exceed the gas bearing load capacity. Inspection results from after each of the 8 g, 12 g, and 18 g acceleration exposures were completed without any significant wear observed on running surfaces or change in performance measured before and after the test. Tests 3 and 4 have been delayed and are currently being rescheduled.

Extended Operation Testing. Finally, tests are used to observe performance during nominal conditions over thousands of hours of operation. Stirling convertor testing was initiated in 1999 at GRC and has accumulated over 624,000 hrs, where 177,000 are associated with varying generations of the ASC Engineering units. Data collected during earlier ASC-E and -E2 tests provided guidance for design improvements which enhance reliability.

Technology Transfers: GRC provided a variety of unique capabilities for ASRG throughout 2011 and 2012, including in-process inspection of flight hardware and providing test support equipment to enable unattended operation. These technology transfers enhanced contractor capabilities for specialized production processes and tests.

Nondestructive Evaluation. The in-process nondestructive evaluation (NDE) of flight heater heads enabled inspection of finish machined heater heads for any casting defects in the thin-walled high temperature superalloy material. Two procedures were implemented to screen for casting defects. The first procedure, GRC's x-ray Microfocus Computed Tomography (CT) system, was selected to identify casting imperfections in the thin wall and taper region. Able to detect defects as thin as 11-14 microns in width, the state-of-the-art capability was able to detect the majority of casting defects.

The second screening technique that the heater head assemblies went through was the high-temperature (HT) leak test, designed to detect helium leaks caused by through-thickness defects that were too thin for detection using Microfocus CT scanning. A residual gas analyzer response from the tested heater heads were compared to that of a calibrated leak standard to verify requirements. The heater head was pressurized with helium and radiantly heated to simulate the pressure and temperature conditions anticipated in application. The test rig is shown in Figure 2.

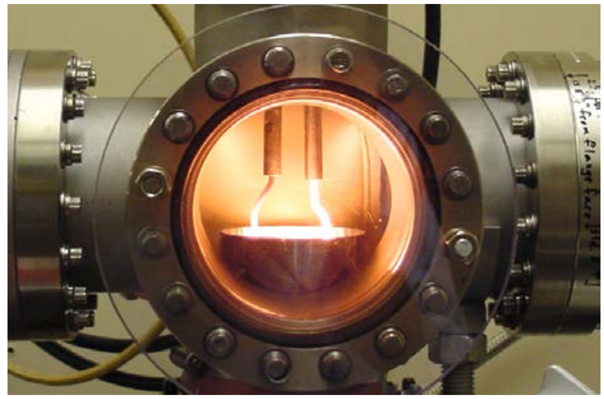

Figure 1. High-Temperature Leak Test rig at GRC.

When the NDE effort was completed in 2013, a total of 34 heater head assemblies had been processed. These efforts were completed to ensure that the heater heads selected for use on flight were of the utmost quality, able to maintain hermeticity and meet the thermal and structural requirements of the ASC.

Test Support Equipment. To support ongoing E3 production, ground support equipment is being provided to Sunpower to enable autonomous continuous operation of convertors. Rack components, including the Failsafe Protection Circuits and APS Buffer Circuit, prevent higher-than-desired piston amplitudes during unattended continuous operation. Also, long life electric heat sources are being provided to enable longer duration testing without the need for more frequent tear down of the test setup, minimizing disruptions during production and post delivery testing.

High-Fidelity Computation. In an effort to improve accuracy of performance predictions, a high-fidelity computational model was developed to predict convertor net heat input, a key parameter needed to determine thermal-to-electric conversion efficiency. Performance predictions were provided to Lockheed Martin for ASRG FDR and to Sunpower for inclusion in the end item data packages for the first four ASC-E3s delivered.

Conclusion: In late 2013, the ASRG Flight contract began termination, largely due to budget restrictions. However, NASA is continuing development of the ASC for future Stirling Radioisotope Generator (SRG). GFX continue to support ongoing ASC-E3 production as part of the new SRG project at GRC.