The Next Generation Radioisotope Thermoelectric Generator Project - Overview and Progress Status

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The Next Generation Radioisotope Thermoelectric Generator (Next Gen RTG) Project is a spaceflight system project within NASA's Radioisotope Power Systems (RPS) Program. The project, in partnership with the Idaho National Laboratory (INL) / Battelle Energy Alliance (BEA), will build and deliver an unfueled, flight qualified Radioisotope Thermoelectric Generator (RTG) system based on RPS Program needs. The Next Gen RTG Project aims to assure the availability of high-power, vacuum-rated RTGs to enable future deep space missions. The Project team is developing that capability through a multi-phase effort that leverages the heritage General Purpose Heat Source - RTG (GPHS-RTG) design and available legacy hardware.

The Project's primary aim is to re-establish the capability to manufacture a silicon germanium (SiGe) unicouple based thermoelectric converter and associated hardware with minimal changes to the heritage GPHS-RTG design. The project will also refurbish the GPHS-RTG Flight Unit #5 (F-5) located at INL and verify its compliance with heritage GPHS-RTG requirements. This paper will detail the project's plans for the development of these systems. Management approaches, technical challenges, and risks will also be discussed.

I. INTRODUCTION

NASA has recognized the need to develop and provide reliable power sources for future deep space missions. The Next Gen RTG project was established as part of a holistic effort to both make power systems available to future missions, and to explore advances in technology to optimize system performance.

The Next Gen RTG Project's key objective is to assure the availability of high power, vacuum rated RTGs. The Project team is developing that capability through a multi-phase effort that leverages the heritage GPHS-RTG design. The SiGe unicouple-based converter technology was developed in the mid-1970's as part of the Multi-Hundred Watt (MHW) RTG program. The MHW- RTGs are still successfully operating on the Voyager 1 and 2 spacecraft more than 45 years after launch. With development of the modular General Purpose Heat Source (GPHS) the SiGe unicouple-based converter was once again selected as the thermoelectric technology for the GPHS-RTG. The GPHS-RTG was initially employed on the Ulysses and Galileo missions. GPHS-RTGs were also selected for use on the Cassini-Huygens and Pluto New Horizons missions[1,2]. Heritage production of GPHS-RTG units resulted in a qualification unit (Q-1) and multiple flight units. GPHS-RTG flight unit F-5 was assembled in support of the Galileo and Ulysses missions. Based on performance characteristics of the flight units, F-5 was ultimately utilized as a flight spare for these missions as well as a backup for the Cassini- Huygens mission.

NASA and the Department of Energy (DOE) have a long history of collaboration and cooperation for the successful development and delivery of space nuclear power systems. This project in particular leverages the capabilities of each organization while ensuring that the management and lessons from the GPHS-RTG program are carried forward[3]. The multi-phase Project plans for the following system variants ("Mods"):

1. Mod 0 seeks to refurbish the GPHS-RTG Flight Unit #5 (F-5) and verify its compliance with heritage requirements. In addition, Mod 0 is investigating the option to increase the available SiGe unicouple inventory available for additional Mod 0 or Mod 1 RTGs by harvesting unicouples from legacy Multi-Hundred Watt (MHW) RTGs currently stored at INL.
2. Mod 1 seeks to re-establish the capability to manufacture the "build to print" SiGe unicouple based thermoelectric converter and balance of plant hardware designs while accommodating the use of the Step- 2 GPHS modules. The goal is to minimize variation from the heritage GPHS-RTG design. The project will conduct protoflight testing to deliver the first unfueled Mod 1 flight unit.
3. Mod 2, which is not currently an active part of the Project, would explore development of thermoelectric technologies that will significantly improve RTG efficiency. These technologies, once they reach a Technology Readiness Level (TRL) suitable for transition

into a maturation phase, are intended to be “drop-in”, minimizing the amount of modification and rework required to supply missions with improved power characteristics.

II. RE-ESTABLISHMENT OF RTG PRODUCTION

The primary objective of the Next Gen Project is the re-establishment of production of a SiGe unicouple-based RTG. The project aims to accomplish this by leveraging heritage designs, updating those designs for current standards, and maintaining a production capability to meet the needs of the science community.

II.A. Philosophy of Heritage Design

The project was given direction by the RPS Program to re-establish the GPHS-RTG under the umbrella of the Next Gen RTG. The GPHS-RTG design (Figure 1) is a flight proven RTG design with seven generators being flown on four separate missions. Performance can be straightforwardly mapped using previous data from those missions as well as lessons learned from building and using those RTGs. Utilizing the previous design balances technical, cost and schedule risks with supporting a 2030 mission.

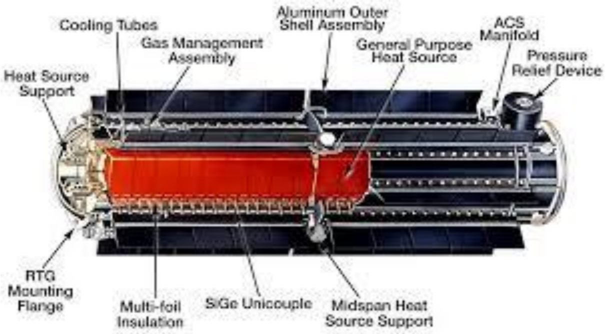

Fig. 1. The General-Purpose Heat Source Radioisotope Thermoelectric Generator (GPHS-RTG)[4]

The Next Gen Mod 1 RTG will re-establish the GPHS-RTG Balance of Plant (BOP) and SiGe unicouple production capabilities using a build-to-print approach which starts with the heritage design that was last produced over 20 years ago and proceeds with the goal of minimizing changes to that heritage design.

This approach begins with the review of heritage GPHS-RTG design documents and standards, manufacturing equipment and processes, assembly, integration, and test requirements. The Next Gen RTG Project will determine how that development and qualification workflow can be reproduced today with the goal of minimizing changes.

With using a heritage design comes the inherent potential for obsolete vendors, components, parts and the need to re-establish manufacturing processes using modern equipment and newly produced materials. Taking this into account the project has taken the approach that the design reviews for the Next Gen RTG project will focus on the obsolescence in the design. This gives the project the opportunity to review the potential changes while maintaining the heritage design as much as possible. The project will participate in the reviews along with the program and independent review board members that the RPS program will assign.

II.B. Key Requirements

The core requirements for the NextGen RTG are centered around the re-establishment of the SiGe unicouple and associated converter technology manufacturing capability and maintaining the successful heritage design of the GPHS-RTG as much as possible in order to provide a long-life power system to support the future of deep space exploration.

Requirements on the Next Gen RTG Mod 1 will be compared against those of the heritage design. This applies to technologies, manufacturing processes, assembly and integration processes, design environments, safety requirements, testing, etc. Requirements will be assessed against the technologies, processes, and standards applicable today. Implementing new requirements may require trade studies to determine cost and schedule impacts to the project. Maintaining heritage requirements due to programmatic constraints may require the approval of a waiver or agreement to a deviation with the applicable requirement’s governing authority.

II.C. Challenges

INL has sifted through mounds of boxes and paperwork to find appropriate heritage information to pass along to the project and contractor. While they have supplied many items, there are still items that are missing. This requires the project to redevelop old documentation or drawings. These challenges are inherent when reestablishing a project from a previous project that relied on paper documentation that was difficult to control. As such, the project is requiring that all documentation be converted to electronic format and drawings be remade in Computer Aided Design (CAD) files and stored electronically. This effort will help ensure that documentation, in the future, will be easily recoverable and better controlled.

The project is also attempting to redevelop the requirements set for the GPHS-RTG in the Next Gen RTG era to address conflicts between heritage and modern-day requirements. Some new requirements may have been incorporated for new environmental standards, or new technical standards. Each Next Gen RTG variant will need to prove the design meets or exceeds the new standards or provide waivers or deviations.

Other potential challenges could involve components that were off the shelf previously but no longer exist. An example of one of these components is the pressure relief device (PRD). The PRD is a critical component of the generator design providing two critical functions: 1) it isolates internal components of the RTG from the atmospheric environment thus preventing oxidation of those internal components, and 2) upon activation, the RTG internal cover gas is vented to space thus achieving the optimal thermal heat transfer environment for peak performance. A trade study will be conducted on the PRD, as the heritage device is not readily available. The trades will determine if a heritage PRD is required or if current off-the-shelf PRDs are useable.

II.D. Enhancement Assessment

With a full thermal inventory of 4500 W, corresponding to a heat source stack of 18 Step-0 or Step-1 GPHS modules, the heritage GPHS-RTG design was capable of producing approximately 300 W of Beginning-of-Life (BOL) power. The transition to the use of thicker Step-2 GPHS modules means that a stack of only 16 modules (4000 W of nominal thermal inventory) can be accommodated in the heritage design. This constraint translates into the current best estimate of about 245 W for the BOL power of the build-to-print, base Next Gen RTG Mod 1 design.

II.D.1 Enhancement options trade space

The RPS Program requested the Next Gen RTG Project, in reestablishing the GPHS-RTG production capability as the Next Gen RTG Mod 1, include enhancement trades to their Statement of Work to industry to determine what potentially cost effective / performance enhancements may be pursued. In addition to electrical power performance, an inherited challenge the project may need to address are environments for as yet undefined missions that could be launched on a number of different launch vehicles. The heritage GPHS-RTG flight units were analyzed and tested for the launch environments of the Space Transportation System and then qualified by analysis for launch on Atlas and Titan-Centaur vehicles. The suite of potential launch vehicles for missions using the NextGen RTG is considerably different, and may include vehicles from SpaceX, Blue Origin, United Launch Alliance, and the Space Launch System. Launch loads imparted to the Next Gen RTG can be quite different with these launch vehicles. Also, launch loads transmitted to the RTG depend on the spacecraft configuration, the number of RTGs required by the mission, and the orientation of the RTGs relative to the thrust axis of the launch vehicle.

An assessment of the following options is of particular interest and being conducted by the Next Gen RTG Project’s industry contractor:

a) A design that allows for a shorter unit whose number of GPHS modules is ½ the number of GPHS modules in the full-sized Mod 1 RTG (simple approach to modularity)

b) A design that uses as many as 18 Step-2 GPHS modules (Maximizes thermal inventory)

c) A design that is modified from heritage in order to be fully compliant with requirements after being tested to the launch environments for these launch vehicles and upper stages.

II.D.2 Preliminary power performance assessment

In support of the Enhancement Assessment exercise, the Project utilized the existing RTG Lifetime Performance Prediction Model (LPPM) tool to independently predict system-level performance on the baseline and enhancement options under consideration. The LPPM was initially developed under the name “DEGRA” in support of the MHW-RTG Program which developed and utilized the SiGe unicouple converter technology[5,6]. For the GPHS-RTG, which uses the same SiGe unicouple design, the LPPM was most recently used in support of the 20-year-long Cassini mission that had three units[7].

When considering Step-2 GPHS-RTG-derived Mod 1 RTG configurations that include more than 16 modules, the LPPM utilized the following methodology: 1) the cylindrical section of the housing was stretched in proportion to the larger stack sizes to accommodate the extra heat sources and 2) the unicouples were redistributed along the stretched section so that the unicouple spacing could accommodate the longer stack of heat sources, keeping the same number of couples per heat source. An additional test case was evaluated, where the number of unicouples was reduced from the original 572 down to 512, so that the ratio of available thermal inventory to unicouples matched that of the heritage design.

For comparison purposes, all calculations were conducted using a deep space environment for all 17 years of operation, with no initial storage period. All calculations used a 30 V load voltage and each GPHS starting thermal inventory was set at 250 Wth.

A summary of the initial results to date is illustrated in figure 2, showing that when switching to the Step-2 heat source stack, a small degradation in thermal efficiency (higher ratio of Multi-Layer Insulation to unicouple effective view areas) and electrical wiring resistance (increased unicouple-to-unicouple spacing) results in a small performance penalty of just a few Watts. Keeping the heat per couple constant, a linear progression in power output drop is seen from 18 to 17 to 16 Step-2 heat source configurations (lines 2, 3, 5). As expected, reducing the number of couples (line 4) in the 16-Step-2 base helps recover some of the system efficiency by enabling the SiGe unicouples to operate back to its original nominal design temperatures.

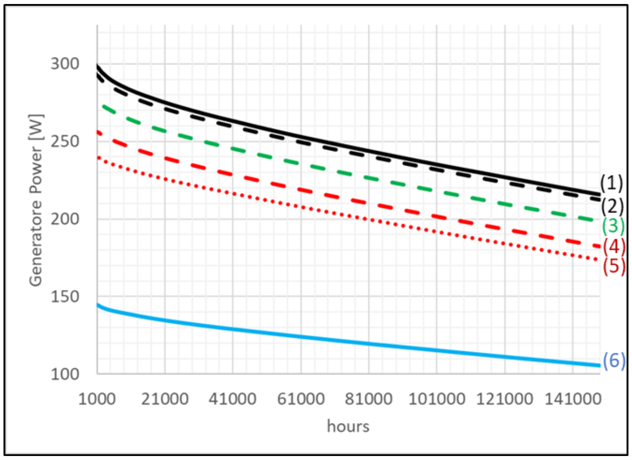

Fig. 2. Preliminary power performance assessment of potential enhancement options for the GPHS-RTG-derived Next Gen RTG Mod 1. The heritage 18 Step-1 GPHS-RTG (1, solid line) is compared with a stretched 18 Step-2 option (2), a stretched 17 Step-2 option (3), a build-to-print base version (5) and then the base version with a reduced set of unicouples (4). Finally, a single half-size 9-Step-2 option (6) is also displayed.

II.E. Timeline

The current timeline puts the delivery of the first Next Gen RTG Mod 1 unit in the 2027 timeframe, ready for fueling by BEA-INL to meet the needs of a mission. At this time, Phase 4 of the project would introduce production capability of the Next Gen RTG Mod 1.

III. THERMOELECTRIC CONVERTER CHALLENGES

The thermoelectric converter collects the high-grade heat from the GPHS modules and, operating across a large temperature differential, it converts a relatively small fraction of that heat into DC electrical power, with the "waste heat' being transferred to the generator radiator housing and fins. The converter consists of an array of hundreds of thermoelectric couples interconnected in a series-parallel laddering circuitry, for enhanced reliability, that meets the voltage output range requirement. The laddering circuitry design will continue to operate even if a unicouple fails in either the open or short circuit mode, and the circuit loops are arranged such as to minimize the net magnetic field of the generator. The couples are assembled within a highly effective, vacuum-rated insulation comprised of multiple interchanging layers of quartz cloth and molybdenum foil that typically enables 90% or more of the available heat to flow through the unicouples and help maximize system efficiency.

III.A. Silicon Germanium Unicouple Background/History

Since the Next Gen RTG Mod 1 is focused on utilizing the GPHS-RTG heritage design, the thermoelectric couples are silicon germanium (SiGe) "unicouples" of basically the same design (Figure 3) as those first used on the LES 8/9 and Voyager 1/2 spacecrafts[8]. The unicouples are supported in a cantilevered fashion from the aluminum housing outer case and, in turn, the unicouples support the insulation package with the aid of a lightweight molybdenum frame. This assembly is called the thermopile.

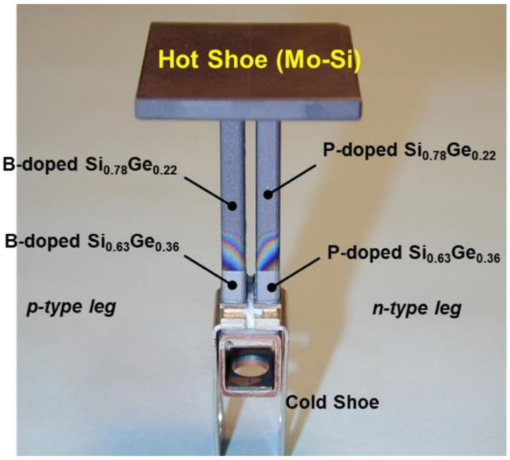

Fig. 3. The cantilevered silicon-germanium unicouple without its thermal insulation packaging ("unwrapped").

At beginning-of-life, under nominal load voltage and deep space operating conditions, each couple produces a little more than 0.5 W. The top of the couple (hot shoe) collects heat from the GPHS at about 1035°C while the bottom of the couple, bolted to the generator housing, rejects waste heat at about 270°C (Ref.4)

The SiGe unicouple design finds its roots in the SiGe Air-Vac technology developed for terrestrial systems[9] in the early 1960's by the Radio Corporation of America (RCA). At that time, the first space RTGs had been successfully developed and utilized using PbTe thermoelectric couple technology[1]. However, with the perspective of long-term space missions (> 5 years) on the horizon, there was a desire to explore other thermoelectric materials and couple technologies that could offer higher performance and in particular lower degradation rates. This effort started in the mid-1960's with the initial attempts to understand the temperature limitations of Si-rich SiGe alloys and what design changes over the Air-Vac technology were required to take advantage of the plutonium-238-based heat sources[10]. An extensive development campaign was initiated in support of the MHW-RTG Program[11], with the SiGe unicouple design being finalized around the 1973-1974 timeframe[12] by RCA and General Electric Astro-Space. The MHW-RTG system has an array of 312 couples, and a number of electrically-heated (ETG) and fueled units were produced until 1977. The SiGe unicouple production line was mothballed until

1979 for the Galileo and Ulysses GPHS- RTG Program. The production line was again stopped for a few years until it was reactivated around 1991, at what was now Lockheed Martin Astronautics, for the Cassini GPHS- RTG program. The last SiGe unicouples were produced around 1998.

III.B. Challenges

There is now data on the operation of SiGe unicouple-based RTGs for operations in excess of 45 years, thanks to the Voyager missions. This extraordinary performance is enabled by the demonstrated graceful behavior of the low degradation of the SiGe unicouple performance. Degradation from the thermoelectric unicouple and the multi-layer thermal insulation results in annual power losses that are only a fraction of a percent, after the first couple of years. The remaining power losses are due to the unavoidable decay of the radioactive heat source, and losses associated with that reduction in heat flux. As noted in the preceding section, the heart of the technology was developed 50 years ago, and the production line was stopped 25 years ago with the facilities having now disappeared and equipment, and documentation removed and/or placed in long term storage. As a result, reestablishing the SiGe production capability is the core of the critical path for the Mod 1 effort, that requires meeting a series of technical and logistical challenges.

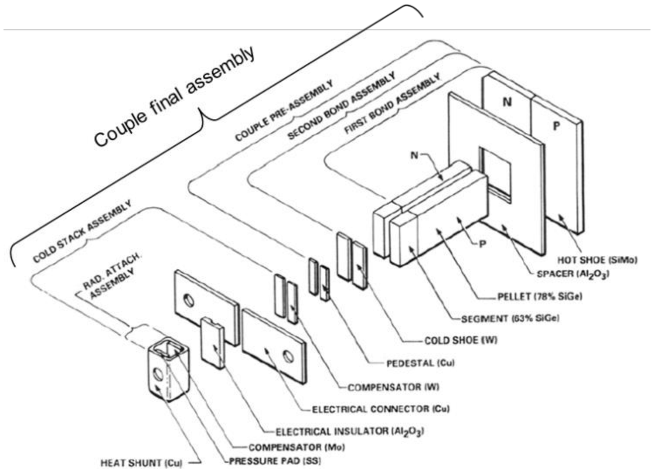

Fig. 4. View of a cantilevered silicon-germanium unicouple (without its thermal insulation packaging) showing the major assembly components[13].

The technical challenges are driven by the heritage techniques employed to produce the SiGe alloys and the silicon molybdenum (SiMo) materials. The technique relies on vacuum chill-casting of the molten precursors followed by pulverization, powder blending and hot-pressing with hot ejection. Modern efforts on SiGe research and development in the thermoelectric community have utilized for many years powder metallurgy techniques that are well controlled and result in very homogeneous powder batches that can be fairly easily sintered into high density compacts. In contrast, the heritage technique results in a controlled but highly inhomogeneous compositional powder blend with a unique morphology. The success of subsequent component fabrication and unicouple assembly steps is totally dependent on the prepared materials morphology and controlled inhomogeneity. Previous attempts at deviating from the heritage process first developed in the early 1970's have not been successful to date in achieving either the same levels of reliable production yields and/or maintaining the remarkable long-term performance of the couples[14,15]. Consequently, it is important to note that an important challenge in reestablishing the production line is the necessity to exercise the production steps end-to-end (from materials to insulation wrapped SiGe unicouple) and to verify that the long-term performance is on par with heritage couples by conducting life testing on small scale modules with prototypic thermal insulation packaging under accelerated and nominal operating conditions[16].

III.C. Unicouple Re-establishment Plan

To successfully tackle the technical challenges requires addressing the logistical challenges as expeditiously as possible. The Next Gen RTG project's selected industry team is not the historical performer, and as a result the facilities and equipment capabilities need to be recreated at the contractor sites. In addition, due to the "generational gap" the expertise needs to be rebuilt while leveraging remaining government knowledge base and laboratory capabilities.

The prime contractor, Aerojet Rocketdyne, has been focusing on establishing the key facilities for the SiGe unicouple production line at Teledyne Energy Systems, Inc., with the exception of the SiGe and SiMo materials synthesis being subcontracted to a third party, RGS Development, due to their experience and existing facility for chill-casting SiGe materials. The RGS capability has been modified to allow their sheet-casting process to produce castings with the heritage form factor (a critical process parameter). The other key component of the converter thermopile, the Multi-Layer Insulation (MLI), is being developed by Ball Aerospace, who have extensive experience in that field.

Because of the significant time required for defining, procuring, and installing the necessary production line equipment, the Project is also facilitating an effective partnership between the industry and key government laboratories that have extensive experience with this technology, as well as ready-to-use facilities and equipment to be able to conduct pathfinder materials and couple development activities. This activity is building upon the work of a SiGe Task Force started in mid-2020's by the RPS Program Office and then integrated into the Project structure. Using part of the remaining inventory of materials and parts from the Cassini RTG Program production line, that effort showed that heritage procedures could be reasonably well adapted to modern lab-scale equipment to produce components and assemble SiGe unicouples with beginning- of-life performance in-family with previously fabricated unicouples[17]. Specifically, the Project is currently supporting risk reduction activities that aim to assess initial production batches of SiGe materials and, if meeting a preliminary set of physical and transport property criteria, utilize them to fabricate new “pathfinder” unicouples suitable for extended performance testing (>5000 hours). A key objective is to build up industry expertise by exploring the end-to-end fabrication processes and conducting life testing prior to the full set of production scale facilities and equipment being up and running.

IV. REFURBISHMENT OF LEGACY HARDWARE

In addition to the primary re-establishment of a full flight RTG production capability, the Project is also undertaking a refurbishment of the F-5 GPHS-RTG and associated flight hardware from storage. This serves as both a chance to study the technical aspects of the GPHS-RTGs and an opportunity to provide a flight RTG faster than the production re- establishment would allow.

IV.A. Inspection of Heritage RTGs

The GPHS-RTG F-5 unit was originally fueled at the DOE Mound Facility in 1984. The F5 unit served as a flight spare for Galileo, Ulysses, and Cassini missions. Lockheed Martin (LM), a DOE prime contractor, in 1999 orchestrated and partially executed a comprehensive plan to demonstrate flight readiness of the F-5 unit[18]. In 2002, F-5 was shipped to the Idaho National Laboratory, then known as Argonne National Laboratory-West, where it was subsequently de-fueled in 2005. It was at this time that F-5 incurred damage to the molybdenum frame components and several of the unicouple hot shoes were damaged following post fueling shipping and handling operations.

The GPHS-RTG Qualification Unit (Q-1) was identical to the Flight Unit RTGs with the exception that the Q-1 was more heavily instrumented to allow for the necessary data collection to qualify the GPHS-RTG design. The unit was initially tested as an electrically heated unit in 1983 and later tested as a fueled unit at the Mound facility through 1984 and then placed on life testing through the early 90’s.

Both the Q-1 and F-5 units were considered viable options for supplying the needs of the Mod 0 project. To determine the state and configuration of these two units, INL conducted an extensive visual inspection to assess the condition and configuration of both units. The results of the inspection and assessment played a key role in selecting F-5 as the Mod 0 GPHS-RTG and in developing a plan to refurbish the F-5 unit.

IV.B. Plan for Refurbishment

The Next Gen project team collaborated and developed a strategy that would provide the greatest assurance of a reliable flight ready F-5 GPHS-ETG. The plan consisted of several examinations, corrective actions, and testing laid forth as check points; with each check point culminating in a review by the Project Team to analyze and assess the results and data. The purpose of establishing the check point reviews was to allow for a concerted decision on whether to proceed with the next check point refurbishment effort.

A primary focus of the early check points was the F-5 unicouples state of health and reconditioning the molybdenum frame that was damaged during de-fueling. Several tests and examinations were investigated, researched, and derived to provide a level of assurance and confidence that the F-5 unicouples and thermoelectric circuitry remain intact and functional. Several fragments from the damaged F-5 unicouple hot shoes, recovered from the generator, will undergo various non-destructive and destructive examination to verify that the vital characteristics and functional state of both the damaged and undamaged unicouple hot shoes are acceptable. A test of the unicouple legs, bonds, cold stack assembly and thermoelectric couple pair circuitry will be done to provide a qualitative level of the condition of the unicouples. Repair and reconditioning of the damaged molybdenum frame will be performed to eliminate potential interference issues and ensure that the F-5 unit can be fueled, assembled, and sealed.

Later check points shifted the attention to the functional performance of F-5 as an electrically heated unit by proposing the conductance of a thermal vacuum atmospheric chamber (TVAC) test of F-5 with the Electrical Heat Source (EHS) installed and operating as well as a final heated vibration test. Several heritage EHS units exist but the condition and functionality are unknown. A TVAC power test will be conducted on a unit that is selected to verify that the EHS still operates. This EHS will then be used for the F-5 heated TVAC and vibration tests. Acceptance level vibration testing levels will be evaluated to determine adequacy of the RTG for flight. An ambient air power performance test would be conducted pre and post TVAC and vibration test to verify the operability and power output capability of the F-5 GPHS-RTG.

Upon satisfactory completion of the established checkpoints, the F-5 unit would be qualified for flight and be ready for fueling should a mission choose to utilize F-5.

V. OTHER LEGACY HARDWARE FOR RISK REDUCTION

The Radio Corporation of America (RCA) initially developed and produced the SiGe Unicouple for the MHW-RTG. Subsequently, General Electric (GE) Astrospace Division (later Lockheed Martin Astronautics) reestablished production of the unicouple and initiated production of the GPHS-RTG. Following the decommissioning of the GE/LM GPHS-RTG production line, a significant inventory of legacy hardware was transferred to Idaho National Laboratory (INL) for storage and potential future use. This hardware included flight qualified components as well as custom developed tooling used in unicouple and GPHS-RTG production.

Items of significant interest are a fully machined GPHS-RTG outer shell, fin/cooling tube assemblies and flight SiGe unicouples (qty: 443). The SiGe unicouples are brand new units that have been maintained in dry box storage at INL.

The Next Gen project will leverage this legacy inventory to help minimize risk in support of the Mod 0 and Mod 1 efforts. Furthermore, the Mod 0 project includes investigating the feasibility of harvesting SiGe unicouples from the four legacy MHW-RTGs currently stored at INL with the option of harvesting unicouples from 2 additional MHW-RTGs. The Program/Project conducted a decision point review in November 2022 and authorized, based on INL's proposed plan and identified risks, INL to proceed with harvesting the MHW-RTG unicouples. Based on preliminary harvesting process yield estimates, INL anticipates an overall yield rate in the low 70 percent. This yield rate would result in recovering approximately 910 out of 1248 unicouples (4 MHW-RTGs). The harvested unicouples would undergo some level of re-certification testing to qualify them as acceptable for flight.

In the case of the Mod 0 work, the heritage hardware may be used to support the refurbishment of the F5 unit. In the case of Mod 1, the legacy components can be used to augment the re-establishment on the production line should issues arise. This would help offset any potential delays in producing SiGe unicouples or the associated balance of plant hardware necessary to produce the initial ETG.

VI. CONCLUSIONS

The Next Generation Radioisotope Thermoelectric Generator project team is preparing and executing work on the Mod 0 and Mod 1 RTGs to provide the scientific community a power source for the next deep space exploration mission. While the complexities of the project will bring about challenges, the project is confident that the team structure and expertise will allow each one to be successfully overcome. Re-establishing a production line that has been idle for 30 years is not an easy task but by leveraging heritage technology, the team will be able to provide deep space exploration power for a mission by 2030.

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