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PATH TO A NEXT GENERATION RADIOISOTOPE THERMOELECTRIC GENERATOR (RTG)

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The Next Generation RTG Project (Next Gen RTGP) is one of three NASA-led projects commissioned by the Radioisotope Power Systems (RPS) Program. NASA HQ created the RPS Program in 2009 to ensure investments made in RPS technologies and systems would best meet future mission needs.

As commissioned by the RPS Program, the main objective of the Next Gen RTGP is to mature an RPS technology and transition it to a new vacuum rated flight system design to ultimately allow DOE to fuel and deploy the Next Gen RTG for NASA mission needs for a non-atmosphere power solution. The Next Gen RTGP is offering system designers access to thermoelectric research previously conducted within the RPS Program as a potential energy conversion technology to meet that objective.

The Next Gen RTGP works with DOE to provide system design contracts, and leverages an interagency partnership between the RPS Program and the DOE Office of Nuclear Energy to provide technically feasible power system solutions. The contracts are through Idaho National Laboratory (INL).

I. Project Background and Overview

The objective of the Next Gen RTGP is to develop and qualify a new vacuum rated RPS by 2028 with a performance floor no less than that of the historic GPHS-RTG. This requires the Project to identify and mature a thermoelectric conversion technology leading to a successful flight system design. The Project plans to accomplish this objective in three phases. The first phase is a conceptual study of potential energy conversion technologies that operate optimally in vacuum. The end of the first phase will result in a chosen technology moving into the second phase. The second phase ends when the chosen energy conversion technology is ready for the design phase three. Once the project receives authorization from the RPS Program to move into the flight system design, phase three begins. The agent to to acquire flight designs and systems for future missions is INL.

The RPS program has made previous investments in energy conversion technologies that operate in a vacuum. The Next Gen RTGP system designers will have access to the research performed by NASA in potential technologies.[1] One such technology investment is the energy conversion technology work done at Jet Propulsion Laboratory (JPL) and another technology the system designers may potentially use was developed at the Applied Physics Laboratory (APL) and funded by other federal agencies.

Part of the NASA investment in potential energy conversion technologies includes system trades and studies that support the ongoing NASA work in technology development. The use of potential work performed by NASA in energy conversion technologies, and the system trades and studies supporting it, will be at the discretion of the system design contractors.

I.A. Previous Thermoelectric Research

Throughout the last three decades, NASA's steady investment in thermoelectric research and development, mostly at JPL, has led to the identification of higher performance materials and the successful demonstration of proof-of-principle devices with twice the conversion efficiency (~ 15%) compared with state-of-practice technologies at beginning-of-life (BOL).

The RPS investment in converter technology is based on advanced high temperature thermoelectric materials and segmented device configurations first selected in 2006 for potential application to future high performance generator concepts. Since 2006, NASA has continued its assessment of additional thermoelectric materials and related device technologies researched and developed throughout the U.S. and international research community.

In recent years, some of these materials have been integrated in NASA's efforts to advance the readiness of converter technology capable of long term operation (17 years or more) at elevated temperatures (up to 1273 K). In 2016, the Radioisotope Power System Program conducted an exhaustive study of the characteristics of a an RTG that would "best" fulfill Planetary Science Division (PSD) mission needs.

As part of this study, an evaluation of relevant (TRL > 2) converter technologies was completed. Within the operating temperature range of interest to a Next Gen RTG, key attributes of these technologies included: a) A high dimensionless thermoelectric figure of merit (ZT); b) a high likelihood of maintaining chemical and mechanical stability; c) a high likelihood that the thermoelectric transport properties would remain stable over the targeted operating lifetime; d) the ability to be integrated into efficient thermoelectric devices (≥12%) and; e) the ability to proceed within a couple of years to a technology maturation phase (TRL 3/4 to TRL 5/6) with reasonably low programmatic risk.

At the conclusion of this study in 2017, with insight on key technical parameter (KTP) goals for a future RTG and a desire to pursue a modular system architecture (Figure 1), a set of thermoelectric materials and device configurations were recommended for continued converter TRL advancement. The possible device configurations use various thermoelectric materials that include skutterudite, zintls, and $La_{3-x}Te_4$/composites as shown in the table in Figure 3.

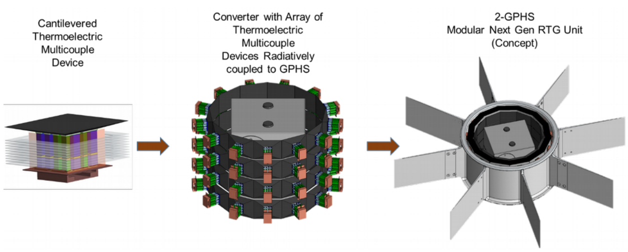

Fig. 1. Modular Next Gen RTG Concept with Converter Array of Cantilevered Multicouple Devices.

	p- type Thermoelectric Leg: Materials for Segments	
Configuration	Low	High
Segmented	9-4-9 Zintl	14-1-11 Zintl
Segmented	Skutterudite	14-1-11 Zintl
Unsegmented	None	14-1-11 Zintl

	n-type Thermoelectric Leg: Materials for Segments	
Configuration	Low	High
Segmented	1-2-2 Zintl	$La_{3-x}Te_4$/composite
Segmented	Skutterudite	$La_{3-x}Te_4$/composite
Unsegmented	None	$La_{3-x}Te_4$/composite

Fig. 2. Materials and Device Leg Configurations**.**

Using the recommended set of material configurations, the current potential energy conversion technology development is focused on advancing the TRL of the material configurations. This includes extended (up to 5000 hours of test) performance data on a set of “low fidelity” devices operated in a relevant environment under nominal and accelerated conditions. These devices (currently under development) are configured as basic cantilevered multicouples (see Figure 3 for current device technology progression), but offer the ability to develop device technologies, fabrication procedures and assembly procedures addressing most of the challenges in advancing maturity. The combination of materials-, elements- and device-level test data and the demonstrated ability to fabricate such devices are offered to the system vendors during the first phase of the project and they will propose what to use as the project transitions to the Technology Maturation Phase 2.

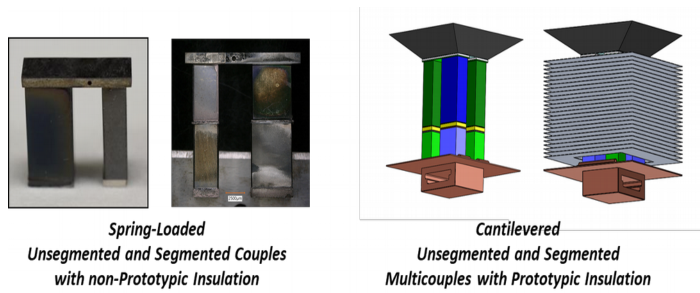

Fig. 3. Current Technology Development Status: Device Development Progression from Spring-Loaded Couples to Cantilevered Multicouples.

The current technology work is aided by a robust system engineering effort that is helping to provide a basis for preliminary device design(s) and having a solid understanding of its required operating conditions (relevant environment(s)) throughout the targeted system concept design life. Current efforts are focused on understanding the size of the design space by conducting trade studies and determining key sensitivities to projected system-level requirements to ensure the relevancy of current converter technology development activities. The current status of technology advancement achieved across thermoelectric materials, elements, and device categories is summarized in a document that will be provided to the system design contractors during the first phase of the contract.

I.B. System Trades Supporting Previous Thermoelectric Research

The energy conversion technology System Engineering trades and studies the RPS Program has invested in will inform Technology Development efforts with system-level design criteria, environments assessments and requirements, and design constraints. It provides essential guidance to RPS Technology Development because no TE technology is viable without a conceptual RTG design configuration to verify successful development results. System engineering ensures successful and efficient implementation of any potential TE technology as the TE technology design and RTG system design are linked together. The current System Engineering work will provide system designers thermoelectric information on:

- anticipated thermal environments
- anticipated mechanical / structural environments, and
- expected chemical environments from certain selected generator materials

These are all environments any potential TE technology will have to survive and operate in, as well as integrated test planning, operational conditions profiles, system performance maps, and targeted degradation rates relevant to any energy conversion technology the system vendor chooses for the Next Gen RTG system. The generator system engineering effort will specifically provide guidance and information on:

- generator hot-side design configurations and materials
- generator cold-side design configurations and materials
- generator insulation methodologies and materials
- desired and targeted specific power ranges
- expected temperature design ranges
- expected mechanical stress and dynamic design ranges

This generally can be accomplished with a combination of analytic studies performed using general thermal, thermoelectric, mechanical stress and dynamics, and computer-aided design software tools, like SolidWorks, ANSYS, COMSOL, NASTRAN, and Thermal Desktop.

Some assumptions/constraints for configuration tradeoff studies provided by the RPS Program include:

- GPHS Step-2 at BOL: 250 Wthermal
- Vacuum-only RTGs
- Modularity (from 2-GPHS to 16-GPHS configurations)
- Degradation rate ≤ 1.9% average per year over design life
- Largest variant fits in one DOE shipping cask, 9904

These assumptions and constraints emanate from various RPS Program requirement documents to be updated as the project proceeds, and will eventually bound the RTG design domain to ensure a verifiable and validated Next Gen RTG design can be defined and targeted.

II. CONCLUSIONS

The Next Gen RTGP has an objective to develop and qualify a new vacuum rated RPS by 2028 with a performance floor no less than that of the historic GPHS-RTG. Reaching the objective includes identifying an energy conversion technology during the first phase of the project that has the highest likelihood of success during the second Technology Maturation phase of the project. The system design contractors will choose the energy conversion technology.

After the successful completion of the Technology Maturation of the chosen technology, the RPS Program will authorize the Next Gen RTGP to begin the design of the flight system, or the third phase of the Project.

Information on the energy conversion technologies invested in by the RPS Program are available to the system design contractors to aid in their evaluation of existing technologies. System trades and studies are part of the technology development underway, and are also available to the contractors if proposed.

REFERENCES

1. T. J. Sutliff, et al, “Radioisotope Power Systems – An Interagency Program Status,” Nuclear and Emerging Technologies for Space, American Nuclear Society Topical Meeting, Feb. 25-28, 2019.