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RADIOISOTOPE POWER SYSTEMS - AN INTERAGENCY PROGRAM STATUS

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Radioisotope power systems (RPS) have been in use in the United States for over 50 years. RPS-enabled NASA missions have utilized space nuclear power allowing them to explore planets, moons, and interstellar space. This exploration resulted in changes to our understanding of our Solar System and our place within it.

In 2009, NASA HQ created a NASA program to ensure investments made in RPS technologies and systems would be best utilized by future missions. The RPS Program seeks to ensure the availability of RPS for the exploration of the solar system in environments where conventional solar or chemical power generation is impractical or impossible.

The RPS Program, in partnership with the DOE Office of Nuclear Energy began, and continues to operate as an interagency partnership to provide technologically robust power system solutions to robotic spacecraft and exploration missions that otherwise would not be feasible. This paper provides a synopsis of current activities after a decade of formal interagency partnering.

I. PROGRAM CONTENT AND STRUCTURE

The NASA RPS Program consists of multiple program office elements as well as system development projects. These projects mature RPS-needed technologies and transition them into flight system designs, ultimately allowing DOE to fuel and deploy RPS for NASA missions.

The projects of the RPS Program include three NASA-led projects leveraging thermoelectric and Stirling/dynamic energy conversion investments. Two of these projects are coupled with DOE to acquire system design contracts which could lead to availability of a flight system. In addition, the DOE implements activities managing needed Production Operations functions for ongoing production of heat source material and subsequent manufacturing into its final flight form. This interagency scope is codified in accordance with a 2016 Memorandum of Understanding and lower-tier agreements.[1, 2]

I.A. Acquiring Flight Systems

Without power, missions to destinations throughout our solar system would be unable to perform their scientific exploration objectives. Visiting destinations such as Saturn or Pluto necessitated use of nuclear power systems, as solar or chemical (battery) based power solutions are impractical. Figure 1 illustrates the rich history of NASA missions enabled by RPS power. The reconnaissance phase (flyby) of the major solar system bodies has been completed. However, much remains to be explored. Landing and traversing a local environment will take a broadly different set of exploration vehicles, and thereby new power systems capabilities.

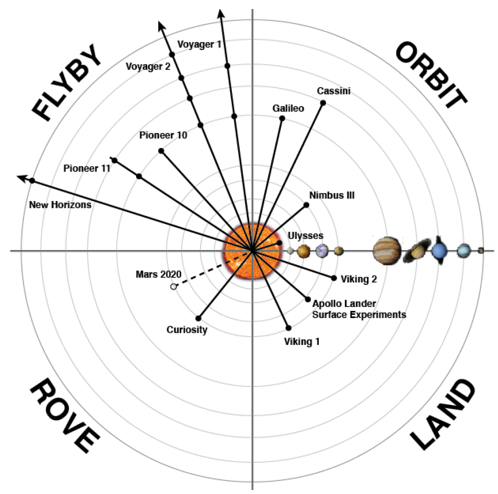

Fig. 1. NASA RPS Mission History

Historically, the DOE independently provided technological investments that led to development of a flight RPS for NASA missions. In recent history, the responsibility for investment in such technologies and the flight systems transitioned to the end-user, NASA.

Three RPS projects are maturing targeted technologies to enable flight system designs to be developed through an unfueled qualification unit stage. The projects are NASA-managed technology development projects, until such time the technologies are sufficiently matured to proceed into a NASA-led flight design effort. Accommodating both spaceflight and nuclear systems requirements requires a close relationship between organizations to be maintained. Each project has two major roles:

(1) development and maturation of technology, and

(2) transition results into flight radioisotope power system capabilities.

Recognizing the end-state for the design process requires fueling, testing and delivery for launch of a system containing a nuclear heat source, the system acquisition and design process is conducted using a DOE-acquired institution. The RPS Program's projects are employing the Idaho National Laboratory (INL) contractor as the agent to acquire flight designs and to fulfill future mission needs.

As an example, the RPS Program has commissioned a next-generation radioisotope thermoelectric generator (Next Gen RTG) project that has a primary requirement to develop and qualify a new vacuum-rated RPS by 2028.[3] The NASA-managed Next Gen RTG project is offering system designers access to the thermoelectric research previously conducted within the RPS Program as a potential energy conversion technology. The final technology selection will be at the discretion of the contractor. The project is partnered with INL to emplace contracts to initiate system studies, leading to execution of a technology maturation process (of the NASA-funded or other technologies), and culminating with a flight design/test process. Subsequent flight systems would be fabricated, fueled and flown based on identification of specific mission needs.

I.B. Managing nuclear production capabilities

Management of the production capabilities for nuclear facilities requires specialized processes, skills, and security that are well understood and remain the purview of DOE. However, in 2014, direction was received to transfer investment responsibility to the end-user, NASA, for the capabilities that would be needed for future NASA RPS missions. Within those capabilities, the re-establishment of heat source plutonium-dioxide (HS-PuO_2) production was identified and has been implemented. Now that production has reached a steady-state campaign mode, the totality of production operations is managed as a singular enterprise.

In 2017, DOE and NASA began transition of delivery of RPS fueled clads from a mission-driven approach to a Constant Rate Production (CRP) strategy. The CRP strategy integrates efforts to produce new HS-PuO_2 with fueled clad manufacturing, where a blending of old and new fuel takes place.

CRP is targeting production of an average rate of 1.5kg per year of new HS-PuO_2 by 2025, with an interim goal of achieving an average production of 400g per year of new material by 2019. In conjunction with new HS-PuO_2 production, the new material, when blended with existing HS-PuO_2, will be processed into fueled clads (FCs) on an ongoing basis. A steady-state rate of manufacturing of 10-15 FCs per year is planned to develop an inventory for future missions with the added benefit of maintaining technical staff expertise. As NASA potential mission needs evolve, DOE will develop and provide projections that fine tune the production rates needed in order to address the potential NASA mission cadence. Such a tuning will serve

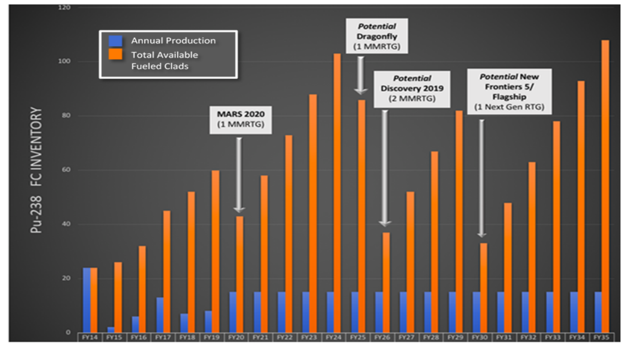

Fig. 2. Heat Source Supply and Mission Demand are in balance using CRP

to minimize over-production, yet fulfill mission needs with minimal risk. Figure 2 illustrates the current fueled-clad supply-mission demand planning.

I. C. Other investments

The RPS Program Office initiated a new Fundamental Research (FR) element of the Program to mature low technology readiness level (TRL) work that is system cross-cutting or innovative in support of future RPS technology development efforts. The work includes 2-year cycles for proposal winners to conduct high-payoff research and develop low-TRL technologies that may become a basis for additional maturation towards inclusion in future flight system designs. These efforts could also serve as risk mitigation for future RPS system developments. Additionally, the teaming of industry, academia, and government is encouraged to foster an environment conducive to technology development and utilization. The FY19-20 cycle includes work scope to enable advancements in thermoelectrics, thermionic materials, alternative Stirling applications, and Ericsson thermodynamic cycle-based technology. The Program also recognizes there are critical capabilities that, if left unsupported between RPS mission deployments, would not be sustained. The FR element also fulfills the sustainment requirement levied by the Program's stakeholders. Further, FR aims to ensure that the RPS Program product portfolio remains relevant to NASA HQ objectives.

II. OPERATIONAL CONSIDERATIONS

The support provided to missions in many cases begins with the mission proposal phase. To prepare for a mission to propose usage of an RPS, the RPS Program and DOE are asked by NASA HQ to develop a cost model for hardware and services. This most recently was done for the Discovery 2019 Announcement of Opportunity, in which NASA allows usage of up to two Multi-Mission Radioisotope Thermoelectric Generators. The costs developed for the proposing mission teams to use, if RPS is baselined, took advantage of savings resulting from the CRP fuel fabrication approach, as well as other efficiencies being championed through the RPS Program and DOE.

A second cross-organizational operational area ensures appropriate public safety considerations have been conducted for radioisotope-enabled missions. The Program is responsible for coordinating National Environmental Policy Act (NEPA) and Nuclear Launch Safety (NLS) and Approval activities for missions flying RPS power and for development of multi-mission databooks describing launch environments an RPS might experience, in support of NLS. The RPS Program follows a documented process for nuclear launch approval management which involves working with numerous NASA, DOE, and other organizations to ensure nuclear launch approval is achieved in a manner that ensures safety and environmental protection, while making the best use of available data and resources.

As with the hardware support provided to missions, the RPS Program seeks to ensure the NEPA and NLS processes are as efficient as possible, while not sacrificing safety. There are a number of parallel efforts underway to streamline and improve the nuclear launch approval process.[4] These include:

- Potential revisions to the NASA regulations implementing NEPA to make NASA's internal regulations more flexible
- The development of a Programmatic Environmental Assessment (PEA) to provide NEPA coverage for future RHU-only missions
- A similar effort by DOE to establish a Documented Safety Analysis (DSA) for RHU-only missions, and
- Potential revisions to the presidential directive covering nuclear launches, to provide more guidance and clarity in the process.

III. OUTLOOK

The interagency activities underway to develop and utilize RPS are enabling a renaissance of space exploration beyond that possible with conventional solar power. Missions to deep space and to dark-shadowed regions of the moon, for example, rely on radioisotope powered spacecraft to accomplish their objectives. Missions using RPS have conducted extended operations of four or more times that possible using solar power.[5]

The current NASA investments made across agency boundaries are ensuring heat sources are readily available; the emergence of improved, and possibly new, flight systems continue, broadening the power-performance range for missions; and other operational cost-saving activities are continually assessed and implemented when viable. These investments are fundamentally altering the potential usage of RPS in the decades to come.

IV. CONCLUSIONS

The NASA RPS Program was created a decade ago to provide continuity for the NASA missions that require nuclear power to complete their exploration objectives. The NASA RPS Program is closely partnered with the DOE in implementation of the totality of RPS content. Recent updates to the inter-agency working arrangement continue to enable future systems development. Playing to the strengths of each Agency, NASA is leading technology maturation and flight systems developments, while DOE continues to manage and maintain the nuclear system and production operations processes that, together, enable exploration for the NASA mission community.

Radioisotope power systems developed through this partnership could support missions to some of the most extreme environments in the solar system, probing the secrets of Jupiter's ocean moon Europa, surveying the liquid lakes of Saturn's moon Titan or touring the rings and moons of the ice giant planet Uranus. With this vital technological capability, the possibilities for exploration and discovery are limited only by our imaginations.

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