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SPACE EXPLORATION

Improved Planning and Communication Needed for Plutonium-238 and Radioisotope Power Systems Production

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Accessible Version

GAO-18-161T

Chairman Babin, Ranking Member Bera, and Members of the Subcommittee:

I am pleased to be here today to discuss our recent work on radioisotope power systems. The National Aeronautics and Space Administration (NASA) has long used radioisotope power systems (RPS) to generate reliable electrical power and heat energy for long-duration space missions. RPS can operate where solar panels or batteries would be ineffective or impossible to use, such as in deep space or in shadowed craters, by converting heat from the natural radioactive decay of plutonium-238 (Pu-238) into electricity.[1] The Department of Energy (DOE) and its predecessor agencies have been providing Pu-238 and fabricating RPS for NASA and other federal agencies for more than 5 decades.[2]

In 2011, with funding provided by NASA, DOE initiated the Pu-238 Supply Project (Supply Project) to reestablish the capability to domestically produce Pu-238.[3] According to DOE documents and agency officials, DOE currently maintains about 35 kilograms (kg) of Pu-238 isotope designated for NASA missions, about half of which currently meets the power specifications for spaceflight. However, given NASA's current plans for solar system exploration, this supply could be exhausted within the next decade. Specifically, NASA plans to use about 3.5 kg of Pu-238 isotope for one RPS to power the Mars 2020 mission. NASA may also use an additional 10.5 kg of Pu-238 isotope for its New Frontiers #4 mission if three RPS are used.[4] If DOE's existing Pu-238 supply is used for these two missions, NASA would be forced to eliminate or delay future missions requiring RPS until DOE produces or acquires more Pu-238.

[1]Pu-238 is defined as Pu-238 oxide, also known as "heat source" plutonium oxide or "bulk-oxide", and is the form used to power RPS. Pu-238 isotope is a precursor to Pu-238 oxide.

[2]The Atomic Energy Act of 1954 authorizes DOE to provide systems that meet the special nuclear material needs of other federal agencies. Under a 1991 agreement with NASA, which was revised in 2016, DOE is responsible for maintaining our nation's capability to support the development, production, and safety of NASA's space exploration missions that use RPS.

[3]Historically, Pu-238 was produced domestically or was purchased from Russia. Domestic Pu-238 production ended in 1988, and DOE has not purchased material from Russia since 2009.

[4]NASA has offered up to 3 RPS for the New Frontiers Mission and plans to make a mission selection in July 2019.

My remarks today are based on our recent report on NASA's use of radioisotope power systems that are powered by plutonium 238,[5] which we are releasing today. Our report examined (1) how NASA selects RPS for missions and what factors affect NASA's demand for RPS and Pu-238; and (2) DOE's progress in meeting NASA's RPS and Pu-238 demand, and what, if any, challenges DOE faces in meeting the demand. Today, I will discuss the key findings and recommendations from that report.

For our report, we reviewed documentation on how NASA considered mission requirements during the agency's planning for recent missions that considered or used RPS as a power source. We also interviewed officials from the Planetary Science Division (PSD) of NASA's Science Mission Directorate and from the Human Exploration and Operations Mission Directorate. In addition, we reviewed documentation related to DOE's efforts to develop the Supply Project and DOE's RPS production process. We also interviewed officials from DOE's Office of Nuclear Energy as well as officials involved in RPS work at three DOE national laboratories—Idaho National Laboratory (INL), Los Alamos National Laboratory (LANL), and Oak Ridge National Laboratory (ORNL)—and conducted site visits to ORNL and INL. More detailed information on the objectives, scope, and methodology of our work can be found in the September report. The work upon which this statement is based was conducted in accordance with generally accepted government auditing standards.

In summary, we found that NASA selects RPS for missions based primarily on scientific objectives and that several factors may affect NASA's demand for RPS and Pu-238. For example, RPS have been typically used on NASA's most expensive and highest priority missions. Based on expected funding levels, NASA can only support two or three of these missions per decade. We also found that DOE has made progress meeting NASA's demand for RPS and Pu-238, but the agency faces some challenges in reaching full production goals. For example, DOE does not maintain a comprehensive system for tracking RPS production risks. In addition, DOE's management approach does not allow for the agency to adequately communicate long-term production challenges to NASA. We made several recommendations to DOE to address these

[5] GAO, *Space Exploration: DOE Could Improve Planning and Communication Related to Plutonium-238 and Radioisotope Power Systems Production Challenges,* GAO-17-673 (Washington, D.C.; Sept. 8, 2017).

issues. DOE agreed with our recommendations and outlined actions it planned to take to address them.

Background

RPS are long-lived sources of spacecraft electrical power and heating that are rugged, compact, highly reliable, and relatively insensitive to radiation and other effects of the space environment, according to NASA documentation. Such systems can provide spacecraft power for more than a decade and can do so billions of miles from the sun. Twenty-seven U.S. missions have used RPS over the past 5 decades. The current RPS design, the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG), converts heat given off by Pu-238 into about 120 watts of electrical power at the beginning of its life—a 6 percent power conversion efficiency. One MMRTG contains 32 general purpose heat source (GPHS) fuel clads in the form of pressed Pu-238 pellets encapsulated in iridium.

NASA's PSD science portfolio includes a wide array of missions that seek to address a variety of scientific objectives and answer many questions about the solar system, from how life began to how the solar system is evolving. Scientific and mission objectives influence the types of equipment needed for the mission, including the mission's power source. According to NASA officials we interviewed, missions in NASA's PSD portfolio are generally classified in three ways:

- **Flagship.** Flagship missions are the largest and most expensive class of NASA's missions, costing $2 billion or more, and are given the highest priority for resources, including funding, infrastructure, and launch support. Past Flagship missions that have used RPS include the Galileo, Cassini, and Curiosity missions. NASA's Mars 2020 mission is a planned Flagship mission using RPS.
- **New Frontiers.** New Frontiers missions focus on enhancing our understanding of the solar system and have a development cost cap of $850 million.[6] To date, there has been one New Frontiers mission using RPS (New Horizons).

[6]Mission cost caps are in fixed fiscal year 2015 dollars and do not include certain costs, such as those related to the launch vehicle and operations.

- **Discovery.** Missions in the Discovery program have a development cost cap of $450 million to $500 million and have shorter development time frames, according to NASA officials and documentation. No Discovery mission has been powered by RPS.

DOE oversees the design, development, fabrication, testing, and delivery of RPS to meet NASA's overall systems requirements, specifications, and schedules. DOE's goal under its Supply Project is to reach a full Pu-238 production rate of 1.5 kg per year by 2023, at the earliest, with a late completion date of 2026. DOE also established an interim production rate of 300 to 500 grams per year by 2019, to ensure an adequate supply of Pu-238 for NASA's near-term missions, before the full production rate goal is achieved. The Supply Project involves a number of steps across several DOE national laboratories, including the use of two DOE research reactors—the High Flux Isotope Reactor at ORNL, and the Advanced Test Reactor at INL.

NASA began fully funding DOE's Supply Project in 2011, and since 2014, has been responsible for funding all aspects of RPS production operations, according to NASA documents.[7] NASA funds DOE's efforts to build, test, and fuel RPS, as well as to update equipment and sustain staffing levels associated with RPS production between missions. Since 2014 NASA has provided, on average, approximately $50 million per year to support DOE's ongoing operations and maintenance of RPS production equipment. Since its inception until early 2017, DOE has used a short-term and incremental segmented management approach to manage the Supply Project.[8]

[7]Prior to 2014, DOE provided funding for the infrastructure related to RPS production at DOE facilities, and NASA provided funding for mission-specific RPS production activities.

[8]Under this management approach, DOE established short-term segments of Supply Project work to be connected to time frames over which DOE could more reliably predict funding from NASA.

NASA Selects RPS for Missions Based Primarily on Scientific Objectives, and Several Factors May Affect NASA's Demand for RPS and Pu-238

NASA selects RPS to power its missions primarily based on scientific objectives and mission destinations. According to NASA officials we interviewed, the need for RPS is usually apparent based on the mission's scientific objectives and destination. For instance, an RPS is more likely to be needed for a mission to a distant planet, where minimal sunlight reduces the effectiveness of solar power. NASA officials we interviewed stated that, consistent with the National Space Policy, the agency uses RPS when they enable or significantly enhance a mission, or when alternative power sources, such as solar power, might significantly compromise mission objectives.[9] NASA prioritizes mission selection based on missions identified in the National Academy of Sciences' decadal survey report, which represents the highest priorities of the scientific community and includes many missions that require the use of RPS.[10]

Prior to the establishment of DOE's Supply Project in fiscal year 2011, NASA officials we interviewed stated that mission selections were influenced by the limited amount of available Pu-238. These same officials told us that missions are now selected independently from decisions about how they will be powered. However, projected availability of Pu-238 is factored into whether an RPS is available for a specific mission opportunity.

In addition to the scientific objectives of planned and potential space exploration missions, several other factors may affect NASA's demand for RPS and Pu-238:

[9]U.S. Office of Science and Technology Policy, *National Space Policy of the United States of America* (Washington, D.C.: June 28, 2010).

[10]The National Academy of Sciences' decadal survey report presents a 10-year program of science and exploration with the potential to yield revolutionary new discoveries. The National Aeronautics and Space Administration Transition Authorization Act of 2017 states that the NASA Administrator should set science priorities by following guidance provided in this decadal survey report.

- **Costs associated with missions that typically require RPS.** According to NASA officials, RPS have typically been used on Flagship missions that cost $2 billion or more. NASA can support no more than one mission using RPS about every 4 years—or two to three missions per decade—based on expected agency funding levels.
- **Cost of RPS relative to mission costs.** According to NASA officials, New Frontiers missions may be good candidates to use RPS; however, given the cost cap for this mission class, one RPS would account for about 9 percent of the mission's budget, while three RPS would account for almost 14 percent. For Discovery missions, for which the cost of using RPS would represent a large portion of a Discovery mission budget, a single RPS would represent more than 17 percent of a mission's development cap.
- **DOE's production capability.** According to DOE officials we interviewed, it can take up to 6 years to acquire, fuel, test, and deliver a new RPS for a NASA mission. According to DOE and NASA officials we interviewed, given the current floor space dedicated to RPS development at INL and limits on staff exposure to radiation at LANL, DOE only has the capacity to produce three to four RPS at one time. To accommodate DOE's current RPS production capability, NASA officials we interviewed said they will not select two consecutive missions requiring RPS.

Technological advances may reduce the demand for Pu-238 and thus RPS. For example, according to NASA officials, advances in solar power technology have realistically expanded the ability to use solar power for missions for which it would not have been considered before, and these advances could help address low levels of light intensity for deep space missions. NASA also is developing new RPS technologies that may reduce its demand for Pu-238 and thus RPS. For example, NASA officials told us that they plan to invest in dynamic RPS technology that could increase RPS efficiency and require less RPS to achieve mission power. NASA research indicates that dynamic RPS designs could be more than four times as efficient as the current MMRTG design.[11]

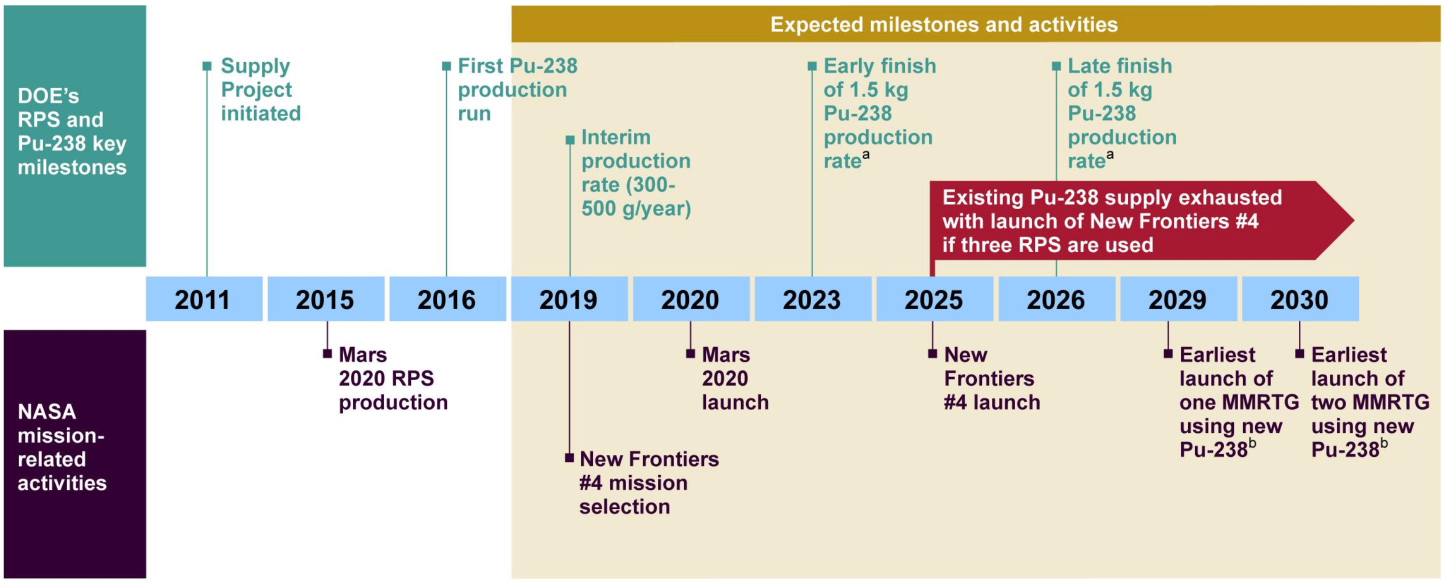
[11]In addition, new thermoelectric materials being researched by NASA may lead to increased RPS efficiency. One such material, skutterudite, could result in an RPS with a 25 percent beginning-of-life efficiency improvement and a 50 percent increase of end-of-life power output when compared to the current MMRTG.

The Supply Project goal of producing 1.5 kg of Pu-238 per year was established to support two to three PSD missions using RPS each decade, and NASA does not anticipate other potential users to affect demand for RPS or Pu-238, according to NASA and DOE officials and documentation we reviewed. DOE planning documents and NASA officials we interviewed stated that current RPS and Pu-238 production levels expected from the Supply Project are intended to only meet PSD's demand. NASA officials said that they did not account for potential demand from other potential users within NASA, the national security community, or commercial sectors when establishing current Pu-238 production goals.

DOE Has Made Progress Meeting NASA's RPS and Pu-238 Demand, but Faces Challenges Reaching Full Production Goals

DOE has made progress meeting NASA's future demand for Pu-238 to fuel RPS. A chronology of key DOE planned RPS and Pu-238 production activities, and NASA's mission-related activities, are shown in figure 1.

Figure 1: Chronology of Key Department of Energy and National Aeronautics and Space Administration Radioisotope Power Systems and Plutonium-238 Production Activities



DOE	Department of Energy
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
NASA	National Aeronautics and Space Administration
Pu-238	plutonium-238
RPS	radioisotope power system

Source: GAO analysis of DOE and NASA information. | GAO-18-161T

[a]DOE has established a date range of 2023 to 2026 to achieve full production of 1.5 kg of Pu-238 per year; however, as of June 2017, DOE officials said they expect to reach full production no earlier than 2025.

[b]Earliest launch dates assume delivery of 1.5 kg of Pu-238 by the start of fiscal year 2026.

DOE demonstrated a proof of concept for new Pu-238 production, and has made approximately 100 grams of new Pu-238 isotope under its Supply Project, since the project's inception in 2011. However, given DOE's Supply Project and RPS production schedule, and NASA's current space exploration plans to use up to four RPS for its Mars 2020 and New Frontiers #4 missions, DOE's existing Pu-238 supply will be exhausted by 2025.

Moreover, DOE officials we interviewed from INL, LANL, and ORNL identified several challenges, including perfecting and scaling up chemical processing and the availability of reactors, that need to be overcome for DOE to meet its projected Supply Project goal of producing 1.5 kg per year of Pu-238 by 2026, at the latest. If these challenges are not overcome, DOE could experience delays in producing Pu-238 to fuel RPS for future NASA missions.

DOE's ability to meet its production goal and support future NASA missions is at risk if certain steps for chemical processing necessary for the production of Pu-238 are not improved and scaled up. According to DOE officials we interviewed, DOE is still in the experimental stage and has not perfected certain chemical processing measures required to extract new Pu-238 isotope from irradiated targets, creating a bottleneck in the Supply Project and putting production goals at risk.

In addition, reactor availability will be necessary for DOE to achieve its Pu-238 production goals. Officials we interviewed at INL and ORNL said that achieving 1.5 kg of Pu-238 per year is contingent on the availability of positions within both the High Flux Isotope Reactor (HFIR) and the Advanced Test Reactor (ATR) to irradiate neptunium targets for conversion to Pu-238 isotope.[12] DOE officials said HFIR can produce approximately 600 grams of Pu-238 isotope and they plan to use positions within ATR to achieve full production goals; however, ATR has not been qualified for Supply Project work. In addition, DOE officials said that ATR's availability for the Supply Project may be limited due to competition from other users. DOE officials said that they will be unable to meet full Pu-238 production goals if positions in ATR, which are already over-utilized, are not available for Pu-238 isotope production and that they do not have a plan to address this challenge.

These and other challenges identified in our September 2017 report may place DOE's RPS and Pu-238 production goals at risk, in part, because of the short-term and incremental segmented management approach DOE had used to manage the Supply Project since its inception in 2011 through early 2017. In March 2017, DOE officials we interviewed said that the agency anticipated moving to a constant GPHS production rate approach to help provide funding flexibility and stabilize RPS production staffing levels between NASA missions. In June 2017, DOE officials we interviewed said that implementing a constant GPHS production rate approach would also address other previously identified challenges associated with RPS production and the Supply Project and therefore

[12]Positions are locations within the reactors where targets are bundled and placed for the irradiation process. Only certain positions are suitable for Pu-238 production. According to DOE documentation, HFIR has 22 positions within the reactor, 20 of which are suitable for Pu-238 isotope production. According to INL documentation and officials we interviewed, ATR has 75 positions within the reactor, of which 9 are suitable for Pu-238 isotope production.

decided to discontinue its short-term and incremental segmented management approach.

However, DOE officials we interviewed did not describe how the new constant GPHS production rate approach would help them address some of the longer-term challenges previously identified by the agency, such as scaling up and perfecting chemical processing. We found that DOE has yet to develop an implementation plan for the new approach, with defined tasks and milestones, that can be used to show progress toward assessing challenges, demonstrate how risks are being addressed, or assist in making adjustments to its efforts when necessary. Our previous work has shown that without defined tasks and milestones, it is difficult for agencies to set priorities, use resources efficiently, and monitor progress toward achieving program objectives.[13]

In our September 2017 report, we recommended that DOE develop a plan that outlined interim steps and milestones that would allow the agency to monitor and assess the implementation of its new approach for managing Pu-238 and RPS production. DOE agreed with our recommendation and noted it was in the process of implementing an approach for the RPS supply chain that was more responsive to NASA's needs, among other things. DOE also noted that it was developing an integrated program plan to implement and document the agency's new approach and expected this to be completed in September 2018. We believe that the development of an integrated program plan is an important step and that any such plan should include defined tasks and milestones, so that DOE can demonstrate progress toward achieving its RPS supply chain goals.

In addition, in our September 2017 report we identified another factor that could undermine DOE's ability to inform NASA about previously identified challenges to reach its full Pu-238 production goal. We found that DOE does not maintain a comprehensive system for tracking RPS production risks and, instead, relies on individual laboratories to track and manage risks specific to their laboratories. *Standards for Internal Control in the Federal Government* call for agency management to identify, analyze,

[13]GAO, *Defense Health Care Reform: Actions Needed to Help Ensure Defense Health Agency Maintains Implementation Progress*, GAO-15-759 (Washington, D.C.: Sept. 10, 2015), and *Biobased Products: Improved USDA Management Would Help Agencies Comply with Farm Bill Purchasing Requirements*, GAO-04-437 (Washington, D.C.: Apr. 7, 2004).

and respond to risks related to achieving defined objectives.[14] We recommended that DOE develop a more comprehensive system to track systemic risks, beyond the specific technical risks identified by individual laboratories. Doing so would better position DOE to assess the long-term effects of the challenges associated with its Pu-238 and RPS production objectives. DOE agreed with our recommendation and stated that the agency would include steps to ensure that its risk assessment system would include comprehensive programmatic risks.

Finally, in our September 2017 report we found that DOE's new approach to managing RPS and Pu-238 production does not allow for DOE to adequately communicate long-term challenges to NASA. It is also unclear how DOE will use its new management approach to communicate to NASA challenges related to Pu-238 production. As a result, NASA may not have adequate information to plan for future missions using RPS. *Standards for Internal Control in the Federal Government* call for agency management to use quality information to achieve agency objectives and communicate quality information externally through reporting lines so that external parties can help achieve agency objectives and address related risks. In our September 2017 report, we recommended that DOE assess the long-term effects that known challenges may have on Pu-238 production quantities, time frames, and required funding, and communicate these potential effects to NASA. DOE stated that it agreed with our recommendation and would work with NASA to identify, assess, and develop plans to address known challenges. DOE also stated that the agency expected to complete this effort in September 2019.

Chairman Babin, Ranking Member Bera, and Members of the Subcommittee, this concludes my prepared statement. I would be pleased to respond to any questions that you may have at this time.

GAO Contact and Staff Acknowledgments

If you or your staff have any questions about this statement, please contact Shelby Oakley at (202) 512-3841 or OakleyS@gao.gov. In addition, contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this statement. Individuals who made key contributions to the report on which this testimony is based

[14]GAO, *Standards for Internal Control in the Federal Government,* GAO-14-704G (Washington, D.C.: September 2014).

are Jonathan Gill (Assistant Director); Samuel Blake, Kevin Bray, John Delicath, Jennifer Echard, Cindy Gilbert, Timothy Guinane, John Hocker, Michael Kaeser, Jason Lee, Tim Persons, Danny Royer, Aaron Shiffrin, Kiki Theodoropoulos, Kristin VanWychen, and John Warren.

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