Shortage of plutonium-238 jeopardizes NASA's planetary science missions

Scientific societies and advisers urge Congress to approve funding to restart production of the radioisotope, which provides the only alternative to solar power for spacecraft.

Cornell University astronomer James Bell thought he had a great proposal for a planetary mission for NASA's New Frontiers program. His probe would explore the cloud of asteroids that follows Jupiter in its orbit around the Sun. But while the science was compelling, he says, powering the spacecraft was problematic. In NASA's 2009 solicitation of proposals, the use of radioisotope power systems was specifically excluded. Bell and his team had no choice but to equip his would-be probe with massive solar arrays sufficient to generate power where sunlight is 1/25th its brightness on Earth. That drawback, he says, doomed the proposal.

Bell's experience illustrates a quandary facing upcoming missions to the outer solar system, and to places like the lunar poles and some craters, where sunlight is faint or never shines: The plutonium-238 that has fueled past missions in those environments is running out. There is only enough left to fuel two of the four NASA planetary missions due for launch before 2020, says Jim Adams, deputy director of NASA's planetary science division. Absent new domestic production of ^{238}Pu or purchases from Russia, NASA will be unable to explore beyond Jupiter or to probe hostile environments, he says.

Since 1961, ^{238}Pu-fueled radioisotope thermoelectric generators (RTGs) have powered 26 NASA spacecraft used for navigation, meteorology, communications, and explorations of the Moon, the Sun, Mars, Jupiter, Saturn, and the outer solar system. The longevity of the two Voyager probes launched in 1977 is testament to the RTG's reliability and long life. The devices are simple; without moving parts, they convert the heat generated by the decay of ^{238}Pu directly into electricity. For missions in permanent shade or where sunlight is too dim, RTGs are the only alternative power source.

NASA's projected mission requirements for plutonium-238

	Power requirement (W)	^{238}Pu usage (kg)
Mission scheduled for launch in 2010–14		
Mars Science Laboratory	100	3.5*
Missions envisioned for launch in 2015–19		
Discovery 12	280	1.8
Lunar Precursor†	280	1.8
Mars (radioisotope power systems and heater units)	280	1.8
Missions envisioned for launch in 2020–24		
Major outer planets mission (Europa)	612	21.3*
Discovery 14	280	1.8
New Frontiers 4	280	1.8
Missions envisioned for launch in 2025–30		
New Frontiers 5	280	1.8
Discovery 16	280	1.8

**Mars Science Laboratory* is designed to use the radioisotope thermoelectric generators, and the major outer planets mission is currently expected to use RTGs. The rest of the missions assume the use of advanced Stirling radioisotope generator (ASRG) technology, reducing the quantity of ^{238}Pu required by a factor of four to meet the power requirements.

†Exploration systems will require a small quantity of ^{238}Pu starting with ASRGs needed for the *Lunar Precursor* mission. The combined exploration and science system requirements will not exceed an average production rate of 1.5 kg per year once the Department of Energy has established production capability for ^{238}Pu.

DOE/NASA

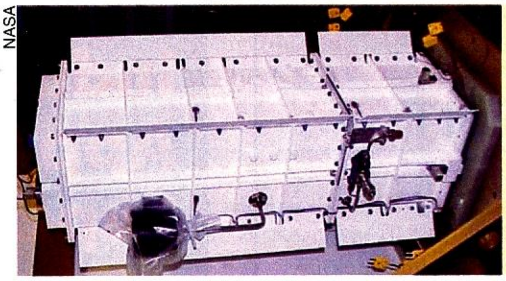
Who should pay?

But Congress has refused to provide the funding to restart production. Lawmakers last year rejected an Obama administration request for $30 million in fiscal year 2010 for the Department of Energy (DOE) to initiate ^{238}Pu production. Although the appropriators did not dispute the need for new material, they argued that NASA, the customer, should pay the cost. The White House came back with an FY 2011 request of $15 million for each agency. The appropriations process was still pending as PHYSICS TODAY went to press, although Senate appropriators have again rejected funding for DOE's portion.

Russia, which had sold the isotope for NASA use since 1992, halted sales in 2009, pending the negotiation of a new agreement between the two governments. Although DOE says it expects to procure "a limited amount" of Russian ^{238}Pu, it warns that may not happen for three or four years. Adams says past deliveries from Russia have often been unexpectedly delayed.

In November NASA's Astronomy and Astrophysics Advisory Committee wrote to NASA administrator Charles Bolden, DOE Secretary Steven Chu, and key lawmakers warning that delay in the restart would not only hamper NASA missions to the outer solar system, "but may well impede development and implementation of future astrophysics missions requiring significant power resources operating in deep space beyond Earth orbit." Similar warnings have been issued by the American Astronomical Society and other scientific organizations. In a report issued in 2009, a committee of the National Research Council (NRC) admonished that "continued inaction will exacerbate the magnitude and the impact of future ^{238}Pu shortfalls, and it will force NASA to make additional, difficult decisions that will reduce the science return of some missions and postpone or eliminate other missions until a source of ^{238}Pu is available."

US output ended in 1988 with the shutdown of DOE's last tritium production reactor. Unlike the fissile and far more plentiful ^{239}Pu isotope, ^{238}Pu has no nuclear weapons application.



An advanced Stirling radioisotope generator now in development could power a spacecraft using only one-quarter the plutonium-238 needed to fuel current-generation power sources.

How much is needed?

In June DOE and NASA issued a congressionally mandated plan for ^{238}Pu production, putting the price tag at \$75 million to \$90 million. That's well below the \$150 million the NRC committee estimated in its 2009 report, which was titled *Radioisotope Power Systems: An Imperative for Maintaining U.S. Leadership in Space Exploration*. The interagency plan says an annual output of 1.5 kg of ^{238}Pu will meet NASA's needs. The plan is to irradiate targets of neptunium-237 at the High Flux Isotope Reactor at Oak Ridge National Laboratory and at the Advanced Test Reactor at Idaho National Laboratory, then chemically extract the ^{238}Pu. But production will require up to three years for undesirable isotopes to decay following irradiation, say DOE officials, so new material won't be available until later this decade.

But NASA's requirements could be far greater than the interagency plan states. The NRC panel found a need for 5 kg/year. The lower figure assumes the successful development of a new radioisotope power technology that promises a factor of four reduction in the amount of ^{238}Pu needed. The advanced Stirling radioisotope generator (ASRG) offers a huge improvement in heat-to-electricity conversion efficiency—29%, compared with the RTG's 6%. So, for example, the RTG that will power a rover when the *Mars Science Laboratory* (*MSL*) sets down on the red planet contains 3.5 kg of ^{238}Pu (see table). An equally powerful ASRG would require just 0.9 kg. The Mars mission is set for launch in November of 2011.

But ASRGs aren't yet fully proven. Unlike RTGs, which have no moving parts, ASRGs incorporate a free-piston Stirling engine that converts heat to mechanical energy. Moving parts obviously raise reliability issues. Still, NASA hopes ASRGs will become available for planetary missions that launch in 2015 and beyond. Adams says the agency has invested heavily in the technology, and engineering models continue to undergo tests at NASA's Glenn Research Center. An indication of NASA's confidence in the technology was the agency's invitation that proposals for an upcoming Discovery-class mission incorporate up to two ASRGs in their designs. Discovery probes are explicitly smaller and require shorter development times, in comparison to large, expensive missions such as the *MSL* or *Cassini*. For its part, DOE plans to build and qualify ASRGs that are ready for launch in late 2014.

Still, NASA isn't quite ready to bet the farm on ASRGs. It's setting aside enough ^{238}Pu to equip a post-2020 mission to Europa with tried and true RTGs—even though that mission hasn't been authorized yet by Congress. Notes Adams, "It would be inappropriate to apply previously unflown power technology" to a mission that was top ranked on the NRC's most recent decadal survey on planetary science.

Apart from the need to conserve the costly material, minimizing ^{238}Pu use is desirable for environmental and health considerations. A NASA analysis says the probability of a successful launch for the *MSL* is very high—96.7%. Although that leaves a 3.3% chance of some sort of accident, the agency maintains the likelihood of a failure releasing radioactive material onboard is only 0.4%. Even then, the analysis notes, the average dose to individuals in the launch area would be 5–10 millirem, less than a dental x ray. Still, each launch with ^{238}Pu undergoes a safety review that culminates with a sign-off from the president's science adviser.

David Kramer

National initiatives recruit and retrain science teachers

Businesses, nonprofit organizations, and the White House are betting on K–12 STEM teachers to forestall the "gathering storm" forecasted by the National Academies.

For US Education Secretary Arne Duncan, the 2009 Program for International Student Assessment (PISA) scores, released last month, were a wakeup call. Once again, US high-school students ranked near the middle of the pack in science, math, and reading, the three areas of focus for the PISA, which tested 15-year-olds in more than 75 countries. In a press release, Duncan said that a slight increase in US students' science ranking from below average is "not much to celebrate." For a knowledge economy, "being average in science is a mantle of mediocrity."

Duncan also took aim at what he felt distinguished perennial PISA frontrunners South Korea and Finland from the US. "[Their practices] show clearly that America has to do much more to elevate the teaching profession, from the recruitment and training of teachers to their evaluation and professional development."

Duncan's response reflects the Obama administration's support for initiatives that aim to recruit and develop K–12 math and science teachers. Last September, President Obama unveiled