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AVOIDING HEU IN SPACE REACTORS: AN EMERGING CONSENSUS

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Several years ago, it was assumed that prospective U.S. space power reactors would utilize fuel of highly enriched uranium (HEU) – despite such uranium being nuclear weapons-usable and therefore disfavored for civilian applications under longstanding U.S. and international nonproliferation policy. More recently, however, a U.S. government consensus has emerged opposing HEU use in space reactors, and instead advocating fuel of low-enriched uranium (LEU), which is not suitable for nuclear weapons under International Atomic Energy Agency guidelines. This paper first documents the emergence of the consensus against HEU space reactors and then recommends that the American Nuclear Society promote research and development of LEU-fueled space reactors, which may be the only politically plausible pathway for the United States to achieve nuclear power in space.

I. INTRODUCTION

Several years ago, it was assumed that prospective U.S. space power reactors would utilize fuel of highly enriched uranium (HEU) – despite such uranium being nuclear weapons-usable and therefore disfavored for civilian applications under longstanding U.S. and international nonproliferation policy. In January 2018, the U.S. government even tested a prototype of such a reactor using HEU fuel at a national laboratory.[1] More recently, however, a U.S. government consensus has emerged opposing HEU use in space reactors, and instead advocating fuel of low-enriched uranium (LEU), which is not suitable for nuclear weapons under International Atomic Energy Agency guidelines. This U.S. government consensus is remarkably broad, encompassing both the Executive and Legislative branches of government, both the House and Senate, and both the Republican and Democratic parties. The alternative of LEU-fueled space power reactors appears feasible, based on research conducted by the National Aeronautics and Space Administration (NASA) and the Department of Energy (DOE), and awaiting research and development (R&D) of some technical aspects. This paper first documents the emergence of the consensus against HEU space reactors and then recommends that the American Nuclear Society (ANS) promote research and development of LEU-fueled space reactors, which may be the only politically plausible pathway for the United States to achieve nuclear power in space.

II. BACKGROUND

The U.S. government consensus against HEU-fueled space power reactors is motivated by the desire of U.S. officials to sustain, rather than undermine, more than four decades of progress in the U.S.-led international nonproliferation policy of minimizing HEU outside of nuclear weapons.[2] The proliferation risks of HEU are well known.[3] Fifty kilograms of HEU is sufficient for a simple, gun-type nuclear weapon like the one dropped on Hiroshima, which would be straightforward even for terrorists to construct. Much less HEU would be sufficient for an implosion bomb having multi-kiloton yield, which states could accomplish and perhaps some terrorists.[4] Accordingly, the amount of HEU in even a small space power reactor, like the one tested in 2018, would be sufficient for one or more nuclear weapons. If the United States were to proceed with HEU space reactors, it could increase not only nuclear proliferation risks – due to other countries following the precedent – but also nuclear terrorism risks arising from the requisite terrestrial fuel cycles including in the United States.

The U.S. government initiated its HEU minimization policy in the 1970s.[5] Since then, the scope of the policy has grown to encompass many types of nuclear facilities: foreign research reactors, U.S. university and commercial research reactors licensed by the Nuclear Regulatory Commission (NRC), U.S. government research reactors operated by the Department of Energy (DOE), and foreign and domestic processing plants that produce medical isotopes. In addition, during the past six years, Congress has funded research and development of Navy LEU fuel in hopes of replacing HEU fuel for propulsion of submarines and aircraft carriers.[6] Most recently, in 2019, the U.S. Army mandated that proposed designs of its new Mobile Nuclear Power Plant (MNPP) must utilize LEU fuel.[7]

A guiding principle of the U.S. HEU minimization policy has been to avoid exceptions, on grounds that if any country were granted an exception for a facility, then other countries would demand exceptions too, potentially unravelling the policy. That is why, even though the U.S. government's original goal was to reduce foreign use of HEU, the implementation started by converting two domestic research reactors.[5] When the U.S. government momentarily violated this principle in the late 1980s, by proposing to build a new HEU-fueled research reactor, European countries reacted by threatening to stop converting their reactors from HEU to LEU – until the U.S. plan was abandoned in 1995.[5]

U.S. policy acknowledges that converting some facilities from HEU to LEU may require R&D, justifying a delay in but not an exemption from conversion. Among U.S. research reactors that had used HEU fuel, 17 already have been converted to LEU fuel, another is expected to close, and R&D is ongoing to achieve conversion of the final six. In countries supplied by the United States with enriched uranium, dozens of research reactors have been converted from HEU to LEU, and the final two are scheduled to be converted within a decade. In these countries, after the 1970s, only one additional HEU-fueled research reactor was constructed, and the U.S. government steadfastly refused to provide HEU due to the no-exception policy, which explains why the operator is now converting to LEU fuel.[8] For medical isotope production, the U.S. government likewise rejected foreign appeals for exceptions, so that only one major producer in the world still uses HEU targets, and it will fully convert to LEU targets by next year.[9] The Army offers no exception from its LEU requirement for MNPPs. The Navy must await further R&D before it can decide whether to convert to LEU propulsion reactors, but Congress has rejected appeals to exempt submarines from the LEU R&D requirement that also applies to aircraft carriers.[10] Thus, the U.S. government appears to have avoided exceptions from the HEU minimization policy in any domain – except obviously the U.S. nuclear weapons stockpile.

III. CONSENSUS ON LEU SPACE REACTORS

The spark for emergence of the U.S. government consensus against HEU space power reactors was the January 2018 test of the HEU-fueled prototype. U.S. nonproliferation officials quickly realized that proceeding with such a reactor could sabotage decades of hard-won international progress on HEU minimization. Even many advocates of space nuclear power came to oppose the HEU-fueled version because they realized the nonproliferation controversy might derail space nuclear power entirely.

Two legislative initiatives demonstrate that the Congressional opposition to HEU space reactors is bipartisan and bicameral. In June 2019, Rep. Bill Foster, a Democrat and the only physicist in the U.S. Congress, successfully added an amendment enacted as part of an appropriations bill. As he explained on the floor of the House of Representatives, the “Amendment directs NASA to work toward the development of a LEU space power reactor….The problem is that if all the spacefaring nations of the world start using large amounts of weapons-grade material in their space reactors, then it will be difficult to ensure that this Material would not be diverted to weapons programs in space and on Earth. If the U.S. develops a LEU space power reactor design, it is likely that this type of reactor design will be adopted as a de facto standard by other spacefaring nations, making Earth and space a safer place.”[11]

In September 2020, the Republican-controlled Senate Commerce Committee reported to the full Senate a NASA Authorization bill including Section 506 on “Prioritization of Low-Enriched Uranium Technology.” It provides as follows: “(a) *Sense of Congress*.--It is the sense of Congress that…HEU presents security and nuclear nonproliferation concerns…[T]he use of LEU in place of HEU has security, nonproliferation, and economic benefits, including for the national space program. (b) *Prioritization of Low-enriched Uranium Technology*.--The Administrator shall establish and prioritize, within the Space Technology Mission Directorate, a program for the research, testing, and development of a space surface power reactor design that uses low-enriched uranium fuel. (c) *Report on Nuclear Technology Prioritization*.--Not later than 120 days after the date of the enactment of this Act, the Administrator shall submit to the appropriate committees of Congress a report that-- (1) details the actions taken to implement subsection (b); and (2) identifies a plan and timeline under which such subsection will be implemented.”[12]

The Executive Branch of the U.S. government also now favors LEU space reactors. In February 2020, NASA and DOE completed the final draft of a “trade study,” comparing HEU versus LEU as fuel for space reactors. The report is not publicly available, but in June 2020 its findings were publicly characterized by the Deputy Chief Engineer of NASA’s Space Technology Mission Directorate, at the ANS Annual Meeting. The study, he said, “Concluded that moderated HALEU-fueled reactors are competitive in mass with HEU-based designs.”[13] (HALEU is “high assay” LEU, enriched above five percent but below 20 percent.) This undermined the main rationale of HEU proponents – that LEU would significantly increase the mass of a space power reactor and thus preclude or sharply increase the expense of launching it.[14]

Also in February 2020, NASA’s Budget Estimate stated that its nuclear fission power project “will seek to identify design trades and collaborative opportunities with industry, and to the extent feasible take advantage of the interagency investment in a common fuel source for both nuclear power and propulsion systems.”[15] Since NASA already had embraced LEU for propulsion reactors, this statement provided an economic-efficiency rationale for using LEU fuel also in space power reactors. In November 2020, the press reported that the Nuclear Technology Portfolio Lead in NASA’s Space Technology Mission Directorate had concluded that, “A low enriched form of nuclear fuel will power the nuclear core" of future space power reactors.[16]

The White House first demonstrated concern over HEU-fueled space reactors in its August 2019 "National Security Presidential Memorandum on the Launch of Spacecraft Containing Space Nuclear Systems." The policy declared that, "Due to potential national security considerations associated with nuclear nonproliferation, Tier III [the most restrictive] shall also apply to launches of spacecraft containing nuclear fission systems and other devices with a potential for criticality when such systems utilize any nuclear fuel other than low-enriched uranium…The President's authorization shall be required for Federal Government launches in Tier III."[17]

The White House amplified its concern over HEU space reactors in its December 2020 "Space Policy Directive–6, the National Strategy for Space Nuclear Power and Propulsion." This directive effectively banned HEU-fueled reactors except in the absence of any alternative way of accomplishing the mission. It declares that, "The use of HEU in space nuclear power and propulsion systems should be limited to applications for which the mission would not be viable with other nuclear fuels or non-nuclear power sources."[18]

NASA is already implementing this new policy, according to the agency's March 2021 presentation to an NRC regulatory conference, stating that it "prefer[s] HALEU fission reactor solutions based on [the] March 2020 DOE study that showed masses comparable to HEU systems."[19] NASA also revealed that the "current government reference design calls for a segmented moderated HALEU reactor" for the fission surface power project. The government also continues to mandate LEU for nuclear thermal propulsion, as codified in a December 2020 statement of work: "The reactor shall use high assay low-enriched uranium (HALEU) fuel, or uranium fuel with lower levels of enrichment."[20]

IV. ACHIEVING SPACE NUCLEAR POWER

The NASA/DOE trade study of February 2020 documented that LEU reactors, by employing a moderator to thermalize neutrons, can avoid a large mass penalty in comparison to the baseline fast HEU reactor that excludes a moderator. The study also noted that LEU reactors "have greater complexity" and thus require additional R&D.[13] Such research, which DOE already is supporting, reportedly focuses on two potential moderators: zirconium hydride (ZrH) and yttrium hydride (YH). ZrH is the more mature technology, but YH could avoid hydrogen loss at higher temperature.

In light of the U.S. government consensus against HEU space reactors, pursuing R&D on LEU space reactors may be the only politically plausible pathway for NASA to achieve nuclear power in space. In addition, providing results of such research to other countries could reduce their perceived need to produce or handle HEU, thereby decreasing risks of diversion or theft for nuclear weapons and mitigating international security concerns and tensions.

Accordingly, the ANS and its Aerospace Nuclear Science and Technology Division could best facilitate space nuclear power by advocating R&D of LEU space power reactors. By contrast, if the ANS were to promote HEU-fueled space reactors, despite the U.S. government consensus against them, it might inadvertently undermine prospects for any space nuclear power. Simply put, in the context of space exploration, the pro-nuclear position is anti-HEU.

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