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AVOIDING HIGHLY ENRICHED URANIUM FOR SPACE POWER

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To provide power for a Mars or lunar surface mission, NASA is developing a nuclear reactor that would use fuel of weapons-grade, highly enriched uranium (HEU), in apparent ignorance or disregard of decades of U.S.-led international efforts to eliminate the use of HEU fuel in nuclear reactors to reduce risks of nuclear proliferation and nuclear terrorism. This paper reviews the history and progress since 1978 of international efforts to eliminate HEU as fuel in research reactors, naval propulsion reactors, and medical-isotope production. It then explores the costs and benefits for the U.S. space-reactor program of substituting fuel of low-enriched uranium (LEU), which would increase weight requirements but reduce security costs, eliminate proliferation and terrorism concerns, and mitigate political risk. The paper illustrates the political risk arising from the proposed use of nuclear weapons-grade reactor fuel by reference to the case of the Advanced Neutron Source, which was an advanced U.S. research reactor designed in the 1980s and then canceled in 1995 on grounds that its proposed HEU fuel presented "a non-proliferation policy concern."

I. FOUR DECADES OF U.S. EFFORTS TO ELIMINATE HEU FUEL IN REACTORS

The proliferation and terrorism risks of HEU fuel have been widely recognized for at least four decades. If terrorists or countries got hold of a sufficient quantity of HEU, they could set off a nuclear weapon explosion simply by slamming two pieces of the material together. This was the design principle of the Hiroshima bomb, which killed tens of thousands in 1945. A smaller amount of HEU could be used to make a weapon of similar yield employing an implosion assembly, the principle behind the Nagasaki bomb. In either case, the resulting devastation from blast effects, fire, and high radiation would dwarf that from an improvised "dirty bomb," which would only disperse much smaller amounts of radioactive material.

In 1978, the United States initiated an international effort, the Reduced Enrichment for Research and Test Reactors (RERTR) Program, to phase out HEU fuel from nuclear research reactors by converting them to higher-density LEU fuel, to reduce risks of proliferation and terrorism without significantly degrading reactor performance.[1] Since then, around the world, 96 civilian research reactors had been converted or shut down by October 2016.[2] Conversion to LEU fuel has been highly successful, according to a recent survey, which reported that "operators overwhelmingly perceived any negative impacts to be outweighed by positive ones."[3] In addition, since 1980, more than 20 large (>1 MW) new research reactors have been designed to use LEU fuel.[4] Moreover, by 2020, all major worldwide producers of Mo-99 for radio-pharmaceuticals, except in Russia, are expected to have successfully converted from HEU to LEU "targets" for their production processes. Due to these efforts, worldwide use of HEU for research reactors and pharmaceutical production has been slashed by several hundred kilograms annually to less than one ton per year, and the decline is expected to continue. More recently, Congress has started funding the U.S. Navy to explore converting to LEU fuel its nuclear propulsion reactors in aircraft carriers and submarines.[5]

II. BACKGROUND ON HEU AND SPACE REACTORS

Potential use of HEU fuel in any country's space reactor program raises at least two significant security risks. First, the ground-based infrastructure – for fabricating, transporting, and test irradiating fuel – would create vulnerabilities for terrorists or criminals to steal HEU and fabricate a crude fission weapon, or for the country to divert HEU for nuclear weapons. (Security measures to reduce these risks would also add considerable cost, compared to LEU fuel.) Second, any country's HEU-fueled space reactor would establish a precedent that other countries could use to justify their own production of HEU, thereby exacerbating proliferation and terrorism dangers.

Although there have been no launches in recent years, from 1967 to 1988 the Soviet Union launched into space 35 nuclear reactors, all fueled with HEU. These reactors provided power for satellite radars that tracked U.S. naval vessels. The United States launched one reactor into space, in 1965, also HEU-fueled. (Space reactors should not be confused with radioisotope thermoelectric generators, which produce smaller amounts of energy for space missions from the radioactive decay of plutonium-238 or other radioisotopes.) No country is known currently to be planning a launch, but several are contemplating future space reactors, still based on HEU fuel. In a 2009 paper, Japanese scientists explored an LEU-fueled reactor design for a notional deep-space probe, but until recently no country had conducted a serious assessment of the penalties to reactor weight or mission capability (or any possible benefits) from converting to LEU.[6]

In light of the recent pause in space-reactor launches, I previously had made the following recommendations: "Countries contemplating future [space reactors] should utilize this window of opportunity to conduct feasibility assessments of potential conversion [to LEU], before that is precluded by serious planning of HEU-fueled missions. In the United States, the White House Office of Science and Technology Policy could ask the Department of Energy [DOE] to engage the RERTR program for such a study, building upon a preliminary assessment conducted in 1994 by the DOE's Office of Nuclear Energy. The international community also should correct a drafting error in the 1992 UN General Assembly resolution on space reactors that aimed to ban plutonium fuel, but did so imprecisely by mandating that such reactors must use HEU fuel. An amendment should clarify that LEU is not only acceptable but preferable if feasible."[7]

More recently, Dr. Edwin Lyman of the Union of Concerned Scientists and I made additional recommendations: "The U.S. government needs to practice what it preaches. No competitor would forego bomb-grade uranium if NASA charges ahead with use of this dangerous material. Now is the moment to make clear that the global norm against highly enriched uranium in reactors applies to space missions too. . . . Admittedly, it would take some time to perfect a new space reactor using low-enriched uranium. Fortunately, there is no great rush. Just last month, NASA's chief of human spaceflight, William Gerstenmaier, acknowledged that the space agency's budget lacks funding for a manned mission to Mars, estimated to cost $100 billion to $1 trillion over a quarter-century. . . . Taxpayer dollars and private capital would be better spent developing space reactors that use safe low enriched uranium, so these systems can be ready when the U.S. government eventually marshals the funds for a mission to the red planet, or beyond."[8]

III. SMART LEU PLAN FOR PROPULSION

The United States is currently developing new space nuclear reactors for both nuclear thermal propulsion (NTP) and surface power. The propulsion reactor is based on LEU fuel,[9] explicitly to stay consistent with longstanding U.S. policy to minimize HEU fuel to reduce risks of nuclear terrorism and nuclear proliferation (and associated security costs).

A 2016 NASA presentation explained as follows: "Current US policy strongly discourages the use of highly enriched uranium (HEU) in civilian applications. Low enriched uranium (LEU) NTP systems should be considered to significantly reduce security-related cost, schedule, and programmatic impacts, and to avoid generating opposition based on non-proliferation concerns. . . . Even if allowed, security requirements associated with the use of HEU could result in very significant impacts to the cost and schedule of development, qualification, and utilization of nuclear thermal propulsion (NTP) systems that use HEU. The use of low enriched uranium (LEU) is internationally accepted. LEU is used in a wide variety of fission systems throughout the world, including commercial and university reactors."[10]

In May 2016, a NASA factsheet added: "A shift to low enriched uranium (LEU)—defined as a concentration of lower than 20 percent uranium-235—offers several potential advantages for a nuclear propulsion development program. Security regulations for an LEU system could be less burdensome on the project budget and schedule. Handling regulations for an LEU source are similar to those for a university research reactor, opening up the development effort to partnerships with industry and academia. . . . An advantage of an LEU-based system is the possibility of total containment testing at a conventional propulsion test facility such as Stennis Space Center, which further reduces cost and complexity."[11]

In February 2017, a NASA presentation reported that "initial LEU conceptual designs [are] very promising." It also delineated the multiple benefits of LEU fuel: "Directly reduce cost through savings related to safeguards and security; Indirectly (and more significantly) reduced cost through enabling use of an optimal development approach and team; Consistent with ongoing programs to convert operational Highly Enriched Uranium (HEU) systems to LEU; Consistent with US policy." In particular, this NASA presentation cited a White House "Fact Sheet" from 2012, which stated: "The United States is committed to eliminating the use of HEU in all civilian applications, including in the production of medical radioisotopes, because of its direct significance for potential use in nuclear weapons, acts of nuclear terrorism, or other malevolent purposes."[12]

IV. UNWISE HEU PLAN FOR SURFACE POWER

In contrast to NASA's enlightened focus on LEU fuel for the planned propulsion reactor, NASA has focused on HEU fuel for the planned surface-power reactor – ignoring HEU's downsides in terms of terrorism and proliferation, additional security costs, and political risk. In January 2018, initial tests were conducted on this system.[13]

The Kilopower, or KRUSTY, reactor uses 30kg of weapons-grade HEU in its core.[14] This is more than sufficient for a nuclear weapon. Indeed, the U.S. government requires maximum security for even a fraction of that amount – a mere 5kg.[15] Proponents of this system envision five such reactors on the surface of Mars. Testing and then deploying such a system would therefore require hundreds of kilograms of weapons-grade HEU, sufficient for many nuclear weapons.[16]

The first known U.S. government reconsideration of HEU for a surface space reactor was contained in a White Paper published by Los Alamos National Laboratory (LANL) in August 2017.[17] The paper starts by acknowledging that HEU has higher energy density, so a greater mass of LEU is required to produce the same energy – a downside for space missions in which minimizing weight is typically a high priority. The paper estimates that an LEU reactor would weigh at least 40 percent more than an HEU reactor for the same energy output. However, for the basic KRUSTY design, the paper says "higher mass is the only significant negative of using LEU – in fact, the LEU system may be slightly easier to develop."

The paper then explains that the "primary reasons to use LEU are political and economic," including national security. In addition to the nonproliferation policy imperative to avoid HEU, the paper underscores that "HEU can be expensive to process, test, transport and/or launch." Evidence from existing facilities, it says, "indicates annual security costs in the ten's of millions and facility infrastructure costs that can range from ten's to hundred's of millions." The paper also reports that "Recent NASA studies on the launching of HEU indicate a cost on the order of ten million per month at the launch site." Further security costs, it notes, could also arise because "An HEU launch might require a large specialized force on standby in case retrieval is needed."

The paper estimates that lower security costs for LEU could roughly offset the higher costs for a heavier reactor: "While no definitive conclusion can be made, the launch costs for LEU are probably about equal or only a few 10's millions more expensive than HEU."

The lower security requirements for an LEU reactor would crucially enable it to be developed less expensively at commercial facilities. The LANL paper states: "For a commercial space reactor effort, LEU is probably the only option and could prove to be much cheaper. Based on the cost reductions for rockets developed privately versus those developed by government, it can be assumed that development costs of a commercial space reactor could be anywhere from 10% to 50% of the cost of a government developed space reactor. For a reactor concept like KiloPower this could mean a cost in the 10's of millions instead of 100's of millions."

Given that reactor development costs would be much lower with LEU, while reactor launch costs would be roughly the same with LEU (due to decreased security costs), it appears clear that LEU would be less expensive than HEU for a surface power reactor. This is the case even before considering the substantial political risk entailed by HEU.

V. POLITICAL RISK FROM HEU: LESSONS FROM THE ADVANCED NEUTRON SOURCE

The major political risk for a space reactor program relying on HEU fuel is that the program eventually could be canceled due to controversy over the weapons-grade fuel. This is not merely a hypothetical concern. Exactly such a scenario played out for a planned U.S. government research reactor a quarter-century ago.

In the late 1980s, the U.S. Department of Energy announced plans to build a new HEU-fueled reactor, the Advanced Neutron Source, initiated by the presidential administrations of Ronald Reagan and George H.W. Bush.[18] Allied countries were outraged, because Washington had demanded that they convert their research reactors from HEU to LEU and avoid building new reactors fueled by HEU. This led to a near revolt at the 1987 annual RERTR meeting, as reported at the time: "DOE's decision to go ahead with a new reactor fueled with HEU, in apparent disregard for the RERTR program, led to open conflict during a conference in Grenoble, France . . . The Europeans were not amused. French officials told DOE representatives flatly that they would insist on using HEU in their best research reactors if the United States builds the new facility."[19]

The U.S. plan for a new HEU-fueled reactor also created a dangerous precedent. In Germany, the operator of the FRM-II reactor, under development at the time, decided to pursue an HEU-fueled design on grounds that Washington had created an exception for state-of-the-art reactors. As the German operator explained to a reporter in 1987, "To some extent, it's a matter of competition . . . I also think that it is a matter of fairness."[20] A subsequent press report explained that "foreigners derided America's attitude as a colossal double standard: It was OK for the U.S. to use bomb-grade fuel but not for other countries."[21]

Eight years later, in 1995, the U.S. government was compelled to cancel its planned new reactor. President Bill Clinton's administration explained that this decision was made at least partly because the HEU fuel presented "a non-proliferation policy concern."[22] Since that cancelation, the U.S. DOE has failed to construct a new reactor-based neutron source, despite the significant aging of its two remaining such reactors (the ATR and HFIR). Thus, the initial ill-considered decision to pursue HEU fuel contributed to derailing any new reactor. This is an important lesson for advocates of space nuclear power.

VI. CONCLUSION

HEU fuel, due to its higher U-235 density, typically enables a smaller reactor mass and volume than LEU fuel. But HEU fuel has many other downsides: proliferation risk, terrorism risk, costs for security, inhibiting of commercial development due to security constraints, and political risk of cancelation due to controversy over the use of nuclear weapons-grade fuel. These downsides of HEU fuel far outweigh the benefit of reduced reactor mass and volume. The ongoing development of nuclear thermal propulsion is on a promising track by focusing on LEU fuel. By contrast, the ongoing development of space surface reactor power, including the initial KRUSTY test in January 2018, is misguidedly focused on HEU fuel. Continuing to rely on HEU fuel would inhibit commercial development, increase costs for security, and significantly increase the risk of cancelation due to political controversy. In this light, NASA would be well advised to shift its space surface power reactor development from HEU fuel to LEU fuel as soon as possible.

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