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A Strategy for Building Space Nuclear Systems That Fly

NASA's new directive to design, build, and deploy a nuclear reactor on the moon by 2030 will require a commitment to implementation, leadership from the White House, and learning from six decades of failures.

At 4:04 p.m. on April 3, 1965, a rocket lifted off from Vandenberg Air Force Base carrying SNAP-10A, the first and only US nuclear reactor ever to operate in space. The reactor itself was small enough to fit in a wastepaper basket, generating 600 watts of electric power for an experimental electric thruster. It operated for just 43 days before a voltage regulator failed. Still circling Earth safely at an altitude of 1,300 kilometers, SNAP-10A remains a lonely artifact of American ambition in space.

In the decades since, there have been about a dozen start-stop-restart efforts to launch a nuclear fission system in space. Programs have envisioned nuclear systems for propulsion as well as for power. They were established by both civil and defense agencies, with plans ranging from prototype systems to full-scale missions. In sum, the United States has spent tens of billions of dollars (there is no official tally) on undelivered space nuclear power and propulsion.

In the last two decades alone, projects have included NASA's Jupiter Icy Moons Orbiter (JIMO)/Prometheus mission to explore the moons of Jupiter in the early 2000s; the NASA–Department of Energy (DOE) experiment named the Kilopower Reactor Using Stirling Technology (KRUSTY) to demonstrate fission power in the late 2010s; and the recently canceled NASA-DARPA Demonstration Rocket for Agile Cislunar Operations, or DRACO, collaboration to demonstrate nuclear thermal propulsion. In each, high-level enthusiasm gave way to paper studies, research and development, and some hardware development—in the case of KRUSTY, an actual successful ground experiment. But all succumbed to budget cuts and subsequent organizational drift. SNAP-10A remains both a technical achievement and a strategic indictment: proof that the capability was there, but the system to scale it was never built.

In contrast, the Soviet Union, and later Russia, fielded more than 30 nuclear space reactors between the 1960s and 1980s, mostly for radar surveillance missions in low Earth orbit. They proved that with sufficient mission pull, programmatic focus, and institutional will, space nuclear systems can be designed, built, launched, and operated routinely. Now China, in collaboration with Russia, has announced plans to place a reactor on the Moon's surface. If successful, that system will not only power a base; it will establish a precedent, set operating norms, and shape access to valuable parts of lunar terrain.

Against this backdrop, the United States is once again trying to break the cycle. In December 2020, the White House's Space Policy Directive–6 instructed NASA to create a fission power plant that could be demonstrated on the Moon by 2027, with the intention of scaling it up for Mars exploration. In response, NASA directed minimal funds toward a mid-2030s launch of a small (40 kilowatt-electric) system for the Moon. In November 2024, NASA publicly announced that it had selected nuclear fission as the primary power generation technology for crewed missions to Mars.

Then, in August 2025, Sean Duffy, who is both the US secretary of transportation and NASA's acting administrator, upped the stakes, issuing a directive to design, build, and deploy a high-power nuclear reactor delivering at least 100 kilowatts of electric power on the lunar surface by the first quarter of 2030. The announcement was framed as part of a broader shift toward permanent infrastructure on the Moon and Mars. This would elevate the plan from a one-off technology demo to the foundation of a scalable power architecture for civil, commercial, and national security uses on the Moon and beyond.

For those concerned about the future of US leadership in space, this directive is an exciting new development. However, history shows that when it comes to space nuclear power, the United States is far better at setting goals than seeing them through. After six decades of failure, the central question is what it would take to move this program, unlike its many predecessors, to successful completion.

The future of space exploration is nuclear

The future of US human space activities, including any sustained presence on the Moon and a human mission to Mars, requires the continuous, robust power that only nuclear fission can provide. As the United States shifts away from one-shot, flag-planting exercises toward long-duration, infrastructure-heavy missions, the solar power that has often provided power on previous missions will not be sufficient. Solar lets you visit. Nuclear lets you build.

On the Moon, where night lasts two-weeks and some craters are permanently shadowed, solar power is intermittent and fragile. Batteries cannot carry a base through the hundreds of hours of darkness on the lunar south pole. By contrast, a fission reactor can provide stable power through any lunar condition, enabling life support, excavation, water extraction, oxygen generation, data processing, and more.

On Mars, the case for nuclear fission is even stronger. Photovoltaic output is degraded by both distance from the sun and frequent planet-wide dust storms. We have calculated that it would require over a dozen football field–sized solar panels to generate 100 kWe. NASA has selected fission as the surface power baseline for Mars crewed missions precisely because the agency recognizes that there is no other technology that meets the power demands of a sustainable outpost.

In national security, nuclear power makes it possible to do persistent sensing from space, along with large-aperture radar, secure communications, or rapid repositioning without large and vulnerable solar farms. In addition, powerful lasers and large autonomous satellite networks need steady, reliable power beyond what solar can provide. For defense, nuclear power offers durability, staying power, and the ability to maneuver, all of which will increasingly matter in future military space operations.

Going forward, space nuclear power is essential to develop the industrial processes that would drive a space economy. For example, ice prospecting—a goal shared by NASA and the private sector—is power hungry. Extracting and processing lunar ice into water, oxygen, and hydrogen fuel requires steady kilowatts to run drills, pumps, and cryogenic plants through the two-week lunar night. Beyond the Moon, proposals for orbital data centers and in-space computer clusters—serving AI workloads, secure communications, or defense applications—will require hundreds of kilowatts of continuous power far from Earth. None of these sectors can move from wishful PowerPoints into reality without reliable nuclear power in space.

Why has space nuclear failed to launch?

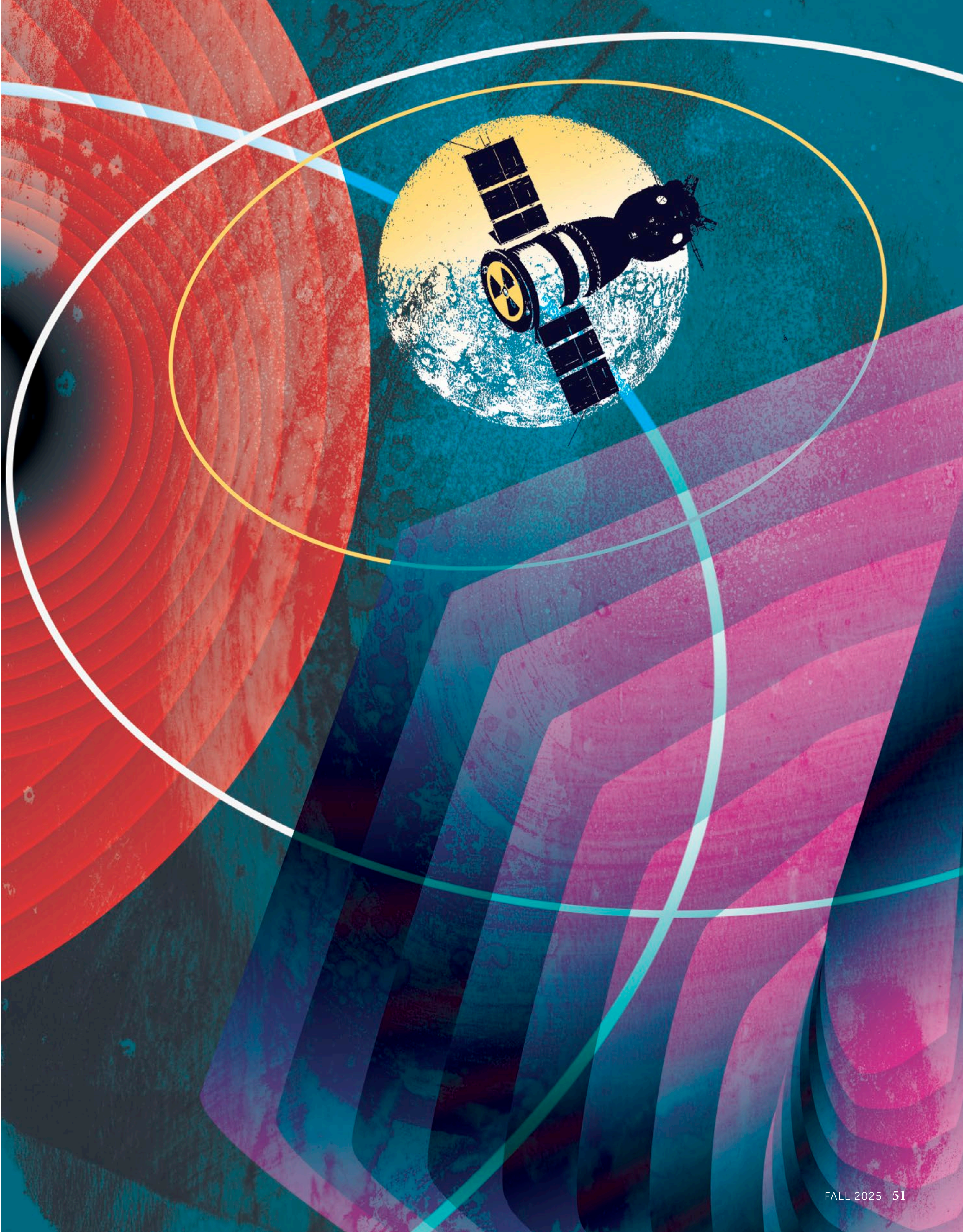
With the strategic value of space nuclear power becoming clearer, Secretary Duffy's 2025 directive sets a firm date on the calendar, raising the possibility that the United States may finally overcome the hurdles it has faced in the past. But to do so, decisionmakers must take lessons from past systemic failures that were related to four core issues: mission pull, technological overreach, timelines, and leadership. Without directly addressing these four areas, the current initiative may suffer the same fate as its predecessors.

The central reason previous programs have failed is that they lacked "mission pull." In most cases, space nuclear programs began with bottom-up technology development rather than as a top-down requirement to meet a larger need or specific mission. In this sense, space nuclear proposals were solutions in search of a customer. Without a deadline for deployment, or an institutional home that demanded the solution, the programs had no urgency. Without urgency, there was no sustained funding. Without funding, there was no constituency to fight for its survival. Put simply, programs lacked an anchoring mission, resulting in open-ended technology development with no deployment pathway. Indecision and drift filled the vacuum. To be successful, any plan to develop nuclear power for space must have a named user, a deployment plan, and a date on the calendar.

Another reason previous efforts failed was technological overreach, causing projects to collapse under the weight of their own ambition. By aiming for breakthrough performance without building the necessary foundation, too much was attempted too fast. A textbook example of overreach is NASA's JIMO/Prometheus program, which attempted to leap from paper to a flagship mission to Jupiter before validating systems in lower-risk environments. The program paired multiple untested systems: a new reactor design, unproven power conversion systems, and a "space bus" that did not yet exist and had no vehicle capable of launching it. As cost estimates spiraled above $20 billion, there was friction in the poorly defined partnership between NASA, DOE, and private companies. By 2005, after spending over $400 million, JIMO/Prometheus was canceled. For the current effort to succeed, its ambition must be matched with step-by-step attention to iteration.

The third factor is timelines—a perennial issue for space development, but particularly vexing for nuclear power.

Illustration by Shonagh Rae



While US political and budgetary windows operate on one-, two-, and four-year cycles, developing and deploying space nuclear systems requires longer time frames. Programs must survive changes in administration, swings in congressional interest, and evolving agency priorities to survive. This mismatch breeds instability and makes programs highly vulnerable to delay, downscoping, or outright cancellation. It also discourages industry from investing: Without committed buyers beyond NASA, firms will resist cost-sharing and want government to bear nearly all the risk. To be successful, space nuclear programs must be structured in bite-sized, sequential milestones—each achievable within a political cycle—so that real progress is visible, momentum is locked in, and cancellation becomes harder for the next administration or Congress.

Perhaps the most persistent and damaging obstacle for nuclear power in space has been fragmented leadership. Unlike the US Navy's reactor program, which succeeded because it vested cradle-to-grave authority in the single office of the Navy Nuclear Propulsion Program, space nuclear has never had a central owner. Responsibilities are spread across multiple agencies—NASA for spacecraft integration; DOE for fuel and safety; the Department of Defense for national security missions as well as launch; the Federal Aviation Administration for launch authorization for commercial missions; and the Nuclear Regulatory Commission for oversight—yet none has both the mission demand and budgetary control to carry a program from start to finish. As a result, programs drift without clear accountability, interagency disputes slow progress, regulatory red tape balloons, and budget lines are vulnerable because no single institution defends the entire program. Fragmentation also discourages industry investment, since companies cannot rely on a single empowered counterpart to align requirements and shepherd systems through to flight. The lesson is clear: Success requires a central authority with real budget power, milestone control, and the mandate to integrate across agencies. Without such unifying authority, space nuclear will continue to falter under divided responsibility and institutional drift.

Choosing the right path forward

Secretary Duffy's August directive to build a nuclear reactor on the Moon by 2030 represents a rare moment of opportunity. By combining a big-goal outcome with fixed-price, milestone-based commercial contracting approaches, this new initiative appears poised to overcome two historical barriers: mission pull and timeline mismatch. But it still risks overreach and is silent on empowered leadership.

The goal of making a reactor that produces more than 100 kilowatts of electric power on the lunar surface by 2030 is ambitious. Requirements include not only designing and testing a first-of-its-kind fission core but also solving a multitude of complex technological challenges. Each of these challenges may require multiple years of work on its own. Yet the initiative calls for them to be delivered all at once, and by commercial companies, some of which have never executed a project this complex. No single commercial firm has experience spanning the full set of overlapping domains: nuclear materials production and safeguards, reactor physics and safety qualification, power conversion and thermal management in space, not to mention the challenges of getting the equipment to the Moon and managing it there.

Based on our research on previous nuclear programs, we recommend two sets of actions to help ensure that this framework can be made functional to land a working nuclear reactor on the Moon by 2030.

First, the program must pass what we call the Manhattan Project test (see sidebar): naming one accountable leader with real authority (à la Admiral Hyman Rickover of the nuclear navy, who controlled budgets, technical trades, and safety decisions from design through deployment), locking in a multiyear funding ramp, and ensuring that the mission is framed as a strategic imperative.

Second, government agencies must be empowered in an enabling role to make the commercial model viable, with program leadership coming directly from the White House. It may seem counterintuitive that a plan for commercially led development, launch, and operation of nuclear power in space requires such significant and high-level government leadership. But beyond the Manhattan Project test requirements, success also requires a commitment to execution: supports in place to anchor and encourage progress to mature the technology, synchronize infrastructure, and enable flexible regulation. Not only are these functions best performed by the government, but they require exceptionally high-level authority—specifically, the White House.

The most daunting aspect of this project is developing the advanced technology required for a 100-kilowatt reactor to function in space. From turbomachinery that works in a vacuum and microgravity, radiators that can reject waste heat efficiently, and autonomous systems that can operate without human intervention or repair, the technical bar is very high, and terrestrial analogs will not cut it. Making the necessary advances in these areas will require significant government funding, and work may need to be done at NASA centers or DOE laboratories that have the necessary skill sets in place. The scrappy commercial start-ups, as capable as they are in bringing ingenuity and speed to the table, must be supported by sophisticated R&D that only the government can fund.

In addition to R&D funding, the United States must also field infrastructure—a working chain of nuclear fuel supply, component and system fabrication, assembly and fueling in shielded environments, thermal testing, and payload integration for launch in a tight time frame. Each of these links in the chain requires facilities, permits, supply contracts, transport approvals, and workforce. Right now, the pieces

THE MANHATTAN PROJECT TEST: Three Conditions for Strategic Momentum

Every major US program that has succeeded at speed and scale—whether the Manhattan Project under General Leslie Groves, the Nuclear Navy under Admiral Hyman Rickover, or Operation Warp Speed under Dr. Moncef Slaoui—met three critical conditions.

A leader with real authority. There must be a single, empowered program office with full control over budget, milestones, technical trades, and integration, not just coordination across agencies. Without this, decisions are deferred, accountability is diluted, and timelines slip. The system must know who is in charge, and that person or office must be able to act.

Adequate, stable, multiyear funding. Space nuclear cannot survive on one-year appropriations subject to annual review and political volatility. It requires predictable, adequate funding locked in across the full development arc, sufficient to attract serious industry partners and drive technology maturation and infrastructure investment.

Strategic urgency. The program must be animated by a purpose big enough to align institutions. It must not be treated as a science experiment or contingency option. It must be seen, and communicated, as a national strategic imperative to establish the urgency that unlocks fast approvals, interagency cooperation, and real commitment.

The presence of all three of these conditions does not ensure success. But the absence of any one of them guarantees failure.

are scattered across national labs, vendors, and test ranges. They are siloed, underfunded, and often constrained by bureaucratic red tape. The 2030 goal only works if the timeline for infrastructure is matched to the timeline for the mission, enabling government-funded work to start immediately.

No matter who is responsible for development, regulatory issues will loom large in a successful launch. In particular, the government must make an early decision on an indemnification approach comparable to that used for commercial terrestrial nuclear power plants. In addition, it must apply the untested 2019 process for authorizing launches that carry fission systems, and align independent nuclear safety review, environmental review under the National Environmental Policy Act, export control regulations, and licensing. A mission of this size and speed requires a clear path for authorizing on-surface operations on the Moon—with all major regulatory decisions rolling out on schedule. Rather than being seen as an after-the-fact process, regulatory work products must be treated as deliverables in tandem with technology and infrastructure milestones.

Given these critical and extensive roles for government, White House coordination will be the lynchpin of this mission. Space nuclear efforts have repeatedly faltered because leadership is fragmented. The president should declare this initiative as a national priority, rather than just a NASA project. Then a leader should be named within the White House—or within the National Space Council, if there is one—with the authority to align budgets, schedules, and technical milestones across the relevant agencies; resolve interagency disputes; and set and enforce deadlines for infrastructure and launch approval. With White House coordination to cut across agency stovepipes, enforce accountability, and surmount the many foreseeable (and unforeseeable) barriers that will arise, the project is much more likely to meet its deadlines. Without such empowered leadership, delays will multiply.

Secretary Duffy's directive is a chance to reframe this country's approach to accomplishing space missions. If it functions like past programs—with loose governance, sporadic funding, and unrealistic scoping—it will meet the same fate as previous missions. If, instead, the initiative meets the Manhattan Project test and takes advantage of the opportunity to focus the considerable strengths and infrastructure of the government to support this effort in full, it will prove that the United States can fly reactors in space, not just publish papers about them, while safely advancing space exploration.

Beyond completing the mission, demonstrating that commercial contracting saves money and accelerates delivery would be a uniquely American triumph. But it will require government scaffolding that no private company can supply. Treating "commercial" as a substitute for leadership is not innovation; it is abdication.

With these pillars in place, the 2030 goal is achievable; without them, the United States risks repeating history. And this time, failure would not only waste taxpayer money but also hand the advantage to rival nations on the Moon. As the government begins moving forward on the aims of the NASA directive, it must reckon with the mission's real goal: rather than simply launching a single nuclear reactor into space, the United States is launching into a new era as a nuclear power in space.

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