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Pulsed Nuclear Space Propulsion and International Law: Some Preliminary

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PULSED NUCLEAR SPACE PROPULSION AND INTERNATIONAL LAW: SOME PRELIMINARY OBSERVATIONS

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ABSTRACT

Pulsed Nuclear Space Propulsion, researched in the 1950s and 1960s by such eminent physicists as Freeman Dyson, Ted Taylor, Theodore von Karman, and Hans Bethe, involves propelling large spacecraft using compact nuclear explosions from specialized atomic devices. This technology is often known by the name of the Air Force project in which it was developed: Orion.

It has long been believed that the 1962 Limited Test Ban Treaty prohibits the use of nuclear pulse space propulsion. After a survey of the Orion project and its results and a review of the applicable law, this Article concludes that language in the 1967 Outer Space Treaty may override the Test Ban agreement to permit non-weapons use of nuclear explosives for propulsion.

With a new space race taking place and with important actors such as China not subject to the Test Ban Treaty at all, the subject of pulsed nuclear space propulsion deserves another look.

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We hope that this Article serves as a springboard for further discussion.

TABLE OF CONTENTS

I. INTRODUCTION

AFTER A LONG HIATUS, the world is entering a new space race. The United States is home to rapid progress in commercial space launch capability and has made plans for a rapid return to the Moon. Trips to Mars are also being treated seriously. Companies are pursuing the exploitation of asteroid resources propelled by, in the words of Harvard Smithsonian astrophysicist Martin Elvis, love, fear, and greed.[1]

Meanwhile, the People's Republic of China is proceeding aggressively with a new space station and another one under development,[2] as well as missions to the Moon[3] and Mars[4] that are

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[1] *See generally* MARTIN ELVIS, ASTEROIDS: HOW LOVE, FEAR, AND GREED WILL DETERMINE OUR FUTURE IN SPACE 2 (2021).

[2] *See* Andrew Jones, *China's Tiangong Space Station*, SPACE.COM (Aug. 24, 2021), https://www.space.com/tiangong-space-station [https://perma.cc/M35Y-64PR] ("In May 2021, China launched Tianhe, the first of the orbiting space station's three modules, and the country aims to finish building the station by the end of 2022. CMSA [Chinese Manned Space Agency] hopes to keep Tiangong inhabited continuously by three astronauts for at least a decade. The space station will host many experiments from both China and other countries.").

[3] Dan Hastings, *China to Soon Land on the Moon Before NASA – 'Aggressive Competitor'*, EXPRESS, https://www.express.co.uk/news/world/1519733/china-moon-

widely seen as precursors to human missions. China is actively researching designs for enormous space stations and spacecraft hundreds or over a thousand meters long.[5] Even countries such as New Zealand[6] and Luxembourg[7] are getting into the act.

So far, these space efforts have involved chemical rockets, and newer programs—in particular, SpaceX's, which has already lowered launch costs to low Earth orbit by a factor of twenty[8]—promise substantially increased capabilities compared to the Space Shuttle or the big Russian and American expendable boosters of Cold War vintage.

Given what is known about such future vehicles as SpaceX's Starship/Super Heavy combination,[9] it seems plausible that lunar and Martian bases and colonies will be established with reusable chemical rockets as the major source of propulsion.

Chemical rockets have inherent limits, however, and NASA, along with various space agencies of other nations, have begun

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landing-before-NASA-aggressive-competitor-ont [https://perma.cc/L3M7-2G9M] (Nov. 11, 2021, 9:00 AM).

[4] Arjun Kharpal, *China Plans to Send Its First Crewed Mission to Mars in 2033 and Build a Base There*, CNBC, https://www.cnbc.com/2021/06/24/china-plans-to-send-its-first-crewed-mission-to-mars-in-2033.html [https://perma.cc/U4W3-SE4Q] (June 24, 2021, 11:41 AM).

[5] Georgina Torbet, *China Will Study How to Build a Massive Spacecraft over a Half-Mile Long*, DIGIT. TRENDS (Aug. 28, 2021), https://www.digitaltrends.com/news/china-one-kilometer-spacecraft/ [https://perma.cc/SX35-TW5M].

[6] New Zealand hosted a launch site for startup space company Rocket Lab. *See* Jeff Foust, *Rocket Lab Launches Two BlackSky Satellites, Wins Synspective Contract*, SPACENEWS (Dec. 9, 2021), https://spacenews.com/rocket-lab-launches-two-blacksky-satellites-wins-synspective-contract/ [https://perma.cc/KDH3-WEV2]; *see also* Business Wire, *Rocket Lab Launches 109th Satellite to Orbit*, YAHOO FIN. (Dec. 8, 2021), https://ca.finance.yahoo.com/news/rocket-lab-launches-109th-satellite-021900337.html [https://perma.cc/2UK4-LVUB] ("Rocket Lab has three launch pads at two launch sites, including two launch pads at a private orbital launch site located in New Zealand . . . .").

[7] *Luxembourg, a Rising Star in the Space Industry*, DELOITTE, https://www2.deloitte.com/lu/en/pages/technology/articles/luxembourg-space-industry-companies.html [https://perma.cc/CE5A-9BAP].

[8] Wendy Whitman Cobb, *How SpaceX Lowered Costs and Reduced Barriers to Space*, CONVERSATION (Mar. 1, 2019, 6:39 AM), https://theconversation.com/how-spacex-lowered-costs-and-reduced-barriers-to-space-112586 [https://perma.cc/NG5Y-AX8F] ("When the space shuttle was in operation, it could launch a payload of 27,500 kilograms for $1.5 billion, or $54,500 per kilogram. For a SpaceX Falcon 9, the rocket used to access the ISS, the cost is just $2,720 per kilogram.").

[9] *See generally* Joey Roulette, *What is Starship? SpaceX Builds Its Next-Generation Rocket*, N.Y. TIMES (Feb. 11, 2022), https://www.nytimes.com/article/elon-musk-starship.html [https://perma.cc/8QQY-EU2K].

thinking about nuclear space propulsion.[10] Nuclear thermal rockets, in which a radioactive core heats gases to provide thrust, have been known since the 1960s, and while none have flown in space, engines have been tested on the ground and the technology is well understood.[11] Nor are such rockets especially controversial beyond the baseline of controversy that arises whenever the word "nuclear" is employed.[12]

There is, however, another more powerful form of nuclear space propulsion: pulsed nuclear space propulsion. It too has never been tested in space, though much research and engineering were done on Earth in a project involving such eminent physicists as Freeman Dyson, Ted Taylor, Hans Bethe, Theodore von Karman, and others.[13] If nuclear thermal rockets provide the prospect for much more efficient space transport, pulsed nuclear propulsion provides the prospect for utterly game-changing capabilities, potentially allowing a nation that adopts it to leapfrog the competition by orders of magnitude.

Some important questions stem from the fact that the "pulse" in pulsed nuclear propulsion is an atomic explosion, albeit a small and focused one.[14] Among those issues are legal questions, mainly involving the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies[15] (Outer Space

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[10] *See Accelerating Deep Space Travel with Space Nuclear Propulsion Before Subcomm. on Space & Aeronautics of the H. Comm. on Sci., Space & Tech.* (2021) (opening statement of Bhavya Lal, Senior Advisor for Budget and Finance, NASA), https://science.house.gov/hearings/accelerating-deep-space-travel-with-space-nuclear-propulsion [https://perma.cc/D59J-NT7J] ("If we want to explore the cosmos . . . we need to develop mass-efficient, high-energy solutions that can power space vehicles . . . Nuclear fission systems can provide such solutions . . .").

[11] *See 6 Things You Should Know About Nuclear Thermal Propulsion*, OFF. OF NUCLEAR ENERGY, U.S. DEP'T OF ENERGY (Dec. 10, 2021), https://www.energy.gov/ne/articles/6-things-you-should-know-about-nuclear-thermal-propulsion [https://perma.cc/4LQ7-MWW6].

[12] *See, e.g.*, *10 Reasons to Oppose Nuclear Energy*, GREEN AM., https://www.greenamerica.org/fight-dirty-energy/amazon-build-cleaner-cloud/10-reasons-oppose-nuclear-energy [https://perma.cc/L634-GV4E].

[13] GEORGE DYSON, PROJECT ORION: THE TRUE STORY OF THE ATOMIC SPACESHIP 91 (2002). For an excellent and technically detailed history of this project, see generally *id.*

[14] G.R. SCHMIDT, J.A. BONOMETTI & P.J. MORTON, NUCLEAR PULSE PROPULSION - ORION AND BEYOND 2–3 (2000).

[15] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, Jan. 27, 1967, 18 U.S.T. 2410, 610 U.N.T.S. 205 [hereinafter Outer Space Treaty].

Treaty) and the Limited Test Ban Treaty of 1963[16] (Test Ban Treaty). This Article will outline the nature and capabilities of pulsed nuclear propulsion and the reasons why it may prove enormously tempting in the context of an all-out space race. It will then explore the extent to which existing space law poses barriers to this technology and what nations seeking to employ the technology might do in response.

II. CHEMICAL AND NUCLEAR THERMAL ROCKETS

Rocket engines are basically heat engines.[17] In a chemical rocket, the combustion of a fuel and oxidizer—for example, hydrogen and oxygen, or even gunpowder[18]—generates heat, which causes a rapid expansion of gases.[19] If those gases are propelled out the back of the engine, the action/reaction principle of Newton's third law causes the rocket to move forward.[20] In a nuclear thermal rocket, the heat is provided by the reactor. A fluid medium (such as liquid hydrogen) can be superheated by passing it through the reactor core.[21] What follows is the same process that occurs in a chemical rocket—the rapidly expanding

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[16] Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, Aug. 5, 1963, 14 U.S.T. 1313, 480 U.N.T.S. 43 [hereinafter Test Ban Treaty].

[17] MARTIN J.L. TURNER, ROCKET AND SPACECRAFT PROPULSION: PRINCIPLES, PRACTICE AND NEW DEVELOPMENTS 35 (2d ed. 2006). It is possible to utilize the rocket principle while employing methods other than heat to drive the reaction mass—for example, electromagnetic catapults shooting reaction mass out the back and ion engines are not precisely heat engines—but as a general description, this statement is accurate. *See generally* Tim Wright, *How Things Work: Electromagnetic Catapults*, SMITHSONIAN MAG. (Jan. 2007), https://www.smithsonianmag.com/air-space-magazine/how-things-work-electromagnetic-catapults-14474260/ [https://perma.cc/VQD9-S55R]; *Ion Propulsion*, NASA, https://www.nasa.gov/centers/glenn/about/fs21grc.html [https://perma.cc/9N3K-NBC3] (Aug. 6, 2017).

[18] Gunpowder contains its own fuel in the form of charcoal and sulfur, and it has an oxidizer in the form of potassium nitrate, commonly known as saltpeter. *See generally Gunpowder*, NAT'L PARK SERV., https://www.nps.gov/casa/learn/historyculture/gunpowder.htm [https://perma.cc/AM6A-9CE3] (May 4, 2015); *see also Saltpetre*, ENCYC. BRITANNICA https://www.britannica.com/science/saltpeter [https://perma.cc/2SZ9-WPPJ] (Aug. 15, 2022).

[19] *Combustion*, GLENN RSCH. CTR., NASA, https://www.grc.nasa.gov/www/k-12/airplane/combst1.html#:~:text=Combustion%20is%20a%20chemical%20process,fuel%20is%20usually%20a%20liquid [https://perma.cc/G6QF-WK3Z] (May 13, 2021).

[20] *See Newton's Laws of Motion*, GLENN RSCH. CTR., NASA, https://www1.grc.nasa.gov/beginners-guide-to-aeronautics/newtons-laws-of-motion [https://perma.cc/594B-D2KZ].

[21] *See* OFF. OF NUCLEAR ENERGY, U.S. DEP'T OF ENERGY, *supra* note 11.

gases are propelled out the back, Newton's third law takes effect, and the rocket moves forward.

Nuclear thermal rockets are far more efficient than chemical rockets. Efficiency is measured by "specific impulse," with higher numbers indicating greater efficiency, and chemical rockets tend to have specific impulses in the low hundreds.[22] Nuclear thermal rockets have specific impulses in the thousands.[23] Some other rocket engines, such as ion rockets, have even higher specific impulses, but at the price of producing very weak thrust.[24] Chemical rockets can produce much higher thrusts than ion engines but at low efficiency.[25] Nuclear thermal rockets can produce much higher thrust at a high level of efficiency, making them much more appealing for space voyages that would take too long, or require too limited a payload, with chemical rocket propulsion.[26] The original post-Apollo Mars mission plans involved nuclear thermal engines, and NASA and the Department of Energy conducted numerous experiments in the 1960s and 1970s, test-firing working engines in projects including NERVA and Kiwi.[27] Though the engineering was sophisticated—nuclear rocket science is still rocket science—the principles were well understood, and implementation was comparatively straightforward.[28] Yet nuclear thermal rockets have their own limits in

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[22] Robert A. Braeunig, *Basics of Space Flights: Propellants*, ROCKET & SPACE TECH., http://www.braeunig.us/space/propel.htm?fbclid=IWAR3B__RA9AyaVg0PEaTwG75Fr6NUK2JSqgYtMO2ifDUWZNO5P9-uVCYiJkw [https://perma.cc/WBX3-9ZZN].

[23] *See* ANNE CHARMEAU, BRANDON CUNNINGHAM & SAMIM ANGHAIE, ULTRAHIGH SPECIFIC IMPULSE NUCLEAR THERMAL PROPULSION 29–31 (2009).

[24] *Ion Propulsion: Farther, Faster, Cheaper*, GLENN RSCH. CTR., NASA (May 2, 2008), https://www.nasa.gov/centers/glenn/technology/Ion_Propulsion1.html [https://perma.cc/SB26-GT7U].

[25] *Id.*; *see also 3 Types of Chemical Rocket Engines*, FIREHAWK (Mar. 26, 2021), https://www.firehawkaerospace.com/news/3-types-of-chemical-rocket-engines [https://perma.cc/FX4X-QJKN].

[26] *See* CHARMEAU ET AL., *supra* note 23, at 29–31.

[27] Beginning in 1964 with the Kiwi-B4D, through 1969 with the XE engine, the U.S. government conducted dozens of tests on fifteen different models of nuclear thermal rocket engines. *See* KENNETH GATLAND, THE ILLUSTRATED ENCYCLOPEDIA OF SPACE TECHNOLOGY: A COMPREHENSIVE HISTORY OF SPACE EXPLORATION 214–17 (1st ed. 1981) (listing nuclear thermal rocket tests that were conducted and discussing plans for Mars missions using nuclear thermal propulsion).

[28] *See id.* at 215–16 (explaining the basic principles and feasibility of nuclear thermal rockets in the 1960s and 1970s, but also explaining why the project in America was ultimately abandoned).

terms of reaction mass and exhaust temperature that make them not entirely satisfactory for ambitious missions.[29]

Now the U.S. government is funding new research into nuclear space propulsion as the United States enters into what looks like a new "space race" with China.[30] So far, that research—at least the research that has been made public—involves nuclear thermal propulsion.[31] But there is another way.

III. PULSED NUCLEAR PROPULSION

Pulsed nuclear propulsion was also studied in the early years of the space age. Even in pre-space years, physicist Stanislaw Ulam proposed using nuclear explosions to propel a spacecraft,[32] and a nuclear "bomb" powered space vehicle was mentioned in Robert Heinlein's 1940 (pre-nuclear era) story, *Blowups Happen*.[33] But in the late 1950s, as the Golden Age of nuclear physics research was going on, General Atomics hired a number of leading physicists to research and design a spacecraft using this principle.[34] The project was named Orion.[35]

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29 EUGENE F. MALLOVE & GREGORY L. MATLOFF, THE STARFLIGHT HANDBOOK: A PIONEER'S GUIDE TO INTERSTELLAR TRAVEL 57 (1989) ("Chemical rockets are severely limited by energy; for all their storm and fury they are quite puny . . . Nuclear [thermal] fission rockets—potentially much richer in energy—are, like their chemical rocket cousins, severely constrained in performance by temperature limits. The most advanced imaginable materials and cooling systems place an upper cap on [thermal] fission nuclear rocket specific impulse. Ion engines, on the other hand, are power-limited rather than temperature limited . . . It almost seemed that nature had 'rigged the deck' with these Scylla and Charybdis problems: too much temperature or too little energy or power. To save the day, enter *pulsed* nuclear propulsion . . . ").

30 *See* Mark Lewis, *Back to the Future with Nuclear Power in Space*, BREAKING DEF. (Sept. 22, 2021, 7:03 AM), https://breakingdefense.com/2021/09/back-to-the-future-with-nuclear-power-in-space/ [https://perma.cc/D5YV-UP4X] (discussing the U.S. government's renewed interest in nuclear propulsion); Stephen Chen, *China's Space Programme Will Go Nuclear to Power Future Missions to the Moon and Mars*, S. CHINA MORNING POST (Nov. 24, 2021, 11:00 PM), https://www.scmp.com/news/china/science/article/3157213/chinas-space-programme-will-go-nuclear-power-future-missions [https://perma.cc/ZN58-UBJH].

31 Lewis, *supra* note 30.

32 *See* DYSON, *supra* note 13, at 22–24.

33 *See* ROBERT HEINLEIN, BLOWUPS HAPPEN (1940), available at https://metallicman.com/laoban4site/blowups-happen-full-text-by-robert-heinlein/ [https://perma.cc/7VHS-8VW2].

34 *Cf.* Jeremy Bernstein, *Reflections on Project Orion*, 5 INFERENCE 1, 3 (2020), https://inference-review.com/assets/pdf/articles/reflections-on-project-orion.pdf [https://perma.cc/UD4R-VVNY] (recounting the history of the project and naming several notable physicists that were involved in it).

35 *See id.*

Earlier nuclear tests had revealed that graphite-covered steel objects could survive within a few feet of a nuclear detonation, despite the tremendously hot (over 100,000 degrees) temperatures present.[36] A thin layer of stagnating plasma along the surface protected the object below.[37] In some cases, these graphite-covered objects (big steel balls) were propelled a considerable distance from the detonation site.[38]

It is not a tremendous surprise that when you set off an atomic bomb next to something, that something will *move*.[39] That it could also remain essentially intact, however, was considerably more surprising.[40] The challenge for the Orion team was to produce a spacecraft that could function after being subjected to not one but many nearby nuclear detonations and that could be steered and navigated by an onboard crew.[41]

This turned out to be easier than it sounds. The Orion spacecraft design that resulted involved a large steel "pusher" plate behind a rather large spacecraft with a total weight of over 4,000 tons.[42] That sort of design is very different from the spaceships we are used to today.[43]

In the old science-fiction movies, spaceships looked like, well, ships. They had massive steel girders, thick bulkheads, and rivets

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36 Glenn Harlan Reynolds, Opinion, *Cassini Was Great, but We Could Do Better If America Wasn't the Fussy Superpower*, USA TODAY, https://www.usatoday.com/story/opinion/2017/09/18/we-missed-opportunity-put-americans-saturn-1970-glenn-reynolds-column/675060001/ [https://perma.cc/BWZ8-JNM3] (Sept. 18, 2017, 1:43 PM); *see also* LOS ALAMOS NAT'L LAB'Y, NATIONAL SECURITY SCIENCE: A HALF CENTURY OF LOS ALAMOS IN SPACE 22–24 (2011), https://cdn.lanl.gov/files/NSS-Issue1-2011.pdf [https://perma.cc/TPT9-UNAR].

37 LOS ALAMOS NAT'L LAB'Y, *supra* note 36, at 27.

38 DYSON, *supra* note 13, at 68–71.

39 GLENN H. REYNOLDS, AN ARMY OF DAVIDS: HOW MARKETS AND TECHNOLOGY EMPOWER ORDINARY PEOPLE TO BEAT BIG MEDIA, BIG GOVERNMENT AND OTHER GOLIATHS 182 (2006).

40 *Id.*

41 *See* John Loeffler, *Project Orion: The Atomic Starship that Never Got Off the Ground*, INTERESTING ENG'G (Aug. 01, 2021), https://interestingengineering.com/project-orion-the-atomic-starship-that-never-got-off-the-ground [https://perma.cc/P3FL-UAAU].

42 *See* Andrew J. Dunlop, *The Other Orion Spacecraft*, LABROOTS (Apr. 17, 2015, 8:27 AM), https://www.labroots.com/trending/space/929/the-other-orion-spacecraft [https://perma.cc/UPY4-UYW5] ("[Orion] would weigh roughly 4000 tons and have a crew of up to a hundred and fifty people . . . ."); SCHMIDT ET AL., *supra* note 14, at 4 (depicting Orion's pusher-plate design); REYNOLDS, *supra* note 39, at 182.

43 *See* DYSON, *supra* note 13, at 2–4 (discussing differences between chemical rockets and Orion).

everywhere. They also had big crews with bunks, staterooms, and mess halls.[44] Now we know better, of course—spaceships are not big, massive constructions made of steel. They are cramped gossamer contraptions of composites and exotic alloys designed to keep the weight down.[45] Reynolds has previously described the Orion spacecraft: "Orion was big, clunky, and mechanical[-]featuring springs, hydraulic shock absorbers, and other nineteenth-century-style accoutrements. To handle the shock, it needed to be big. It probably would have had rivets."[46]

In theory, "one of the greatest appeals of Orion" was that over a wide range, "the bigger you made it, the better it worked."[47] As Reynolds has noted previously:

> While chemical rockets scale badly—with big ones much harder to build than small ones—Orion was just the opposite. That meant that large spacecraft, capable of long missions, were not merely possible, but actually easier to build, for a variety of reasons, than small ones. Bigger spaceships meant more mass for absorbing radiation and shock, more room to store fuel, [a smaller proportion of total size needed for radiation shielding,] and so on.[48]

The Orion design achieved enormously high thrust, combined with enormously high efficiency.[49] Given that atomic explosions are involved, the high thrust is not a surprise. The efficiency, however, is staggering. While nuclear thermal rockets might achieve a specific impulse of 2,000,[50] Orion could at least double that, while lifting something the size of a skyscraper into orbit and accelerating it to speeds that no chemical or nuclear thermal rocket could touch. Theoretical studies suggested that specific impulses on the order of 10,000 to 100,000 were possi-

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44 *See generally* Madison Troyer, *50 Best Space Movies of All Time*, STACKER (Aug. 19, 2022), https://stacker.com/stories/3346/50-best-space-movies-all-time (discussing older science-fiction, space movies).

45 *See, e.g.*, *Orion*, NASA, https://www.nasa.gov/specials/orionfirstflight/.

46 REYNOLDS, *supra* note 39, at 183.

47 *Id.*; *see also* DYSON, *supra* note 13, at 259 ("The Orion program, on paper, worked better and better the bigger it got.").

48 REYNOLDS, *supra* note 39, at 183.

49 *See* Stan Tackett, *The Mini-Mag Orion Space Propulsion System*, NUCLEAR NEWSWIRE (Apr. 25, 2013, 7:00 AM), https://www.ans.org/news/article-1313/mini-mag-orion/ [https://perma.cc/A5HB-MHQX].

50 Reaching a specific impulse of 2,000 is an aspirational goal for nuclear thermal rockets—most aim for a mere 900. *See* OFF. OF NUCLEAR ENERGY, U.S. DEP'T OF ENERGY, *supra* note 11 (naming a specific impulse of 900 seconds as the "initial target" for nuclear-powered rockets).

ble,[51] which would make Orion at least two orders of magnitude more efficient than the most powerful chemical rockets.[52]

For a short, Apollo-style "flags and footprints" mission, Orion was overkill. But for more serious large-scale and long-distance exploration, it was very promising. The 1958 motto of the Orion crew was "Saturn by 1970."[53] And they thought they could do it; the physicists were already planning journeys and meeting with the life-support engineers from the nuclear submarine builder Electric Boat division (a division of General Atomics' corporate parent, General Dynamics) to draw on the expertise those engineers had developed in keeping people both alive and reasonably cheerful on round-the-world submerged cruises.[54]

To the big-name physicists working on the project in 1958, it seemed like a dream—a way to use their extensive nuclear weapons expertise on something peaceful, something that would open up the solar system to humanity, rather than on creating ever more efficient tools for killing large numbers of people.[55] Nuclear tests took place verifying the ability of the components to survive nearby—it turned out that coating metallic objects with non-metallic substances like Bakelite drastically improved their resistance to the nuclear fireball, and working models were tested.[56] These were non-nuclear, but the nuclear aspects of the project were considered less difficult than ensuring reliable ejection and detonation of the explosive devices and stability of the craft when launching.[57]

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[51] *See* MALLOVE & MATLOFF, *supra* note 29, at 60–61, 64–66 ("[M]uch higher specific impulse is possible, perhaps 10^4 to 10^6> seconds . . . Orion project reports spoke of estimated specific impulse in the range 2000 to 6000 seconds with possible extension to the 10,000- to 20,000-second range in the succeeding generation. . . .").

[52] *See* discussion *supra* Part II.

[53] DYSON, *supra* note 13, at 6; *see also* FREEMAN DYSON, DISTURBING THE UNIVERSE 110 (1979) [hereinafter FREEMAN DYSON].

[54] DYSON, *supra* note 13, at 76.

[55] *See, e.g.*, JOHN MCPHEE, THE CURVE OF BINDING ENERGY: A JOURNEY INTO THE AWESOME AND ALARMING WORLD OF THEODORE B. TAYLOR 180 (1974) ("We have for the first time imagined a way to use the huge stockpiles of our bombs for better purpose than for murdering people. My purpose, and my belief, is that the bombs which killed and maimed at Hiroshima and Nagasaki shall one day open the skies to man.").

[56] DYSON, *supra* note 13, at 71; *see also* FREEMAN DYSON, *supra* note 53, at 113 (describing flight tests of an experimental pulse ship named "Hot Rod" at Point Loma, California).

[57] DYSON, *supra* note 13, at 169–80.

As John McPhee notes in his biography of one of the Orion scientists, Ted Taylor:

> No chemical rocket making slow ferries to the nearby moon was ever going to hint at the vehicular capabilities necessary for enterprises on such a scale. Ted Taylor's Orion was something quite different, though. Large enough to carry machine shops and laboratories, it could move through space at about a hundred thousand miles an hour, top speed. Whenever the day might come that people would earnestly wish to get about in the solar system, this would be the way to do it.[58]

Things seemed auspicious, but it was not to be:

> The subsequent development of nuclear pulse propulsion in theory and experiment was so promising that it seems only by chance, politics, and extraordinary circumstances that *today* nuclear pulse powered spaceships are not zipping with ease across the Solar System. If nuclear pulse propulsion development had run its course, by now fast ships would be transporting people and instruments among the planets while tortoiselike chemical rockets stayed where they belong, in Earth orbit.[59]

As George Dyson notes regarding the years of research and hardware testing, "[t]hroughout seven years of work, nothing turned up that conflicted fundamentally with the optimism of 1958."[60] And he quotes Freeman Dyson: "The end result was a rather firm technical basis for believing that vehicles of this type could be developed, tested, and flown . . . The technical findings of the project have not been seriously challenged by anybody. Its major troubles have been, from the beginning, political."[61]

Orion, in fact, faced non-technical obstacles that proved far more formidable than the science and engineering involved. One was bureaucratic; the other was legal; though the two were intertwined.

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58 MCPHEE, *supra* note 55, at 172.

59 MALLOVE & MATLOFF, *supra* note 29, at 60. Indeed, there were plans to expand Orion to a possible interstellar role. *See* Robert L. Forward, *Ad Astra!*, *in* INTERSTELLAR TRAVEL AND MULTI-GENERATIONAL SPACESHIPS 29, 38 (Yoji Kondo, Frederick C. Bruhweiler, John Moore & Charles Sheffield eds., 2003) ("Enough work has been done on the concept, especially the survivability of the pusher plate under repetitive nuclear blast shocks, to determine that nuclear pulse propulsion is a technologically feasible concept . . . These ideas for an interplanetary rocket have been extrapolated into a design for a starship.")

60 DYSON, *supra* note 13, at 256.

61 *Id.* (quoting Freeman J. Dyson, *Death of a Project*, 149 SCIENCE 141, 141 (1965) [hereinafter Freeman Dyson]).

On the bureaucratic side, Orion had trouble finding a home. The Air Force backed much of the early research but was not interested in what was an essentially peaceful project.[62] There were some efforts to justify Orion as a way of creating an indestructible space nuclear deterrent that would do for the Air Force what nuclear submarines had done for the Navy, leading to a skeptical President John F. Kennedy inspecting an eight-foot-high model of an Orion space battleship festooned with Minuteman missiles, but these efforts were never taken seriously.[63] Meanwhile, NASA, already committed to Apollo, was uninterested in taking on another big project at the time, particularly one that involved nuclear explosions.[64]

The other barrier was the Limited Test Ban Treaty, which forbids nuclear explosions in the atmosphere and outer space.[65] Though it might well have been possible to negotiate an exception for things such as Orion, there was insufficient bureaucratic support to make that happen.[66] Freeman Dyson later wrote, "[t]he, Test Ban Treaty of 1963, prohibiting nuclear explosions in the atmosphere and in space, made Orion flights illegal. Before one could revive Orion one would have to abrogate or renegotiate the treaty."[67]

This is widely believed but not necessarily correct, as we will argue below. It is also worth noting that there are now spacefaring powers such as France, and particularly the People's Republic of China, that have not signed or ratified the Test Ban Treaty,[68] or that might be quite willing to abrogate it, at least in part, in the service of obtaining a dominant position in the new space race.[69]

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62 *See* Brent Ziarnick & Peter Garretson, *Starfleet Was Closer than You Think*, SPACE REV. (Mar. 16, 2015), https://www.thespacereview.com/article/2714/1[https://perma.cc/9HTF-6XR9]; *see also* SCHMIDT ET AL., *supra* note 14, at 5–6.

63 DYSON, *supra* note 13, at 204–07, 221–22.

64 *Id.* at 264–69.

65 Test Ban Treaty, *supra* note 16, art. I.

66 DYSON, *supra* note 13, at 234 ("Technically, one could rather easily have made a test ban that would still allow Orion to develop as a non[-]secret project with international support and that's what we would have liked . . . But politically it was just obviously absurd at that time.").

67 FREEMAN DYSON, *supra* note 53, at 114.

68 *See* Test Ban Treaty, *supra* note 16; *Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water*, U.N. TREATY COLLECTION, https://treaties.un.org/pages/showDetails.aspx?objid=08000002801313d9 [https://perma.cc/LKH9-EZ6U].

69 *See* Glenn Harlan Reynolds, *International Space Law in Transformation: Some Observations*, 6 CHI. J. INT'L L. 69, 79 (2005).

Another barrier might lie in language of the Outer Space Treaty prohibiting the stationing of "nuclear weapons or any other kinds of weapons of mass destruction" in outer space.[70] Though this might seem a more potent barrier given that essentially every nation has joined the Outer Space Treaty,[71] and withdrawing from it would be a far more fraught act, in fact, that provision is no barrier to Orion-type spacecraft.[72] And some related language in the Outer Space Treaty may even vitiate the Limited Test Ban's burdens.[73] What is more, the emerging new space race may give one or more national actors cause to develop this technology.

IV. ORION IN THE 21ST CENTURY

Though the United States continued research into Orion for a few years after the adoption of the Limited Test Ban Treaty,[74] that Treaty marked the end of any serious effort to build a working spacecraft. The continuing work was largely an effort to wrap up research and archive its findings in the event that the nation might want to deploy Orion at some later time.[75] Many of the project's principals, as noted above, thought that the capabilities Orion represented were so dramatic that it would sooner or later be needed.[76]

By the time of the 1967 Outer Space Treaty's signing, the pace of the "space race" had become much less urgent. Both the United States and the Soviet Union were racing to reach the Moon first,[77] but in truth, each was probably more afraid of the other one beating it out than actually desirous of being first itself. Whether or not we wanted missile bases and colonies on the Moon, we certainly did not want our adversaries to have

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70 Outer Space Treaty, *supra* note 15, art. IV.

71 *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, U.S. DEP'T OF STATE (June 30, 2017), https://www.state.gov/wp-content/uploads/2019/05/225-Outer-Space-Treaty-website-1.pdf [https://perma.cc/HLA6-77NL].

72 *See* discussion *infra* Part V.

73 *See* discussion *infra* Parts V–VI.

74 Orion research stopped in 1965, and the Test Ban Treaty is dated 1963. Freeman Dyson, *supra* note 61, at 142.

75 DYSON, *supra* note 13, at 268–69.

76 *See* discussion *supra* Part III.

77 Adam Mann, *What Was the Space Race? Origins, Events and Timeline*, SPACE.COM, https://www.space.com/space-race.html [https://perma.cc/8UTB-FP3E].

them in our place.[78] The provisions of the 1967 Treaty essentially eliminated the stakes by taking them off the table.[79] Missile bases as well as "national appropriation" of the Moon and other celestial bodies were banned.[80] A curtailed Apollo program made it to the Moon on momentum (though several missions and virtually all of the Apollo Applications program were cancelled except for Skylab), but absent a major prize, the race did not seem worth the effort.[81] Both the United States and the Soviet Union backed off and reduced their (civilian) space efforts dramatically.[82]

A half century later, things are happening again. Though not driven by the same Cold War propaganda dynamics as the 1960s space race, the new space race is heating up.[83] It, too, will be driven in part by national prestige but also by a desire for money and military supremacy in a new sphere of human activity.[84]

In this new race, the capabilities offered by Orion are likely to look tempting again. Using Orion technology, space stations big enough to require dozens of launches for their construction could be placed in orbit in a single mission.[85] Likewise, a base could be placed on the Moon, complete with crew, in one launch.[86] And, of course, military missions calling for extensive hardware in space become much more feasible when it is possible to launch much more hardware at once.

In this sort of environment, governments—whether of the United States, China, Russia, or other potential space powers

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78 *See id.*

79 Glenn H. Reynolds, *International Space Law: Into the Twenty-First Century*, 25 VAND. J. TRANSNAT'L L. 225, 230 (1992).

80 Outer Space Treaty, *supra* note 15, arts. II, IV.

81 WALTER A. MCDOUGALL, THE HEAVENS AND THE EARTH, A POLITICAL HISTORY OF THE SPACE AGE 421–22 (1985) (describing abandonment of later plans for Apollo missions and Apollo Applications, with retention of Skylab).

82 *Id.* at 429–30 ("[A]lmost two-thirds of all Soviet spacecraft [by the early 1970s] were presumptively military . . .").

83 *The New Space Race*, ENCYC. BRITANNICA, https://www.britannica.com/explore/space/the-new-space-race/ [https://perma.cc/82A8-4KMB].

84 *Id.* In a post-Sputnik White House briefing, then-Vice President Richard Nixon, displaying "technical knowledge greater than that of some of the panelists," stressed the geopolitical impact of "a backward country coming up from nowhere" to score a triumph in outer space. *See* MCDOUGALL, *supra* note 81, at 204.

85 *See generally* NASA, NASA'S PLAN FOR SUSTAINED LUNAR EXPLORATION AND DEVELOPMENT 7–9, https://www.nasa.gov/sites/default/files/atoms/files/a_sustained_lunar_presence_nspc_report4220final.pdf [https://perma.cc/QR6R-HLDE].

86 *See generally id.*

such as India—may be tempted to deploy Orion spacecraft. In doing so, they would face a number of legal arguments under international law. But how big a barrier would those arguments pose? At one level, not much of a barrier. When nations want something badly enough, they are often willing to simply ignore international law or to engage in specious arguments.[87] In the case of Orion, however, there are some not-so-specious responses to claims of international illegality.

V. PROBLEMS FOR ORION UNDER THE OUTER SPACE TREATY

Article IV of the Outer Space Treaty provides that parties "undertake not to place in orbit around the [E]arth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner."[88] This would seem to be a barrier for a spacecraft propelled by nuclear explosions. It is true that the Treaty's ban on nuclear weapons is deliberately incomplete.[89] Nuclear ballistic missiles pass through space in flight, and there was no desire (at least on the part of the United States and the Soviet Union) to have the Treaty ban those,[90] nor does the Treaty ban fractional orbital bombardment systems of the sort recently tested by the People's Republic of China.[91] It is also arguable that an Orion craft that took off

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[87] *See, e.g.*, James Fukazawa, *Does the U.S. Space Force Violate the Outer Space Treaty?*, DENVER J. INT'L. L. & POL'Y (Apr. 28, 2020), http://djilp.org/does-the-u-s-space-force-violate-the-outer-space-treaty/ [https://perma.cc/93RD-FHYU].

[88] Outer Space Treaty, *supra* note 15, art. IV.

[89] *See, e.g.*, Pavle Kilibarda, *Space Law Revisited (2/3): Are Weapons of Mass Destruction Prohibited in Space?*, HUMANITARIAN L. & POL'Y. (Dec. 21, 2016), https://blogs.icrc.org/law-and-policy/2016/12/21/space-law-weapons-mass-destruction/ [https://perma.cc/CAX6-J88H].

[90] *See* Daryl Kimball, *The Outer Space Treaty at a Glance*, ARMS CONTROL ASS'N, https://www.armscontrol.org/factsheets/outerspace [https://perma.cc/2DYC-K7WF] (Oct. 2020) ("The [Outer Space Treaty] . . . does not prohibit the launching of ballistic missiles, which could be armed with [weapons of mass destruction] warheads, through space.").

[91] A fractional orbital bombardment system, as its name suggests, places nuclear weapons in a less-than-complete orbit, thus remaining within the terms of the Outer Space Treaty. *See* Bleddyn Bowen & Cameron Hunter, *Chinese Fractional Orbital Bombardment*, ASIA-PAC. LEADERSHIP NETWORK 4 (2021), https://cms.apln.network/wp-content/uploads/2021/11/FINALBowenHunterPolicyBrief.pdf [https://perma.cc/STB5-63XV] ("[A] FOBS [fractional orbital bombardment system] would not breach the [Outer Space Treaty] if it never completed an orbit and is technically 'in transit' in space[,] which is practically permitted even if it did carry nuclear weapons."). It is comparatively easy, how-

from Earth and proceeded directly on a mission into deep space would not be covered by the Treaty because it would not be in orbit around the Earth or on a celestial body or "stationed" in space, since "station" implies some sort of permanent position or steady trajectory.[92]

But while such arguments may have some force, they are not necessary where Orion is concerned. The Outer Space Treaty, after all, only bans nuclear *weapons*.[93] It does not ban nuclear explosives as such. This is underscored, as Bin Cheng has suggested, by the language that pairs "nuclear weapons" with "other kinds of weapons of mass destruction," meaning that only nuclear weapons intended to cause mass destruction are covered, and weapons powered by nuclear explosions—like bomb-pumped X-ray lasers used to shoot down ballistic missiles—would arguably not be covered by the ban because they do not cause mass destruction akin to that created by a traditional nuclear explosion.[94]

Regardless of that question, the nuclear explosives used to power an Orion spacecraft have an even stronger argument for legitimacy, which is that they are not weapons at all. Not only do these nuclear explosives differ from traditional nuclear weapons

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ever, to convert that fractional orbit into a complete orbit if desired. *See generally* Tyler Rogoway, *China Tested a Fractional Orbital Bombardment System That Uses a Hypersonic Glide Vehicle: Report*, DRIVE: WAR ZONE (Oct. 18, 2021, 3:06 PM), https://www.thedrive.com/the-war-zone/42772/china-tested-a-fractional-orbital-bombardment-system-that-uses-a-hypersonic-glide-vehicle-report [https://perma.cc/FT7L-85US].

92 *See* Outer Space Treaty, *supra* note 15, art. IV.

93 *Id.* (it also bans weapons of mass destruction).

94 *See* BIN CHENG, STUDIES IN INTERNATIONAL SPACE LAW 465 (1997); *see also* Stephen Gorove, *Arms Control Provisions in the Outer Space Treaty: A Scrutinizing Reappraisal*, 3 GA. J. INT'L & COMPAR. L. 114, 115, 117–18 (1973) ("The initial problem presented by the Treaty is the lack of a definition of what constitutes a 'nuclear weapon' or a 'weapon of mass destruction.' It may be presumed that all arms which utilize atomic energy in accomplishing their intended purpose, irrespective of their size or destructive force, would be regarded as nuclear weapons . . . Both paragraphs one and two of article IV express the underlying policy of prohibiting only certain uses of atomic and other weapons of mass destruction in outer space, yet not completely outlawing their use."). Presumably, a peaceful explosive used in a spacecraft's propulsion system would not count as an "arm" nor would it exert "destructive force." *See* Reynolds, *supra* note 69, at 79 ("'[W]eapons' is a term of art. A nuclear bomb for the destruction of cities is a weapon. But is a nuclear explosive intended for spacecraft propulsion a weapon? Or simply a 'device?' It seems quite plausible to me—and certainly plausible enough to satisfy a nation looking for legal cover—that the ban on nuclear weapons in orbit does not extend to such a circumstance.").

in their construction—being designed to produce relatively small, clean explosions that are directional in nature—they simply are not intended to serve as weapons of any sort.[95] (Because of their very different design, these devices would likely be relatively easy to monitor, if that were desired.[96])

The distinction between weapon and non-weapon grows out of intent.[97] A weapon is a tool used for harming someone.[98] Without the element of harm, a tool is just a tool. Just as gasoline in the tank of a car is fuel, while flaming gasoline sprayed at an enemy is a weapon, so too the nuclear explosives that power an Orion spacecraft are fuel, not weapons.

Article IV of the Outer Space Treaty recognizes this distinction by providing that military technology can be used in space so long as it us used for peaceful purposes.[99] Immediately after the nuclear weapons provision quoted above, the Treaty provides: "The use of military personnel for scientific research or for any other peaceful purposes shall not be prohibited. The use of any equipment or facility necessary for peaceful exploration of the [M]oon and other celestial bodies shall also not be prohibited."[100] This "any equipment" provision reflects the understanding of the drafters that equipment originally designed for military purposes often has capabilities that are useful in scientific research and exploration.

Thus, the nuclear explosives used to propel an Orion spacecraft are not prohibited because they are simply not weapons. As Jack McCall writes, President John F. Kennedy summed up the difference well: "When asked what the difference between the Atlas rocket that launched astronaut John Glenn's capsule and the same nuclear-tipped Atlas missiles directed toward the Soviet Union, JFK responded simply: 'Attitude.'"[101] Since the Treaty

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95 *See* SCHMIDT ET AL., *supra* note 14, at 8; *Nuclear Weapons Primer*, WIS. PROJECT ON NUCLEAR ARMS CONTROL, https://www.wisconsinproject.org/nuclear-weapons/ [https://perma.cc/DE2Y-L8WC] (describing creation of a massive nuclear explosion for use as a weapon).

96 *See generally Safety of Nuclear Power Reactors*, WORLD NUCLEAR ASS'N, https://world-nuclear.org/information-library/safety-and-security/safety-of-plants/safety-of-nuclear-power-reactors.aspx [https://perma.cc/7KPS-PZRZ] (Mar. 2022) (explaining ease of monitoring nuclear reactors).

97 *See Weapon*, BLACK'S LAW DICTIONARY (11th ed. 2019).

98 *Id.*

99 Outer Space Treaty, *supra* note 15, art. IV.

100 *Id.*

101 Jack H. McCall, Jr., *"The Inexorable Advance of Technology"?: American and International Efforts to Curb Missile Proliferation*, 32 JURIMETRICS J. 387, 426 (1992).

bans only nuclear weapons, nuclear explosives that are not weapons would not be covered. The Outer Space Treaty's explicit approval of "any equipment" that is "necessary for peaceful exploration" of space underscores the reasonableness of this reading and perhaps also provides an independent ground for regarding Orion spacecraft as permitted under the Treaty—if an Orion spacecraft is necessary for peaceful exploration of space and celestial bodies, then it "*shall not* be prohibited."[102] Thus, the nuclear-weapons language of Article IV does not ban an Orion spacecraft, while the "any equipment" clause forbids the banning of Orion spacecraft, which, given the tremendous capabilities offered by Orion, certainly qualifies as necessary for many kinds of space activity.[103]

VI. PROBLEMS FOR ORION UNDER THE LIMITED TEST BAN TREATY

The Test Ban Treaty may pose more problems for the deployment of an Orion vehicle than the Outer Space Treaty does. Indeed, some years ago, Reynolds wrote with Robert P. Merges that Orion experiments "were abandoned after the ratification of the Test Ban Treaty, whose plain ban on 'any nuclear weapon test explosion or any other nuclear explosion' . . . in outer space does not admit of any loophole that would support nuclear ex-

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[102] Gorove, *supra* note 94, at 115 (emphasis added).

> A similar argument may be predicated on the language in paragraph two that allows the use of military personnel for scientific research or for any other peaceful purposes. Thus, scientific research is regarded by the drafters as an activity basically of a peaceful character. This is the connotation that may reasonably be drawn from the use of the phrase "for scientific research or for any other peaceful purposes." It may then be safe to assume that no scientific research is prohibited by the Treaty regardless of whether or not it is conducted by civilian or military personnel . . . The drafters of the Treaty have indicated that scientific research should not be curtailed and realistically they have allowed the use of military personnel to further such research. It is reasonable to conclude that regardless of its objective or where it takes place, scientific research is favored by the Treaty terms.

Id. at 122.

[103] *See* Outer Space Treaty, *supra* note 15, art. IV. One is reminded of Supreme Court Chief Justice John Marshall's ruminations on the meaning of "necessary" versus "absolutely necessary" in the famous case of McCulloch v. Maryland, 17 U.S. 316, 414–15 (1819).

plosive propulsion."[104] This statement is not entirely incorrect, but it turns out to be incomplete.

First, as noted at the time, many nations are not signatories to the Test Ban Treaty.[105] Most significantly, the People's Republic of China is a signatory but has not ratified the Treaty,[106] and as an up-and-coming space power with broad ambitions, China seems like a likely candidate for deploying an Orion spaceship. For non-signatory countries, the Test Ban Treaty, which certainly has not entered into customary international law in a way that would bind non-signatories, poses no barrier at all.[107]

Second, of course, any party to the Test Ban Treaty may propose amendments thereto,[108] or may simply withdraw upon the giving of three months' notice.[109] A nation planning an Orion launch might give such notice or simply ignore the waiting period and transmit its notice contemporaneously with a successful launch—a procedural delict to be sure but one unlikely to result in significant consequences.[110]

Most intriguingly, a nation might proceed to launch an Orion spacecraft upon the principle that the Test Ban Treaty simply

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104 GLENN H. REYNOLDS & ROBERT P. MERGES, OUTER SPACE: PROBLEMS OF LAW AND POLICY 61 (2d ed. 1997) (alteration in original).

105 *Id.*; *see also Status of Signature and Ratification*, CTBTO, https://www.ctbto.org/the-treaty/status-of-signature-and-ratification/ [https://perma.cc/FUG9-FYSG]; Test Ban Treaty, *supra* note 16.

106 CTBTO, *supra* note 105 (indicating that China has not ratified the Test Ban Treaty).

107 REYNOLDS & MERGES, *supra* note 104, at 61 ("Although ORION technology is in some ways rather crude, its crudity may well be offset by its ability to deliver extremely powerful propulsion with relatively few new technical demands, allowing a new space power (such as a third world country not bound by the Test Ban Treaty) to perform impressive feats without developing the sophisticated technologies possessed by more experienced space powers."); *see also* CTBTO, *supra* note 105.

108 Test Ban Treaty, *supra* note 16, art. II. It is likely that the deployment of Orion craft by non-signatories would lead to amendment of the Test Ban Treaty among its signatories to permit an Orion craft, if not to outright abandonment of the Test Ban Treaty. REYNOLDS & MERGES, *supra* note 104, at 61 ("Such uses by countries not signatories to the Test Ban Treaty might well lead to an amendment of the treaty to allow its signatories to do the same—or to pressure on nonsignatories to conform to its limits."). How effective such pressures might be against a nation like China is unclear.

109 Test Ban Treaty, *supra* note 16, art. IV ("Each party shall in exercising its national sovereignty have the right to withdraw from the Treaty if it decides that extraordinary events, related to the subject matter of this Treaty, have jeopardized the supreme interests of its country. It shall give notice of such withdrawal to all other Parties to the Treaty three months in advance.").

110 *See id.*

does not apply because of the "any equipment" language from Article IV of the Outer Space Treaty mentioned above. When treaties conflict, the one that is ratified later in time controls.[111] Thus, even a signatory to the Test Ban Treaty might argue that its prohibitions were implicitly modified by the language of the Outer Space Treaty permitting the use of "any equipment" that is "necessary for peaceful exploration" and providing that the use of such equipment "shall . . . not be prohibited."[112] Under this reading of the Outer Space Treaty, the provisions of the Test Ban Treaty remain in force, except to the extent that they might "prohibit" use of "necessary" space technology such as Orion. In that manner, even signatories to the Test Ban Treaty would be free to proceed with Orion.

Though novel, this reading is not even a strained one. The Test Ban Treaty was always primarily an environmental agreement, not an arms-control instrument.[113] But what of the environmental consequences of an Orion launch from Earth?

VII. FISSION AND FALLOUT

Any reference to the word *nuclear* tends to trigger fears of radiation and fallout.[114] What kind of nuclear fallout is associated with the launch of a nuclear spacecraft?

Orion is powered by nuclear explosions. A byproduct of nuclear explosions is ionizing radiation from atomic fission. Broken atoms continue to radioactively decay or emit particles of varying sizes in the form of ionizing radiation in order to get to an ideal stable state.[115] When this happens with an atomic detonation on Earth, the result is typically radioactive dust called

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[111] *Cf.* Julian G. Ku, *Treaties as Laws: A Defense of the Last-in-Time Rule for Treaties and Federal Statutes*, 80 IND. L.J. 319, 325 (2005) (citing Whitney v. Robertson, 124 U.S. 190, 194 (1888)), ("This [last-in-time] doctrine holds that when a treaty and federal statute conflict, whichever was enacted last in time controls."); Taylor v. Morton, 23 F. Cas. 784, 785 (C.C.D. Mass. 1855)).

[112] Outer Space Treaty, *supra* note 15, art. IV.

[113] REYNOLDS & MERGES, *supra* note 104, at 54 ("The primary goal of the Limited Test Ban Treaty was not arms control, but the prevention of global nuclear contamination."); *see also* Test Ban Treaty, *supra* note 16, pmbl. (noting that this Treaty sought to contribute to the protection of the environment). This testing was quite a problem during the era of unlimited atmospheric nuclear testing. *See generally Nuclear Testing: 1945-2009*, CTBTO, https://www.ctbto.org/nuclear-testing/history-of-nuclear-testing/nuclear-testing-1945-today/ [https://perma.cc/V9N4-FJM2].

[114] *See supra* note 12 and accompanying text.

[115] *Radioactive Decay*, U.S. EPA, https://www.epa.gov/radiation/radioactive-decay [https://perma.cc/H66W-FDPQ] (Apr. 12, 2022).

"fallout" that settles at varying distances downwind.[116] The fallout continues its radioactive decay, and the fallout and its decay ionize atoms and molecules, thus destabilizing them or, in the presence of fissile material, possibly generating further fission reactions.[117] When this ionizing radiation interacts with a target, atoms within the target can become ionized and possibly break apart.[118] These reactions with live tissue (humans) are the kind of interactions that cause unwanted and harmful biological effects.[119]

At the time Orion was developed, any resulting radioactivity seemed unimportant. In those days, the nuclear powers were engaging in frequent nuclear testing in the atmosphere, the oceans, and even sometimes in outer space,[120] and the amount of fallout Orion would have contributed to the Earth's environment would have been a tiny fraction of what was already being produced. As Freeman Dyson writes, "We calculated that even our most ambitious program of Orion flights would add only about one percent to the contamination of the environment that the bomb tests were then causing. One percent did not seem so bad."[121]

Today, that baseline of massive worldwide atmospheric testing no longer exists. To many, any amount of radioactivity, however

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[116] *See, e.g.*, *Fallout*, OXFORD LEARNER'S DICTIONARY, https://www.oxfordlearnersdictionaries.com/definition/american_english/fallout [https://perma.cc/39V9-P949].

[117] *See Fissile Material*, U.S. NUCLEAR REGUL. COMM'N, https://www.nrc.gov/reading-rm/basic-ref/glossary/fissile-material.html [https://perma.cc/J8SE-9V4S] (Mar. 9, 2021) (defining "fissile material"); *see generally* J.A.B. Gibson & D.H. Peirson, *Radiation Dose and Ionization from Radioactive Fallout*, 220 NATURE 464, 464–66 (1968) (describing expected doses of ionizing radiation from nuclear fallout).

[118] *See generally* EPA, *supra* note 115.

[119] *See* JAMES E. TURNER, ATOMS, RADIATION, AND RADIATION PROTECTION 362–63 (3d ed. 2007).

[120] *See, e.g.*, 9 July 1962: 'Starfish Prime,' Outer Space, CTBTO, https://www.ctbto.org/specials/testing-times/9-july-1962starfish-prime-outer-space [https://perma.cc/7AK7-QV57] ("On 9 July 1962, the United States conducted the 'Starfish Prime' nuclear test, one of a series of five aimed at testing the effects of nuclear weapons in high altitudes [and] lower outer space."); *see also* Jessica Miley, *Cold War Nuclear Tests Still Affecting Life at the Bottom of the Ocean*, INTERESTING ENG'G (May 17, 2019) (internal citation omitted), https://interestingengineering.com/cold-war-nuclear-tests-still-affecting-life-at-the-bottom-of-the-ocean [https://perma.cc/J8ED-UT9P] ("Animals living in the deepest trenches of the ocean carry radioactive carbon from nuclear tests carried out during the Cold War.").

[121] FREEMAN DYSON, *supra* note 53, at 114–15.

low, is unacceptable.[122] And even Dyson and his cohorts were troubled by the deaths that might result: "I studied carefully the literature concerning the biological effects of radiation and arrived at estimates that the fallout from each Orion takeoff would statistically cause between one-tenth and one human death by radiation-induced cancer."[123] Radiation-induced cancers depend on a number of factors: length of exposure, dose of exposure, type of exposure, the person's age at the time of exposure, and tissue penetration—just to name a few.[124] Acute radiation poisoning is evident within days, but latent effects from lower level radiation exposure may take years to appear, making direct correlations between exposure and cancer extremely difficult to prove.[125]

Dyson's sensitivity does him credit, though it is perhaps ironic in someone who engaged in nuclear weapons research, a field where "megadeaths"—millions of deaths—are a standard metric.[126] The worst nuclear "accident"[127] at Chernobyl led to thirty deaths within the first few weeks and over 6,000 cases of thyroid

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122 *See generally* Int'l Atomic Energy Agency [IAEA], *Fact Sheet: Radiation in Everyday Life*, https://www.iaea.org/Publications/Factsheets/English/radlife (noting that exposure to high doses of radiation is harmful to human health, but there is less scientific certainty about the health effects of exposure to low doses).

123 *Id.* at 115.

124 *See generally* COMM. ON THE BIOLOGICAL EFFECTS OF IONIZING RADIATION (BIER V), NAT'L RSCH. COUNCIL, HEALTH EFFECTS OF EXPOSURE TO LOW LEVELS OF IONIZING RADIATION: BEIR V 5–6 (1990) (describing risk factors that cause radiation exposure to be more or less carcinogenic).

125 *See* DONALD J. PECK & EHSAN SAMEI, HOW TO UNDERSTAND AND COMMUNICATE RADIATION RISK 3–5, https://www.imagewisely.org/-/media/Image-Wisely/Files/CT/IW-Peck-Samei-Radiation-Risk.pdf [https://perma.cc/SWL8-AEGX] (Mar. 2017).

126 *See Megadeath*, DICTIONARY.COM, https://www.dictionary.com/browse/megadeath [https://perma.cc/2VMU-JGXC] ("[A] unit of one million deaths: used in estimating or predicting the fatalities that would occur in a nuclear war."); HERMAN KAHN, ON THERMONUCLEAR WAR 169 (2007) ("It was difficult for people to distinguish in the early 1950's between 2 million deaths and 100 million deaths.").

127 The RBMK-type reactors used at Chernobyl were fundamentally flawed and unsafe. *See* Bethel Afework, Jordan Hanania, Kailyn Stenhouse & Jason Donev, *RMBK*, ENERGY EDUC., https://energyeducation.ca/encyclopedia/RBMK [https://perma.cc/A8HW-J35P] (July 21, 2018). The combination of an unsafe reactor incorrectly operated might be better termed extreme negligence or reckless conduct. *See Chernobyl Accident 1986*, WORLD NUCLEAR ASS'N, http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/chernobyl-accident.aspx [https://perma.cc/FF56-ES3R] (Apr. 2022).

cancer by the year 2005.[128] By today's standards, an estimated one death per launch might seem unacceptable on its face. But compared to deaths from existing modes of transportation,[129] Orion fallout would have a trivial impact.

VIII. CURRENT CONSEQUENCES FROM TRANSPORTATION

When comparing these numbers to health statistics associated with commonly accepted means of transportation, the fallout numbers begin to look quite negligible. For example, approximately 38,000 premature deaths per year globally are attributed to Nitrogen Oxide (NOx) from vehicular diesel exhaust gas emissions.[130] This impact is particularly felt in Europe, where 11,500 out of 28,500 deaths per year are linked to NOx emissions from diesel vehicle engines.[131] Although the mighty diesel is most likely on its way out,[132] there are still approximately 15 million diesel vehicles driving around the Federal Republic of Germany,[133] an ironic risk given the country's decision to shut down its nuclear reactors after Fukushima.[134] If diesel engine use continues, this number could increase worldwide to 183,600 premature deaths per year.[135]

Other studies paint a direr picture, estimating 385,000 global premature deaths in 2015 from vehicles (diesel and gasoline), stationary engines, and ships.[136] Massive container ships are ex-

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128 *Assessments of the Radiation Effects from the Chernobyl Nuclear Reactor Accident*, U.N. SCI. COMM. ON THE EFFECTS OF ATOMIC RADIATION, https://www.unscear.org/unscear/en/areas-of-work/chernobyl.html [https://perma.cc/685H-9DME].

129 *See infra* Part VIII.

130 *Diesel Fumes Lead to Thousands More Deaths than Thought*, NEW SCIENTIST & PRESS ASS'N (May 15, 2017), https://www.newscientist.com/article/2131067-diesel-fumes-lead-to-thousands-more-deaths-than-thought/ [https://perma.cc/JT2V-WEJZ].

131 *Id.*

132 *See* Robert Ferris, *Diesel Is on the Decline, but Don't Count It out Yet*, CNBC (June 19, 2020, 8:00 AM), https://www.cnbc.com/2020/06/19/diesel-is-on-the-decline-but-dont-count-it-out-yet.html.

133 Paul Hockenos, *End of the Road: Are Diesel Cars on the Way Out in Europe?*, YALE ENV'T 360 (Apr. 12, 2018), https://e360.yale.edu/features/end-of-the-road-are-diesel-cars-on-the-way-out-in-europe [https://perma.cc/GG6U-3MXR].

134 *See Germany: To Phase Out or Not to Phase Out? Phase Out!*, K=1 PROJECT: CTR. FOR NUCLEAR STUD., COLUMB. (Aug. 1, 2012), https://k1project.columbia.edu/a13 [https://perma.cc/MDD7-B52D].

135 NEW SCIENTIST & PRESS ASS'N, *supra* note 130.

136 Dan Rutherford & Josh Miller, *Silent but Deadly: The Case of Shipping Emissions*, INT'L COUNCIL ON CLEAN TRANSP. (Mar. 22, 2019), https://theicct.org/

treme offenders; particulate from these container ships creates massive amounts of sulfur dioxide, which leads to acid rain.[137] Although such ships are subject to country-specific restrictions while at port, once on the high seas, these ships burn heavy and dirty fuel, spewing far more particulate than any internal combustion engine on land.[138] This heavy fuel is 3,500 times dirtier than automotive diesel,[139] and we have already pointed to the health implications associated with diesel engines. A 2007 study estimated that up to 60,000 deaths annually were linked to shipping emissions, with a further estimation that the number would increase 40% by 2012.[140] Given the heavy reliance on ocean liners and online shopping, those numbers have increased more than the 2007 study projected and are getting worse.[141]

Those transportation risks are associated with inhalation of toxins from fossil fuels, but air travel also results in radiation exposure.[142] Our atmosphere on earth at sea level protects us from cosmic radiation—the higher you go, the thinner the atmosphere, and the less the protection.[143] For example, residents of the Mile High City of Denver, Colorado, experience higher

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blog/staff/silent-deadly-case-shipping-emissions [https://perma.cc/284H-YU5N].

137 Harald Franzen, *Think Diesel Cars Are Dirty? Try Ships!*, DEUTSCHE WELLE (Aug. 29, 2017), https://www.dw.com/en/think-diesel-cars-are-dirty-try-ships/a-40278610 [https://perma.cc/S5GF-CNGD].

138 *See id.*

139 *Id.*

140 James J. Corbett, James J. Winebrake, Erin H. Green, Prasad Kasibhatla, Veronika Eyring & Axel Lauer, *Mortality from Ship Emissions: A Global Assessment*, 41 ENV'T SCI. & TECH. 8512, 8514–15 (2007).

141 *See* Mark Dwortzan, *Smarter Regulation of Global Shipping Emissions Could Improve Air Quality and Health Outcomes*, MIT NEWS (Aug. 17, 2021), https://news.mit.edu/2021/smarter-regulation-global-shipping-emissions-could-improve-air-quality-health-outcomes-0817 [https://perma.cc/GSQ5-SYGV] (reporting that 94,000 premature deaths were associated with maritime shipping in 2015 and that "[e]missions from shipping activities around the world account for nearly 3 percent of total human-caused greenhouse gas emissions, and could increase by up to 50 percent by 2050").

142 *Radiation from Air Travel*, CDC, https://www.cdc.gov/nceh/radiation/air_travel.html (Dec. 7, 2015) [https://perma.cc/LMC8-J83A]; *see also Doses in Our Daily Lives*, U.S. NUCLEAR REGUL. COMM'N, https://www.nrc.gov/about-nrc/radiation/around-us/doses-daily-lives.html [https://perma.cc/Y6H8-LSP5] (Apr. 26, 2022).

143 *Cosmic Radiation*, U.S. EPA, https://www.epa.gov/radtown/cosmic-radiation#:~:text=TO%20learn%20more-,About%20Cosmic%20Radiation,the%20radiation%20around%20the%20earth [https://perma.cc/PA3U-F4ZU] (May 16, 2022).

radiation exposure.[144] Flying at a typical altitude exposes a person to approximately 0.003 millisieverts per hour.[145] A sievert is a unit of radiation measurement that takes into account the biological effects of radiation—low-level radiation exposure is not likely to interact significantly with tissue, whereas high levels of radiation exposure is.[146] Think radio wave versus x-ray. So, spending 100 hours on a plane per year results in an excess exposure of 0.3 mSv per year. For comparison, an average American is exposed to 0.062 mSv in a year (i.e., with background radiation, standard medical procedures, etc.).[147] Exposure to 1 Sv increases the risk of cancer by about 5%,[148] so over a 10-year period, simply flying an average of 100 hours per year can increase your risk of cancer by 0.015%. Assuming a population of about three billion in 1960 and Dyson's rough estimate of one human death per launch, it is clear that risk of cancer from commercial air travel can far outweigh the estimated risk from an Orion launch.

Now that we have established that risk to humans based on fallout from an Orion launch is insignificant in the face of existing transportation risks, let us turn to methods of fallout reduction.

IX. FALLOUT REDUCTION

Fallout is generated by the rocket's propulsion—radiation born at the explosion location will primarily be located between the explosion location and the pusher plate.[149] According to General Atomics, most fission products would not be trapped within Earth's atmosphere due to their hemispherical escape path around the vehicle and their extremely high velocity.[150]

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144 *Biological Effects of Radiation*, U.S. NUCLEAR REGUL. COMM'N (Dec. 2004), https://www.hsdl.org/?view&did=28420 [https://perma.cc/VL9H-QBJQ].

145 Timothy J. Jorgensen, *Air Travel Exposes You to Radiation – How Much Health Risk Comes with It?*, CONVERSATION (June 7, 2017, 10:37 PM), https://theconversation.com/air-travel-exposes-you-to-radiation-how-much-health-risk-comes-with-it-78790 [https://perma.cc/2639-6TFH].

146 *See generally Measuring Radiation*, U.S. NUCLEAR REGUL. COMM'N, https://www.nrc.gov/about-nrc/radiation/health-effects/measuring-radiation.html [https://perma.cc/G7UL-TF4Q] (Mar. 20, 2022).

147 U.S. NUCLEAR REGUL. COMM'N, *supra* note 142.

148 *See* PECK & SAMEI, *supra* note 125.

149 *See* GEN. ATOMIC DIV., GEN. DYNAMICS, *Nuclear Pulse Space Vehicle Study: Conceptual Vehicle Designs and Operational Systems* § 3.1.1 (Sept. 19, 1964), https://www.classe.cornell.edu/~seb/celestia/orion/files/19770085619_1977085619.pdf [https://perma.cc/9RQ5-3AAC].

150 *Id.* § 5.1.2.

Nevertheless, General Atomics estimated that some radiation would still be trapped in the atmosphere and travel to Earth's surface, although "in times less than the [S]trontium[-]90 half-life."[151] Strontium-90's half-life is about 29.1 years, and it is a beta emitter (electron or positron)—a form of ionizing radiation, which can damage living tissue.[152]

One way to reduce fallout would be to direct the fission products in the direction of the vehicle as it travels out of the Earth's atmosphere.[153] Another way to reduce or even avoid fallout generated would be to launch the nuclear rocket using chemical rockets to an altitude sufficient to reduce nuclear material caught in the Earth's atmosphere.[154] Generally, fission products would not be trapped in the atmosphere at an altitude of 150 km.[155] As we have noted above with regard to Orion, the bigger the better,[156] but launching a huge nuclear rocket with our current chemical boosters might seem counterproductive. General Atomics, however, accounted for such inefficiencies and suggested that a massive nuclear rocket would nevertheless need to be constructed in orbit, and efficiencies gained overall would most likely outweigh any detriment to such a scheme.[157]

Redirection of fission products and assembly of the unit in outer space are estimated to reduce fission-product trappage in the atmosphere on the order of 10-6,[158] but launch of the rocket from Earth generates another type of fallout, known as groundburst, that is associated with contamination of ground material that is pulled in at launch, irradiated, and spewed elsewhere.[159] One suggestion to cure this includes use of an extremely thick launchpad,[160] but it seems that the most logical

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151 *Id.*

152 *Radioisotope Brief: Strontium-90 (Sr-90)*, CDC (Aug. 18, 2005), https://emergency.cdc.gov/radiation/isotopes/pdf/strontium.pdf [https://perma.cc/8X3P-5Z48].

153 *See* GEN. ATOMIC DIV., GEN. DYNAMICS, *supra* note 149, § 5.1.2.

154 *Id.* § 5.5.2.

155 *Id.* § 5.1.2.

156 *See supra* note 47 and accompanying text.

157 *See id.* § 5.5.2.

158 *Id.* § 5.1.2.

159 *Cf.* NAT'L RSCH. COUNCIL, EFFECTS OF NUCLEAR EARTH-PENETRATOR AND OTHER WEAPONS 92 (2005) (discussing this type of fallout in the context of nuclear weapons).

160 *See* Wayne Smith, *The Case for Orion*, SPACE DAILY (Mar. 12, 2003), https://www.spacedaily.com/news/nuclearspace-03h.html [https://perma.cc/NL7J-P7H9] ("It[']s as straightforward as that. The Orion team discovered that a thick metal plate can withstand close proximity nuclear blasts very well.").

suggestion is to assemble the nuclear rocket in space. Indeed, this seems to be NASA's current approach for nuclear transport.[161]

The authors of the General Atomics study also suggest a complete redesign to eliminate fission-product release.[162] One redesign includes the use of fusion instead of fission. Whereas the use of fission harnesses atomic energy through breaking atomic bonds, the use of fusion harnesses the energy through its release upon fusing particles together—fission releases atomic binding energy from a large nucleus while fusion releases excess binding energy no longer needed from individual atoms.[163] Although the sun is very successful at fusion, humans have had less success replicating this clean energy source on Earth. Recent promising breakthroughs indicate that this could be a viable option, albeit expensive,[164] but for the purposes of this Article, we will assume the nuclear-pulsed rocket is propelled by fission reactions.

X. FALLOUT AS "CONTAMINATION" UNDER THE OUTER SPACE TREATY

Aside from its limitations on nuclear weapons in orbit,[165] the Outer Space Treaty, in Article IX, requires that parties avoid "harmful contamination" of the Moon and other celestial bodies, and possibly also of outer space itself.[166] The latter is not clear. The precise language is, "States Parties to the Treaty shall pursue studies of outer space, including the [M]oon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter."[167]

161 *See, e.g.*, Elizabeth Howell, *US Military Wants Nuclear Rocket Ideas for Missions. Near the Moon*, SPACE.COM (May 10, 2022), https://www.space.com/darpa-nuclear-rocket-earth-moon-space.

162 *See* GEN. ATOMIC DIV., GEN. DYNAMICS, *supra* note 149, § 2.4.

163 *See* Matthew Lanctot, *DOE Explains . . . Nuclear Fusion Reactions*, OFF. OF SCI., U.S. DEP'T OF ENERGY, https://www.energy.gov/science/doe-explainsnuclear-fusion-reactions [https://perma.cc/L5VR-ZAN3]; *Nuclear Explained, U.S. Energy Info. Admin.* https://www.eia.gov/energyexplained/nuclear/ (July 7, 2022).

164 *See* David Abel, *After Years of Doubts, Hopes Grow That Nuclear Fusion Is Finally for Real and Could Help Address Climate Change*, BOS. GLOBE, https://www.bostonglobe.com/2021/12/22/science/after-years-doubts-hopes-grow-that-nuclear-fusion-is-finally-real-could-help-address-climate-change/ [https://perma.cc/4BWM-TNPP] (Dec. 22, 2021, 5:46 PM).

165 Outer Space Treaty, *supra* note 15, art. IV.

166 *Id.* art. IX.

167 *Id.*

This raises two questions. First, does the prohibition on harmful contamination apply to outer space as well as to the Moon and other celestial bodies? Second, does radioactive fallout from Orion count as harmful contamination?

It is clear from its language that the prohibition has no application to any sort of contamination that takes place entirely on Earth, so atmospheric fallout from an Orion launch would not be covered. Do the "them" and "their" in Article IX apply to both outer space and to the Moon and other celestial bodies, or do they apply solely to the latter? Both interpretations seem plausible, but which one is more plausible?

Discussions of contamination under Article IX generally seem to turn on biological contamination—the contamination of, say, Mars with Earth bacteria, or the "back contamination" of Earth with alien life brought here from another planet.[168] Article IX provides no definition of "contamination" or "harmful,"[169] leaving us to fall back on general meanings. Those are not clear, but for the provision to apply to Orion, it must cover outer space, and whatever radioactive emissions produced by Orion while it is operating beyond the atmosphere must count as "contamination" for the purposes of the Treaty.[170] As a general matter, the notion of "contaminating" outer space with radiation is an absurdity—outer space is immense beyond imagining and generally features levels of radiation that would be lethal on Earth. It is possible that sufficient radioactive exhaust might be trapped within the Earth's magnetic fields to produce local contamination, but to the extent that happens, such would represent contamination of Earth (and not with "extraterrestrial matter," the only kind recognized by the Treaty as a harm to Earth), rather than outer space or the Moon and other celestial bodies, and hence would fall outside the Treaty.[171] And, of course, radioac-

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[168] *See* Louis de Gouyon Matignon, *Harmful Contamination, Harmful Interference and Space Debris*, SPACE LEGAL ISSUES (Oct. 7, 2019), https://www.spacelegalissues.com/harmful-contamination-harmful-interference-and-space-debris/ [https://perma.cc/4MDY-ZCXJ] (describing "harmful contamination" as involving "biological contamination of a planetary body by a space probe or spacecraft"). For a popular discussion, see Glenn Harlan Reynolds, *Why I Hope There's No Life on Mars*, POPULAR MECHS. (Dec. 3, 2008), https://www.popularmechanics.com/space/moon-mars/a3778/4294346/ [https://perma.cc/8UR9-BX9Q].

[169] *See* Outer Space Treaty, *supra* note 15; *see also* Reynolds, *supra* note 69, at 77 (noting that the "Outer Space Treaty only bans 'harmful contamination'" and that not all contamination is likely to be harmful).

[170] *See* Reynolds, *supra* note 69, at 77.

[171] *See* Outer Space Treaty, *supra* note 15, art. IX.

tive contamination is not "biological contamination," which seems to be what Article IX envisions. While the matter is not entirely free from doubt, the "harmful contamination" language would not appear to prevent the operation of an Orion spacecraft. At the very least, as we have illustrated, there would be many plausible arguments that an Orion-launching nation could deploy in defense of its launch, with the likely result being, at most, a dispute among jurists.

Also arguing against the "harmful contamination" language's application to outer space, even near-Earth space, is that one harmful form of pollution in near Earth space—orbital debris—has not been seen as triggering this provision.[172] Though NASA's Administrator Bill Nelson sharply criticized a recent Russian anti-satellite (ASAT) test that generated copious space debris, threatening satellites and the International Space Station, his statement did not even mention the Outer Space Treaty.[173] This would also seem to undercut the application of other Article IX provisions requiring States Parties to be guided by "the principle of co-operation and mutual assistance," to conduct all their activities in outer space "with due regard to the corresponding interests" of other Party States, and to consult before any activity that might cause "harmful interference" with other nations' activities in space.[174] Again, this provision was not referenced in complaints about the Russian ASAT test,[175] suggesting that NASA does not regard the provision as applicable here. (Presumably, the Russians, by their actions, have indicated a similar sentiment.) It thus seems unlikely that the "harmful contamination" or "harmful interference" provisions of Article

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[172] *See* Michael B. Runnels, *On Clearing Earth's Orbital Debris & Enforcing the Outer Space Treaty in the U.S.*, AM. BAR ASS'N (Jan. 13, 2022), https://www.americanbar.org/groups/business_law/publications/blt/2022/01/orbital-debris/ [https://perma.cc/3GYE-SNES] ("[N]either the [Outer Space Treaty] nor [the] Liability Convention compellingly disincentivize debris creation in orbit.").

[173] *See* Hanneke Weitering, *NASA Chief Bill Nelson Condemns Russian Anti-Satellite Test*, SPACE.COM (Nov. 16, 2021), https://www.space.com/nasa-chief-condemns-russian-anti-satellitw-test [https://perma.cc/JV7D-WKTS]; *see also* Christopher J. Borgen, *Russia's ASAT Test and the Development of Space Law*, LIEBER INST., WEST POINT (Nov. 21, 2021), https://lieber.westpoint.edu/russia-asat-test-development-space-law/ [https://perma.cc/H3HZ-XAAJ] ("[W]hile various public statements by States characterized the [Russian ASAT] test as reckless or dangerous, language explicitly framing it as a violation of the [Outer Space Treaty] seems to be lacking.").

[174] Outer Space Treaty, *supra* note 15, art. IX.

[175] *See* Borgen, *supra* note 173.

IX would be widely seen as applying to any pollution caused by an Orion launch, on or off the Earth.

Likewise, the Convention on International Liability for Damage Caused by Space Objects (Liability Convention)[176] might conceivably apply to harm done by an Orion launch, both on Earth and in space. The Liability Convention applies to both military and civilian activity in space and provides for the absolute liability of launching states for damage caused by their space objects on the surface of the Earth or to aircraft in flight.[177] The Liability Convention also provides for liability based on fault where the damage is to space objects of another launching state elsewhere than on the surface of the Earth.[178] The harm caused by fallout on Earth would appear too diffuse to fall under the Liability Convention—how does one assess damages for a random life, or fraction of a life, lost to cancer from fallout radiation amid all the other deaths for cancer in the same population? Though there is (some) precedent for the Liability Convention being applied in the case of radiation harm on Earth caused by a spacecraft, the circumstances involved the crash of a reactor-equipped Soviet spy satellite, which is pretty much at the core of the Liability Convention's coverage.[179] As for harm to other space objects, liability based on fault requires some sort of standard of fault (i.e., negligence),[180] and determining what constitutes reasonable care in launching a new variety of nuclear-powered spacecraft would be difficult. In some cases—for example, where an out-of-control Orion craft rams into a space station or satellite—liability would be easy to assess. But those kinds of cases would be independent of the nuclear nature of the Orion craft.

Aside from these arguments, it is possible to imagine more general environmental arguments made against the fallout from an Orion launch, not drawing on the Test Ban Treaty or the Outer Space Treaty at all. Those arguments are unlikely to go very far, however, because international environmental law does

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176 Convention on International Liability for Damage Caused by Space Objects, *opened for signature* Mar. 29, 1972, 24 U.S.T. 2389, 961 U.N.T.S. 187 [hereinafter Liability Convention].

177 *Id.* art. II.

178 *Id.* art. III.

179 *See* Alexander F. Cohen, *Cosmos 954 and the International Law of Satellite Accidents*, 10 YALE J. INT'L L. 78, 78–81 (1984) (describing the facts of the satellite accident and explaining the legal consequences for the Soviet Union).

180 *See* John C.P. Goldberg & Benjamin C. Zipursky, *The Strict Liability in Fault and the Fault in Strict Liability*, 85 FORDHAM L. REV. 743, 744–46 (2016).

not itself go very far. The fact that a treaty was needed to put an end to atmospheric tests by most powers—and that some nations that refused to join the Treaty continued to perform atmospheric tests without penalty—illustrates that there is no general international law norm against fallout. Such arguments, like any arguments, may be made in the public sphere, but they are unlikely to carry much weight.

XI. ANALYSIS AND CONCLUSION

As Walter MacDougall has noted, space law began with a struggle between the "natural law" school of space law, associated with early space lawyer (and President of the International Astronautical Federation) Andrew Haley, and the "positivist school" associated with Myres McDougal of Yale Law School.[181] It is fair to say that the positivist school won out.[182] McDougal's approach to international jurisprudence held that norms can be determined only from patterns of common usage and from the expectations and actions of national elites.[183]

Viewing the legal issues surrounding an Orion launch in those terms, the discussion above indicates that there are no serious legal barriers to the deployment of an Orion spacecraft or, at least, no barriers serious enough to deter a nation otherwise determined to take advantage of Orion capabilities from doing so. International law is, of course, real law but it is law whose sanctions tend to be weak and diffuse.[184] The cost to a nation of violating international norms tends to be small, unless those norms are very strong ones.[185] And nations are willing to face some costs in pursuit of what they see as important objectives.[186]

To a nation determined to achieve primacy in space, the Orion drive offers a very powerful tool for achieving that objec-

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181 MCDOUGALL, *supra* note 81, at 188.

182 Id. ("The two schools could aptly be termed the idealist and the realist. The most striking vindication of the realistic positivists was the fact that the secret NSC decisions had already rendered the space law debate academic . . . Many space law theorists expressed their disgust with this narrow nationalism and hypocrisy, but their cries of 'space for peace' and 'space for all mankind' carried no further than if they had been shouted in the vacuum of space itself. The irony is that those enthusiastic about the human adventure in space should have been rejoicing. Competition was the engine of spaceflight.").

183 *Id.*

184 *See* Harold Hongju Koh, *Why Do Nations Obey International Law?*, 106 YALE L.J. 2599, 2631–36 (1997).

185 *See generally id.* at 2600–01, 2631–36.

186 *Id.* at 2635–36.

tive. While there are legal arguments against the deployment of an Orion spacecraft,[187] they are not particularly strong arguments, and for each such argument, there seems to be a counterargument that is at least as plausible. In those circumstances, the legal cost of going forward likely seems to be very manageable.

Those concerned with limiting the deployment of Orion or—perhaps more sensibly and achievably—with ensuring that nations that deploy it do so in as safe and considerate a manner as possible, should probably seek to establish general principles of safety and considerateness that go beyond the very limited provisions of Article IX of the Outer Space Treaty and of the Liability Convention. Establishing a norm of liability for harm caused by deliberately created debris, as in the case of the recent Russian ASAT test, might establish a useful precedent.[188] It is not clear to us that there is a strong desire to do any of these things on the part of the international community, but that might change.

At any rate, as things stand, we face a future in which enthusiasm for nuclear pulse propulsion is likely to grow along with the intensity of competition for space resources and national prestige, and one in which international law is unlikely to stand as a significant barrier to such developments. Indeed, the enthusiasm for nuclear pulse propulsion may not be limited to governments, as figures such as Jeff Bezos and Elon Musk lead the way in many areas of space development.[189] Those wishing to see

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187 Leonardo P. Caselli, *Space Demilitarization Treaties in a New Era of Manned Nuclear Spaceflights*, 77 J. AIR L. & COM. 641, 642, 654 (2012).

188 For a discussion on problems with current space law regarding orbital debris, and some suggestions for improvement, see Robert P. Merges & Glenn H. Reynolds, *Rules of the Road for Space?: Satellite Collisions and the Inadequacy of Current Space Law*, 40 ENV'T L. REP. 10009, 10010–11 (2010).

189 George Dyson's book even received a strong positive Amazon review from none other than Amazon founder (as well as space-colonization enthusiast and founder of private space company Blue Origin) Jeff Bezos. *See* Jeff Bezos, Review for *Project Orion: The True Story of the Atomic Spaceship*, AMAZON (Apr. 14, 2002), https://www.amazon.com/gp/customer-reviews/R1PUHS86W2V5F4/ref=cm_cr_getr_d_rvw_ttl?ots=1&ie=UTF8&ASIN=0805072845 [https://perma.cc/S7RJ-VJDB]. Bezos wrote: "For those of us who dream of visiting the outer planets, seeing Saturn's rings up close without intermediation of telescopes or charge-coupled devices, well, we pretty much *have* to read 'Project Orion.' In 1958, some of the world's smartest people, including famous physicist Freeman Dyson (the author's father), expected to visit the outer planets in 'Orion,' a nuclear-bomb propelled ship big enough and powerful enough to seat its passengers in lazy-boy recliners. They expected to start their grand tour by 1970. This was not pie-in-the-sky optimism; they had strong technical reasons for believing they could do it. To pull this book together, George Dyson did an astonishing amount

limits on Orion-type spacecraft would be well advised to seek new international agreements rather than rely on treaties from the mid-20th Century.

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of research into this still largely classified project. And, maybe because he's connected to Orion through his father, the author captures the strong emotion of the project and the team. Highly recommended." *Id.*