Open-Source Nukes: Still the Right Idea

Karl T. Muth[1]

In the absence of an international marketplace for nuclear armaments, the fabrication of such weapons is customarily prerequisite to their deployment. Therefore, exerting control over who possesses the capability to construct nuclear weapons serves as an effective means of regulating their possession and potential use. For over a decade, Professor Karl T. Muth has advanced a minority perspective: that the natural scarcity and careful custody of fissile materials is the paramount safeguard against both accidental and intentional nuclear weapon deployment, rather than secrecy of knowledge concerning weapons construction. In an era where information disseminates at the velocity of the Internet, Muth argues that attempting to sequester knowledge of technology–predating even the microwave oven–is not only futile but should not be part of any serious, modern arms control strategy.

This Article delves into a series of historical and contemporary events—including recent developments in Iran and the Democratic People's Republic of Korea ("DPRK")—to demonstrate how arms control could be equally effective, or even substantially enhanced, while openly sharing safe, tested designs for relatively low-yield fission weapons. By contrasting secrecy (the concealment of weapon construction methodologies) with scarcity (the limited availability of essential weapon ingredients)

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This Article is dedicated to the memory of our Lillian, who enriched the lives of everyone she met and who, with modern nuclear medicine, fought cancer with dignity and bravery; your parents miss you every day. 🖤

as competing yet historically-complementary paradigms, the Article explores the problematic effects (and imagined safety) of a secrecy-centric regime; these include an increased likelihood of clandestine laboratories or subterranean nuclear testing in proximity to populous areas and a heightened opacity in dialogues between nations that are nuclear-armed (or, potentially, secretly nuclear-armed).

This piece is both timely and controversial. Amid ongoing discourse regarding Iranian and North Korean capabilities and intentions—and coinciding with the eightieth anniversary of the only deployment of nuclear payloads in armed conflict (in Japan on August 6 and 9, 1945)—this work presents a provocative and detailed proposal. It is ideally suited as a centerpiece for debate among policymakers, scholars, and graduate students across disciplines such as history, law, international policy, and technology ethics. Rich with citations and spanning a substantial period, this piece also offers valuable insights for researchers, historians, or futurists considering or critiquing the rationale behind employing secrecy and scarcity strategies in other high-tech areas of research, nearly all of which have both knowledge (secrecy) and ingredient (scarcity) prerequisites.

Nuclear bombs cannot possibly remain a 'secret weapon' at the exclusive disposal of this country for more than a few years. The scientific facts on which their construction is based are well-known to scientists of other countries.

- *The Franck Report (circulated to Truman's advisors in secret on June 21, 1945)*[2]

To me, it's very simple. Iran cannot have a nuclear weapon.

- *President Donald J. Trump*[3]

The United States has great strength and patience, but if it is forced to defend itself or its allies, we will have no choice but to totally destroy North Korea.

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[2] JAMES FRANCK ET AL., REPORT OF THE COMMITTEE ON POLITICAL AND SOCIAL PROBLEMS (1945) (noting as the report was classified and has been released only in parts until thirty or so years ago, the best recitation of its direct quotations, including this one, and pertinent passages is contained within Lawrence S. Wittner's excellent research in this area in the 1990s); LAWRENCE S. WITTNER, THE STRUGGLE AGAINST THE BOMB: ONE WORLD OR NONE: A HISTORY OF THE WORLD NUCLEAR DISARMAMENT MOVEMENT THROUGH 1953 25 (1993) (noting many believe this report represented the last opportunity to prevent a massive number of Japanese civilian casualties in nuclear attacks later that year).

[3] Franco Ordoñez & Deepa Shivaram, *Trump Says He Wants the U.S. to Take Ownership of the Gaza Strip*, NPR (Feb. 4, 2025, 8:22pm), https://www.npr.org/2025/02/04/nx-s1-5287012/trump-netanyahu-ceasefire-gaza [https://perma.cc/CMP5-94CC].

- *President Donald J. Trump*[4]

I write this in late 2024, the year in which the Nobel Peace Prize was awarded to Japanese survivors of American nuclear bombings via Nihon Hidankyo,[5] *an organization that works to support these people and their communities and families. Nuclear weapons, and even more so nuclear warfare, inevitably pose a risk of horrific, irreversible damage to people, nations, and the natural environment; this is not an article in favor of nuclear proliferation. But this is an international law and policy piece in favor of adopting more realistic and pragmatic approaches as to nuclear weapons and, hopefully, reducing the civilian suffering that often*[6] *accompanies national nuclear aspirations.*

This Article argues our current approach to stifling nuclear proliferation is neither effective nor safe and that, as we approach the eightieth anniversary[7] *of the first use of nuclear weapons on the battlefield, our policy approach must change.*[8] *A change is overdue. A set of prohibitions that force nuclear weapons research to be done in the most clandestine, most dangerous conditions has had, and continues to have, unintended effects that put innocent civilian lives needlessly at risk.*

Ten years ago, in London at a meeting subject to Chatham House rules,[9] *the author gave remarks in favor of open-source nukes, a phrase that drew gasps and quietly-set-down glasses around the room.*[10] *And my position and belief has not changed in the*

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[4] Meghan Keneally, *From 'Fire and Fury' to 'Rocket Man,' the Various Barbs Traded Between Trump and Kim Jong Un*, ABC NEWS (June 12, 2018, 12:27AM), https://abcnews.go.com/International/fire-fury-rocket-man-barbs-traded-trump-kim/story?id=53634996 [https://perma.cc/LK3V-AQZJ].

[5] *Nihon Hidankyo Facts*, NOBEL PRIZE, https://www.nobelprize.org/prizes/peace/2024/nihon-hidankyo/facts/ [https://perma.cc/VSW7-P9LS] (last visited Feb. 17, 2025).

[6] Michael McCarthy, *Nuclear Bomb Test Fallout May Cause Many US Cancers*, 350 LANCET 415, 415 (1997).

[7] The United States used nuclear weapons against Japan during the Second World War in August of 1945. For an excellent educational explanation of these events, *see generally* History.com Editors, *Bombing of Hiroshima and Nagasaki*, HISTORY (July 31, 2024), https://www.history.com/topics/world-war-ii/bombing-of-hiroshima-and-nagasaki [https://perma.cc/549H-J7UJ].

[8] *See generally* Anton La Guardia, *The Perils of the World's Third Nuclear Age*, ECONOMIST (Nov. 20, 2024) https://www.economist.com/the-world-ahead/2024/11/20/the-perils-of-the-worlds-third-nuclear-age [https://perma.cc/9GND-SQPK] (discussing a new nuclear era with many more armed actors and coexistence of nuclear and high-yield thermonuclear devices).

[9] Thank you to The Reform Club, at whose 104 Pall Mall clubhouse this spirited evening of debate occurred.

[10] *Cf.* Andrew Futter, *Explaining the Nuclear Challenges Posed by Emerging and Disruptive Technology: A Primer for European Policymakers and Professionals*, NON-PROLIFERATION & DISARMAMENT PAPERS, Mar. 2021, at 1 ("It is now unusual to participate in any academic or policy discussion about nuclear issues that does not make reference to the range of technologies that are undermining or might weaken the frameworks for managing nuclear risk."); Noah Smith, *Japan*

intervening decade. Indeed, this is not a position undertaken lightly and is a position the author now supports more fervently than ever. Ten years before that (over twenty years ago now), Morten Maerli, Annette Schaper, and Frank Barnaby argued that the "technical barriers [or secrecy of technical aspects] should not be regarded sufficient to avoid future nuclear terrorism."[11] With each passing year, their argument becomes more prescient; while uranium does not become more prevalent on earth (or meaningfully easier to enrich to weapons-grade levels), knowledge disperses every year to both the benefit of humanity and the detriment of knowledge-focused nuclear arms control frameworks.

It is not a new idea to keep the world safer by sharing knowledge and, in so doing, preventing unneeded detours and experimentation. In 1959, an engineer named Nils Bohlin at Volvo invented the modern three-point seatbelt so familiar to today's motorists.[12] Though Mr. Bohlin's employer, Volvo Personvagnar, applied for and received patents[13] protecting the design, a decision was made to make it available free of charge to any manufacturer.[14] By sharing the three-point seatbelt, Volvo allowed standardization around a safe, tested design and saved an estimated 1,000,000 plus lives globally.[15] In addition, it discouraged duplicative engineering at other firms to invent rival designs and the pain and suffering that no doubt would have accompanied automobile crashes where passengers wore inferior seatbelts. Everyone would benefit from an analogous gain in nuclear safety achieved by sharing safe, tested basic nuclear weapons designs, eliminating the need for iterative nuclear weapons development like that in of first wave nuclear powers during mid-to-late twentieth century.

Broadly, this Article fits into a comprehensive, interdisciplinary

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and South Korea Need Nuclear Weapons: The Case for Controlled, Limited Nuclear Proliferation, NOAHPINION (Feb. 26, 2024), https://www.noahpinion.blog/p/japan-and-south-korea-need-nuclear [https://perma.cc/EDU9-V97L] (noting blog author is a PhD economist and former senior journalist in Bloomberg's Tokyo bureau who argues adding countries to a nuclear-armed list does not exacerbate global risk and may decrease regional geopolitical risk in Asia).

[11] Morton Bremer Maerli et al., *The Characteristics of Nuclear Terrorist Weapons*, 46 AM. BEHAV. SCI. 727, 727 (2003).

[12] Douglas Bell, *Volvo's Gift To The World, Modern Seat Belts Have Saved Millions Of Lives*, FORBES (Aug. 13, 2019, 8:59AM), https://www.forbes.com/sites/douglasbell/2019/08/13/60-years-of-seatbelts-volvos-great-gift-to-the-world/. Note the seatbelt design discussed here is over a decade <u>*newer*</u> technology than nuclear weapons.

[13] *See*, *e.g.*, U.S. Patent No. 3,043,625.

[14] *The Three-Point Safety Belt*, VOLVO GRP., https://www.volvogroup.com/en/about-us/heritage/three-point-safety-belt.html (last visited Apr. 23, 2025).

[15] *The 3-Point Safety Belt Has Saved More Than a Million Lives So Far - It Could Save Over a Hundred Thousand Lives a Year*, VOLVO (Jan. 8, 2009), https://www.media.volvocars.com/us/en-us/media/pressreleases/18406 [https://perma.cc/H2WJ-MF3R].

discussion around nuclear openness and transparency that also includes arguments like Frank von Hippel's long-standing advocacy for more global openness about nuclear testing,[16] *how the "transparency and openness" pillar of the Nuclear Regulatory Commission and Department of Energy's relationship*[17] *should manifest, and the question of whether nuclear devices (reactors, weapons, satellite and space station power units, etc.) should have their designs explained, scrutinized, and improved publicly or privately (secretly)*[18] *and, if the latter, how a sturdy set of global best practices can ever be expected to successfully evolve. To emphasize the importance of openness, the consequences of a secrecy-centric regime are explored in Section V, infra.*

This Article describes how nuclear weapons are designed, produced, stored, maintained, tested, and transported within the United States and touches briefly on how other countries perform these functions. The Article then delves into the core of the argument: the safest way to ensure the number of nuclear weapons used in anger remains at two (and used by accident remains at zero) rather than advancing to some larger number(s) is to make tested, trusted, robust designs for nuclear weapons open-source. The Article next outlines what has happened in recent history in two places, Iran and North Korea, and why these activities pose grave threats both to local populations and global security. Finally, the Article discusses recent events in the Middle East as informative, if not illustratively analogous. In sum, the Article seeks to force the reader to ponder nuclear device design secrecy not as a monolithic proposition, but as a set of trade-offs.

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[16] I generally agree with von Hippel's positions. *See*, *e.g.*, Frank N. von Hippel, *Transparency for Nuclear Weapons Test Sites*, 73 PHYSICS TODAY 10, 11 (2020) ("All 184 signatories to the CTBT would do well to support additional test-site transparency measures . . . ."); *but see* Jeffrey Lewis, *Subcritical Experiments*, ARMS CONTROL WONK (Dec. 20, 2012), https://www.armscontrolwonk.com/archive/206011/subcritical-experiments/ [https://perma.cc/5WPZ-LCME] (advocating for secrecy-aligned policies rather than disclosure-aligned policies).

[17] U.S. NUCLEAR REGUL. COMM'N, INTEGRATED REGULATORY REVIEW SERVICE MISSION TO THE UNITED STATES 1 (2023), https://www.nrc.gov/docs/ML1125/ML112510158.pdf [https://perma.cc/Y4CL-XBCT] ("Since its creation in 1975, the NRC has viewed openness as a critical element for achieving the agency's mission to regulate the Nation's civilian use of radioactive materials and thereby protect people and the environment.").

[18] *Ensuring Nuclear Reactor Designs Meet High Standards of Environmental Protection*, ENV'T AGENCY OF U.K. (Aug. 1, 2024), https://environmentagency.blog.gov.uk/2024/08/01/ensuring-nuclear-reactor-designs-meet-high-standards-of-environmental-protection/ [https://perma.cc/VY97-4CKF] ("The Environment Agency's New Reactors Assessment Team is carrying out assessments of three small modular reactor nuclear power station designs.").

I. INTRODUCTION

The size of nuclear arsenals should be reduced and states should abide by arms control treaties into which they have entered and which are still binding upon them.[19] However, the time has come to focus on control of fissile material and abandon control of basic weapons designs (there are multiple design lineages[20] for nuclear weapons at this point in history and five major design lineages for thermonuclear weapons,[21] not all of which offer the same benefits, yields, safety/storage considerations, or other characteristics). To achieve this

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[19] As to the United States, though reasonable legal scholars disagree on this point, the author believes the Treaty Power requires the Senate's involvement in the making of treaties, but that a President can withdraw from a treaty without notice or Senate approval; George W. Bush's exit from the Anti-Ballistic Missile Treaty in 2002 would be a recent, pertinent example of this. Wade Boese, *U.S. Withdraws From ABM Treaty; Global Response Muted*, ARMS CONT. TODAY (July/Aug. 2002), https://www.armscontrol.org/act/2002-07/news/us-withdraws-abm-treaty-global-response-muted [https://perma.cc/5KVQ-7UJG].

[20] This figure includes the obvious French influence on 1950s-era Israeli reactor and (theoretical) weapons design, post-1970s American influence on Taiwanese (theoretical) weapons design, and British influence on the now-abandoned South African nuclear weapons program (which is a separate lineage, albeit abandoned). The post-Soviet design lineage in Russia can be seen as a continuous arc and the North Korean designs seem very related to the Chinese design lineage, with spherical single-stage fission weapons and two-stage thermonuclear warheads of various yields and warhead profiles. *See* U.S. DEP'T OF DEFENSE, THE EFFECTS OF NUCLEAR WEAPONS 26–132 (Samuel Glasstone & Philip J. Dolan eds., 3d ed. 1977) (noting this was prepared for the Dept. of Defense and Dept. of Energy as standard text whose introductory chapters cover all basic Western and NATO-aligned designs for fission weapons and also includes Asian countries); *see generally* CHUCK HANSEN, U.S. NUCLEAR WEAPONS: THE SECRET HISTORY (1988).

[21] The five figures are based off the original American design, the French design, the two distinct Soviet (and post-Soviet-Russian) lineages of hydrogen bomb design, and the British design, which is arguably a derivative of the American design. These have been written about at some length by both technical authors and historians, and it is impossible to summarize the differences in design approach and device architecture in a footnote in a non-technical piece such as this one. *See generally* RICHARD RHODES, DARK SUN: THE MAKING OF THE HYDROGEN BOMB (1995); Chuck Hansen, *The Swords of Armageddon: U.S. Nuclear Weapons Development Since 1945* (2d ed. 2007) (considered by scholars to be the most comprehensive discussion of nuclear weapons design and development available to civilians).

transition, the posture of the international community must transition from one of secrecy and prohibition to one of shared knowledge and prevention of indigenous nuclear device experimentation and new lineages of devices.[22]

In the context of this article, "prohibition" refers to the policy posture that led to the "born secret" doctrine in the United States.[23] In short, "born secret" means that certain areas of research are so consequential from a national security standpoint that rather than allowing inventions to be created and patented and then sequestered, it is considered preferable from a policy standpoint for these innovations to be considered secret *ab initio*.[24] This doctrine is both enshrined in legislation and defined in fuller form in the somewhat-obscure definition of Restricted Data in the National Industrial Security Program Operating Manual:

> [A]ll data concerning (1) design, manufacture, or utilization of atomic weapons; (2) the production of special nuclear material; or (3) the use of special nuclear material in the production of energy, but shall not include data declassified or removed from the Restricted Data category pursuant to section 142 [of the Atomic Energy Act].[25]

Although the concept of Restricted Data may have been appropriate in the 1940s or 1950s and while some design aspects may still be developing and worthy of secrecy, CNWDI provides guidelines[26] already for this much narrower

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[22] In this Article, "lineages" are seen as originating from major indigenous improvements to design. So, the Israeli adaptation of French sodium-cooled reactors would not be an indigenous design improvement, but significant improvements to the M-51 submarine-launched nuclear system or ASMP-A air-launched nuclear system would create an Israeli lineage of weapons that is distinct and substantially indigenous in origin. Occasionally, things occur outside these lineages when technologies or designs explored initially by one nation are then further iterated upon by another power; an example would be deep research by France into thorium salt breeder reactors as part of that country's France 2030 program which was studied and led to a substantially differentiated lineage of Chinese thorium salt reactor designs, the first of which is a ten-megawatt reactor to be built in the Gobi Desert (the last reactor China built in this design lineage was only twenty percent as powerful, *compare* Emily Waltz & Yu-Tzu Chiu, *Why China is Building a Thorium Molten-Salt Reactor*, IEEE SPECTRUM (Dec. 30, 2024), https://spectrum.ieee.org/chinas-thorium-molten-salt-reactor [https://perma.cc/5GTA-YJ4R], *with France Awards Grants for Molten Salt Reactor R&D*, WORLD NUCLEAR NEWS (Mar. 22, 2024), https://www.world-nuclear-news.org/Articles/France-awards-grants-for-molten-salt-reactor-R-D [https://perma.cc/3V7L-LY3T].

[23] The prohibition of speech regarding nuclear weapons designs and the surrounding areas of science was first discussed in depth by Harold P. Green, who was the Atomic Energy Commission's counsel after WWII and who worked on the Oppenheimer case. He discusses the "born secret" doctrine and the problems, constitutional and otherwise, with its prohibitions. *See generally Harold* P. Green, *Information Control and Atomic Power Development*, 21 LAW & CONTEMP. PROBS. 91 (1956).

[24] *See generally* Justin Myers, *Born a Crime: Nuclear Secrets and Congress's Unconstitutional Infringement on the President's Secrecy Powers*, 21 DARTMOUTH L.J. 1 (2025).

[25] Atomic Energy Act of 1954, 42 U.S.C. §§ 2274–2277 (2018).

[26] Critical Nuclear Weapon Design Information, a narrow information category regularly examined and revised by the Department of Defense, is separate from the broad "born secret" rule the Department of Energy created and which it may not even be able to enforce. For details on why the broad concept of "born secret" may be invalid as a prior restraint matter, *see United States v. Progressive Inc.*, 467 F. Supp. 990 (W.D. Wis. 1979) (resulting in ambiguity regarding to what extent

pool of knowledge. On the other hand, arguably, the proliferation of the basic best practices of designing and assembling nuclear devices poses little threat to society at large while saving millions of people from being exposed to the risks of living near nuclear device development.

Through casual conversation, scholastic curiosity, international co-authorship, and typical intellectual promiscuity people with a working knowledge of physics and a curiosity about nuclear devices may unknowingly commit substantial crimes under the Atomic Energy Act.[27] Indeed, if one takes the "born secret" doctrine seriously and also takes the plain meaning of the provision *supra* literally, an undergraduate-level classroom discussion involving a crude diagram of a nuclear device on a chalkboard might subject the professor to criminal sanctions.[28]

Further, it is unclear what kinds of scientific discussions, especially if they involve collaborators at foreign universities[29] or researchers at foreign companies, might become criminal. It may not even be in a science department where these at-least-theoretically *verboten* discussions might occur. When studying at the University of Chicago, the author attended a philosophy and ethics lecture related to the ethics of building a "doomsday device," meaning a Kahn-esque[30] machine designed to eliminate life on earth; such discussions almost always involve building thermonuclear hydrogen bombs of arbitrarily large sizes.[31]

Today, it may actually—albeit counterintuitively—make the world safer to make the basic knowledge about the safe construction of nuclear weapons public,

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the Department of Energy can restrain speech, including scientific or even casual or journalistic discussion of nuclear weapon designs).

[27] 42 U.S.C. §§ 2274–2277 (imposing criminal sanctions on people who share, disclose, or irresponsibly handle nuclear secrets).

[28] The "born secret" doctrine essentially makes nuclear weapons technology secret *ab initio* and *inter omnia*. Law and policy scholar Howard Morland famously, and correctly, argued this amounts to a permanent, omnipresent gag order on anyone with knowledge of how to construct nuclear devices. *See generally* Howard Morland, *Born Secret*, 26 CARDOZO L. REV. 1401 (2005) (arguing "born secret" doctrine creates substantial prior restraint problem and possibly other problems of serious constitutional concern).

[29] In 1982, researchers Sagie and Glass published their work on how to generate small quantities of fusion plasmas, an important substance to study in physics, astronomy, and other areas, including advanced materials science. This work was completed at, and published by, the University of Toronto; however, U.S. universities might have been timid to publish it as the techniques described (particularly on pages 9 and 14) could also be used to make atomic weapons. *See* D. SAGIE & I. I. GLASS, EXPLOSIVE-DRIVEN HEMISPHERICAL IMPLOSIONS FOR GENERATING FUSION PLASMAS 9, 14 (1982), https://apps.dtic.mil/sti/pdfs/ADA121652.pdf [https://perma.cc/WWN4-JHDT].

[30] Herman Kahn wrote several papers for the RAND Corporation, theorizing that a series of large thermonuclear weapons linked to a computerized trigger could ensure that the Earth would be uninhabitable in the event of a Soviet first strike. *See generally* HERMAN KAHN & EVAN JONES, ON THERMONUCLEAR WAR (Routledge 2017) (1962).

[31] The 1954 Castle Bravo test empirically demonstrated the possibility of designing and building thermonuclear weapons of essentially any practically imaginable size and yield; Castle Bravo was a 15-megaton 1954 nuclear test in the central lagoon of a circular archipelago in the western Pacific Ocean. *Castle BRAVO at 70: The Worst Nuclear Test in U.S. History*, NAT'L SEC. ARCHIVE, https://nsarchive.gwu.edu/briefing-book/nuclear-vault/2024-02-29/castle-bravo-70-worst-nuclear-test-us-history (last visited Apr. 30, 2025).

as this renders unnecessary the most dangerous stage of knowledge development likely to be approached empirically.[32]

> We decided long ago that the dangers of excessive and unwarranted concealment of pertinent facts far outweighed the dangers which are cited to justify it . . . [a]nd there is very grave danger that an announced need for increased security will be seized upon by those anxious to expand its meaning to the very limits of official censorship and concealment. That I do not intend to permit to the extent that it is in my control. And no official of my Administration, whether his rank is high or low, civilian or military, should interpret my words here tonight as an excuse to . . . withhold from the press and the public the facts they deserve to know.[33]

The materials to construct a nuclear weapon are exotic and rare, but the basic architecture of the weapon system itself is relatively simple.[34] To keep what is fundamentally 1940s technology classified in even its most general design specification is like trying to keep the design of a microwave oven secret forever,[35] yet this is precisely the prevailing policy approach with the prevailing policy framework. The analogy is not a joke or exaggeration; the microwave oven wasn't invented until three years after the first nuclear reactor was built at the University of Chicago.[36]

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[32] Empirically, meaning in a research arc requiring detonation of nuclear devices for testing and confirmation, as opposed to theoretical or computer-simulated exploration of nuclear device development.

[33] John F. Kennedy, The President Addresses the American Newspaper Publishers' Association (Apr. 27, 1961) (transcript available at John F. Kennedy Presidential Library and Museum, original handwritten remarks archived in Harvard's library system, 79 John F. Kennedy Street, Cambridge, MA). Kennedy was referring to the general environment of secrecy, not to nuclear secrets in particular, but the principles stated are broadly applicable to any scenario where the "excessive and unwarranted concealment of pertinent facts" is supposedly justified by a topic or technology having a "need for increased security."

[34] Donald MacKenzie & Graham Spinardi, *Tacit Knowledge, Weapons Design, and the Uninvention of Nuclear Weapons*, 101 AM. J. SOCIO. 44, 48–50 (1995) (explaining how important design knowledge regarding nuclear weapons resides primarily in humans who guard these secrets jealously, not government files or impenetrable computer systems).

[35] The first patent for a microwave oven was not filed until after nuclear devices had been dropped on Hiroshima and Nagasaki; countertop microwave ovens weren't available until the mid-1960s at a then-very costly $5,000. The first patent for a microwave oven was dated October 8, 1945 (*see* U.S. Patent No. 2,495,429).

[36] Percy Spencer invented the microwave oven in 1945 while employed at Raytheon; this was three years after the famous first self-sustaining nuclear reaction at the University of Chicago on December 2, 1942. An early microwave oven can be seen at Raytheon's Woburn, Massachusetts research building, where it sits near the building cafeteria. Those interested can learn more about the CP-1 reactor at the University of Chicago by visiting the site of the reactor at 5625 South Ellis Ave. on the University of Chicago's campus; it is one of my favorite places to take students on campus tours and features a wonderful sculpture by Henry Moore. None of this work was lucrative, with Spencer being paid only two dollars for the patent on the microwave and physics graduate students working at the reactor site in Chicago while being paid thirty cents an hour for their time (which was the minimum wage in 1942 and the prevailing wage at the University of Chicago for lab assistants during WWII).

To appreciate the difficulty of keeping these technologies secret,[37] consider that certain nuclear experiments have now become scout troop challenges and high school science fair topics. Teenager David Hahn (who would later serve aboard the nuclear aircraft carrier USS Enterprise) built a breeder reactor in his mother's garden shed in an (unusually dangerous and somewhat misguided) attempt to earn a "nuclear energy" merit badge from his local scout troop; Taylor Wilson, another teenager harboring ambitions unrelated to Hahn's forays into teenaged nuclear science, built a functional, dangerous nuclear device at age fourteen.[38] Though France has been more open about its weapons designs,[39] in part because of its population's oscillation[40] as to the idea of anything nuclear

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[37] *See generally* Robert Harney et al., *Anatomy of a Project to Produce a First Nuclear Weapon*, 14 SCI. & GLOB. SEC. 163 (2006).

[38] In 2008, a young man named Taylor Wilson became the youngest person to build a working Farnsworth-lineage nuclear fusion device at age 14. Years earlier, David Hahn, a teenager at the time, successfully built a neutron source (breeder reactor) in his mother's potting shed; Hahn's experiments were sophisticated enough that he also enriched thorium to a level >9,000 times purer than any known incidence in the natural universe. Stuff You Should Know, *The Story of the Nuclear Boy Scout*, HEART RADIO (Feb. 22, 2024), https://www.iheart.com/podcast/1119-stuff-you-should-know-26940277/episode/the-story-of-the-nuclear-boy-153155060/ [https://perma.cc/BQ3B-YLUA].

[39] Including the development, cost to taxpayers, and production volume of the TN81 thermonuclear system. *See, e.g.*, Loi 2013-1168 du 18 décembre 2013 relative à la programmation militaire pour les années 2014 à 2019 et portant diverses dispositions concernant la défense et la sécurité nationale [Law No. 2013-1168 of December 18 2013 on Military Programming for 2014 to 2019 and Supporting Various Placements Concerning Defense and National Security], JOURNAL OFFICIEL DE LA REPUBLIQUE FRANÇAISE [J.O.] [OFFICIAL GAZETTE OF FRANCE], Dec. 19, 2013, art. 1.; *Projet de loi de Finances des Armées 2023—LPM année 5 [Draft Armed Forces Finance Bill 2023 - LPM year 5]*, MINISTÈRE DES ARMÉES (2023), https://www.defense.gouv.fr/sites/default/files/ministere-armees/Projet%20de%20loi%20de%20finances%20-%202023%20-%20LPM%20ann%C3%A9e%205.pdf [https://perma.cc/ND2Y-4AXQ] (entailing a detailed discussion of budgeting, including addenda discussing nuclear-weapons-related projects).

[40] France's resistance to adopting, maintaining, or scuttling nuclear technology has oscillated substantially over the years. On September 24, 2009, France (along with the other four signatories to the Non-Proliferation Treaty) pledged to move toward "a world without nuclear weapons" consistent with Article IV of the Treaty, and with President Sarkozy's comments on March 21, 2008—and again on June 17 of that year—each time promising the French nuclear arsenal would be reduced to under 300 warheads. *See generally* Treaty on the Non-Proliferation of Nuclear Weapons art. 4, July 1, 1968, 729 U.N.T.S. 161 (being executed by various signatories on various summer 1968 dates in Western European capitals, Moscow, and Washington, D.C.); *see also* Robert S. Norris & Hans M. Kristensen, *French Nuclear Forces, 2008*, 64 BULLETIN ATOM. SCIENTISTS 52, 54-55 (2008). But only one year later, President Sarkozy said, "Deterrence remains for France an absolute imperative. Nuclear deterrence is for us the Nation's life insurance policy." *See Latest Vintage from Champagne: New Rafale Jets Now Carrying New ASMP-A Missiles and New TNA Nuclear Warheads!*, ACTION OF CITIZENS FOR NUCLEAR DISARMAMENT (July 5, 2010), https://www.acdn.net/spip/IMG/article_PDF/Latest-Vintage-from-Champagne-New_a636.pdf [https://perma.cc/M8ZM-3JYH] Note that President Macron has since echoed Sarkozy's goal of "under 300 nuclear weapons," most recently on February 7, 2020, but it is unclear what this means incrementally or in terms of near-term disarmament policy. *See* Hans. M. Kristensen et al., *French Nuclear Weapons, 2023*, 79 BULLETIN ATOM. SCIENTISTS 272, 274 (2023); *see also* Jean-Louis Lozier, *French Nuclear Policy*, INT'L CTR. DEFENCE & SEC. 1 (Jan. 2023), https://icds.ee/wp-content/uploads/dlm_uploads/2023/01/ICDS_Brief_French_Nuclear_Policy_Jean-Louis_Lozier_January_2023.pdf [https://perma.cc/44GN-9J6U] ("France's nuclear deterrence has been the main pillar of its defence strategy for about sixty years."); *French Nuclear Weapons Policy and Black Swans*, CTR. ARMS CTRL. & NON-PROLIFERATION BULLETINS (Apr. 23, 2010), https://armscontrolcenter.org/french-nuclear-weapons-policy-and-black-swans/

for any use case, it has never published schematics or specifics for the weapon types presumably carried by the nuclear submarine in the Atlantic that is the de facto flagship of France's *force de dissuasion*.[41] France has, however, made several disclosures about early designs, as the fourth country to develop nuclear weapons.[42] And the minutes of meetings between French[43] and Israeli scientists in 1949[44] at the Saclay Nuclear Research Centre are often studied by diplomacy, international law, physics, and policy students and are sometimes cited as the origin point for the Israeli nuclear program.[45] While strict controls should

[https://perma.cc/D4W5-HFZU] ("France relied on a triad of air, land and sea based nuclear weapons for its deterrence until 1996, when President Chirac announced the retirement of France's land-based missile facilities.").

[41] This doctrine requires one nuclear-powered, nuclear-armed submarine to always remain present in the Atlantic (France has four such submarines). The United Kingdom has a similar policy. *See* Sam Francis, *Starmer Says He is Prepared to Use Nuclear Weapons*, BBC (June 3, 2024), https://www.bbc.com/news/articles/czvvy0ppdxko [https://perma.cc/W4KL-GBEV].

[42] The degree of enthusiasm among scientists and historians, particularly military historians, for the French nuclear program varies enormously, and is correlated with the nationality of the observer. For a critique of French origin, *see generally* Benoît Pelopidas & Sébastien Philippe, *Unfit for Purpose: Reassessing the Development and Deployment of French Nuclear Weapons,* 21 ROUTLEDGE TAYLOR & FRANCIS GRP. 243, (2023). For a more upbeat assessment, albeit a semi-autobiographical one, *see Lancement d'un missile balistique stratégique M51 [Launch of an M51 Strategic Ballistic Missile],* MINISTÈRE DES ARMÉES (Apr. 20, 2023), https://www.defense.gouv.fr/marine/actualites/lancement-dun-missile-balistique-strategique-m51 [https://perma.cc/CQL7-SJDM].

[43] The history of the French nuclear program is deserving of, and has received, substantial scholarship in a separate lineage of political history. For a succinct discussion of France's initial energy and stalling ambitions, *see generally* The Editorial Staff, *La politique du nucléaire civil : chronologie de 1952 à 2024 [Civil Nuclear Policy: Timeline From 1952 to 2024]*, FR. REPUBLIC VIE PUBLIQUE, https://www.vie-publique.fr/eclairage/271540-la-politique-du-nucleaire-civil-chronologie-1952-2024 [https://perma.cc/K79U-LFNJ] (Sep. 3, 2024). For a more lengthy and scholarly accounting of events and policies during different periods, *see generally* Felix Torres, *Le système nucléaire français des années 1950 à nos jours, acteurs et structures: Une mise en perspective [The French Nuclear System from the 1950s to the Present Day, Actors and Structures: A Perspective]*, 634 LA REVUE DE L'ÉNERGIE 76 (2016).

[44] This meeting created the first bits of the scientific canon that would be expanded upon in the 1950s as Prime Minister Ben Gurion formally established a nuclear weapons program in Israel in that decade as an ultimate deterrent. *See* AVNER COHEN, ISRAEL AND THE BOMB 48 (1998).

[45] The cross-pollination of French nuclear knowledge to Israel likely did not originate from some deep initial affection for the new state of Israel among the French; rather, it likely stemmed from French ambition to sell Israel a sodium-cooled reactor and the experience of shared defeat in the 1956 Suez crisis (as well as both having been excluded from American-British nuclear technology collaborations). *See* JULIAN SCHOFIELD, STRATEGIC NUCLEAR SHARING 50–58 (Jim Whitman ed., 2014). For more information on the French technology available during different periods for sharing with (or secrecy from) the Israelis, *see generally* M. Duval & D. Mongin, *Histoire des Forces Nucleaires Francaises Depuis 1945 [History of French Nuclear Forces Since 1945],* 59 POLITIQUE ÉTRANGÈRE 288, 290, (1994). For the Israeli view of the same period and issues, including technology transfer from France, *see generally* Schlomo Aronson's excellent writing on the topic: SCHLOMO ARONSON, THE POLITICS AND STRATEGY OF NUCLEAR WEAPONS IN THE MIDDLE EAST: OPACITY, THEORY, AND REALITY, 1960–1991, AN ISRAELI PERSPECTIVE (1992).

remain on the key ingredients needed to create, build, and maintain a nuclear arsenal, basic designs[46] should be freely available.[47]

II. WHAT "OPEN-SOURCE NUKES" MEANS

The idea of "open-source nukes" is not that everyone should have nuclear weapons; not at all. Rather, the idea is that states seeking to construct nuclear weapons should do so safely and use designs that are known, both through theoretical soundness and empirical testing, to function properly and endanger as few non-targets as possible. Considerations include ease of storage and maintenance,[48] risk during transportation or in volatile situations, and use of fusing and fail-safe trigger assemblies and not prone to "open circuit fire"[49] Open-source nukes means nukes one may find in an online archive that includes behind-the-state-of-the-art-but-very-safe nuclear weapon design schematics. In essence, this is a best practice archive of nuclear weapons construction that would feature a variety of designs optimized for safety and transportability.

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[46] It is very hard for a nation with little test data from other nations and little experience empirically measuring nuclear device yields to accurately and consistently predict yields. Unfortunately, this also means that any serious program will likely involve extensive weapons testing. RICHARD RHODES, THE MAKING OF THE ATOMIC BOMB 170–178 (1986) (discussing difficulty estimating yields *ex ante*).

[47] All nuclear device design discussions are theoretically "born secret" and governed by that doctrine, which creates "a permanent gag order" stopping anyone from discussing details of nuclear devices or their construction, *see* Morland, *supra* note 25, at 1401. Multiple scholars have critiqued this doctrine as untenable, *see generally* Ian M. Dumain, *No Secret, No Defense: United States v. Progressive*, 26 CARDOZO L. REV. 1323 (2004) (discussing Morland's earlier argument in detail). Robert A. Rosenbaum et al., *Government Censorship and Academic Freedom*, 69 ACADEME 15a, 15a (1983). At least in theory, an undergraduate physics professor who draws a cartoonish diagram of a nuclear weapon on a blackboard, despite this being *publicly-well-understood and unclassified information*, might be violating multiple rules and regulations regarding sensitive information: "A regulation proposed by the Department of Energy to require any holder of *unclassified information relating to nuclear energy* to assure the government that this information is protected in a manner similar to other restricted materials in its possession." (emphasis added). *See also Presidential Directive on Safeguarding National Security Information*, DEP'T OF JUST. (Mar. 1983), https://www.cia.gov/readingroom/docs/CIA-RDP89B00236R000300270022-8.pdf [https://perma.cc/4BDX-6BT5] (noting it effectively classifies previously public information due to content). Difficulties in discussing nuclear and high-energy physics due to fear of prosecution or government intervention are not theoretical. *See* Sarah Scoles, *Navigating a Career in Secret Physics*, PHYSICS TODAY (Nov. 7, 2019), https://pubs.aip.org/physicstoday/online/5748 [https://perma.cc/AP6L-HXLZ] (discussing the inability to publish research as a deterrent for some to accept positions at certain facilities, laboratories, and universities and also discussing U.S. tendency toward overclassification of even now-well-understood designs and technologies).

[48] Aaron Mehta, *US Completes $9B B61-12 Nuclear Warhead Upgrade*, BREAKING DEFENSE (Jan. 7, 2025), https://breakingdefense.com/2025/01/us-completes-9b-b61-12-nuclear-warhead-upgrade/ [https://perma.cc/N766-PKRD] (noting the American nuclear arsenal goes through constant cycles of monitoring, maintenance, and upgrade. The most recent update was a nine-billion-dollar overhaul and upgrade of nuclear warheads, which was successfully completed.).

[49] For an in-depth discussion of why these rudimentary considerations are so important (and are vulnerable to surprisingly varied solutions from a technical standpoint) *see generally* ROBERT S. NORRIS ET AL., NUCLEAR WEAPONS DATABOOK, VOL. V, BRITISH, FRENCH, AND CHINESE NUCLEAR WEAPONS (1994). The possibility of an "open circuit fire," meaning a trigger on the primary conventional charge in the weapon might be vulnerable to firing when not intended, was investigated as part of the investigation of the Palomares and Thule nuclear accidents, which were both incidents in which nuclear weapons of American design and manufacture had their

Fringe groups, lobbying groups, journalists, and conspiracy theorists have propagandized fear over concerns of nuclear accidents or shadowy nuclear arms deals.[50] However, the proliferation of usable, weapons-grade fissile material is largely fiction and fantasy,[51] not policy and politics. The prevailing secrecy and intrigue surrounding nuclear weapons designs, inventories, and development interferes with efforts to keep the global community informed about real threats.

A. What Would the "Open-Source Nuke Archive" Contain?

The archive, as envisioned, would contain basic designs for warheads, fuses/triggers, warhead sleeve elements that allow the weapon to be inserted into a missile fuselage or other delivery system, access ports and maintenance "keyholes," and also architectural drawings of storage rooms/buildings, manufacturing equipment, and maintenance facilities. [52] Finally, the archive would include a series of supplemental documents able to instruct a person of reasonable acumen how to avoid major malfunctions or problems.

Importantly, the open-source archive would only contain plans for nuclear weapons and would specifically not include designs for higher-yield thermonuclear weapons. It would contain detailed descriptions of specific pieces of mechanisms useful to people with ordinary training in the relevant field, design trade-offs that might influence the selection of some designs over others, and relevant warnings about designs or design elements that have been discovered to be unstable, unsafe, or obsolete.

B. What Is an Architectural Versus Ingredient Mode of Constraint?

There are two regulatory schema, which operate as competing, non-exclusive control vectors, that can be used to make something scarce. They can be thought

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[50] Various provocateurs have signaled to the public that nuclear weapons technology is more mobile, more merchantable, or more manufacturable than most experts typically believe; examples include mainstream media outlets stoking fear Russia might sell weapons from its arsenal to Iraq, Iran, North Korea, or Nigeria and lobbyist types raising the possibility of a nuclear black market for weapons of the kind often depicted in *Mission: Impossible* or James Bond films, despite little evidence from intelligence officials, academic experts, or economists that such markets exist or have reason to exist, given the implications of a purchased weapon's use as a threat or bargaining chip, let alone as a battlefield or terrorism tool. *See* Joseph E. Stiglitz, *Nukes for Sale*, FORBES (June 19, 2013), https://www.forbes.com/forbes/2002/0527/054.html [https://perma.cc/HRH4-X6K9]; The *Nuclear Black Market,* Ctr. for Strategic & Int'l Stud., https://www.csis.org/programs/former-programs/warfare-irregular-threats-and-terrorism-program-archives/nuclear-black-market [https://perma.cc/2J3A-37C2].

[51] *See generally* Karl Muth & Daniel Wang, *Agent 007: A License to Bill*, 15 HARV. J. SPORTS & ENT. L. 333 (2024).

[52] *See* Todd Postma, *Documentation and Diagrams of the Atomic Bomb*, U.C. BERKELEY LIBR. ARCHIVES (1998), https://people.csail.mit.edu/boris/nuc-bomb.html#III.H [https://perma.cc/C4J8-M27D] (noting critical role fuse design and fuse placement play); *see generally* MARK WOLVERTON, NUCLEAR WEAPONS 148, Fig. 10 (2022) (noting long-range bomber delivery); PETER A. GOETZ, A TECHNICAL HISTORY OF AMERICA'S NUCLEAR WEAPONS at Vol 2., (2d ed. 2020); RHODES, *supra* note 47 (noting there is no reliable source of information allowing an average person to safely embark on weapons assembly without the need for testing).

of broadly as scarcity and secrecy.[53] If one wanted to prevent people from making Chicago-style hot dogs, one could try to destroy or classify all knowledge about how to make Chicago-style dogs or could try to restrict access to sweet pickle relish, spicy capsicum annuum, chopped white onions, and other essential ingredients. Restricting hot dog making knowledge would be a "secrecy" or "architectural" constraint while restricting the hot dog condiments would be a "scarcity" or "ingredient" constraint. This conceptual taxonomy was likely first discussed by Larsen and Smith in their 2005 doctrinal volume,[54] but is now commonly used both in the discussion of nuclear weapons and in other contexts where both know-how and physical ingredients might be subject to sanctions or restrictions.[55]

The first schema is to restrict access to the ingredients needed to manufacture the thing and the second schema is to restrict access to the knowledge, designs, or engineering elements needed to manufacture the thing. In the case of nuclear weapons, it is not practical to forever restrict the knowledge needed to build a nuclear weapon (nor the nuclear ambitions of all states), but it is possible to spread knowledge that will make the weapons created as safe as possible to produce, handle, store, and (but hopefully not) use. Thanks to the Internet and other advances, knowledge flows more freely, predictably, and with fewer realistic prohibitions than in 1946.[56] In a world of free-flowing knowledge, an architectural mode of constraint (limiting basic knowledge about how to build nuclear weapons) is not only impracticable, it may actually make the world less safe, as argued using the real-world examples of rogue state development efforts in Parts V (a), (b). Meanwhile, an ingredient mode of constraint is highly desirable and should continue to be a top priority, especially as usable fissile material reasonably close to the Earth's surface at significant purity ratios is relatively rare and its occurrence is somewhat

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[53] This is true of nuclear, biological, and chemical weapons, but most interesting in the case of nuclear weapons, as the ingredients involved are legitimately rare and with few substitutes; uranium has unusual properties and ready substitutes have not (yet) been discovered. *See generally* G.H. Lander et al., *The Solid-State Properties of Uranium*, 43 ADVANCES IN PHYSICS 1 (1994). As a result, the ingredients for nuclear weapons are far easier to control than the basic knowledge needed to build nuclear weapons, which can nowadays be sent around the world via e-mail; to better understand the naturally occurring locations of substantial uranium deposits and its inaccessibility due to rarity, *see generally* Patrice Bruneton & Michel Cuney, *Geology of Uranium Deposits*, *in* URANIUM FOR NUCLEAR POWER. 11, 54 (Ian Hore-Lacy ed. 2016).

[54] *See* JEFFREY A. LARSEN & JAMES M. SMITH, A HISTORICAL DICTIONARY OF ARMS CONTROL AND DISARMAMENT at 26, 130–131, 180 (2005).

[55] *See*, *e.g.*, Götz Neuneck, *The Deep Crisis of Nuclear Arms Control and Disarmament: The State of Play and the Challenges*, 2 J. PEACE & NUCLEAR DISARMAMENT 431, 437–39 (2019) (discussing secrecy/scarcity or knowledge/ingredients dichotomy in context of fission weapons); *see also* Manuel Herrera, *The European Union and the Treaty on the Prohibition of Nuclear Weapons: Let's Agree that We Disagree*, 36 PEACE REV. 323, 325–26 (2024) (discussing secrecy vs. scarcity dichotomy as diplomatic impasse); Kjølv Egeland, *A Theory of Nuclear Disarmament: Cases, Analogies, and the Role of the Non-Proliferation Regime*, 43 CONTEMP. SEC. POL'Y 106, 108–11 (2022) (drawing conclusions by applying similar framework to specific historical contexts).

[56] *See* Atomic Energy Act of 1946, Pub. L. No. 79-585, 60 Stat. 755.

predictable.[57] Finally, there is essentially no large commercial market for enriched fissile material (let alone completed weapons, despite many James Bond, Jack Ryan, and *Mission: Impossible* plotlines to the contrary), so material discovered generally[58] is not shipped around the world for pecuniary gain or available for purchase (even for well-heeled terrorist organizations).[59]

C. Where Is Fissile Material Located On Earth?

Nearly all scholars taken seriously on the topic of nuclear materials exploration (whether for nuclear energy or nuclear weapons uses) cite that the lack of nuclear-armed conflict in the world since the 1940s has something to do with the natural allocation of fissile material around the world.[60] Uranium, which is the main element of concern, is not evenly distributed on Earth.[61] On the contrary, the relatively small country of Kazakhstan accounts for more than 40 percent[62] of the known uranium deposits.[63] Namibia and Uzbekistan also

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[57] *See generally cf.* Anouk S. Rigterink, *Natural Resources and Civil Conflict*, 5 ECON. PEACE & SEC. J. 17 (2010).

[58] *See* Jay Ganglani, *Alleged Yakuza Leader Admits Trafficking Nuclear Materials from Myanmar*, CNN (Jan. 9, 2025, 12:35 AM), https://www.cnn.com/2025/01/09/us/myanmar-yakuza-uranium-smuggling-us-hnk-intl/index.html [https://perma.cc/35WX-J242] (noting that, while extremely rare, trafficking in fissile material is not impossible or unprecedented).

[59] *See generally* Keir A. Lieber & Daryl G. Press, *Why States Won't Give Nuclear Weapons to Terrorists*, 38 INT'L SEC. 80 (2013).

[60] *See generally* Jane A. Plant et al., *Uranium Ore Deposits – Products of the Radioactive Earth*, 38 REV. MINERALOGY 255 (1999); Michel Cuney, *Uranium and Thorium: The Extreme Diversity of the Resources of the World's Energy Minerals*, *in* NON-RENEWABLE RESOURCE ISSUES: GEOSCIENTIFIC AND SOCIETAL CHALLENGES 91(Richard Sinding Larsen & Friedrich W. Wellmer eds., 2012); *see also* Richard Rhodes & Denis Beller, *The Need for Nuclear Power: Viewpoint on the World's Challenging Energy Future,* 42 J. INT'L ATOMIC ENERGY AGENCY BULL. 43, 43–50 (2000).

[61] The International Atomic Energy Agency performs, among other surveys, a survey of the worldwide distribution of uranium deposits and has since the early days of the Agency; the most recent survey was published in 1995 and no geopolitically-significant known major deposits have appeared since 1995, with the largest recent known major deposit being discovered in the Australian outback in 1993. *World Distribution of Uranium Deposits,* INT'L ATOMIC ENERGY AGENCY (2018) (describing contemporary empirical findings and historical findings of earlier reports), https://www.iaea.org/publications/12314/world-distribution-of-uranium-deposits [https://perma.cc/4LQ8-G358].

[62] Though the amount of uranium on Earth is fixed and some subset of that is reachable by conventional, known mining techniques, uranium does vary in value like all metal commodities and these prices primarily respond not to new discoveries (which are exceedingly rare) but rather to export controls or limitations on the sale of existing supplies. Despite occupying only 1.83% (2,724,900 km² / 148,940,000 km² x 100) of the world's land mass, Kazakhstan represents 43% of known uranium supply. *See generally*, *e.g.,* Jed Graham, *Uranium Stocks Jump on Supply Fears; World's Top Producer Halts Cameco Project*, INV. BUS. DAILY (Jan. 2, 2025, 4:15 PM), https://www.investors.com/news/uranium-stocks-cameco-venutre-kazakhstan-halted-ccj/ [https://perma.cc/AX27-5TAF].

[63] *See* Bruneton & Cuney, *supra* note 55, at 11. However, substantial amounts of uranium exist in other countries. Saudi Arabia recently announced plans to mine and sell uranium openly on the world market, causing some to worry about material control and monitoring integrity. *See* W. Dahdouh, *Saudi Arabia Announces Plans to Enrich and Sell Uranium*, AL JAZEERA (Jan. 14, 2025), https://www.aljazeera.com/news/2025/1/14/saudi-arabia-announces-plans-to-enrich-and-sell-uranium [https://perma.cc/L73X-4SGP].

have non-negligible amounts of uranium.[64] The Colorado plateau (which, despite its name, stretches between Colorado, Utah, New Mexico, and Arizona in the so-called "four-corners" region) has substantial theoretical deposits, though some have posited deep uranium deposits below several miles of mixed rock (as is true on the Colorado plateau)[65] may not be reachable with current exploration technology.[66]

D. Why Do "Dirty Bombs" Fall Outside This Constraint Regime?

Dirty bombs are poorly defined but, as understood in the mainstream and in journalistic parlance, are not strictly nuclear devices.[67] Rather, they are typically conventional devices purposefully contaminated with materials that make an area unpleasant to occupy, which may include radioactive material (including radioactive waste salvaged for illicit use from medical/chemotherapy processes or industrial machinery or power plants)[68] but also can contain chemical contaminants (toxins) or other agents robust to violent distribution (for instance, anthrax and smallpox can be packaged for aerosol dispersal by explosive means).[69] The first "dirty bomb" was probably a diseased cadaver floated down a river toward an enemy encampment, and, a thousand years later, was hurled by catapult over a castle wall.[70]

The goal of dirty bombs has not changed much since their inception;[71] dirty bombs do not generally do maximum concussive/explosive damage but do make

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[64] *See generally Geological Classification of Uranium Deposits and Description of Selected Examples*, INT'L ATOMIC ENERGY AGENCY 1, 14–15, 21, 104 (Apr. 2018), https://www-pub.iaea.org/MTCD/Publications/PDF/TE1842_web.pdf [https://perma.cc/Z8VS-BPLD].

[65] The plateau is a mixture of sandstone, shale, limestone, and granite that is notoriously difficult to penetrate with tunneling and blasting techniques. Hydraulic fracturing combined with horizontal (lateral) drilling has been used to locate and extract small amounts of uranium, but at enormous exploration expense. Currently, over 1500 uranium deposits/districts were listed in the IAEA World Distribution of Uranium Deposits database and five are on, under, or adjacent to the Colorado plateau area. *See id*. at 192, 240, 250–274 (describing type of deposits prevalent in Western United States).

[66] Even the most sophisticated current axial drilling technologies have serious constraints when asked to explore deep in hard rock (such as granite) at oblique angles far from the surface. Zhaowei Sun et al., *Hard Rock Drilling Characteristics Under Axial-Torsional Isofrequency Impact: Insights for Improving Efficiency of Deep Energy Mineral Excavation*, GEOENERGY SCI. & ENG., June 27, 2024, at 1, [https://perma.cc/BHZ3-SFQD] (empirical study illustrates limitations of current technology in breaking through rock to reach buried energy-relevant materials).

[67] Alexis Rump et al., *Medical Management of Victims Contaminated with Radionuclides After a "Dirty Bomb" Attack*, 5 MIL. MED. RES. 27, 28 (2018) (distinguishing between nuclear attacks and conventional acts that spread nuclear material without nuclear detonation).

[68] *Id*. at 27–29.

[69] LEON GRAY, DIRTY BOMBS AND SHELL SHOCK: BIOLOGY GOES TO WAR 43 (2018) (discussing using conventional explosives to spread infectious agents including anthrax).

[70] *See History of Biowarfare*, PBS, https://www.pbs.org/wgbh/nova/sciencenow/0401/02-hist-01.html [https://perma.cc/HC3E-D86E] (last visited Feb. 17, 2025).

[71] *Backgrounder on Dirty Bombs*, U.S. NUCLEAR REGUL. COMM'N (Feb. 23, 2022), https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-dirty-bombs.html [https://perma.cc/6G6R-V57L].

an area difficult to inhabit[72] or costly to clean up.[73] Explosives are the common distribution system, but a "dirty bomb" need not go "boom" when activated; in the broadest "martial contaminant" sense, it could be a pneumatic/aerosol non-explosive device or even a dissolvable poison placed in a town's water supply.[74] Because modern explosive dirty bombs at their simplest might be a conventional pipe bomb containing dynamite united with a packet of hazardous material,[75] they do not have the design or effect of a nuclear weapon. Nor do they aspire to have a similar effect. Rather, they may contain hazardous materials (nuclear or otherwise) to be spread by the principal explosion. As a result, they cannot be constrained by architectural constraint because there is no fundamental similarity in dirty bomb architecture.[76] Instead, they must be constrained by traditional policework and monitoring materials of interest or devices that arouse suspicion.[77]

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[72] This is broadly a tactic to deny enemy forces access to an area. *See* Maj. Kirk Shoemaker, *Avoiding Strategic Miscalculation*, USANCA 38–40, https://www.usanca.army.mil/LinkClick.aspx?fileticket=h5caswaesNE%3D&portalid=114 [https://perma.cc/3DRN-R7E9] (discussing U.S. Army readiness to fight and win in intentionally contaminated battlespaces).

[73] Noah D. Lichtenstein, *The Hanford Nuclear Waste Site: A Legacy of Risk, Cost, and Inefficiency*, 44 NAT. RESOURCES J. 809, 809–10 (2004) ("Today, large quantities of these radioactive substances have been detected in the ground water beneath the site, contaminating the water that feeds the Columbia River. Faced with this enormous threat to personal and environmental safety, the federal government is now struggling with financing and implementing the estimated 50-year, $60 billion remediation plan—the largest and most expensive environ mental cleanup project in history.") (internal citations omitted).

[74] For a discussion of such attacks, *see generally* JONATHAN MEDALIA, CONG. RSCH. SERV., RL32595, NUCLEAR TERRORISM: A BRIEF REVIEW OF THREATS AND RESPONSES (2004). In two London attacks, hazardous solids were dissolved in innocuous substances (perfume and tea, respectively); *see Ex-Spy Skripal Was a 'Sitting Duck,' Inquiry Told*, BBC News (Dec. 2, 2024), https://www.bbc.com/news/articles/cj6z2d7xnnro [https://perma.cc/4DAW-FE3K]; *see also* Luke Harding, *Alexander Litvinenko and the Most Radioactive Towel in History*, THE GUARDIAN (Mar. 6, 2016, 1:00PM), https://www.theguardian.com/world/2016/mar/06/alexander-litvinenko-and-the-most-radioactive-towel-in-history [https://perma.cc/9KE9-6ZXC].

[75] *Dirty Bombs*, U.S. NUCLEAR REGUL. COMM'N 1, https://www.nrc.gov/docs/ML0510/ML051020528.pdf [https://perma.cc/6PU4-YPRB] (last visited Apr. 30, 2025) (describing radioactive dirty bomb as "type of radiological dispersal device (RDD) that combines a conventional explosive, such as dynamite, with radioactive material.").

[76] Nearly any explosive or high-energy pneumatic release can be made into a "dirty bomb" by simply adding a contaminant. *See generally* Jennifer C. Bulkeley, *Decontamination and Remediation After a Dirty Bomb Attack*, 14 NONPROLIFERATION REV. 113 (2007).

[77] These devices are the origin of the "see it, say it, sorted" announcements common at London Underground and Eurostar stations, as well as the UK's commercially-served airports. For a general discussion of concerns about suspicious packages and devices (potential bombs) on public transport and how the public may help in contributing to the policing effort (over 90% of participants called out unattended luggage, which might contain a bomb, as suspicious), *see* Holly Jefferis et al., *See It, Say It, Sorted, Suspicious Behaviour on Public Transport*, 14 ASSESSMENT & DEV. MATTERS 4 (2022) (attributing campaign specifically as response to 2004 Madrid train bombing and similar mass casualty explosive device terrorist events). For a broader description of the UK campaign, *see* Victoria Sophie Hazebrouck, *See it. Say it. Sorted. An Empirical Analysis of the Influence of the British Vigilance Campaign*, 2020 IEEE/ACM CONFERENCE PAPERS, https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=9381412 [https://perma.cc/LA54-N446] (discussing effects of campaign and aspects of campaign's design, implementation, and reception).

A dirty bomb might be a fishing boat loaded with explosives and radioactive waste moored in Gravesend Bay near Brooklyn and rigged to explode during the morning rush hour. Or it might take the form of a pair of satchel charges rigged to the 16th Street viaduct at Clark Street in Chicago, where sufficiently powerful charges could collapse the viaduct, block Clark Street, and flood the underpass below with the hazardous materials like chlorine and acetone often moved by tanker car over this route. Alternatively, a dirty bomb could be inside an unmarked box truck intended to collapse the San Mateo-Hayward Bridge while also contaminating the broader San Francisco Bay area with a cloud of radioactive waste. After the Three Mile Island incident in the United States, concerns materialized that radioactive material could be salvaged by parties with bad intentions and utilized either in dirty bomb style attacks or in contamination attempts at locations like water treatment plants.[78]

Some may envision that nuclear material is only obtained from military sites or nuclear power plants, but this is untrue. Much of the material most feared from a dirty bomb perspective is the less pure, but still problematic, material that can be harvested from the oil and gas industry, from fertilizer manufacturing,[79] from coal powerplants,[80] from unrelated mining activities,[81] and discarded medical equipment.[82] This Article's proposition focuses on nuclear weapons that require a specific design regime, a specific detonation procedure, and a specific set of materials and mechanisms. Because dirty bombs are outside these constraints, they are beyond the scope of this Article.

III. WEAPONS PRACTICES AMONG NATO-ALIGNED AND NON-NATO NUCLEAR STATES

State actors and international regulatory efforts enjoy varying degrees of success controlling the supply, transport, and sale of potentially-dangerous materials; the regulatory approach invoked for nuclear materials often diverges from the approach used for other weapons or weaponizable goods (e.g., modern demolition explosives, multi-stage solid fuel rocket engines, and other potentially harmful explosive devices).[83]

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[78] *See Backgrounder on the Three Mile Island Accident*, U.S. NUCLEAR REGUL. COMM'N (Mar. 28, 2024), https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html [https://perma.cc/Q5JJ-Y6N3].

[79] *See* Brad Anderson, *Florida's Building A Test Road from Radioactive Waste*, CARSCOOPS (Jan. 2, 2025, 3:15PM), https://www.carscoops.com/2025/01/epa-allows-florida-firm-to-build-pilot-road-with-radioactive-material/ [https://perma.cc/2W9G-8AA5].

[80] Levels of radioactivity both at coal powerplants and from coal-fired plant waste have been discussed and studied at least since the mid-1980s. *See generally e.g.*, Jacob Tadmor, *Radioactivity from Coal-Fired Power Plants: A Review*, 4 J. ENVIRON. RADIOACTIVITY 177 (1986).

[81] Geoffrey Wendle, *Radioactivity in Mines and Mine Water*, 98 J. ZA INST. MINING & METALLURGY 87, 89–90 (1998).

[82] Shreekumar Menon & Vagish Kumar, *Weaponizing Radioactive Medical Waste - The Looming Threat*, 5 INT'L J. NUCLEAR SEC. 1 (2019).

[83] To understand the multilateral approach to arms control and why (and how) nuclear material regulation so greatly diverges from the regulatory framework utilized to monitor the sale and

A. NATO States

While NATO is aligned around the inventory, maintenance, and transport practices concerning nuclear warheads (the explosive "core" item itself) and nuclear-capable weapons systems (which might include a missile, ship, airplane, or even suitcase that could deliver nuclear warheads to their targets),[84] alignment does not, in this case, mean uniformity. The key governing document in international law is the Non-Proliferation Treaty (or, in its full and far-less-often-used title, The Treaty on the Non-Proliferation of Nuclear Weapons),[85] which is a multilateral effort to codify the principles of UN Security Council Resolution 502.[86] Israel and Taiwan are non-signatories and affirmatively ambiguous as to their nuclear capabilities. The United States, because of its treaty obligations and an unusual set of precedents, remains relatively open about its nuclear inventory and the composition of that inventory.[87] It is also the only NATO Member State where authority for maintaining, and thereby assuring, readiness of the nuclear arsenal does not reside with the person of terminal executive power or the head of state, but instead with a member of the president's cabinet (the Secretary of Energy).[88]

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possession of conventional explosives or other arms, *see generally* Eric Stein, *Legal Restraints in Modern Arms Control Agreements*, 66 AM. J. INT'L L. 255, 258–60 (1972) (describing treaty and other legal mechanisms to control arms availability).

[84] NATO's Nuclear Deterrence Policy and Forces, NATO (Nov. 30, 2023), https://www.nato.int/cps/en/natohq/topics_50068.htm [https://perma.cc/VT7Q-GWEN] ("NATO is committed to arms control, disarmament and non-proliferation").

[85] Treaty on the Non-Proliferation of Nuclear Weapons, *supra* note 38 (noting this treaty was up for cyclical review and re-ratification every five years until, in 1995, the treaty was unconditionally extended indefinitely).

[86] *See generally* S.C. Res. 1540 (Apr. 28, 2004); S.C. Res. 2310 (Sept. 23, 2016); *see also* United Nations Disarmament Commission, U.N. Office for Disarmament Affairs, https://disarmament.unoda.org/institutions/disarmament-commission/ [https://perma.cc/BBZ5-SMBP] (last visited Apr. 30, 2025) (describing history and context of non-proliferation and disarmament efforts).

[87] The State Department releases a precise declassified inventory count of nuclear warheads in the form of annual fact sheets. The most recent report lists 3,748 nuclear warheads in the inventory as of September 2023. *See Transparency in the U.S. Nuclear Weapons Stockpile*, U.S. DEP'T OF STATE, https://www.state.gov/bureau-of-arms-control-deterrence-and-stability/releases/2024/07/transparency-in-the-u-s-nuclear-weapons-stockpile [https://perma.cc/55AM-8TA6] (last visited Apr. 30, 2025).

[88] *See Dep't of Energy*, ENERGY.GOV, https://obamaadministration.archives.performance.gov/agency/department-energy.html [https://perma.cc/M7GL-4Y4R] (last visited Feb. 16, 2025) ("DOE enhances the security and safety of the nation through its national security endeavors: maintaining a safe, secure, and effective nuclear weapons stockpile in the absence of nuclear testing and managing the research, development, and production activities and associated infrastructure needed to meet national nuclear security requirements; accelerating and expanding efforts to reduce the global threat posed by nuclear weapons, nuclear proliferation and unsecured or excess nuclear materials; and, providing safe and effective nuclear propulsion for the U.S. Navy.").

Nuclear weapons programs are historically less transparent than nuclear power programs,[89] even in higher-transparency nations, but transparency does not by itself make nuclear incidents impossible. This includes the loading of nuclear weapons on warplanes that were not meant to be nuclear-armed.[90] In less transparent, less regulated, less monitored contexts, one can imagine incidents also occur (even if they are not disclosed). And even conventional (non-nuclear) weapons loading is a delicate process and mishaps are not unheard-of: in November of 2023, an American F-16C sat on a ramp near a British F-15E.[91] While operating a weapons loader, the operator was injured and thrown from the vehicle. The vehicle, then unmanned, continued under its own power in reverse and hit the external targeting pod of the F-15E, then struck the landing gear assembly of the F-15E, and finally ran into the F-16C and ignited a fire that engulfed that jet, causing over thirty million dollars in damage to the American and British fighters.[92] One can imagine the mishap would have been even more costly had nuclear munitions been, knowingly or unknowingly,[93] in the process of being loaded.

B. Non-NATO States

The extent of the Chinese and Russian nuclear programs is a matter of controversy in the West and reasonable minds can differ as to these governments' degree of adherence to treaty regulations,[94] deviation between public statements and actual behavior, and condition or maintenance of nuclear arsenals.[95] Most public observations concerning the Chinese nuclear program

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[89] *See generally* Anna Pikulicka-Wilczewska, *Poland and Canada Sign Nuclear Power Cooperation Agreement*, REUTERS (Jan. 28, 2025), https://www.reuters.com/business/energy/poland-canada-sign-cooperation-agreement-nuclear-power-2025-01-28/ [https://perma.cc/3F45-JT8W]; *see also generally* Kaula Nhongo, *Namibia Seeks Investment in Nuclear Power from China*, YAHOO! NEWS (Jan. 6, 2025), https://www.yahoo.com/news/namibia-seeks-investment-nuclear-power-170712114.html [https://perma.cc/N434-R6KB]

[90] The now-notorious "Barksdale incident" involved an Air Force bomber accidentally loaded with six nuclear weapons in 2007. *Nuke-Armed B-52 Mistakenly Flown Over U.S.*, CBS NEWS (Sept. 5, 2007).

[91] David Cenciotti, *Ground Mishap Involving F-16 and Weapons Loader Results in $30 Million Damage*, THE AVIATIONIST (Oct. 20, 2024, 11:02 PM), https://theaviationist.com/2024/10/20/f-16-hit-by-weapons-loader-report/ [https://perma.cc/556W-PT57].

[92] *Id.*

[93] *See generally* Stephen Losey, *You Can Call 2007 Nuke Mishandling an Embarrassment, But…*, AIR FORCE TIMES (June 25, 2019), https://www.airforcetimes.com/news/your-air-force/2019/06/25/you-can-call-2007-nuke-mishandling-an-embarrassment-but-dont-call-it-the-minot-incident/ [https://perma.cc/T3R4-JPRE] (noting nuclear weapons were accidently loaded onto a B-52 bomber and flown to Louisiana).

[94] China routinely has bilateral conversations that are incongruent with Western nuclear control concepts. For instance, its recent discussions with Namibia about nuclear technology has raised concerns and is in some ways similar to predatory infrastructure agreements China has made with other African nations. *See* Nhongo, *supra* note 88. As to predatory terms in Sino-African infrastructure projects, *see generally* Karl Muth, *African Infrastructure with Chinese Characteristics*, HARV. AFR. POL. J. 52 (2020) (discussing Chinese diplomacy, statecraft, and bargaining tactics inconsistent with norms and policies of Western nations).

[95] *See* Hans M. Kristensen & Matt Korda, *Russian Nuclear Weapons, 2021*, 77 BULL. ATOMIC SCIENTISTS 90, 92 (2021).

suggest the Chinese government is modest in its discussions of both its nuclear arsenal and its delivery systems; for instance, its newest intercontinental ballistic missile, the DF-41, is believed to have a range of 9,300 miles and capability to hit the continental United States.[96] Russia's test site, which is far north on the Novaya Zemlya landmass in the Arctic Ocean,[97] was the site for 130 or more Russian nuclear weapons tests and is where the most powerful nuclear weapon ever detonated was tested in 1961[98] (and where, in 2023, Russia tested a nuclear-powered cruise missile).[99] Rear Admiral Andrei Sinitsyn, in an interview with Rossiyskaya Gazeta in September of 2024, stated he is ready to resume Russian nuclear weapons testing "at any moment" to improve this technology.[100]

Rogue state conversations away from NATO geographies often focus on Iran and North Korea, with mainstream news outlets awaiting (and often even forecasting) nuclear news.[101] Little is known about how weapons or weapons components are developed, handled, or stored in either Iran or North Korea.

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[96] *See* Nectar Gan, *China Fires ICBM into Pacific Ocean in First Such Public Test in Decades as Regional Tensions Flare*, CNN, https://www.cnn.com/2024/09/25/asia/china-icbm-test-pacific-ocean-intl-hnk/index.html https://perma.cc/56BW-4PNW (Sep. 26, 2024, 12:21 AM).

[97] *Central Test Site of Russia on Novaya Zemlya*, NTI, https://www.nti.org/education-center/facilities/central-test-site-of-russia-on-novaya-zemlya/ [https://perma.cc/U4U4-RGDP] (last visited Apr. 15, 2025).

[98] William J. Broad, *New Video Shows Largest Hydrogen Bomb Ever Exploded*, N.Y. TIMES (Aug. 25, 2020), https://www.nytimes.com/2020/08/25/science/tsar-bomba-nuclear-test.html [https://perma.cc/VFZ3-7WKB].

[99] Referred to as the "Burevestnik test," Putin claimed this test was successful (a successful sequel to a 2019 test), though Western experts are uncertain what precisely was being tested and what would define success. *See* Riley Mellen, *Russia May Be Planning to Test a Nuclear-Powered Missile*, N.Y. TIMES (Oct. 2, 2023), https://www.nytimes.com/2023/10/02/video/russia-nuclear-missile.html [https://perma.cc/YL3M-MKS9].

[100] Andrew Osborn, *Russian Nuclear Test Chief Says Moscow is Ready to Resume Testing 'At Any Moment'*, REUTERS (Sep. 17, 2024, 9:33 AM), https://www.reuters.com/world/europe/russian-nuclear-test-chief-says-moscow-is-ready-resume-testing-at-any-moment-2024-09-17/.

[101] *See*, *e.g.*, Pablo Robles & Chloe Sang-Hun, *Why North Korea's Latest Nuclear Claims Are Raising Alarms*, N.Y. TIMES (June 2, 2023), https://www.nytimes.com/interactive/2023/06/02/world/asia/north-korea-nuclear.html ("North Korea's new wave of propaganda suggests that it has succeeded in miniaturizing its nuclear warheads . . . ."); David E. Sanger, *Putin Once Tried to Curb North Korea's Nuclear Program. That's Now Over.*, N. Y. TIMES (June 19, 2024), https://www.nytimes.com/2024/06/19/us/politics/putin-kim-russia-nuclear.html [https://perma.cc/5W5H-RTEX]; William J. Broad, *To Build a Nuclear Bomb, Iran Would Need Much More Than Weeks*, N.Y. TIMES (Oct. 2, 2024), https://www.nytimes.com/2024/10/02/science/iran-nuclear-weapon.html [https://perma.cc/6SXM-AYKW]; David E. Sanger, *Iran Makes 'Dramatic' Leap to Produce Near-Bomb-Grade Fuel, but to What End?*, N.Y. TIMES (Dec. 6, 2024), https://www.nytimes.com/2024/12/06/us/politics/iran-nuclear-fuel.html [https://perma.cc/S6BN-8WAT]; Laurence Norman, *Iran Sharply Expands Stockpile of Nuclear Fuel Ahead of Trump's Return*, WALL ST. J. (Nov. 19, 2024, 12:31 PM), https://www.wsj.com/world/middle-east/iran-sharply-expands-stockpile-of-nuclear-fuel-ahead-of-trumps-return-95fed87d; Joby Warrick, *Iran Signals a Major Boost in Nuclear Program at Key Site*, WASH. POST (June 19, 2024), https://www.washingtonpost.com/national-security/2024/06/19/iran-nuclear-enrichment-fordow/.

However, recent events have revealed some characteristics of Iranian missile systems previously not widely known.[102]

C. "Near-Nuclear" Countries (Taiwan, Japan,[103] Israel, etc.)

Some states have either not declared their widely-suspected nuclear capabilities (Israel)[104] or are believed to be able to, given the correct ingredients, assemble nuclear weapons on relatively short notice (Japan).[105] These states would benefit, as would their neighbors, from not having to engage in confirmation testing wherein designs are actually detonated in order to gather data, check design characteristics, and improve upon early-phase designs. The concept of warehoused ingredients related to nuclear weapons and "ready for assembly" nuclear weapons is not a new one. In 2006, the United States accidently shipped nuclear weapons components to Taiwan;[106] the Air Force refers to this incident as "a mis-shipment of sensitive missile components" while the Chinese mainland still disbelieves the four nuclear weapon fuses were accidently shipped to Taiwan.[107]

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[102] Susannah George et al., *What Iran's Attack on Israel Revealed About its Weapons*, WASH. POST (Apr. 17, 2024) (discussing Iran's intermediate-range ballistic missiles), https://www.washingtonpost.com/world/2024/04/17/iran-israel-attack-drones-missiles/.

[103] Japan's three nuclear principles officially forbid the country from 1) producing, 2) possessing, or 3) allowing nuclear weapons in Japanese-controlled territory; this has been Japan's official policy since 1967. *Three Non-Nuclear Principles*, MINISTRY OF FOREIGN AFF. OF JAP., https://www.mofa.go.jp/policy/un/disarmament/nnp/#:~:text=My%20responsibility%20is%20to%20achieve,line%20with%20Japan's%20Peace%20Constitution [https://perma.cc/4NLF-WH63] (last visited Apr. 16, 2025).

[104] *See* Louis R. Beres, *Navigating Chaos: Israel, Nuclear Ambiguity and the "Samson Option"*, BEGIN-SADAT CENT. FOR STRATEGIC STUD. (Mar. 10, 2024), https://besacenter.org/navigating-chaos-israel-nuclear-ambiguity-and-the-samson-option/ [https://perma.cc/BF98-CNNR] (discussing Israel's policy of purposeful ambiguity as to its nuclear capabilities as inadequately guiding and intolerably vague in a now-ignited region).

[105] Experts vary on how long it would take for Japan to assemble a nuclear weapon and in what scenarios it would desire nuclear counterstrike capability, but many experts believe Japan could achieve nuclear capability within months rather than years, making it a de facto nuclear nation. Robert Windrem, *Japan Has Nuclear 'Bomb in the Basement,' and China Isn't Happy*, NBC NEWS (Mar. 11, 2014, 5:31 AM), https://www.nbcnews.com/storyline/fukushima-anniversary/japan-has-nuclear-bomb-basement-china-isn-t-happy-n48976; *see also* Gordon G. Chang, *Japan's New Leader Wants Nuclear Weapons*, NEWSWEEK, https://www.newsweek.com/japans-new-leader-wants-nuclear-weapons-opinion-1968235 [https://perma.cc/GH2B-ZMBJ] (Oct. 13, 2024, 12:06 PM).

[106] *See generally* John Ruwitch & Ben Blanchard, *China Concern Over U.S. Nuclear Parts Mistake in Taiwan*, REUTERS (Mar. 26, 2008, 5:44 AM), https://www.reuters.com/article/world/china-concern-over-us-nuclear-parts-mistake-in-taiwan-idUSN25385989/); Suzanne Goldenberg, *Pentagon Admits to Mistakenly Shipping Nuclear Material to Taiwan*, GUARDIAN (Mar. 25, 2008, 1:39 PM), https://www.theguardian.com/world/2008/mar/25/usa.nuclear [https://perma.cc/8YQZ-3E9M]; Josh White, *Nuclear Parts Sent to Taiwan in Error*, WASH. POST (Mar. 25, 2008), https://www.washingtonpost.com/archive/national/2008/03/26/nuclear-parts-sent-to-taiwan-in-error/78f0869e-bdd9-489f-af03-5413e39ffc56/.

[107] Reuters, *supra* note 114.

While above-ground nuclear testing by aspiring nuclear states is unlikely, in part due to global surveillance[108] of nuclear weapons testing activity. Small event testing in caverns or other natural hidden sites is imaginable. This type of testing may have occurred and been masked by seismic background activity; this is particularly true in poorly-mapped desert regions of Iran[109] where it could be hard to discern a small nuclear experiment from natural variations in seismic activity.

IV. DESIGN DISTRIBUTION

In an open-source archive, sophisticated state actors would deposit easy-to-interpret designs that would be correctly interpreted by an engineering team of typical skill, not needing to be versed in the state-of-the-art in nuclear weapons design. The archive would be accessible to anyone with Internet access. The primary goal of the archive is not to distribute knowledge, but rather to obsolesce the need for each state to perform empirical nuclear weapons research[110] including, particularly, above-ground or below-ground testing of prototype nuclear devices. Nuclear weapons progress is otherwise difficult without periodic testing.[111] This is in part because the materials science and device engineering questions encountered in nuclear weapons design are nontrivial. But this is also due to the fact that nuclear weapons development features natural breakover points at which key design decisions must be made.[112]

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[108] *CTBT: International Monitoring System*, U.S. DEP'T STATE, https://2009-2017.state.gov/t/avc/rls/212176.htm#:~:text=Key%20Point%3A%20The%20International%20Monitoring,consist%20of%20337%20monitoring%20facilities [https://perma.cc/WM2A-J3SG] (last visited Apr. 16, 2025).

[109] An area to the southeast of Semnan is widely suspected of hiding an underground testing site and it is internationally disputed whether an earthquake that originated 12 km below the surface near the city of Aradan in Iran (at 35.42° N and 52.78° E) was truly an earthquake or a below-ground nuclear test. If this was a testing event, Iran failed to declare it to the International Atomic Energy Agency. *Iran Testing First Nuclear Bomb? Strange Earthquake Sparks Speculations*, ECON. TIMES (Oct. 9, 2024), https://economictimes.indiatimes.com/news/defence/unusual-earthquake-raises-alarms-is-iran-testing-its-first-nuclear-bomb/articleshow/114043414.cms [https://perma.cc/6YMU-9DSM].

[110] Though my position as to establishing an open-source archive of basic weapons designs to eliminate unsafe or primitive weapons development laboratory work is admittedly in the minority, people have for many years voiced support for giving nuclear power technology to North Korea and other states in an effort to avoid these states' construction of primitive or defective indigenous designs that may threaten civilians, water supplies, or the environment more generally. For instance, over thirty years ago Peter Hayes wrote a piece considering whether the United States should give light water reactor technology to North Korea. *See*, *e.g.*, Peter Hayes, *Should the United States Supply Light Water Reactors to Pyongyang?,* NAPSNET SPECIAL REPORTS (Nov. 16, 1993),

https://nautilus.org/napsnet/napsnet-special-reports/should--he-united-states-supply-light-water-reactors-to-pyongyang/.

[111] *See generally* NUCLEAR MATTERS HANDBOOK 2020, *supra* note 108. To understand why underground experiments are so useful to nuclear aspirants, *see generally* U.S. CONGRESS OFFICE OF TECHNOLOGY ASSESSMENT, OTA-ISC-114, CONTAINMENT OF UNDERGROUND NUCLEAR EXPLOSIONS (1989) (while incremental advances are possible with mathematical calculations and theoretical models, at key points empirical destructive testing is preferable, if not strictly necessary).

[112] *See generally* The Associated Press, *Supercomputers Can't Perfectly Simulate Nuclear Blasts: Experts*, CBC (Oct. 18, 2006, 9:13 AM), https://www.cbc.ca/news/science/supercomputers-can-t-perfectly-simulate-nuclear-blasts-experts-1.597887 [https://perma.cc/7EMM-BAUV].

The international community of nuclear-capable powers already make this regulatory distinction in nuclear reactor design,[113] and the obvious next step is to expand the sharing of safe designs and best practices to weapons. Recently, when Google looked at building small-site reactors for its datacenters and Microsoft looked at reviving the Three Mile Island facility to power its AI and Azure projects,[114] an open discussion about reactor design and safety was part of the process.[115]

V. WHAT HAPPENS IN THE ABSENCE OF OPEN-SOURCE NUKES

To consider the merits of an open-source system, which concededly is not the state of the world one would have hoped for in the late 1940's, one must also consider the status quo and the dangers under the current system of intellectual embargo. In short, this leads to disastrous risks and awful incentives for many nuclear-aspirant actors. Without a commonly-accessible archive of nuclear weapons development knowledge, actors will be left to pursue their own research paths which will, almost inevitably, involve empirical testing events. Even prior to early testing phases, potentially-dangerous facilities will need to be built, often in clandestine or disguised locations.

In the case of Iran and North Korea, there a risk to a large number of unaware civilians during development phases and needlessly subjecting innocents to nuclear accident risk. Note the risk of a mishap or safety oversight at a clandestine buried facility is not the only risk to the city dwellers above a nuclear site. A missile strike[116] or successful sabotage of a nuclear research

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[113] NATO-aligned governments publish information both on safe reactor designs currently being produced/built and conceptual designs not yet commonly used. *See generally*, *e.g.*, S.R. Greene et al., *Pre-Conceptual Design of a Fluoride Salt-Cooled Small Modular Advanced*

High-Temperature Reactor, OAK RIDGE NAT'L LABORATORY (Dec. 2010), https://info.ornl.gov/sites/publications/files/Pub26178.pdf [https://perma.cc/2PHK-8ZAR] (describing in detail a sodium-cooled reactor design published by U.S. government).

[114] Almost certainly the enormous power demands of technologies like advanced artificial intelligence, centralized high-performance compute sites, and quantum computing will drive demand for so-called micro-reactors as power sources. *See generally* Tim De Chant, *Nuclear Startup Deep Fission Plans to Bury Micro-Reactors to Power Data Centers*, TECHCRUNCH (Jan. 7, 2025, 12:48 PM), https://techcrunch.com/2025/01/07/nuclear-startup-deep-fission-plans-to-bury-micro-reactors-to-power-data-centers/ [https://perma.cc/Y9SZ-HEQV].

[115] *See* Michael Franco, *Google Goes Nuclear in World-First Small Reactor Agreement*, NEW ATLAS (Oct. 16, 2024), https://newatlas.com/energy/google-goes-nuclear/ [https://perma.cc/LJH2-AQPK]; *see also* Casey Crownhart, *Why Microsoft Made a Deal to Help Restart Three Mile Island*, MIT TECH. REV. (Sept. 26, 2024), https://www.technologyreview.com/2024/09/26/1104516/three-mile-island-microsoft/ [https://perma.cc/W7AX-5LVS].

[116] *See* Zachary Cohen et al., *US Intelligence Agencies Believe Israel is Likely to Strike Iranian Nuclear Facilities This Year*, CNN POL., https://www.cnn.com/2025/02/13/politics/us-intelligence-israel-strike-iran-nuclear/index.html [https://perma.cc/42GH-B9EJ] (Feb. 13, 2025, 5:01 PM).

facility might have a similar effect to a dirty bomb incident,[117] releasing nuclear material that could poison or kill civilians.[118]

A. Iranian Case Study

Iran has steadily increased its stockpile of enriched material for five years and now has enough material to build "several" nuclear weapons.[119] But, beyond the accumulation of enriched material, Iran's research ambition endangers innocent people in Iran every day. The use of laboratories below populated areas to conduct nuclear research activities means that civilian populations above ground may be affected by the release of dirty-bomb-like amounts of radiological materials from being near, or downwind from, the release of radiological materials.[120]

It is alleged by Western powers that Iran also engages in research in an improved tunnel complex near the holy city of Qom and in nearby areas.[121] Iran only officially acknowledges it engages in fuel enrichment in this area.[122] The use of religious sites, dense civilian populations, or protected areas of natural beauty to disguise operations at (or to deter adversaries from striking)

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[117] *See* Garett Welch, *IAEA Warns of Risks at Russian Nuclear* Plant, ARMS CONTROL ASSOC. (Sept. 2024), https://www.armscontrol.org/act/2024-09/news/iaea-warns-risks-russian-nuclear-plant [https://perma.cc/K4RM-PDM6] (critiquing Russian attacks on Ukrainian nuclear powerplants, IAEA Director-General Rafael Mariano Grossi stated "[t]hese reckless attacks [on two nuclear facilities in contested areas] endanger nuclear safety at the plant and increase the risk of a nuclear accident").

[118] In the wake of the containment failure at the Chernobyl facility in Russia in 1986, over 200,000 civilians had to be evacuated to other areas, with most not allowed to take their belongings. *See Frequently Asked Chernobyl Questions*, IAEA (Jan. 6, 2005), https://www.iaea.org/newscenter/focus/chernobyl/faqs [https://perma.cc/K4TU-ZRRG].

[119] *See Iran's Enriched Uranium Stockpile '10 Times Limit'*, BBC (Sep. 4, 2020), https://www.bbc.com/news/world-middle-east-54033441 [https://perma.cc/4P7C-KZUQ]; *Iran's Enriched Uranium Stockpile 12 Times Limit, Says IAEA*, BBC (Nov. 11, 2020), https://www.bbc.com/news/world-middle-east-54912402 [https://perma.cc/LJ4L-9DYB]; Bethany Bell & David Gritten, *Iran Nuclear: IAEA Inspectors Find Uranium Particles Enriched to 83.7%*, BBC (Mar. 1, 2023), https://www.bbc.com/news/world-middle-east-64810145 [https://perma.cc/CXA3-GHYG]; David Gritten, *Israel Hit Part of Iran Nuclear Programme, Netanyahu Says*, BBC (Nov. 19, 2024), https://www.bbc.com/news/articles/cy0l1ep34pro [https://perma.cc/8SDK-2D8B] ("The IAEA also says Iran has produced enough highly enriched uranium to build several nuclear weapons since the US abandoned a nuclear deal").

[120] *See generally* Harold L. Beck & Burton G. Bennett, *Historical Overview of Atmospheric Nuclear Weapons Testing and Estimates of Fallout in the Continental United States*, 82 HEALTH PHYSICS 591 (2002) (explaining health effects and downwind fallout dynamics from release of nuclear material upwind from populated areas).

[121] Julian Borger & Patrick Wintour, *Why Iran Confessed to Secret Nuclear Site Built Inside Mountain*, THE GUARDIAN (Sep. 26, 2009), https://www.theguardian.com/world/2009/sep/25/iran-nuclear-uranium-enrichment-intelligence [https://perma.cc/6ELH-G54J] (discussing Qom facility's unusual location).

[122] The "broader Natanz complex" is how this site is described in some nuclear regulatory documents. *See generally* David Kay, *The Tunnels of Natanz*, 106 NAT'L INTEREST 18 (2010) (describing tunnels around Iranian nuclear research complex and difficulty of understanding purpose or extent of same).

subterranean nuclear installations is not a new idea;[123] the very first nuclear reactor was hidden in a vast manmade series of rooms and tunnels beneath a college football stadium.[124] It is unclear what other facilities may exist in Iran; ambiguous facilities have in the past turned out to be related to its nuclear program,[125] raising the question of whether more such facilities exist that have not yet been discovered.

B. North Korean Case Study

It would not be obvious even to astute and observant civilians whether their homes, offices, or schools are nearby clandestine nuclear weapons research sites. The North Korean clandestine nuclear program includes, at a minimum, production of material, design and production of weaponry, and storage and maintenance of completed warheads; the best Western intelligence estimates as of summer 2024 suggest North Korea has secretly assembled fifty or more nuclear warheads and accumulated enough nuclear material for nearly 100 nuclear weapons.[126] While the complete list of North Korean nuclear research locations is unknown in the West, there are multiple locations at which nuclear weapons research occurs and confirmed nuclear tests have occurred at three of these sites.[127]

As was true with the first secret, eventually dismantled, reactor in the United States hidden below the football field of the University of Chicago's campus,[128] nuclear reactors in cities or near population centers pose threats to innocents on the surface even if they are properly designed and operated in a

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[123] If we want to know where nuclear weapons might be escaping detection, one thing to think about is where conventional weapons are hidden. In the autumn of 2024, Israel found large weapons caches hidden under a cemetery, for instance. *See* TOI World Desk, *Watch: Israel Finds Secret Hezbollah Tunnel Under Cemetery, Loaded with Weapons*, THE TIMES OF INDIA (Nov. 11, 2024), https://timesofindia.indiatimes.com/world/middle-east/watch-israel-finds-secret-hezbollah-tunnel-under-cemetary-loaded-with-weapons/articleshow/115159197.cms [https://perma.cc/GM67-KLGK].

[124] *See* Louise Lerner, *The First Nuclear Reactor, Explained*, UCHICAGO NEWS, https://news.uchicago.edu/explainer/first-nuclear-reactor-explained [https://perma.cc/T5CH-PUTR] (last visited Mar. 29, 2025).

[125] *See generally* 171 Cong. Rec. S1471 (daily ed. Mar. 4, 2025) (statement of Sen. Schmitt) (noting Colby, nominated to serve as Undersecretary of Defense for Policy, pledged to provide the Commander-in-Chief "with the best possible military options to deny Iran a nuclear weapon. If confirmed, I would regard it as my responsibility to ensure that the Secretary and the President have the best possible military options for this purpose"); *see also* Tom Vanden Brook, *Trump's Pick for Pentagon Post Says Military Force an Option to Prevent Nuclear Iran*, USA TODAY (Mar. 4, 2025), https://www.usatoday.com/story/news/politics/2025/03/04/elbridge-colby-nuclear-iran-military-force-trump/81387370007/ [https://perma.cc/KJ3U-DVJ3].

[126] *See Arms Control and Proliferation Profile: North Korea*, ARMS CONTROL ASS'N (June 2024) https://www.armscontrol.org/factsheets/arms-control-and-proliferation-profile-north-korea [https://perma.cc/94VP-33S9] ("North Korea is estimated to have assembled 50 nuclear warheads, as of January 2024, and to have the fissile material for an estimated 70-90 nuclear weapons, as well as advanced chemical and biological weapons programs.").

[127] Six confirmed tests occurred between 2006 and 2017, the 2006 test surprising the world and leading to UN Security Council Resolution 1718 in response, while the program's progress or direction since then has been subject to even greater secrecy. *Id*.; United Nations S.C. Res. 1718, U.N. Doc. S/RES/1718 (Oct. 14, 2006).

[128] *See* Lerner, *supra* note 142.

subterraneous setting, as even a simple graphite reactor could suffer "primitive meltdown, with the pile catching fire and the uranium spewing more radiation."[129] Fires are particularly problematic in underground nuclear sites due to their convective characteristics which cause large movements of potentially contaminated air. After a fire at the Iranian nuclear site at Natanz, the State Department said it was "monitoring reports of a fire at an Iranian nuclear facility" and that the "incident serves as another reminder of how the Iranian regime continues to prioritize its misguided nuclear program to the detriment of the Iranian people's needs[.]"[130]

The Author enjoys giving prospective students and tourists tours of the University of Chicago's campus; an obligatory stop on such tours is the site of the world's first nuclear reactor.[131] But the stop often prompts a question from prospective students: "What if there had been a nuclear disaster?" Contamination of urban areas is not well understood, but nuclear site incidents in cities are not unknown; "To date, experience with urban decontamination of building materials—specifically hard, porous, external surfaces—is limited to nuclear weapon fallout and nuclear reactor accidents."[132] More urgent than the (still concerning) problem of porous brick or pavement harboring nuclear radiation for years or decades is the problem of safe drinking water.[133]

It is likely, according to research in recent years, that at least one nuclear facility is concealed near the city of Pyongyang.[134] The industrial area to the east of the northerly bend of the Taedong River can be seen on Google Earth and has drawn attention to the area since the press believes Kim Jong Un visited a facility in the area around the time he claimed he possessed a secret facility near Pyongyang capable of producing weapons-grade uranium.[135] The North Korean weapon tested in 2017 (the last major in-the-open test the international community had the opportunity to witness and analyze) was unimpressive; such

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[129] *See* Katie Mingle, *Did A WWII Nuclear Experiment Make the U Of C Radioactive?*, WBEZ CHI. (July 6, 2019, 6:30 AM), https://www.wbez.org/curious-city/2019/07/06/did-a-wwii-nuclear-experiment-make-the-u-of-c-radioactive [https://perma.cc/V59Q-GTM7].

[130] *See* Jon Gambrell, *Analysts: Fire at Iran Nuclear Site Hit Centrifuge Facility*, ASSOCIATED PRESS (July 2, 2020, 3:28 PM), https://apnews.com/article/50c3e7f6445ae99def6bdc65fbce6c42 [https://perma.cc/H9CL-CKLB].

[131] Author has proudly served on a graduate Admissions Committee at the University of Chicago since 2009 and lived (without fear of ambient radiation seventy years after the Pile-1 reactor was shut down) near campus.

[132] Michael D. Kaminski, Sang Don Lee, and Matthew Magnuson, *Wide-Area Decontamination in an Urban Environment After Radiological Dispersion: A Review and Perspectives*, *Abstract*, 305 J. HAZARD. MAT. 67, 67 (2016).

[133] *See* Hyo-Joon Jeong et al., *Radiological Risk Assessment for an Urban Area: Focusing on a Drinking Water Contamination*, 36 ANNALS OF NUC. ENERGY 1313, 1314–16 (2009) (focusing on theoretical intentional release of cesium-137 by North Korea to poison South Korean residents).

[134] *See* Gian Gentile et al., *Four Problems on the Korean Peninsula: North Korea's Expanding Nuclear Capabilities Drive a Complex Set of Problems*, RAND 13 (Jan. 11, 2019), https://www.rand.org/pubs/tools/TL271.html (discussing hidden North Korean sites).

[135] *See generally* C. Kenneth Quinones, *North Korea's Underground Construction*, NAUTILUS INST. (Oct. 5, 1998), https://nautilus.org/napsnet/napsnet-policy-forum/north-koreas-underground-construction/ [https://perma.cc/TT6L-QWLV].

a weapon creates a fireball a third of mile in radius and spreads fatal radiation over a radius of 1.22 square miles (for reference, that's not enough to cover Central Park in fatal radiation if the weapon went off in the middle of the park, which is 2.5 miles in the longer dimension).[136] For comparison, the U.S. Castle Bravo nuclear weapon produces a fireball 12 square miles in size and would kill nearly 5 million New Yorkers if detonated at the same location, injuring about 5.4 million more.[137]

In addition to clandestine, subterranean weapons development, the city of Yongbyon, North Korea is currently experimenting with its own design for a light water reactor. As part of the Yongbyon reactor complex, which already houses an experimental reactor in the five-megawatt range, there is alleged to be an effort to enrich weapons-grade materials.[138] It is unclear whether an IRT-2000 ex-Soviet reactor at the Yongbyon site is in good enough condition to operate.[139] There is no shortage of possible sites for North Korean nuclear research activity, even if one does not include suspected hidden sites in or near Pyongyang, which is part of what has made international efforts to investigate North Korea's capabilities so fraught.[140]

C. Reducing Risk to Innocent Residents

Nuclear weapons research, especially for less-resourced, less-experienced, and less-sophisticated actors, poses real risks to nearby populations. The same activities that disguise clandestine research can make proper safeguards and safety best practices more difficult to implement.[141] Underground research

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[136] *See* Jordan King, *Nuclear Bomb Map Shows How US, Russian, North Korean Weapons Compare*, NEWSWEEK (Dec. 2, 2024, 3:00 AM), https://www.newsweek.com/nuclear-bomb-map-us-russia-north-korea-1993568 [https://perma.cc/JMQ4-V6R5].

[137] *Id.*

[138] This allegation recurs in interactions between U.S. diplomats and international nuclear inspectors and North Korean officials; various North Korean officials either boast or demur when asked about the capabilities of these facilities. The New York Times has done particularly well reporting over the years on the growing sophistication of North Korea's facilities and programs. *See generally* David E, Sanger, *North Koreans Unveil New Plant for Nuclear Use*, N.Y. TIMES (Nov. 20, 2010), https://www.nytimes.com/2010/11/21/world/asia/21intel.html [https://perma.cc/78YZ-KCE5]; Choe Sang-Hun, *North Korea's New Reactor Raises Fears of Increased Plutonium Production*, N.Y. TIMES (Dec. 22, 2023), https://www.nytimes.com/2023/12/22/world/asia/north-korea-nuclear-reactor-plutonium.html [https://perma.cc/3BZU-5BQQ]; Choe Sang-Hun, *North Korea Gives First Glimpse of Weapons-Grade Uranium Factory*, N.Y TIMES (Sep. 13, 2024), https://www.nytimes.com/2024/09/13/world/asia/north-korea-nuclear-weapons.html [https://perma.cc/KEF4-S4VS].

[139] *See generally* Joseph F. Bermudez Jr., *Yongbyon Declassified Part II: Progress on Building IRT-2000 Reactor*, BEYOND PARALLEL (July 16, 2018), https://beyondparallel.csis.org/yongbyon-declassified-part-ii/ [https://perma.cc/4YWR-2ULW].

[140] North Korea has built secret reactors or nuclear facilities not only in its own territory, but as far away as Syria. *See* King Mallory, *North Korean Sanctions: Evasion Techniques,* RAND Corp. 4–5, https://www.rand.org/content/dam/rand/pubs/research_reports/RRA1500/RRA1537-1/RAND_RRA1537-1.pdf [https://perma.cc/JH3E-7T65] (last visited Apr. 18, 2025).

[141] Consider how difficult it is to implement even the basic nuclear site best practices when a facility is hidden, unknown to local first responders or emergency room physicians, and unable to be

facilities in either natural caverns (in Iran or in the case of terrorist groups that may not be aligned with state actors) or excavated bunker facilities (in Iran and North Korea) pose special hazards, as they may be difficult to discover, but may also be difficult to properly ventilate, difficult to keep clean, and difficult to properly service with skilled technical support, fast containment response, or emergency medical services in the event of a mishap.[142]

Baby Boomer-generation Americans who grew up downwind from American above-ground nuclear weapons research tests (the eldest Western people exposed to nuclear weapons fallout) suffer health effects, such as higher cancer rates, even if they were thousands of miles from U.S. nuclear tests.[143] Having as few people as possible nonconsensually exposed to hazardous nuclear material, even in tiny quantities, is a positive policy outcome for all and should be viewed as universally desirable.[144]

D. Israeli 2024 Campaign as Risk Vector Example

As Israel's 2024 strikes in Beirut on alleged underground caches (with substantial collateral damage) show,[145] a nuclear laboratory mishap is not the only way clandestine locations may threaten unsuspecting civilian populations above. An actor seeking to disable a clandestine subterranean research facility might need to penetrate surface areas to reach it; U.S. Defense Secretary Lloyd

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accessed except by a small number of experts and high-clearance vetted officials. *See* Mingle, *supra* note 149; Int'l Atomic Energy Agency [IAEA], *IAEA Nuclear Energy Series: Industrial Safety Guidelines for Nuclear Facilities*, Publication No. NP-T-3.3 (Dec. 2018) (noting basic best practices).

[142] Urban tunnel projects are particularly difficult to design, maintain, and ensure safety around. *See* Rouzbeh Vakili, et al., *Geo-Structural Challenges for Advancing Tunnel Design and Construction*, 26 STRUCTURE MAG 12, 12–13 (2019).

[143] Steven Simon et al., *Fallout from Nuclear Weapons Tests and Cancer Risks*, 94 AM. SCIENTIST 48, 48–57 (2006).

[144] Even small doses of radiation can have substantial effects on both the health and longevity of humans, whether the exposure occurs during industrial/environmental accidents or as the result of warfare. *See generally* Kamiya Kenji-san et al., *Long-Term Effects of Radiation Exposure on Health*, 386 LANCET 469 (2015); Paul R. Erlich et al., *Long-Term Biological Consequences of Nuclear War*, 222 SCIENCE 1293 (1983).

[145] Laila Bassam & Riham Alkousaa, *Powerful Israeli Airstrike in Central Beirut Kills 20, Lebanese Health Ministry Says*, REUTERS (Nov. 23, 2024, 3:03 PM), https://www.reuters.com/world/middle-east/least-four-missiles-fired-strike-that-rocked-beirut-security-sources-say-2024-11-23/; *see also* William Christou, *Israel Claims Hezbollah Bunker Under Beirut Hospital Holds Millions of Dollars*, GUARDIAN (Oct. 21, 2024, 5:35 PM), https://www.theguardian.com/world/2024/oct/21/israel-claims-hezbollah-bunker-under-beirut-hospital-holds-millions-in-cash [https://perma.cc/P9HS-WNUW]. To destroy an underground nuclear research facility's bunker would be similar to, or more difficult than, destroying the contents of a bank vault in terms of damage to the surrounding area and structures. *See* William Christou, *Israeli Airstrikes on Lebanon Hit Branches of Hezbollah-Linked Bank*, GUARDIAN (Oct. 21, 2024, 12:34 PM), https://www.theguardian.com/world/2024/oct/21/israeli-airstrikes-on-lebanon-hit-branches-of-hezbollah-linked-bank-al-qard-al-hassan [https://perma.cc/V5ZV-GXRR].

Austin said[146] of a B-2 bomber[147] dropping a BGU-57 deep penetration munition, "This was a unique demonstration of the United States' ability to target facilities that our adversaries seek to keep out of reach, no matter how deeply buried underground, hardened or fortified."[148] This was a "demonstration" surely of interest to Tehran and Pyongyang.

In autumn 2024, Israel attempted to destroy hidden weapons, which are often stashed in Lebanese homes in the port cities of Beirut and Tyre,[149] to highlight the difficulty of segregating clandestine subterranean facilities from above-ground benign construction. Militarily important tunnels, underground rooms, and materiel troves are a common feature below the surface of Lebanon but cannot be attacked without collateral damage.[150] A social media message posted by the Israel Defense Forces ("IDF") on September 25, 2024[151] highlights the problem of military and civilian assets being vertically co-located:

> THIS is how close Hezbollah's weapons are located to communities in Israel. Each picture shows different civilian houses in southern Lebanon that had weapons ready to be used to kill Israelis. We are operating in this area in order to eliminate the presence of terrorist infrastructure that threatens our civilians.[152]

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[146] Jon Gambrell, *US Long-Range B-2 Stealth Bombers Target Underground Bunkers of Yemen's Houthi Rebels*, ASSOCIATED PRESS (Oct. 17, 2024), https://apnews.com/article/us-airstrikes-yemen-houthi-rebels-israel-hamas-war-99721f7f952d66d6da27e24dc3c189c3 [https://perma.cc/3MP6-5G5R].

[147] *See generally* Jon Harper, *Air Force Seeks More Survivable Bomber Fleet*, 102 NAT'L. DEF. 26 (2017) (discussing extensively the B-2 program and its possible successors).

[148] Gambrell, *supra* note 178.

[149] Stephen Farrell et al., *As It Happened: Israel Launched Airstrikes on Lebanon Monday, Hezbollah Fired Rockets Into Israel*, REUTERS (Sept. 24, 2024), https://www.reuters.com/world/live-updates-israel-mounts-airstrikes-hezbollah-lebanon-2024-09-23/; *see also* Tucker Reals & Chris Livesay, *Israel Launches Deadly Strikes on Hezbollah in Lebanon, Warns People in Beirut and Elsewhere to Evacuate*, CBS NEWS (Nov. 24, 2024, 9:59 AM), https://www.cbsnews.com/news/israel-lebanon-hezbollah-war-gaza-hamas-idf-airstrikes/ [https://perma.cc/9JUJ-LX99] ("Israel said it was targeting Hezbollah weapons hidden in residential buildings."); Maayan Lubell et al., *Lebanon Says Israeli Airstrikes Kill at Least 492, Residents Flee from South*, REUTERS (Sept. 24, 2024, 2:11 PM), https://www.reuters.com/world/middle-east/israeli-military-says-it-is-striking-hezbollah-targets-lebanon-2024-09-23/ ("Israel warned people in Lebanon to evacuate areas where it said the armed movement was storing weapons.").

[150] *See Israel Unearths a Web of Tunnels Used by Hezbollah in Southern Lebanon,* CBS News (Oct. 19, 2024, 8:34 AM), https://www.cbsnews.com/news/israel-unearths-hezbollah-web-tunnels-souther-lebanon-middle-east/ [https://perma.cc/BBJ2-QVGA] ("The Israeli military has combed through the dense brush of southern Lebanon for the past two weeks, uncovering what it says are Hezbollah's deep attack capabilities — highlighted by a tunnel system equipped with weapons caches and rocket launchers that Israel says pose a direct threat to nearby communities . . . . Israel says the tunnels are stocked with supplies and weapons and are outfitted with lighting, ventilation and sometimes plumbing, indicating they could be used for long stays.").

[151] Israel Defense Forces (@IDF), TWITTER (Sept. 25, 2024, 2:31 PM), https://x.com/IDF/status/1839024994829148290.

[152] *Id.*

The post was accompanied by a map overlay graphic showing the location of weapons stashes and the impracticability of destroying military assets of Hezbollah without harming nearby civilian structures.[153]

Similar issues have occurred throughout the conflict in Gaza[154] and, more recently, in the attempts to flush fighters and destroy resources in Lebanon and Yemen,[155] which are both places where weapons and combatants have been hidden under innocuous buildings. In late October 2024, the IDF revealed that over half a billion dollars of gold, diamonds, cash, and items related to valuable cryptocurrency wallets were hidden below a hospital in Lebanon.[156] "The bunker was deliberately placed under a hospital, and it holds more than half a billion dollars in cash and gold," said Rear Adm. Daniel Hagari.[157]

One can imagine Iran, North Korea, or a similar actor concealing nuclear weapons research or production locations in a similar context. A laboratory or weapons production facility under a hospital would be difficult to strike and dangerous to sabotage, risking destruction or contamination in the unaware civilian world above. But this collateral damage may not, by itself, be a sufficient deterrent, given recent events.[158] One way to reduce the total amount of nuclear

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[153] *Id.*

[154] *See* Aldofo. Arranz et al., *Inside the Tunnels of Gaza*, REUTERS (Dec. 31, 2023, 10:00 AM), https://www.reuters.com/graphics/ISRAEL-PALESTINIANS/GAZA-TUNNELS/gkvldmzorvb/ (noting while much has been written on these tunnels, the graphics in the REUTERS in-depth report on the topic are particularly illustrative.).

[155] *See* Chris Pandolfo & Yonat Frilling, *IDF Finds Hezbollah Weapons Cache in Underground Tunnel*, FOX NEWS (Dec. 28, 2024, 8:44 PM), https://www.foxnews.com/world/idf-finds-hezbollah-weapons-cache-underground-tunnel-video [https://perma.cc/BKK8-RBJ2]; *see also* Tom O'Connor, *Houthis Expand Underground Bases—That Could Be a Big Problem for the US*, NEWSWEEK (May 2, 2024, 11:33 AM), https://www.newsweek.com/houthis-expand-underground-bases-yemen-1896266 [https://perma.cc/KY2D-RPQL]; Jon Gambrell, *Stealth Bombers Unleash Attacks on Houthi Sites*, ARK. DEMOCRAT GAZETTE (Oct. 18, 2024, 3:21 AM), https://www.arkansasonline.com/news/2024/oct/18/stealth-bombers-unleash-attacks-on-houthi-sites/ [https://perma.cc/M4DS-VEFV] ("The Houthis have refurbished tunnels that once held Scud missiles when Yemen was ruled by strongman Ali Abdullah Saleh, according to an analysis in April by the International Institute for Strategic Studies. Those sites include the al-Hafa and Jebel Attan military bases, the former Presidential House and the Yemen state television compound in Sanaa, analyst Fabian Hinz wrote.").

[156] Israeli video later confirmed the presence of a bunker under al-Sahel Hospital in Beirut, which was identified on or before 21 Oct. 2024 by Israeli forces. ET Online, *Hezbollah Bunker Under Hospital Used for Financial Activities? Israel Releases Shocking Video of Hidden $500 Million in Gold, Cash*, ECON. TIMES, https://economictimes.indiatimes.com/news/international/global-trends/hezbollah-bunker-under-hospital-used-for-financial-activities-israel-releases-shocking-video-of-hidden-500-million-in-gold-cash/articleshow/114453152.cms [https://perma.cc/ER7P-DB7A] (Oct. 21, 2024, 5:30 PM).

[157] Louis Casiano, *Hezbollah Hiding More Than $500M in Gold, Cash Under Hospital in Lebanon, IDF Says*, FOX NEWS (Oct. 21, 2024, 9:54 PM), https://www.foxnews.com/us/hezbollah-hiding-500m-gold-cash-hospital-lebanon-idf-says [https://perma.cc/8JPW-KYUS] (noting Rear Adm. Hagari is referred to occasionally by the IDF, including within its website, as a Brigadier General, but in the Israeli system these are essentially synonymous NATO-OF-6-equivalent ranks).

[158] *How to Use "Maximum Pressure" to Stop an Iranian Bomb*, ECONOMIST (Jan. 30, 2025), https://www.economist.com/leaders/2025/01/30/how-to-use-maximum-pressure-to-stop-an-iranian-bomb [https://perma.cc/N9SP-XUVN] ("Hawks in Israel's government want to bomb Iran's nuclear sites.").

device research undertaken under such conditions and in problematic geographies is to publish approved, safe designs and thereby provide an alternative to the development of new indigenous nuclear devices.

VI. CONCLUSION

While an open-source archive of nuclear weapons designs is a perennially controversial proposition, my conviction that this is the correct policy to minimize risk to innocent civilians and the risk of nuclear accident during nuclear weapons development in nuclear-aspirant and newly-nuclear states has only hardened in the past decade-plus since the Author first discussed this concept. Further, the concept that nuclear energy technology (and, with it, nuclear weapons technology) will be restricted to a small number of highly-economically-developed, fundamentally-somewhat-aligned, and successfully-treaty-constrained actors is not only unlikely but almost inevitably incorrect. To say 1940s weapons technology will be forever contained by restricting knowledge is like saying only a dozen countries will be able to understand how to produce microwave ovens.

The mechanism (unilateral, caucus, treaty) for the creation of the archive and its periodic improvement or updating is less important than its conception and initial implementation. Without the creation of an open-source archive of basic designs and best practices, nuclear weapons development will occur in a haphazard, distributed, less-informed, and often clandestine way that is far more likely to lead to nuclear accidents, civilian casualties, and international misunderstandings. The current path will, left unchecked, punctuate the next century with an avoidable nuclear incident risk that is globally endemic, difficult to combat through surveillance, uninsurable in scale and scope, and impossible to police through diplomacy.

Policymakers at the highest levels of national and international coalitions must urgently consider the construction and release of an open-source archive of nuclear-weapons-technology-related knowledge to prevent, making unnecessary, basic empirical nuclear device research in, near, or below areas populated by innocent civilians. Acting today may save lives tomorrow.