STUDENT NOTES

Advanced Reactors and Nuclear Terrorism: Rethinking the International Framework

Cameron Tarry Hughes*

> *Nuclear technology . . . embodies a nearly unbelievable power to destroy, but at the same time an extraordinary power to create—to enrich our lives, to provide the electric power by which we may read at night, to produce potable water from the ocean's brine, to help cure deadly diseases, and to enable science and industry to advance in innumerable ways that can improve the quality of life for people in all societies.*[1]

INTRODUCTION

While nuclear energy today provides about 10% of global electricity generation in reliable, carbon-free form,[2] the immense destruction tied to its origins casts a long shadow. Nuclear reactors were first promoted as a means to turn the terrible power of the atomic weapon into a tool of "universal, efficient, and economic usage."[3] This tension between terrible and peaceful power underlies the expansive nonproliferation regime of international law, a framework meant to keep nuclear technology from being diverted from this peaceful use to weapons-making.

Now, with the advent of advanced reactors—a new class of nuclear reactor technology billed as cleaner, cheaper, and safer than traditional reactors—it is time to ask again: how do we keep this technology from being misused? This paper will address how advanced reactors will fit into the existing international legal framework that is meant to combat nuclear terrorism. It will argue that the international treaties, resolutions, and conventions which safeguard nuclear

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1. Christopher Ford, U.S. Special Representative for Nuclear Nonproliferation, The Promise and Responsibilities of Peaceful Uses of Nuclear Energy, Remarks to 19th Annual Conference on Disarmament Issues (Aug. 26, 2007) (transcript available online at https://perma.cc/LVT7-VURV).

2. *Nuclear Electricity*, INT'L ENERGY AGENCY (Sept. 2022), https://perma.cc/9PAG-ENTF.

3. President Dwight D. Eisenhower, Atoms for Peace Speech, Address Before the General Assembly of the United Nations in New York City (Dec. 8, 1953) (available online at https://perma.cc/2CMH-B97X).

technology from terrorist acquisition must be modified to fully account for the technological differences of advanced reactors from traditional reactors.

Advanced reactors are intended to and likely will be deployed to countries without existing nuclear programs, countries which may also be outside the realm of traditional nonproliferation-focused treaties or multistate organizations.[4] However, while some reactor designers claim that their design inherently supports nonproliferation regardless of an external protective regime, the focus of such "safer" designs is reducing *accidents* that cause release of radioactive material into the environment, either through passive cooling or fuel that withstands higher temperatures without cracking.[5] Whether such designs inherently make it more difficult to proliferate nuclear weapons is far less clear; in fact, some advanced reactor characteristics meant to increase safety likely require more attention to properly safeguard the technology.

At the same time, although the threat of proliferation has remained steady, the threat of terrorist acquisition and use of nuclear weapons has increased over the past few decades. While some states, namely North Korea, Iran, and Syria, have violated their nonproliferation commitments and tried to acquire nuclear weapons, their neighboring signatories to the Non-Proliferation Treaty have not followed suit.[6] In preventing widespread acquisition of nuclear weapons, then, the framework for nonproliferation has worked. On the other hand, terrorist groups have shown increasing willingness to cause widespread, sometimes indiscriminate harm compared to their politically targeted 1980s counterparts who targeted specific political organizations.[7] Since the turn of the century the world has seen al Qaeda destroy the World Trade Center, North Caucasus dissidents bomb the Boston Marathon, and the Islamic State (ISIL) execute coordinated attacks in Paris in November 2015, among other European incidents in the past decade. Meanwhile, the International Atomic Energy Agency received reports of 149 incidents of nuclear material going missing, some of which directly involved "illegal possession of, and attempts to sell, nuclear material or radioactive sources, with four of these incidents involving nuclear material" between 2013-2014 alone.[8]

4. *See, e.g.*, Alan Ahn, Josh Freed, Jake Kincer, Jessica Lovering, Todd Moss, Ryan Norman, & Lindsey Walter, *2022 Map of the Global Market for Advanced Nuclear: Emerging International Demand*, THIRD WAY (Oct. 24, 2022) https://perma.cc/MG8Z-RFKJ.

5. *See, e.g.*, *Molten Salt Reactors*, WORLD NUCLEAR ASS'N, https://perma.cc/7NTB-X776 (last updated May 2021) ("When tests were made on the [molten salt reactor], a control rod was intentionally withdrawn during normal reactor operations at full power (8 MWt) to observe the dynamic response of core power. Such was the rate of fuel salt thermal expansion that reactor power levelled off at 9 MWt without any operator intervention.").

6. William Tobey, *Squaring the Nonproliferation Circle*, 26 J. OF INT'L SEC. AFFS. 47, 48 (2014).

7. *See id.* at 48 (citing a 1986 declassified intelligence report and explaining al Qaeda's willingness to cause wide damage). *But see* Christopher McIntosh & Ian Storey, *Between Acquisition and Use: Assessing the Likelihood of Nuclear Terrorism*, INT'L STUD. Q. 289 (2018) (rejecting the idea that modern-day terrorists would use nuclear weapons).

8. Peri L. Johnson, *Facilitating the Entry into Force and Implementation of the Amendment to the Convention on the Physical Protection of Nuclear Material: Observations, Challenges and Benefits*, 94 NUCLEAR L. BULL. 9, 10 n.3 (2014).

This paper addresses a gap in scholarship by bringing together these two topics of contemporary relevance, advanced reactor technology and the threat of nuclear terrorism. Significant scholarship has occurred separately on international frameworks to combat terrorism and legal frameworks to license and trade advanced nuclear reactors. On the former, the committees of each Convention on terrorism meet every few years to review state implementation, new and existing threats, and new areas ripe for international cooperation. On the latter, state and international initiatives on advanced reactors are too numerous to count, but most relevant to this paper, the 2018 International Atomic Energy Agency (IAEA) Symposium on International Safeguards featured a plenary on how advanced reactor technology maps onto the existing safeguards scheme.[9]

First, this paper will provide a factual and legal background of three topics key to understanding these issues: (a) the technology of the different types of advanced reactors, (b) the nature of the threat posed by nuclear terrorism, and (c) a high-level overview of the international nonproliferation regime. This paper then evaluates each of the four primary international legal agreements focused on preventing nuclear terrorism and addressing potential gaps in each when mapped onto advanced reactor technology. Finally, this paper will evaluate the cross-cutting issues with fitting advanced reactor technology into this international framework, issues that may not address a particular legal provision of an agreement but still merit consideration to fully protect advanced reactor technology from misuse.

I. THE THREAT OF NUCLEAR TERRORISM IS STATISTICALLY SMALL BUT VERY REAL

Defining "nuclear terrorism" starts with defining "terrorism." There is no universal definition of terrorism, which can cover acts both individual and organized, and can be done for a variety of reasons.[10] Both the U.N. and the International Convention on the Suppression of Acts of Nuclear Terrorism have working definitions of terrorist *acts*.[11] For example, the latter act defines a terrorist act as one "intended or calculated to provoke a state of terror in the general public or in a group of persons or particular persons," excluding consideration of *why* such acts were committed.[12] Taking its cue from this Convention, keeping the definition of terrorism relevant to trade of nuclear reactors, this paper defines "terrorism" as

9. *See Programme Overview*, *IAEA Symposium on International Safeguards*, INT'L ATOMIC ENERGY AGENCY (Nov. 2018), https://perma.cc/7NU4-XQVF.

10. Walter Gehr, *The Universal Legal Framework Against Nuclear Terrorism*, 79 NUCLEAR L. BULL. 5, 8 (2007); Brecht Volders, *Building the Bomb: A Further Exploration of an Organizational Approach to Nuclear Terrorism*, 33 TERRORISM & POL. VIOLENCE 1012, 1014 (2021) ("Different studies of terrorism focus on different levels—such as the individual level or the organizational level—and come from a variety of backgrounds—such as international relations, political science, history, or communication studies.").

11. Gehr, *supra* note 10, at 8; S. C. Res. 1566 ¶ 2 (Oct. 8, 2004); International Convention on the Suppression of Acts of Nuclear Terrorism art. 6, *opened for signature* Sept. 14, 2005, T.I.A.S. No. 15-1030, 2445 U.N.T.S. 89 [hereinafter ICSANT].

12. ICSANT, supra note 11, at art. 6 ("[C]riminal acts within the scope of this Convention. . . are under no circumstances justifiable by considerations of a political, philosophical, ideological, racial,

non-state individuals or groups who commits the acts described in the U.N. Security Council Resolution 1566:

> criminal acts, including against civilians, committed with the intent to cause death or serious bodily injury, or taking of hostages, with the purpose to provoke a state of terror in the general public or in a group of persons or particular persons, intimidate a population or compel a government or an international organization to do or to abstain from doing any act, which constitute offences within the scope of and as defined in the international conventions and protocols related to terrorism.[13]

This definition covers both individual and organized action, recognizing that it is far more likely that a group can obtain a nuclear weapon than it would be for an individual.[14]

The threat of "nuclear terrorism" leverages a broad range of technology. To date, a terrorist attack has not yet involved a nuclear weapon, but such attacks have been considered before, making the possibility a credible threat.[15] Efforts to prevent nuclear terrorism largely focus on preventing a terrorist group from achieving "'operational' nuclear status." Operational status means possessing any of the many possible nuclear devices, from "sufficient weaponizable nuclear material" to an operational warhead, and then putting that that nuclear device into a "delivery system" such as an "extant warhead, rocket, truck, boat, shipping container, construction of an ad hoc device in situ."[16] Broadly, however, the threat of terrorist *acquisition* of nuclear weapons means a terrorist group acquiring either a fully-made nuclear weapon or enough highly enriched uranium to make a nuclear weapon.

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ethnic, religious or other similar nature and are punished by penalties consistent with their grave nature.").

13. S.C. Res. 1566, ¶ 3 (Oct. 8, 2004).

14. Volders, *supra* note 10, at 104-15, 1021 ("I have extrapolated from the Los Alamos case study that the organizational design of the group. . . shapes the resource allocation, the level of autonomy and information-sharing, and the clear and compelling goals.").

15. Alexis Rump, Patrick Ostheim, Stefan Eder, Cornelius Hermann, Michael Abend & Matthias Port, *Preparing for a "Dirty Bomb" Attack: the Optimum Mix of Medical Countermeasure Resources*, 8 MIL. MED. RSCH. 1, 2 (2021) ("In 1995 authorities found a container of radioactive cesium in Moscow's Ismailovsky Park after a TV station had been contacted about the cache. In 1998 a container filled with radioactive material was found attached to a mine hidden near a railway line in Chechnya. In 2004 a large number of household smoke detectors containing small quantities of americium-241 were found at a raid of a terrorist cell cache in London."). Additionally, the first National Security Strategy published post-9/11 acknowledged and planned for the possibility of rogue states transferring weapons of mass destruction to terrorist organizations. David S. Jonas & Christopher Swift, *Reformulating the Nuclear Nonproliferation Regime: Al-Qaeda, Global Terrorism, and the Rogue State Paradigm*, 13 UCLA J. INT'L L. & FOREIGN AFFS. 337, 342 (2008) (citing NATIONAL SECURITY STRATEGY OF THE UNITED STATES OF AMERICA 5, 14 (Sept. 17, 2002), available at https://perma.cc/JZ2V-UDGH).

16. McIntorsh & Storey, *supra* note 7, at 290 n.5.

There is significant debate about how realistic such a threat is.[17] Since intact nuclear weapons are often the pride of their respective countries' militaries, some consider it extremely unlikely a terrorist group could procure an intact weapon.[18] In that case, terrorists must acquire a nuclear weapon without help from state actors. Such acquisition could involve stealing highly enriched uranium or weapons technologies from sites in Russia, Belarus, or South Africa, for example.[19] This kind of theft is not impossible; the International Atomic Energy Agency has documented 320 incidents likely to be "connected with trafficking or malicious use" of nuclear material since 1993.[20]

On the other hand, given the financial and technical difficulties of acquiring a nuclear weapon, some scholars believe that the most likely scenario is a non-state actor procuring one directly from a state hostile to the United States. For instance, the United States has long been on guard against a non-allied state like Iran or Iraq acquiring and transferring a nuclear weapon to a terrorist group like Hezbollah or Al-Qaeda, respectively.[21] Some view the assistance of such states as not only possible, but necessary for terrorist acquisition of a nuclear weapon—one could argue that "[b]ut for the safe havens and financial support rogue state regimes provide, the prevailing presumption is that these otherwise marginal actors would lack the technical and material resources necessary to be considered threatening states. . ."[22]

Scholars have produced a volume of literature over the past decade with a range of predictions about the likelihood of terrorist acquisition of a nuclear device.[23] What is clear, however, is that the consequences would be quite serious, and that regardless of likelihood it is a threat to be taken seriously.[24] Most relevant to understanding how advanced reactors challenge the current paradigm is evaluating how the technological aspects of nuclear weapons procurement or development and map onto advanced reactor technology.

Given how difficult it is to enrich HEU to a grade useful for weapons, the most likely way a terrorist could make a nuclear weapon would be to acquire HEU or

17. MATTHEW BUNN, SECURING THE BOMB 2010: SECURING ALL NUCLEAR MATERIAL IN FOUR YEARS at v (2010) ("No one knows the real likelihood of nuclear terrorism.").

18. Naeem Salik, *Nuclear Terrorism: Assessing the Danger*, 38 STRATEGIC ANALYSIS 173, 177, 179 (2014).

19. BUNN, *supra* note 17, at viii.

20. *IAEA Incident and Trafficking Database, 2022 Factsheet*, INT'L ATOMIC ENERGY AGENCY, https://perma.cc/DAS4-WPQV.

21. Jonas & Swift, *supra* note 15, at 342.

22. Jonas & Swift, *supra* note 15, at 342-43.

23. For more reading on this topic, *see generally* BUNN, *supra* note 17; GORDON CORERA, SHOPPING FOR BOMBS: NUCLEAR PROLIFERATION, GLOBAL INSECURITY, AND THE RISE AND FALL OF THE A.Q. KHAN NETWORK (2006) (describing in-depth what was arguably the most famous rogue proliferation attempt).

24. Sharon Squassoni, *Nuclear Energy and Nonproliferation: Today's Challenges*, *in* BUSINESS AND NONPROLIFERATION: INDUSTRY'S ROLE IN SAFEGUARDING A NUCLEAR RENAISSANCE 17, 18 (John P. Banks & Charles K. Ebinger, eds., 2011) (quoting former IAEA Director General as saying, "The gravest threat the world faces today. . . is that extremists get hold of nuclear or radioactive materials.").

plutonium from a state, such as by stealing it from a stockpile or from the small, "easy-to-handle" HEU fuel units in a research reactor.[25] Once a terrorist has acquired enough HEU or plutonium, it is comparatively very easy to make a simple weapon.[26]

At a high level, making a nuclear weapon capable of achieving a fission chain reaction is a difficult task.[27] Creating an improvised nuclear device with, say, an explosive yield of one kiloton—the equivalent of 1,000 tons of TNT—would require a malicious actor to amass more than 8kg plutonium or 25kg highly enriched uranium.[28] Once such fissile material is acquired, a terrorist group would need to assemble experts in "nuclear physics, explosives chemistry, metallurgy, mechanical and electronic engineering and machining of special metals" to make the weapon components.[29] Then, a terrorist group must obtain "high explosives, precision machining equipment and a first-generation nuclear weapon design."[30]

While each of these steps would be logistically difficult, the most technologically difficult of these steps is acquiring the fissile material: highly enriched uranium (HEU) or plutonium.[31] Uranium found in nature—also called unenriched uranium—contains 99.3% of the uranium isotope U-238 and 0.7% of the isotope U-235.[32] Enrichment of 20% U-235 is "considered the baseline enrichment threshold for nuclear weapon use," although realistically only highly enriched uranium of 90% or more U-235 is considered "weapons grade."[33] Acquiring HEU involves separating the U-235 from U-238 and creating a mixture with a 20% or more U-235. This enrichment process is technically difficult because the

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25. Matthew Bunn & Anthony Wier, *Terrorist Nuclear Weapon Construction: How Difficult?* 607 ANNALS AM. ACAD. POL. & SOC. SCI. 133, 137 (2006).

26. R. Scott Kemp, *The Nonproliferation Emperor Has No Clothes*, 38 INT'L SEC. 39, 41-42; *Terrorists' Nuclear Capabilities*, COUNCIL ON FOREIGN RELS., https://perma.cc/7ZUF-BR47 (last updated Jan. 1, 2006, 7:00 AM) ("But other daunting problems remain, including recruiting scientific experts in a broad array of disciplines, obtaining specialized industrial equipment, and avoiding the chemical and radiological hazards inherent in working with nuclear materials and high explosives.").

27. Bunn & Wier, *supra* note 25, at 133-34 ("[A]n attack by nonstate terrorists using an actual nuclear explosive—self-made or stolen—would clearly be among the most difficult types of attack to carry out.").

28. Wyn Q. Bowen, Matthew Cottee & Christopher Hobbs, *Multilateral Cooperation and the Prevention of Nuclear Terrorism: Pragmatism Over Idealism*, 88 INT'L AFFS. 349, 352 (2012).

29. Salik, *supra* note 18, at 176-77. Also, the experts in these fields are "rare and . . . well known," making it unlikely that "these people could remain involved in the project for months or maybe a year without arousing the suspicion of their families, friends and/or government agencies." *Id.*

30. Bowen et al., *supra* note 28, at 352.

31. Kemp, *supra* note 26, at 41-42 (2014).

32. *Uranium Enrichment*, U.S. NUCLEAR REG. COMM'N, https://perma.cc/K3XH-KSEJ (last updated Dec. 2, 2020). An isotope is a way of classifying an atom of an element by its mass, specifically based on the number of neutrons the atom has. Puja Daya, *What are Isotopes?*, INT'L ATOMIC ENERGY AGENCY (Aug. 19, 2022), https://perma.cc/Z7LR-6TF6. This paper will use the traditional U- symbology to identify isotopes of uranium.

33. A. Nilsson, C. Jorant, A. Finan, E. Redmond & K. Luongo, *Identifying Preliminary Criteria for Safeguarding Advanced Nuclear Reactors*, at 3, IAEA-CN-267 (2018); Bunn & Wier, *supra* note 25, at 135.

two isotopes have "essentially identical chemical properties," and it is logistically difficult because separation techniques are "tightly-controlled" secrets.[34] Just possessing uranium far from guarantees creation of a nuclear weapon. For example, in 2014, ISIL conquered the Iraqi city of Mosul, home to Mosul University. The university allegedly had a 40kg stockpile of uranium, but because the uranium was unenriched at the time Mosul fell, experts on terrorism studies are not concerned about ISIL creating a nuclear warhead from this stockpile.[35]

Plutonium, the other fissile material used in nuclear weapons, does not occur in nature and is made when U-238 absorbs extra neutrons, meaning it can be produced as a byproduct of fission in a nuclear reactor. While weapons grade plutonium means a concentration of 90% Pu-239, plutonium "of any isotopic composition other than those with very large fractions of Pu-238 is 'weapon-usable.'"[36] In any amount, plutonium is technologically easier to enrich than uranium because one must remove different elements rather than different isotopes; however, plutonium enrichment is logistically difficult because the process is highly radioactive, usually requiring heavily shielded equipment and some remote-handled equipment.[37]

For any type of threat, the preventative focus is on safeguards. Safeguarding efforts focus on preventing "dual use" technology—technology that can be used for either a civilian or a military purpose—from being used to create a nuclear weapon. In the context of nuclear energy, an effective safeguards regime prevents components within the nuclear energy life cycle, such as uranium enrichment technology, from being used for non-energy purposes. This next section will explain the technology of advanced reactors with a focus on which technological elements may pose a dual-use opportunity and thus need to be safeguarded.

II. What Are Advanced Reactors?

This section will explain advanced reactor technology, divided into three broad technological categories: molten salt reactors, high-temperature reactors, and fast reactors. Then, this section will detail how the design of each category of reactor could support nonproliferation efforts without needing additional treaties.

34. Bunn & Wier, *supra* note 24, at 135.

35. Anna Bella Korbatov, Erika Suzuki & Bethany L. Goldblum, *The Fight Against Nuclear Terrorism Needs Global Cooperation—and the IAEA*, 71 BULL. ATOMIC SCIENTISTS 67, 67-68 ("Intelligence sources later learned that the seized nuclear materials were not enriched and that there was little chance they could be used for weapons fabrication; the unenriched uranium posed more risk as a toxin than as an improvised nuclear device."). Note, however, that ability to create a nuclear warhead is separate from ability to create a cruder weapon like a dirty bomb. *See* Gregory S. Jones, *ISIS and Dirty Bombs*, THE RAND BLOG (June 3, 2016), https://perma.cc/DUM4-AG94.

36. Bunn & Wier, *supra* note 25, at 136.

37. *How Do Nuclear Weapons Work?*, UNION OF CONCERNED SCIENTISTS, https://perma.cc/Y5DR-W4GS (last updated Jul. 12, 2018).

A. Overview of Advanced Reactor Technology

When most people think of a nuclear reactor, they think of a reactor designed in the 1950s: a massive orb of concrete and steel that produces over 1000 MW of power per unit—each unit enough to power at least half a million homes.[38] These traditional reactors use water as a moderator[39] and run on fuel rods containing some mixture of the fissile isotope U-235[40] An advanced reactor is any nuclear reactor with significant technological advancements over this existing thermal reactor structure.[41] While some definitions of advanced reactors include small water-cooled reactors, this paper adopts a definition of advanced reactors that excludes water-cooled reactors since this definition is both clearer and more widely used.[42] These non-water-cooled advanced reactors generally fall into three technological categories: molten salt reactors, high-temperature gas reactors, and fast reactors.[43]

This section provides an explanation of these three categories of advanced reactor, namely their technological differences from traditional water-cooled reactors.

38. *Nuclear Power Reactors*, WORLD NUCLEAR ASS'N https://perma.cc/8RNG-4KTE (last updated Mar. 2023) (explaining the basic design of a nuclear reactor); *What is a Megawatt?*, UTILIPOINT (Feb. 24, 2012), https://perma.cc/38LM-Y9LR (explaining electricity measurements and stating that 1 MW at 75% capacity can power between 460,000 and 900,000 homes depending on regional use norms); *U.S. Nuclear Capacity Factors: Resiliency and New Realities*, AM. NUCLEAR SOC'Y (May 29, 2020, 5: 30PM), https://perma.cc/WMJ6-MUFY (showing nuclear reactors in the United States run at a capacity factor of about 90%); WORLD NUCLEAR ASS'N, WORLD NUCLEAR PERFORMANCE REPORT 2022 at 6 Fig. 4 (available at https://perma.cc/FCM7-CVUR) (showing global nuclear capacity factor of about 80%).

39. A moderator slows down the neutrons released by fission. By slowing them down, the moderator helps sustain a chain reaction. *NUCLEAR 101: How Does a Nuclear Reactor Work?*, U.S. DEP'T OF ENERGY (Mar. 29, 2021), https://perma.cc/QT9X-QHJG.

40. *Nuclear Power Reactors*, WORLD NUCLEAR ASS'N https://perma.cc/8RNG-4KTE (last updated Mar. 2023); *Neutron Moderator*, ENERGY EDUC., https://perma.cc/Q545-YFNR.

41. MARK HOLT, CONG. RSCH. SERV., R45706, ADVANCED NUCLEAR REACTORS: TECHNOLOGY OVERVIEW AND CURRENT ISSUES (2019) ("An "advanced nuclear reactor" is defined in legislation enacted in 2018 as "a nuclear fission reactor with significant improvements over the most recent generation of nuclear fission reactors."); *Advanced Nuclear Power Reactors*, WORLD NUCLEAR ASS'N https://perma.cc/G533-PDWF (last updated Apr. 2021) (categorizing advanced reactors as "clean, safe and cost-effective means of meeting increased energy demands on a sustainable basis, while being resistant to diversion of materials for weapons proliferation and secure from terrorist attacks"); Vincent Gonzales & Lauren Dunlap, *Advanced Nuclear Reactors 101*, RESOURCES FOR THE FUTURE (Mar. 26, 2021), https://perma.cc/NW53-KM5S ("These advanced nuclear reactors extend beyond traditional reactors, offering the opportunity of safer, cheaper, and more efficient generation of emissions-free electricity, as well as heat for industrial processes.").

42. *See* MARK HOLT, CONG. RSCH. SERV., R45706, ADVANCED NUCLEAR REACTORS: TECHNOLOGY OVERVIEW AND CURRENT ISSUES (2019). This paper also excludes fusion reactors, which have fundamentally different physics at play and hence different fuel, containment, systems, and risk. Cameron Tarry, *Fusion 101*, CLEARPATH (Apr. 30, 2020), https://perma.cc/VLF6-CWJ8.

43. MARK HOLT, CONG. RSCH. SERV., R45706, ADVANCED NUCLEAR REACTORS: TECHNOLOGY OVERVIEW AND CURRENT ISSUES 1 (2019) (categorizing non-water-cooled reactors as high temperature gas reactors, fast reactors, and molten salt reactors); Nilsson et al., *supra* note 33, at 2 (using a three category breakdown but defining high-temperature gas-cooled reactors by their most common fuel, TRISO fuel).

1. Molten Salt Reactors

Molten salt reactors are reactors in which fissile material[44] is dissolved in a liquid salt, usually a fluoride or chloride salt.[45] While current water-cooled reactors use uranium-based fuel, the fissile material for molten salt reactors can be thorium, uranium, or plutonium.[46] Because the fuel is liquid, a molten salt reactor can be refueled while operating instead of needing to shut down every 18-24 months to refuel.[47] This "online refueling" also means that fission products can be constantly removed while the reactor is operating, such as by an adjacent reprocessing loop.[48] This constant operation and removal means that the fuel within the reactor retains fuel-quality amounts of the fissile material for much longer, leading to higher burnup and less waste.[49] Removal of fissile material has the added benefit of reducing the likelihood of escaping radiation; when fission products are removed, there is less decay heat emanating from the reactor core, so in case of a reactor shutdown the core is unlikely to overheat and cause a safety incident. The impacts that this design change has on safeguards will be discussed later in this paper.

2. High-temperature Gas-cooled Reactors

High-temperature gas-cooled reactors (high-temperature reactors) use coolants that operate at high temperatures of 700-1,000˚C, compared to 330˚C for light-water thermal reactors.[50] The defining feature of high-temperature reactor design is the encapsulated fuel used in them.[51] The most prominent fuel design is tri-isotropic (TRISO) pellets, a millimeter-wide particle of uranium fuel covered in three layers of coating.[52] TRISO pellets are more resistant to neutron irradiation,

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44. Fissile material is material "capable of undergoing fission after capturing low-energy thermal (slow) neutrons." This definition includes U-235 and Pu-239. *Fissile Material*, U.S. NUCLEAR REGUL. COMM'N, https://perma.cc/LMR3-ZA6L (last updated Mar. 9, 2021).

45. Andrew Worrall, Benjamin R. Betzler, George Flanagan, David Eugene Holcomb, Jianwei Hu, Donald N. Kovacic, A. L. Qualls & Louise G. Worrall, Symposium on International Safeguards, *Molten Salt Reactors and Associated Safeguards Challenges and Opportunities* 1 (2018).

46. *Id.*; *Molten Salt Reactors*, WORLD NUCLEAR ASS'N, https://perma.cc/LSB7-HB8V (last updated May 2021).

47. *Nuclear Power Reactors*, WORLD NUCLEAR ASS'N, https://perma.cc/8RNG-4KTE (last updated Mar. 2023).

48. Worrall et al., *supra* note 45, at 1; *Molten Salt Reactors*, WORLD NUCLEAR ASS'N, https://perma.cc/LSB7-HB8V (last updated May 2021).

49. *Molten Salt Reactors*, WORLD NUCLEAR ASS'N, https://perma.cc/LSB7-HB8V (last updated May 2021).

50. MARK HOLT, CONG. RSCH. SERV., R45706, ADVANCED NUCLEAR REACTORS: TECHNOLOGY OVERVIEW AND CURRENT ISSUES 8 (2019). Because they can produce such high heat in addition to electricity, high-temperature reactors are attractive for deep decarbonization as an industrial heat replacement source. *Gas Cooled Reactors*, INT'L ATOMIC ENERGY AGENCY, https://perma.cc/AN3J-DWFN.

51. Nilsson et al., *supra* note 33, at 2-3; MARK HOLT, CONG. RSCH. SERV., R45706, ADVANCED NUCLEAR REACTORS: TECHNOLOGY OVERVIEW AND CURRENT ISSUES 8 (2019).

52. Int'l Atomic Energy Agency, *High Temperature Gas Cooled Reactor Fuels and Materials*, at 19-20, IAEA Doc. TECDOC-1645 (Mar. 2010).

have natural containment of the fissile material from the coatings, and can withstand extreme temperatures within a reactor without melting.[53] The uranium in TRISO pellets are enriched to a higher level than current thermal reactor fuel—8-20% enrichment compared to 3-5%.[54] In some designs the pebbles can be added while the reactor is operating.[55] In addition to the above benefits from the TRISO pellets, most high-temperature reactor designs have "passive" safety features. For example, many have passive cooling systems that remove decay heat by conduction and radiation heat transfer through other outlets in the reactor itself.[56]

3. Fast Reactors

When atomic fission occurs in a nuclear reactor, the atom releases its neutrons are released at high speed. In thermal reactors used today, the neutrons are slowed down by collision with molecules in the reactor coolant—hydrogen in water-cooled reactors, deuterium in heavy water-cooled reactors, and carbon or graphite in gas-cooled reactors.[57] In a fast reactor, those neutrons are not slowed down, but fission when colliding with other fissile material at a high speed.[58] This difference in fission means that fast reactors work best when fuel is not primarily U-235 like in fuel today, but instead is based on plutonium, americium, or U-238.[59]

Fast reactors have one key danger: plutonium. If not using plutonium for fuel, some designs can still breed plutonium, which could be used to create weapons-grade fissile material if separated from the uranium mixture.[60] Some reactors tackle this problem in design. For example, Russia's BREST fast reactor and the

53. *TRISO Particles: The Most Robust Nuclear Fuel on Earth*, U.S. DEP'T OF ENERGY (July 9, 2019), https://perma.cc/9GJF-SJ6P (implying that resistance to neutron irradiation means better fuel performance); Nilsson et al., *supra* note 33, at 2. In a traditional, large water-cooled reactor, part of the reactor design is a containment vessel: a building or shell meant to "confine fission products that otherwise might be released to the atmosphere in the event of an accident." *Containment Structure*, U.S. NUCLEAR REG. COMM'N, https://perma.cc/YXZ9-UM8L (last updated Mar. 9, 2021). If a fuel itself has containment properties, that means the fuel is doing the work that would be expected of that additional building or shell—the consequence being it's much harder to have an accident since the fuel wouldn't release fission products in the first place.

54. Nilsson et al., *supra* note 33, at 2; *Uranium Enrichment*, U.S. NUCLEAR REGUL. COMM'N, https://perma.cc/SX4K-WD8Z (last updated Dec. 2, 2020). The X-energy Xe-100 high temperature reactor will take TRISO pellets enriched to 15.5%. *X-energy is Developing a Pebble Bed Reactor That They Say Can't Melt Down* U.S. DEP'T OF ENERGY (Jan. 5, 2021), https://perma.cc/YUQ4-TCXF.

55. Yongde Liu, Bing Xia, Jiong Guo, Yujie Dong, Zaizhe Yin & Zuoyi Zhang, Symposium on Int'l Safeguards, *Safeguards Challenges and Consideration on Nuclear Safeguards for HTR-PM* 2 (2018). China's HTR-PM and X-energy's Xe-100 are examples of this. *See id.* at 1; *see also X-energy is Developing a Pebble Bed Reactor That They Say Can't Melt Down*, U.S. DEP'T OF ENERGY (Jan. 5, 2021), https://perma.cc/YUQ4-TCXF.

56. *See* Yongde Liu et al., *supra* note 55, at 1-2. For example, the Chinese HTR-PM reactor design has a long (11m) and thin (3m) reactor core to allow for easy natural heat dissipation. *Id.*

57. Fast Reactor Technology, ARGONNE NAT'L LAB'Y, https://perma.cc/6GDH-NRKV (last updated Apr. 1, 2020).

58. *Id.*

59. Fast Reactor Technology, ARGONNE NAT'L LAB'Y, https://perma.cc/6GDH-NRKV (last updated Apr. 1, 2020); *Fast Neutron Reactors*, WORLD NUCLEAR ASS'N, https://perma.cc/5GY6-JQH2 (last updated Aug. 2021).

60. *See* Nilsson et al., *supra* note 33, at 5.

French Atomic Energy Commission's gas-cooled fast reactor breed plutonium in their cores instead of in a blanket assembly outside the core, making it more technically difficult to illicitly remove plutonium.[61] Fast reactors without these additional design features could require special safeguards.

B. Advanced Reactors Are Often Designed With Built-in Nonproliferation Safeguards

Given the seriousness of nuclear proliferation and the extent of the international legal scheme built to prevent it, the engineers behind many advanced reactors designed them to reduce amount of proliferable material available globally or to make proliferation more difficult. For one, molten salt reactors are designed to reduce the amount of plutonium or other spent nuclear material that needs to be stored, which can reduce the world's stockpiles of plutonium. Those molten salt reactors that take plutonium fuel can use the plutonium from thermal reactor spent fuel; taking spent plutonium as fuel in addition to producing less waste in the first place means that operational molten salt reactors help reduce the global amount of spent nuclear material needing to be stored, safeguarded, and monitored.[62]

Some features of high-temperature reactors support nonproliferation goals as well. Although the uranium in TRISO pellets is enriched to a higher level—8–20% compared to the traditional 3-5%—that enrichment is still below the 20% threshold defined as HEU that poses a realistic proliferation threat.[63] Even with its slightly higher enrichment level, TRISO fuel reaches high burnup compared to traditional fuel, making it arguably less attractive as a material for proliferation because there is a lower end quantity of plutonium.[64] Additionally, because TRISO pellets are designed to withstand high pressures and temperatures within a reactor core, they are impossible to use as radioactive material in a "dirty bomb"—a type of nuclear weapon that combines an explosive like dynamite

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61. *Fast Neutron Reactors*, WORLD NUCLEAR ASS'N, https://perma.cc/5GY6-JQH2 (last updated Aug. 2021). Russia is the furthest in developing fast reactors, with its BN-800 in Beloyarsk already testing the use of reprocessed MOX fuel on an industrial scale. E.N. Avrorin, A.V. Gulevichm V.A. Simonenko & A.N. Chebeskov, *Fast Reactors, Fuel Cycles and Problem of Nuclear Nonproliferation* , at 2, IAEA Doc. CN 245-104 (2018).

62. *Molten Salt Reactors*, INT'L ATOMIC ENERGY AGENCY, https://perma.cc/SPP7-BP2D. Canada is already exploring this benefit: UK company Moltex Energy is constructing a demonstration 300 MW-electric "Stable Salt Reactor" in New Brunswick, Canada. The Moltex SSR-W uses a liquid chloride salt fuel with 25% reactor-grade plutonium, and once operational it will consume the spent plutonium fuel produced by Canada's CANDU thermal reactors. *Molten Salt Reactors*, WORLD NUCLEAR ASS'N, https://perma.cc/LSB7-HB8V (last updated May 2021); *Moltex Energy Canada*, CANADA'S SMALL MODULAR REACTOR ACTION PLAN, https://perma.cc/WD4E-J24W (last updated Dec. 18, 2020).

63. Nilsson et al., *supra* note 33, at 2 (describing TRISO pellet enrichment); *Uranium Enrichment*, U.S. NUCLEAR REG. COMM'N, https://perma.cc/SX4K-WD8Z (last updated Dec. 2, 2020). The X-energy Xe-100 high temperature reactor will take TRISO pellets enriched to 15.5%. *X-energy is Developing a Pebble Bed Reactor That They Say Can't Melt Down*, U.S. DEP'T OF ENERGY (Jan. 5, 2021), https://perma.cc/YUQ4-TCXF.

64. Yongde Liu et al., *supra* note 55, at 2 (explaining the lower proliferation risk of high-temperature reactors).

with radioactive material to disperse the radioactive material for wide contamination.[65]

Fast reactors have several technological differences from thermal reactors that may be relevant to nonproliferation. First, the concentration of fissile isotopes in both fresh and spent fuel is several times higher than it is in fuel for thermal reactors. Second, liquid metal or salt coolants are used, which are opaque and make it more difficult for outsiders to visually inspect the fuel assemblies. Third, the "breeders" used to burn fuel more efficiently can produce plutonium, potentially requiring special controls. Finally, the closed cycle of fast reactors means reprocessing—the separation of uranium from plutonium in spent fuel—is a necessary part of the reactor system.[66]

The different ways that advanced reactors are designed compared to traditional thermal reactors means that the existing nonproliferation and anti-terrorist scheme must be adapted to account for advanced reactors' technological differences.

III. THE TREATIES, CONVENTIONS, AND RESOLUTIONS ON NONPROLIFERATION AND TERRORISM MUST BE MODIFIED TO ACCOMMODATE THE CURRENT ADVANCED REACTOR DESIGNS

A. *Overview of the Existing Nonproliferation and Anti-terrorist Regimes*

This paper addresses two broad types of legal agreements: nonproliferation and anti-terrorist. "Nuclear proliferation" means the acquisition of nuclear weapons by states that did not previously have them. "Nonproliferation" refers to the efforts to stop this wider acquisition.[67] "Anti-terrorist" means preventing non-state actors from using nuclear weapons to commit terrorist acts.

When applied to nuclear weapons, both types of agreements face the challenge that much nuclear technology is dual-use and can be used both for peaceful and military purposes. Further, the market for nuclear materials is global and involves many non-state actors, making it challenging for international watchdogs to track potential proliferation activity.[68]

The core of the nonproliferation regime is the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and the IAEA safeguards system created to support it.[69] This legal structure is supplemented by the Convention on the Physical

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65. *Id.*; *Backgrounder on Dirty Bombs*, U.S. NUCLEAR REG. COMM'N (Feb. 23, 2022), https://perma.cc/3QTC-NKYU.

66. Avrorin et al., *supra* note 61, at 3; CONG. RSCH. SERV., RS22542, NUCLEAR FUEL REPROCESSING: U.S. POLICY DEVELOPMENT 1 (2008).

67. TOM COPPEN, THE LAW OF ARMS CONTROL AND THE INTERNATIONAL NON-PROLIFERATION REGIME: PREVENTING THE SPREAD OF NUCLEAR WEAPONS 2 (Koninklijke Brill NV 2016).

68. *Id.* at 6; John P. Banks & Charles K. Ebinger, *Introduction: Planning a Responsible Nuclear Energy Future*, *in* BUSINESS AND NONPROLIFERATION: INDUSTRY'S ROLE IN SAFEGUARDING A NUCLEAR RENAISSANCE 1, 7 (John P. Banks & Charles K. Ebinger, eds., 2011) ("Companies operating in the civilian nuclear industry serve as a lynchpin in this [nonproliferation] system."); *see, e.g.*, *Members*, NUCLEAR SUPPLIERS ASS'N (2018), https://perma.cc/2ZQM-7N4Z.

69. *See* COPPEN, *supra* note 67, at 4.

Protection of Nuclear Material (CPPNM), which regulates protection of nuclear material in transportation, as well as state-level trade controls and non-legal international organizations like the Nuclear Suppliers Group.[70] Although the regime is international in scope, its details are local: nonproliferation requirements largely place the burden on state-level actors, namely by establishing national licensing regimes and export controls.

The international anti-terrorist framework was bolstered after 9/11 with the adoption of two key agreements: the International Convention for the Suppression of Acts of Nuclear Terrorism (ICSANT) and U.N. Security Council Resolution (UNSCR) 1540. Broadly speaking, ICSANT places requirements on states to strengthen their domestic laws against terrorism, while UNSCR 1540 creates a global cooperative entity to facilitate state-to-state assistance in combatting terrorism. As with nonproliferation treaties and organizations, much of the focus is on states in these anti-terrorist structures.

Despite different purposes, nonproliferation treaties and anti-terrorist treaties employ similar tools and therefore share similar defects. The purpose of nonproliferation treaties is to prevent states from developing nuclear capabilities in their national militaries.[71] The purpose of anti-terrorist nuclear treaties is, as the names imply, preventing non-state actors from acquiring nuclear weapons or enough nuclear material to conduct nuclear terrorism. For both types of treaties, international cooperation is vital. Dozens of countries possess nuclear material, requiring international harmonization of state-level protection; furthermore, trade of nuclear material and technology is inherently global, necessitating supranational structures and standards to protect that material and technology from being stolen.[72]

This section explains the basics of the key treaties for nonproliferation and anti-terrorism and points out their gaps as applied to advanced reactors. Much of the content of these treaties can reasonably cover advanced reactors; the most significant gaps lie in treaty implementation, which relies on states to understand and effectively regulate the untested technology of advanced reactors.

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70. *See* COPPEN, *supra* note 67, at 10; *Convention on the Physical Protection of Nuclear Material (CPPNM) and its Amendment*, INT'L ATOMIC ENERGY AGENCY, https://perma.cc/Q4GU-P44Z; *The Nuclear Suppliers Group (NSG) at a Glance*, ARMS CONTROL ASS'N, https://perma.cc/42GY-PQN6 (last updated Mar. 2022).

71. *See, e.g.*, Statute of the International Atomic Energy Agency art. III(A)(5), Oct. 23, 1956 (listing a purpose of the IAEA as "[t]o establish and administer safeguards designed to ensure that special fissionable and other materials, services, equipment, facilities, and information. . . are not used in such a way as to further any *military purpose*; and to apply safeguards. . . to any of that *State's* activities in the field of atomic energy") (emphasis added) [hereinafter IAEA Statute].

72. BUNN, *supra* note 17, at 10; *see also, e.g.*, G.A. Res. 60/288 (Sept. 8, 2006) (encouraging cooperating not only among state-level actors, but regional and subregional organizations to thoroughly protect against terrorism).

B. Treaty on the Non-Proliferation of Nuclear Weapons

1. What the Treaty Does

The Treaty on the Non-Proliferation of Nuclear Weapons (NPT) is the "cornerstone of the global nuclear non-proliferation regime."[73] Opened for signature in 1968, the NPT has since been signed by 191 states, including all five nuclear weapon states.[74] The NPT is structured around three pillars: nonproliferation of nuclear weapons; peaceful uses of nuclear energy; and disarmament of nuclear weapons.[75] While the NPT upholds the "inalienable" right to use peaceful nuclear energy, it does not automatically guarantee the same right to develop "sensitive nuclear technologies" that can be used for either peaceful or non-peaceful purposes; enriching uranium and reprocessing spent fuel are two of these sensitive technologies.[76] Non-nuclear weapon state signatories promise "not to manufacture or otherwise acquire" nuclear weapons; in turn, nuclear weapons states promise not to transfer any nuclear weapons to such states or assist them in manufacturing nuclear weapons.[77] Thus, a nuclear weapon state—three of which export nuclear reactor technology[78]—can help a non-nuclear weapon state develop a nuclear energy program, but the general consensus is that for any technology which could be diverted to weapons production, that developmental assistance must go hand-in-hand with safeguards.[79]

73. UNITED Nations, *Treaty on the Non-Proliferation of Nuclear Weapons*, https://perma.cc/RQS2-6KD3.

74. *Id.*

75. DANIEL H. JOYNER, INTERPRETING THE NUCLEAR NON-PROLIFERATION TREATY 75 (2011).

76. *Safeguards to Prevent Nuclear Proliferation*, WORLD NUCLEAR ASS'N, https://perma.cc/87ZF-N28B (last updated Apr. 2021). "Sensitive nuclear technology" is "any information (including information incorporated in a production or utilization facility or important component part thereof) which is not available to the public and which is important to the design, construction, fabrication, operation or maintenance of a uranium enrichment or nuclear fuel reprocessing facility . . ." Nuclear Nonproliferation Act of 1978 § 3203, 22 U.S.C. § 3201 et seq.

77. Treaty on the Nonproliferation of Nuclear Weapons arts. I, II, *opened for signature* July 1, 1968, 21 U.S.T. 483, 729 U.N.T.S. 161 [hereinafter NPT].

78. The three nuclear weapons states of United States, Russia, and China manufacture and export nuclear reactor technology. *See* Westinghouse Electric Company, *Westinghouse Selected for Poland's New Nuclear Power Program*, WESTINGHOUSE (Nov. 2, 2022) https://perma.cc/547Z-83VV (United States); Dr. Matt Bowen & Hon. Paul Dabbar, *Reducing Russian Involvement in Western Nuclear Power Markets*, COLUM. CTR. ON GLOB. ENERGY POL'Y (May 23, 2022), https://perma.cc/22K8-3M4X ("42 of [the reactors] in operation in other countries were of the Russian VVER type. . . [and] 15 Russian-designed reactors were under construction in other nations.") (Russia); Merlin Boone, *A Tale of Misadventure on China's Atomic Belt and Road*, U.S.-CHINA PERCEPTION MONITOR (May 21, 2022), https://perma.cc/WSP2-NK4E (China). France builds and operates nuclear reactors in France and the UK only. EDF, *Nuclear Generation* (Oct. 2022), https://perma.cc/6XSX-NFPS.

79. *See, e.g.*, Christopher Ford, *Nuclear Technology Rights and Wrongs: The NPT, Article IV, and Nonproliferation*, *in* REVIEWING THE NUCLEAR TREATY 237, 237-38, 271. (Henry Sokolski, ed., 2010); *see also* Robert Zarate, *The NPT, IAEA Safeguards and Peaceful Nuclear Energy: An 'Inalienable Right,' but Precisely to What?*, *in* FALLING BEHIND: INTERNATIONAL SCRUTINY OF THE PEACEFUL ATOM 226, 267 (Henry D. Sokolski, ed., 2008).

Safeguards are the treaty's method of achieving the nonproliferation goal.[80] Under Article III, non-nuclear weapon states must enter into safeguards agreements with the IAEA so that the IAEA can verify a state is not diverting nuclear technology from peaceful energy uses to weapons uses.[81] More specifically, the IAEA undertakes four processes to implement safeguards: (i) collecting and evaluating information; (ii) developing a state-level safeguards approach; (iii) planning, conduct, and evaluation of safeguards activities both at nuclear sites and from IAEA headquarters; and (iv) analyzing and drawing conclusions about the information collected.[82] Information comes from the states themselves, from independent IAEA verification and evaluation, and from open sources or third parties.[83]

Since 2005, the IAEA has implemented safeguards under the "state-level concept" instead of judging the effectiveness of safeguards as "the extent to which the safeguards objective is attained," as some have described it, the IAEA focuses on a state's success in complying with its safeguards obligations, which are laid out in states' agreements under the NPT.[84] This state-level focus means that safeguards can be narrowly tailored to the state's particular relationship to nuclear material and facilities.[85] In case of non-compliance or detection that nuclear material has been diverted "for purposes unknown," the IAEA inspector writes a report and submits it to the IAEA Board of Governors; the Board then considers which of the actions in Article XII.C of the IAEA Statute to take, including requiring the State to remedy its non-compliance, reporting the non-compliance to the U.N. General Assembly, and if the state does not remedy the issue, suspending assistance to the member state or any rights and privileges associated with IAEA membership.[86]

In practice, IAEA safeguards involve many physical tools, including sampling of environmental and nuclear material, applying seals to nuclear material and equipment, and monitoring nuclear facilities with surveillance cameras and other remote tools.[87] During different stages in a facility's lifecycle, inspectors conduct

80. *See* NPT, *supra* note 77 at Preamble ("Undertaking to co-operate in facilitating the application of International Atomic Energy Agency safeguards on peaceful nuclear activities. . .").

81. NPT, *supra* note 77, arts. III.1, III.4.

82. INT'L ATOMIC ENERGY AGENCY, IAEA SAFEGUARDS: SERVING NUCLEAR NON-PROLIFERATION 4-5 (2021).

83. *Id.* at 5.

84. Valery Bytchkov & Jill N. Cooley, *IAEA Safeguards System: Implementing the State-Level Concept*, *in* THE FUTURE OF IAEA SAFEGUARDS: REBUILDING THE VIENNA SPIRIT THROUGH RUSSIAN-U.S. EXPERT DIALOGUE 28-29 (Nuclear Threat Initiative, 2020).

85. Bytchkov & Cooley, *supra* note 84, at 31. For example, in developing a state level approach to safeguards, the IAEA will consider the state's nuclear fuel cycle and related technical capabilities, the state's accounting for and control of nuclear material, and the level of cooperation and experience the IAEA has with that state. *Id.*

86. IAEA Statute, *supra* note 71, at art. XII.C; John Carlson, Vladimir Kuchinov & Thomas Shea, *The IAEA's Safeguards System as the Non-Proliferation Treaty's Verification Mechanism*, NUCLEAR THREAT INITIATIVE 18 (2020).

87. *IAEA Reports on Nuclear Plant Operation and Safeguards*, NUCLEAR ENG'G INT'L (June 30, 2020) https://perma.cc/T3GM-RY8H.

safeguards visits to confirm that a design matches what was declared, that no modifications have been made, and that the equipment installed is appropriate for containing sensitive materials. IAEA representatives also conduct inspections both routinely and randomly once a facility is in operation.[88] Under the Additional Protocol to the NPT, state representatives grant IAEA inspectors access to such facilities and provide information about the state's research, development, manufacture, and export of nuclear technologies for IAEA verification.[89] To date, 139 states plus Euratom have signed Additional Protocol agreements with the IAEA.[90]

The very purpose of the NPT is to prevent *state* proliferation of nuclear weapons. However, the IAEA safeguards regime mandated by the NPT form the backbone of nonproliferation efforts regardless of actor by providing such a robust method of monitoring and verifying nuclear material. Further, if states are tracking and reporting their use of nuclear materials, it follows that watchdogs like the IAEA could detect whether material has gone missing or is being misused, such as by a terrorist group. Thus, to prevent terrorist misuse of advanced reactor technology, it is vital that the international nonproliferation regime (focused on states) adapts to properly address the potential threats posed by advanced reactors.

2. Potential Gaps in the NPT as Applied to Advanced Reactors

There is an inherent tension between Articles I and IV in that if nuclear weapons states seek to help non-nuclear weapon states build nuclear reactors for peaceful purposes, they must be extremely careful to prevent such reactor technology from being used to manufacture nuclear weapons. Because the NPT does not explicitly prohibit or permit specific uses of nuclear technology, the United States looks to the intent behind a state's potential acquisition of uranium enrichment and stockpiling technology, for example; "when there is no reasonable economic or technical justification for an assertedly peaceful use," the United States will consider the acquisition a violation of Art. IV and will not export the technology.[91] If the non-nuclear weapons state has a reasonable peaceful use, then the United States will permit export so long as the export and use are subject to safeguards.[92]

88. *IAEA Safeguards Overview: Comprehensive Safeguards Agreements and Additional Protocols*, INT'L ATOMIC ENERGY AGENCY, https://perma.cc/R8BN-TB4Z.

89. *Id.*

90. *Status List, Conclusion of Additional Protocols*, INT'L ATOMIC ENERGY AGENCY, https://perma.cc/7MD6-N86A (last updated Dec. 31, 2022). Euratom is the European research organization focused on peaceful nuclear energy development. *Euratom,* ENEA, https://perma.cc/3FQT-YDXY. This number of signatories, while large, still has key gaps—two member states of the Nuclear Suppliers Group, Argentina and Brazil, have yet to sign Additional Protocol agreements. *Id.*; *see also* Mark Hibbs, *Nuclear Suppliers Group and the IAEA Additional Protocol*, CARNEGIE ENDOWMENT FOR INT'L PEACE (Aug. 18, 2010), https://perma.cc/JA4H-XEJ4.

91. Eldon V.C. Greenberg, *Peaceful Nuclear Energy and the Nuclear Nonproliferation Treaty*, *in* REVIEWING THE NUCLEAR NONPROLIFERATION TREATY 105, 120 (Henry Sokolski, ed., 2010).

92. *Id.*

Advanced reactors challenge this delineation of technology by pushing what is involved in fuel cycle technology. While molten salt reactors can reduce the amount of stockpiled plutonium by burning it as fuel, there is a real chance that a state could seek acquisition of plutonium beyond existing stockpiles for purported reactor-use-only. That acquisition would be a valid Art. IV action, but it is difficult to imagine nuclear weapon states voluntarily shipping plutonium to non-nuclear weapon states. For high-temperature reactors, states could argue an Art. IV right to enrich uranium up to 20% to make TRISO fuel, far above the existing 5% threshold of current fuel rod production. To eliminate this tension, nuclear weapon states could host nuclear fuel banks for molten salt and high-temperature reactor fuel, prohibiting non-nuclear weapon states from accessing the fuel creation process. While the idea of a fuel bank has been suggested for decades,[93] the fact that advanced reactors present an entirely different class of fuel technology could mean a fresh start for the idea—the means to make TRISO fuel, for example, are not yet as widely known as the means to enrich uranium up to 5% and is therefore more practical to consolidate knowledge about.

Fast reactors blur the lines between fuel processing and fuel use by having the ability to create plutonium as part of the energy-creating reaction and the closed-cycle system meaning internal fuel reprocessing and use. Traditionally, reprocessing technology is one requiring stringent safeguards if a state is permitted to have it at all, while plutonium creation is nearly universally barred. For fast reactors to be exported at all, nuclear weapon states and the non-governmental organizations involved in nuclear exports[94] should explicitly require safeguards on all fast reactors and related technology as a condition of export rather than presuming they are covered under export controls for sensitive nuclear technology.

3. Potential Gaps in the Safeguards Regime as Applied to Advanced Reactors

Because the NPT itself is does not address safeguards in-depth, any other potential gaps spring from the IAEA safeguards regime. This regime relies on the ability of IAEA inspectors and state monitoring entities to catalogue, track, and verify the nuclear material in a reactor or other nuclear facility. Those verification methods and tools rely on structural assumptions about nuclear reactors, as its system is based on large light-water reactors.[95] The chief structural assumption is that each nuclear reactor is an "item facility" within which all nuclear material can be observed, counted, and thus controlled.[96] Fuel is assumed to be enriched around 5% U-235. Reactors are refueled during outages, during which nuclear

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93. *See, e.g.,* WORLD AT RISK: THE REPORT OF THE COMMISSION ON THE PREVENTION OF WEAPONS OF MASS DESTRUCTION PROLIFERATION AND TERRORISM 48-49 (2008); Eric Brewer & Charles B. Curtis, *International IAEA LEU Bank*, NUCLEAR THREAT INITIATIVE, https://perma.cc/H7R6-LLQX. A fuel bank is a centralized place for countries with peaceful nuclear programs to purchase nuclear fuel without needing to produce it within their own borders. *See, e.g.*, Brewer & Curtis, *supra* note 93.

94. *See, e.g.*, *About the NSG*, NUCLEAR SUPPLIERS GRP., https://perma.cc/TY3D-QF8W (last updated 2022).

95. Nilsson et al., *supra* note 33, at 3.

96. *Id.*

material can be inspected and verified. There can be no secret irradiation that is not visible to an inspector.[97] Because of the technological differences between thermal reactors and molten salt, high-temperature gas, and fast reactors, each of these advanced reactor types poses challenges to the assumptions made by IAEA safeguards regime.

Molten salt reactor engineers at the U.S. Oak Ridge National Laboratory have identified four features of molten salt reactors that create a "potential paradigm shift" in safeguards: (1) fuel salt continuously moving in and out of the core, (2) fuel salt constantly changing in temperature and isotopics, (3) no decay time between irradiation and when measurements of the reactor must be taken, and (4) lack of accessibility to the containment and associated infrastructure after one day of operation.[98] These four differences essentially all create one consequence: it is more difficult for an IAEA inspector to verify that nuclear material is actually where it is supposed to be and is being used how it is supposed to be. A full, accurate safeguards evaluation of a molten salt reactor requires new technical assessments and "more stringent nuclear material accountancy measures" to verify the quantity and location of all nuclear material.[99] Exactly how these tools must change is difficult to identify at present, since there are no operating molten salt reactors in existence, and unlike for fast reactors there is no historical information about their operation.[100] The diversity of reactor designs in development further complicates any attempt to design a singular tool to verify nuclear material in molten salt reactors. A modeling and simulation tool, for example, to predict the temperature and isotopic characteristics of a liquid salt fuel at any time in a reactor's operation must take into account the specifics of the reactor being analyzed: the liquid fuel combination, the material removal and feed rates, radiation and containment shielding properties, and other reactor design characteristics.[101]

High-temperature reactors pose similar verification challenges. A reactor using a pebble bed with TRISO fuel pellets can contain anywhere from 220,000 to 420,000 pellets in the reactor core.[102] This high number of individual pellets with nuclear material, in addition to the continuous refueling of some designs, means that tracking the number, condition, and location of every piece of nuclear material as is expected in safeguards is exceptionally challenging. An added challenge is that the TRISO design is not universal, with some proposed plants using

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97. *Id.*

98. Worrall et al., *supra* note 45, at 3.

99. Worrall et al., *supra* note 45, at 3; *see also* Worrall et al., *supra* note 45 at 8 ("These features necessitate the development and use of sophisticated modelling and simulation tools for tracking the isotopic masses and signatures throughout the reactor and associated auxiliary processing, and as a function of time as the fuel salt evolves.").

100. Worrall et al., *supra* note 45, at 5; *Molten Salt Reactors*, WORLD NUCLEAR ASS'N https://perma.cc/T22W-JBQK (last updated May 2021).

101. Worrall et al., *supra* note 45, at 3–5.

102. Yongde Liu et al., *supra* note 55, at 2; X-energy Xe-100 Reactor Initial NRC Meeting, (Sept. 11, 2018), https://perma.cc/NV7N-KXXQ.

different pellets than others.[103] The use of different fuel may mean that the verification tools for safeguards must be plant-specific, a huge undertaking compared to the current standardized tools.

An issue adjacent to TRISO pellet production is uranium enrichment. Safeguards focus on the uranium enrichment stage of the fuel cycle because it is a "highly sensitive" point that can be used for either peaceful or military uses of nuclear technology.[104] Because TRISO pellets use uranium enriched to 8-20% rather than 3-5%, the production of TRISO fuel could be an attractive target for anyone seeking a source of enriched uranium to further process into weapons grade material. The current IAEA safeguards regime should be sufficient to protect TRISO fuel enrichment facilities, with simply more attention paid to those facilities rather than new safeguards tools. One unanswered, yet vital, question is how easy it would be to extract the enriched uranium from within the TRISO fuel pellets, and thus whether special safeguards must be applied to the transportation, storage, and handling of TRISO pellets as a potential material for weapons development. Presumably, if the TRISO pellets can withstand the extreme temperatures and stress in a nuclear reactor core without cracking, they would be difficult for any bad actor to extract uranium from. The IAEA should investigate TRISO pellet proliferation risks and issue an advisory report. Alternatively, since the first TRISO pellet production facilities are sited in the United States, the U.S. Department of Energy could fund a study into the same to advise the other nuclear weapon states on TRISO's risks—so long as such a study would not compromise domestic national security and would be in full compliance with existing international education initiatives.

Fast reactors are the most similar to thermal reactors of the three advanced reactor types and are thus the easiest to apply existing safeguards to. They are refueled during outages like a traditional thermal reactor, enabling easier monitoring. Fuel can be identified and followed through the reactor cycle.[105] Fast reactors have potential to breed plutonium, and the closed cycle in many designs means that reprocessing is a part of the reactor design. Neither of those threats need result in new, innovative verification procedures. Rather, any separated and stored plutonium could require additional verification of the type currently used for stored nuclear materials at any reactor site.[106] The one technological element of fast reactors that could require additional safeguards is that the coolants are opaque, which could make some monitoring during operation more difficult.

103. Sonal Patel, *The Allure of TRISO Nuclear Fuel Explained*, POWERMAG (Mar. 1, 2021), https://perma.cc/A8XC-KZWM (explaining that U.S.-based Ultra Safe Nuclear Corporation uses a proprietary "Fully Ceramic Microencapsulated" fuel while the company X-energy aims to use its own TRISO manufactured fuel).

104. *Safeguards to Prevent Nuclear Proliferation*, WORLD NUCLEAR ASS'N, https://perma.cc/35AW-CV2Q (last updated Apr. 2021).

105. Nilsson et al., *supra* note 33, at 4.

106. Nilsson et al., *supra* note 33, at 5.

IAEA inspectors should work with signatory states who are interested in developing fast reactors to collaborate on new inspection tools for these coolants.

C. Convention on the Physical Protection of Nuclear Material (CPPNM)

1. What the Convention Does

Adopted in 1979, the Convention on the Physical Protection of Nuclear Material (CPPNM) establishes legal obligations on parties regarding "the physical protection of nuclear material used for peaceful purposes during international transport; the criminalization of certain offences involving nuclear material; and international cooperation. . . in the case of theft, robbery or any other unlawful taking of nuclear material or credible threat thereof."[107] With 151 signatory parties, the CPPNM is the most adhered-to multilateral treaty overseen by the IAEA.[108] Additionally, and importantly for preventing nuclear terrorism, its focus is on nuclear material regardless of who seeks to use that material, meaning it applies to both state and non-state actors' use of nuclear materials.

Originally the scope of the CPPNM was restricted to the physical protection of nuclear material during *international transport*.[109] The CPPNM was amended in 2005 to include "physical protection of nuclear facilities and nuclear material used for peaceful purposes in domestic use, storage and transport."[110] Nuclear material means plutonium, except that enriched above 80% Pu-238; and any uranium with U-235 or U-233 above the levels found in nature.[111] Any nuclear material not subject to the CPPNM must still be "protected in accordance with prudent management practice."[112]

The amended CPPNM has three goals: physical protection of nuclear material used for peaceful purposes when in international transport, criminalization of offenses involving such material, and international cooperation in preventing and responding to those offenses.[113] Under physical protection, each state has a legal commitment to "establish, implement and maintain an appropriate physical protection regime applicable to nuclear material and nuclear facilities under its jurisdiction," which includes establishing a "competent" legislative and regulatory authority and to "take other appropriate measures necessary."[114] Additionally, the Amendment requires each state party to implement their national physical protection regimes without prejudice to other provisions of the convention and to apply,

107. Convention on the Physical Protection of Nuclear Material, *opened for signature* Mar. 3, 1980, 1456 U.N.T.S. 101 [hereinafter CPPNM]. The CPPNM is the *only* internationally legally binding document regarding the physical protection of nuclear materials. Peri Lynne Johnson, *Facilitating the Entry into Force and Implementation of the Amendment to the Convention on the Physical Protection of Nuclear Material: Observations, Challenges and Benefits*, 2014 NUCLEAR L. BULL. 9, 13-14 (2014).

108. Johnson, *supra* note 107, at 16.

109. CPPNM, *supra* note 107, at art. 2(2).

110. *Id.*

111. *Id.* at art. 1(a)-(b).

112. *Id.* at art. 2A.4(b) (amended).

113. *See* Johnson, *supra* note 107, at 16.

114. CPPNM, *supra* note 107, at art. 2A.1, 2A.2(a), (c) (amended).

so far as reasonable, a list of twelve "Fundamental Principles of Physical Protection of Nuclear Material and Nuclear Facilities" in Article 3.[115] These Principles reflect widely accepted tools of nuclear safety like having a robust security culture within all organizations involved in nuclear safety, implementing "defense in depth" by requiring multiple layers and methods of protection, and creating quality assurance programs to check physical protection standards.[116]

Under the criminalization prong, the CPPNM originally required states to criminalize "intentional commission" of acts including unauthorized "receipt, possession, use, transfer, alteration, disposal or dispersal of nuclear material and which causes or is likely to cause death or serious injury to any person or substantial damage to property;" "theft or robbery of nuclear material;" and any threat "to use nuclear material to cause death or serious injury to any person or substantial property damage."[117] The 2005 Amendment also added "an act directed against a nuclear facility, or an act interfering with the operation of a nuclear facility, where the offender intentionally causes, or where he knows that the act is likely to cause, death or serious injury to any person or substantial damage to property or to the environment" from radiation exposure.[118] The consequence of environmental damage from radiation and the use of any threat to carry out the acts listed were also added to several sections of Art. 7.[119]

Finally, the amended CPPNM provides for international cooperation in prevention, detection, and response to adverse incidents regarding physical protection of nuclear materials.[120] Such cooperation is provided for not only in cases of "credible threat of sabotage of nuclear material," but also provides that states and the IAEA should help other states develop means of "protecting threatened nuclear material, verifying the integrity of the shipping container or recovering unlawfully taken nuclear material."[121] In other words, state parties and the IAEA are meant to help states develop both proactive and reactive tools for safeguarding nuclear material during its entire lifecycle.

2. Potential Gaps as Applied to Advanced Reactors

Gaps in the CPPNM fall into two categories: structural gaps and implementation gaps. Structurally, the CPPNM's definition of "nuclear material" includes uranium above natural levels and any plutonium under 80% Pu-238 but makes no reference to thorium. Perhaps this omission is because the naturally occurring isotope thorium-232 cannot undergo fission, but when irradiated in a reactor it becomes the fissile U-233.[122] Moreover, although using thorium as a fuel would

115. *See id.* at art. 2A.3 (amended); Johnson, *supra* note 105, at 18.
116. *See* CPPNM, *supra* note 107, at art. 3.
117. *Id.* at art. 7.
118. *Id.* at art. 7(e) (amended).
119. *See* Johnson, *supra* note 107, at 19.
120. *Id.* at 20.
121. CPPNM, *supra* note 107, at art. 5.2-3.
122. Smriti Mallapaty, *China Prepares to Test Thorium-Fuelled Nuclear Reactor*, 597 NATURE 311, 312 (2021).

require a fundamental overhaul of the fuel cycles in countries using uranium fuel, both China and India are pursuing thorium-based reactors as part of their nuclear programs.[123]

At a higher level, the CPPNM emphasizes the state's role to the exclusion of international action. In the new Fundamental Principles, the amended CPPNM leaves responsibility for "the establishment, implementation and maintenance of a physical protection regime within a State Party. . . *entirely* with that State" (emphasis added). Article 2A requires each state to "establish, implement and maintain an appropriate physical protection regime" to protect nuclear material and facilities from sabotage, implemented via a "legislative and regulatory framework to govern physical protection."[124] Discretion to evaluate threats is also left with the states.[125] Thus, to protect nuclear material under the CPPNM, a state must evaluate the likelihood of such a threat, create a competent licensing authority to protect against that threat, and regulate the transport of nuclear material so as to adequately address that threat.[126] This series of actions presents a large practical burden to smaller states who would be otherwise interested in acquiring nuclear reactors for peaceful uses; if they need to develop a protection program entirely from scratch, entirely within their own borders, then the government may turn to other energy sources.

In implementation, this state focus creates somewhat easy opportunities for terrorist groups to obtain nuclear material. If a state fails to fully implement the CPPNM, there is no fallback to prevent theft or misuse of nuclear material.[127] Although it is reasonable to take into account different states' national licensing schemes, forms of non-state threat, and transportation infrastructure, such reliance poses a challenge given how new and diverse advanced reactors are to licensing regimes. This state-level focus means states must establish comprehensive licensing scheme that reasonably understands and adapts to the technological differences of advanced reactors; if states do not, they cannot adequately assess

123. *Id.*

124. CPPNM, *supra* note 107, at art. 2A.

125. CPPNM, *supra* note 107, at art. 2A.3, Fundamental Principle G (amended) ("The State's physical protection should be based on the State's current evaluation of the threat.").

126. *See* Noah Deogratias Luwalira, Sec'y & Chief Exec. Officer, Atomic Energy Council, Presentation at the International Conference on Physical Protection of Nuclear Material and Nuclear Facilities: Uganda's Experience in the Implementation of the CPPNM and its Amendment at 1 (Nov. 14, 2017) (transcript available in the Full Conference Programme of the IAEA International Conference on Physical Protection of Nuclear Material and Nuclear Facilities) ("The implementation of the CPPNM and its amendment therefore requires the establishment of a strong legal and regulatory framework that support all oversight mechanisms on the applications and movements of all nuclear materials and all radioactive sources.").

127. *See id.* at 2-4. Although Uganda ratified the CPPNM in 1980, it had no national nuclear regulatory system until 2008 and no way of monitoring the quantity and category of nuclear materials until a registry was established in 2011. Until these national systems were implemented, Uganda experienced "incidents of orphan and disused sources out of regulatory control ending up in unauthorized possession," which "posed a nuclear security threat" that only full implementation of the CPPNM could remedy. *Id.*

and protect against the possible threats of nuclear material as the CPPNM requires them to do.

The burden of creating a licensing regime out of whole cloth will fall unevenly on states. Several advanced reactor developers aim to deploy their advanced reactors to states without existing nuclear energy programs at all, meaning a licensing and transportation structure must be built from scratch to fulfill the CPPNM. While they could look to the IAEA or countries like the United States for advice, those entities' resources to help could be either practically or legally restricted, based on the number and location of the states asking for advice. Regulating transportation of advanced reactor fuel could also be burdensome for states without nuclear reactors but which are used for transportation; TRISO fuel involves many smaller pellets compared to traditional fuel rods which could be far more difficult to adequately account for in transportation, for example. Additionally, that some advanced reactors are modular, meaning they could be moved from factory to building site, could create an opportunity for illicit conduct of the reactors themselves in transit through a country.[128] This is especially a problem because while the CPPNM requires states to cooperate in cases of sabotage, theft, or any unlawful taking of nuclear material, few states have actually criminalized the smuggling of nuclear materials across borders, and those that have often use very broad language that does not reflect the suggested language from the IAEA.[129] This lack of harmonization could make it difficult to track and prosecute theft of any advanced reactor across borders.

Further, the state approach puts an additional burden on countries without existing nuclear energy programs, who must criminalize possession of nuclear material far beyond what their national regulatory bodies normally oversee. For example in Croatia, a non-nuclear country, the national Act and Ordinance on the Physical Security of Radioactive Sources, Nuclear Material and Nuclear Facilities leaves much open to interpretation. It requires the holder of a license to be fully liable for implementation of physical protection and for the manner of implementation to be prescribed by the regulatory office.[130] Yet representatives from the State Office for Radiological and Nuclear Safety, the regulatory body,

128. *See* CPPNM AND ITS 2005 AMENDMENT: FIVE QUESTIONS 3 (available online at https://perma.cc/6TWX-6R2A). ("Even countries with little or no nuclear material on their territory need to join the amended Convention to ensure that they are not unwittingly used for transit.") [hereinafter FIVE QUESTIONS].

129. Cristina Siserman Gray, Prae-Doc Researcher & Ph.D. Candidate in Int'l L., U. Vienna, Comparative Analysis on the National Approaches for the Legal Implementation and Criminalization of the Offenses under the Convention for the Physical Protection of Nuclear Material (CPPNM) and its Amendment at 7 (Nov. 14, 2017) (transcript available in the Full Conference Programme of the IAEA International Conference on Physical Protection of Nuclear Material and Nuclear Facilities).

130. *See* Marijo Medic & Sasa Medakovic, Croat. State Off. for Radiological & Nuclear Safety, Changes in Croatian Legal and Regulatory Framework for Physical Protectio at 203 (Nov. 14, 2017) (transcript available in the Full Conference Programme of the IAEA International Conference on Physical Protection of Nuclear Material and Nuclear Facilities) ("The holder of the approval for performance of operations shall be liable for the implementation of physical protection of ionizing radiation sources and nuclear installations and shall bear the costs of its implementation; and The

acknowledged that a more robust framework was needed that could take into account "the classification of nuclear facilities and nuclear and radioactive materials, radioactive sources and radioactive waste in relation to its use, the possible impact and consequences of the abuses," as well as the nuclear safety concepts prescribed in the Amendment to the CPPNM like defense in depth.[131]

3. Recommendations

To remedy the structural gaps, the state parties to the CPPNM could incorporate thorium and require increased international cooperation in a new Amendment to be introduced at the next review conference. However, given that the 2005 Amendment has yet to go into effect in the nearly twenty years since its drafting, it seems unlikely any state party could convince all 151 member states to adopt yet another amendment. Therefore, a "soft power" solution, while non-binding, may be the most practical route to closing the gaps in the CPPNM.

The simplest way to encourage states to close their gaps in CPPNM implementation would be through encouragement at the next CPPNM review conference. States with advanced reactor programs could lay out the above potential threats, explain advanced reactor technology, and lay out concrete ways other state participants can strengthen their domestic regulations.

The CPPNM's emphasis on international cooperation also creates an obvious solution: international organizations with non-binding authority can encourage and assist states to implement needed changes in their domestic licensing systems. For example, such organizations could help smooth out the uneven burden of implementation that the state-level focus places on national regulatory regimes. The requirement that states designate Points of Contact for communication could mean that states can share regulatory strategies and technical expertise, lessening the burden on any one state to understand advanced reactor technology on an expert level.[132] Organizations like the above-mentioned Nuclear Suppliers Group or the Global Initiative to Combat Nuclear Terrorism (GICNT) could provide a conduit for international cooperation.[133] All five nuclear weapon states, the

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manner of implementation of the physical protection shall be prescribed in an ordinance issued by the director of the Office in cooperation with the minister in charge of internal affairs.")

131. *Id.* at 3-4 ("Croatia does not have a large number of sources of ionizing radiation and there are no recorded cases of attempted theft or sabotage. But regardless of the above, there is a clear need to take all necessary measures to reduce the risk of such events to the smallest extent possible.").

132. FIVE QUESTIONS, *supra* note 128, at 6-7. For an example of how these things can be shared while remaining in compliance with international law, see *International Programs*, U.S. NUCLEAR REG. COMM'N, https://perma.cc/PS5T-MRBR (last updated Aug. 30, 2022).

133. *The Global Initiative to Combat Nuclear Terrorism*, U.S. DEP'T OF STATE, https://perma.cc/DX7M-N7QA. GICNT is a voluntary organization of 89 countries and six international organizations which works together to implement "broad nuclear security goals" and has supervised over 100 interstate activities to that effect. *Id.*; *see also* WORLD AT RISK: THE REPORT OF THE COMMISSION ON THE PREVENTION OF WEAPONS OF MASS DESTRUCTION PROLIFERATION AND TERRORISM 51 (2008) (recommending additional use of GINCT to prevent nuclear terrorism).

nuclear armed states of India, Israel, and Pakistan,[134] and other countries with "significant nuclear infrastructure," all are members of GICNT.[135] Through the GICNT-organized nuclear security reviews, states developing advanced reactors could present example regulatory regimes to other state participants to encourage regulatory harmonization.

D. International Convention on the Suppression of Acts of Nuclear Terrorism

1. What the Convention Does

The International Convention on the Suppression of Acts of Nuclear Terrorism (ICSANT) was adopted on April 15, 2005 by the United Nations General Assembly, but international organizations had been trying since the 1930s to establish prohibitions against international terrorism in "all its forms and manifestations."[136] Any person commits an offense under ICSANT if they unlawfully possess radioactive material; if they make or possess a device to cause any type of harm; if they intend to commit such an act; or if they help someone else commit such an act.[137] Instead of directly criminalizing these acts, ICSANT requires states to make such acts a crime.[138]

ICSANT's definition of "nuclear material" is functionally identical to the CPPNM's definition but also covers radioactive material, defined as: "nuclear material and other radioactive substances which contain nuclides which undergo spontaneous disintegration. . ."[139] This broader definition of covered material enables ICSANT to prohibit any "device" that uses radioactive material, as defined, to cause or threaten to cause "death, serious bodily injury or substantial damage to property or the environment."[140]

While focusing on individual acts, ICSANT, like other international legal instruments, places its primary responsibilities on states to make the prohibited acts crimes.[141] The classic "extradite or prosecute" requirement of international law is required by Art. 11: if states do not prosecute offenders within their national court systems, they must agree to extradite perpetrators to states that are willing to prosecute the perpetrators.[142]

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134. *World Nuclear Forces*, STOCKHOLM INT'L PEACE RES. INST. (2012), https://perma.cc/AB4N-QEHM.

135. Salik, *supra* note 17, at 181-82.

136. Odette Jankowitsch-Prevor, *International Convention for the Suppression of Acts of Nuclear Terrorism*, 2005 NUCLEAR L. BULL. 7, 7 (2006).

137. ICSANT, *supra* note 11, at art 2.

138. *Id.* at art. 3, § 5-6.

139. *Id.* at art. 1, § 1.

140. *Id.* at art. 1, § 4.

141. *Id.* at arts. 3, 5, 6. ICSANT places four chief obligations on states: to take "all practicable measures" to prevent and counter commission of terrorist acts; to establish jurisdiction over attempted terrorist acts within a state; to exchange information relevant to detecting, preventing, suppressing, and investigating potential terrorist acts; and to ensure radioactive material is protected per the IAEA's recommendations. *Id.* at arts. 7-9.

142. *Id.* at art. 11; *see* Gehr, *supra* note 10, at 8; *Analytical Guide to the Work of the International Law Commission*, INT'L L. COMM'N, https://perma.cc/2MGM-7LV3 (last updated June 6, 2022).

2. Potential Gaps as Applied to Advanced Reactors

There are no obvious ways in which advanced reactors cannot neatly slot into ICSANT's framework. ICSANT is more focused on criminalizing actions that had not been criminalized than in prescribing responses to those crimes, so there are no novel implementation issues raised by the technological innovations of advanced reactors. ICSANT's definitions of the relevant crimes are also broad enough to include advanced reactor technology: "radioactive material" includes advanced reactor fuels just as clearly as it does traditional nuclear fuels, and any "device" using such radioactive material includes advanced reactors.

The one significant drawback to ICSANT is not unique to ICSANT compared to other international conventions, nor is it unique to advanced reactors as applied to ICSANT. Like CPPNM, ICSANT places the burden on states to protect against nuclear terrorism within states' legislative and judicial structures. This state-level burden should not create problems for protecting against nuclear terrorism using advanced reactors, so long as states criminalize acts with the broad definitions ICSANT recommends. However, there could be gaps in the legal framework to prevent terrorism if states assume, as mentioned, that ICSANT and CPPNM overlap, or if they are slow to implement ICSANT's requirements in the first place.

These are not issues that can be fixed by the text of ICSANT, but perhaps could be lessened by further international cooperation and encouragement. If advanced reactors are to be deployed to countries without existing nuclear energy regimes, such deployment should be conditioned upon full implementation of ICSANT within the target country. Better education about the mobility of advanced reactors—that they could be mobile while in operation, or that they could be fabricated in a factory and shipped as non-operational but fully intact to their permanent site—could convince states without nuclear energy programs of the necessity of implementing the full regime against nuclear terrorism by illustrating how new reactor technology could pass through their country. These efforts could likely be done by existing committees or international organizations like GICNT, discussed above, or the UNSCR 1540 Committee, discussed below.

E. U.N. Security Council Resolution 1540

1. What the Resolution Does

U.N. Security Council Resolution (UNSCR) 1540 was adopted in 2004 in response to two international developments. First, global attention turned to combatting terrorism after 9/11. Second, the revelation that A.Q. Khan had helped North Korea, Iran, and Libya avoid international sanctions and develop nuclear weapons programs alarmed nonproliferation watchdogs about the state of illicit nuclear trafficking.[143] Thus, the purpose of UNSCR 1540 is to "plug the gaps" in

143. Huma Rehman & Afsah Qazi, *Significance of UNSCR 1540 and Emerging Challenges to its Effectiveness*, 39 STRATEGIC STUD. 48, 50 (2019); *OBITUARY AQ Khan, Father of Pakistan's Atomic Bomb and Centre of Proliferation Scandal, Dies*, REUTERS (Oct. 10, 2021), https://perma.cc/K9ZG-SQBA.

the international framework for nonproliferation and prevention of nuclear terrorism. It does so by expanding treaty regimes focused on states to also cover non-state actors, and by requiring all U.N. member states—regardless of their relationship to other nonproliferation conventions or treaties—to craft domestic nonproliferation measures.[144] UNSCR 1540 places three primary obligations on U.N. member states: not to support non-state actors who seek weapons of mass destruction, including nuclear weapons; to adopt and enforce laws prohibiting non-state actors from acquiring or using such weapons; and to establish other domestic controls to limit non-state acquisition and use of such weapons.[145] It also includes preventative measures to supplement the NPT's largely reactive ones.[146] Implementing such expansive prohibitions helps ensure "malicious actors do not have access to the world's most dangerous weapons and related materials."[147]

Like other U.N. security resolutions, UNSCR 1540 carries out its obligations through committee. The 1540 Committee is responsible for monitoring states' implementation of the resolution's provisions.[148] It hosts a website that houses reports, reviews, and briefings, in order to help advise the U.N. Security Council on what actions are needed to further reduce the risk of nuclear terrorism.[149] The Committee also supports individual states in their implementation by assisting with voluntary national implementation plans and facilitating discussions within international, regional, and sub-regional organizations on best practices and lessons learned.[150] Members also can offer state-level support to each other.[151]

To date, the 1540 Committee has identified gaps in many states' national frameworks.[152] The largest remaining gap is in states' efforts to implement the "transport" obligation of UNSCR 1540.[153] Some of these gaps can be linked to the resolution's wording: for example, the words "shall adopt and enforce

144. Salik, *supra* note 17, at 177; S.C. Pres. Statement 2014/7 (May 7, 2014) (available online at https://perma.cc/P9Z9-9WPL); Rehman & Qazi, *supra* note 143, at 53.

145. *UNSCR 1540 Fact Sheet*, U.S. DEP'T OF STATE, https://perma.cc/Y3MN-QRAE.

146. *See* COPPEN, *supra* note 67, at 12.

147. *UNSCR 1540 Fact Sheet, supra* note 145.

148. Gehr, *supra* note 10, at 10.

149. *UNSCR 1540 Fact Sheet, supra* note 145; *Committee Approved Matrices*, 1540 COMM., UNITED NATIONS, https://perma.cc/8XSQ-NXXA.

150. *UN Security Council Resolution 1540 (2004),* UNITED NATIONS, https://perma.cc/2KL7-PRWT.

151. *See, e.g.*, *UNSCR 1540 Fact Sheet, supra* note 145.

152. *Id.* Particularly, in 2016 the Committee noted that not all states had adopted legislation to implement the resolution, but even if they had, "in many instances not all the obligations under paragraph 2 of 1540 would have been covered by such legislation" such as preventing access to nuclear weapons or including penalty and enforcement measures for those who do acquire material to make nuclear weapons. Rep. of the S.C. Comm. Established Pursuant to Resolution 1540 (2004), transmitted by Letter dated 9 December 2016 from the Chair of the Security Council Comm. Established Pursuant to Resolution 1540 (2004) Addressed to the President of the Security Council, ¶¶ 55, 59-62, U.N. Doc. S/2016/1038 (Dec. 9, 2016).

153. *Id.* (noting that only 106 states have transport measures in place).

appropriate effective laws" (emphasis added) have subjective undertones, allowing states to use the words differently in their national legislation.[154]

2. Potential Gaps as Related to Advanced Reactors

The failure of states to fulfill the transport obligation is the most glaring issue with UNSCR 1540, although it is important to distinguish that this is an issue not with agreement *drafting*, but with agreement *implementation*. If advanced reactors can be transported easily through states, it becomes vital for states to fully implement UNSCR's transport obligation. However, because UNSCR 1540's very purpose is to fill in gaps in prevention of nuclear terrorism, and because the 1540 Committee already has made so much headway in monitoring and reporting on states' implementation, there is a yet-unseen *opportunity* for the 1540 Committee to address the gaps in the framework to prevent nuclear terrorism that are created by advanced reactor technology. For example, the 1540 Committee experts could work with states to make sure their domestic licensing regimes take into account advanced reactor technology, such as by preparing to protect the physical transportation of TRISO fuel or modular advanced reactor components, or by developing domestic inspection techniques to verify that an opaque coolant in a fast reactor is working as it should. Alternatively, the United States could lead an effort to "build a political-level consensus" for nuclear security standards and then work directly with states to implement the essential elements of those standards around their nuclear stockpiles.[155] While a political commitment is obviously less effective than a legal commitment, U.S. leadership in this area could lend such an effort enough legitimacy to adequately bridge the security gap.

IV. CROSS-CUTTING CHALLENGES FOR PREVENTING NUCLEAR TERRORISM FROM ADVANCED REACTOR TECHNOLOGY

Mapping advanced reactor technology onto the international framework for preventing nuclear terrorism poses several challenges. First, there is no "one size fits all" approach for advanced nuclear technology regulation,[156] nor for implementing safeguards regimes.[157] Thus, there is far from one approach to fitting advanced reactors into the anti-terrorism framework, making any recommendation of a verification tool or domestic licensing structure inherently prone to disagreement. There is also a "chicken-and-egg" problem with regulating—and

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154. Rehman & Qazi, *supra* note 143, at 55.

155. BUNN, *supra* note 17, at xii.

156. *See, e.g.*, *Part 53 – Risk Informed, Technology-Inclusive Regulatory Framework for Advanced Reactors*, U.S. NUCLEAR REG. COMM'N, https://perma.cc/M9QE-YFBQ (last updated Mar. 9, 2023) (providing an overview of the United States' approach to regulating advanced reactors using a "technology-inclusive" licensing approach rather than the prescriptive approach of previous licensing paths). Compare this approach with that in 10 CFR Part 50. For a journalistic explanation of the difference, see Paul Day, *New Generation of Reactors Needs Licensing Leap*, REUTERS (Mar. 9, 2023), https://perma.cc/T9BX-RCB9.

157. Nilsson et al., *supra* note 33, at 1.

implementing safeguards for—advanced reactors. To enable safe, cost-effective deployment and trade, clear domestic and international regulations are needed ahead of time. However, knowing exactly the potential dangers any reactor poses requires detailed knowledge of its design, and many advanced reactor designs are still conceptual.[158] This is a problem faced by countries currently figuring out how to license advanced reactors for domestic deployment, so perhaps these countries can collaborate on lessons learned when recommending an international framework.

A. Traditional Monitoring May Not Detect Misused Advanced Reactor Technologies

The traditional safeguards regime relies on a three-pronged system: verification, supervision, and compliance.[159] A key tool for verification is "review:" for example, state intelligence analysts reviewing information from seismographic stations, hydro-acoustic stations, radionuclide stations, and satellites to detect and differentiate potential nuclear tests.[160] This type of review works; in 1983, photographs taken by satellites or spy-planes were reviewed by intelligence analysts and compared with known technical specifications to identify construction of a restricted radar in Abalakovo, Siberia.[161]

The efficacy of such review is already undermined by some Generation III technologies. Gas centrifuges, which can be used to enrich HEU, do not produce significant enough radioactive signatures to be detectable at "significant distances;" they can be housed in a "building with no identifying features that would easily escape detection by visual satellite imaging;" and their low energy consumption compared to a traditional nuclear reactor cannot be detected by thermal-infrared imaging.[162] The Soviet Union developed centrifuges that were undetected for thirty-four years, until they were revealed after the Soviet Union's collapse, despite being under the heaviest scrutiny that the U.S. and its allies could employ.[163]

To be fair, modern review may be stronger than that at the height of the Cold War; of the six state programs to develop nuclear weapons, only one, Iraq, was *not* detected before it reached maturity.[164] There is no consensus on why, exactly, the other five were detected. For Pakistan and South Africa, for instance, the

158. *See, e.g.*, Avronin et al., *supra* note 61, at 5 ("The current designs of new fast reactors are conceptual except for projects in Russia To truly develop an optimized safeguards approach, the size and design of the new fast reactor would need to be better defined.").

159. COPPEN, *supra* note 67, at 49.

160. *Id.* at 58.

161. *Id.*

162. Kemp, *supra* note 26, at 48-49. Kemp also notes that any noticeable energy consumption from the electricity grid could be avoided by using a natural gas or diesel fueled generator to power the centrifuge. *Id.* at 49.

163. *Id.*

164. *Id.* at 52.

international intelligence community was tipped off when those states tried to procure nuclear-adjacent technology from privately run companies.[165]

Without fully understanding where traditional monitoring is failing, it is difficult to recommend fixes to those problems. At most, this paper can view advanced reactors as a chance for a new start with new technology and thus recommends setting new norms. Since many advanced reactor designs for export come from the United States, the United States could provide the IAEA with enough information about U.S. designs to permit IAEA inspectors to conduct more thorough review. The U.S. Department of Energy could also fund studies into new monitoring techniques, to be conducted alongside the construction and operation of the inaugural advanced reactors in the United States. While such efforts cannot change the way other countries react to IAEA inspections, they could make the technology itself easier to understand and thus easier to monitor.

B. The Burden That Safeguards Place on State-level Controls Necessitates Robust State-level Advanced Nuclear Licensing

The CPPNM and UNSCR 1540 highlight how important it will be for states to create regulatory regimes for advanced reactors. However, many state licensing regimes remain unable to properly license advanced reactors. National licensing regimes are built around large light- or heavy-water reactors, meaning they are prescriptive in requirements based on a reactor design and are mismatched to the particular safety and security threats advanced reactors could pose.[166] For example, the traditional licensing process in the U.S.—a regime from which many states draw guidance for their own national systems—requires active management to prevent radioactive material from escaping, whereas advanced nuclear systems often have passive safety features like natural circulation and convention that make active systems moot.[167] The U.S. Nuclear Regulatory Commission is currently revisiting this presumptive approach but has not yet concluded how prescriptive its new licensing approach will be.[168] Until at least one country figures out how to license advanced reactors, it will be difficult to trust that the international safeguards framework, which itself relies on state licensing, can adequately protect against misuse of advanced reactor technology.

This issue merits international cooperation, perhaps through IAEA coordination, GICNT, or the 1540 Committee, so that states can learn licensing best practices from each other and implement those recommendations in their domestic regulatory environments. Additionally, since the United States has been a leader in domestic nuclear regulation, the U.S. Department of State and the U.S.

165. *Id.* at 53.

166. Mohammad Modarres, *Advanced Nuclear Power Plant Regulation Using Risk-Informed and Performance-Based Methods*, 94 RELIABILITY ENG'G AND SYS. SAFETY 211, 211 (2009).

167. *See* Maxine Segarnick & Sachin Desai, *Technology-Neutral Licensing of Advanced Reactors: Evaluating the Past and Present NRC Framework*, 2019 NUCLEAR L. BULL. 37, 38 (2019).

168. *Part 53—Risk-Informed, Technology-Inclusive Framework for Advanced Reactors*, U.S. NUCLEAR REGUL. COMM'N, https://perma.cc/4GK7-GPA9 (last updated Oct. 4, 2022).

Nuclear Regulatory Commission Office of International Programs could run joint training programs for countries seeking to import advanced reactors. Finally, given how many international organizations claim to promote cross-national nuclear regulatory cooperation, one of those organizations—the IAEA, the OECD's Nuclear Energy Agency, or the World Nuclear Association—could host regulatory "boot camps" similar to their trainings in international nuclear law. The possibilities for international regulatory cooperation are many and fruitful; of all the problems mentioned in this paper, developing domestic regulatory regimes is the one with the most resources at the ready to solve it.

CONCLUSION

Advanced reactors pose new and exciting benefits for peaceful uses of nuclear technology: they are smaller, safer, more flexible, and more modular than traditional thermal reactors. They create opportunities for nuclear energy to be deployed to countries and regions where nuclear has not yet gone, expanding the benefits of peaceful uses of nuclear energy further across the globe. Just as advanced reactor technology is gaining steam, so is the threat of nuclear terrorism. Preventing this threat from becoming a reality requires far more verification, cooperation, and implementation than combatting nonproliferation, simply due to the differences between terrorist and state-actor threats. While the international scheme for preventing nuclear terrorism is robust, aspects of it are called into question by advanced reactor technology. Each level of defense—international agreements, IAEA safeguards, and state-level controls—could be undermined if these levels do not adapt to take into account the ways in which advanced reactor technology is fundamentally different from thermal reactor design.

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