ISSUE BRIEF

Building a path toward global deployment of fusion: Nonproliferation and export considerations

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EXECUTIVE SUMMARY

Fusion—the process that powers the sun—is arriving and a global race is under way. Fusion has long been considered the "holy grail" of energy as it promises low-cost, always-on clean power with low environmental impacts and an essentially everlasting supply of fuel. For many concepts, a one-liter water bottle filled with liquid fusion fuel can power a home for 800–900 years.

While it has appeared just out of reach for decades due to physics and engineering challenges, those challenges are being overcome, and it now appears fusion is on the path to commercialization—which could lead to rapid global deployment. Significant technology milestones have been reached, and more than $8 billion globally has poured into dozens of privately funded fusion ventures.[1] Many of these plan to demonstrate their approaches by mid-decade, with power on the grid to follow.[2] Indeed, one company has even announced a firm customer for a fusion power plant, a scenario that could put fusion power on the grid before the end of the decade.[3]

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The **Atlantic Council Global Energy Center** develops and promotes pragmatic and nonpartisan policy solutions designed to advance global energy security, enhance economic opportunity, and accelerate pathways to net-zero emissions.

1 Alejandro de la Garza, "The U.S. Nuclear Fusion Breakthrough Is a Huge Milestone—but Unlimited Clean Energy Is Still Decades Off," *Time*, December 13, 2022, https://time.com/6240746/nuclear-fusion-breakthrough-milestone-clean-energy/.

2 Sam Wurzel, "The Global Fusion Race Is On," Fusion Energy Base, October 28, 2024, https://www.fusionenergybase.com/article/the-global-fusion-race-is-on; "The Global Fusion Industry in 2023," Fusion Industry Association, July 12, 2023, https://www.fusionindustryassociation.org/wp-content/uploads/2023/07/FIA–2023-FINAL.pdf.

3 "Helion Announces World's First Fusion Energy Purchase Agreement with Microsoft," Helion Energy, May 10, 2023, https://www.helionenergy.com/articles/helion-announces-worlds-first-fusion-ppa-with-microsoft/.

The world urgently needs fusion. As it grapples with deepening energy security crises while facing a growing demand for reliable clean energy, it must also figure out how to double the world's energy supply by 2050. This increase is crucial for raising the global standard of living and bringing reliable, affordable power to the nearly one billion people who currently lack consistent access to electricity.[4] Fusion energy could play a transformative role in global efforts for secure, clean, affordable baseload power, while ensuring the United States and its allies achieve energy dominance and lead the future global energy economy.

This urgency has spurred widespread political and governmental support for fusion. In the United States, the White House held a 2022 summit looking to bring commercial fusion devices to the point of grid deployment within the decade.[5] This coincided with an announcement the same year from the US Department of Energy that a national laboratory had achieved scientific energy breakeven, defined by the department as the threshold at which a fusion device produces more energy (at the target level) than was delivered by the lasers to the target.[6] In April 2023, the US Nuclear Regulatory Commission (NRC) initiated the establishment of a regulatory framework for fusion, regulating the technology separately from fission, a seminal decision that set forth a logical pathway for fusion's deployment.[7]

The United States might be leading in fusion investment, with more than $6 billion, but is not alone in this race.[8] The United Kingdom is also at the forefront of commercial fusion, developing in 2021 a UK Fusion Strategy to support commercialization. The United Kingdom updated that strategy in 2023 and, like the United States, established a separate regulatory framework for fusion that differs from that for fission, in 2022.[9]

A number of other countries are showing significant interest, including Japan, Russia, and China, which have invested heavily in the technology, setting up a race to see who can deploy it first. Japan, home to the world's largest experimental tokamak JT-60SA, has provided more than $2.8 billion to its National Institute for Fusion Science and has private-sector ambitions to deploy a 50–100 megawatt (MW) fusion machine in 2034.[10] Russia, the initial pioneer of the tokamak design, is developing and manufacturing the critical first wall panels and is setting new performance records at its T-15MD tokamak.[11] China has made global leadership in fusion a national priority, developing multiple prototype generators, fostering multiple startups, and establishing a national consortium backed by state-owned enterprises to greatly increase its resources directed toward fusion deployment.[12] With roughly $2 billion, China invested more in fusion than the United States overall in 2023 and 2024.[13]

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4 "World Energy Outlook 2024," International Atomic Energy Agency, October 2024, https://www.iea.org/reports/world-energy-outlook-2024.

5 "Readout of the White House Summit on Developing a Bold Decadal Vision for Commercial Fusion Energy White House," White House, April 19, 2022, https://bidenwhitehouse.archives.gov/ostp/news-updates/2022/04/19/readout-of-the-white-house-summit-on-developing-a-bold-decadal-vision-for-commercial-fusion-energy/

6 "DOE National Laboratory Makes History by Achieving Fusion Ignition U.S. Department of Energy," US Department of Energy, December 13, 2022, https://www.energy.gov/articles/doe-national-laboratory-makes-history-achieving-fusion-ignition.

7 Brooke P. Clark, "Staff Requirements Memorandum—SECY-23-0001—Options for Licensing and Regulating Fusion Energy Systems," US Nuclear Regulatory Commission, April 13, 2023, https://www.nrc.gov/docs/ML2310/ML23103A449.pdf.

8 Wurzel, "The Global Fusion Race Is On"; "Helion Announces $425M Series F Investment to Scale Commercialized Fusion Power," Helion Energy, Inc., January 28, 2025, https://www.helionenergy.com/articles/helion-announces-425m-series-f-investment-to-scale-commercialized-fusion-power/.

9 "Towards Fusion Energy: the UK Fusion Strategy," UK Departments for Energy Security and Net Zero and Department for Business, Energy & Industrial Strategy, last updated October 16, 2023, https://www.gov.uk/government/publications/towards-fusion-energy-the-uk-fusion-strategy"; Regulation Decision to Help 'Accelerate' Fusion Energy Progress," UK Atomic Energy Authority, June 20, 2022, https://www.gov.uk/government/news/regulation-decision-to-help-accelerate-fusion-energy-progress#:~:text=The%20government%20will%20legislate%20to,nuclear%20regulatory%20and%20licensing%20requirements.

10 Yuka Obayashi, "Japan Start-up Aims to Launch World's First Steady-State Fusion Reactor in 2034," Reuters, August 30, 2024, https://www.reuters.com/business/energy/japan-start-up-aims-launch-worlds-first-steady-state-fusion-reactor-2034-2024-08-30/.

11 "Russia Completes Tests on First Wall Panels for ITER," World Nuclear News, January 11, 2024, https://world-nuclear-news.org/Articles/Russia-ready-to-mass-produce-first-wall-panels-for.

12 Jennifer Hiller and Sha Hua, "China Outspends the U.S. on Fusion in the Race for Energy's Holy Grail," *Wall Street Journal*, July 8, 2024, https://www.wsj.com/world/china/china-us-fusion-race-4452d3be; "China Launches Fusion Consortium to Build 'Artificial Sun,'" Nuclear Newswire, January 9, 2024, https://www.ans.org/news/article-5668/china-launches-fusion-consortium-to-build-artificial-sun/; "Hanhai Juneng Completed an Angel Round of Financing of Tens of Millions of Yuan, Led by Huaying Capital," iNews, September 17, 2024, https://inf.news/en/economy/27a5419084562258318a9fe30a270271.html. Example Chinese ventures include ENN, Startorus Fusion, Energy Singularity, and HHMax, the latter of which publicly discussed its intent to directly model a US company's approach.

13 Wurzel, "The Global Fusion Race Is On."

Countries are looking for solutions to enable fusion's safe and rapid deployment

As fusion draws increasingly closer to realizing its transformative potential, governments have sought to understand the best policies to promote and regulate this technology at commercial scale, including whether fusion poses a proliferation concern and what should be done to address it.

In its decision to regulate fusion separately from fission, NRC Commissioners concluded that proposed private-sector fusion approaches do not carry the same proliferation risks as nuclear reactors, with one stating, for example, that they "cannot be readily adapted to produce special nuclear material such that they would present significant proliferation risk."[14] Nonetheless, commissioners asked the NRC staff to explore whether "controls-by-design approaches, export controls, or other controls are necessary for near-term fusion energy systems" to address any potential proliferation concerns.[15] The United Kingdom, which has also decided to differentiate between regulations for fusion and those for fission, is further evaluating the issue and in 2023 "committed to providing clarity to the fusion sector" on these topics.[16] The International Atomic Energy Agency (IAEA), the intergovernmental organization that promotes the safe and peaceful use of nuclear energy (including the implementation of its nuclear safeguards regime), has a number of separate ongoing projects on fusion deployment, including looking at nonproliferation.[17]

These explorations must be balanced by developers' need for certainty as they deploy the first plants over the next decade and get ready to scale up thereafter. As NRC Chair Christopher Hanson said in his vote on fusion's regulatory framework, "There are dozens of developers racing toward pilot scale commercial fusion. While the precise future of fusion energy in the United States is uncertain, it is incumbent on the agency to provide as much regulatory certainty as possible given what we know today."[18]

Using the path laid for fission won't work for fusion and puts global energy security at risk

As the global community tries to catch up with the pace of fusion's development, some have suggested simply applying the approach that currently exists for fission reactors to fusion power plants.[19] Yet, while the current world has been built around fission, the path forward for fusion cannot use the same approach.

One challenge is that the current model for fission, with its focus on closely policing fissionable material and the fission-specific nuclear fuel cycle, does not match with how fusion works. Fission-powered reactors are governed by a stringent international nonproliferation and security framework. This framework has been essential because of fission reactors' use of fissionable materials—such as enriched uranium and plutonium—in both their fuel and the waste they generate, which are essential components for nuclear weapons.[20]

This regulatory regime is underpinned by the global Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and implemented

14 "Commissioner David Wright Voting Record SRM-SECY-23-0001," March 9, 2023, https://www.nrc.gov/docs/ML2310/ML23103A440.pdf. "Special nuclear material" refers to materials such as enriched uranium or plutonium.

15 Clark, "Staff Requirements Memorandum."

16 "Towards Fusion Energy."

17 See, e.g.: "Legal and Institutional Issues of Prospective Deployment of Fusion Facilities," International Atomic Energy Agency, January 2023, https://conferences.iaea.org/event/345/contributions/29903/attachments/15865/26650/6_Khoroshov.pdf.

18 "Chair Chris Hanson Voting Record SRM-SECY-23-0001," March 31, 2023, https://www.nrc.gov/docs/ML2310/ML23103A438.pdf.

19 As one example, amendment of the NPT was proposed by some participants at a DOE Fusion Energy and Nonproliferation Workshop in January 2023. See: "Fusion Energy and Nonproliferation Workshop," US Department of Energy, National Nuclear Security Administration, Office of Defense Nuclear Nonproliferation, March 5, 2023, https://sites.google.com/pppl.gov/nonproliferationworkshop/workshop-i-2023/final-report. Although the IAEA has generally stated that facility-level safeguards (defined below) do not apply to fusion power plants, in some publications it notes that this position could change. See, e.g.:"Fusion Key Elements," International Atomic Energy Agency, 2024, https://www-pub.iaea.org/MTCD/Publications/PDF/p15764-P2099E_web.pdf. See also: Alexander Glaser and Robert J. Goldston, "Proliferation Risks of Magnetic Fusion Energy: Clandestine Production, Covert Production and Breakout," IAEA Nuclear Fusion, March 2012, https://iopscience.iop.org/article/10.1088/0029-5515/52/4/043004/pdf.

20 The term fissionable material generally refers to isotopes of the heavy elements in the periodic table that are capable of undergoing fission. It generally consists of two types of material: special fissionable material (similar to special nuclear material under the Atomic Energy Act), which generally means enriched uranium or plutonium, and unenriched materials that can be used to create special fissionable materials, which are generally called source material and include unenriched uranium or thorium. See: "Safeguards Glossary," International Atomic Energy Agency, 2022, 35–36, https://www.iaea.org/publications/15176/iaea-safeguards-glossary; "42 U.S. Code 2014—Definitions," Legal Information Institute, Cornell Law School, last visited January 3, 2025, https://www.law.cornell.edu/uscode/text/42/2014.

by the IAEA through activities such as its safeguards program.[21] However, the NPT and associated Safeguards Agreements focus on elements in the periodic table specifically used for nuclear fission, including source material (such as thorium and unenriched uranium) and special fissionable material (such as plutonium and enriched uranium)—grouped together as fissionable material—as well as equipment "especially designed or prepared for" the production, processing, or use of special fissionable material.[22] This is because these materials are the ingredients and technology required for all nuclear weapons and explosive devices.

Fusion, in contrast, operates on entirely different principles and materials. Unlike fission reactors, fusion does not use fissionable material.[23] Instead, it employs isotopes of lighter elements like hydrogen and helium, which reside on the opposite end of the periodic table from the heavy elements used in fission and are more easily available. These elements are incapable of fueling a nuclear weapon in the absence of the fissionable material already subject to, and closely overseen by, IAEA safeguards programs.[24] As noted by the NRC staff, commercial fusion power plants under development in the United States are not expected to create fissionable material. The IAEA has summed it up plainly: "A fusion system that does not use, process, produce or otherwise have source and special fissionable material is not subject to IAEA safeguards."[25]

Extending the existing safeguards regime—particularly the facility-level measures deployed at fission reactors—to fusion power plants would essentially force a square peg into a round hole. This would create crippling regulatory burdens and uncertainty without delivering clear benefits to global safety, right when the industry needs to successfully deploy its first power plants and rapidly move to scale. At a time when the United States and its allies are in a bitter competition with geopolitical competitors for control of global energy supplies, hyper-cautious action could have dire consequences for the energy security of the United States and its allies. Moreover, renegotiating the fundamental fission safeguards frameworks at a time when global nonproliferation goals are under duress—particularly from the war in Ukraine and Russia's exit from existing nuclear treaties—risks damaging the broader existing nonproliferation regime.[26]

A practical route forward

Instead of amending the current fission-based safeguards regime (and likely the NPT itself) to include fusion, at a cost of hobbling fusion developers, this paper proposes a practical approach that leverages existing nonproliferation tools, including export controls, to enable fusion's safe and effective deployment.

While fusion's risk profile is inherently limited, it is important to recognize that fusion technologies and materials, including neutron emission and tritium (a hydrogen isotope used in some fusion approaches), could potentially be misused. The good news is that existing multilateral export control frameworks currently successfully regulate proliferation-associated aspects of fusion technology. These export controls are supplemented with additional frameworks and tools already in use by the IAEA and national governments to regulate civilian applications of radioactive materials. More specifically, a practical approach forward to address fusion non-proliferation can include as its core elements:

- dual-use export controls that already apply today to many aspects of existing fusion technologies;
- existing licensing and security tools that would already police radioactive materials of concern, such as tritium at fusion power plants;

21 "Treaty on the Non-Proliferation of Nuclear Weapons (NPT)," United Nations, March 1970, https://disarmament.unoda.org/wmd/nuclear/npt/; "IAEA Safeguards: Serving Nuclear Non-Proliferation," International Atomic Energy Agency, 2023, https://www.iaea.org/sites/default/files/18/09/sg-serving-nuclear-non-proliferation.pdf.

22 "Treaty on the Non-Proliferation of Nuclear Weapons (NPT)," Articles III.1–III.2.

23 Some countries have envisioned fission-fusion hybrid systems, which we do not include in this paper as they already fall within the existing framework for fission, such as the NPT and IAEA safeguards requirements. None of the commercial fusion technologies being pursued in the United States by commercial developers are fission-fusion hybrid systems.

24 "Tritium Stewardship," Savannah River National Laboratory, last visited December 12, 2024, https://www.srnl.gov/research-areas/national-security/weapons-production-technology/tritium-stewardship/.

25 "IAEA World Fusion Outlook 2023," International Atomic Energy Agency, October 2023, https://www-pub.iaea.org/MTCD/Publications/PDF/FusionOutlook2023_web.pdf.

26 John Mecklin, "2024 Doomsday Clock Statement," *Bulletin of the Atomic Scientists*, January 23, 2024, https://thebulletin.org/doomsday-clock/current-time/; Neil MacFarquhar, "Russia Pulled Out of a Nuclear Test Ban Treaty. Here's What That Means," *New York Times*, November 2, 2023, https://www.nytimes.com/2023/11/02/world/europe/russia-nuclear-test-ban-treaty.html.

- IAEA Additional Protocol tools such as complementary access, which—paired with safeguards that already exist on fission nuclear fuel-cycle activities—give the IAEA and governments a broad capability to monitor for concerns; and
- leadership by developers as they make their first fusion deployments to build trust with stakeholders and allow for lessons learned.

This approach is flexible enough to address fusion's risks for the foreseeable future. And when fusion is on the cusp of true mass deployment, with mature fusion power plants in operation and hundreds more ordered, that could be an appropriate time to learn from experience and examine if these existing systems need to be substantially amended—while keeping the approach distinct from those used for fission reactors.

In summary, a fusion-specific regulatory approach that combines export controls, existing licensing and inspection tools, and company-led transparency can reconcile the promise of fusion energy with the imperative of global security. A careful, phased pathway that leans on the many protections already in place is the only one that allows for a proactive stance against potential technology abuse, while enabling the United States and its allies to lead the world in fusion deployment and reestablish global energy dominance.

INTRODUCTION: FUSION IS ON THE GLOBAL HORIZON

Fusion energy—the release of energy during the merging of light elements—has long been pursued for its potential to produce an immense amount of energy-dense, baseload clean electricity, without substantial accident risks or waste. Thanks to decades of advancements in enabling technologies such as power electronics, magnets, lasers, and computational modeling, applied research in fusion has accelerated to the point where the technology is close to commercial deployment.[27] There are now dozens of fusion companies in the United States alone. Globally, companies have raised more than $8 billion in private capital, and many of them anticipate deploying their approaches to fusion energy within a decade.

Indeed, within the next few years, multiple companies are seeking to demonstrate fusion energy—and, in a few cases, even electricity production—with construction of the sector's first power plants to follow.[28] To this end, the White House in 2022 held a fusion summit, expressing a desire for fusion and confidence about its inclusion on the grid in the 2030s.[29] This coincided with an announcement from the US Department of Energy that the National Ignition Facility at Lawrence Livermore National Laboratory had achieved scientific energy breakeven, the threshold at which a fusion device produces more energy than the system required to drive the reaction.[30] In April 2023, the NRC established a regulatory framework for fusion under its current byproduct materials regime used for licensing industrial uses of radioactive materials. This decision to regulate fusion separately from fission enabled the industry and set it on a clear pathway to deployment.[31] This decision was followed shortly by the announcement of the world's first purchase agreement for fusion power, to be delivered this decade.[32]

The United Kingdom is also at the forefront of commercial fusion progress, developing a UK Fusion Strategy to support commercialization in 2021 and updating it in 2023.[33] The UK government has also established a regulatory framework for fusion, separating it from fission.[34] Many other countries are showing significant interest, including Russia and China. Russia, the initial pioneer of the tokamak design, is developing and manufacturing the critical first wall panels for International Thermonuclear Experimental Reactor (ITER) and is setting new performance records at its T-15MD tokamak.

27 Christopher Helman, "Fueled By Billionaire Dollars, Nuclear Fusion Enters a New Age," *Forbes*, January 4, 2022, https://www.forbes.com/sites/christopherhelman/2022/01/02/fueled-by-billionaire-dollars-nuclear-fusion-enters-a-new-age/?sh=7fec725929f3; "Next Generation Magnet Technology Paves the Way to Commercial Fusion Power," Tokamak Energy, September 23, 2021.

28 "A Closer Look at SPARC's Burning Plasma Ambitions," Nuclear Newswire, October 5, 2020, https://www.ans.org/news/article-2257/a-closer-look-at-sparcs-burning-plasma-ambitions/; "Helion Raises $500 Million, Targets 2024 for Demonstrating Net Electricity from Fusion," Helion Energy, November 5, 2021, https://www.helionenergy.com/articles/helion-raises-500m/.

29 "Readout of the White House Summit on Developing a Bold Decadal Vision for Commercial Fusion Energy White House."

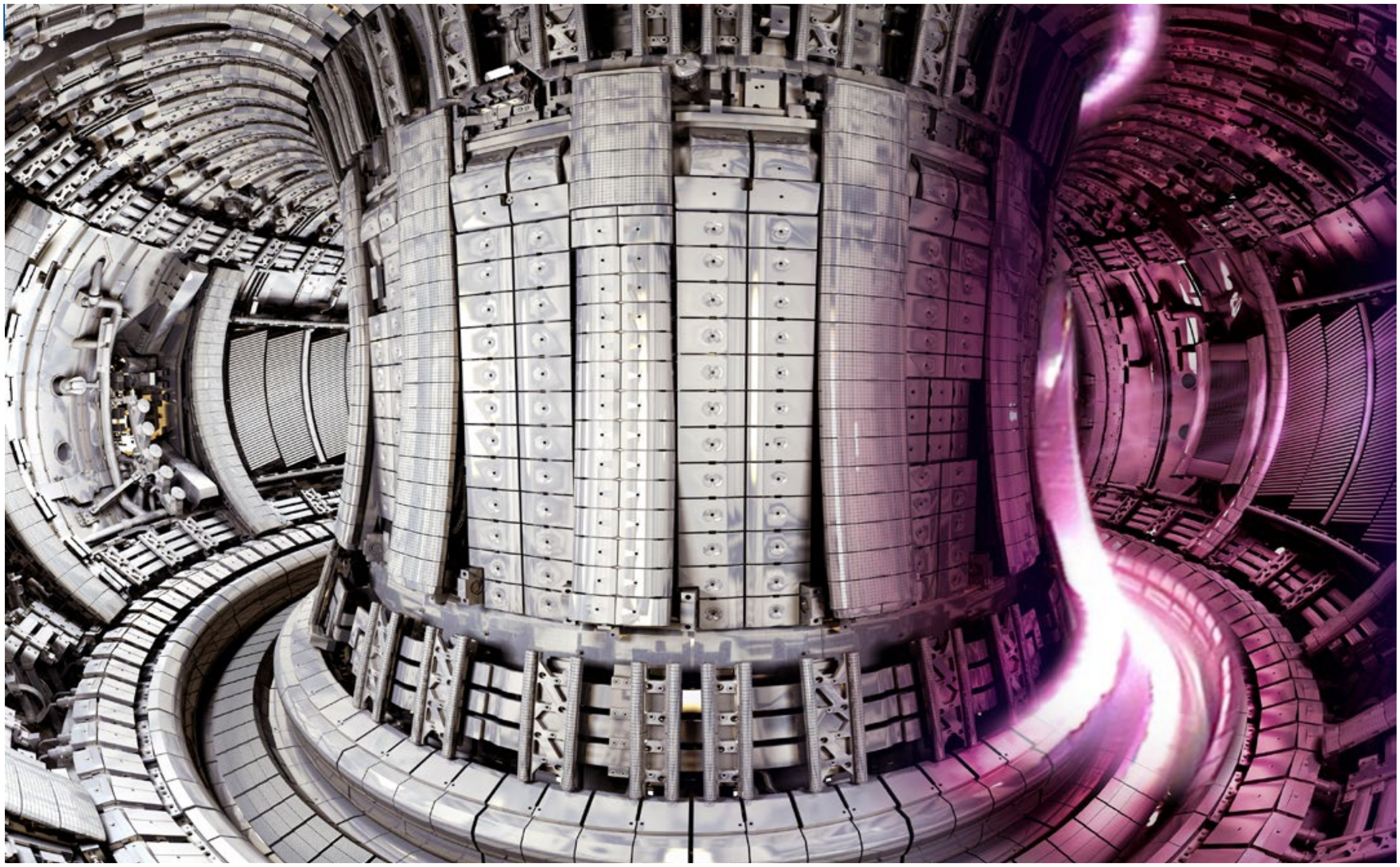
30 "DOE National Laboratory Makes History by Achieving Fusion Ignition U.S. Department of Energy."

31 Clark, "Staff Requirements Memorandum."

32 "Helion Announces World's First Fusion Energy Purchase Agreement with Microsoft."

33 "Towards Fusion Energy."

34 "Regulation Decision to Help 'Accelerate' Fusion Energy Progress."



The UK's Joint European Torus has played a significant role in advancing global fusion energy research. Source: United Kingdom Atomic Energy Authority

China has heavily invested in the technology, investing more than any country but the United States, and has made clear that it wants to win the race to global deployment. This includes the establishment of a national consortium to greatly increase resources toward fusion deployment and the launch of multiple new ventures.[35] In the last two years, China's investment exceeded $2 billion, outstripping that of the United States.[36] The Chinese government recognizes that, although the United States leads in innovation, the race belongs to whomever can deploy the technology first and, from there, dictate global energy security in the decades to come.[37]

The advent of commercial fusion energy will induce a paradigm shift in global efforts to deploy affordable, clean baseload energy to meet rising energy demand across the world. First and foremost, fusion fuels—isotopes of hydrogen, helium, lithium, and boron—are generally easy to procure or can be produced directly within the fusion power plants themselves. Many fusion generators are designed to facilitate mass manufacture, as they comprise small components assembled in factories and are expected to be deployable without substantial site-specific tailoring and with limited environmental impact.

Although fusion is a nuclear technology, the physics behind it have the potential to greatly simplify the needed regulations to ensure the safe and secure operations of plants, especially when compared to facilities like nuclear fission reactors. Importantly, fusion cannot go "critical" and, unlike traditional nuclear power plants, creates no high-level waste. As stated by the chair and ranking members of the US Senate committee that oversees nuclear regulation, "leading scientists from around the world have determined that fusion does not pose safety concerns similar to fission."[38] This aligns with statements by the NRC's own staff, which concluded in a 2023 paper to the commission that proposed private-sector fusion

35 Hiller and Hua, "China Outspends the U.S. on Fusion in the Race for Energy's Holy Grail."

36 Wurzel, "The Global Fusion Race Is On."

37 Angela Dewan and Ella Nilsen, "The US Led on Nuclear Fusion for Decades. Now China Is in Position to Win the Race," CNN, September 19, 2024, https://www.cnn.com/2024/09/19/climate/nuclear-fusion-clean-energy-china-us/index.html.

38 "Senators Carper and Captio Letter to NRC Chairman Applauds Work to Craft Regulatory Path for Fusion," Fusion Industry Association, August 2022, https://www.fusionindustryassociation.org/senators-carper-and-capito-letter-to-nrc-chairman-applauds-work-to-craft-regulatory-path-for-fusion/.

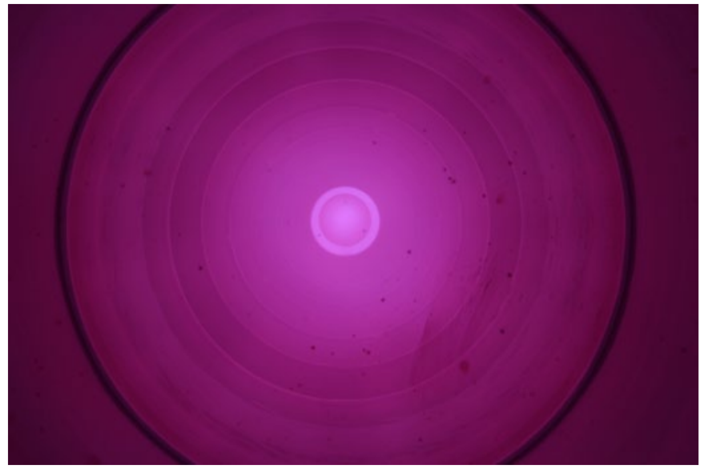
approaches did not carry the same proliferation risk as nuclear reactors, and "cannot readily be adapted to produce special nuclear [fissile] material such that they would present significant proliferation risk."[39]

Given these advantages, fusion could be rapidly deployed once it is proven, making it one of the few technologies capable of meeting the current global need for a gigawatt of clean energy per day to meet the minimum targets for 2050 zero-carbon generation goals. Fusion could provide a significant part of the global power supply within two decades, filling much of the need for affordable, reliable, secure, and carbon-free power. Indeed, global energy dominance will be dictated by who can master the deployment of fusion energy at scale.

PAVING A PATH FOR FUSION DEPLOYMENT

It is essential to prepare now for global fusion deployment. By proactively ensuring a secure framework, private companies will have a safe and effective pathway for worldwide scaling as soon as they demonstrate commercial viability. As described by the White House Office of Science and Technology Policy: "[W]e simply don't have the time to wait. We need all the clean technology we can get, as soon as is humanly possible. Fusion is one of the critical technologies that, if successful, would be a game-changer for addressing these issues."[40]

Proliferation is an important part of that discussion and, given fusion's fast deployment, questions are starting to arise about how to regulate its limited impacts. Most countries simply want to give the companies in their jurisdictions clear rules. In establishing a regulatory path for fusion, for example, the NRC commissioners asked the agency's staff to explore going forward if "controls-by-design approaches, export controls, or other controls are necessary for near-term fusion energy systems" to address any potential proliferation concerns."[41] The United Kingdom is likewise further evaluating the issue and in



An end-on view of Helion Energy's sixth-generation fusion prototype shows a fuchsia glow, which comes from the hydrogen Balmer series (emission of visible light due to excitation and recombination). Source: Helion Energy

2023 "committed to providing clarity to the fusion sector" on these topics.[42]

Meanwhile, the IAEA, which helps manage the current global safeguards regime for fission power plants, also has a number of separate ongoing projects on fusion deployment, including evaluating whether nonproliferation concerns exist.[43] In 2023, the IAEA published the first edition of the "World Fusion Outlook," as the agency appeared to kick off a concerted effort around fusion deployment and associated safety, security, and nonproliferation evaluations.[44] It states at the outset that "[w]e are closer than ever to making fusion energy generation a reality" and discusses activities the IAEA has undertaken to support fusion energy development since 1958.[45]

These explorations are balanced by developers' need for certainty as they deploy the first plants over the next decade and get ready for scalng deployment after that. As Hanson said in

39 "Policy Issue, Notation Vote, SECY-23-0001, Options for Licensing and Regulating Fusion Energy Systems," January 3, 2023, https://www.nrc.gov/docs/ML2227/ML22273A163.pdf; see also: "Commissioner David Wright Voting Record SRM-SECY-23-0001."

40 Sally M. Benson and Costa Samaras, "Parallel Processing the Path to Commercialization of Fusion Energy," Office of Science and Technology Policy, Executive Office of the President, June 3, 2022, https://www.whitehouse.gov/ostp/news-updates/2022/06/03/parallel-processing-the-path-to-commercialization-of-fusion-energy/.

41 Clark, "Staff Requirements Memorandum."

42 Ibid.

43 "Legal and Institutional Issue of Prospective Deployment of Fusion Facilities."

44 "IAEA World Fusion Outlook 2023"

45 Ibid. at 7, 61.

his vote on fusion's regulatory framework, "There are dozens of developers racing toward pilot scale commercial fusion. While the precise future of fusion energy in the United States is uncertain, it is incumbent on the agency to provide as much regulatory certainty as possible given what we know today."[46]

Given that the current world is built around fission, some individuals and entities have suggested simply applying what we already have for fission to fusion. In conferences in the United States in 2023, for example, some participants "discussed the prospect of, and associated timelines associated with possibly amending the NPT or Safeguards Agreements to address fusion systems," including the creation of new IAEA model agreements.[47] Although the IAEA has generally stated that safeguards—particularly the controls and measures that apply to fission reactors and nuclear fuel-cycle facilities—do not apply to fusion power plants, it has noted that this position could always change in the future.[48] The possibility of applying a fission-specific approach to fusion could prove crippling to deployment, however.

FUSION'S FUNDAMENTAL DIFFERENCES FROM FISSION WARRANT A DISTINCT GLOBAL APPROACH

There is no such thing as a free lunch in energy—all types of energy production have some form of impact. Given fusion's near-term prospects, now is the time to start thinking about the road forward for global deployment of fusion energy—enabling the growth of this key clean energy technology while ensuring appropriate measures to address its limited proliferation risk. This involves not just identifying existing global nonproliferation and export control tools that can apply, but also assessing their adequacy for implementation to fusion given the nature of the risk.

Fusion is often associated with fission, its opposite nuclear reaction. Both involve manipulating atoms to obtain energy. However, in critical ways they are very different forms of energy. Fission energy poses a unique proliferation concern because it uses fissionable material (source material and special fissionable material), which when suitably processed is the core element of all nuclear weapons. As a result, the global nonproliferation framework addresses the intentional handling, use, and production of fissionable material to manage nuclear weapons proliferation concerns.

Fusion, on the other hand, does not use or produce fissionable material and does not rely on a fuel cycle that involves those materials. Its fuels are at the opposite end of the periodic table and cannot create a chain reaction necessary for a feasible nuclear weapon. Therefore, the current regime appropriately does not apply such stringent controls to fusion fuels, equipment, or technology—and it should not in the future.

This paper illustrates a better path in which different existing tools can be used to appropriately address the limited proliferation risks associated with fusion. Given the growing discussion, it is important at the outset to draw the distinction between the safeguards-based nonproliferation regime that exists today—which focuses on source and special nuclear material—and what is needed to govern the safe deployment of fusion.

A global nonproliferation regime with a focus on "safeguarding" fissionable material

Before describing why the fission-based regime should not apply to fusion in the same way, it is helpful to provide background about how that regime developed.

The nuclear age, which began at the end of World War II, saw humanity's mastery of nuclear fission reactions—for both peaceful uses and nuclear weapons. Controlling the safe deployment of this technology was among the first orders of business for the United Nations.[49] The world recognized the great potential of applications of nuclear energy, while also recognizing the risks associated with nuclear weapons.

It quickly became clear that special fissionable material and the source material it came from (uranium and thorium) needed to be closely controlled. Because fissionable material is uniquely essential to nuclear weapons, safeguarding that material could effectively prevent nuclear weapons proliferation. At the same time, other materials (such as stainless steel and electronics) mattered much less and were unrestricted in a manner that enabled continued industrialization and modernization. This applies even to thermonuclear weapons (sometimes called

46 "Chair Chris Hanson Voting Record SRM-SECY-23-0001."

47 "Fusion Energy and Nonproliferation Workshop," at 25.

48 "Fusion Key Elements."

49 "Establishment of a Commission to Deal with the Problems Raised by the Discovery of Atomic Energy," United Nations, 1946, https://digitallibrary.un.org/record/671200?ln=en.

hydrogen bombs), as the base of these weapons still relies on fissionable material, and the tritium and/or lithium located inside acts as a booster to a fission-centric process.[50]

By 1970, the world had established the NPT, which forms the basis of the legal framework governing the use of fissionable materials. It established a carefully negotiated balance. The five recognized nuclear weapons states would commit to disarmament as a guiding principle, while the rest of the world would submit to a verification framework in exchange for the technical know-how and material to harness fission for peaceful applications.[51] The NPT mandates a comprehensive framework using IAEA safeguards to verify the peaceful use of nuclear materials by countries without nuclear weapons, which are commonly referred to as non-nuclear weapon states.

The NPT concerns the application of safeguards over source or special fissionable material, as well as equipment "especially designed or prepared for" creating special fissionable material.[52] The NPT's scope was carefully negotiated such that, considering both nuclear weapons and peaceful uses of nuclear technology, controls should be only implemented to "the extent necessary" to ensure peaceful use.[53] The NPT is one of the most widely adopted treaties in history, with 191 countries as states party.[54] In the modern world, it is difficult to imagine a more widely accepted treaty with such lasting significant impact.[55]

The key verification tool promoted by the NPT is the IAEA safeguards system,[56] a collection of activities and agreements between the IAEA and member states allows the United Nations (UN) nuclear watchdog to verify "the fulfilment of [a country's] obligations assumed under [the NPT] with a view to preventing diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices."[57] The IAEA is an autonomous entity within the UN framework, and it has executed bilateral and multilateral safeguards agreements of varying types (the most common being the comprehensive safeguards agreement, or "CSA") with more than 180 countries around the world—including India, Pakistan, and Israel, which are non-states parties to the NPT.[58]

Safeguard agreements apply IAEA safeguards and related oversight on "all source or special fissionable material in all peaceful nuclear activities within [the country's] territory," with specific guidance on controlling and accounting for "nuclear material" (defined as sources of special fissionable material).[59] At a high level, the IAEA safeguards program is a holistic evaluation of a country's compliance with nuclear nonproliferation goals, and the IAEA and national

50 Robert S. Norris and Thomas B. Cochran, "Thermonuclear Warhead," Britannica, last visited February 2024, https://www.britannica.com/technology/thermonuclear-warhead.

51 Today, four additional states outside of the NPT are understood to have nuclear weapons: India, Pakistan, Israel (ambiguous), and North Korea. But, for the globe at large, this balance sought by the NPT remains in effect.

52 "Treaty on the Non-Proliferation of Nuclear Weapons," Articles III.1–III.2.

53 "First Resolution of the United Nations Establishing the UN Atomic Energy Commission," Article 1(5)(b), January 24, 1946. https://docs.un.org/en/A/RES/1(I). The UN Atomic Energy Commission's early discussions on nuclear control and the prevention of proliferation influenced later efforts to craft the NPT—including the scope of the NPT.

54 Ibid.

55 To be sure, the NPT hasn't completely eliminated the spread of nuclear weapons. As noted earlier, India, Pakistan, North Korea, and—many believe—Israel have atomic weapons. These countries, along with South Sudan, have stayed out of the NPT. Still, they remain outliers.

56 "Treaty on the Non-Proliferation of Nuclear Weapons," (discussion text). The safeguards regime predates the NPT but, as a practical matter, aligns with and is executed in light of the NPT.

57 "The implementation of IAEA safeguards comprises four fundamental processes, namely (i) the collection and evaluation of information, (ii) the development of a safeguards approach for a State, (iii) the planning, conduct and evaluation of safeguards activities, including in-the-field and at Headquarters, and (iv) the drawing of safeguards conclusions." The safeguards regime predates the NPT but, as a practical matter, aligns with and is evaluated in light of it. "Treaty on the Non-Proliferation of Nuclear Weapons," Article III.1.

58 "Safeguards Agreements," International Atomic Energy Agency, https://www.iaea.org/topics/safeguards-agreements.

59 "The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons," International Atomic Energy Agency, June 1972, paragraphs 1, 28, 106, and 112, https://www.iaea.org/sites/default/files/publications/documents/infcircs/1972/infcirc153.pdf.

governments look at a wide variety of information—including public information, voluntary disclosures, and more—to evaluate a country's compliance with its nonproliferation commitments.

The core of these agreements is a set of controls, verification measures, inspections, and more that apply directly to facilities that use nuclear materials, specifically fission-specific fuel-cycle facilities such as fission reactors, enrichment facilities, and places that contain fissionable material—for simplicity, referred to in this paper as "facility-level safeguards."[60] Control, accountancy, and surveillance of fissionable material form core tenets of this regime.[61]

Safeguards provide a robust regime to prevent, deter, and detect nuclear weapons proliferation. However, they come with a significant cost. IAEA safeguards, particularly the facility-level safeguards applied to fission reactors, entail significant amounts of work for the IAEA and its inspectors. They also require support from government officials within states with safeguards agreements and commercial operators implementing safeguards (including pausing operations to facilitate inspections). Still, despite some acknowledged challenges, the safeguards regime underpinned by the NPT has generally been effective in preventing the spread of nuclear weapons to additional states, while fostering peaceful uses of nuclear material for more than half a century.[62]

As noted above, the NPT was carefully drafted to establish a legal regime over "(a) source or special fissionable material, or (b) equipment or material especially designed or prepared for the processing, use or production of special fissionable material."[63] The phrase "equipment especially designed" is specific and has a well-established, limited scope of meaning.

A "long-standing list of key equipment determined to be especially designed or prepared for the production or use of special fissionable material," is found in the trigger list.[64] This list was established in 1974 by the Zangger Committee—also called the NPT Exporters Committee—comprising thirty-nine members who worked together to determine which materials qualify as "especially designed or prepared material" under Article III.2 of the NPT.[65] A similar trigger list was later established by the forty-eight-member Nuclear Suppliers Group (NSG) and also reflected those components "especially designed or prepared for" nuclear reactor or fuel-cycle end use, and which should directly be subject to safeguards under the NPT.[66] These trigger lists were essentially adopted in updates to the safeguards agreements called the Additional Protocol (Annex II).[67] (For purposes herein, we refer to the Zangger Committee list as the trigger list).

The trigger list includes—and is also limited too—nuclear reactors, fuel fabrication facilities, reprocessing plants, enrichment facilities, heavy-water facilities, conversion facilities, and key components and materials.[68] Each of these

60 Ibid. Also see: "Safeguards Glossary."

61 "IAEA Safeguards Overview: Comprehensive Safeguards Agreements and Additional Protocols," International Atomic Energy Agency, last visited February 2024, https://www.iaea.org/publications/factsheets/iaea-safeguards-overview. (Measures "authorized under NPT-type comprehensive safeguards agreements—largely are based on nuclear material accountancy, complemented by containment and surveillance techniques, such as tamper-proof seals and cameras that the IAEA installs at facilities.") In the United States, materials controls and accountancy are supplemented by a specialty physical security regime that exists for those sites that have fissionable material, such as fission power plants. See: "Nuclear Material Control and Accounting," US Nuclear Regulatory Commission, last visited December 2021, https://www.nrc.gov/materials/fuel-cycle-fac/nuclear-mat-ctrl-acctng.html.

62 Tero Varjoranta, "Meeting Safeguards Challenges," International Atomic Energy Agency, December 3, 2013, https://www.iaea.org/newscenter/statements/meeting-safeguards-challenges; "IAEA Safeguards."

63 Treaty on the Non-Proliferation of Nuclear Weapons," Articles III.2.

64 Glaser and Goldston, "Proliferation Risks of Magnetic Fusion Energy."

65 "Communication Dated 18 February 2020 Received from the Permanent Mission of Denmark Regarding the Export of Nuclear Material and of Certain Categories of Equipment and Other Material," International Atomic Energy Agency, March 5, 2020, https://zanggercommittee.org/download/18.6a32cf891717bf4c02d11/1672310882188/infcirc209r5.pdf; "Zangger Committee," Nuclear Threat Initiative, last updated May 8, 2024, https://www.nti.org/education-center/treaties-and-regimes/zangger-committee-zac/#:~:text=The%20Trigger%20List%20was%20first,amended%20several%20times%20since%20then; "About Zangger Committee," Zangger Committee, last visited February 2024, https://zanggercommittee.org.

66 "Participants," Nuclear Suppliers Group, last visited February 2024, https://www.nuclearsuppliersgroup.org/index.php/en/about/participants; "Communication Received from the Parliament Mission of Kazakhstan to the International Atomic Energy Agency Regarding Certain Member States' Guidelines for the Export of Nuclear Material, Equipment and Technology," International Atomic Energy Agency, October 18, 2019, https://www.iaea.org/sites/default/files/publications/documents/infcircs/1978/infcirc254r14p1.pdf.

67 "INFCIRC/540 (Corrected), Model Protocol Additional to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards," International Atomic Energy Agency, 1997, https://www.iaea.org/sites/default/files/infcirc540c.pdf.

68 Uranium occurs naturally in a mix of isotopes, the most common of which is U-238. The lighter isotope U-235 is better suited for fission chain reactions, so most nuclear reactors rely on low-enriched U-235 fuel for their operations.

facilities and components are tied to nuclear end uses related to processing, using, or producing special fissionable material as envisioned under the NPT. As stated by governments in interpreting the NPT, a guiding question in interpreting the trigger list is "do the items meet the [especially designed or prepared] criteria for the processing, use, or production of special fissionable material?"[69] This focus on applying the NPT facility-level safeguards regime to nuclear reactors and the nuclear fuel cycle is echoed by language in the NPT which discusses to applying safeguards "with respect to source or special fissionable material."[70]

What belongs under safeguards should be considered carefully because an expansive range of materials—including fiber optics, steel, and screws—can also contribute to the making of a nuclear weapon. However, if the nonproliferation regime were to control everything that could potentially touch a nuclear weapon, implementation would become a burden, require immense costs, and be out of alignment with the consensus purpose to "control atomic energy to the extent necessary to ensure its use only for peaceful purposes."[71]

As a result, the nonproliferation framework deliberately chooses to focus on fissionable material and apply comprehensive safeguards controls to those facilities that play a direct role in the fission nuclear fuel cycle. Indeed, the IAEA itself summarizes this in its "2023 World Fusion Outlook," in which it states that a "fusion system that does not use, possess, produce, or otherwise have source and special fissionable material is not subject to IAEA safeguards."[72]

Fusion's technical case does not warrant changes to the safeguards regime

As stated, the safeguards regime tied to the NPT applies to source and special fissionable material along with equipment "especially designed or prepared for" use or production of such materials. Therefore, fusion power plants, including the fusion generator and fuel (such as tritium, lithium, helium, and boron) would not be subject to the associated facility-level requirements and inspections. This is consistent with the decisions made, at the creation of the NPT and throughout the life of the IAEA safeguards regime, not to include fusion.[73]

The primary theoretical risk raised with fusion is that fusion technology enables the creation of neutrons in sufficient quantities to generate special fissionable material from source material—but this does not occur in a vacuum.[74] If a bad actor, such as a rogue state with sophisticated engineering capabilities, wanted to produce special fissionable material using a fusion power plant, it would need to place meaningful quantities of source material in a specific fashion to be irradiated within the generator's structure, and then effectively extract that material and reprocess it—all in secret.

A commercial fusion generator simply could not do this without substantial modification and certainly is not intended for this use; otherwise, it would be a fission facility and not a fusion facility. A fusion generator converted to produce special fissionable materials would likely need, at minimum, modified handling systems to introduce source material, modifications to shielding and blanket systems, potential redesigns

69 "INFCIRC/539/Rev.7, Communication Received from the Permanent Mission of the Republic of Kazakhstan to the International Atomic Energy Agency on Behalf of the Participating Governments of the Nuclear Suppliers Group," International Atomic Energy Agency, November 5, 2019, https://www.iaea.org/sites/default/files/publications/documents/infcircs/1997/infcirc539r7.pdf.

70 "Treaty on the Non-Proliferation of Nuclear Weapons," Articles III.1. In practice, and for the purposes here, the scope of safeguards prescribed by Articles III.1 and III.2 of the NPT are very similar.

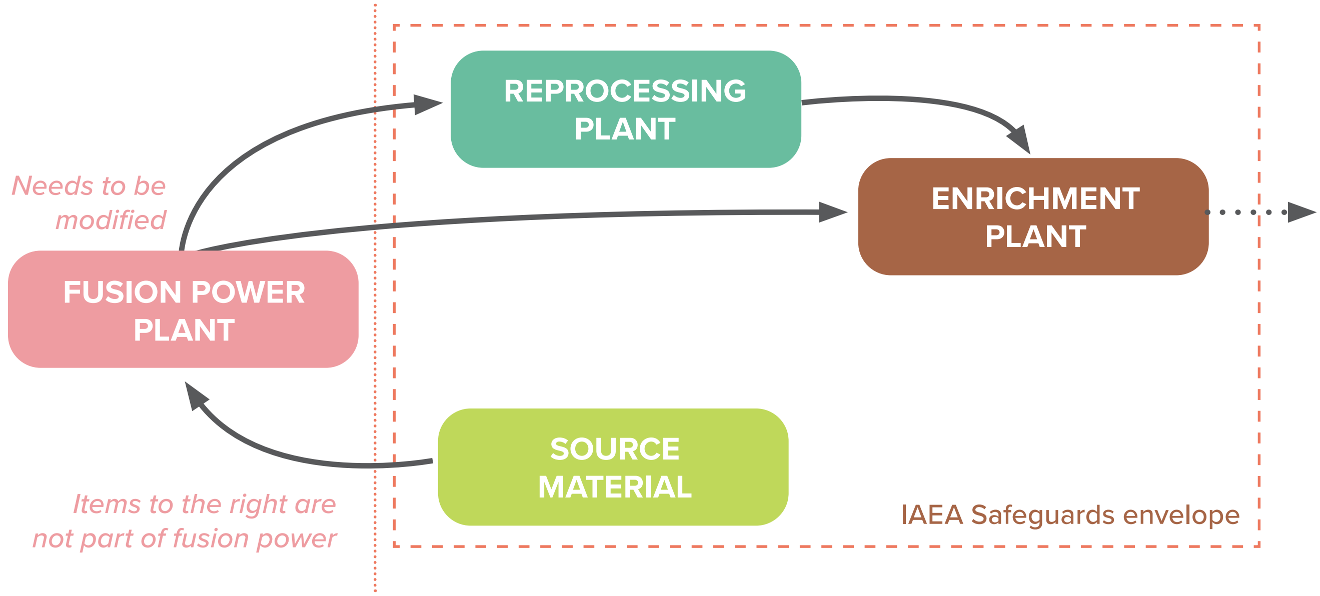
71 "First Resolution of the United Nations Establishing the UN Atomic Energy Commission."

72 "2023 World Fusion Outlook."

73 For example, fusion has been excluded from US Department of Energy export control regime specifically for safeguards of nuclear technologies that can create special fissionable material. See: "Code of Federal Regulations," National Archives, last visited January 3, 2025, https://www.ecfr.gov/current/title-10/chapter-III/part-810?toc=1; "Atomic Energy Act of 1954," GovInfo, last visited January 3, 2025, section 57b, https://www.govinfo.gov/content/pkg/COMPS-1630/pdf/COMPS-1630.pdf; "The Department of State Bulletin," Office of Public Communication, Bureau of Public Affairs, 1968; "Documents on Disarmament," United States Arms Control and Disarmament Agency, September 1969. During the negotiations of the NPT text, the US permanent representative to the United Nations said in 1968 that "controlled thermonuclear fusion technology will not be affected by the treaty."

74 The process of breeding special fissionable material via neutron irradiation entails introducing and exposing source material to fusion neutrons in a specific manner, and then extracting and purifying the material after irradiation.

FIGURE 1: Fusion and the the IAEA safeguards envelope



Illustrative diagram showing that the hypothetical pipeline to produce special fissionable material with fusion systems requires fission-based steps that are subject to safeguards. Note that a fusion power plant does not require the items in the IAEA safeguards envelope to otherwise operate commercially, and they are not part of the commercial fusion fuel cycle. Source: graphic created by authors.

of pumps, and entire additional facilities.[75] These would also appear to require knowledge transfer that would be subject to export controls.

In addition, in some cases using fusion systems for proliferation would require a dramatic and noticeable switch that is hard to miss—instead of producing power, these facilities would likely need power, up to many tens of megawatts or more.[76] Analysis supports that, for this and other reasons, such clandestine facilities would be easy to detect and they would fall under the scrutiny of existing IAEA safeguards through the Additional Protocol.[77] Under this protocol in most states, per the IAEA, "the IAEA may seek access to a fusion plant which is not using nuclear material to assure the absence of undeclared nuclear material and activities at such a plant."[78]

Thus, commercial fusion generators themselves do not raise concerns about proliferation of special fissionable material unless these facilities are dramatically modified into a different, easily discernible fission-fusion hybrid facility, which would itself qualify for safeguards. The IAEA has existing tools to address this specific case (more on these below).

Separate from neutron generation, the use of tritium—a material that can boost the yield of a fission-based nuclear weapon—in fusion power plants does not change the analysis. Tritium itself cannot feasibly create a nuclear weapon, and expanding facility-level safeguards to tritium destroys the bright line that currently exists within the safeguards regime. For decades, industrial facilities and fusion research machines have held many grams of tritium without the application of

75 For example, fusion technology can produce enough neutrons to convert kilograms of source material into special fissionable material. See: Glaser and Goldston, "Proliferation Risks of Magnetic Fusion Energy." However, as noted, the technology would need to be applied toward a device specifically geared for that task—and would need to be altered by a third-party bad actor. Commercial fusion technologies under development do not use source or special fissionable material in the fusion system and would need to be heavily modified in order to effectively accept it. Such systems would be subject to the global safeguards regime.

76 Ibid., Section 2.

77 Ibid.

78 "IAEA World Fusion Outlook 2023," at page 25. Relatedly, the IAEA may seek complementary access under Article 4(a)(ii) of the Additional Protocol to verify the completeness and accuracy of information provided io it.

safeguards. All this time, the global nonproliferation community has not decided to place tritium under IAEA safeguards (despite active consideration during efforts to update and expand the IAEA's authority), and there is no clear evidence commercial fusion generators provide a materially qualitative or quantitative different risk than those facilities.[79]

It is also worth asking whether applying safeguards measures to fusion power plants would add a meaningful benefit over protections that would otherwise be in place for tritium diversion. In any fusion power plant, tritium will already be carefully controlled and monitored for safety purposes, as it poses a hazard to humans if incorporated into the body or the environment.[80] Tritium and its associated technologies are regulated under domestic nuclear regulations and export control frameworks, including the dual-use export control regime discussed below, and therefore already fall under the safety and security oversight of government authorities. For example, dual-use controls require that the destination and end use of the exported technology or material be evaluated, and destination state safety and security frameworks be assessed as part of this process. Separate approaches exist for securing radioactive materials to prevent their use for radiological dispersal devices (RDD), which could be considered for fusion and tritium in the longer term.[81]

And any uncertain benefit must be weighed against the incredible uncertainty that reopening the safeguards regime will likely have on fusion deployment, if not the global safeguards framework as a whole. As stated by the NRC's chair, the growing private sector needs certainty in order to make its first deployments.[82] Successful deployments in the coming decade will give humanity an incredible new tool to provide people with the affordable clean energy they need and every country in the world the chance to be energy secure.

Changing fundamental aspects of how fusion should be regulated risks completely pausing investment and progress at a formative stage. There is also the added risk that opening these fundamental agreements could give certain countries an opportunity to weaken the current fission nonproliferation regime altogether, especially at a time when the risk of nuclear confrontation is increasing.

A TAILORED APPROACH FOR FUSION USING EXISTING TOOLS

The current safeguards regime appropriately focuses on the material required to develop a nuclear weapon and therefore does not legally or technically apply to fusion. However, as noted, there are hypothetical scenarios in which a well-funded bad actor (following an extensive research and development effort) could theoretically use a deep understanding of the underlying fusion technology to build new fusion devices that are designed for different purposes. Given this focus on technology and not material, export controls are the most effective approach to preventing fusion technology from falling into the hands of such actors. Fortunately, these controls already apply, giving a clear path forward for regulators and developers.

79 In the 1990s, the IAEA secretariat, with the support of several states, proposed that tritium and tritium recovery facilities be added to Annex I of the Additional Protocol as an indicator of weaponization and fuel-cycle activities. However, they were ultimately not included as they were not deemed essential to the IAEA's safeguards system. Compare: "Model Protocol Additional to the Agreement(s) between the State(s) and the International Atomic Energy Agency for the Application of Safeguards," to "GC(40)/17, Strengthening the Effectiveness and Improving the Efficiency of the Safeguards System, Report by the Director General to the General Conference, International Atomic Energy Agency, August 23, 1996, https://www.iaea.org/sites/default/files/gc/gc40-17_en.pdf (showing tritium was considered but eventually not included). Indeed, despite the lack of a qualitative difference in risk, it is not clear quantitatively that the tritium inventories anticipated at commercial fusion power plants would differ from today's industrial users. As a sample of anticipated tritium inventories among private-sector fusion companies, General Fusion has preliminarily estimated that its commercial fusion power plant will have 2–4 grams of tritium in total inventory at any time, and Commonwealth Fusion Systems has preliminarily estimated 50–90 grams. See: ""Fusion Demonstration Plant," General Fusion, October 27, 2021, https://www.nrc.gov/docs/ML2129/ML21299A313.pdf (part of a larger set of presentations provided to the NRC, see specifically slide 27, pdf page 29, discussing inventories for commercial plants); Commonwealth Fusion Systems, "Fusion Attributes in the Private Industry Context," Commonwealth Fusion Systems, March 30, 2021, https://www.nrc.gov/docs/ML2109/ML21090A288.pdf (part of a larger set of presentations provided to the NRC, see specifically slide 6, pdf page 81, discussing inventories for the ARC commercial plant). Some other fusion technologies, such as Helion Energy's, do not use tritium as a fuel but instead produce it as a product, which can be stored independently onsite or in a separate facility (with the amount in the vacuum vessel preliminarily estimated to be in the micro-gram quantities). See: "Helion Energy: Supplementary Safety Case Analysis," Helion Energy, Inc. March 23, 2022, https://www.nrc.gov/docs/ML2208/ML22081A057.pdf ((part of a larger set of presentations provided to the NRC, see specifically slide 119). In comparison, the JET facility in the United Kingdom was approved to hold almost 100 grams of tritium. A.C. Bell, et al., "The Safety Case for JET D-T Operation," Fusion Engineering and Design, Vol. 47, December 1999, https://www.sciencedirect.com/science/article/abs/pii/S0920379699000800.

80 "EPA Facts about Tritium," US Environmental Protection Agency, last visited February 2024, https://semspub.epa.gov/work/HQ/175261.pdf.

81 See, e.g.: "Code of Conduct on the Safety and Security of Radioactive Sources," International Atomic Energy Agency, 2004, https://www.iaea.org/publications/6956/code-of-conduct-on-the-safety-and-security-of-radioactive-sources.

82 "Chair Chris Hanson Voting Record SRM-SECY-23-0001."

The countries involved in the fusion research center ITER applied export controls for the facility's construction and found limited issues. Source: ITER

Taking advantage of the dual-use export control regime

A regime already exists to police the exchange of technology and know-how distinct from the safeguards framework: the global dual-use export control regime. Fusion is not the first technology that can be used for both commercial and military purposes. Anything from laptops to software to high-strength steel can be used for everyday commercial applications but can also create national security risks if abused.

As a result, there exists a broad global regime that controls exports of technology that can have national security, foreign policy, proliferation, missile, chemical, biological, stability, crime, or terrorist concerns.[83] In the United States, an extensive dual-use export controls framework exists. It covers thousands of different components and is enforced by the US Department of Commerce's Bureau of Industry and Security. It is a powerful regime, as evidenced by the use of export controls to substantially hinder Chinese companies ZTE and Huawei after they were found to be diverting civilian semiconductor technologies to military applications.[84] Moreover, the regime in the United States has recently been strengthened by new statutes that increase its scope, tools available to enforce it, and penalties for violations.[85]

In fact, this dual-use regime already applies to key technologies required for fusion. Although the NSG excluded fusion from its safeguards-based trigger list, it also established an export controls-based dual-use list (sometimes called Part 2 Guidelines), which delineates controls on second-level technologies used in the nuclear supply chain that could carry proliferation concerns. This includes several technologies directly or indirectly related to fusion, including aspects of power

83 "Dual Use Export Licenses," US Department of Commerce Bureau of Industry and Security, last visited February 2024, https://www.bis.doc.gov/index.php/all-articles/2-uncategorized/91-dual-use-export-licenses.

84 See, e.g.: Eunkyung Kim Shin, et al., "US Government Imposes $1.19 Billion Fine Against ZTE for Violating US Sanctions and Export Controls," Baker McKenzie, March 23, 2017, https://sanctionsnews.bakermckenzie.com/us-government-imposes-1-19-billion-fine-against-zte-for-violating-us-sanctions-and-export-controls/; "Explainer: The U.S. Export Rule that Hammered Huawei Teed Up to Hit Russia," Reuters, January 24, 2022, https://www.reuters.com/business/us-export-rule-that-hammered-huawei-teed-up-hit-russia-2022-01-24/.

85 See, e.g.: "The U.S. Export Control System and the Export Control Reform Act of 2018," Congressional Research Service, June 7, 2021, https://crsreports.congress.gov/product/pdf/R/R46814.

electronics, neutron generators, lasers, the fuels required for fusion (such as tritium, lithium, helium-3, and boron), and the technologies to make or handle those materials.[86]

The Part 2 Guidelines instruct NSG members to prohibit exports of these technologies or related equipment where, among other things, there is reasonable risk of the technology's diversion to weapons development. Indeed, export controls were successfully applied to, and evaluated by, individual countries for the construction in southern France of the ITER facility, a fusion research and development center involving thirty-five countries, with limited issues identified.[87]

Therefore, the regime as it applies today already covers components associated with fusion. And once fusion is deployed, this regime can further adapt lessons learned to be ready for the broader global deployment of commercial fusion.

Dual-use export controls are coordinated by individual nations and responsible multilateral organizations such as the NSG and Wassenaar Arrangement, which can amend national laws or guidance much faster than a treaty can be renegotiated. As a result, these controls can adapt to the needs and challenges of fusion much more quickly. The NSG Part 2 Guidelines are periodically updated, as are the national export control regimes that the guidelines influence. Indeed, controls for fusion components might naturally need to be tailored as fusion scales, to enable global commercialization while still capturing relevant technologies.

The export control regime captures a scope of relevant countries similar to the current fission safeguards regime. Most middle and large economies around the world have adopted export control regimes aligned with international standards and multilateral regimes. In addition to the forty-eight countries in the NSG—capturing the main producers of sophisticated nuclear components—UN Security Council Resolution 1540 led to a substantial expansion of export control regimes across all UN member states.[88] Even countries that are not members of the NPT, such as India and Israel, have export control laws that are in material aspects aligned with the NSG regime, giving the export control regime arguably greater buy-in than the safeguards program.[89]

Because NSG members (and those that implemented Resolution 1540) have agreed to control the export of covered technologies in the first instance, other countries outside of this group simply would not have access to the technology without a license. To get a license, recipient countries would need to establish relevant proliferation protections. And to this end, export controls can be more effective when a technology is nascent and there is a chance to control its spread at the outset—which is the case with fusion today.

Combining with additional tools to create a path forward

Beyond applying export controls around fusion, additional tools exist to ensure fusion can deploy rapidly but safely. As mentioned above, licensing requirements around tritium and other radioactive materials to ensure safety, and security requirements to ensure non-diversion of radioactive materials into radiological dispersal device, can ensure fusion materials are not diverted to weapons purposes.

The Additional Protocol empowers the IAEA, working with states under their own safeguards agreements with the IAEA, to conduct "complementary access" (such as location-specific environmental sampling) to address suspicious activities at or near non-safeguarded facilities.[90] The tools under the Additional Protocol were created specifically to identify where facilities outside the traditional fission supply chain are being manipulated to create a proliferation risk, and (along with

86 See, e.g.: Bureau of Industry and Security Export Control Classification Numbers (ECCNs) 3A231, Neutron generator systems, etc.; 1C235, Tritium, tritium compounds, etc.; 1C234, Helium-3, etc.; 1B233, Lithium isotope separation facilities or plants, etc.; 1A231, Target assemblies and components for the production of tritium, etc.; 0D999, specific software for neutrons calculations, etc. These ECCNS can be found on the Commerce Control List. "Commerce Control List," 15 C.F.R. Part 744, as of February 9, 2025, https://www.ecfr.gov/current/title-15/subtitle-B/chapter-VII/subchapter-C/part-774.

87 "e-News, Issue 34, ITER and Export Control," US Burning Plasma Organization, July 2009, https://burningplasma.org/newsandevents/?article=enews&issue=071509.

88 "UN Security Council Resolution 1540," United Nations, 2004, https://disarmament.unoda.org/wmd/sc1540/.

89 See, e.g.: "Remarks of Kevin J Wolf, Assistant Secretary of Commerce for Export Administration," US Department of Commerce, Bureau of Industry and Security, 2016, https://www.bis.doc.gov/index.php/update-2016/1191-remarks-of-kevin-j-wolf-assistant-secretary-of-commerce-for-export-administration; ("India's aligning its export controls with those of the multilateral Export Control Regimes resulted in India's successful accession to the MTCR and current consideration for membership of the Nuclear Suppliers Group."); "Israel Export Control Information," US Department of Commerce, Bureau of Industry and Security, last visited January 3, 2025, https://www.bis.doc.gov/index.php/licensing/220-eco-country-pages/1147-israel-export-control-information. ("Although Israel is not a member of the Australia Group, Missile Technology Control Regime, Nuclear Suppliers Group, or Wassenaar Arrangement, Israel implements controls in line with these regimes and requires authorization for exports of all items listed on their control lists.")

90 "INFCIRC/540 (Corrected), Model Protocol Additional to the Agreement(s) Between State(s) and the International Atomic Energy Agency for the Application of Safeguards."

safeguards on the existing nuclear fuel cycle) could be well-suited for fusion in the longer term.[91] The IAEA has already made clear it intends to lean on those tools for first fusion deployments.[92]

Finally, it is up to the burgeoning fusion community to continue to show leadership. Safety and security always need to be front and center as the technology deploys. To this end, leading companies should endeavor to work closely with regulators and other stakeholders, such as the IAEA, as the first plants connect to the grid.

In summary, the right approach to fusion doesn't double down on applying fission-era safeguards to fusion facilities but uses four flexible tools to address fusion's risks for the foreseeable future. These include:

- dual-use export controls that already apply today to many aspects of existing fusion technologies;
- existing licensing and security tools that would already police radioactive materials of concern, such as tritium at fusion power plants;
- IAEA Additional Protocol tools such as complementary access, which—paired with safeguards that already exist on fission nuclear fuel-cycle activities—give the IAEA and governments a broad capability to monitor for concerns;
- leadership by developers as they make their first fusion deployments to build trust with stakeholders and allow for lessons learned.

The industry and other stakeholders can then build on the lessons learned to plot the future in a way that balances safety and the expeditious deployment of this potentially world-changing technology. It is no surprise that the IAEA said in its "2023 World Fusion Outlook" that "States may use other non-safeguards tools to effectively manage the limited proliferation risks from fusion," referring to the protections described above such as export controls.[93]

And when fusion is on the cusp of true mass deployment, with mature plant designs in operation and hundreds more ordered, countries and regulators could look back with years of actual experience specific to the technology. At that time, nations that are leading in deployment can examine if these existing systems need to be more substantially amended, and how to do that without slowing the deployment of fusion at scale.

CONCLUSION

Fusion has the potential to deliver clean, firm, abundant energy to address our energy security and clean energy needs. Today's leaders are looking for how to strike the right balance, to give future generations a chance to make that world a reality while protecting against the dangerous proliferation of nuclear weapons.

The fission-based nonproliferation model is the wrong tool for the job. The IAEA safeguards regime undergirded by the NPT has been intentionally designed to focus on fission and fissionable material rather than fusion technologies. From the inception of the first safeguards agreements and the NPT itself, fusion has been deliberately excluded from the types of measures applied to fission reactors, a position that has been reinforced in subsequent international agreements. Subjecting fusion to the same safeguards as fission would be a monumental legal, policy, and diplomatic challenge—one likely impractical in the current geopolitical climate—and would create crippling uncertainty for the industry for unclear gain. Such an action is also not supported from a technical standpoint, as the risk of fusion technology diversion is already policed using current capabilities.

A much clearer path forward exists that takes advantage of existing capabilities, which regulators can act on today, and provides needed certainty for developers. This path includes export controls, existing licensing and IAEA tools, and transparency between regulators and first movers. These elements, in combination, will enable fusion to get on the grid rapidly and safely across the world, ensure global energy dominance for the United States and its allies, and form the foundation of an innovative approach to reducing the already low proliferation risks associated with this technology as it scales in the long term.

91 "Inventory of International Nonproliferation Organizations and Regimes, Additional Protocol," James Martin Center for Nonproliferation Studies, last updated September 23, 2015, https://media.nti.org/pdfs/iaea_Additional_protocol_16.pdf.

92 "IAEA World Fusion Outlook 2023," at pages 25, 34.

93 "IAEA World Fusion Outlook 2023."

ABOUT THE AUTHORS

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Before joining Helion, Desai spent his career in energy deployment, working on regulatory issues across technologies before focusing on nuclear power and then fusion energy. As an attorney at the law firm of Hogan Lovells. Desai became a leading voice on fusion regulation, helping to inform the development of the US Nuclear Regulatory Commission's approach to fusion energy. He has continued this work at Helion, where he routinely speaks with federal and global regulatory bodies, members of Congress, the US Department of Energy, and other key voices within the fusion sector.

Desai has a master's degree in aerospace engineering from Cornell University, and a law degree from Harvard Law School, where he was editor-in-chief of the *Harvard Environmental Law Review*. He is a board member of the Fusion Industry Association, a member of the International Group of Legal Experts on Fusion Energy, and an advisory board member of the Columbia University Center on Global Energy Policy Nuclear Energy.

Michael Hua is currently the director of radiation safety and nuclear science at Helion Energy, a fusion energy company based in Everett, Washington. The scope of Hua's team spans radiation safety and licensing, nuclear engineering (diagnostics, design, and neutronics), fuel cycle management (chemical engineering, vacuum systems, and tritium), materials science, and advanced plasma concepts.

Prior to Helion, Hua earned his PhD from the University of Michigan, focusing on neutron detection for nuclear nonproliferation, worked in the advanced nuclear technology group at Los Alamos National Laboratory, and spent time in the intelligence community working on nuclear counterproliferation. He has published in both policy and scientific journals.

Being on the forefront of the burgeoning fusion industry and leveraging his background in nuclear nonproliferation, Hua has been leading conversations on the scope of nonproliferation and safeguards measures for fusion systems and plants. These conversations span presentations, panels, and plenaries at the Institute of Nuclear Materials Management annual meetings; technical and consultancy meetings at the International Atomic Energy Agency (IAEA); and, leading the discussions and writing of the IAEA document on nonproliferation and fusion.

Amy Roma is a nonresident senior fellow with the Atlantic Council's Global Energy Center and a Partner and the Global Energy Practice Leader at the international law firm Hogan Lovells. In her practice, Amy advises clients on a wide range of legal, business, and policy matters involving the nuclear fission and fusion industry—with a focus on deploying first-of-a-kind projects. She has testified before Congress several times on nuclear energy and fusion issues and was recognized as one of the "Top 10 Most Innovative Lawyers" in North America by the Financial Times, and again this December as the "Most Innovative Lawyer in the Technology Sector" for her work to enable mass deployment of microreactors and fusion facilities. The *National Law Journal* has declared her as a Top 50 "great mind impacting the crucial intersection of energy production and the environment."

Amy has also led a number of high impact humanitarian initiatives, included leading the legal efforts to send the New England Patriots' private team plane to China in March 2020 to pick up and donate nearly two million N95 masks, and spearheading a number of high-risk evacuations and resettlements from Afghanistan. In addition to her JD, Amy holds an MBA with a focus in finance and leadership from the University of Virginia.

Jessica Bufford has worked for over ten years on nuclear security, safeguards, nonproliferation and arms control. Most recently, she served as a senior program officer for Nuclear Threat Initiative's (NTI) nuclear material security team. In this role, she led a community-building initiative among diverse stakeholders working to deploy US-developed advanced reactors. She also supported efforts to increase global action on nuclear security through the Global Dialogue on Nuclear Security, develop innovative multilateral approaches to disarmament verification through the International Partnership on Disarmament Verification, and facilitate cooperation with China on nuclear security issues through Track 1.5 engagements.

Prior to joining NTI, Bufford worked in the division of nuclear security at the IAEA. While at the IAEA, she supported the universalization of the Convention on the Physical Protection of Nuclear Material (CPPNM) and its 2005 Amendment and preparations for the review of the CPPNM Amendment in 2021. She also facilitated coordination of nuclear security activities with other international organizations and initiatives. Bufford has also worked on materials management and minimization at the US Department of Energy National Nuclear Security Administration, and worked previously at NTI as a Herbert J. Scoville Fellow.

Bufford received a master's degree in nonproliferation and terrorism studies, with a certificate in conflict resolution, from the Monterey Institute of International Studies and bachelor's degrees in political science and French from Austin College.

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Previously, Siebens was also an associate with the nuclear security program at the Stimson Center, where she worked with the private sector performing analysis to develop comprehensive nuclear security standards, and incentivize industry stakeholders to reduce the risks posed by nuclear terrorism.

Siebens is a graduate of East Carolina University and earned her master's degree from the North Carolina State University School of Public and International Affairs. Throughout her career, she has published and presented with numerous organizations including the International Nuclear Law Association, the International Atomic Energy Agency, the Institute for Nuclear Materials Management, and the World Institute for Nuclear Security. She regularly briefs the US Congress on matters related to the development of advanced nuclear reactors, and the application of nuclear security and safeguards.

Andrew Proffitt is the regulatory policy lead for Helion Energy, where he leads regulatory policy implementation at the state, federal, and international levels to enable the initial and scaled deployment of fusion energy. Prior to joining Helion, he worked at the US Nuclear Regulatory Commission (NRC) for fourteen years in a wide array of roles including acting branch chief of advanced reactor licensing and senior project manager for fusion. Proffitt led the development of the policy paper providing options to the commission for licensing and regulating fusion machines and served as the NRC's external contact for the Fusion Industry Association (FIA), US Department of Energy (DOE), fusion energy companies, non-governmental organizations, and other interested stakeholders.

Previously at the NRC, Proffitt served as a nuclear engineer focusing on fuel design and design basis accident analysis for small modular reactor designs. He also served as the agency's lead project manager for accident tolerant fuel where he developed an agency-wide project plan, coordinated commission briefings and Senate hearings, conducted a phenomena identification and ranking table exercise, and oversaw development of NRC guidance. In this role, Proffitt interfaced with DOE, the Nuclear Energy Institute, Electric Power Research Institute, industry leading utilities, and other stakeholders.

Proffitt also served as a technical assistant in the Japan Lessons-Learned Division implementing safety improvements at domestic nuclear power plants following the Fukushima event. He began his career at the NRC as a reactor systems engineer specializing in fuel design and transient analysis of operating reactors. He holds a bachelor's degree in nuclear engineering from the University of Tennessee.

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