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11 Nuclear disarmament, nuclear energy, and climate change

Exploring the linkages

Matthew Bunn

Abstract
Preventing nuclear war and avoiding catastrophic climate change are two of the most basic challenges facing human civilization in the twenty-first century. While these are separate issues, these challenges are linked in several ways, and both may be affected by the future of nuclear energy. For nuclear energy to provide any substantial part of the low-carbon energy needed in the second half of the twenty-first century would require dramatic growth. This chapter provides an overview of the constraints and risks of nuclear energy growth on that scale, and the necessary steps to address them. In particular, use of nuclear energy at that scale would place unprecedented demands on global systems for verification, control, and security for weapons-usable nuclear materials. Deep reductions in nuclear arms and their eventual prohibition will also require new approaches to managing the vast global stocks of weapons-usable nuclear materials. Politically, nuclear energy may not be able to grow on the scale required unless governments and publics are confident that it will not contribute to the spread of nuclear weapons, creating another link between climate mitigation and nuclear nonproliferation and disarmament.

Introduction

Preventing nuclear war and avoiding catastrophic climate change are two of the most fundamental challenges facing human civilization in the twenty-first century. The horrifying devastation of a nuclear war could set humanity back centuries. Failure to mitigate climate change sufficiently could also cause human suffering on a terrible scale. Hence, both these challenges must be met in order for there to be any hope of building a just and peaceful world. In many ways, these are separate challenges, with separate problems that are the biggest barriers to progress. But there is also a variety of links between them.[1]

First, there is the direct link—the possibility that nuclear war could cause a climate catastrophe. Modeling since the mid-2000s has suggested that smoke from even a modest number of cities attacked with nuclear weapons would rise up into the stratosphere and block a fraction of the sun's light at global scales, interfering with agriculture and potentially putting a billion people at risk of starvation.[2] This possibility of a "nuclear famine" has added another supporting argument to calls for complete nuclear disarmament, and has been an important part of the the humanitarian effects of nuclear weapons movement. A more recent analysis using a detailed fire model, however, suggests that little of the smoke from burning cities would rise high

[1] For a broad survey of historical links, see Christine Parthemore, Chapter 10in this volume.
[2] See, for example, Alan Robock, Luke Oman, Georgiy L. Stenchikov, Owen B. Toon, Charles Bardeen, and Richard P. Turco, "Climatic Consequences of Regional Nuclear Conflicts," *Atmospheric Chemistry and Physics*, Vol. 7, No. 8 (2007), pp. 2003–2012. The evolution of the "nuclear winter" and "nuclear fall" literature is reviewed in more detail in Parthemore, Chapter 10 in this volume.

enough to avoid being brought back to earth by rain and other weather, and that much of what cooling effect did occur at long distances would tend to concentrate at the poles, dramatically reducing the projected human impact.[3] As this latter analysis comes from experts at a US nuclear weapons laboratory (Los Alamos), and given the importance of the issue, research by additional, independent groups is necessary to explore whether these conclusions are robust.

Second, there are political and governance links. Coping successfully with either climate change or nuclear disarmament would require mobilizing political forces across the world and building stronger structures for global governance that are more responsive to current needs. Success in political mobilization and governance-building in either of these domains would create habits of cooperation, strengthened global institutions, and reduced tensions between the global haves and the have-nots that could be helpful in addressing the other. But negative connections are not hard to find either. World political leaders have only so much attention they can devote to global issues: more attention devoted to one existential challenge is likely to mean less devoted to another. And failures in either nuclear disarmament or mitigating climate change could exacerbate tensions and disagreements, making success in the other arena more difficult to achieve.

Third, there are security links. Although there remain serious controversies over the likely links between climate change and conflict, there are grounds for concern that if we fail to mitigate and adapt to climate change sufficiently, the resulting droughts, floods, crop failures, and other natural disasters could increase conflicts, insecurity, and streams of refugees in multiple regions around the world.[4] Increased conflict and fears of conflict could drive additional states to seek nuclear weapons, though few climate-driven conflicts are likely to be of the large-scale conventional invasion or nuclear coercion types for which nuclear weapons are a plausible response. Increased conflict and fears of conflict would also make large-scale growth of nuclear energy both riskier and less likely.

Fourth, there are technological links. Large-scale expansion of nuclear energy is one of the options for low-carbon energy supply. Today, renewables and efficiency, backed up by the newfound abundance of natural gas, are providing the most economic means to cut carbon emissions in many markets. But in the long term, as the world moves to very deep decarbonization, and use of natural gas without carbon capture is no longer tolerated, non-intermittent low-carbon sources such as nuclear energy could be quite important as a backup to renewables.

There are both tensions and synergies between large-scale nuclear energy use to mitigate climate change and nuclear disarmament. On the one hand, nuclear energy could pose challenges to disarmament. A terawatt-scale global civilian nuclear energy infrastructure would involve massive flows of nuclear material and huge capacities to produce weapons-usable nuclear material. These would have to be managed with extraordinary care to avoid contributing to risks of the spread of nuclear weapons or to risks of instability in the final stages of nuclear disarmament.

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3 Jon Reisner, Gennaro D'Angelo, Eunmo Koo, Wesley Even, Matthew Hecht, Elizabeth Hunke, Darin Comeau, Randall Bos, and James Cooley, "Climate Impact of a Regional Nuclear Weapons Exchange: An Improved Assessment Based on Detailed Source Calculations," *Journal of Geophysical Research: Atmospheres,* Vol. 123 (2018), pp. 2752–2772.

4 For a useful overview of the literature on climate-conflict links, see Joshua Busby, "The State of the Field in Climate Security," *Duck of Minerva,* March 16, 2018, available at: http://duckofminerva.com/2018/03/the-state-of-the-field-in-climate-and-security.html. For a recent account of links among climate, security issues, and nuclear issues, see Working Group on Climate, Nuclear, and Security Affairs, *Report One: A Framework for Understanding and Managing the Intersection of Climate Change, Nuclear Affairs, and Security* (Washington, DC: Center for Climate Change and Security, 2017).

On the other hand, progress on nuclear disarmament may be an important enabler for large-scale nuclear energy growth. Politically, nuclear energy may not be able to grow on the scale required for it to be an important contributor to mitigating climate change unless governments and publics are confident that such growth will not contribute to the spread of nuclear weapons. But additional steps to reduce that danger may only gain the necessary sustained support among non-nuclear-weapon states if they see that the nuclear weapon states are genuinely making progress toward disarmament.

The remainder of this chapter focuses on the potential links between nuclear energy as an option for mitigating climate change and nuclear disarmament. First, it outlines the scale of growth required for nuclear energy to play a significant role. Second, it provides a brief overview of the constraints on, and risks of, nuclear energy growth on the scale required, and steps that might be taken to address them. Third, it focuses in particular on the unprecedented demands that nuclear energy use at that scale would place on global systems for verification, control, and security for weapons-usable nuclear materials and facilities capable of producing them. That section will also discuss approaches to managing the deep global stocks of weapons-usable nuclear materials that would have to be dealt with if deep reductions in nuclear arms and their eventual prohibition are to be achieved. Fourth, the chapter will discuss the political links between sustaining and strengthening the global nonproliferation regime, nuclear disarmament, and large-scale growth of nuclear energy. Fifth, the chapter will explain why protecting nuclear weapons, weapons-usable nuclear materials, and nuclear facilities from terrorists and thieves will be essential to nuclear energy, nuclear nonproliferation, and nuclear disarmament, making nuclear security the foundation of all three pillars of the nuclear Non-Proliferation Treaty (NPT). Finally, the chapter will offer a few conclusions and suggested next steps.

Current nuclear dangers

Before proceeding further, however, it is important to emphasize that at present the most urgent question is not so much how to achieve disarmament but how to avoid near-term nuclear catastrophes—including the very real potential of the collapse of the nuclear arms control structures that have regulated the strategic nuclear balance for the past half-century.[5] Today there is an intense crisis in US-Russian relations, with each side seeing the other as a critical strategic threat—a level of hostility that has not been seen in decades and contributes to the risk of inadvertent conflict. In addition, each side accuses the other of violating the Intermediate-Range Nuclear Forces (INF) treaty—and the belief that Russia is violating is poisoning prospects for future agreements on Capitol Hill and in the US administration. The New START treaty, unless extended, expires in early 2021, less than three years away at this writing, and that extension, even if agreed, takes it only to early 2026. With the intense domestic political polarization in the United States, unless the political atmosphere changes dramatically and the INF violations are successfully addressed, it is hard to imagine putting together a treaty that Russia will accept and that can get a two-thirds vote in the US Senate by

[5] For a useful discussion of the crisis in U.S.-Russian arms control, see Alexei Arbatov, Chapter 9 in this volume. For arguments that the combination of increased counterforce threats and missile defenses will interfere with arms reductions and perhaps lead to an arms race, see Kier Lieber and Daryll Press, Chapter 3 in this volume, and Wu Riquiang, Chapter 13 in this volume. Of course, states seeking to preserve their deterrents in the face of such threats have more options than simply increasing numbers, as suggested by the new types of strategic nuclear weapons announced by Russian President Vladimir Putin in March 2018.

2026. Hence it is possible that the international community will have to find ways to regulate the nuclear balance without further arms control treaties.[6]

Meanwhile, the United States under President Trump has pulled out of the Joint Comprehensive Plan of Action (JCPOA) with Iran, increasing the risks of nuclear proliferation and conflict in the Middle East, and at this writing (October 2018) is making unrealistic demands for near-term complete North Korean denuclearization, creating a serious risk that disappointment will drive a return to the brink of war. Pakistan and India are engaging in a nuclear arms competition, shifting toward dangerous tactical nuclear weapons, and enunciating doctrines that, if implemented as announced, would lead to nuclear war. The states with nuclear arsenals are modernizing them, rejecting the recently negotiated nuclear weapons ban treaty out of hand, and failing to engage in any disarmament talks at all. With no progress on arms reductions, the Comprehensive Test Ban Treaty, a fissile material cutoff, or a Middle East Weapons of Mass Destruction Free Zone, the prospects for the 2020 review of the NPT look grim. In short, there is considerable work to be done to shore up the international arms reduction and nonproliferation efforts that will be the essential foundations if progress toward nuclear disarmament is ever to be achieved.

The scale of the nuclear-climate challenge

At the same time, providing the energy the world needs without frying the planet poses a truly immense challenge. The International Energy Agency (IEA) estimates that $60 trillion in investment in energy supply and end-use technologies will be needed through 2040 to meet demand in its New Policies Scenario—which roughly matches the Paris commitments—with a further $9 trillion needed to achieve targets compatible with a 2 degree increase in global temperatures. Total final energy consumption in 2040 in these two scenarios would be 16 terawatts (TW) or 13 TW, respectively.[7] Global energy consumption at roughly those scales is likely to continue thereafter, and by the second half of the twenty-first century, mitigating climate change is likely to require that nearly all of this energy come from very low-carbon sources.

Hence, for nuclear energy or any other energy source to provide a really significant part of the total supply—say, 10–15 percent or more—would require growth on the scale of 1–2 TW, the equivalent of 1,000–2,000 one-gigawatt-electric (GWe) reactors or an even larger fleet of smaller plants. Achieving one TW of nuclear energy by 2050—while replacing nearly all of the existing plants as they reach the end of their lives by that time—would require adding roughly 30 GWe to the grid worldwide *every year* between now and 2050. That is roughly 10 times the nuclear capacity the world was adding annually in the decade before the Fukushima Daiichi disaster. Hence, for nuclear energy to provide even a tenth of the low-carbon energy likely to be needed in 2050 would mean convincing the organizations that decide what types of power plants to build that nuclear energy is ten times *more* attractive than it seemed before the Fukushima accident.

That is not impossible, but it is likely to be a heavy lift. Reactions to the Fukushima accident substantially reduced projections of global nuclear energy growth, with some countries abandoning nuclear energy altogether and others slowing their nuclear construction plans. In 2010, before the accident, the International Atomic Energy Agency's "high" projection for

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6 See, for example, Sergey Rogov, "Can the U.S. and Russia Find a Path Forward on Arms Control? How to Prevent a Dangerous Escalation," *Foreign Affairs,* May 22, 2018.

7 International Energy Agency, *World Energy Outlook 2017* (Paris: IEA, 2017), p. 101, and pp. 648–649, converted from millions of tons of oil equivalent.

nuclear energy in 2050 was 1,415 GWe, and its "low" projection for 2050 was 590 GWe; by 2017, these projections had each declined by a third, to 864 GWe and 382 GWe.[8] Nuclear energy may end up playing a bigger role after 2050, when very deep decarbonization will be required and intermittent renewables may need non-intermittent backup beyond storage.

Large-scale nuclear energy growth implies nuclear energy spread. If nuclear reactors become sufficiently attractive that existing nuclear states want to build hundreds of new ones, they will be attractive enough that many other countries will want to build them as well. That should be included in any assessment of the proliferation and disarmament implications of terawatt-scale nuclear energy use.

Nuclear energy constraints and risks

A wide range of constraints and risks have limited nuclear energy's growth in the past and could do so in the future unless appropriately addressed through modified policies, new technologies, or both.

Economics

Nuclear power is only likely to grow on a large scale if it is economically competitive with other energy sources, particularly low-carbon sources. Nuclear energy is competitive today in markets such as China, which: (1) can build reactors at lower cost and on shorter schedules than is typical in Europe or the United States; (2) offers low-cost government-backed financing for state-owned nuclear companies, and stable nuclear electricity prices; and (3) has a market with little competition from cheap natural gas. But in many markets, new nuclear plants are simply uncompetitive today.[9] Policies that provide low-cost financing and smooth the way for rapid construction can help, and many developers of advanced reactors claim their systems will be cheaper than current systems (and possibly able to provide industrial heat as well as electricity), but this remains to be demonstrated.

Accident risks: real and perceived

Similarly, to grow to terawatt scale, nuclear energy would probably have to achieve—and be seen to have achieved—very high levels of safety. Another Fukushima-scale catastrophe would likely doom prospects for such large-scale nuclear growth. Nuclear safety will have to improve if multiplying the number of reactors by threefold or even fivefold is not to increase the annual risk of a major accident by a similar factor. Yet even maintaining the levels of safety that have been achieved with improvements after the Fukushima accident may be a challenge, for as nuclear energy spreads, it is increasingly going to move to developing countries with lower ratings in World Bank indicators for regulatory effectiveness and control of corruption, raising obvious concerns. Here, too, both policy and technology could make a difference. On the policy side, investing in ensuring that regulators have the authority, resources, expertise, and culture needed to develop and enforce effective safety rules, and taking steps to build strong safety cultures throughout the industry, can make an immense difference. In the longer term, many advanced reactor designs are striving for increased passive safety, including, in some cases, reactors where even cutting off all cooling and walking away without doing anything to respond would not lead to a radioactive release—or so the designers claim.

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8 International Atomic Energy Agency, *Energy, Electricity, and Nuclear Power Estimates for the Period up to 2050* (Vienna: IAEA, 2010), p. 17; IAEA, *Energy, Electricity, and Nuclear Power Estimates for the Period up to 2050* (Vienna: IAEA, 2017), p. 19.

9 See, for example, Lazard, *Lazard's Levelized Cost of Energy Analysis—Version 11.0* (New York: Lazard, November 2017).

Terrorism risks: real and perceived

Terrorists could also cause a large reactor accident, for example by destroying power and cooling systems or draining water from a spent fuel pool. While a great deal has been done to improve nuclear safety around the world since the Fukushima accident, new steps to protect nuclear reactors from sabotage have been less substantial. Here too, both policies focused on stronger security requirements and security cultures and technological improvements focused on making it more difficult to cause a major radioactive release (whether by accident or on purpose) can reduce the risk significantly.[10] Nuclear security and its relation to nuclear energy, non-proliferation, and disarmament are discussed in more detail below.

Siting and public acceptance

Gaining public approval for new nuclear reactor sites is proving to be a major constraint on nuclear energy—even in authoritarian countries such as China.[11] Avoiding further nuclear melt-downs is by far the most important step to build public acceptance. Beyond that, on the policy side, strong and visible actions to ensure safety, combined with careful, step-by-step processes to listen to and build trust with local communities will be critical. On the technology side, if advanced reactors offer not only enhanced safety but more understandable, demonstrable safety, that could help build public confidence. Proposals for factory-built offshore nuclear plants—if implemented with appropriate safety and security—could make it possible to site large nuclear plants near the demand centers represented by coastal cities.

Nuclear waste management

A 1.5 TW nuclear energy infrastructure, if operated on a once-through cycle, would generate 20,000–40,000 metric tons of spent fuel every year (depending on the burnup). That may seem like an enormous amount, but it should be remembered that a *single* 1 GWe pulverized coal power plant generates well over 500,000 tons of toxic solid waste every year—not even counting the immense quantities of carbon dioxide waste it dumps into the atmosphere. The difficulty of siting nuclear waste repositories has been an enormous and lasting political problem for nuclear energy; but Finland and Sweden have now successfully sited nuclear waste repositories with the support of the local communities, showing it can be done, with an appropriate focus on building trust.[12] In the interim, the technology of dry casks makes it possible to store spent fuel cheaply, safely, and securely for decades, providing an important element of flexibility for whatever long-term use or disposal option is ultimately chosen.[13] *If* nuclear wastes are managed appropriately—something the United States and the Soviet Union, among others, both failed to do during the Cold War—the actual hazard to humans or the

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[10] Matthew Bunn, Martin B. Malin, Nickolas Roth, and William H. Tobey, *Preventing Nuclear Terrorism: Continuous Improvement or Dangerous Decline?* (Cambridge, MA: Project on Managing the Atom, Belfer Center for Science and International Affairs, Harvard Kennedy School, 2016), available at: http://belfercenter.ksg.harvard.edu/files/PreventingNuclearTerrorism-Web.pdf.

[11] For descriptions of recent siting controversies in China, see, for example, Hui Zhang, *China's Enrichment Capacity: Rapid Expansion to Meet Commercial Needs* (Cambridge, MA: Project on Managing the Atom, Harvard Kennedy School, August 2015), pp. 17–18. For a description of the Chinese government's efforts to build public support, see Yue Guo and Tao Ren, "When It Is Unfamiliar to Me: Local Acceptance of Planned Nuclear Power Plants in China in the Post-Fukushima Era," *Energy Policy,* Vol. 100 (2017), pp. 113–125.

[12] See, for example, Henry Fountain, "On Nuclear Waste, Finland Shows U.S. How it Can be Done," *New York Times,* June 9, 2017, available at: www.nytimes.com/2017/06/09/science/nuclear-reactor-waste-finland.html.

[13] Matthew Bunn, John P. Holdren, Allison Macfarlane, Susan E. Pickett, Atsuyuki Suzuki, Tatsujiro Suzuki, and Jennifer Weeks, *Interim Storage of Spent Nuclear Fuel: A Safe, Flexible, and Cost-Effective Approach to Spent Fuel Management* (Cambridge, MA: Project on Managing the Atom, Harvard University, and Project on Sociotechnics of Nuclear Energy, University of Tokyo, June 2001).

environment per kilowatt-hour generated is quite small and occurs primarily tens to hundreds of thousands of years in the future. With repositories built in large areas of rock or salt, so they could be continually expanded by further drilling, handling the volumes of waste from a terawatt-scale nuclear enterprise would not be a major obstacle to nuclear power growth.

Proliferation resistance

Proliferation risk is not the first thing most countries consider when deciding to build a nuclear power plant. Nevertheless, nuclear energy is not likely to get the government, investor, and public support needed to grow to the terawatt scale without reasonable confidence that this will not mean a major increase in proliferation risk. These potential risks are discussed in more detail below.

Government and industrial capacity

Many countries simply do not have the trained personnel, regulatory structures, or other elements required to safely launch a nuclear energy program today. Even countries that have nuclear energy programs have to invest in maintaining relevant capacity. The huge delays and cost overruns in the construction of nuclear power plants in the United States and Europe in recent years have occurred in part because the relevant companies had not built nuclear plants for decades and had lost the capacity to do so efficiently. China, which is building more nuclear plants than any other country, is investing in training personnel, building up the group of companies capable of providing key elements of construction or services, expanding the capacity of its nuclear regulators, and more. In the future, simpler, more automated reactors with greater degrees of passive safety, combined with factory rather than on-site construction, could reduce these capacity constraints, particularly if combined with new business models in which reactors might be operated by trained foreign staff rather than requiring local operators everywhere.

Regulatory delays

Expanding nuclear energy to terawatt-scale by mid-century or shortly thereafter would require extraordinarily effective approaches to nuclear regulation, stringent enough to ensure high standards of safety and security yet nimble and flexible enough to avoid unneeded delays in gaining approvals. In many countries, regulatory delays are likely to be an important factor constraining the pace of nuclear energy growth.

Integration into evolving grids

Traditionally, nuclear energy has primarily provided baseload electricity. In future electric grids dominated by intermittent renewables, it would be helpful if nuclear plants could do more to follow the load, and even provide peaking power if needed. Nuclear plants already have the technical capacity to do significant load following. Some advanced reactor designers are exploring concepts that might be able to store some of their energy until it was needed or use some of their heat to produce hydrogen that could be burned to drive a turbine and provide peaking power when needed.

Uranium supply

Uranium is abundant and is not likely to be a major constraint on nuclear energy growth in this century, contrary to arguments often raised. The resources described in the regular joint report on the subject from the International Atomic Energy Agency and the Nuclear Energy Agency would be sufficient to fuel 65,000 GWe-years of reactor operations on a once-through cycle.[14]

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[14] "Uranium Resources," in Mujid Kazimi and Ernest J. Moniz, co-chairs, *The Future of the Nuclear Fuel Cycle* (Cambridge, MA: Massachusetts Institute of Technology, 2009), pp. 31–42.

But as those agencies acknowledge, the amount reported every year is just a "snapshot," and in fact, the world has been finding uranium faster than it has been using it for decades. One might expect that the easiest-to-mine resources would be used first, leading to ever-rising prices. But that ignores the simultaneous advance of technology. The data shows that on average, the real price trend of mined minerals throughout the twentieth century was down, not up.[15] If conventional resources of uranium ever do run low, there is the possibility of recovering uranium from seawater (a supply of billions of tons), if advancing technology succeeds in reducing the costs of that process.[16] In short, there is no need for reprocessing and fast-neutron reactors to produce and recycle plutonium to extend uranium resources, at least for many decades to come.

Managing the proliferation and disarmament implications of nuclear energy growth

Increasing global nuclear energy deployments to the terawatt scale could pose substantial challenges to global efforts to limit the spread of nuclear weapons and to nuclear disarmament. But the severity of these challenges would depend on the institutional and technical approaches that were put in place to manage them.[17]

In and of themselves, light-water reactors operating with low-enriched uranium (LEU) fuel—which cannot sustain an explosive nuclear chain reaction—under IAEA safeguards pose quite modest proliferation risks. They do produce plutonium in their spent fuel—and, contrary to the view sometimes expressed by the nuclear industry, that reactor-grade plutonium is quite usable in nuclear weapons[18]—but the plutonium is roughly one percent by weight in large, intensely radioactive fuel assemblies, and cannot be accessed for use in nuclear weapons unless countries also have facilities for reprocessing (that is, for chemically separating the plutonium from the spent fuel). They do provide a core of personnel trained in nuclear matters and a bureaucratic power base for a country's nuclear advocates, but both of these would contribute only modestly to a country's efforts to launch a nuclear weapons program.

It is the fuel cycle supporting these reactors that provides the key technologies required for the production of potential nuclear bomb material—either enrichment, which can produce highly enriched uranium (HEU), or reprocessing, which separates plutonium from spent fuel. A huge expansion of global fuel cycle activities would be required to support a 1,500-GWe nuclear energy deployment. On a "once-through" cycle (with uranium enrichment, but no reprocessing), such a deployment would consume over 300,000 tons of uranium a year, and over 180 million "kilogram-separative work units" (kg-SWU) of enrichment work. Since it

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15 See Erich A. Schneider and William C. Sailor, "Long-Term Uranium Supply Estimates," *Nuclear Technology,* Vol. 162 (June 2008), pp. 379–387.

16 Recent estimates of the cost are high, though technological developments have recently cut them in half. See Jungseon Kim *et al.*, "Uptake of Uranium from Seawater by Amidoxime-Based Polymeric Absorbent: Field Experiments, Modeling, and Updated Economic Assessment," *Industrial & Engineering Chemistry Research,* Vol. 53 (2014), pp. 6076–6083.

17 For an overview of proliferation and nuclear energy, see Matthew Bunn, "Proliferation-Resistance (and Terrorism-Resistance) of Nuclear Energy: How to Think About the Problem," presentation at the Engineering and Public Policy Seminar, Carnegie Mellon University, December 12, 2014, available at: www.belfercenter.org/sites/default/files/.legacy/files/prolif-resist-talk-2014.pdf. For broad discussions of relevant issues, see "On the Global Nuclear Future, Vol. 1," *Daedalus* (Fall 2009), and "On the Global Nuclear Future, Vol. 2," *Daedalus* (Winter 2010).

18 For a brief but authoritative unclassified discussion, see U.S. Department of Energy, Office of Arms Control and Nonproliferation, *Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives*, DOE/NN-0007 (Washington, DC: DOE, 1997), available at: www.osti.gov/bridge/servlets/purl/425259-CXr7Qn/webviewable/425259.pdf, pp. 37–39.

requires just under 3,000 kg-SWU to enrich enough HEU for one bomb, this means the global enrichment capacity would be sufficient to produce over 60,000 nuclear weapons per year. If, instead of a once-through cycle, the 1,500 GWe were entirely fast reactors fueled by a combination of natural or depleted uranium and their own reprocessed plutonium, this would require reprocessing and recycling over 2,000 tons of plutonium every year, enough for over 300,000 nuclear weapons a year.[19] Clearly, the requirements for verification and safeguards to ensure that not even one bomb's worth of material or of enrichment capacity was diverted to weapons use would have to be extraordinarily stringent.

More important, perhaps, is the question of *where* the enrichment or reprocessing capacity would be located. Today, major commercial enrichment and reprocessing facilities exist in only a few countries, most of which are nuclear weapon states. One could imagine that enrichment would remain concentrated in this way, as the countries which dominate the enrichment market have invested billions of dollars in developing efficient enrichment technologies, making it difficult for others to compete. (Today, the market is over-supplied and enrichers are losing money, making it a particularly unpromising market for new entrants to join.) But over several decades, one could also imagine that such huge enrichment demands would lead to a number of additional countries establishing major enrichment facilities.

On the reprocessing side, today, reprocessing is uneconomic and performed by only a few countries, some of whom, such as the United Kingdom, are phasing out their programs.[20] Of the reprocessing countries, all but Japan are nuclear weapon states, and South Korea seems to be the only other non-nuclear-weapon state seriously contemplating a form of reprocessing (known as pyroprocessing) in the near term. Similarly, fast reactors designed to produce more plutonium than they consume (known as "breeders") are so far more expensive than LWRs, and few countries have near-term plans to commercialize them, despite tens of billions of dollars in global R&D investment over the decades.[21] But if these economic incentives were to change over the decades, one could also imagine a future spread of reprocessing capabilities.

There are at least six categories of proliferation risk associated with the spread of enrichment and reprocessing technologies, including:

1. *Breakout*: Any state with an enrichment or reprocessing plant under its national control could expel inspectors and begin producing nuclear bomb material.
2. *Diversion or misuse*: Alternatively, a state with such a facility could attempt to produce nuclear weapons material covertly, without inspectors noticing.
3. *Sneakout:* States with enrichment or reprocessing technology could seek to build covert plants that would not be detected.
4. *Technological transfer or leakage:* The more states and companies have access to these sensitive technologies, the more potential there is that the technology will be transferred to others, intentionally or inadvertently.

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19 For a useful overview of material flows through a global nuclear energy deployment of this size, see John Deutch and Ernest J. Moniz, co-chairs, *The Future of Nuclear Power* (Cambridge, MA: Massachusetts Institute of Technology, 2003), available at: http://web.mit.edu/nuclearpower/pdf/nuclearpower-full.pdf, pp. 117–129.

20 International Panel on Fissile Materials, *Plutonium Separation in Nuclear Power Programs: Status, Problems, Prospects of Civilian Reprocessing Around the World* (Princeton, NJ: IPFM, 2015), available at: http://fissilematerials.org/library/rr14.pdf.

21 Thomas B. Cochran, Harold A. Feiveson, Walt Patterson, Gennadi Pshakin, M.V. Ramana, Mycle Schneider, Tatsujiro Suzuki, and Frank N. von Hippel, *Fast Breeder Reactor Programs: History and Status* (Princeton, NJ: IPFM, 2010), available at: http://fissilematerials.org/library/rr08.pdf

5. *Expanded momentum for further spread:* In some cases, if leading nuclear energy states or regional powers pursue enrichment or reprocessing, it becomes more difficult to convince other states not to.
6. *Theft of nuclear material:* The more facilities are producing, using, or processing material suitable for use in nuclear weapons, the more chances there are for adversaries to find a way to steal it. Since enrichment plants typically produce only LEU, this concern applies more forcefully to reprocessing and the other elements of the plutonium fuel cycle, though it also applies to research reactors fueled with HEU.

Hence, limiting the spread of enrichment and reprocessing technology should continue to be a major focus of nonproliferation policies. Clearly, enrichment and reprocessing matter for disarmament as well. It is hard to imagine how disarmament would be feasible, attainable, or desirable in a world in which many states controlled facilities that gave them the physical capacity to produce the material for hundreds or thousands of bombs every year unless broader international transformations had made the acquisition of nuclear weapons fundamentally unattractive.[22]

The nuclear material in nuclear weapons themselves poses a related issue. Dismantling the world's stocks of nuclear weapons would free hundreds of tons of plutonium and HEU, which will have to be secured, verified, and ultimately eliminated. On the scale of global energy needs, the resulting stocks are small, but the world's stocks of separated plutonium and HEU are sufficient to manufacture over 200,000 nuclear weapons.[23] Here, nuclear energy can play a direct role in disarmament: the HEU can readily be blended with less enriched uranium to produce LEU fuel for nuclear power plants, as was done in the 500-ton U.S.-Russian HEU Purchase Agreement. Disposition of excess plutonium is much more difficult, given the huge expenses and security challenges involved in processing it into reactor fuel; it appears that in a number of countries it may make more sense to dispose of the plutonium as a waste. (In the United States, a huge factory to turn excess plutonium into fuel was recently canceled after its life-cycle cost ballooned from $1–$2 billion to $40–$50 billion.[24]) As a near-term step, stocks of excess material should be placed in highly secure storage facilities under international monitoring and committed never again to be used in nuclear weapons.[25]

Institutional and technical steps to address proliferation and disarmament challenges

What should be done to address these challenges? Both institutional and technical steps could help.

Preserving the regime

First, of course, it is crucial to maintain and strengthen the NPT and the broader nuclear nonproliferation regime. From stronger safeguards to better steps to prevent illicit technology procurement to expanded efforts to address the factors that lead states to seek nuclear weapons,

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22 For a similar judgment, see James Acton, Chapter 6 in this volume.

23 For a useful account of these stocks and what to do with them, see Harold A. Feiveson, Alexander Glaser, Zia Mian, and Frank N. von Hippel, *Unmaking the Bomb: A Fissile Material Approach to Nuclear Disarmament and Nonproliferation* (Cambridge, MA: MIT Press, 2014).

24 Paul Sonne and Steve Mufson, "Billions of Dollars Later, Energy Department Pulls the Plug on Partly Built Nuclear Fuel Plant," *Washington Post,* May 11, 2018.

25 Matthew Bunn, "Plutonium Disposition: What Are We Trying to Accomplish?" presentation to the Committee on Disposal of Surplus Plutonium in WIPP, U.S. National Academy of Sciences, November 29, 2017.

there is a great deal that needs to be done.[26] In particular, the "hard cases" of Iran and North Korea need to be resolved or at least managed. As discussed below, progress on disarmament is likely to be essential to getting international political agreement on stronger nonproliferation steps.

Limiting the spread of enrichment and reprocessing

Second, several steps should be taken to limit the spread of enrichment and reprocessing technology. On the policy side, this could include steps to convince states they do not need enrichment and reprocessing as a "hedge" for a future nuclear weapons option;[27] to structure incentives to convince countries to rely on international fuel markets for reliable fuel supply rather than building their own enrichment or reprocessing plants; to convince suppliers not to transfer enrichment and reprocessing technologies to states that do not already have them;[28] and to prevent illicit transfers of technologies that would help states build their own enrichment and reprocessing plants.[29]

Reducing incentives to build enrichment facilities

In recent years, the IAEA, Russia, and the United States have all established LEU stores that countries could draw on if they ever suffered a disruption in fuel supply, intended to increase states' confidence in their ability to rely on international supply rather than enriching their own fuel. Russia sold shares in its Angarsk enrichment plant, helping to convince Kazakhstan, the world's largest uranium exporter, that it did not need to invest in its own enrichment plant to increase the value-added from its uranium mining. Russia, in its recent reactor contracts, offers both long-term fuel supply contracts and spent fuel take-back contracts, so countries do not have to worry about managing their own spent fuel, and have a strong incentive to rely on Russian-supplied fuel. In the future, such "fuel leasing" approaches—perhaps combined with repositories open to receiving spent fuel from many countries—could give countries very strong incentives to prefer international fuel supply to producing their own (and then being forced to manage their own spent nuclear fuel).[30]

Limiting the spread of reprocessing

Unlike uranium enrichment, reprocessing is not required for the main approaches to nuclear energy in use today, and is so costly that countries already have strong incentives not to pursue it. As a result, few countries are reprocessing today; Japan is the only non-nuclear-weapon state doing so. Its Rokkasho-mura reprocessing plant, capable of separating eight tons of plutonium every year, has suffered decades of delay and many billions of dollars in cost overruns, and is utterly unnecessary, as Japan already has tens of tons of plutonium from past reprocessing in Europe and has little prospect of building large breeder reactors in the near term to use the plutonium. Despite the money already invested, it would be very much in Japan's national

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[26] For a useful overview (now somewhat dated) of the NPT and the broader nonproliferation regime, see George Bunn, "The Nuclear Nonproliferation Regime and Its History," in George Bunn and Christopher Chyba, eds., *U.S. Nuclear Weapons Policy: Confronting Today's Threats* (Washington, DC: Brookings, 2006).

[27] See, for example, Steven Mufson, "Why Does Saudi Arabia Want to Spend Billions to Enrich its Own Uranium?," *Washington Post,* March 19, 2018.

[28] See, for example, Fred McGoldrick, with Matthew Bunn, Martin Malin, and William H. Tobey, *Limiting Transfers of Enrichment and Reprocessing Technology: Issues, Constraints, and Options* (Cambridge, MA: Belfer Center for Science and International Affairs, Harvard Kennedy School, May 2011).

[29] For a summary of current efforts and recommendations for next steps, see Matthew Bunn, Martin B. Malin, William C. Potter, and Leonard S. Spector, eds., *Preventing Black-Market Trade in Nuclear Technology* (Cambridge: Cambridge University Press, 2018).

[30] John Deutch, Arnold Kanter, Ernest Moniz, and Daniel Poneman, "Making the World Safe for Nuclear Energy," *Survival*, Vol. 46, No. 4 (Winter 2004–2005), pp. 65–80.

interest to cancel the plant, saving money, reducing safety and security risks, responding to public concerns, and avoiding nonproliferation challenges—but such a cancelation appears unlikely.[31]

For years, South Korea has pushed for US agreement to allow it to use an approach to reprocessing known as "pyroprocessing" on US-obligated spent fuel. Contrary to some claims, this approach does not appear to offer substantial reductions in proliferation risk compared to traditional reprocessing, and it is also costly and unnecessary.

At the same time, China, despite having very little success with its small "pilot" civilian reprocessing plant, has begun construction of a larger one and is negotiating with France to buy a very large one. China is also building a demonstration fast neutron reactor—again, despite having very little success so far with a smaller experimental facility—and planning a commercial-scale fast-neutron reactor.[32] While China is already a nuclear weapon state, it is likely to be the leading nuclear energy state of the twenty-first century, and if it sends the message that reprocessing and breeder reactors are essential elements of the future of nuclear energy, it will be harder to convince other countries not to follow suit.[33] The United States and other interested countries should cooperate with each of these countries to facilitate the establishment of dry cask stores for spent fuel, explore options for direct repository disposal of spent fuel, and assess the economics and other factors involved in pursuing reprocessing.

Mitigating the risks of enrichment and reprocessing facilities

To the extent that reprocessing and enrichment facilities do spread—and for the plants that already exist—it will be important to adopt measures to mitigate the proliferation and disarmament challenges these plants pose. More stringent safeguards (including, ultimately, safeguards on such facilities in states with nuclear weapons, an essential part of a fissile cutoff agreement) and more stringent security measures to prevent theft of weapons-usable material will be needed. Increased automation and technical approaches that leave the material in forms less attractive for use in nuclear weapons can help reduce the risks of theft (though they may have less impact on the risk of host state proliferation).

Multinational control of fuel cycle facilities

Placing facilities under some form of multinational control could also reduce the risks posed by purely national facilities. This could involve facilities being controlled by an international organization such as the IAEA, or simply entities from multiple countries owning shares in facilities and participating in their overall control (for example, having seats on a board of directors), that is already the case with the URENCO enrichment facilities, for example. This would somewhat increase the political barriers to countries seizing the facilities and using them to produce weapons material. International partners might also get the right to have staff working at the facilities, or to have a voice in decisions about whether to expand facilities, build new facilities, and the like, increasing transparency beyond what is available from IAEA safeguards alone. The concept of multinational facilities has a long history and has been implemented in some cases, such as URENCO or the old Eurochemic reprocessing facility that once operated in Belgium.

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[31] James M. Acton, *Wagging the Plutonium Dog: Japanese Domestic Politics and Its International Security Implications* (Washington, DC: Carnegie Endowment for International Peace, 2015), available at: https://carnegieendowment.org/files/Plutonium_Dog_final.pdf

[32] Matthew Bunn, Hui Zhang, and Li Kang, *The Cost of Reprocessing in China* (Cambridge, MA: Project on Managing the Atom, Harvard University, January 2016).

[33] Ibid.

While Mohammed ElBaradei was Director-General of the IAEA, he argued that if disarmament was ever to be achieved, all enrichment and reprocessing facilities would have to come under international control.[34] Despite myriad studies and proposals, the only concrete step that has been taken since then is the establishment of an IAEA-controlled LEU fuel bank in Kazakhstan. Nevertheless, ElBaradei, like the Acheson-Lilienthal report before him, was almost certainly correct that multinational control of any facilities handling or capable of producing nuclear weapons material is likely to be an essential pillar of a nuclear disarmament regime.

Technical options for proliferation resistance

A variety of proposed nuclear systems could offer important nonproliferation advantages. Some systems, for example, envision what might be called "breeding in place," without reprocessing; after initial start-up, they might never need further supplies of either enriched uranium or plutonium. Such systems could substantially reduce global enrichment and reprocessing demands; future proliferators would not have the excuse Iran offered for building its enrichment capabilities. Some proposed systems would be built in factories with built-in fuel, brought to operational sites, operated for a period, and then brought back intact, so that the state where they were deployed would never need its own enrichment or reprocessing capacity and would never need access to the reactor's fuel. Some proposals involve offshore nuclear power plants, which could be towed away if a state chose to violate its nonproliferation obligations. Unfortunately, while a variety of proposals have been made for reprocessing concepts claimed to be more proliferation-resistant than traditional plutonium-uranium redox extraction (PUREX) reprocessing, all of these concepts still pose substantially more proliferation risk than not processing the spent fuel.[35]

So far, the potential benefits of advanced nuclear reactors are hoped-for properties, not demonstrated ones. It is worth remembering the warning offered decades ago by Admiral Hyman Rickover, founder of the US nuclear navy, that an "academic reactor" would always have a huge number of advantages that a "practical reactor" that was actually being built would not have.[36] That, unfortunately, often remains the case today.

In short, nuclear energy growth to the terawatt scale could pose serious challenges for nonproliferation and disarmament. But with institutional steps to strengthen the global nonproliferation regime and limit the spread of enrichment and reprocessing technologies, and advanced nuclear systems that would do little to spread sensitive materials, facilities, or expertise, one could imagine widespread global use of nuclear power that would pose only modest proliferation risks.

A fusion alternative?

For the long term, nuclear fusion could potentially provide an important alternative to nuclear fission. While some start-up firms pursuing fusion believe they can bring products to market soon, most analysts do not expect commercial fusion energy facilities to be available for purchase before 2050 or beyond.

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[34] Mohammed ElBaradei, "Nuclear Energy: The Need for a New Framework," IAEA Director General Statement, April 17, 2008, available at: www.iaea.org/newscenter/statements/nuclear-energy-need-new-framework

[35] U.S. National Nuclear Security Administration, *Draft Nonproliferation Impact Assessment for the Global Nuclear Energy Partnership Programmatic Alternatives* (Washington, DC: NNSA, December 2008). The study concluded that there were only "minor differences in the proliferation risk" between PUREX and other processing approaches (p. 68).

[36] Admiral Hyman Rickover, memorandum, June 5, 1953.

Fusion energy could potentially have many advantages.[37] Fusion reactors could not have accidents leading to major releases of radioactivity, as any accidental shift in configuration would cut off the fusion reaction, and there is too little reactive material in the core at any one time to cause much contamination. While fusion reactors, too, would create neutrons that could be used to produce fissile material, they would not require either enrichment or reprocessing, and would not produce any weapons-usable material under ordinary circumstances; overall, the proliferation risk they pose would be sharply lower. They would generate dramatically less contaminated nuclear waste (mainly the structural elements of the reactor itself, when it had outlived its life). And they would have a virtually unlimited fuel supply, drawing deuterium from seawater.

To date, however, the physics and engineering challenges of fusion energy have been formidable—and the projected costs for most concepts remain high. The huge cost of the International Thermonuclear Experimental Reactor (ITER)—now up to roughly $20 billion, for a machine that would not generate any energy for sale—suggests that substantial further work will be needed to find concepts that can be commercially viable.

At the same time, however, there are private companies who believe they have found approaches that will make it possible to provide fusion energy at competitive costs in the next few decades.[38] The world would be better off if they proved to be correct—but the chances are slim. Nevertheless, given fusion's potential importance to society, governments should continue to provide robust support for R&D and the eventual demonstration of fusion energy technologies.

Political connections between nuclear energy, nonproliferation, and disarmament

As noted above, nuclear energy is unlikely to get the support it needs to grow to the terawatt scale unless governments and publics believe that such growth will not create major new nuclear weapons risks. Hence, there is a political connection between achieving nonproliferation progress and the future of nuclear energy.

At the same time, as just discussed, limiting the proliferation risks of large-scale nuclear growth is likely to require international agreement to implement major new institutional and technical steps. Given the intense political polarization between the nuclear haves and the have-nots (and among the nuclear haves) that currently prevails, gaining such international agreements will be difficult. Non-nuclear-weapon states are only likely to offer their support for stronger nonproliferation measures—which they see as more constraints on them—if they see the nuclear weapon states making progress on disarmament, showing they are willing to accept more constraints on their own programs. Hence, in the long term, progress on disarmament will indirectly be an important enabler of large-scale nuclear energy growth.

In recent global discussions of nuclear security, many non-nuclear-weapon states have expressed concern that the focus on nuclear security is merely a smokescreen to cover up the nuclear weapon states' failures to meet their NPT Article VI obligations to negotiate in good faith toward nuclear disarmament. They have urged a renewed focus on the "three pillars" of the NPT—nonproliferation, disarmament, and peaceful uses of nuclear energy.

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[37] For a seminal analysis comparing the long-term advantages and disadvantages of fusion and fast-neutron reactors (from back in the days when uranium was expected to be scarce), see Wolf Häfele, John P. Holdren, Günther Kessler, and Gerald L. Kulcinski, *Fusion and Fast Breeder Reactors* (Laxenburg, Austria: International Institute for Applied Systems Analysis, July 1977).

[38] See, for example, Ray Rothrock, "What's the Big Idea?" *Issues in Science and Technology,* Vol. 32, No. 2 (Winter 2016), available at: http://issues.org/32-2/whats-the-big-idea/.

This view is fundamentally misguided, as security for nuclear weapons, weapons-usable nuclear material, and nuclear facilities is the essential foundation for each of the three pillars—each of which is important in its own right, and in synergy with the others.

- *Nuclear security and disarmament.* States with nuclear weapons will not dismantle all their weapons if they believe other states or terrorist groups might suddenly get stolen nuclear weapons or nuclear bombs made from stolen nuclear material.
- *Nuclear security and peaceful uses.* Especially after Fukushima, nuclear power will only be able to gain the support needed for large-scale growth if nuclear facilities and stockpiles are seen to be both safe and secure. A nuclear catastrophe resulting from terrorist action, like another Fukushima-scale accident, would probably end any realistic prospect of growth to the scale required for nuclear energy to play a major part in mitigating climate change. Nuclear security is also important for the safe use of nuclear technologies for medical, agricultural, industrial, and other purposes, balancing the benefits and risks of these technologies to maximize their net benefit to society.
- *Nuclear security and nonproliferation.* Similarly, nuclear nonproliferation cannot be reliably achieved if states or terrorist groups might gain the means to a nuclear weapon capability overnight through a smuggled nuclear weapon or nuclear weapons material.

Conclusion and next steps

To survive and to achieve sustainable human well-being, humanity must meet both the challenge of avoiding nuclear war and the challenge of powering the world without causing catastrophic climate change. While in many ways these are separate problems, there are important links. In particular, while large-scale growth of nuclear energy could be an important tool to meet the climate challenge, growth at that scale could, if not well managed, pose challenges for nuclear nonproliferation and disarmament.

Laying out all the steps needed for a safe and secure future for nuclear energy and nuclear weapons is beyond the scope of this chapter. Nevertheless, a few steps are clearly needed, to address immediate dangers and to lay long-term foundations for future success.

Addressing dangers in the near term

Several steps should be taken to reduce immediate dangers; if these are not addressed, disarmament is unlikely to be feasible or attainable. First, the United States and Russia should negotiate a resolution to the charges of violations of the INF Treaty and extend New START to 2026. Second, the participating states should find the means to maintain the Joint Comprehensive Plan of Action (JCPOA), address the longer-term risks of Iran's nuclear program, and eliminate or reduce the risks posed by North Korea's nuclear weapons program. Third, states parties should work to maintain and strengthen the NPT and the broader nonproliferation regime. Fourth, states, companies, and civil society organizations should take steps to reduce the chance that reprocessing and enrichment will spread to additional countries. Fifth, the same institutions should work to strengthen nuclear safety and nuclear security worldwide, reducing the risks of accidental or intentional catastrophes as close to zero as reasonably achievable. Sixth, relevant states should take steps to reduce the risks of conflicts and inadvertent escalation between nuclear-armed states, including particularly the United States and Russia, the United States and North Korea, the United States and China, and India and Pakistan.

Laying long-term foundations for future success

The international community should take a number of steps to lay the foundation for a longer-term nuclear energy contribution to mitigating climate change. First, there is a need to conduct in-depth assessments of the potential role of nuclear energy and other non-intermittent low-carbon energy sources as backups to intermittent sources in future deeply decarbonized energy systems, considering cost, reliability, and other factors. Second, it is essential to avoid further catastrophes like the Fukushima Daiichi accident, and to build international approaches focused on continuous improvement toward excellence in both safety and security. Third, governments should provide R&D and demonstration support sufficient to bring several advanced reactor concepts to commercial availability by mid-century and focus R&D on those systems with the greatest potential economic, safety, security, and nonproliferation advantages. Fourth, governments and companies should design all future nuclear facilities to build in high standards of safety, security, proliferation-resistance, and provisions for effective international safeguards from the beginning.

Similarly, the international community should take a range of steps to lay the foundation for longer-term nonproliferation and disarmament progress in the context of potential nuclear energy growth. First, and most obviously, the United States and Russia should begin negotiating a follow-on arms reductions agreement to New START and begin exploring approaches to multilateral arms reductions as reductions proceed. Second, the international community should expand discussions of disarmament implementation and verification to include managing future nuclear energy systems in the context of disarmament. Third, relevant states should work toward the establishment of "fuel leasing," multinational repositories, or other approaches to cradle-to-grave fuel services, giving countries strong incentives to rely on an international supply for their nuclear fuel. Fourth, it is important to conduct in-depth assessments of the proliferation and disarmament implications of different approaches to multilateral control of fuel cycle facilities, followed by pilot implementation of an approach judged to be promising, for example, by bringing international partners into the management of an existing facility (such as by selling shares). Fifth, the international community should support a range of analyses of approaches to ensuring international security in a world without nuclear weapons and ensuring stability as nuclear forces are reduced toward zero.[39] Sixth, the international community should seek to build international consensus around a set of activities related to nuclear weapons development that should never be conducted in non-nuclear-weapon states (or, after disarmament, in any states).[40] Seventh, nuclear weapon states and states outside the NPT should begin placing all their enrichment and reprocessing facilities and all their excess fissile materials under international monitoring and invite the IAEA to verify all blending or disposal of weapons-usable nuclear material. Eighth, states that possess nuclear weapons should preserve relevant records, facilities, and materials to facilitate verification of declarations of past production of fissile materials and nuclear weapons. Ninth, the international community should add verification of baseline stockpile declarations and means to build confidence in the absence of covert stocks to international initiatives focusing on verification of disarmament.

Of course, perhaps the most fundamental step to lay the foundation for long-term progress in both nonproliferation and nuclear disarmament would be to work to resolve the myriad

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39 See, for example, James Acton, *Deterrence During Disarmament: Deep Nuclear Reductions and International Security* (London: International Institute for Strategic Studies, 2011).

40 Toby Dalton, Wyatt Hoffman, Ariel E. Levite, Li Bin, George Perkovich, and Tong Zhao, *Toward a Nuclear Firewall: Bridging the NPT's Three Pillars* (Washington, DC: Carnegie Endowment for International Peace, March 2017), available at: http://carnegieendowment.org/files/CP_301_Dalton_et_al_Firewall_Final_Web.pdf.

international conflicts that help drive the demand for nuclear weapons. If the Arab-Israeli conflict and the other conflicts setting the Middle East on fire were resolved, if India and Pakistan found ways to live together in harmony in South Asia, if the division of the Korean peninsula were ended, and if Europe returned to the principles of the Organization for Security and Cooperation in Europe, the prospects for nonproliferation and disarmament would be greatly improved. Here again, the links arise: building a more peaceful world is not likely to be possible without successfully addressing climate change—and a more peaceful world would also be a world in which large-scale growth of nuclear energy to help mitigate climate change would be a more plausible possibility.

This is just a preliminary list of steps, though a challenging one. The feasibility and attainability of each of these steps can be debated. But these actions, if taken, would help make disarmament more feasible, desirable, and attainable, laying the foundation for a world in which nuclear technology helped contribute to sustainable development while nuclear weapons began to fade from the scene.