Dædalus

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Fall 2009

on the global nuclear future, vol. 1

Inside front cover: U.S. President Barack Obama at Hradcanske Square in central Prague, April 5, 2009. Photograph © REUTERS/Petr Josek.

Dædalus is designed by Alvin Eisenman.

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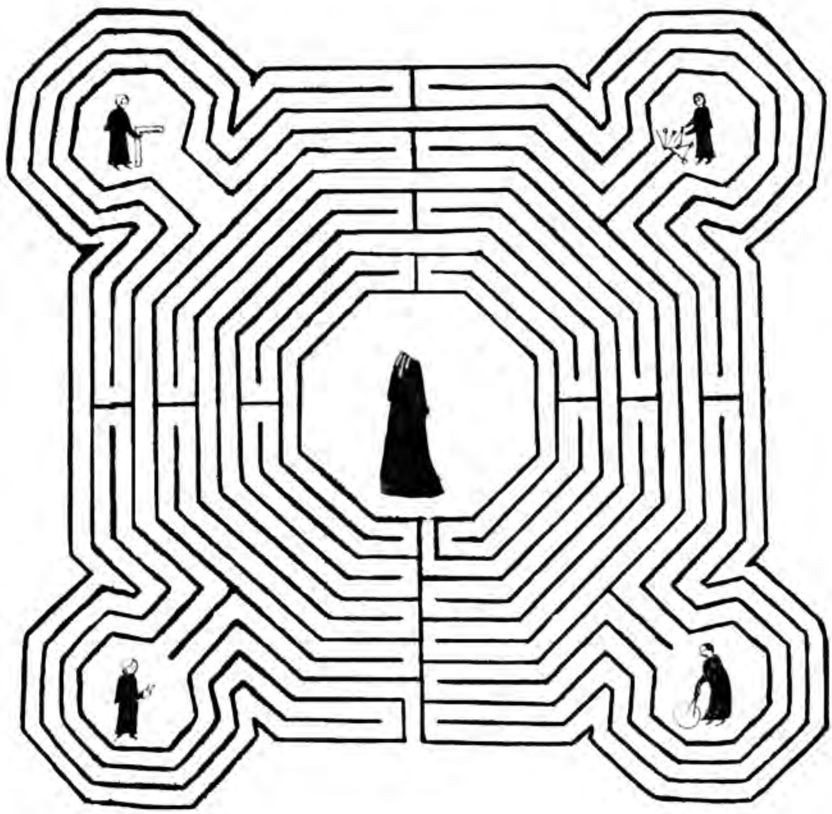

The pavement labyrinth once in the nave of Reims Cathedral (1240), in a drawing, with figures of the architects, by Jacques Cellier (c. 1550 – 1620)

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The Global Nuclear Future, Volume 1
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The Global Nuclear Future, Volume 2
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Steven E. Miller & Scott D. Sagan

Nuclear power without nuclear proliferation?

> Today, the Cold War has disappeared but thousands of those weapons have not. In a strange turn of history, the threat of global nuclear war has gone down, but the risk of a nuclear attack has gone up. More nations have acquired these weapons. Testing has continued. Black market trade in nuclear secrets and nuclear materials abound. The technology to build a bomb has spread. Terrorists are determined to buy, build or steal one. Our efforts to contain these dangers are centered on a global non-proliferation regime, but as more people and nations break the rules, we could reach the point where the center cannot hold.
>
> – President Barack Obama
> Prague, April 5, 2009

The global nuclear order is changing. Concerns about climate change, the volatility of oil prices, and the security of energy supplies have contributed to a widespread and still-growing interest in the future use of nuclear power. Thirty states operate one or more nuclear power plants today, and according to the International Atomic Energy Agency (IAEA), some 50 others have requested technical assistance from the agency to explore the possibility of developing their own nuclear energy programs. It is certainly not possible to predict precisely how fast and how extensively the expansion of nuclear power will occur. But it does seem probable that in the future there will be more nuclear technology spread across more states than ever before. It will be a different world than the one that has existed in the past.

This surge of interest in nuclear energy – labeled by some proponents as "the renaissance in nuclear power" – is, moreover, occurring simultaneously with mounting concern about the health of the nuclear nonproliferation regime, the regulatory framework that constrains and governs the world's civil and military-related nuclear affairs. The Nuclear Non-Proliferation Treaty (NPT) and related institutions have been taxed by new worries, such as the growth in global terrorism, and have been painfully tested by protracted crises involving nuclear weapons proliferation in North Korea and potentially in Iran. (Indeed, some observers suspect that growing interest in nuclear power in some countries, especially in the Middle East, is not unrelated to Iran's uranium enrichment program and Tehran's movement closer to a nuclear weapons capability.) Confidence in the NPT regime seems to be eroding even as interest in nuclear power is expanding.

This realization raises crucial questions for the future of global security. Will the growth of nuclear power lead to increased risks of nuclear weapons proliferation and nuclear terrorism? Will the nonproliferation regime be adequate to ensure safety and security in a world more widely and heavily invested in nuclear power? The authors in this two-volume (Fall 2009 and Winter 2010) special issue of *Dædalus* have one simple and clear answer to these questions: It depends.

On what will it depend? Unfortunately, the answer to that question is not so simple and clear, for the technical, economic, and political factors that will determine whether future generations will have more nuclear power without more nuclear proliferation are both exceedingly complex and interrelated. How rapidly and in which countries will new nuclear power plants be built? Will the future expansion of nuclear energy take place primarily in existing nuclear power states or will there be many new entrants to the field? Which countries will possess the facilities for enriching uranium or reprocessing plutonium, technical capabilities that could be used to produce either nuclear fuel for reactors or the materials for nuclear bombs? How can physical protection of nuclear materials from terrorist organizations best be ensured? How can new entrants into nuclear power generation best maintain safety to prevent accidents? The answers to these questions will be critical determinants of the technological dimension of our nuclear future.

The major political factors influencing the future of nuclear weapons are no less complex and no less important. Will Iran acquire nuclear weapons; will North Korea develop more weapons or disarm in the coming decade; how will neighboring states respond? Will the United States and Russia take significant steps toward nuclear disarmament, and if so, will the other nuclear-weapons states follow suit or stand on the sidelines?

The nuclear future will be strongly influenced, too, by the success or failure of efforts to strengthen the international organizations and the set of agreements that comprise the system developed over time to manage global nuclear affairs. Will new international or regional mechanisms be developed to control the front-end (the production of nuclear reactor fuel) and the back-end (the management of spent fuel containing plutonium) of the nuclear fuel cycle? What political agreements and disagreements are likely to emerge between the nuclear-weapons states (NWS) and the non-nuclear-weapons states (NNWS) at the 2010 NPT Review Conference and beyond? What role will crucial actors among the NNWS – Japan, Iran, Brazil, and Egypt, for example – play in determining the global nuclear future? And most broadly, will the nonproliferation regime be supported and strengthened or will it be questioned and weakened? As IAEA Director General Mohamed ElBaradei has emphasized, "The nonproliferation regime is, in many ways, at a critical juncture," and there is a need for a new "overarching multilateral nuclear framework."[1] But there is no guarantee that such a framework will emerge, and there is wide doubt that the arrangements of the past will be adequate to manage our nuclear future effectively.

The authors in both this and the subsequent volume address these and other vexing issues that will affect the spread of nuclear power and the spread of nuclear weapons. As is necessary to understand such a complex set of real-world issues, the authors represent diverse academic disciplines (including physical sciences, engineering, and social sciences) and many professions (including lawyers, nuclear regulators, nuclear industry executives, and experienced diplomats and political leaders). As is appropriate to address a global issue, the authors come from many different countries, from both NWS and NNWS. And as is appropriate for an objective intellectual enterprise, the authors represent both strong advocates for and skeptics of the global expansion of nuclear power, as well as both supporters and opponents of complete nuclear weapons disarmament.

In this introductory essay, we aim first to demonstrate why the question of which states will develop nuclear power in the future matters for global security. To do so, we briefly discuss the connections between nuclear power, nuclear proliferation, and terrorism risks; we present data contrasting existing nuclear-power states with potential new entrants with respect to factors influencing those risks. Second, we introduce major themes addressed by the authors in both volumes, and explain why the expansion of nuclear power, the future of nuclear weapons disarmament, and the future of the NPT and related parts of the nuclear control regime are so intertwined. Finally, we conclude with some observations about what is new and what is not new about current global nuclear challenges. The American Academy of Arts and Sciences has published three important special issues of *Dædalus* on nuclear weapons issues in the past – in 1960, 1975, and 1991 – and reflecting on the differences between the concerns and solutions discussed in those three issues and the nuclear challenges we face today is both inspiring and sobering.

Although many experts talk about the "expansion" or "renaissance" of nuclear power around the globe, it is important to differentiate between two related phenomena: a potential *growth* in the production of nuclear energy in states that currently have nuclear power facilities and the potential *spread* of nuclear power plants and related facilities to states that are new entrants to the "nuclear energy club." Figure 1 lists the existing nuclear-power states and the aspiring states that have requested IAEA assistance in exploring nuclear programs, by regions of the world. With respect to climate change, it would, in theory, make relatively little difference which nations increase their use of nuclear energy (and other non-carbon-producing energy technologies); what matters is the overall global reduction in carbon emissions. With respect to the safety and security dimensions of the nuclear future, however, it will matter greatly which states acquire what kinds of nuclear technology. Thus, there are three broad reasons to be concerned about an unconstrained spread of nuclear power to new nations that have not previously managed the technology.

First, for nuclear energy programs to be developed and managed safely and securely, it is important that states have domestic "good governance" characteristics that will encourage proper nuclear operations and management. These characteristics include low degrees of corruption (to avoid officials selling materials and technology for their own personal gain as occurred with the A.Q. Khan smuggling network in Pakistan), high degrees of political stability (defined by the World Bank as

Figure 1
Expansion versus Spread: Existing and Aspiring Nuclear Power States

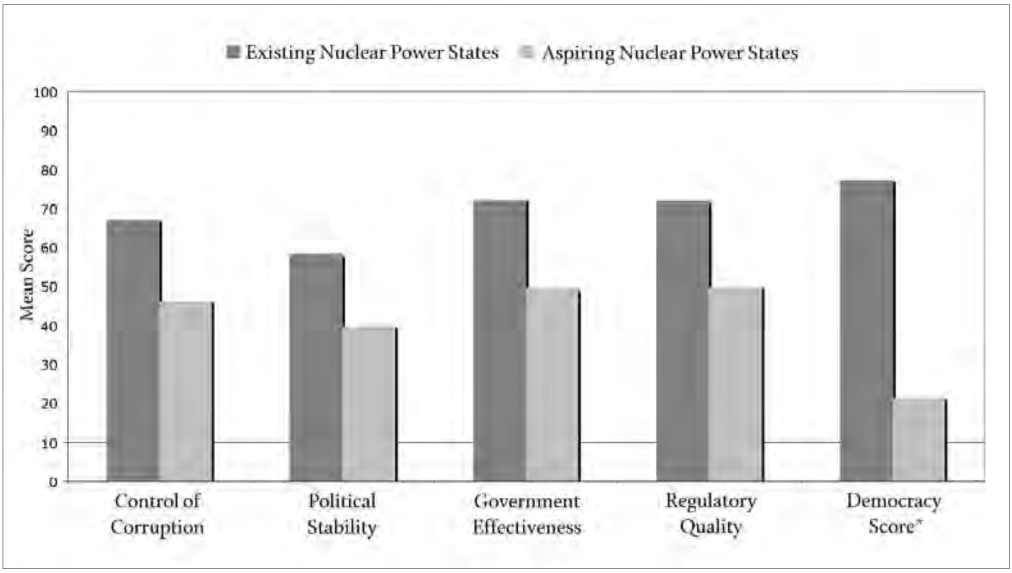
Americas	Western Europe	Eastern Europe	Central and South Asia	East Asia/ Oceania	Middle East	Africa
Existing Nuclear Power States Argentina Brazil Canada United States Mexico **Aspiring Nuclear Power States** Bolivia Chile Dominican Republic El Salvador Haiti Jamaica Peru Uruguay Venezuela	**Existing Nuclear Power States** Belgium Finland France Germany Netherlands Spain Sweden Switzerland United Kingdom	**Existing Nuclear Power States** Armenia Bulgaria Czech Republic Hungary Lithuania Romania Russia Slovakia Slovenia Ukraine **Aspiring Nuclear Power States** Belarus Croatia Estonia Greece Latvia Poland	**Existing Nuclear Power States** India Pakistan **Aspiring Nuclear Power States** Bangladesh Georgia Kazakhstan Mongolia Sri Lanka	**Existing Nuclear Power States** China Japan Korea **Aspiring Nuclear Power States** Indonesia Malaysia Myanmar Philippines Singapore Thailand Vietnam	**Existing Nuclear Power States** Iran **Aspiring Nuclear Power States** Bahrain Egypt Israel Jordan Kuwait Oman Qatar Saudi Arabia Syria Turkey UAE Yemen	**Existing Nuclear Power States** South Africa **Aspiring Nuclear Power States** Algeria Ghana Kenya Libya Morocco Namibia Nigeria Senegal Sudan Tanzania Tunisia

Sources: IAEA Power Reactor Information System, www.iaea.org/programmes/a2; Frank N. von Hippel, ed., "The Uncertain Future of Fission Power," review draft, www.fissilematerials.org; Polity IV Project, *Political Regime Characteristics and Transitions, 1800 – 2007*, www.systemicpeace.org/inscr/inscr.htm. Figure © Scott D. Sagan.

"likelihood that the government will be destabilized or overthrown by unconstitutional or violent means, including politically-motivated violence and terrorism"), high governmental effectiveness scores (a World Bank aggregate measure of "the quality of the civil service and the degree of its independence from political pressures [and] the quality of policy formulation and implementation"), and a strong degree of regulatory competence. Fortunately, we have a great deal of information measuring these domestic good governance factors across the globe. Unfortunately, the data highlight the grave security challenges that would be created if there were rampant proliferation of nuclear energy production facilities to each and every state that has expressed interest to the IAEA in acquiring nuclear power. The World Bank publishes annual aggregate data, derived from multiple sources, on each of these good governance characteristics, and, as shown in Figure 2, the average scores of the potential new nuclear-energy states on each of these dimensions is significantly lower than the scores of states already possessing nuclear energy.

Second, all NNWS under the NPT must accept IAEA safeguards inspections

Figure 2
Governance, Corruption, and Democracy



*Measurement for Democracy Score is mean Polity IV score on a 100-point scale. Sources: World Bank, *World Governance Indicators, 1996 – 2007*, info.worldbank.org/governance/wgi/index/asp; Polity IV Project, *Political Regime Characteristics and Transitions, 1800 – 2007*, www.systemicpeace.org/inscr/inscr.htm.
Figure © Scott D. Sagan.

on their nuclear power facilities in order to reduce the danger that governments might cheat on their commitments not to use the technology to acquire nuclear weapons; therefore, it is illuminating to examine the historical record of NNWS violating their NPT commitments. Here there is one very important finding about how domestic political characteristics influence the behavior of NPT members: each known or strongly suspected case of a government starting a secret nuclear weapons program, while it was a member of the NPT and thus violating its Article II NPT commitment, was undertaken by a non-democratic government.[2] (The confirmed or suspected historical cases of NPT member states starting nuclear weapons programs in violation of their Treaty commitments include North and South Korea, Libya, Iraq, Yugoslavia, Taiwan, Iran, and Syria, all of which were non-democratic at the time in question.) It is therefore worrisome that, as Figure 2 shows, the group of potential new states seeking nuclear power capabilities is on average significantly less democratic than the list of existing states with nuclear energy capabilities.

Third, states that face significant terrorist threats from within face particular challenges in ensuring that there is no successful terrorist attack on a nuclear facility or no terrorist theft of fissile material to make a nuclear weapon or dirty bomb. Figure 3 displays data from the United States Counterterrorism Center comparing the five-year totals of terrorism incidents in the existing states that have nuclear power facilities and the IAEA list of aspiring states. India and Pakistan, both of which have nuclear weapons and nuclear power facilities and which face severe terrorist

Figure 3
Nuclear Power and Terrorism

Incidents of terrorism in past five years, current nuclear power states		Incidents of terrorism in past five years, current and aspiring nuclear power states	
India	4,462	India	4,462
Pakistan	3,687	Pakistan	3,687
Russia	1,302	Thailand*	3,301
Spain	313	Israel*	2,775
France	277	Russia	1,302
United Kingdom	220	Philippines*	1,061
Iran	56	Sri Lanka*	702
China	31	Turkey*	403
Mexico	29	Algeria*	327
Ukraine	25	Spain	313

Asterisk denotes aspiring nuclear power state. Source: Worldwide Incidents Tracking System, National Counterterrorism Center (NCTC), http://wits.nctc.gov/Main.do. Figure © Scott D. Sagan.

threats from homegrown and outsider terrorist organizations, clearly lead the pack. But as Figure 3 shows, the states that are exploring developing nuclear power would take up six of the slots on a "terrorist top ten risk list" if each of them develops civilian nuclear power in the future.

These figures clearly represent worst-case estimates about the security implications of the spread of nuclear power, for as a number of authors in these volumes note, many of the aspiring states will not be able to progress with nuclear power development programs any time soon due to financial or other constraints. Indeed, most of the growth in nuclear power over the coming decade is likely to come from new plants in states that already operate nuclear power plants. But the figures do dramatically highlight the intertwined political, technical, and economic challenges we face if the world is to see both the expansion and spread of the use of nuclear power on a global scale. It seems almost certain that some new entrants to nuclear power will emerge in the coming decades and that the organizational and political challenges to ensure the safe and secure spread of nuclear technology into the developing world will be substantial and potentially grave. The proposals in these two volumes – for international control of the fuel cycle, for sharing best practices for physical security, and for enhancing the international nuclear safety regime – are designed to mitigate the inherent security risks that the nuclear renaissance will bring.

The essays collected in these two volumes of *Dædalus* focus on three broad, interlocking subjects: nuclear power, nuclear disarmament, and nuclear proliferation. The new nuclear order that will emerge years hence will be the result of the interplay of state motives for pursuing nuclear power and constraints on that pursuit. Contributors to the volumes consider in detail the changing technical, economic, and environmental factors that are making nuclear power seem more attractive around the globe. But they also address factors inhibiting the growth of nuclear power: enormous capital costs, the need for public subsidies, limited industrial capacity to build power plants, inadequate electricity grids, the possible emergence of alternative energy technologies, concern about the cost and risks associated with nuclear wastes, public fear of nuclear technology, as well as concern about the security risks created by the possible spread of weapons-usable nuclear technologies. When the constraints are taken into account, it may well be that the spread of nuclear power will be neither as fast nor as extensive as many anticipate.[3] Nevertheless, some expansion and spread seems inevitable, and accordingly these volumes consider the standards for safety and physical protection that must be met to reduce the risks that could emerge along with the spread of civilian nuclear power capacity.

Concerns about proliferation (whether to states or terrorists) arise at the intersection of nuclear power and nuclear weapons. Indeed, the connection between power and weapons is somewhat inevitable because key technologies in the nuclear sector – notably, uranium enrichment and plutonium reprocessing capabilities – are relevant to both. In the nonproliferation context, this is the dual-use dilemma: many technologies associated with the creation of a nuclear power program can be used to make weapons if a state chooses to do so. When a state seems motivated to acquire nuclear weapons, a nuclear power program in that state can appear to be simply a route leading to the bomb or a public annex to a secret bomb program. The crisis over Iran's nuclear activities is a case in point. Depending on what capabilities spread to which states, especially regarding uranium enrichment and plutonium reprocessing, a world of widely spread nuclear technologies could be a world in which more states, like Iran, would have the latent capability to manufacture nuclear weapons. This could easily be a world filled with much more worry about the risk of nuclear proliferation – and worse, a world where more states possess nuclear weapons. A fundamental goal for American and global security is to minimize the proliferation risks associated with the expansion of nuclear power. If this development is poorly managed or efforts to contain risks are unsuccessful, the nuclear future will be dangerous.

Nuclear power without nuclear proliferation?

What can be done to limit future proliferation risks? The contributors to these volumes explore two fundamental answers to that question. First, some authors discuss policies that could create a world in which the incentives to acquire nuclear weapons are minimized. If nuclear weapons remain the currency of the realm, if they are the ticket to the high table of international politics, if they are believed to confer enormous diplomatic and security benefits, if the existing NWS insist on the necessity to retain their nuclear weapons for the indefinite future, then it will be very difficult over the long run to make the case that for all other states nuclear weapons are unnecessary and undesirable. On the other hand, the context for future nuclear decision-making will be very different if that context is a world where nuclear weapons are being devalued and marginalized and where the NWS are reducing their arsenals and perhaps even heading meaningfully in the direction of eliminating nuclear weapons altogether. This is why the nuclear disarmament debate comes into play in considering the future global nuclear order.

The disarmament-nonproliferation connection is formally codified in the famous Article VI of the NPT, which calls for the NWS (and all other states) to make good faith efforts to achieve nuclear disarmament. Under the general rubric of arms control, work over several decades has gone toward efforts to regulate, constrain, reduce, and eliminate nuclear weapons – efforts that have helped contain the dangers of nuclear rivalry. Nevertheless – and despite their obligations under Article VI and their repeated rhetorical commitments to nuclear disarmament – the NWS have not, in the opinion of many observers, moved genuinely and significantly in the direction of nuclear disarmament.[4] Indeed, there have been multiple statements by some government officials in NWS that suggest that they are firmly committed to keeping nuclear weapons indefinitely, and the failure of the U.S. Senate to ratify the Comprehensive Test Ban Treaty (CTBT) and help bring that Treaty into force opens up the prospect of testing new nuclear weapons in the future. The result has been growing dissatisfaction among many key NNWS about the failure of the NWS to live up to their NPT obligations, recurrent acrimonious collisions over Article VI at NPT review conferences, mounting frustration with and disaffection from the NPT regime, and a consequent protracted inability to address other key NPT issues in a constructive fashion. From the perspective of many NNWS, Article VI was one of the core bargains of the NPT and the weapons states are simply not living up to their end of the bargain.

The current debate over nuclear disarmament is crucial to the evolution of the global nuclear order for two reasons. One way or the other, the debate will influence future incentives to acquire nuclear weapons, and it will have significant implications in terms of preserving, effectively managing, and strengthening the NPT regime. It is therefore very important that nuclear disarmament has now made it onto the public and policy agenda in a prominent way, having been galvanized by the efforts of four distinguished American statesmen and reinforced by President Obama's remarkable embrace of the nuclear disarmament objective in his speech in Prague in April 2009.[5] It is generally understood that nuclear disarmament is a long-term goal, not an immediate policy objective. Yet much can be done in the interim to constrain nuclear forces and reduce their role in international politics; such steps can help to address the concerns that have commonly arisen in the nonproliferation context. The origins, rationale, meaning, and prospects of nuclear disarmament are therefore addressed in these volumes of *Dædalus*.

Future proliferation risks can also be limited in a second fundamental way: by preserving and improving the nonproliferation regime, that system of rules and institutions that is meant to allow the use of civilian nuclear power while providing reassurance against the use of nuclear technology for weapons purposes. As the protracted nuclear crises of recent decades – Iraq, Iran, North Korea – have shown, the system is not perfect or foolproof even today. But looking to the future, will the nonproliferation regime be adequate in a world where there is more nuclear knowledge and technology spread across more states? The essays collected in the second volume confront that question. Some of the essays explore various ways in which the nonproliferation regime could be improved: transparency could be enhanced, safeguards bolstered, the IAEA further empowered to monitor nuclear programs and explore suspicious activities. NPT rules can be more uniformly and universally enforced, with exceptions like the U.S.-India nuclear deal not permitted. The nuclear fuel cycle can be organized in a way that minimizes the spread of sensitive dual-use technology; various schemes for assuring fuel supplies could reduce the need and incentive for individual states to acquire enrichment capabilities, for example. Any fuel-cycle arrangement or agreed norm that limits the spread of enrichment and reprocessing technology will greatly circumscribe the proliferation risks associated with expanded nuclear power. It would also be desirable to find more effective methods of enforcement when instances of noncompliance are discovered. These ideas and more are examined in volume two.

But the NPT is a nearly global regime – all but four states are members (Israel, India, and Pakistan never joined, and North Korea withdrew in 2003) – and none of the ideas for improving the regime will be feasible if they do not inspire wide assent among NPT members. The regime therefore must be considered from a diverse set of national perspectives in order to gauge what steps might be possible and what constraints will need to be addressed in order to adapt the nonproliferation regime to the emerging global nuclear order. It is far from certain that key NNWS will share the diagnoses and support the remedies preferred by the Western nonproliferation community.[6] The essays in these *Dædalus* volumes address these contrasting perspectives, and the decision to include authors from multiple NWS and NNWS was designed to ensure that the analysis does not suffer from American-centric or NWS biases.

The growth and spread of nuclear power raises a set of concerns about the risk of nuclear proliferation and nuclear terrorism; working on the problem of nuclear proliferation raises the issue of nuclear disarmament. These topics do not completely overlap, but it is not possible to think comprehensively about the future of the global nuclear order without considering them together and without appreciating the extent to which they are interrelated.

Nuclear power without nuclear proliferation?

This two-volume special issue of *Dædalus* represents the fourth time that the American Academy has dedicated its journal to issues concerning arms control and nuclear weapons. Special issues were published on "Arms Control" in 1960, on "Arms, Defense, and Arms Control" in 1975, and on "Arms Control: Thirty Years On" in 1991. It is valuable to look back on the articles in these volumes, and the strategic issues upon which they focused, in order to appreciate the significant successes that have occurred in the past, as well as to understand the enduring nature of many of the problems we face and the novelty of some emerging challenges.

The 1960 volume, a product of a special summer study at the American Academy, is widely recognized as a seminal contribution to the development of arms control as a tool to reduce the danger of nuclear war and to manage Soviet-U.S. relations. Indeed, it has been called "the Bible" of arms control, and "the Cambridge school" has been credited with identifying and promoting three key insights that helped maintain nuclear peace during the height of Cold War tensions.[7] First, the authors strongly argued for the creation of a high threshold between conventional military forces and nuclear forces, in stark contrast to the earlier plans developed during the Eisenhower administration to use nuclear weapons earlier in any conflict with the Soviet Union or the People's Republic of China – the so-called Massive Retaliation doctrine. Second, while the *Dædalus* authors cannot be credited with being the first to identify the maintenance of "secure second-strike forces" as a prerequisite for nuclear deterrence stability (credit for that insight belongs to Albert Wolhstetter and Warren Amster[8]), the *Dædalus* authors were the first to argue that the pursuit of secure second-strike forces was a *mutual* interest between the USSR and the United States, and thus that arms control negotiations could usefully seek constraints on offensive and defensive forces with this form of strategic stability as an objective. Third, the *Dædalus* authors identified the prevention of the spread of nuclear weapons to new nations as a key national security interest and arms control objective. Again, this was an innovative argument coming at the end of the Eisenhower administration, which had widely distributed nuclear power technology under the Atoms for Peace program and was considering providing nuclear weapons to U.S. NATO allies in Europe.

The 1960 *Dædalus* authors went on to become a veritable "Who's Who" of arms control during the Cold War, both in terms of scholarship and government service: Herman Khan, Edward Teller, Henry Kissinger, Paul Doty, Thomas Schelling, and Hubert Humphrey. All were relatively young men at the time, but they were to play even more important roles in developing U.S. grand strategy and arms control in subsequent years. With the benefit of hindsight, however, it is as interesting to note the major future security issues that were *not* addressed in the 1960 volume as it is to recognize those that were. Concerns about nuclear proliferation focused primarily on states within U.S. and Soviet alliance systems – in NATO and the Warsaw Pact, and to a lesser degree, China. The idea that many states in what was then deemed the "third world" might be capable of producing nuclear weapons was generally beyond the horizon of vision for the authors.[9] Similarly, future fears about the danger of nuclear terrorism were simply not on the intellectual agenda of the early 1960s: indeed, it is noteworthy that in his *Dædalus* essay Herman Khan feared what he called "nuclear diffusion" primarily because it would provide nuclear weapons to "criminal organizations" and give the Soviets a new opportunity "to act as agent-provocateurs."[10] Finally, it bears mentioning that the 1960 "Bible" of arms control was written entirely by American authors. In the Cold War atmosphere of 1960, Americans might speculate on Soviet or Chinese views about nuclear weapons, but it was not possible for experts or policy-makers from either Communist state to contribute directly to the emerging literature.

Much had changed by the time the special issue on "Arms, Defense, and Arms Control" appeared in 1975. As suggested by the title, arms control had become a significant part of U.S. foreign policy, and many of the essays were now devoted to analyzing how best to balance potential arms control agreements with the Soviet Union with perceived U.S. national security requirements for secure and effective nuclear weapons delivery systems. In contrast with the 1960 authors, many of whom used early game theory methods and assumed "rational actors" inside both the United States and the Soviet Union, the 1975 *Dædalus* authors developed new ideas about how domestic politics, organizational interests, and bureaucratic politics influenced defense programs and arms negotiations.[11] The NPT had been negotiated and had come into force in 1970, and that development, coupled with India's 1974 test of a "peaceful nuclear explosive," led to much more attention on proliferation dangers in the developing world. This *Dædalus* issue therefore had a much less bilateral Soviet-U.S. focus, with essays addressing the spread of nuclear weapons and other advanced military systems from the superpowers to third-world states around the globe.[12] Nevertheless, the discussion was still taking place exclusively among Americans, and not one expert from an allied nation, much less a Cold War rival or a neutral third-world state, contributed to the 1975 *Dædalus* volume.

The contributions to the 1991 volume, "Arms Control: Thirty Years On," were written amid great geopolitical change, as the Cold War ended and the Soviet Union was breaking into separate independent states. It is not entirely surprising therefore that many of the essays – indeed, even the volume's title – have a historical emphasis: looking in the rear-view mirror at the role of arms control in the Cold War, albeit with attempts to use that history to predict possible future trends. The 1991 volume did have more international authors, with a leading Russian nuclear strategist, Andrei Kokoshin (who was soon to become a senior Ministry of Defense official), contributing an essay, along with articles by leading European arms control specialists Lawrence Freedman and Johan Jørgen Holst.[13] Many of the specific arms control topics addressed in the volume, such as the conventional weapons balance in Europe and the spread of chemical weapons, are simply no longer as significant a concern today as they were in the waning years of the Cold War and the start of a new, uncertain era in international politics. Other issues addressed by the *Dædalus* contributors, however, notably the failure of leading powers to negotiate a CTBT and concerns about the fragility of the NPT and its future ability to constrain states from acquiring nuclear weapons, remain as salient today as they were in 1991.

This special double issue on "The Global Nuclear Future" thus stands in a proud line of *Dædalus* volumes seeking to bring new ideas into the global public policy debate about how to reduce the risks of nuclear proliferation and nuclear weapons use. We do so, however, in the context of a new global topic: how to manage the potential growth and spread of nuclear power. And this special double issue includes far more voices from NNWS, among U.S. allies and others in the developing world, because their governments' decisions will be as important in determining the global nuclear future as are decisions made in Washington.

We hope that the analyses presented in these *Dædalus* volumes will inform and influence policy debates in both NWS and NNWS in the future. Today, the nature of the global nuclear future remains highly uncertain. What is clear is that the decisions we make in the coming years regarding arms control and disarmament, the spread of nuclear power technology, and the reform of international regimes will strongly determine whether a hopeful or frightening nuclear future emerges just over the horizon.

ENDNOTES

1 Mohamed ElBaradei, "Nuclear Energy: The Need for a New Framework," International Conference on Nuclear Fuel Supply: Challenges and Opportunities, Berlin, Germany, April 17, 2008; www.iaea.org.

2 The evidence is presented in Harald Müller and Andreas Schmidt, "The Little Known Story of De-Proliferation: Why States Give Up Nuclear Weapon Activities," in *Forecasting Proliferation*, ed. William Potter (Stanford, Calif.: Stanford University Press, forthcoming, 2010).

3 For an excellent overview, see Sharon Squassoni, *Nuclear Energy: Rebirth or Resuscitation?* (Washington, D.C.: Carnegie Endowment for International Peace, 2009).

4 See Christopher A. Ford, "Debating Disarmament: Interpreting Article VI of the Treaty on the Non-Proliferation of Nuclear Weapons," *The Nonproliferation Review* 14 (3) (2007): 402–428, and Scott D. Sagan, "Good Faith and Nuclear Disarmament Negotiations," in *Abolishing Nuclear Weapons: A Debate*, ed. George Perkovich and James A. Acton (Washington, D.C.: Carnegie Endowment for International Peace, 2009), 203–212.

5 See George P. Shultz, William J. Perry, Henry A. Kissinger, and Sam Nunn, "A World Free of Nuclear Weapons," *The Wall Street Journal*, January 4, 2007.

6 See Deepti Choubey, *Are New Nuclear Bargains Attainable?* (Washington, D.C.: Carnegie Endowment for International Peace, 2008).

7 This paragraph follows the excellent analysis in Jennifer E. Sims, "The American Approach to Nuclear Arms Control: A Retrospective," *Dædalus* 120 (1) (Winter 1991): 251–272.

8 Albert Wolhstetter, "The Delicate Balance of Terror," *Foreign Affairs* (January 1959), and Warren Amster, "A Theory for the Design of a Deterrent Air Weapons System" (San Diego: Convair-General Dynamics Corporation, 1955).

9 For exceptions see Paul Doty, "The Role of Smaller Powers," William T. R. Fox, "Political and Diplomatic Prerequisites of Arms Control," and Herman Kahn, "The Arms Race and Some of its Hazards," all from *Dædalus* 89 (4) (Fall 1960).

10 Kahn "The Arms Race and Some of its Hazards," 777.

11 See especially Graham T. Allison and Frederic A. Morris, "Armaments and Arms Control: Exploring the Determinants of Military Weapons," and John Steinbruner and Barry Carter, "Organizational and Political Dimensions of Strategic Posture: The Problems of Reform," both from *Dædalus* 104 (3) (Summer 1975).

12 See especially F. A. Long, "Control from the Perspective of the Nineteen-Seventies," and Abram Chayes, "Nuclear Arms Control after the Cold War," both from *Dædalus* 104 (3) (Summer 1975).

13 A. A. Kokoshin, "Arms Control: A View from Moscow," Johan Jørgen Holst, "Arms Control in the Nineties: A European Perspective," and Lawrence Freedman, "Arms Control: Thirty Years On," all from *Dædalus* 120 (1) (Winter 1991).

Richard K. Lester & Robert Rosner

The growth of nuclear power: drivers & constraints

Many countries around the world are taking a fresh look at nuclear power. An important cause of what has come to be called the global nuclear renaissance is the prospect of severe disruptions to the earth's climate brought about by continued increases in greenhouse gas emissions, primarily from the combustion of fossil fuels. Nuclear power occupies a unique position in the debate over global climate change as the only carbon-free energy source that is already contributing to world energy supplies on a large scale and that is also expandable with few inherent limits. These attributes are regularly highlighted by nuclear energy advocates and now, increasingly, by some formerly anti-nuclear activists, even as other environmentalists remain strongly opposed to this technology.

The list of countries in which nuclear expansion is being either vigorously pursued or at least seriously considered is long. Several countries in Asia and Eastern Europe with active nuclear power programs have recently announced plans to accelerate those programs. The most important case is China, whose gargantuan appetite for coal caused it recently to overtake the United States as the world's largest emitter of greenhouse gases. In anticipation of continued rapid economic growth and, to a lesser degree, to limit its fossil fuel consumption, last year the Chinese government announced its intention to double its previous target for nuclear power growth by the year 2020. Large numbers of new nuclear plants are also planned in South Korea, Japan, India, and Russia.

Elsewhere, in countries where an earlier wave of nuclear development faltered years ago and the prospects for new nuclear construction have long seemed dim, the terms of the debate have shifted, in some cases dramatically. In Sweden, the government recently decided to overturn a ban on new nuclear power plant construction that had been in effect since 1980. The U.K. government has announced its support for a large program of new nuclear power plant construction. Other European countries, such as Italy, Spain, and Belgium, are reassessing their current approach to nuclear power. Even in Germany, where for many years official policy has called for the phase-out of the country's nuclear power program by 2020, there appear to be growing doubts about the advisability of that policy. In the United States, where the last order for a nuclear power plant was placed more than 30 years ago, 17 applications to build 26 new nuclear power reactors had been filed with the Nuclear Regulatory Commission as of April 2009.

In addition, about 50 countries – almost all of them emerging economies – have declared an interest in nuclear energy to the International Atomic Energy Agency (IAEA).[1] Some, including Turkey, Indonesia, and the United Arab Emirates, have moved a considerable way toward building their first nuclear power reactors, while others are still in the early stages of considering the option, and at present it appears unlikely that more than about 20 of these countries will actually have a nuclear power program in place by 2030.

The IAEA reports that 44 nuclear units, with a capacity of almost 40 gigawatts electric (GWe), are currently under construction. According to the World Nuclear Association, a trade group, at least 70 new units are being planned in the next 15 years worldwide, and another 250 units have been proposed, suggesting that from 470 GWe to as much as 750 GWe will be in place by 2030.

The lengthening list of countries with nuclear programs and plans is striking for its diversity. It includes advanced and developing economies, large and small countries, highly urbanized and sparsely populated countries, countries with a long history of nuclear development and countries with almost none, and countries with no indigenous energy resources and countries with extensive deposits of both uranium and fossil fuels. This diversity of national circumstances, when coupled with new technological developments in the nuclear energy field, opens up the possibility that the world's civilian nuclear industry will in the future develop along divergent pathways. This would be something of a departure from the recent past and raises a number of challenging questions for policy-makers, business practitioners, investors, and others.

In its earliest years, the nuclear power industry also seemed destined to develop along many different trajectories. Nuclear power reactor developers in Canada, the United Kingdom, France, the Soviet Union, Japan, and the United States each introduced a different type of nuclear power reactor technology. National strategies for the nuclear fuel cycle also differed significantly. Eventually, the light water reactor technology that was first introduced in the United States came to dominate the global nuclear power industry. Light water reactors now account for more than 90 percent of installed nuclear capacity worldwide, although today the leading suppliers of this technology are French and Japanese. (The only other power reactor technology with a significant market presence internationally has historically been the Canadian CANDU design.)

There is today a fairly high degree of uniformity in the nuclear plans and programs of most of the major nuclear countries, and nuclear power is one of the most highly globalized of all industries. The nuclear power plant supply industry is dominated by a small number of large global suppliers of light water reactor equipment and technology. National regulatory standards and practices are harmonized to a substantial degree. National strategies for the nuclear fuel cycle are also aligned, and major fuel cycle service providers operate globally. And a new class of global nuclear power plant investor-operators is emerging, led by the French utility EDF, whose joint ventures with nuclear power companies in China and the United States, and its recent purchase of the U.K. nuclear operator British Energy, have established it as an important player in all of the world's largest nuclear power markets.

This global convergence has yielded a number of benefits, including economies of scale and accelerated learning. The case for international coordination and standardization of strategies and practices is further strengthened by the special care with which nuclear technology and materials must be handled, and the international consequences of local nuclear accidents or missteps. From time to time this strategic convergence has also served the purposes of nuclear industry leaders and government policymakers, providing them with a sort of strength-in-numbers defense against local critics. A few years ago, when President George W. Bush announced his support for closing the nuclear fuel cycle in the United States, the new policy was welcomed by the French, British, and Japanese, in no small part because it seemed to legitimize their own longstanding commitment to a closed nuclear fuel cycle, including reprocessing and mixed-oxide fuel use. Thirty years earlier, when the United States abandoned its plans to reprocess spent nuclear fuel and sought to persuade others to do likewise as a nonproliferation measure, the outraged reactions from Europe and Japan were partly stimulated by a fear that the American policy reversal would give ammunition to domestic critics of their own reprocessing plans, which they had no intention of abandoning.

The attractions of nuclear conformity remain strong today, yet the prospect of divergent development pathways may now be greater than at any time since the earliest days of the nuclear power industry. What are the implications of this for nuclear energy growth? How might it affect the course of international nonproliferation efforts?

The increased focus on nuclear energy is motivated by a wide range of other factors in addition to the very low carbon footprint, including:

- *Increasing energy and water demand, coupled with strained supply sources.* Global population growth in combination with industrial development and expectations of rising living standards will lead to a doubling of worldwide electricity consumption by 2030. These pressures are also leading to shortages of fresh water, and increasing calls for energy-intensive desalination plants. Nuclear energy offers significant opportunities to meet the increasing requirements for electricity base load and to produce industrial-scale clean water.
- *Economics.* Until the onset of the global economic crisis, increasing fossil fuel prices had the effect of improving the relative competitiveness of nuclear power.[2] If, as seems probable, future carbon emissions will be taxed at progressively higher rates, the effect will again be to strengthen the competitiveness of nuclear power.
- *Insurance against future price exposure.* A longer-term advantage of uranium over fossil fuels is the small contribution of the former to the total cost of nuclear electricity, and thus the relatively low impact of increased uranium prices on electricity costs. This relative insensitivity to fuel price fluctuations offers a way to stabilize power prices in deregulated markets.
- *Security of energy supply.* Nuclear energy offers a hedge against the vulnerability to interrupted deliveries of oil and gas.

The specific reasons for the current nuclear revival vary by country. Population growth, accompanied by economic development, has led to strong growth in electricity demand in many countries. In some of these, a lack of fossil fuel resources has made nuclear an obvious choice to meet the new demand. In others where fossil fuels are abundant but relatively expensive, nuclear is seen as a hedge against further fuel price increases and price volatility, and sometimes as an enabler of greater export earnings from the domestic fossil endowment. For countries with no fossil fuels, nuclear is also cited as a form of insurance against supply or price disruptions. And in most countries, as we have already noted, climate change is a driver of the renewed interest in the nuclear energy option. That is certainly true of the United States, where the current talk of a nuclear energy renaissance would surely be more muted were it not for concerns over greenhouse gas emissions.

Many climate scientists have concluded that the worst risks of climate change might be avoidable if the atmospheric concentration of CO_2 can be kept below 550 parts per million (ppm), or roughly twice the pre-industrial level. The current CO_2 concentration is about 380 ppm, with smaller amounts of other, more potent greenhouse gases, such as methane and nitrous oxide, adding another 70 ppm of CO_2-equivalent. Emissions of greenhouse gases (GHGs) continue to rise, and the total GHG concentration is increasing at an accelerating rate – currently somewhere between 2 and 3 ppm per year.[3] In its latest assessment, the Intergovernmental Panel on Climate Change (IPCC) has estimated that a doubling of the atmospheric concentration of GHGs relative to the pre-industrial level would eventually (after a few centuries) cause an increase in the globally averaged surface temperature that most likely would fall in the range of 2 to 4.5°C, with a 50 percent probability of remaining below 3°C and a small but significant probability of exceeding 5°C. These are globally averaged figures, and expected temperature changes in large areas of the world would be substantially greater, accompanied by substantially greater local fluctuations.[4]

Some analysts, weighing the risks involved, have concluded that a 550 ppm limit on CO_2 concentration (corresponding to a total GHG concentration of about 670 ppm) would go beyond the bounds of rational risk-taking, and advocate a more restrictive limit. The European Union has adopted the goal of capping the expected equilibrium global average temperature at 2°C, corresponding to a stabilized GHG concentration of about 450 ppm CO_2-equivalent. Since this level has already been reached (although the offsetting effect of aerosol cooling lowers the effective GHG concentration to about 380 ppm), the EU goal is extraordinarily ambitious and almost certainly unrealistic. Most policy-level discussions are currently focused on CO_2 stabilization targets in the 450 to 550 ppm range, even though the scientific consensus is that significant ecological and economic damage is very likely at such levels. Yet even the upper end of this range will be extremely difficult to achieve. The world relies on fossil fuels for more than 80 percent of its primary energy supplies today, and under "business as usual" conditions, annual energy-related CO_2 emissions (which account for a large fraction of the world's GHG emissions) would likely increase threefold by the end of this century.[5] This in turn would imply atmospheric CO_2 concentrations in the 700 to 900 ppm range by the year 2100, with the expected global average temperature increase eventually exceeding 6°C. There is thus a large gap between business-as-usual projections and what will be required to reduce the risk of climate change.

To remain below the limit of 550 ppm, global emissions would have to peak in the next 10 to 20 years, and then fall to a level well below year 2000 emissions. Equity considerations will require that wealthy countries accept higher targets for emissions cuts than poor countries, and several recent reports have advocated reductions of 60 to 80 percent in the advanced countries by the year 2050. President Obama recently called for a reduction in U.S. carbon emissions of more than 80 percent by the year 2050. Such cuts are likely to require even greater reductions in the power sector because in other sectors the maximum achievable reductions may be smaller. A key question here will center on the transportation sector, and how rapidly that sector can be weaned off liquid fossil fuels via some combination of (renewable) advanced biofuels and hybrid or electric vehicles.

Stabilizing the CO_2 concentration in the 450 to 550 ppm range will require rapid, large-scale decarbonization of the global energy supply system beginning, in effect, immediately, combined with vigorous and continuing worldwide improvements in the efficiency of energy use. The longer the delay in embarking on this path, the more difficult it will be to achieve the end goal. Because carbon dioxide molecules released into the atmosphere stay there for about a century on average, a ton of carbon emitted today will have roughly the same effect as a ton emitted at any time over the next several decades. So it is appropriate to think of a global, intergenerational "budget" of carbon emissions that corresponds to a given stabilization target. The more of the emissions budget that is used up in the near term, the steeper and more painful the cutbacks in emissions will have to be in later years. What happens during the next few decades is therefore likely to be decisive. If, by the end of this period, the link between economic activity and carbon emissions has not been broken and if significant progress toward decarbonization of global energy supplies has not been made, the world will have lost almost all chance of avoiding serious and perhaps catastrophic damage from global climate change. It is also important to recognize that we will not be bailed out in this time frame by laboratory breakthroughs that have yet to be made. Most of the heavy lifting during the next few decades will have to come from low-carbon energy systems whose attributes are already fairly well understood, if not yet commercialized.

Current trends are not encouraging. In the first half of this decade, the carbon intensity of the global energy supply system actually increased, reversing an earlier declining trend.[6] Extraordinary efforts will be required to achieve significant decarbonization of energy supplies by mid-century, with all low-carbon energy sources and technologies – solar, wind, geothermal, biomass, nuclear, and coal use with carbon capture and storage – likely to be needed on a large scale. In each case, formidable technological, economic, and institutional obstacles stand in the way of scale-up, and there are no guarantees that they will be overcome. If any one of these technologies – including nuclear – were to be taken off the table, the difficulty of achieving the climate stabilization target would be much greater still. This is the strongest argument for nuclear power.[7]

The contribution that nuclear power will actually make to reducing carbon emissions over the next few decades depends upon how rapidly it can be scaled up, and recent history is sobering. The existing global fleet of 436 commercial nuclear power reactors, with a total net installed capacity of about 370 GWe, provides about 16 percent of the world's supply of electricity today. Depending on how the accounting is done, the emissions avoided by the nuclear fleet amount to about 650 million tons of carbon per year, or 9 percent of the current global emissions total.[8] But it has taken about 40 years for the nuclear industry to reach this level, and in the future the rate of expansion will need to be much faster if nuclear is to play a significant role in reducing carbon emissions. In business-as-usual scenarios published by the International Energy Agency and separately by the IPCC, CO_2 emissions are expected to reach about 41 gigatons (GT) per year (that is, 45 percent above today's level) by 2030 and perhaps 45 – 50 GT (60 – 80 percent above today's level) by 2050.[9] If new nuclear power plants were called upon to eliminate, say, 25 percent of the increase in CO_2 emissions that would otherwise occur in these business-as-usual scenarios, roughly 700 – 900 GWe of new nuclear capacity would have to be added by 2050.[10] In other words, in order to achieve the goal of displacing one quarter of the projected increase in carbon emissions, at least twice as much nuclear capacity would have to be built in the next 40 years as was built in the last 40. In fact, since many existing nuclear plants will reach the end of their useful life during this period and will have to be replaced, the actual requirement would be closer to three times the earlier result.

Circumstances can easily be imagined in which the call on nuclear would be greater still, since it is far from clear that the other non-fossil energy sources will be able to grow as rapidly as would be required to meet the other 75 percent of the carbon displacement target. (However ambitious these nuclear growth scenarios might seem, the growth requirements for other non-fossil energy sources are at least as challenging.) Moreover, by mid-century the global rate of carbon emissions will probably need to be well *below* its current level in order to achieve an eventual CO_2 stabilization goal of 550 ppm, in which case the demand for all low-carbon sources, including nuclear, will be even greater.

In short, much may be riding on how rapidly nuclear power can be scaled up. If so, we will have to act fast – probably even faster than at the height of the first nuclear expansion. But this kind of expansion is currently blocked by a thicket of obstacles, and if the pace of nuclear growth is to accelerate, the characteristically long cycle times in the nuclear power industry – that is, the time it typically takes to move from initial planning of a new investment in a nuclear power plant or fuel cycle facility to the start of operation – will have to be reduced. But how realistic is this?

Many of the reasons for the long leadtimes in the nuclear power industry are familiar and long-standing: protracted siting and licensing proceedings; underlying concerns over nuclear safety and waste disposal and, in some cases, nuclear proliferation; and the high costs of nuclear investments. Other problems have emerged more recently. The worldwide financial crisis has greatly complicated the prospects for financing capital-intensive projects of all kinds, including nuclear power plants. Moreover, the global industrial infrastructure required to support essential elements of nuclear power construction is at present inadequate to meet the needs of a broad nuclear power resurgence. For example, there is at present just one global supplier of the ultra-large forgings needed to make major nuclear components such as reactor pressure vessels, and the waiting list for delivery of these components has been lengthening. The electric grid infrastructure in many parts of the world is currently unable to support the deployment of large nuclear power plants. Serious shortages of human capital are also in prospect, and will be exacerbated by the approaching retirement of many highly educated and trained nuclear specialists whose careers began during the first wave of nuclear growth in the 1960s and 1970s. There is a pressing need to attract high-quality students into the nuclear engineering discipline in order to support the growing needs for new power plant design, construction, and safe, efficient, and reliable operation. Similarly, the stringent quality demands associated with the construction of nuclear plants and their supporting infrastructure call for a highly trained trades workforce, which today is seriously depleted and must be rebuilt worldwide.[11]

How these obstacles to nuclear expansion are dealt with will depend on particular national circumstances, which, as already noted, vary widely from one country to another. Moreover, the extent of these differences is likely to grow since more and more countries are likely to be involved. When national population and economic growth trends are taken into account, the unavoidable conclusion is that the group of countries relying heavily on nuclear power will need to expand considerably if nuclear is to make significant contributions to greenhouse gas reductions. An earlier MIT study showed that it will be effectively impossible to achieve an overall level of nuclear deployment large enough to make a significant contribution to reducing greenhouse gas emissions unless all four of the following developments occur[12]: (1) continued large-scale nuclear development in Japan and the other advanced economies of East Asia; (2) a renewal of nuclear investment in Europe; (3) a revival and major expansion of nuclear power in North America; and (4) significant programs in many developing countries, not just China and India, but also other populous countries like Brazil, Mexico, Indonesia, Vietnam, Nigeria, and South Africa.

It is difficult to exaggerate the contrasts between these countries in terms of nuclear capabilities, expectations, and requirements. The most highly evolved nuclear program today is that of France, where 58 nuclear power reactors account for almost 80 percent of that country's electricity supply and more than 40 percent of total primary energy production. In France, the use of nuclear power for conventional electricity generation is now approaching a limit set by the operational constraints of electric power systems. The available nuclear capacity exceeds the total base-load demand for electricity, and many French nuclear power plants are now operated at less than full capacity at certain times of the day and year. For highly capital-intensive facilities such as nuclear plants this is economically sub-optimal. French nuclear planners are exploring the feasibility of using surplus nuclear electricity to displace petroleum use in the transportation sector.[13] Initially the nuclear electricity produced during off-peak periods would be used to produce hydrogen via electrolysis of water. The hydrogen would be combined with biomass and nuclear heat to produce liquid fuels for cars and light trucks. Alternatively, the electricity could be used directly for plug-in hybrid electric vehicles. Subsequently, dedicated base-load nuclear plants could be built to provide hydrogen and process heat for liquid fuels production on a larger scale. This is an interesting possibility since the eventual contribution of nuclear power to carbon emission reductions will depend in part on whether its role in supplying traditional electricity markets can be augmented by displacing petroleum use in the transportation sector. Other unconventional uses of nuclear energy under active development include seawater desalination[14] and the extraction of oil from tar sands. In both cases, fossil fuels currently provide the heat source for the process. Nuclear desalination projects have been implemented in Japan, India, and Kazakhstan, and several new projects – some of them involving cogeneration of electricity and potable water – are under consideration in the Middle East and elsewhere.

For the time being, however, the primary role of nuclear power will continue to be the production of base load electricity. Here there are two possible directions of development. The first is a continuation of the long-term trend toward international convergence around standardized nuclear power reactor technologies, fuel cycle strategies, and operating and regulatory procedures. The benefits of this approach are most clearly discernible in the case of France, whose sustained commitment to a highly centralized program of progressively larger, standardized nuclear power plants supported by a closed nuclear fuel cycle has yielded what by most estimates is the world's most successful nuclear power program. The U.S. nuclear industry, which eschewed this approach in the past, has gradually been moving in this direction, overhauling (and standardizing) reactor control systems for existing plants, with the aim of simplifying operator training and reducing operator error. This approach, together with extensive preventive maintenance programs, has led the U.S. nuclear industry over the past two decades to outstanding performance in both human safety and reactor availability (presently averaging well over 90 percent). Thus one way to reduce cycle times (and, as a side benefit, significantly improve performance) is for everyone to pull in the same direction.[15] And, indeed, broadly speaking this is where we are today. There are certainly important, unresolved questions about the distribution of fuel cycle facilities, especially the sensitive ones, but the basic pathway of nuclear energy development is relatively well defined. It is less clear whether this approach would be successful in the relatively large number of countries that may take up nuclear power on a significant scale for the first time, however, and for this reason, among others, we need to consider the other possible direction of development: the emergence of multiple nuclear development pathways, tailored to individual national circumstances.

The history of nuclear energy development teaches us that this technology has placed formidable demands on those institutions responsible for managing, regulating, financing, and overseeing it, and that the characteristically long cycle times in the industry – and, when they have occurred, its performance problems – can be attributed more or less directly to those heavy institutional demands. The question is whether alternative developmental strategies can be designed that would pose fewer such demands, and hence offer the prospect of more rapid scale-up. A "technocratic fix" for all of these problems is, of course, unrealistic. On the other hand, some configurations of nuclear technology are likely to be less burdensome to their attending institutions than others.

If a nuclear development strategy could be designed to minimize these burdens, and so reduce nuclear cycle times, what criteria would it need to satisfy?

- The first such attribute is cost-effectiveness. From the customer's perspective, a nuclear kilowatt-hour is indistinguishable from a solar or coal kilowatt-hour, so nuclear power must be economically competitive.
- Second, these nuclear systems would rely as much as possible on passive design features to ensure their safety, as opposed to active safety systems requiring intervention by human agents or (more likely) automatically controlled engineered systems.
- Third, such systems would minimize the risk of nuclear theft and terrorism, and also of state-level nuclear weapons proliferation.
- Fourth, on the question of scale (as opposed to scale-up), these systems would be appropriate to the scale of the national electricity grid and other relevant institutional capabilities.[16]
- Finally, any alternative nuclear development pathway would need to be evolutionary, rather than a disruptive, radical shift. The urgency of scale-up is such that only technologies that have either already been tested in the marketplace or at least are close to commercial demonstration could be eligible for consideration.

If these are indeed desirable attributes for alternative nuclear pathways, the obvious place to begin planning new development strategies is to create the best possible story for the open fuel cycle; that is, we should start with what we have, and invest in ways to improve it in terms of cost, safety, environmental concerns, nonproliferation concerns, and scale. This suggests a number of actions. First, we could develop an explicit strategy for dry surface storage of spent fuel for several decades (at both on-site and centralized off-site locations). There are U.S. locations that, with local support, are volunteering as candidate off-site storage sites; we also need a more robust budgetary and management system, probably with very active nuclear utility involvement. Second, we could move toward the development of alternative spent-fuel disposal techniques that scale well for small nuclear programs, that are less expensive than the current mined geologic repository technology, and that are less demanding in their geological requirements. As an example, the deep borehole technology now under active consideration in Europe and elsewhere may meet all of these requirements. Third, we could focus on power plants that are smaller, that rely to a greater degree on passive safety,[17] and that can be built with greater reliance on modular construction techniques. Fourth, we could explore once-through fuel cycles that are designed specifically for direct disposal and proliferation resistance (by, for example, substantially increasing the fraction of fuel actually burned in a once-through cycle).[18]

The one remaining area of uncertainty – related to a possible fifth response – is the long-term uranium fuel supply. The latest edition of the so-called Red Book, the authoritative biennial report produced jointly by the Nuclear Energy Agency of the OECD and the IAEA, estimates that the identified amount of conventional uranium resources that can be mined for less than $130 per kilogram is 5.5 million tons, but world uranium resources in total are expected to be much higher. Based on geological evidence and knowledge of unconventional resources of uranium, such as phosphates, the Red Book considers that more than 35 million metric tons will be available for exploitation. Given that in the entire 60-year history of the nuclear era the total amount of uranium that has been produced adds up to about 2.2 million metric tons, the availability of uranium is evidently not a limiting factor at this stage of nuclear power development. For time scales stretching to the end of this century and beyond, the situation may be different. On that time scale there are two options (not mutually exclusive) for dealing with potential uranium constraints: first, closing the fuel cycle so as to achieve very high (for example, above 90 percent) burnup; second, embarking on an aggressive program to improve the ability to locate and recover uranium resources economically. A life-cycle economic analysis for waste disposal will be needed to determine the efficacy of closing the fuel cycle at that time. If closing the fuel cycle is economically sensible, then any fuel supply problems will be solved as a byproduct. A potential backstop for both options is the recovery of uranium from seawater. Currently, only Japan is pursuing this option in a significant way, and Japanese researchers are advertising a present-day recovery cost of $1,000 per kilogram. That is an order of magnitude more expensive than standard uranium production costs, but the Japanese experience suggests that an eventual goal of $150 per kilogram may be achievable. Since natural uranium currently accounts for only 3 percent of the total cost of nuclear generation, even $300 per kilogram would be attractive and well below the break-even cost for competition with a mixed-oxide fuel cycle scheme with plutonium recycle in light water reactors or with fast burner reactors.[19]

The issues we have outlined here are generally well understood within the energy, technical, and policy communities; but it is unfortunately also true that nuclear energy policies, as they have been implemented both in the United States and abroad, have been largely at odds with these considerations. Given the urgency imposed by the threat of climate change, by strong increases in energy demand worldwide, and by concerns related to energy security, it is high time that public policy and our technical understanding of the nuclear energy challenge are brought into alignment. This is the intent of our paper. In the end, the public policy and technical communities are on a joint learning curve: "For the things we have to learn before we can do them, we learn by doing them."[20]

ENDNOTES

1 See http://www.iaea.org/NewsCenter/News/2009/nuclearrole.html. For a list of the countries that have declared their interest in nuclear power to the IAEA, see the Introduction to this volume by Miller and Sagan.

2 If the uncertainties in the credit markets persist, the economic competitiveness of nuclear energy will erode. Because of the high capital intensity of nuclear energy projects, the cost of nuclear electricity is particularly sensitive to the availability of financing at competitive rates.

3 Other anthropogenic activities, such as the release of aerosols, have a cooling effect, and the net warming effect of anthropogenic releases currently amounts to the equivalent of about 380 ppm of CO_2. Note that there is often confusion about the form in which these concentrations are expressed, that is, as CO_2 only, as CO_2 plus other GHGs, and as CO_2 plus other GHGs combined with the net cooling effect of aerosols.

4 How long before climate equilibrium is reached depends sensitively on the details of the scenario under which the atmosphere's GHG concentration finally equilibrates.

5 Leon E. Clarke, James A. Edmonds, Henry D. Jacoby, Hugh M. Pitcher, John M. Reilly, and Richard G. Richels, "Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations," Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Climate Change Research (U.S. Department of Energy, 2007).

6 Michael R. Raupach et al., "Global and Regional Drivers of Accelerating CO_2 Emissions," *Proceedings of the National Academy of Sciences of the United States of America* 104 (2007): 10288–10293.

7 To be specific, for nuclear energy to be a "game changer" in bringing emissions down to these levels, nuclear energy would need to be the key backbone for the electrical grid to: (1) power homes, businesses, and factories so that the economic growth prospects for both the developed and developing world are robust; (2) provide the electricity for plug-in hybrids and all other electric vehicles as a replacement for fossil fuels; and (3) enable the production of clean water, hydrogen, and other by-products such as process heat for large manufacturing operations.

8 This calculation assumes that the nuclear plants displaced coal-fired plants. The avoided emissions from the equivalent amount of natural gas-fired capacity would be about 40 percent of this total.

9 For the former figure, see *World Energy Outlook* 2008 (International Energy Agency, 2008). For the latter figure, see Fig. 3.9 of Working Group III Report, "Mitigation of Climate Change," from the *Fourth Assessment Report* (Intergovernmental Panel on Climate Change, 2007).

10 This assumes that these nuclear plants displaced coal-fired electricity generation.

11 The difficulties recently encountered by the French firm AREVA in building a nuclear plant in Finland, the first in a new generation of large pressurized water reactors, are a reminder of how important the availability of highly trained trades, including civil construction, is to keeping this type of project on budget.

12 *The Future of Nuclear Power: An Interdisciplinary Study* (Massachusetts Institute of Technology, 2003).

13 We are grateful to Charles Forsberg for drawing this to our attention. See also Charles W. Forsberg, "Meeting U.S. Liquid Transport Fuel Needs with a Nuclear Hydrogen Biomass System," *International Journal of Hydrogen Energy* (forthcoming).

14 Argonne National Laboratory is completing a detailed cogeneration study in Jordan. The study team found that, because of the significant demand for clean water in the region, cogeneration is a viable economic approach.

15 Unfortunately, at the moment the U.S. nuclear utilities are pulling in five separate directions with their design choices: the ABWR (Hitachi-GE) and ESBWR (GE) for boiling water reactors and the EPR (UniStar), AP-1000 (Westinghouse), and APWR (Mitsubishi) for pressurized water reactors.

16 For example, building gigawatt-scale nuclear plants assumes the presence of an appropriately scaled electric grid infrastructure. If this is not present (as it is not in many developing countries), then one needs to turn to different technologies, namely, grid-appropriate (modular) nuclear reactors. However, the economics needs to be carefully

considered here. In a recent Argonne study for a small developing country considering nuclear energy, we found that when the "overnight" capital cost increased to $3,500/kW or higher, the economic viability would be reduced substantially. Lower overnight costs are more likely for plants that have already paid down their first-of-a-kind engineering costs.

17 An alternative is to focus on greater safety system redundancies; but we would argue that ultimately the better approach is to go for technologically simpler and inherently passive safety designs.

18 Some have argued that the Department of Energy should switch gears: the rush to full-scale fuel reprocessing should be replaced with a more robust research program to develop new recycling technologies.

19 Note, however, that one would build breeders only if there is an economic argument for them – and that argument is not related to the cost of nuclear fuel, but is instead related to the financial and political costs of alternative nuclear-waste storage strategies.

20 Aristotle, *The Nicomachean Ethics*, Book II, trans. William David Ross; first published in 1908, republished in 2007 at www.forgottenbooks.org.

Robert H. Socolow & Alexander Glaser

Balancing risks: nuclear energy & climate change

Four convictions motivate this paper.[1] First, *nuclear power could make a significant contribution to climate change mitigation*. To do so, however, nuclear power would have to be deployed extensively, including in the developing world. A "one-tier" world will be required – that is, a world with an agreed set of rules to govern nuclear power that are the same in all countries.

Second, *the world is not now safe for a rapid global expansion of nuclear energy*. Nuclear-energy use today relies on technologies and a system of national governance of the nuclear fuel cycle that carry substantial risks of nuclear weapons proliferation. There are still more than 20,000 nuclear weapons in the world, and in the current international system, nations see these weapons as instruments of power and sources of prestige. These nations have competing interests and long-standing conflicts. There are also subnational groups that resort to force. The risks that a global expansion of nuclear power will facilitate nuclear proliferation and incidents of nuclear terrorism, or even lead to regional nuclear war, are significant. Nuclear war is a terrible trade for slowing the pace of climate change.

Third, *a world considerably safer for nuclear power could emerge as a co-benefit of the nuclear disarmament process*. The national-security community is currently engaged, to an unprecedented degree, in seeking progress toward nuclear disarmament. A by-product of this process could be different technology choices and innovations in the governance of nuclear power – notably, a halt to spent-fuel reprocessing to separate plutonium as well as multinational ownership and control of uranium enrichment facilities. These developments could begin to decouple nuclear power from nuclear weapons.

Finally, *the next decade is critical*. While several approaches to climate change mitigation are available for immediate, rapid scale-up, nuclear power could be so in maybe 10 years, provided the coming decade is used to establish adequate technologies and new norms of governance. Nuclear power ought to be deployed seriously as a mitigation strategy only when and if it can provide a sustainable contribution. The world will not benefit if nuclear power's contribution is withdrawn a decade or two after global scale-up begins, as a result of flaws related to its coupling to nuclear weapons.

Robert H. Socolow & Alexander Glaser on the global nuclear future

There are 3,000 billion tons of carbon dioxide (CO_2) in the atmosphere today, about 800 billion tons more than there were 200 years ago. For centuries further back, the amount of CO_2 in the atmosphere was about constant: the forests and oceans and atmosphere were in approximate equilibrium. Disequilibrium is increasing with every passing year, as human beings bring carbon from deep underground to the surface (in fossil fuel) and burn it.

The climate science and policy communities have positioned warning lights between 3,500 and 4,000 billion tons of CO_2, levels that would be reached in 30 and 60 years, respectively, at today's rate of growth. For such CO_2 levels, although the most favorable outcomes could be benign, the worst outcomes could be catastrophic for human civilization, which has built many of its cities on coasts and has matched its choices of crops to relatively predictable snowmelt, rainfall, and temperature patterns. We are confronted with a risk-management problem of unprecedented complexity.

Everything about climate change is global. The global atmosphere is well stirred and scarcely registers where CO_2 is emitted. Demand for electricity and fuels is driven by middle-class consumption, which takes similar forms in countries with a wide range of per capita CO_2 emissions.[2] Electricity serving air conditioner compressors, computer circuits, incandescent lights, and appliances arrives along wires that, worldwide, run from power plants of only a few kinds. To be sure, nations differ in their endowments of resources; but, even so, a good strategy for mitigating climate change in one country will be a good strategy in many other countries.

A "wedge model," published in 2004, quantifies the task of global climate change mitigation.[3] We human beings today emit 30 billion tons of CO_2 per year by burning fossil fuels. We would emit 60 billion tons per year in 2050 if we were oblivious to climate change (the so-called business-as-usual world), and we can congratulate ourselves if we cut the anticipated 2050 emissions rate in half, emitting CO_2 at the same rate in 2050 as today. A *stabilization wedge* is a campaign or strategy motivated by climate change (that is, not happening for other reasons) that results in 4 billion tons of CO_2 per year not emitted in 2050.

Available options for wedges include energy efficiency wedges, wind wedges, nuclear wedges, and wedges from CO_2 capture and storage (CCS) – capturing the CO_2 produced at coal plants and burying it deep below ground. About eight wedges are needed to pat ourselves on the back, and we can choose a portfolio of them in many ways. A portfolio of wedges is needed because solving climate change with only one or two kinds of wedges is close to impossible. Moreover, there are enough options for the portfolio that none is indispensable. Thus, climate change mitigation can succeed without nuclear power, or any other single option, at some increased overall cost for mitigation.[4]

A nuclear wedge is equivalent to 700 large base load nuclear power plants on the scene in 2050 and 700 equally large base load coal plants not built.[5] The world has the equivalent of about 350 large nuclear plants today, so phasing out nuclear power in favor of coal power is minus half a wedge.

Arguments for giving priority to climate change mitigation are uncomfortable bedfellows with arguments for nuclear power. The dissonance arises among a political constituency, particularly powerful in Europe, for which mitigating climate change is seen as an opportunity for pursuing deep changes in social and economic structures and in values – away from consumerism and centralized authority. To meet this aspiration, climate policy often promotes wind power, solar thermal and solar photoelectric power, and other forms of renewables, relative to nuclear energy. This perspective also underpins the climate-policy focus on energy efficiency as a way to reduce global energy demand.

On the other hand, putting a price on CO_2 emissions as a way to mitigate climate change helps nuclear power. Roughly, an emissions price of $20 per ton of CO_2 gives nuclear power a 2¢/kWh boost relative to power from coal and a 1¢/kWh boost relative to power from natural gas – in both cases assuming that these fossil fuel plants vent rather than capture and store CO_2.[6] Moreover, serious CO_2 management may be accompanied by support for accelerated electrification of the economy to reduce dispersed emissions from transportation and space heating, which would increase overall demand for electric power.

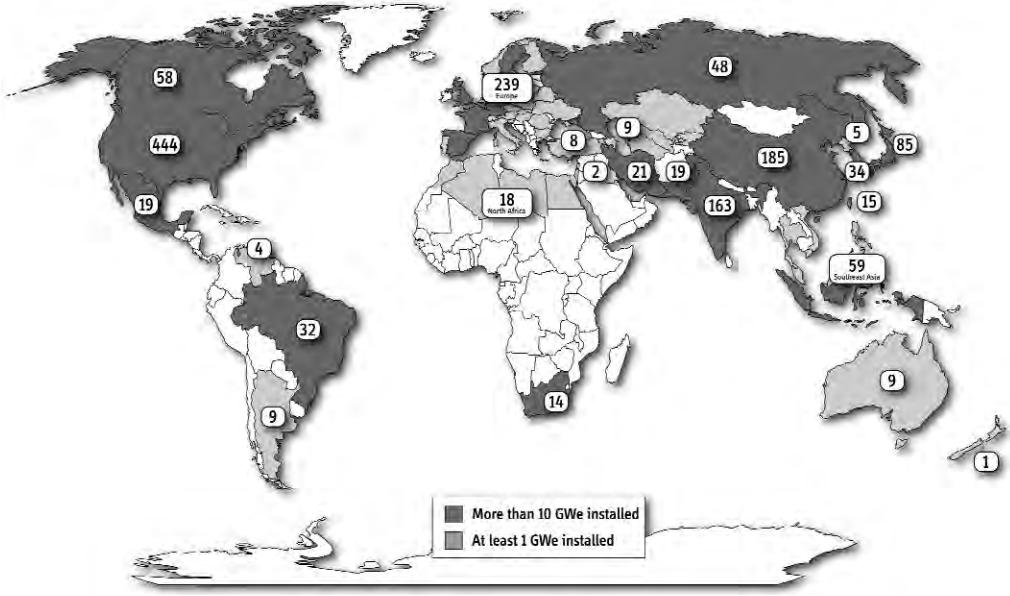
In this paper we consider a nuclear future where 1,500 GW of base load nuclear power is deployed in 2050. A nuclear fleet of this size would contribute about one wedge, if the power plant that would have been built instead of the nuclear plant has the average CO_2 emissions per kilowatt hour of all operating plants, which might be half of the value for a coal plant.[7] Base load power of 1,500 GW would contribute one fourth of total electric power in a business-as-usual world that produced 50,000 terawatt-hours (TWh) of electricity per year, two-and-a-half times the global power consumption today.[8] However, in a world focused on climate change mitigation, one would expect massive global investments in energy efficiency – more efficient motors, compressors, lighting, and circuit boards – that by 2050 could cut total electricity demand in half, relative to business as usual. In such a world, 1,500 GW of nuclear power would provide half of the power.

We can get a feel for the geopolitical dimension of climate change mitigation from the widely cited scenarios by the International Energy Agency (IEA) presented annually in its *World Energy Outlook* (*WEO*),[9] even though these now go only to 2030. The *WEO* 2008 estimates energy, electricity, and CO_2 emissions by region. Its 2030 world emits 40.5 billion tons of CO_2, 45 percent from electric power plants. The countries of the Organisation for Economic Co-operation and Development (OECD) emit less than one third of total global fossil fuel emissions and less than one third of global emissions from electric power production. By extrapolation, at midcentury the OECD could contribute only one quarter of the world's greenhouse gas emissions.

It is hard for Western analysts to grasp the importance of these numbers. The focus of climate change mitigation today is on leadership from the OECD countries, which are wealthier and more risk averse. But within a decade, the targets under discussion today can be within reach only if mitigation is in full gear in those parts of the developing world that share production and consumption patterns with the industrialized world.

The map (see Figure 1) shows a hypothetical global distribution of nuclear power in the year 2050 based on a high-nuclear scenario proposed in a widely cited MIT report published in 2003.[10] Three-fifths of the nuclear capacity in 2050 as stated in the MIT report is locat-

Figure 1
The Geography of a Hypothetical Nuclear Expansion to 1,500 GWe



In this scenario, 58 countries would be using nuclear energy, but only about 40 percent of the capacity would be in non-OECD countries. Source: Based on information from *The Future of Nuclear Power* (MIT, 2003).

ed in the OECD, and more nuclear power is deployed in the United States in 2050 than in the whole world today. The worldview underlying these results is pessimistic about electricity growth rates for key developing countries, relative to many other sources. Notably, per capita electricity consumption in almost every developing country remains below 4,000 kWh per year in 2050, which is one-fifth of the assumed U.S. value for the same year. Such a ratio would startle many analysts today – certainly many in China.

It is well within limits of credulity that nuclear power in 2050 could be nearly absent from the United States and the European Union and at the same time widely deployed in several of the countries rapidly industrializing today. Such a bifurcation could emerge, for example, if public opposition to nuclear power in the United States and Europe remains powerful enough to prevent nuclear expansion, while elsewhere, perhaps where modernization and geopolitical considerations trump other concerns, nuclear power proceeds vigorously. It may be that the United States and other countries of the OECD will have substantial leverage over the development of nuclear power for only a decade or so.

Change will not happen overnight. Since 2006, almost 50 countries that today have no nuclear power plants have approached the International Atomic Energy Agency (IAEA) for assistance, and many of them have announced plans to build one or more reactors by 2020. Most of these countries, however, are not currently in a good position to do so. Many face important technical and economic constraints, such as grid capacity, electricity demand, or GDP. Many have too few trained nuclear scientists and engineers, or lack an adequate regulatory framework and related legislation, or have not yet had a public debate about the rationale for the project. Overall, the IAEA has estimated that "for a State with little developed technical base the implementation of the first [nuclear power plant] would, on average, take about 15 years."[11] This lead time constrains rapid expansion of nuclear energy today.

A wedge of nuclear power is, necessarily, nuclear power deployed widely – including in regions that are politically unstable today. If nuclear power is sufficiently unattractive in such a deployment scenario, nuclear power is not on the list of solutions to climate change.

Nuclear power is not just another wedge. Briefly, here are some of the many distinctive attributes of nuclear power:

- *Time-tested*. Relative to competing wedges like renewable energy and CCS, nuclear power has been in place longer. Commercial nuclear power has been deployed for about 50 years and today is found in 30 countries. Deployment is highly concentrated, however; 10 countries operate more than 80 percent of all power reactors.
- *Small physical flows*. The thermal energy required to produce 1,000 MW of power for a year is released from the fission of only 1 ton of uranium in fuel produced from 200 tons of uranium, but from the burning of 3 million tons of coal. The flip side of compactness, of course, is that danger comes in very small packages: it takes only a few kilograms of fissile material to make a nuclear weapon.
- *Minimal CO_2 emissions*. About 90 percent of the CO_2 is expected to be excluded from the atmosphere if coal power and gas power are combined with CO_2 capture and storage. (The economic optimum percent, to be sure, depends on the CO_2 emissions price.) In that case, the CO_2 emissions from CCS power, nuclear power, and most forms of renewable energy are likely to be comparably small – all emitting less than 100 grams of CO_2/kWh, one-tenth of the value for today's coal plants.
- *Large, centralized plants with fixed output*. To be economic, nuclear plants are large and connected to extensive electricity grids that distribute power over long distances. The power output of nuclear power plants is not easily ramped up and down, rendering it an inflexible component of an electric power system. The inflexibility of base load nuclear power and the intermittency of wind and solar energy share the feature that neither of these low-CO_2 emitters can meet a time-varying demand for electric power without assistance from complementary systems: load-following and peaking plants and storage.
- *Safety makes all plants mutual hostages*. The Three Mile Island and Chernobyl accidents of 1979 and 1986, respectively, taught the world that a nuclear power accident anywhere in the world affects the prospects for nuclear power everywhere. Nuclear energy is more "brittle" than other strategies to mitigate climate change, as one major future accident could overnight nullify the resources and time invested in nuclear power made up to that point.
- *Nuclear power plants are potential military targets*. It is all too likely that a commercial nuclear power plant in a country at war would be attacked, with horren-

dous consequences. No taboo on such attacks exists today.[12]

- *Storage of spent fuel remains a problem*. At the advent of nuclear power, its advocates promised that no future generation would need to attend to our wastes. That goal of early final disposal has proven to be overly ambitious. Today, the second best approach to the waste problem is interim dry-cask storage of nuclear spent fuel, now widely deployed, which provides a century-scale solution while the search for solutions that isolate nuclear wastes for millennia continues.

- *Coupling to nuclear weapons*. With a nuclear power plant comes a fuel cycle, with a front-end that can require uranium isotope enrichment and a back-end that can entail the separation of plutonium and its insertion into commerce. Both the front- and back-end present significant and enduring challenges.

For the rest of this paper, we focus only on the last of these aspects of nuclear power. In our view, the fact that nuclear power is coupled to nuclear weapons is the most disabling attribute of global nuclear power at the present time.

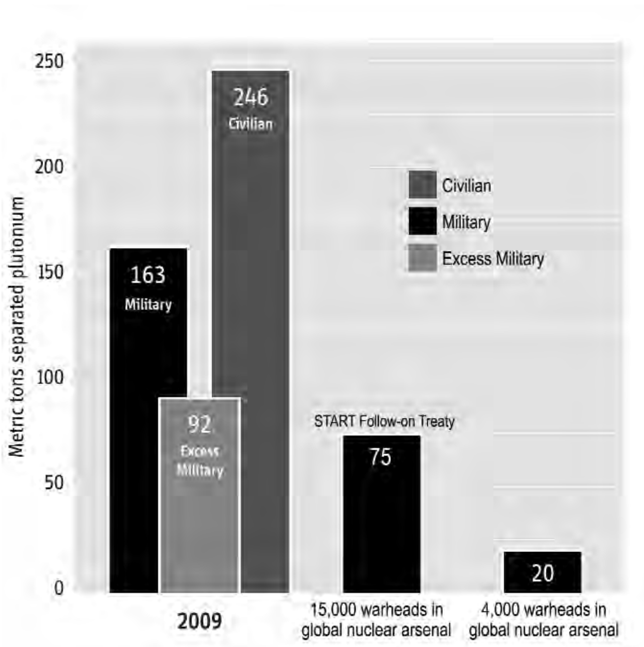
Separated plutonium and highly enriched uranium are the key ingredients for making nuclear weapons. It is widely accepted that the production or acquisition of these fissile materials is the most difficult, visible, and time-consuming step in the proliferation process. Reprocessing and enrichment under national control essentially removes this obstacle and offers – intended or not – important latent proliferation capabilities.

Regarding reprocessing and plutonium recycle, the world is now divided. Six countries reprocess their commercial spent fuel today. France, India, Japan, and Russia are deeply committed to reprocessing; China operates a pilot reprocessing plant and is contemplating commercial reprocessing today; and the United Kingdom is on the verge of abandoning reprocessing. The United States does not reprocess civilian spent fuel nor does it introduce plutonium into its power plants, policies established under Presidents Ford and Carter.

The principal arguments against plutonium recycling are that separation, stockpiling, transport, and use of plutonium create risks of diversion to military purposes and risks of theft, the latter being of particular concern in the context of efforts to prevent nuclear terrorism. Compared to other types of nuclear facilities, reprocessing plants are extremely difficult and costly to safeguard.

The bar graph (see Figure 2) shows the quantities of separated plutonium in the world today. Civilian-separated plutonium and military-separated plutonium are both roughly equal at about 250 tons.[13] Military plutonium is in two categories: material in the weapons complex and material declared "excess" as a result of reductions from previous warhead levels. The bar graph also shows the substantial further reductions in military plutonium associated with nuclear weapons if the world's weapons stockpile is reduced first to 15,000 and then 4,000 warheads.[14] In this process, additional military stocks would become excess and would need to be disposed of. Over time, unless reprocessing of civilian spent fuel swiftly draws to a close, the world can expect to become increasingly preoccupied with latent proliferation and "breakout"[15] associated with civilian-separated plutonium – even if nuclear power does not expand significantly. A global nuclear power expansion

Figure 2
Military- and Civilian-Separated Plutonium Today, and Military Plutonium in Weapons in a Disarming World



We assume an average of 4 kg of plutonium per warhead and a working stock of 20 percent. Civilian stockpiles are based on the latest declarations for the beginning of 2008. The current military stockpile carries an error bar of plus or minus 25 tons, largely because of the uncertainties in the estimate of Russia's inventory. Source: Based on information from International Panel on Fissile Materials, *Global Fissile Material Report 2009* (Princeton, N.J.: IPFM, forthcoming).

with reprocessing makes matters much worse.

So far, no country that decided to pursue commercial reprocessing has managed to balance the rates of separation and use of plutonium, which has led to a continuous increase of civilian plutonium inventories over the past decades – hypothetically enough for more than 30,000 weapons.[16] The flow of plutonium could be enormous in a world with much more nuclear energy. The 2003 MIT report works out the plutonium flows for a scenario with 1,500 GW of nuclear power where 40 percent of total capacity is from breeder reactors.[17] About 1,000 tons of plutonium would be separated from the spent fuel each year to fabricate new fuel for these reactors. The IAEA cannot reduce the overall uncertainty of measurements for the annual material balance in reprocessing plants much below 1 percent.[18] Assuming that 20 large-scale reprocessing plants existed in this world, the uncertainty would be equivalent to 500 kg of plutonium every year for every plant – enough for 60 bombs per year from each of these plants. Within these margins, the IAEA would be unable to confirm with high confidence that all material is accounted for. It is hard to see how these flows and levels of uncertainty could ever be acceptable, in particular with fuel cycles under national control.

Many discussions of a potential global nuclear expansion posit that uranium resources will run short unless the world moves to the "closed" fuel cycle. In the case of the once-through fuel cycle, as noted above, about 200 tons of uranium are mined and purified for every ton of material fissioned each year in a 1 GW reactor. This "inefficiency" has plagued nuclear engineers and reactor designers from the very beginning of the nuclear era. Already in 1944, a group of eminent scientists of the U.S. Manhattan Project devised the concept of the breeder reactor, which would produce more fuel than it consumes, because they were concerned that uranium might be too scarce to build even a small number of bombs.[19] And since the 1950s, several countries have launched plutonium breeder reactor programs, motivated in part by concern that deposits of high-grade natural uranium ore might become scarce as nuclear power expanded.[20]

The argument for reprocessing based on the scarcity of uranium, however, is a weak one. Plutonium fuels will remain non-competitive compared to uranium fuels until the price of uranium increases to more than $500/kg of uranium, about four times its price today.[21] The estimated global reserve is sufficient to fuel thousands of reactors. Even with a major expansion of nuclear power, availability and price of uranium will not significantly affect the viability or competitiveness of the once-through fuel cycle through 2050 and probably even beyond.

Unlike reprocessing, uranium enrichment is an essential part of the nuclear fuel cycle today.[22] As with reprocessing, however, even a relatively small enrichment plant is sufficiently large to support a significant military program. A standard 1 GW reactor requires about 20 tons per year of low-enriched uranium (LEU), which in turn requires 200 tons of natural uranium input to an enrichment plant. The same enrichment plant (the size that Brazil and Iran are currently building) with the same natural uranium input can be used to produce about 600 kg per year of weapons-grade highly enriched uranium (HEU), enough for 25 to 50 weapons per year.

Centrifuge enrichment plants now dominate the modern nuclear fuel cycle, even though it was always understood that the technology is highly proliferation prone.[23] They can be converted quickly from production of LEU to production of HEU.[24] And they can be built clandestinely, a primary concern with Iran's program today.

Even if we assume that the accumulation of separated plutonium can be stopped in a world with a greater role for nuclear power, we are left with the problem of the spread of other sensitive nuclear-fuel-cycle technology (notably, centrifuge enrichment) to non-weapons states. Multinational ownership and control of sensitive fuel-cycle facilities would therefore seem to be a necessary element of a world where nuclear power is deployed widely but risks of nuclear war and nuclear terrorism are smaller than today.

Can nuclear power be decoupled from nuclear weapons? From the very beginning of the nuclear age, it was understood that allowing nuclear facilities to operate under national control, even under international monitoring, carried serious risks. Nonetheless, civilian nuclear energy use and related proliferation risks received little attention for the first 25 years, while the nuclear arms race of the two superpowers was unfolding and the weapons programs in other countries were largely unconstrained.

The debate over alternative, multilateral approaches to the nuclear fuel cycle first engaged the world in the mid-1970s, and is now with us again.[25] The nuclear industry, however, has traditionally been reluctant to acknowledge the connection between civilian and military use of nuclear energy. The Director General of the World Nuclear Association, an industry lobby group, recently said, "[T]he global non-proliferation and safeguards system effectively curtails any link between civil and military programs."[26] He added, "[W]hatever proliferation risk we face would be unaffected even by a 20-fold increase in the global use of safeguarded nuclear reactors."

What degree of decoupling of nuclear power from nuclear weapons could be accomplished with multilateral approaches? To answer this question, one must consider the points of view of both providers and recipients of nuclear technology.[27]

Nuclear-supplier states and today's nuclear-weapons states emphasize the objectives of preventing the further spread of sensitive nuclear technologies and of ensuring that they are used only for peaceful purposes where they remain. Many states, however – in particular, recipient and non-weapons states – have different priorities. For them to support and participate in multilateral approaches and to forgo research and development of certain elements of the fuel cycle, they require specific incentives. Increased energy security through fuel assurances is often not one of them, because most states are already satisfied with the current market structure characterized by several independent and reliable fuel suppliers. The interests of many recipient states lie elsewhere.

Among many non-weapons states, there is broad dissatisfaction with the status and prospects of the Non-Proliferation Treaty (NPT). Their priority is limiting any differential nuclear weapons capability in their region, but they are also unhappy about the implementation of Articles IV and VI, which define rights and obligations with respect to peaceful use and disarmament.[28] The current system of supplier states, which is based in the nuclear-weapons states and a few closely allied countries, is seen as a major expression of a distorted implementation of Article IV.

Some proposals for multilateral approaches to the nuclear fuel cycle tend to increase this tension further by creating a two-tier world of "suppliers" and "users." But other approaches recognize this dilemma. They envision a more active role for non-weapons states in the supplier market, for example, featuring participation in multinational enrichment plants.

Fuel-cycle facilities under multinational ownership and control are not a silver bullet, but they offer several important advantages vis-à-vis plants under national control. At a minimum, multinational plants can serve as a confidence-building measure through regional cooperation and make breakout politically more costly. Moreover, if sensitive technologies are used on a "black-box" basis, as they often are today in the case of centrifuge enrichment plants even in weapons states, participants would not unnecessarily acquire latent proliferation capabilities. Over time, multinational ownership and control could therefore alleviate concerns about parallel clandestine programs.

In support of sustainable one-tier arrangements, multinational ownership of fuel-cycle facilities in the nuclear weapons states and supplier states will be a necessary complement to similar arrangements in non-weapons states and recipient states. Eventually, conversion of all existing national enrichment plants to multinational ownership and control will be required. Enrichment providers will not easily cede control of their existing facilities and place them in a new, and initially uncertain, institutional framework. However, if nuclear disarmament proceeds and deeper cuts in nuclear arsenals are agreed upon, the weapons states – all of which have built or are building large-scale uranium enrichment plants – would themselves have strong incentives to embrace multinational controls as a way to constrain national breakout capabilities and reduce the risk of clandestine enrichment plants.

Nuclear power will confront two major tests in the coming decade. First, issues related to coupling to weapons must be resolved. Second, the cost of nuclear electricity must be demonstrated to be competitive. How should this next decade be used? We identify four priorities.

First, to address the coupling to weapons, the once-through fuel cycle must become the norm. The trend of accumulating stockpiles of civilian plutonium must be stopped and reversed. Current reprocessing must be phased out so that there are no additions to the massive overhangs of separated plutonium now in place in countries that have been reprocessing, and work toward the safe disposal of existing separated plutonium stocks must begin. Moreover, all enrichment plants must be brought under effective multinational ownership and control.

Second, to improve the competitiveness of nuclear power relative to other sources of energy supply, reductions in construction and operating costs will be required. Broadly based sharing of information about the construction of new nuclear power plants is in the interest of the industry; such sharing should result in a firm understanding of the costs when best practices are pursued.[29] Similarly, plant operation procedures for both new and existing plants (including operator training) could be coordinated internationally beyond the levels today.

Not much new capacity is likely to be added to the grid in this decade,[30] but the bottlenecks that today thwart expansion must be addressed. These include production of pressure vessels and other distinctive high-technology components, trained people, and regulatory and legal frameworks. To promote innovation and reduce concerns about the safety of older plants worldwide, incentives that today strongly favor plant-life extension should be revised in favor of retirement and new construction.

Third, during the coming decade, the social contract between the nuclear industry and the public regarding burdening future generations with the management of nuclear waste must be renegotiated, so that interim storage of nuclear waste can become the option of choice for at least several decades. Dry-cask storage can be widely implemented. Development and exploration of potential sites for long-term geologic disposal of nuclear wastes can continue, but with reduced pressure to authorize long-term repositories.[31]

Finally, research and development undertaken in the next one or two decades must support the transition to a nuclear fuel cycle compatible with nuclear energy on a larger scale and in more countries.[32] Some of this activity must explore advanced safeguards techniques and further expand the idea of safeguards-by-design, which recognizes that plant design can "facilitate or frustrate" IAEA safeguards efforts.[33]

We end with four questions that we believe deserve much more discussion, and we provide tentative answers.

Will nuclear energy fare better in a world where climate change is a priority? Not necessarily. Climate change policy could handicap fossil fuels but forcefully promote renewable energy and efficiency. Nuclear power's short-term fate depends more on other factors, notably capital and operating costs, safety record, coupling to nuclear militarization, and the overall sense of competence and responsibility that the industry projects.

Can we have much more nuclear energy without nuclear disarmament? Only with great difficulty. A multilateral nuclear disarmament process might be the most effective way – perhaps the only way – for states to move away from enrichment and reprocessing plants under national control. Proposals for multilateral approaches to the nuclear fuel cycle need to take the nuclear disarmament process, rather than traditional nuclear nonproliferation efforts, as their main frame of reference.

Can we have nuclear energy in a nuclear-weapons-free world? A nuclear-weapons-free world would be more stable and more secure without nuclear energy. But a new framework for the nuclear fuel cycle could make nuclear energy compatible with a nuclear-weapons-free world.

Will the nuclear power cure for climate change be worse than the disease? Every "solution" to climate change can be done badly or well. Done badly, it can be worse than the disease. Making climate change the world's exclusive priority is therefore dangerous. It results in an overemphasis on speed of transformation of the current energy system and a dismissal of the very large risks of going too fast. Looming over energy efficiency is the shadow of excessive regimentation; over renewables, land-use conflicts (with food, biodiversity, and wilderness values); over carbon dioxide capture and storage, the environmental abuses that continue to characterize the fossil fuel industries; and over geoengineering, granting excessive authority to a technocracy. Looming over nuclear power is nuclear war.

The upper limits of climate change are terrifying, amounting to a loss of control of the climate system as positive feedbacks of various kinds set in. Nonetheless, at this moment, and conceding that such calculations can only embody the most subjective of considerations, we judge the hazard of aggressively pursuing a global expansion of nuclear power today to be worse than the hazard of slowing the attack on climate change by whatever increment such caution entails.

If over the next decade the world demonstrates that it can do nuclear power well, a global expansion of nuclear power would have to be – indeed, *should* be – seriously reexamined.

ENDNOTES

[1] The authors have benefited from numerous suggestions from Zia Mian. We are also indebted to Jan Beyea, Harold Feiveson, Steven Fetter, José Goldemberg, Robert Goldston, Robert Keohane, Scott Sagan, Sharon Squassoni, and Frank von Hippel for close readings of an earlier draft.

2 Shoibal Chakravarty, Ananth Chikkatur, Heleen de Coninck, Stephen Pacala, Robert Socolow, and Massimo Tavoni, "Sharing Global CO_2 Emission Reductions among One Billion High Emitters," *Proceedings of the National Academy of Sciences* 106 (29) (2009): 11884 – 11888; www.pnas.org/content/106/29/11884.

3 Stephen Pacala and Robert Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science* 305 (2004): 968 – 972. Here, we slightly redefine a wedge to refer to 4 billion tons of CO_2 per year not emitted in 2050, versus 1 billion tons of *carbon* not emitted *in 50 years* in the 2004 paper.

4 For the purposes of this paper it is a detail that the center of gravity of discussions since wedges were introduced in 2004 has moved toward tougher targets. The "two-degrees" target widely discussed today – an average surface temperature rise limited to 2°C greater than its pre-industrial value – requires that global CO_2 emissions fall to *half* of today's value by 2050. For such a tough target, less than 10 percent of the job is done by one wedge.

5 We define a large plant to be one with a capacity of 1,000 MW, that is, 1 GWe, and base load to mean operating 8,000 hours per year. Our reference base load coal plant, somewhat more efficient than the coal plant one can build today, emits 800 grams of CO_2 for every kilowatt-hour of electricity, or 6.4 million tons of CO_2 per year. The nuclear plant displacing the coal plant has life cycle emissions of about 50 grams of CO_2/kWh; its carbon intensity is 16 times less than a coal plant. Rounding off, 700 nuclear plants emit 4 billion tons less a year than 700 coal plants.

6 We assume today's coal and natural gas plants emit 1,000 and 500 grams of CO_2/kWh, respectively.

7 Think of a nuclear plant displacing a coal plant half the time and a carbon-free renewable power plant the other half of the time, or, equivalently, a nuclear plant displacing a natural gas plant. Confirming this view, in 2006 the carbon intensity of average power was 56 percent of the carbon intensity of coal power; International Energy Agency, *World Energy Outlook* 2008 (Paris: OECD/IEA, 2008), www.worldenergyoutlook.org.

8 One terawatt-hour is 1 billion kWh.

9 *World Energy Outlook* 2008.

10 *The Future of Nuclear Power* (MIT, 2003), web.mit.edu/nuclearpower. In MIT's high-nuclear scenario, 14,100 TWh of nuclear power are produced in 2050, which corresponds to 1,760 GW of base load power running 8,000 hours per year. The MIT report calculates 1,609 GW of "equivalent capacity" by assuming constant output throughout the 8,760 hours of the year. The map rescales the MIT totals to 1,500 GW of base load power to match the deployment scale chosen here.

11 International Atomic Energy Agency, *Considerations to Launch a Nuclear Power Programme*, GOV/INF/2007/2 (Vienna, Austria: IAEA, April 2007).

12 Several nuclear reactors were attacked and destroyed while under construction (that is, without risking radiological contamination): Iraq attacked Iran's Busher reactors during the Iraq-Iran War; Israel destroyed Iraq's Osirak research reactor in 1981 and perhaps another reactor in Syria in August 2007. Attacks on operational reactors were also considered. In 1991, Iraq fired a Scud missile with a cement warhead at Israel, apparently in an attempt to damage the Dimona reactor. The United States considered destruction of North Korea's Yongbyon reactor in the early 1990s to prevent plutonium recovery from the irradiated fuel in the core. India and Pakistan are a notable exception: they have signed an agreement not to attack each other's nuclear installations in the case of war.

13 Separated means unaccompanied by large amounts of radioactivity, and therefore relatively easily accessed. Today, more than 1,500 tons of civilian plutonium have not been separated and are still in spent fuel.

14 Under the planned START Follow-on Treaty, the United States and Russia have agreed to reduce their strategic nuclear warheads to 1,500 – 1,675 by 2016. According to estimates by the Federation of American Scientists, however, each country is expected to retain a total of about 7,000 warheads since they will continue to have non-strategic warheads, weapons in reserve, and weapons awaiting dismantlement. The global stockpile of nuclear weapons could therefore be on the order of 15,000 warheads. In a subsequent reduction, the United States and Russia might reduce to 1,000 – 1,500 total warheads on each side, which could correspond to 4,000 nuclear weapons worldwide.

15 Breakout describes a scenario in which a host state begins production of fissile materials for weapons purposes (without concealing this effort) at a facility that was previously used for peaceful purposes.

16 International Panel on Fissile Materials, *Global Fissile Material Report 2008* (Princeton, N.J.: IPFM, October 2008), Appendix 1A; www.ipfmlibrary.org/gfmr08.pdf. Germany is the only country that managed to stabilize and gradually draw down its plutonium stockpile after having stopped shipping spent fuel for reprocessing (in France and the United Kingdom) in 2005.

17 This is a balanced thermal and fast reactor system in which the plutonium generated in the spent fuel from the fleet of light water reactors is used to fuel a fleet of fast reactors operated in a burner mode. *The Future of Nuclear Power*, Appendix Chapter 4, 124 – 126.

18 Shirley Johnson, *The Safeguards at Reprocessing Plants under a Fissile Material (Cutoff) Treaty*, IPFM Research Report 6 (IPFM, February 2009), www.ipfmlibrary.org/rr06.pdf.

19 Among others, the group included Enrico Fermi and Leo Szilard. Catherine Westfall, "Vision and Reality: The EBR-II Story," *Nuclear News* (February 2004): 25 – 32.

20 Thomas B. Cochran, Harold A. Feiveson, Frank von Hippel, Walt Patterson, Gennadi Pshakin, M. V. Ramana, Mycle Schneider, and Tatsujiro Suzuki, *Fast Breeder Programs: History and Status*, IPFM Research Report 8 (IPFM, forthcoming).

21 For this estimate, we assume typical transaction costs for the various steps of the fuel fabrication process, in particular $1,000/kg and $1,500/kg for reprocessing and MOX fuel fabrication. For the methodology, see *The Future of Nuclear Power*, Appendix Chapter 5.D. Our value for reprocessing is conservative. For example, the levelized cost of reprocessing at Japan's new reprocessing plant is about $3,750/kg. In general, fuel costs of nuclear energy are small compared to capital costs. Costs of standard LEU fuel add up to about 0.9¢/kWh, which is on the order of 10 to 20 percent of the levelized cost of electricity from nuclear energy.

22 The most common reactor type requires LEU (3 to 5 percent uranium-235, as compared to 0.7 percent of this isotope in naturally occurring uranium). LEU is not usable for weapons, but the same enrichment facility can in principle produce weapons-grade HEU (for instance, 90 percent uranium-235). In principle, nuclear energy can be deployed and used without relying on enrichment or reprocessing. For example, Canada's original CANDU reactor design, which is natural-uranium fueled and heavy-water moderated and cooled, requires about 25 percent less uranium than a typical light water reactor.

23 More than 25 years ago, Allan S. Krass and coauthors recommended a shift toward proliferation-resistant enrichment technology, with plants operated under the authority of an International Nuclear Fuel Agency (INFA). With regard to centrifuge technology, they concluded: "Unfortunately . . . a number of operating facilities already exist. Preferably, these facilities should be shut down and dismantled"; Allan Krass, Peter Boskma, Boelie Elzen, and Wim A. Smit, *Uranium Enrichment and Nuclear Weapon Proliferation* (London and New York: Taylor & Francis/Stockholm International Peace Research Institute, 1983); free electronic access at books.sipri.org. Besides centrifuge enrichment technology, there is now also renewed interest in laser isotope separation (LIS), a technology that has been explored off and on since the 1970s as a "next-generation" process for uranium enrichment. In July 2009, Global Laser Enrichment, a joint venture, submit-

ted a license application for a large laser-enrichment plant in the United States; if it decides to move forward, it wishes to begin commercial operation in 2012. Little is known about the details of the LIS process, and no dedicated IAEA safeguards approach now exists. It is likely that the technology will raise proliferation concerns similar to those of centrifuges.

24 Alexander Glaser, "Characteristics of the Gas Centrifuge for Uranium Enrichment and Their Relevance for Nuclear Weapon Proliferation," *Science & Global Security* 16 (1–2) (2008): 1–25.

25 The current debate gained momentum in October 2003 when *The Economist* published an article by IAEA Director General Mohamed ElBaradei, in which he acknowledged the shortcomings of the current nonproliferation regime; "Towards a Safer World," *The Economist*, October 16, 2003.

26 John Ritch, *The Necessity of Nuclear Power: A Global Human and Environmental Imperative*, World Nuclear University, "Key Issues in Today's World Nuclear Industry," Balseiro Institute, San Carlos de Bariloche, Argentina, March 10, 2008, www.world-nuclear.org.

27 For detailed discussion, see: *Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report Submitted to the Director General of the International Atomic Energy Agency*, INFCIRC/640 (Vienna, Austria: International Atomic Energy Agency, February 22, 2005); Alexander Glaser, *Internationalization of the Nuclear Fuel Cycle*, International Commission on Nuclear Non-proliferation and Disarmament, ICNND Research Paper No. 9, February 2009; and Y. Yudin, *Multilateralization of the Nuclear Fuel Cycle: Assessing the Existing Proposals* (New York and Geneva: United Nations Institute for Disarmament Research, 2009).

28 From this perspective, Article IV is particularly unbalanced. Besides guaranteeing the "inalienable right . . . to develop research, production and use of nuclear energy for peaceful purposes without discrimination," Article IV also specifies that states with advanced nuclear technologies should cooperate in contributing to "the further development of the applications of nuclear energy for peaceful purposes, especially in the territories of non-nuclear-weapon States Party to the Treaty."

29 Broad international industry-government coordination is a prominent feature of efforts today to accelerate the commercialization of CO_2 capture and storage.

30 A new study by the U.S. National Academy of Sciences estimates that "as many as five to nine new nuclear plants could be built in the United States by 2020." The National Academy of Sciences and the National Academy of Engineering, *America's Energy Future: Technology and Transformation, Summary Edition* (Washington, D.C.: The National Academies Press, 2009), 112; www.nap.edu/catalog.php?record_id=12710.

31 Richard L. Garwin, "Reprocessing Isn't the Answer," *Bulletin of the Atomic Scientists* (August 6, 2009); www.thebulletin.org/web-edition/op-eds/reprocessing-isnt-the-answer.

32 For example, increasing the burn-up of standard LEU fuel could improve overall economics of the once-through fuel cycle and also reduce uranium requirements to some degree. Using thorium fuel in new light water reactor types as a partial substitute for standard LEU fuel could be another productive field of mid-term research. If implemented sensibly, thorium use would also reduce the total amount of plutonium embedded in spent fuel from light water reactors and perhaps reduce some proliferation concerns of the once-through fuel cycle.

33 Brian Boyer, "Facility Design Can Aid or Frustrate International Safeguards Efforts," *Nuclear Power International* (June 2009).

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The economic future of nuclear power

In the last several years we have seen what appears to be revived global interest in continuing operation of existing nuclear power plants and constructing a new generation of plants.[1] A recent International Atomic Energy Agency (IAEA) report indicates that 24 countries with nuclear power plants are considering policies either to accommodate or encourage investments in new nuclear power plants, and that 20 countries without nuclear power today are considering supporting the use of nuclear power to meet future electricity needs. It projects as much as a 100 percent increase in nuclear generating capacity by 2030.[2] The United States has taken a number of steps to encourage investment in a new fleet of nuclear power plants. The federal safety review and licensing process has been streamlined, and a variety of financial incentives for new nuclear plants are included in the Energy Policy Act of 2005. As of early 2009, license applications for 26 new plants have been filed with the U.S. Nuclear Regulatory Commission (NRC), and additional applications are likely.[3]

This renewed interest appears to reflect a variety of considerations, including a shift toward sources of electricity that do not produce CO_2; the search for lower-cost sources of electricity, stimulated by dramatic increases in fossil fuel prices prior to the current global economic contraction; and (often poorly defined) energy security concerns associated with fossil fuels, especially natural gas.

The potential revival of nuclear power faces a number of risks and challenges that make the anticipated "renaissance" of nuclear power in the United States and other countries quite uncertain. The economics of maintaining the existing fleet of nuclear power plants, investment in new nuclear power plants, and the economic impacts of constraints on CO_2 emissions, not to mention considerations of safety, waste disposal, proliferation, and spent-fuel reprocessing: all impact the feasibility of a nuclear power renaissance.

There are 436 nuclear power plants operating in 30 countries, with combined generating capacity of about 370,000 megawatts of electricity. These plants accounted for about 14 percent of global electricity generation in 2007. The contribution of nuclear power to meet electricity demand varies widely from country to country. For example, in France, 59 nuclear plants generate about 77 percent of the country's electricity; in Japan, 53 plants generate 27 percent of the electricity; and in the United States, 104 plants generate just under 20 percent of electricity. Together, these three countries account for about 57 percent of global nuclear power capacity. In China and India, nuclear power accounts, respectively, for 2 percent and 2.5 percent of the electricity generated there today.

The existing fleet of nuclear power plants is fairly old. About 92 percent of this nuclear capacity is more than 10 years old, and 78 percent is more than 20 years old. This age distribution reflects the fact that almost 30 years ago, developed countries effectively stopped making commitments to build new nuclear plants. (France and Japan are exceptions in this regard.) The most recent nuclear plant completed in the United States began generating electricity in 1996, though construction on it began in 1973. Sweden's most recent operating nuclear plant went into service in 1985, Germany's in 1989, Canada's in 1993, and the United Kingdom's in 1995. Following the 1979 incident at Three Mile Island, Sweden passed a law in 1980 banning the construction of new nuclear plants and requiring a gradual closing of existing nuclear plants. After the Chernobyl incident in 1986, two reactors were closed, in 1999 and 2005. Italy had four commercial nuclear power plants, but shut them down after a referendum in 1987. In 2000, Germany officially announced its intention to phase out nuclear power gradually over time, and two reactors were subsequently closed as part of this process. Other countries, including Spain and the United Kingdom, implemented de facto bans on building new nuclear plants. Most of the global nuclear capacity completed in the last decade is located in Japan, South Korea, China, and India.

The early history of the existing fleet of nuclear plants, especially in the United States, is not a happy one. Many nuclear plants experienced significant construction delays and cost overruns. Many plants planned during the 1970s were abandoned before construction started; some were abandoned after construction began but before completion. Nuclear plants are quite capital intensive. If they are to be economical to build, they must be able to supply electricity for a large fraction of the hours of the year (85 to 90 percent). However, the early operating experience of the existing fleet was poor. For example, in 1985, the capacity factor of nuclear power plants in the United States was only 58 percent.[4] Even today, after a long, steady trend in improvement, the *lifetime* capacity factor of U.S. nuclear plants is only about 78 percent. Capacity factors vary widely from country to country. The lifetime capacity factor is 91 percent in Finland, 86 percent in Switzerland, 73 percent in the United Kingdom, and 75 percent in Canada.[5] Because non-fuel operation and maintenance costs of a nuclear plant are largely fixed, the low capacity factors drove up the operating costs per unit of electricity produced from nuclear plants. Despite being more capital intensive, for many years even the operating costs per unit of electricity produced were higher for nuclear plants in the United States than for coal plants.[6]

Other factors also played a role in the abandonment, since 1980, of commitments to build new nuclear plants in many countries. The price of fossil fuels fell dramatically after its peak in the early 1980s and remained relatively low until 2003. Abundant supplies of cheap natural gas and improvements in thermal efficiency associated with gas combined-cycle generating technology (CCGT) made construction of new CCGT plants attractive alternatives in many countries. In countries with low-cost coal reserves, the relatively low price of coal made coal-fueled generating capacity more attractive than nuclear, despite tightening environmental requirements placed on coal plants.

A number of changes have taken place over the last few years that have led a growing number of countries and investors to view nuclear power more favorably than was the case a decade ago. First, the performance of nuclear plants has improved markedly in the last two decades. These improvements have probably been most dramatic in the United States, and we will focus on the U.S. experience here. Nuclear plant capacity factors in the United States have increased steadily over the last two decades, and the average now hovers around 90 percent. The time required to reload fuel fell from about 100 days in 1990 to about 40 days today. Average nuclear plant operating costs, adjusted for inflation, have declined slowly but continuously over the last two decades. The average operating cost per unit of electricity produced is now significantly lower for a typical U.S. nuclear plant than for a typical coal plant, much lower than for a conventional gas- or oil-fueled steam turbine, and lower than for a modern CCGT, with gas prices above about $4/MMBtu.[7] Safety metrics in the United States have also improved significantly in the last two decades, and organizations that review nuclear plant safety through a detailed peer review process (INPO, the Institute of Nuclear Power Operations, and WANO, the World Association of Nuclear Operators) have helped to identify and diffuse best safety practices to the industry.[8] While the global average capacity factor rose only slowly in the 1990s, to about 82 percent, Belgium, China, Finland, Korea, Mexico, the Netherlands, Romania, Slovenia, and Switzerland have achieved factors exceeding 85 percent, with Germany, Sweden, and Hungary at 84 percent.

A second important consideration was the dramatic increase in fossil fuel prices since 2003 and prior to the collapse in prices that has accompanied the ongoing global economic contraction. This increase made both existing nuclear plants and the construction of new nuclear plants appear much more economically attractive than was the case prior to 2003. The recent volatility in fossil fuel prices is a related consideration. While the prices for uranium have also been quite volatile during the last year, fuel costs are a much smaller fraction of the total costs for a nuclear plant than for a coal or gas plant. Consequently, the case for building and operating a nuclear plant is much less sensitive to variations in fuel prices than is the case for fossil-fueled generating plants.

A third important consideration relates to emerging climate change policies. The generation of electricity from nuclear plants does not produce CO_2, while coal- and gas-fueled plants do. Coal plants in particular produce about twice as much CO_2 per unit of electricity produced than a CCGT. In a climate change regulatory regime that places constraints on CO_2 emissions, nuclear power becomes more attractive economically compared to fossil-fueled alternatives. As a carbon free source of electricity, nuclear power is being looked at more favorably by some environmental groups than was the case a few years ago.

A fourth consideration that the nuclear industry has promoted with policy-makers is "energy security," a phrase used to justify many policy initiatives. Unfortunately, exactly what is meant by energy security is rarely articulated very clearly. It typically refers to concerns about dependence on imports of oil from "unstable" areas of the world and the potential effects of large sudden supply disruptions on the economies of oil importing countries. Developed countries, though, use very little oil to generate electricity. In the United States, about 1.2 percent of the electricity generated in 2007 was from petroleum products, and even then, primarily only in relation to the use of capacity to meet extreme peak demand, for which nuclear power plants are ill suited.[9] Whatever energy security concerns there may be among oil-importing countries, expanding nuclear generating capacity is not the path to a solution.

These energy security considerations extend as well to natural gas, especially in Europe, with its dependence on supplies of natural gas from or through Russia. These concerns have been heightened by Russia's cutoff of supplies to Ukraine, which adversely affected gas supplies available to other European countries. For most European countries, as well as for Japan, China, and India, additional nuclear capacity would displace the use of natural gas to generate electricity, thereby reducing natural gas imports. In this regard, we note that Finland's decision to build a third nuclear plant at Olkiluoto was influenced, at least in part, by the consideration of natural gas-fueled plants as the benchmark alternative. In contrast, natural gas supplies to U.S. consumers come almost entirely from domestic and (reliable) Canadian sources that sell into an integrated competitive North American market for gas and a fully integrated gas pipeline transportation system.

Finally, in the United States the process for obtaining licenses for building nuclear plants was changed, with the goal of making the process more efficient without sacrificing its effectiveness in assuring safety.[10] These reforms reflect a view that the process that governed the licensing of the current fleet of nuclear plants led to unnecessary delays, uncertainty, and excessive increases in construction costs.

Three of the changes to the process are noteworthy. First, the NRC now certifies specific reactor designs. Once approved, the reactor design can then be used at multiple sites without further design review. The NRC has certified four reactor designs and has four more under review. The NRC now also issues early site permits (ESP) for new reactors. By issuing an ESP, the NRC approves one or more sites for a nuclear power facility, independent of an application for a construction license. The NRC has issued three ESPs and one is pending. Finally, the NRC has consolidated what used to be two separate licensing processes – one to construct a plant and a second to operate it – into a single, combined construction and operating license (COL). By issuing a COL, the NRC authorizes the licensee to construct and (with specified conditions) operate a nuclear power plant at a specific site, in accordance with established laws and regulations. The new COL process is now being tested, as COL applications for 26 new nuclear units have been submitted to the NRC. However, to date none has yet completed the process, and so it is still uncertain whether the new process is able to reduce regulatory delays successfully.[11]

The changes in the NRC licensing process anticipated the relatively recent increase in interest in building new nuclear power plants in the United States. Accordingly, there was a new licensing process already in place to accommodate the sudden increase in applications for licenses. Countries that do not have such a nuclear plant safety regulatory infrastructure, or that have allowed their regulatory infrastructures to decay as a result of there being, for decades, no applications to build new plants, will have to build or rebuild these infrastructures before new plants can safely move forward.

These changes have implications for both the existing fleet of nuclear plants and for the incentives to build new ones. During the 1990s, nuclear plants in operation began to close, as they were no longer economical to operate on an incremental cost basis. Eleven plants were closed in the United States during this time, however none has closed since 1998.[12] Rather than closing, most of the existing nuclear plants in the United States are expected to seek and receive 20-year extensions on their initial 40-year licenses. As of April 2009, half of the U.S. fleet has received life-extensions from the NRC. Another 20 plants have applied for life-extensions, and 24 have indicated they will apply.[13] In conjunction with preparing for the life-extension review process, several plants have also invested in new equipment to produce modest increases in generating capacity ("uprating"). In all of these cases, the owners of these plants have justified (to their regulators and their boards) the costs associated with meeting operating and safety requirements to support a 20-year life-extension by demonstrating that the value of the additional electricity produced is greater than the costs incurred.

While policies toward life-extension of the existing fleet of nuclear plants will differ from country to country, we expect that economic and climate change considerations are likely to lead a large fraction of the existing fleet of nuclear plants to continue to operate well beyond the 30- to 40-year lives that were anticipated when they were originally constructed. In France, it is reported, the nuclear operator EDF is likely to continue to seek renewals for existing plants beyond the lives that were anticipated when they were built. Countries like Germany and Sweden, which had planned to phase out nuclear power completely, are now reevaluating those policies.

Of course, if nuclear power is limited to the continued operation of the existing fleet of plants, nuclear power's share of electricity generation will fall over time, as electricity demand continues to grow and maximum capacity factor limits are reached (as they have been in the United States and some other countries). Real growth in nuclear power, therefore, is necessarily dependent on the prospects for building new nuclear power plants.

There are 44 nuclear units under construction globally, with a combined capacity of about 38,000 megawatts, the equivalent of about 10 percent of the generating capacity of the existing global fleet of nuclear plants.[14] Of the 44 plants under construction, 11 are in China, 8 are in Russia, 6 are in India, and 5 are in South Korea. Taiwan, Japan, Ukraine, and Bulgaria each has two plants under construction; Finland, France, and Iran each has one, with a second approved for construction in France. Thus, at present, most construction activity is in developing countries, Russia, or Eastern Europe. As already noted, in the United States 26 applications for licenses for new plants have been filed with the NRC and more are anticipated, though none of these plants is close to commencing construction. The U.K. and Italian governments have indicated that they will adopt policies that will end de facto bans on building new nuclear plants, and interest in acquiring nuclear plants has been expressed by countries in North Africa and the Middle East that currently have no nuclear plants. The IAEA reports that 24 of the 30 countries with nuclear power plants are considering investments in new capacity, and 20 countries that do not now have nuclear power plants are actively considering developing plants in the future to help to meet their energy needs.

How do the costs of building and operating new nuclear power plants compare to alternative generating technologies, with and without a price on CO_2? How do the primary economic and CO_2-mitigation motivations for building new nuclear power plants weigh against other considerations – safety, energy security, access to nuclear technology to obtain weapons capabilities – that may play a role as well? In attempting to answer these questions, we rely heavily on the 2003 MIT study *The Future of Nuclear Power*, which analyzes the cost of generating electricity from nuclear, coal, and CCGT technologies, as well as other issues associated with commercial nuclear power.[15] The cost analysis has since been updated by Yangbo Du and John Parsons to reflect new construction cost and fuel cost information and to adjust for inflation, and we rely here on this update.[16] While the range of values for some of the input variables is likely to vary from country to country, we believe that these numbers provide a good picture of the relative costs of alternative base-load generating technologies.[17]

Because nuclear power plants are much more capital intensive than alternative base-load electric-generating technologies, their economic attractiveness depends heavily on the construction costs of the plants, the cost of capital (or hurdle rate) used by investors to value the cash flow generated by the plants over time, and the lifetime capacity factor of the plant, since this defines the amount of electricity produced per unit of generating capacity that will earn revenues to cover both the operating and the capital costs of a new nuclear plant. In addition, because nuclear plants do not produce CO_2 emissions, policies that place an explicit or shadow price on CO_2 emissions also affect their economic attractiveness compared to fossil-fueled alternatives.

There has been much confusion and debate about the costs of building new nuclear plants. This situation is largely a consequence of the lack of reliable contemporary data for the actual construction costs of real nuclear plants. Few nuclear plants have been built in the last two decades, and reliable cost information is not typically publicly available. Therefore, any estimate of future construction costs is necessarily uncertain. This is evident from the experience with Olkiluoto Unit 3 in Finland, where construction is running more than two years behind schedule and about 40 percent over initial cost estimates. Much more actual cost information is available for coal-fueled and CCGT plants because there is a significant amount of contemporary experience with building new plants in the United States and Europe. Accordingly, construction cost estimates for new coal and new gas plants are likely to be more reliable.

In addition, construction cost information is also quoted in a number of different ways, making meaningful comparisons both difficult and potentially confusing. Reactor vendors also initially quoted extremely optimistic construction cost numbers for the new generation of nuclear plants that were based on engineering cost estimates rather than real construction experience, and excluded some costs that investors must take into account. Construction cost estimates should include all costs that are relevant to the potential investor, including not only the costs incurred to build the plant itself, but also the costs of cooling facilities, land acquisition, insurance, fuel inventories, engineering, permitting, and training.

For cost comparisons to be meaningful they must be based on a common computational format. The standard cost metric used for evaluating the costs of electric-generating plant alternatives is the "overnight cost" of building the plant. This is the cost of building the plant as if it could be built "instantly," that is, using current prices and without the addition of finance charges related to the time required for construction. These costs, as well as differences in cash flow profiles during construction and plant life, are not ignored, but are handled separately in the evaluation of the cash flows required to pay back the total costs of alternative generating technologies once the overnight construction cost estimates are determined. The reason for working with overnight costs rather than just adding up the construction cost dollars expended is to be able to account for different construction periods, rates of inflation, and costs of capital that may be attributed to different technologies, and to express cost comparisons at the same general price levels.

The capacity factor assumed also has important implications for the unit cost that is derived. If the capacity factor is low, then the total cost per unit of electricity produced will be high, since the capital and fixed operating costs must be covered by fewer units of production, and vice versa. The capacity factor of U.S. nuclear power plants today is about 90 percent, and some analyses of nuclear power costs assume that new plants will immediately operate at 90 percent or higher capacity factors. However, while the capacity factors of the existing fleet of U.S. plants today is about 90 percent, their lifetime capacity factor is less than 80 percent. And it is the *lifetime* capacity factor that is relevant for evaluating the costs of an investment in a new plant, since they must recover their investment from the output produced by the plant over its economic lifetime. Globally, lifetime capacity factors were about 82 percent as of 2007, remaining roughly constant since 2000. Only Finland has a fleet of nuclear plants with lifetime capacity factors greater than 90 percent, and only four other countries have fleets with lifetime capacity factors greater than 85 percent. Two recently completed plants in South Korea reached 90 percent capacity factors quickly, but another two had not achieved lifetime capacity factors of 90 percent after six years of operation. Three of the four most recently completed plants in Japan have a lifetime capacity factor of less than 70 percent, and the fourth has a factor less than 80 percent. Low capacity factors in the early years of plant operation are especially burdensome to the economic attractiveness of investment in a nuclear plant since the revenue stream is present valued to evaluate the investment, and weights are larger on early years than on distant years. Overall, we consider the assumption that new plants will operate at 90

Table 1
Costs of Electric Generation Alternatives

	Overnight Cost $/kW	Fuel Cost $/MMBtu	Levelized Cost of Electricity, ¢/kWh
Nuclear	4,000	0.67	8.4
Coal (low)	2,300	1.60	5.2
Coal (moderate)	2,300	2.60	6.2
Coal (high)	2,300	3.60	7.2
Gas (low)	850	4.00	4.2
Gas (moderate)	850	7.00	6.5
Gas (high)	850	10.00	8.7

The low, moderate, and high fuel costs for coal correspond to a $40, $65, and $90/short ton delivered price of Central Appalachian coal (12,500 Btu), respectively. Costs are measured in 2007 dollars.

percent capacity factors almost as soon as they are completed to be very optimistic.

Table 1 displays our estimates of the costs of generating a kWh of electricity for base-load nuclear, coal, and CCGT generating technologies. These cost estimates are updates of the ones contained in the MIT study *The Future of Nuclear Power*, to reflect more recent information, real changes in construction costs, and general inflation. The table shows the capital cost for the three technologies, expressed as an overnight cost per unit of capacity. The overnight cost for construction of a new nuclear power plant is $4,000 per kilowatt of capacity, measured in 2007 dollars. The overnight cost for a coal plant is $2,300/kW, and $850/kW for a CCGT plant. The table also shows the fuel cost for each of the three technologies. The cost of uranium, together with all of the costs for enrichment and fabrication, yields a total fuel cost for nuclear power of $0.67/MMBtu. Because the prices of coal and natural gas are so volatile, and because these can represent a substantial fraction of the cost of producing electricity, we show the cost of electricity under three scenarios for the prices of coal and gas. The moderate coal-price scenario assumes a delivered price of coal of $65/ton, which translates to $2.60/MMBtu, assuming that this is a Central Appalachian coal with 12,500 Btu. The low coal-price scenario is $40/ton, or $1.60/MMBtu, and the high scenario is $90/ton, or $3.60/MMBtu. The moderate natural gas-price scenario is $7.00/MMBtu; the low scenario is $4.00/MMBtu; and the high scenario is $10.00/MMBtu.

The last column of Table 1 shows the calculated cost of electricity for each of the three technologies. This is the price that a generator would have to charge, escalated with inflation, in order to cover its fuel and other operating costs, and to earn a return on its capital equal to the opportunity cost of capital invested in the plant. The required return on capital will depend upon the many institutional arrangements of the electric power industry. Plants may be built either by public authorities or by private companies, and private companies may operate as public utilities under rate-of-return regulation, or may operate under the "merchant model" in which they construct plants at their own risk, earning profits from the sale of the power into competitive wholesale markets. The costs of electricity we show in Table 1 are based on the cost of capital required by private investors operating within this "merchant model." Because of the past poor record of construction of nuclear power plants, because of the enormous uncertainty surrounding the estimated cost of construction of a new nuclear power plant, and because of the uncertainty surrounding the success of the new combined construction and operating license process, *The Future of Nuclear Power* applied a slightly higher cost of capital to nuclear power than to coal- or gas-fired power; the cost update does so as well. A major task facing the U.S. nuclear industry, including the NRC, is proving that construction costs and the risk of delays and overruns have been reduced. Doing so would reduce the required cost of capital and bring down the cost of electricity from nuclear power. The costs shown in Table 1 do not incorporate the benefits of loan guarantees or production tax credits offered under the Energy Policy Act of 2005.

The updated cost of electricity from nuclear power is 8.4¢/kWh. This is higher than the 6.2¢/kWh for coal and the 6.5¢/kWh for gas under our moderate coal- and gas-price scenarios. Under our high coal- and gas-price scenarios, the cost of electricity from coal is 7.2¢/kWh, which remains below that from nuclear, while the cost of electricity from natural gas is 8.7¢/kWh, which is above that from nuclear. The capital cost represents nearly 80 percent of the cost of electricity produced by nuclear power, but only 15 percent of the cost of electricity produced by gas, with coal being an intermediate case. Fuel cost represents approximately 80 percent of the cost of electricity produced by gas, but only 10 percent of the cost of electricity produced by nuclear, with coal again being an intermediate case.

Table 2 displays the same updated numbers but adds a charge for CO_2 emissions. Two levels are considered: \$25/metric ton of CO_2 and \$50/metric ton of CO_2. It is unlikely that large-scale carbon capture and sequestration (CCS) investments would be economical at these levels, so investment in coal with CCS is not an economical substitute at these CO_2 price levels. Even at the lower charge of \$25/metric ton of CO_2, the cost of power from coal in our moderate coal-price scenario is up to 8.3¢/kWh so that nuclear would be competitive with coal. At the higher charge of \$50/metric ton of CO_2, nuclear power is cheaper than coal even at the low coal-price scenario. At the lower charge of \$25/metric ton of CO_2, the cost of power from gas is still less than the cost from nuclear in both the low and the moderate gas-price scenarios. At the higher charge of \$50/metric ton of CO_2, nuclear power is cheaper than gas in both the moderate and high gas-price scenarios, although not in the low gas-price scenario.

These numbers illustrate the tradeoffs facing an investor making a choice on which type of capacity to install. For nuclear power, the main source of uncertainty is at the point of construction. For coal-fired power, the price of coal matters; but the choice society makes about the penalty for carbon emissions is the central driver and risk. For gas-fired power, both the price of natural gas and the charge for carbon are major risks.

Of course, the future of nuclear power will depend on more than conventional

Table 2
Costs of Electric Generation Alternatives, Inclusive of Carbon Charge

			Levelized Cost of Electricity, ¢/kWh	
	Overnight Cost $/kW	Fuel Cost $/MMBtu	with carbon charge $25/t$CO_2$	with carbon charge $50/t$CO_2$
Nuclear	4,000	0.67	8.4	8.4
Coal (low)	2,300	1.60	7.3	9.4
Coal (moderate)	2,300	2.60	8.3	10.4
Coal (high)	2,300	3.60	9.3	11.4
Gas (low)	850	4.00	5.1	6.0
Gas (moderate)	850	7.00	7.4	8.3
Gas (high)	850	10.00	9.6	10.5

The low, moderate, and high fuel costs for coal correspond to a $40, $65, and $90/short ton delivered price of Central Appalachian coal (12,500 Btu), respectively. Costs are measured in 2007 dollars.

economic considerations. In this section, we briefly discuss the most important of those other considerations, though we do not think that the passage of time since its publication in 2003 has changed the conclusions regarding these considerations that can be found in *The Future of Nuclear Power*.

It is imperative that all nuclear facilities – reactors as well as enrichment, fuel storage, and reprocessing facilities – be operated with high levels of safety. While many of the safety metrics for existing reactors have improved significantly in recent years, *The Future of Nuclear Power* argues that the probability of a serious accident remains too high to support a large expansion in the fleet of nuclear plants. We subscribe to that study's recommendations for improving safety in both the short run and the long run. Unless nuclear reactors and the nuclear fuel cycle are perceived virtually to guarantee that there will not be a major accidental release of radioactive materials that would have significant adverse effects on human health and welfare, public support for nuclear power will erode quickly, as it did after the incidents at Three Mile Island and Chernobyl. Moreover, it is important that high safety standards be established and enforced internationally, as an accident in one country can have both direct adverse health and welfare effects on neighboring countries and indirect adverse effects on public acceptance of nuclear power in all countries.

A continuing challenge is the deployment of long-term storage or disposal facilities for the high-level radioactive waste produced by nuclear power plants and fuel-cycle facilities. No long-term spent-fuel storage or disposal facilities are yet in operation. The programs in Finland, Sweden, France, and the United States are the most advanced, though funding for the waste disposal facility planned for Yucca Mountain in Nevada was recently canceled. From a safety perspective, it is not necessary to solve the long-term problem now. Waste fuel can be stored in dry casks in secure facilities for 50 years or more and await further technological, economic, and political developments. However, the absence of a long-term strategy for waste does create potential political problems, and some countries may not proceed with nuclear power until this challenge is resolved.

The expansion of nuclear power must be accompanied by safeguards to assure that it does not lead to the proliferation of traditional nuclear weapons or increase access to highly radioactive materials that could be used in so-called dirty bombs, which use conventional explosives to diffuse these materials widely in an urban area, with potential adverse effects on human health as well as causing costly disruptions in normal commercial and other human activity. The pathways to weapons proliferation arising from the expansion of nuclear power are access to enrichment and reprocessing technology, and ready access to or theft of stocks of reprocessed plutonium or highly enriched uranium. The risks related to diversion of plutonium are potentially higher if reprocessing and recycling of spent fuel is widely adopted. Reactor and fuel-cycle security protocols that can reduce unauthorized access to materials that could be used to create dirty bombs, and the detection of such devices, need more attention at an international level.

The Future of Nuclear Power makes several useful recommendations regarding weapons proliferation. (It does not make policy recommendations related to dirty bombs.) They include (a) strengthening the IAEA's safeguard functions and expanding its authority to inspect suspected illicit facilities; (b) giving greater attention to proliferation risks from enrichment technologies; (c) moving IAEA safeguards to a model built around continuous material protection, control, and accounting, both in facilities and in the transportation of nuclear materials; (d) focusing fuel-cycle research and development on minimizing proliferation risks; and (e) moving forward quickly with agreements to create secure international spent-fuel storage facilities. These continue to be wise recommendations. In addition, efforts to dissuade countries from acquiring enrichment, fuel fabrication, and reprocessing facilities, by creating and providing credible long-term commercial access to international stockpiles of low-enriched uranium nuclear fuel, are also worthy of continuing support.

Our analysis so far has focused on the economic attributes of continued operation and investment in the currently available generation of existing and new light water reactors using an open fuel cycle with low-enriched uranium fuel. We have focused on this reactor/fuel-cycle combination because it continues to appear to represent the lowest cost option for existing and new nuclear power plants at present. Today, the primary alternative to an open fuel cycle using low-enriched uranium is a closed fuel cycle that reprocesses spent fuel by chemically separating the plutonium and depleted uranium from the fission products and minor transuranic elements in the spent fuel (the PUREX – Plutonium-Uranium Extraction – process) and then fabricating a Mixed Oxide (MOX) fuel composed of both plutonium and uranium for "recycling" as reactor fuel in light water reactors. Although the United States originally developed the PUREX process to recover plutonium for use in nuclear weapons, U.S. policy for over three decades has banned exports of reprocessing technology and the use of recycled plutonium in civilian reactors. However, the United States has continued research and development on reprocessing technology, and there continues to be some political and commercial support for lifting the ban on reprocessing and the use of recycled plutonium in reactor fuel used in U.S. reactors. France, Japan, the United Kingdom, Russia, India, and China have and use reprocessing technology, or use MOX fuel produced in other countries.

Most studies conclude that reprocessing spent fuel and fabricating MOX fuel is more costly than using fresh low-enriched uranium.[18] At best, the costs of the open and closed fuel cycles are close to a wash today and over the next few decades. The economic calculus could change if uranium prices were to increase significantly and/or the costs of reprocessing and fuel fabrication were to fall significantly. As we have already indicated, fuel costs are a relatively small fraction of the total costs of new nuclear power plants. Accordingly, the basic economics of nuclear power vis-à-vis alternative fossil-fuel technologies are unlikely to turn on a decision to reprocess and recycle spent reactor fuel or not. Rather, the decision to reprocess and recycle is more likely to be driven by other concerns. Recycling via MOX has no obvious waste disposal benefits, and there is significant concern about the danger of the potential diversion of separated plutonium to make nuclear weapons.

In those countries that have been able to improve the performance of their existing fleet of nuclear plants it will typically be economical to extend their operating lives well beyond 40 years given reasonable forecasts of fossil fuel prices. Imposing explicit or implicit prices on CO_2 emissions makes the economics of life extensions even more compelling. The primary barriers to life-extension of the existing fleet of light water reactors are managerial capabilities to operate the plants safely and at high capacity factors, political pressures to close nuclear plants quickly for reasons other than economics, and regulatory constraints that increase the costs of meeting life-extension criteria.

Of course, merely extending the lives of existing nuclear plants will not constitute a nuclear "renaissance." In this case, nuclear's contribution to the electricity supply will simply shrink over a longer period of time. To stimulate a true nuclear renaissance that leads to significant investments in new nuclear plants, several changes from the status quo will need to take place: (a) a significant price must be placed on CO_2 emissions, (b) construction and financing costs for nuclear plants must be reduced or at least stabilized, and the credibility of current cost estimates verified with actual construction experience, (c) the licensing and safety regulatory frameworks must demonstrate that they are both effective and efficient, (d) fossil fuel prices need to stabilize at levels in the moderate to high ranges used in Tables 1 and 2, and (e) progress must be made on safety and long-term waste disposal to gain sufficient public acceptance to reduce political barriers to new plant investments.

Absent the imposition of explicit or implicit prices on CO_2 emissions, and given the current expected costs of building and operating alternative generating technologies, it does not appear that a large nuclear renaissance will occur based primarily on the economic competitiveness of new nuclear power plants compared to alternative fossil-fueled base-load generating technologies. It does not appear that new nuclear power plants would be a competitive base-load generating alternative to conventional supercritical coal-fueled technology, even with high coal prices. New nuclear plants are competitive with natural gas-fueled CCGT technology only at very high gas prices. The imposition of significant prices on CO_2 emissions makes nuclear competitive with coal-fueled generating technology under all fuel price scenarios, and with gas-fueled CCGT technology when gas prices are at moderate or high levels. A high CO_2 price makes CCGT technology very competitive with coal-fueled generating technology at all fossil-fuel price levels. Thus, with significant CO_2 prices, economic considerations would lead to a shift to gas from coal for new fossil plants, increasing the demand for and price of natural gas to the moderate to high levels. This suggests that with significant CO_2 prices, economic considerations alone would lead to a mix of new nuclear and new CCGT plants with gas prices at moderate to high levels. The higher is the equilibrium gas-price trajectory, the larger would be the share of new nuclear plants.

The economic attractiveness of nuclear power could also be improved if the costs of building and financing nuclear plants could be reduced from the levels indicated by the available information on construction and financing costs that we have relied upon here. It is possible that as new nuclear plants are built around the world, their construction costs will decline significantly as construction experience accumulates. This possibility is one of the rationales for the financial incentives contained in the Energy Policy Act of 2005. Construction costs would have to decline on the order of 20 percent to make nuclear competitive with coal, in the absence of significant CO_2 charges. Financing costs could also be reduced below those assumed here for plants built under supportive cost-of-service regulatory regimes (as in Florida) or as a result of government policies, such as the government loan guarantees provided for in the Energy Policy Act of 2005.

Another consideration is uncertainty about construction costs and capacity factors. We have reasonably good information about the actual costs of building and operating new coal and CCGT plants since many have been built and placed into operation around the world in the last decade. The quality of the construction cost information for new nuclear plants is not nearly as good since there are so few recently constructed plants for which credible construction cost data are available. Du and Parsons' estimates rely on a mix of actual construction cost data and estimates of construction costs found in recent regulatory filings. In addition, the human and manufacturing infrastructure required to produce major nuclear plant components, perform detailed engineering, and construct new nuclear plants has deteriorated significantly in the past decades. This means that a surge in nuclear plant orders will run up against capacity constraints on the supply of key components and labor, leading to higher component manufacturing costs and higher construction costs, until these infrastructures can be rebuilt to support renewed investment in new nuclear generating capacity. The early-life capacity factors of new nuclear plants also vary fairly widely, and the *expected* capacity factor for a new plant during a "break-in" period may be significantly less than the more than 90 percent assumed in more optimistic assessments.

There are other, more difficult-to-quantify barriers to a large deployment of new nuclear power plants. The new licensing system in the United States is untested, and licensing systems in many countries with nuclear plants have not yet been reconfigured to accommodate applications for new plants. Countries without nuclear power must develop and implement regulatory frameworks to license new plants and to ensure that they operate safely. The challenges of developing an effective licensing and safety regulatory framework from scratch have not been fully recognized by those countries considering nuclear power plants for the first time. The Energy Policy Act of 2005 provides financial incentives (in the form of insurance against the costs of regulatory delays) for the first few plants to go through the new U.S. regulatory system, in recognition of the costs that may be imposed on the first few license applicants as the new regulatory framework is fully road tested. We are not aware of similar policies in other countries.

Finally, political constraints driven by concerns about safety, long-term waste disposal, and proliferation may further deter some countries from launching major new nuclear power programs. Another significant accident at an existing nuclear plant anywhere in the world could have very negative consequences for any hope of a nuclear renaissance.

All things considered, the best economic case supporting a significant expansion in nuclear power capacity involves significant CO_2 emissions charges, moderate to high fossil fuel prices (including implicit prices reflecting energy security considerations), declining nuclear plant construction costs, and an efficient licensing regulatory framework.

ENDNOTES

1 The views expressed here are those of the authors and not of the Alfred P. Sloan Foundation or the Massachusetts Institute of Technology.

2 *International Status and Prospects of Nuclear Power* (Vienna, Austria: International Atomic Energy Agency, 2008). Unless otherwise referenced, the information in this paper about the status of nuclear power in various countries is from this report or from the IAEA's online PRIS data sets, www.iaea.or.at/programmes/a2/.

3 U.S. Nuclear Regulatory Commission, www.nrc.gov/reactors/new-reactors/col.html.

4 U.S. Energy Information Administration, *Annual Energy Review* 2007, Table 9.1.

5 We rely on data for both capacity factors and energy availability factors depending on the data available for different countries. A nuclear plant's capacity factor is the ratio of the actual electricity generated divided by the maximum quantity of electricity that could be produced if the plant ran at its capacity for every hour of the year. A plant's energy availability factor is the amount of electricity that a plant is "available" to produce (that is, it is not out of operation due to maintenance or refueling outages) divided by the amount of electricity a plant could produce if it operated at full capacity to produce electricity every hour of the year. Because nuclear plants have low marginal production costs, they are typically producing electricity whenever they are available. Accordingly, the capacity factor and the energy availability factor for a plant are generally very close to one another. We use the term "capacity factor" to refer to data for both capacity factors and energy availability factors.

6 Nuclear Energy Institute, www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/graphicsandcharts/uselectricityproductioncosts/.

7 During 2008, spot natural gas prices at Henry Hub, a major gas trading hub, fluctuated between about $4/MMBtu and about $14/MMBtu.

8 *Annual Energy Review* 2007, Table 9.1; Nuclear Energy Institute, www.nei.org/keyissues/safetyandsecurity/.

9 *Annual Energy Review* 2007, Table 2.1F.

10 U.S. Nuclear Regulatory Commission, http://www.nrc.gov/reactors/new-reactors/col.html.

11 U.S. Nuclear Regulatory Commission, www.nrc.gov/reactors/new-reactors/design-cert.html; www.nrc.gov/reactors/new-reactors/col.html; and www.nrc.gov/reactors/new-reactors/esp.html.

12 *Annual Energy Review* 2007, Table 9.1.

13 Nuclear Energy Institute, http://www.nei.org/resourcesandstats/nuclear_statistics/licenserenewal/.

14 One of these plants is TVA's Watts Bar-2 plant. Construction of the plant began in 1972, was subsequently suspended, and was recently restarted after TVA's apparently successful repowering of Browns Ferry-1.

15 *The Future of Nuclear Power: An Interdisciplinary Study* (MIT, 2003). A short update was recently published, *Update of the MIT 2003 Future of Nuclear Power Study* (MIT, 2009).

16 Yangbo Du and John E. Parsons, "Update on the Cost of Nuclear Power," Working Paper 09-004 (MIT Center for Energy and Environmental Policy Research, 2009).

17 Electricity demand varies widely from hour to hour, day to day, and season to season. The difference between the peak and the trough can be a factor of three. Since large volumes of electricity cannot be economically stored, sufficient generating capacity must be built to meet peak demands reliably. Matching supply and demand economically requires a generation portfolio consisting of base load, cycling, and peaking capacity. Base load capacity is designed to operate during the entire year to meet at least the minimum level of demand sustained for a large fraction of the hours of the year. Cycling capacity is designed to meet the incremental demand that is sustained for a smaller fraction of the hours of the year: the additional demand during the day compared to the demand at night. Peaking capacity is designed to operate for a small number of hours each year when demand is at its peak (for example, on the hottest days in the summer). Wind generators, which are even more capital intensive than nuclear plants, do not fall neatly into either of these traditional categories since the quantity of electricity they produce depends on the speed of the wind rather than on the level of demand or the spot price of electricity.

18 *The Future of Nuclear Power*; Matthew Bunn, Steven Fetter, John P. Holdren, and Bob van der Zwaan, "The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel," Report DE-FG26-99FT4028 (Harvard Kennedy School, Project on Managing the Atom, 2003); Steven Fetter and Frank N. von Hippel, "Is U.S. Reprocessing Worth the Risk?" *Arms Control Today* (September 2005); Guillaume De Roo and John E. Parsons, "Nuclear Fuel Recycling, the Value of the Separated Transuranics and the Levelized Cost of Electricity," Working Paper 09-008 (MIT Center for Energy and Environmental Policy Research, 2009).

Harold A. Feiveson

A skeptic's view of nuclear energy

This paper, while skeptical of the robust nuclear renaissance many in the nuclear industry now predict, is not anti-nuclear. Indeed, nuclear power has many attractions. It is a mature and well-established technology, unlike, for example, carbon capture and storage. Improvements in its operation and reliability in recent years have been striking. It produces little carbon dioxide and can clearly, in principle, play a significant role in combating global warming. Compared to coal-generated electricity in particular, it is relatively clean, producing almost no emissions. Its energy output is not intermittent, as is the case with wind and solar. And though the overall costs of nuclear are rising, they are arguably competitive with other low-greenhouse-gas electric-generation alternatives.[1]

However, despite these many attractions, nuclear power seems to go forward only where governments heavily subsidize its operation, such as in China and India today. As Henry Sokolski has pointed out, "No private bank has yet chosen to fully finance a new nuclear reactor build; no private insurer has yet chosen to insure a nuclear plant against third party off-site damages."[2] In the United States, almost all of the several nuclear plants that are now being considered for future deployment are in states with regulated utilities, where nuclear does not have to compete directly with other generation sources and where rate payers in the state assume much of any risk. Nuclear power growth is stagnant or negative in most of the industrialized countries, and there is still today, outside of China and India, almost no nuclear power in the developing countries. In 2007, world nuclear electricity generation dropped by 2 percent; in 2008, for the first time in nuclear power's history, no new reactor was connected to the grid anywhere. This should all give one pause in dreaming of a nuclear renaissance.

Several factors are pulling back on efforts to expand nuclear power: the very high capital costs inherent in nuclear power, especially given the large size of reactors driven by economies of scale; a continuing strong aversion to nuclear power by skeptical publics concerned with safety, with unresolved questions on how to handle radioactive wastes, and with the risks of nuclear proliferation, despite some recent improvements in favorability ratings; and the rise of renewable energy and other competitors for low-carbon electric generation.

The most striking aspect of nuclear power projections is the tremendous uncertainty about how rapidly or not nuclear capacity will grow worldwide over the next four decades. For example, the *Nuclear Energy Outlook 2008* by the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD) shows low and high scenarios as follows: the high scenario grows to about 600 GW by 2030 and then rapidly grows to almost 1,500 GW by 2050; the low scenario shows no growth to 2030 and then modest growth to 600 GW by 2050. The regional uncertainties are even more marked. For example, for OECD countries in North America, the range of change from 2004 to 2050 is 20 to 275 GW; for OECD countries in Europe, it is -10 to 200 GW; and even for China the range is considerable: roughly 60 to 120 GW.[3] As noted below, the Nuclear Energy Agency's projections for China, even to 2030, may understate the real range of uncertainty.

The high scenario assumes that carbon capture and storage proves not to be very successful; that energy from renewable sources is at the lower end of expectations; that there is early good experience with construction of new nuclear power plants; that carbon trading schemes are widely introduced; and that there is an increased level of public and political acceptance of nuclear power. The low scenario assumes mostly the opposite.[4]

On these points, the trends are mixed. Though there are some beginnings, there are still few substantial efforts underway to demonstrate carbon capture and storage. And while so far there has been no adoption of carbon trading systems outside of Europe, there is a growing expectation that some kind of cap-and-trade or carbon taxing system will eventually be imposed in the United States and elsewhere. On the other hand, renewables are expanding rapidly everywhere; the experience with new nuclear construction has not been good; and public acceptance of growth in nuclear power still appears low. In addition, the price tag for nuclear reactors is high and getting more marked.

The *World Energy Outlook 2008* reference scenario shows global nuclear capacity growing from 368 GW in 2006 to 433 GW in 2030, with a preponderance of this growth in India and China. Russia also had ambitious plans for expansion, but recently announced a sharp adjustment downward.[5] Growth in the United States, OECD countries in Europe, and in the developing countries is projected to be flat at best.

In the United States, despite many recent government incentives and reforms to speed up the regulatory process, there have been no firm orders for new nuclear plants. However, several utilities have filed combined construction and operating license applications with the Nuclear Regulatory Commission (NRC), which is now reviewing the applications; and four of the utilities have signed Engineering, Procurement, and Construction (EPC) contracts in anticipation of NRC approval. Most of the license applications have come from utilities in regulated markets, where risks are borne by rate and tax payers, though at least two have been submitted by merchant utilities.[6] The lesser interest in nuclear in unregulated markets, where the risks are borne by competing market players, is not hard to understand. In a competitive market, the construction of a new nuclear power plant could represent a tremendous risk, as noted, for example, in the May 2008 report from Moody Investors Service.[7]

Nuclear capacity in the European-OECD countries has been on a plateau for a decade, although construction recently began on two reactor projects, the Olkiluoto-3 plant in Finland and the Flamanville-3 reactor in France, both featuring the AREVA Evolutionary Power Reactor. The Olkiluoto-3 project started in 2005 and is now, by all accounts, three years behind schedule and already more than $2 billion over budget.[8] Construction of the Flamanville-3 reactor started in December 2007, and it is too early to see if it will improve on the Olkiluoto performance.

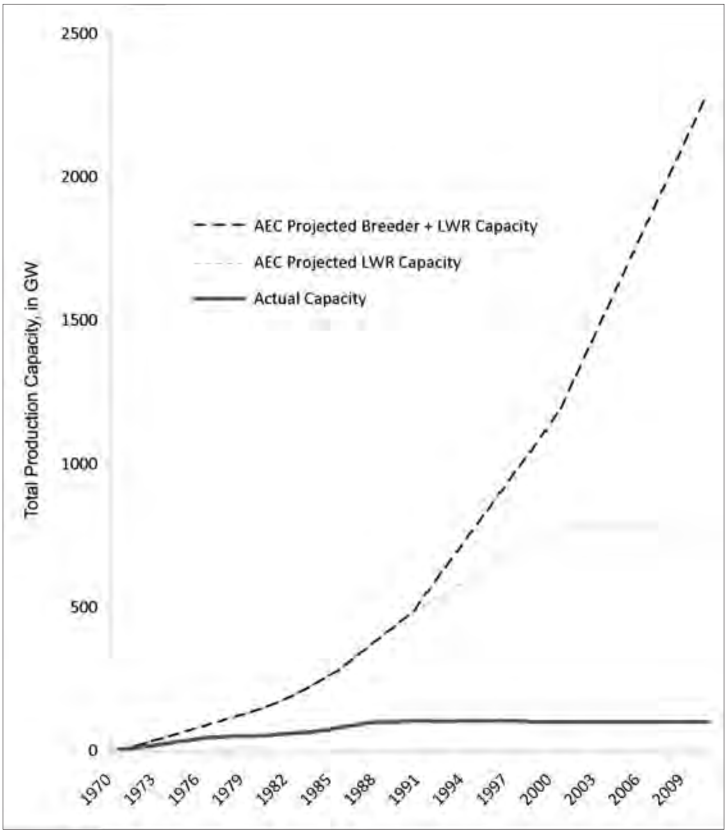
José Goldemberg's essay in this issue points to the several factors that militate against nuclear power in developing countries. For one, nuclear power plants, unlike dams and other infrastructure, are not underwritten by the World Bank or most other international lending organizations. The large investments required for nuclear power therefore compete with the pressing needs for health, education, and poverty reduction. Nuclear energy is also not included in the Kyoto Protocol mechanisms under which the industrialized (Annex 1) states can obtain credits against their own greenhouse gas emissions by investing in reducing emissions from developing countries.[9] Second, with economies of nuclear scale continuing to push reactors to 1 GW size or larger, the grids in many developing countries simply cannot accommodate the reactors. And third, while the largest and more advanced of the developing countries do have economies and grids that could accommodate nuclear power, several, perhaps most, of these countries, Goldemberg emphasizes, have more attractive alternatives, including still largely untapped resources of hydropower and natural gas.

The striking exceptions to the tepid projected growth of nuclear power and the great range of uncertainty are the remarkable projections for India and especially China. In its reference scenario, the *World Energy Outlook 2008* projects that by 2030 China will install an additional 30 GW of nuclear – substantial to be sure, but not unprecedented compared to past nuclear growth in other countries. Some recent statements by Chinese authorities, however, indicate much greater growth. In May 2007, China's National Development and Reform Commission announced that its target nuclear generation capacity for 2030 is 120 to 160 GW! In June 2008, the China Electrical Council projected 60 GW of nuclear capacity by 2020![10] I do not know how realistic these recent projections are; but it is important to note also that the reference scenario of the *World Energy Outlook 2008*, while projecting an additional 30 GW nuclear capacity in China by 2030, also projects an additional 800 GW of coal capacity for the same period, which I will say more about later.

In some respects, the grand Chinese projections mirror those made in the United States in the 1970s (see Figure 1). There are differences to be sure: the U.S. projections were based on very high rates of growth of electricity – roughly twice the rate of GDP growth – while the Chinese electric growth rates assumed are closer to the GDP rates. Nevertheless, the 1970s projections by the United States do represent a cautionary tale of over exuberance, and it may be worthwhile to keep them in mind when evaluating China's plans.

The fairly tepid projections for nuclear power outside of Asia are due to several

Figure 1
The U.S. Atomic Energy Commission Projection of the Growth of Nuclear Power in the United States, 1974



LWR stands for light water reactor, and Breeder refers to liquid metal fast [neutron] breeder reactor (LMFBR). Source: U.S. Atomic Energy Commission, *Proposed Environmental Impact Statement on the Liquid Metal Fast Breeder Reactor* (WASH-1535), 1974.

factors, but two are particularly significant: the extraordinarily high capital investment required, and the continued public wariness about nuclear power, driven by an amalgam of concerns over safety, radioactive waste disposal, and nuclear proliferation.

The recent literature shows a range of costs both for nuclear and its competitors. For nuclear, overnight capital costs projected for new plants range roughly from $3,000 to $5,000/kW, with costs in the United States somewhat on the higher side.[11] When total bus-bar costs are considered, nuclear appears at least arguably competitive with integrated gasification combined cycle coal (IGCC) and combined cycle gas turbine (CCGT) plants, if there is a carbon charge roughly in the range of $30 to $50 per ton of CO_2 emitted. Nuclear also appears reasonably competitive with wind in many regions where the wind is supplemented by compressed air storage to make the wind resource more resemblant of base load.[12]

For the United States, the Energy Information Administration estimates the overnight cost of an advanced nuclear plant to be $3,300/kW,[13] which would imply a capital cost, including interest paid during construction, of something like $4,200/kW. This, however, could be on the low side for plants constructed in the United States, at least as noted below.

Overnight costs for all forms of electric generation have grown over the past few years; but the rise in costs is especially significant for nuclear both because of the large sizes of new nuclear reactors and because the construction period for nuclear is markedly longer than for its principal competitors, thus adding to the total capital cost. Although there have been some paper studies of smaller reactors in the range of 50 to 100 MW, there are few plans to build and widely deploy such reactors. Also, while China and India are deploying small reactors, on the order of 300 GW, and some of these could, in principle, be exported to other countries, the market niches for such reactors appear limited. Studies of high-temperature gas-cooled reactors also contemplate a 100 to 300 MW scale; but none of these reactors is ready to go through the licensing process. Therefore, the new proposed reactors are, for the most part, 1 GW or considerably larger. Also, the principal reactors that are ready to deploy are all light water reactors.[14]

Thus, for example, in a March 2008 filing by Progress Energy with the Florida Public Service Commission, the company estimated the overnight costs for two proposed Westinghouse AP-1000 Reactors (about 1,100 MW each) to be more than $5,000/kW for the first and $3,300/kW for the second. Including project escalation, escalated costs before AFUDC (Allowance for Funds Used During Construction), and AFUDC, the totals came to $8.3 billion and $5.8 billion, respectively, for the two reactors[15] – a tremendous risk for any company or utility. In light of this risk, the credit rating company Standard & Poor's points out that "no utility will commit to a project as large and risky as a new nuclear plant without assurance of cost recovery."[16] *The World Energy Outlook 2008* makes a similar point:

> In the traditional, vertically integrated public service model, the supply company was often a monopoly and could count on recovering the investment and the target return. . . . In the competitive situation now existing in most OECD countries and several non-OECD countries, risks have, to some extent, moved from rate and tax payers to competing market players. This perception of increased risk drives up the investor's required rate of return.[17]

The risks evident in new nuclear construction are compounded by the prospect that the already longer construction period needed for nuclear compared to its competitors could be extended further still, both by public interventions and also by another problem associated with nuclear, if not unique to it: an erosion of construction and operating competence and lack of manufacturing infrastructure due to the almost complete absence of new builds in the United States and Europe over the past many years. If there were a real renaissance, these deficiencies would right themselves over time, with students again going into nuclear engineering, workers again being trained, and so on; but the current lack is certainly one reason for caution in assuming that such a renaissance will happen in the first place.[18]

Simply to replace retired nuclear capacity will require building a large number of new nuclear plants in the coming decades – a challenge given the continuing public skepticism about nuclear power. An opinion poll of 18 countries in 2005, sponsored by the International Atomic Energy Agency (IAEA), found that less than one-third of the public supported building new reactors. Even when prompted specifically about the possible use of nuclear energy to combat climate change, only 38 percent expressed support for an expanded reliance on nuclear power. It should also be noted, however, that more than two-thirds of those polled opposed shutting down nuclear altogether.[19] Also, in some countries, including the United States, the United Kingdom, and Sweden, public acceptance of nuclear appears to be rising, though there are still sizable minorities strongly opposed.[20]

Public skepticism has been driven largely by worries about safety and radioactive waste disposal. Modern nuclear reactors have impressive safety features, and the new designs incorporate still further refinements. Nevertheless, the potential of a catastrophic event (either an accident or some kind of terrorist incident) is always present, and lingering concerns over safety certainly color public views of nuclear power. Aside from the immediate devastation that would be caused by a severe event, it is also widely recognized that were such an event to occur, the entire nuclear enterprise worldwide would be called into question.

Even if the chance of a severe accident were, say, one in a million per reactor year, a future nuclear capacity of 1,000 reactors worldwide would be faced with a 1 percent chance of such an accident each 10-year period – low perhaps, but not negligible considering the consequences.[21] And it is worth emphasizing that while accident probabilities can perhaps be estimated, there is no real or persuasive way to gauge the risk of terrorist attacks on reactors. Until reactors are inherently safe – that is, until there is no credible way in which large amounts of radioactivity could ever be released – the specter of a catastrophic event will hang over the nuclear enterprise.

It is clear also that the unsettled state of radioactive waste disposal remains a component in public worry about nuclear power. Technically, waste disposal might not be an unsolvable problem. In the short term, dry cask storage appears relatively inexpensive and safe; in the long term, geological storage in a repository appears doable and safe. However, politically, solutions are not so easily come by. In the United States, this has been recently highlighted by the apparent demise of the Yucca Mountain repository.[22] While Finland and Sweden (at the moment at least) appear to have found a political path to siting a repository, there has been little progress elsewhere in locating and developing repositories.

One final shadow over a nuclear renaissance is the growing international concern about nuclear proliferation. It is well understood that one of the factors leading several countries now without nuclear power programs to express interest in nuclear power is the foundation that such programs could give them to develop weapons. In this sense, the connection between nuclear power and nuclear weapons could lead to some expansion of nuclear power. But this motive would likely lead, at most, to very modest programs. The nuclear proliferation risk is instead more likely to inhibit nuclear expansion. For one, proliferation worries will surely restrict the amount of encouragement and subsidies that the large industrialized countries will be willing to extend to countries to develop nuclear power.

Certainly if a nuclear renaissance means spreading nuclear power to a score or more of new countries as well as expanding existing programs, then the current governance of the nuclear fuel cycle internationally would have to be much altered, with limits, for example, on national enrichment and reprocessing plants, were there a serious attempt to make nuclear expansion proliferation resistant. Such changes are possible but so far have garnered little support from countries that do not already have national fuel-cycle facilities in operation.

The strongest impulse to a nuclear renaissance is the view that nuclear represents the most developed and economic low-carbon electricity alternative.[23] Other articles in this issue examine nuclear economics in more detail, but let it be granted that nuclear power will be roughly competitive with IGCC coal and CCGT gas if a carbon charge of something like \$30 to \$50 per ton CO_2-equivalent is imposed. Though perhaps more controversial, let it also be granted that wind, combined with compressed air energy storage, will also be roughly competitive with nuclear. Leaving out other possibilities, such as solar and geothermal, among renewables, and end-use efficiency advances, the principal low-carbon alternatives to nuclear are likely to be carbon capture and storage at coal plants; natural gas combined cycle plants (even without carbon capture and storage); wind, both with accompanying storage and as a standalone intermittent source of electricity; and efficiencies in electricity generation.[24] If we then ask which of these alternatives can give the world the biggest greenhouse-gas abatement for the buck, it is not at all clear that nuclear will look as indispensable to climate change policy as its proponents insist. Considering the limited amount of capital available for investment in electric generation overall, investment in nuclear plants could hurt the growth of potentially more effective alternatives.

The *World Energy Outlook* 2008 reports that carbon capture and storage (CCS) is "a promising technology for carbon abatement, even though it has not yet been applied to large-scale power generation." A few CCS projects are under way and several full-scale CCS projects have been announced, varying in scale from industrial prototypes to projects on a 1,200 MW scale, with target dates for deployment between 2010 and 2017.[25] Scientists appear reasonably confident that these projects will confirm that CCS could be competitive with other major carbon mitigation strategies, and that the geological CO_2 storage capacity worldwide would be vast – sufficient to handle CO_2 emissions from fossil-fuel plants for a century or longer.[26] The U.S. Energy Information Agency, for example, estimates that, for an integrated coal-gasification combined cycle plant (IGCC) with CCS, the overnight cost is just over \$3,000/kW, about the same as an advanced nuclear plant, assuming both come on line by 2016 and that the IGCC plant has a construction time two years shorter than the nuclear plant.[27] It is too soon to rely confidently on CCS, but if it does develop as projected, it will be a close competitor to nuclear, probably with similar life-cycle costs and carbon abatement potential.

CCGT natural gas plants, of course, are not carbon free. However, even without carbon capture and storage, if they are replacing coal plants, they will save carbon emissions. A nuclear plant replacing a modern coal plant of 1,000 MW capacity would save about 1.5 million tons of carbon per year; a gas plant replacing the same coal plant would save about half of this, or 0.75 million tons of carbon per year.[28] So the nuclear plant would double the savings. However, a modern gas plant has a capital cost about one-fourth that of a nuclear plant,[29] meaning that for the same capital cost, natural gas could save more than two times the carbon emissions than nuclear! And it could do this far more quickly than possible with a nuclear expansion. Cumulative carbon saved over decades could be far greater than with nuclear.

If a large expansion in gas-generated electricity led to a more rapid rise in the price of natural gas, the greenhouse gas savings might not be worth the cost. But there have been many recent discoveries of natural gas in the United States and elsewhere; in fact, the natural gas resource worldwide appears to be much greater than had been estimated. In addition, a large expansion of wind, as described in further detail below, could release a considerable quantity of gas now being used for base-load generation – as well as substitute more directly for nuclear generation.

While installed capacity of nuclear has been roughly constant worldwide over the past decade, wind capacity has grown dramatically. At the end of 2007, cumulative world wind capacity was more than 94 GW, having grown at an average of more than 25 percent per year for the preceding eight years. In the United States, there have been no new orders of nuclear plants for more than 30 years. By contrast, in 2007, about 8 GW of new wind capacity were installed, with a cumulative capacity at the end of the year of about 17 GW.[30] It appears that another 8 GW or more were installed in 2008. In 2008, the United States Department of Energy completed a study showing the feasibility of a scenario in which wind would contribute 20 percent of total U.S. electricity by 2030; such a contribution would require a wind capacity of about 300 GW.[31] Wind of course is an intermittent source of electricity generation, and its full exploitation will require more new transmission lines than would nuclear, because the strongest wind resources in many parts of the world (including in the United States) are far from demand centers. Nevertheless, wind economics look attractive.

On a capital cost comparison, wind turbines cost about one-half that of nuclear per installed kilowatt;[32] since the capacity factor for wind might be one-half that of nuclear, the carbon savings per capital cost for wind and nuclear might be roughly comparable. But, again, because wind turbines can be installed much faster than could nuclear, the cumulative greenhouse gas savings per capital invested appear likely to be greater for wind.

The wind projections heretofore have been mainly for stand-alone wind turbines without any significant storage. If recent estimates of the potential of compressed air storage prove on target, wind could eventually become a base-load resource, with a still greater upside capacity.

One other potent competitor to nuclear (and to CCS and renewable, too) will be efficiency improvements, both end-state and in the power sector itself. Here I look briefly only at the power sector. Today the world average fuel-to-electricity conversion efficiency of coal-fired power plants is below 35 percent.[33] New coal-fired plants have efficiencies up to 46 percent, and by 2030 the efficiencies of a modern coal plant could reach 50 percent or higher. In its "business as usual" scenario, the *World Energy Outlook* 2008 estimated that worldwide coal generating capacity will roughly double from 2006 to 2030, with an overall average efficiency in 2030 of about 37 to 38 percent (41 percent in OECD countries).[34] Investments that would drive the average efficiency of world coal-fired plants in 2030 from, say, 37 percent to 42 percent would save roughly the same amount of carbon emissions as would replacing 50 percent-efficient coal-fired power plants with 300 GW of nuclear power plants operating at a 90 percent capacity factor.[35]

At a national level, the average efficiency, in 2004, of China's 307 GW of coal-fired plants was 23 percent.[36] By 2030, the *World Energy Outlook* 2008 projects an overall efficiency of roughly 35.6 percent. If this could be raised to 41 percent for the 1,332 GW of coal-fired capacity that China is expected to have on line by 2030, that would save more than four times as much carbon emission on the same basis as would the 36 GW of nuclear capacity that the International Energy Agency expects China to deploy by 2030.[37]

As I initially noted, my analysis is not intended to make a case against nuclear power. The balance of arguments for and against nuclear – on economic, safety, environmental, and other grounds – is examined in the companion articles in this issue. What I have wanted to express is a strong cautionary note to the confident projections of an inevitable nuclear renaissance. In particular, it is important to realize the reasons why nuclear power is largely level or declining in most of the world, outside of Asia, and to underscore that this situation may not reverse, even in the face of the climate change challenge.

ENDNOTES

1 A strong pro-nuclear analysis is provided by *Climate Change and Nuclear Power* 2008 (Vienna, Austria: International Atomic Energy Agency, 2008).

2 Henry Sokolski, "Toward Nuclear Weapons Capability for All?" (Washington, D.C.: New Nuclear Age Foundation, 2008).

3 *Nuclear Energy Outlook* 2008 (Nuclear Energy Agency, 2008), 105.

4 Ibid., 103 – 109.

5 *Uranium Intelligence Weekly*, March 9, 2009, 5.

6 Nuclear Energy Institute, *Status and Outlook for Nuclear Energy in the United States, August* 2009. In summary, this report notes that "given this business environment, a reasoned perspective on the 'renaissance' of nuclear power suggests that it will unfold slowly over time. A successful nuclear renaissance will see, at best, four to eight new plants in commercial operation by 2016 or so."

7 Reported in "Nuclear Renaissance: U.S.A." (NUKEM, June 2008).

8 "Olkiluoto-3 losses to reach 1.7 billion Euros," *World Nuclear News*, February 26, 2009.

9 Nuclear energy is not an option for projects implemented jointly or for the clean development mechanism (CDM); Kyoto Protocol, Articles 6 and 12.

10 Frank von Hippel, *The Uncertain Future of Fission Power*, International Panel on Fissile Materials (IPFM) Research Report 7, 2009 (in preparation); von Hippel's sources

include *State Mid-Long Term Development Plan for Nuclear Power Plants* (2005 – 2020) (China National Development and Reform Commission, October 2007), and *China Nuclear Power* 1 (1 – 4) (2008).

11 "Uncertainties and Variations in Nuclear Power Investment Costs," *Nuclear Technology Review* 2009 (draft) (Vienna, Austria: International Atomic Energy Agency, 2009).

12 Robert H. Williams, "Nuclear Power and its Competitors in a Carbon-Constrained World," Program on Science, Technology, and Society, Massachusetts Institute of Technology, April 23, 2008.

13 *Electricity Market Module*, Table 8.2, Report DOE/EIA-0554 (Energy Information Administration, March 2009).

14 Jacobo Buongiorno, "Near-Term Advanced Reactors for the U.S. Nuclear Industry," Princeton University, February 26, 2009. The reactors discussed included the Advanced Pressurized Water Reactor (AP-1000, 1,100 MW); the Advanced Boiling Water Reactor (ABWR, 1,350 MW); the Advanced Passive BWR (ESBWR, 1,550 MW); the Evolutionary Pressurized Reactor (EPR, 1,600 MW); and the Advanced PWR (APWR, 1,700 MW).

15 "Nuclear Renaissance U.S.A.," in *Market Report* (NUKEM, April 2008), Progress Energy Sidebar. The overnight cost of the second unit is close to that estimated for the AREVA Evolutionary Power Reactor.

16 Swami Venkataraman, "Which Power Generation Technologies Will Take the Lead in Response to Carbon Controls?" (Standard & Poor's, May 11, 2007); quoted in Mycle Schneider and Antony Froggatt, *World Nuclear Industry Status Report* 2007 (The Greens-European Free Alliance Group in the European Parliament, 2008), 11.

17 *World Energy Outlook* 2008 (International Energy Agency, 2008), 155.

18 See, for example, Schneider and Froggatt, *World Nuclear Industry Status Report* 2007, 12 – 13.

19 "Global Public Opinion on Nuclear Issues and the IAEA," prepared by Globescan for the IAEA, October 2005. The poll presented three choices: nuclear is safe, build more plants; use what's there, don't build more; nuclear is dangerous, close down all plants. The fractions of support for these three options were 28 percent, 34 percent, and 25 percent, respectively. So about two-thirds of those expressing an opinion opposed shutting down nuclear power, and the same fraction opposed building additional reactors. The countries polled were Argentina, Australia, Cameroon, Canada, France, Germany, Great Britain, Hungary, India, Indonesia, Japan, Jordan, Mexico, Morocco, Russia, Saudi Arabia, South Korea, and the United States.

20 See *Climate Change and Nuclear Power* 2008, 39.

21 The NRC goal for a large early-release frequency for an advanced (evolutionary) LWR is one in a million per year; Donald Dube, Division of Safety Systems and Risk Assessment, Office of New Reactors, Nuclear Regulatory Commission, memorandum, *White Paper on Implementation of Risk Metrics for New Reactors*, February 12, 2009. See also, Edwin Lyman, "Can Nuclear Plants be Safer?" *Bulletin of the Atomic Scientists* (September/October 2008).

22 The Obama administration's budget policy statement from March 10, 2009 (available at www.whitehouse.gov/omb) noted that "the Yucca Mountain program will be scaled back to those costs necessary to answer inquiries from the Nuclear Regulatory Commission, while the Administration devises a new strategy toward nuclear waste disposal." It might be worth pointing out that the Waste Isolation Pilot Plant (WIPP) in New Mexico was sited without the political furor that has surrounded Yucca Mountain; possibly this was due in part to the fact that this plant is devoted to transuranic wastes and does not contain high-level radioactive wastes.

23 See *Climate Change and Nuclear Power* 2008.

24 The carbon emissions in grams CO_2 per kilowatt-hour of the generation alternative have been estimated as follows considering the full life cycle involved: wind, 9; hydroelectric,

10 – 13; nuclear, 66; natural gas, 440; coal, 960 – 1,050. From B. K. Sovacool, "Valuing the Greenhouse Gas Emissions from Nuclear Power: A Critical Survey," *Energy Policy* 36 (2008): 2950 – 2963.

25 *World Energy Outlook* 2008, 150.

26 R. H. Williams, "Proposed CCS Early Action Initiative for the United States," Discussion Draft v. 10, March 18, 2009.

27 *Electricity Market Module*, Table 8.2.

28 Stephen Pacala and Robert Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," *Science* 305 (2004): 11, 16, and supporting online material. Assuming a lower heating value conversion efficiency to electric energy for coal of 50 percent and gas of 60 percent – both numbers much higher than at present, but possible in modern plants – the authors show that a coal plant will emit about 186 g C/kWh, and a gas plant about half that. A 1 GW electric plant at 90 percent capacity factor produces about 8 terawatt-hours (TWh) of electricity per year. Therefore, a coal plant emitting 186 g C/kWh would emit about 1.5 million metric tons of carbon per year, and a gas plant half as much.

29 *Electricity Market Module*, Table 8.2. The estimates for overnight costs are advanced nuclear, $2,773/kW; advanced gas combined cycle, $877/kW; advanced combustion turbine, $604/kW (with the gas alternatives requiring construction time of two to three years, and advanced nuclear requiring six years).

30 *Annual Report on U.S. Wind Power Installation, Cost, and Performance Trends: 2007* (U.S. Department of Energy, May 2008).

31 *20% Wind Energy by* 2030 (U.S. Department of Energy, July 2008).

32 *Electricity Market Module*, Table 8.2.

33 *World Energy Outlook* 2008, 145 – 146.

34 Ibid., 145.

35 Ibid., 507. The coal electricity generated in 2030 is estimated to be 14,596 TWh, and the emissions from all coal power generation and heat plants to be 13,507 million metric tons of carbon dioxide containing 3,690 million metric tons of carbon. This implies an overall efficiency of about 37 percent. Were the overall efficiency instead raised to 42 percent, the total carbon savings effected by that rise in efficiency would be approximately 437 million metric tons per year. If a 1 GWe nuclear plant at a 90 percent capacity factor replacing a modern coal plant could save 1.5 million metric tons per year, a savings of 437 million metric tons could be effected by the deployment of about 290 nuclear plants.

36 *World Energy Outlook* 2006 (International Energy Agency, 2006), 517. See also Wang Jon, *Energy for Sustainable Development* 7 (4) (2003). In 2004, coal plants in China, operating at a 65 percent capacity factor, generated 1,739 TWh out of a total electricity generation of 2,237 TWh. In 2003, the average coal consumption per kWh was reported as 391 g in China, compared to about 320 g in advanced foreign countries, translating into an electricity efficiency of about 23 percent in China, compared to nearly 30 percent in industrialized countries.

37 *World Energy Outlook* 2008, 531. China's coal electric generation in 2030 is estimated to be 6,335 TWh, and total carbon emitted by coal power generation is estimated to be 6,055 million metric tons of CO_2 (1,654 million metric tons carbon). This implies an efficiency of 35.6 percent. Raising the efficiency to 41 percent, the projection for the average efficiency of coal plants in OECD countries in 2030 would save about 223 million metric tons of carbon per year, which could alternatively be effected by the deployment of 150 GW nuclear, using the rule of thumb that a 1 GW nuclear plant replacing a modern coal plant saves roughly 1.5 million metric tons of carbon.

José Goldemberg

Nuclear energy in developing countries

After 20 years of stagnation, plans to use nuclear power for electricity generation are being revived around the world, usually for the following reasons:

- Nuclear-generated electricity contributes little, on a life-cycle basis, to greenhouse gas emissions and could therefore help in solving global warming problems.
- The eventual introduction of a carbon tax on fossil fuel use, as one instrument to reduce greenhouse gas emissions from thermoelectric stations, would make nuclear-generated electricity more competitive vis-à-vis the use of natural gas and other fossil fuels for that purpose.
- Nuclear energy can contribute to energy security, reducing or eliminating the need for natural gas or other fossil fuels now used frequently for electricity generation.

These are sensible reasons for countries to examine the nuclear option seriously. There are, however, other factors that are much more difficult to analyze because of their political nature, namely the "status" and prestige associated with mastering nuclear technologies. This factor certainly played a role in the efforts of the United Kingdom and France to develop nuclear weapons as an instrument to gain a place at the table among the great powers. In developing countries, nuclear technology has often been viewed as a passport to the first world and to the bureaucratic self-aggrandizement of the nuclear establishment, factors evident in the development of the nuclear capacity of India, for example. It is widely believed that elements of the Indian scientific community, rather than the Indian military, have led the push for India's nuclear weapons program.[1] This is not surprising considering the influence the U.S. Department of Energy's national laboratories have had in decisions to expand research, development, and deployment of new generations of nuclear reactors, despite lack of enthusiasm from the nuclear industry. This was also the case in Brazil, where scientists in the 1950s not only considered building a nuclear reactor with natural uranium and graphite – capable thus of producing plutonium – but also started work on ultracentrifuges to enrich uranium.[2]

To promote a nuclear energy "renaissance," the U.S. government included, in the Energy Policy Act of 2005, significant incentives to encourage the private sector to build new power reactors. For the first reactors built, such incentives (in the form of subsidies and guarantees) are estimated to have the potential to reduce the cost of electricity produced by 30 percent. Although such policies led to a flurry of applications to build new reactors, none has so far been constructed.

Despite the U.S. government's efforts to revive nuclear energy, the prospects for nuclear are not considered very bright in those countries that are part of the Organisation for Economic Co-operation and Development (OECD): the worldwide projections for 2030 by the International Atomic Energy Agency (IAEA) predict, essentially, zero growth in nuclear power generated in the period 2003–2030 from OECD countries.[3] The hopes of a nuclear industry renaissance, therefore, lie almost exclusively in the non-OECD countries, where the installed power is expected to grow from 57 to 132 gigawatts (a net addition of some 75 large nuclear reactors). The French company AREVA, with the active support of the French government, has been engaged in lobbying to sell reactors to a large number of developing countries around the world, at least 13 of which are in the Middle East. Presently only 7.5 percent of existing reactors are in non-OECD countries (mainly in China and India), and since most of them are small, the power generated by them represents only 4.3 percent of total nuclear-generated electricity. According to IAEA projections, this fraction will grow to 15 percent by 2030.

Recently, 50 developing countries[4] that do not have nuclear reactors for electricity production expressed to the IAEA interest in acquiring their first nuclear power plant. Such countries have a gross domestic product (GDP) ranging from US$6 billion (Haiti) to US$657 billion (Turkey) and electric grids ranging from 0.1 gigawatt (Haiti) to 31 gigawatts (Turkey). It is unlikely that countries with a GDP smaller than US$50 billion would be able to purchase a nuclear reactor worth at least a few billion dollars. In addition, electric grids, for technical reasons, must have a minimum of 10 gigawatts to accommodate a large nuclear reactor. Eliminating the countries that do not fit these criteria, we are left with a short list of 16 countries that could be considered serious candidates for purchasing large nuclear reactors: Algeria, Belarus, Chile, Egypt, Greece, Indonesia, Kazakhstan, Kenya, Malaysia, Philippines, Poland, Saudi Arabia, Thailand, Turkey, United Arab Emirates, and Venezuela.

What are the real motivations for these countries in introducing nuclear reactors to their energy system?[5] Concerns about greenhouse gas emissions do not have a high priority in developing nations: neither the Kyoto Protocol nor any other international agreement constrains those emissions for them (they were exempted to assist their development). Additionally, experience shows that in industrialized countries, financing the up-front investments needed for nuclear plants is a major challenge. In most of these countries, nuclear power expanded only when governments facilitated private investment, a practice that is at odds with present strong market liberalization policies. For developing countries, the pivotal problem is the allocation of scarce governmental resources; financial authorities cannot easily justify subsidizing nuclear energy at the expense of more pressing needs in health, education, and poverty reduction.

Nor is the need for energy a sufficient compulsion. Most of the anticipated growth in nuclear energy in the developing world is commonly ascribed to China and India. In recent years, they have become prime markets for nuclear technology imports because their indigenous nuclear programs have been, at best, qualified successes. Yet those countries, and indeed the rest of the developing world, have abundant non-nuclear energy alternatives, too. Cleaner and more efficient coal-burning technologies would reduce emissions not only of greenhouse gases, but also of soot and other by-products that cause local and regional pollution – and they could prove to be easier or less expensive to implement. The average efficiency of coal-burning thermoelectric generation stations is around 30 percent now and could be improved with current technology to reach the significantly higher average efficiency of such plants in the United States or Japan,[6] to say nothing of carbon capture and storage (CCS), which could be available in a few years. Also, many developing nations have underexploited hydroelectric power options: worldwide only around one-third of economically viable hydroelectric potential has been tapped so far, and in sub-Saharan Africa that figure is far smaller. Other renewable energy sources, particularly biofuels for transportation, also have good prospects.[7]

Therefore, excluding the intention to develop nuclear weapons for reasons of national security, the only sensible justification for developing countries to go nuclear is to enhance security of supply. This was an important consideration some 30 years ago in France and Japan, both of which installed large parks of nuclear reactors. Today nuclear electricity accounts for 78 percent of the total electricity produced in France, and 30 percent in Japan. However, there is a fundamental difference between the problems of these countries decades ago and the developing countries today. France and Japan didn't have other options, having exhausted at that time indigenous fuels (or hydro) to generate electricity. The choice was to import fossil fuels (gas and oil, and even coal) or set up nuclear reactors. That's not the case today for many developing countries, including the 16 in Table 1.

Nuclear energy in developing countries

The meaning of energy security when nuclear energy is involved, however, is a double-edged sword: there is no clear distinction between the technology needed for the peaceful uses of nuclear energy (such as the production of electricity) and the manufacture of nuclear weapons. Nuclear reactors need enriched uranium to function, and if the enrichment plants producing the fuel for reactors are devoted to producing uranium with a high degree of enrichment (above 80 percent), that product can be used for weapons. Pakistan followed this route, using information obtained about centrifuges enrichment by a Pakistani technician from a URENCO enrichment plant. Even if a reactor operates with a low degree of enrichment (3 or 5 percent), which is the case for most commercial nuclear reactors, plutonium that can be separated chemically and used for weapons is produced in the fuel elements. India did this as early as 1974, using an imported research reactor from Canada, and North Korea did the same more recently, in a small power plant.

Presently, Brazil, Germany, Iran, Japan, The Netherlands, the United States, China, Russia, India, and Pakistan have enrichment facilities. Russia has an enrichment capacity of approximately 35,000 ton separative work unit (SWU)[8]/year, and all other countries together have another 30,000 ton SWU/

Table 1
Potential Non-Nuclear Sources of Electricity and Their Ratios of Reserves to Production, in Years, in 16 Developing Countries

Country	Potential source(s), with ratio(s) of reserves to production (R/P) in years
Algeria	Abundant natural gas (R/P=43)
Belarus	Natural gas from Russia
Chile	Abundant hydro and good geothermal potentials
Egypt	Abundant natural gas (R/P=43)
Greece	Abundant coal (R/P=55) and peat, good geothermal and wind potentials
Indonesia	Abundant biomass, geothermal energy, natural gas (R/P=33), oil (R/P=10), hydro
Kazakhstan	Very abundant natural gas (R/P>100) and oil (R/P=80)
Kenya	Abundant biomass, good geothermal potential
Malaysia	Biomass, natural gas available (R/P=35)
Philippines	Abundant biomass and geothermal resources
Poland	Abundant coal (R/P=47 to 108)
Saudi Arabia	Abundant oil (R/P=66) and natural gas
Thailand	Abundant biomass, coal (R/P=63 to 96) and natual gas also available (R/P=12)
Turkey	Vast hydro resources (216 TWh technically and 130 TWh economically exploitable, compared to 73 TWh planned, 11 TWh under construction and 35 TWh installed by end 2005)
United Arab Emirates	Very abundant oil (R/P=97) and natural gas (R/P>100), small country with low demand
Venezuela	Abundant hydro, oil (R/P=73) and natural gas (R/P>100) resources

Source: *Survey of World Energy Resources* 2007 (World Energy Council, 2008).

year. About 100 to 120 ton SWU/year is required as the fuel loading of a typical 1,000 MW reactor. The existing enrichment capacity therefore is enough to supply the fuel needs to approximately 600 reactors of 1,000 MW, almost double the existing units in operation.

Although vendors are keen to sell nuclear reactors to developing countries, that by itself does not guarantee energy security since enriched uranium nuclear fuel has to be imported to keep the reactors operating. For that reason, many countries will certainly contemplate the desirability of enriching uranium domestically to avoid dependence on external supplies, which they may fear will come associated with political pressures and demands unrelated to nuclear issues. Two outstanding examples are the cases of Iran and Brazil. In the 1970s, both countries signed agreements with the Federal Republic of Germany to install enrichment plants; the agreements were blocked by the United States. In both cases it became clear that the United States was denying access to nuclear fuels if political conditions were not met. In the case of Iran, the perception was that the United States wanted to promote regime change; in the case of Brazil, that the United States was acting on suspicions that the military government had plans to manufacture nuclear weapons. These perceptions led both governments to encourage national efforts to enrich uranium domestically, rather than to accept the limitations imposed by the United States.

Over the years, nuclear reactors for electricity production were installed in nine developing countries: Argentina, Brazil, China, India, Iran, Mexico, Pakistan, South Africa, and North Korea. Of these countries, five – China, India, Pakistan, South Africa, and North Korea – developed nuclear weapons (although South Africa later dismantled theirs). Argentina and Brazil embarked on programs that could have led to weapons, but decided to abandon the programs in 1991. Only Mexico does not have enrichment facilities. It is unclear at this time if North Korea has them, although it has facilities to reprocess nuclear fuel and separate weapons-grade plutonium. The others installed such facilities despite the fact that the number of reactors in operation in these countries did not justify (from an economic viewpoint) the investments in such large-scale facilities. There is thus a fundamental contradiction between efforts to avoid the proliferation of nuclear weapons and enthusiasm for the spread, for commercial reasons, of nuclear reactors to many developing countries. Recent efforts by North Korea, Iraq, and Iran evidence this contradiction.

These problems are not new; they started in the beginning of the nuclear age, as early as 1945. At that time, the United States had a monopoly on the technology and infrastructure needed to make nuclear weapons, ranging from the uranium ore itself to the purification and enrichment (to the high levels needed for weapons) processes to the know-how in building weapons. With such clout, the United States tried to put nuclear energy developments under international control. The Soviet Union, confident that it could develop nuclear weapons to break the U.S. monopoly, found this unacceptable. U.S. policy-makers were probably under the delusion that it would take the Soviet Union a long time to build its own nuclear devices; but within only four years of the Hiroshima/Nagasaki explosions, the Soviets had done so.

To keep some control of the spread of nuclear technology, President Eisenhower's 1953 program Atoms for Peace offered U.S. help to countries with interest in the civilian uses of nuclear energy. Under the program, reactors using highly enriched uranium were donated to a number of countries for research purposes and for industrial and medical applications. The rationale for such a move – stimulated by well-intentioned leading scientists in the United States, such as I. I. Rabi – was that the spread of nuclear technology was inevitable, so efforts should be made to restrict it to peaceful uses. The United States, which then controlled the worldwide production of enriched uranium (besides the Soviet Union), established tight export control of sensitive nuclear materials. Of course, the program also had commercial motivations: it promised to create a market for nuclear equipment produced in the United States.

Over the years, the United States and the Soviet Union exported hundreds of research reactors using highly enriched uranium to many developing countries. Some of the spent fuel from the reactors was returned to the United States and the Soviet Union, and new shipments of fuel and other materials were closely monitored. In practice, however, the program, despite its positive aspects in making available the use of radioactive isotopes in industry and medicine, often worked against the goal of discouraging nuclear proliferation, because the dissemination of nuclear reactor technology led to the training of thousands of scientists and technicians and the spread of sensitive dangerous materials (such as highly enriched uranium and plutonium). This was certainly the case in India, where an active nuclear establishment was built around the eminent scientist Homi J. Bhabba.

In the 1950s and early 1960s, the United Kingdom, France, and China developed nuclear weapons without significant external help (except possibly in the case of China, which was assisted to some degree by the Soviet Union). The technical barriers to developing nuclear weapons using materials produced in those nuclear reactors nominally dedicated to peaceful uses aren't insurmountable; and the contention that nuclear technology cannot be developed indigenously by developing countries has proved to be false. That any modern industrialized country could develop nuclear weapons led to determined effort in the late 1960s to stop the further proliferation of such weapons to other states (horizontal proliferation). In the 1960s there were also very strong concerns with testing nuclear weapons in the atmosphere, and with the frightening increase of nuclear weapons in the five countries that possessed them, especially the United States and the Soviet Union, both with their thousands of weapons (vertical proliferation).

The Non-Proliferation Treaty (NPT) adopted in 1968 is the main instrument used to address these problems. The Treaty divided states in two categories: nuclear-weapons states (NWS), defined as those that had "manufactured and exploded a nuclear weapon or other explosive nuclear device prior to January 1967" (the United States, the Soviet Union, the United Kingdom, France, and China), and non-nuclear-weapons states (NNWS), which "undertake . . . not to manufacture or otherwise to acquire nuclear weapons or other nuclear explosive devices." In return for this undertaking, NNWS are entitled to "participate in the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of atomic energy." This "grand bargain" was very difficult to achieve, though. The NNWS kept the "inalienable" right to the use of nuclear energy for peaceful purposes, and the NWS agreed to pursue negotiations leading to nuclear disarmament. These negotiations led practically nowhere, and today the NWS commitment to pursue nuclear disarmament is generally considered mostly a rhetorical gesture. A few countries, such as India, Pakistan, Israel, Brazil, and Argentina, wanted to keep their options open, and so did not accept the limitations imposed by the Treaty; indeed, India, Pakistan, and Israel produced weapons in the subsequent years.

The NPT gave the IAEA the job of establishing safeguards and overviewing activities of the signatories in the nuclear area in order to avoid proliferation. Today, essentially all nuclear facilities in NNWS are under safeguards. Nevertheless, the regime was not in the past sufficient to deter countries from developing nuclear capability, so the nuclear powers have tried other approaches to prevent, inhibit, or delay the appearance of new NWS. In addition to physical security measures to secure enriched uranium and plutonium and measures to keep tight control on exports, two other approaches have been tried by the United States to curb the proliferation of nuclear weapons:

- Sanctions ("sticks") to punish nations that embark in such a direction. Libya's renunciation of its nuclear program is often given as an example of the success of this approach.
- Rewards ("carrots"), such as trade or financial benefits. North Korea's behavior (although somewhat erratic) is given as an example of success with this approach.

All of these mechanisms have delayed, to some extent, several countries' efforts toward acquiring the capacity to develop nuclear weapons.

A specific security measure that proved moderately successful was the Reduced Enrichment for Research and Test Reactors (RERTR) program, started by the United States before 1980 and soon followed by a similar program from the Soviet Union. The 250 research and test reactors in use in 1978 were reduced to approximately 134 by 2007, and most of the remaining ones are in the former Soviet Union and in the United States.[9] However, more recently, and particularly after the terrorist attacks of September 11, 2001, it was realized that the stocks of enriched uranium still remaining represented a real threat of proliferation in some problematic countries, and that redoubled efforts should be undertaken to recover the material. As an example, in 2002 the Nuclear Threat Initiative safely moved 48 kg of highly enriched uranium (enough to manufacture two nuclear weapons) from the defunct Vinca nuclear reactor near Belgrade to a facility in Russia. Another example is Congo, which received the HEU research reactor that the United States displayed in 1958 at the second Atoms for Peace conference. Less than two years later, Belgian colonial rule in Congo ended. In 1970, the United States replaced the HEU reactor with a TRIGA (Mark II) reactor operated with LEU. In the process, two fuel rods with fresh fuel went missing; only one was eventually found.[10]

The nuclear renaissance now promoted by the United States has some similarities with the Atoms for Peace program of President Eisenhower – and runs the risk of repeating and amplifying the problems created by that program. Setting up dozens, perhaps hundreds of large nuclear reactors in developing countries means that enormous amounts of enriched uranium will be necessary. The plutonium produced in these reactors could be used for weapons and, further, the enormous amount of radioactive products in the spent fuel in the uranium rods will have to be disposed of.

Associated with the nuclear renaissance are Generation IV (GEN IV) reactors operating with recycled plutonium. Future nuclear systems, such as those that are studied in the GEN IV program and the so-called advanced Fuel Cycle Initiative from the United States, are all aimed at making nuclear energy more sustainable, either by increasing system efficiency or by using closed fuel cycles in which fissile materials are either partially or totally recycled. Such an approach will involve large reprocessing of fuel rods to extract plutonium. Significant scientific and technical challenges must be resolved before these systems are ready for deployment, which is not expected before 2035 – 2040.[11]

It is clear, therefore, that a renaissance would exacerbate two sets of problems that exist already with the present generation of nuclear reactors:

1) Transportation of fuel rods shipped from producing countries and the return of spent fuel (unless they are reprocessed locally); and

2) Building up local enrichment facilities to avoid external dependence.

The widespread circulation of fissile materials – particularly in some politically problematic countries – increases the probability of a fraction of this material falling into the hands of a terrorist group.

Such concerns led a group of very senior former U.S. government officials – George P. Shultz, William J. Perry, Henry A. Kissinger, and Sam Nunn (branded as the "gang of four")[12] – to the conviction that there is no solution to the problem of the spread of nuclear weapons except to seek "a world without nuclear weapons." Naive as it might sound – and none of these former senior officials could be considered "pacifists" or naive – the proposal made some sense from the U.S. perspective. They pointed out that "nuclear weapons were essential to maintaining international security during the Cold War because they were a means of deterrence," which was made obsolete by the end of the Cold War. Presently, however, there is the possibility of nuclear weapons falling into the hands of non-state organizations (and terrorists) to which the concept of nuclear deterrence does not apply at all. Eliminating nuclear weapons altogether and strictly controlling the circulation of materials usable for the manufacture of nuclear weapons would be the only solution to avoid that nightmare.

There is a less benign interpretation of the motivations of Shultz and colleagues, namely that whereas immediately after the end of World War II the only way to stop the Soviet Union from overrunning Western Europe was to strengthen the nuclear weapons capacity of the United States, today the situation has reversed itself. Western Europe is in no real danger from Russian takeover today, and U.S. conventional forces are dominant all over the world, with hundreds of military bases spread around the world. If nuclear weapons are indeed abandoned, that will not weaken U.S. power, but increase it.

One way of tightening control on fissile materials and discouraging nuclear proliferation is to revive and strengthen the NPT, which could be achieved in 2010 by addressing the thorny question of implementation of Article VI. This is well in line with President Obama's statement that he "will make the goal of eliminating all nuclear weapons a central element in our nuclear policy."

Some developing countries, particularly Brazil, which is considered one of the countries capable of producing nuclear weapons – but decided in 1991 not to do so – have recently adopted positions that signal the urgency of coming to terms with the problem of nuclear disarmament, thus strengthening, in some ways, the gang of four's proposal. The Brazilian government's recently issued "National Defense Strategy" states clearly that the country "will not adhere to proposed additions [meaning the Additional Protocol] to the NPT which increase restrictions contained in it without progress by the nuclear weapons states in what is the central premise of the Treaty: their own nuclear disarmament."

The Additional Protocol is presently one of the thorny issues in the efforts to curb nuclear proliferation. There are proposals to make its acceptance a precondition for technical help and access to technology from the Nuclear Suppliers Group, and to make it mandatory to signatories of the NPT, to which several countries have objected. Brazil has refused to accept the Additional Protocol because it claims to have developed, indigenously, ultracentrifuges that use an improved technology, and because unannounced inspections by the IAEA in non-declared nuclear facilities could jeopardize industrial secrets. Brazil otherwise accepts inspections in all declared nuclear facilities, including enrichment facilities, where precautions are taken not to reveal technical characteristics of the centrifuges.

Phasing out nuclear weapons will not come easy, but the many steps that could be taken in that direction (some of which were listed quite clearly in the gang of four's proposal) could help dramatically in "devaluing" the possession of nuclear weapons. Progressive intermediate steps include:

- Extending key provisions of the Strategic Arms Reduction Treaty of 1991;
- Adopting a process for bringing the Comprehensive Test Ban Treaty (CTBT) into effect;
- Adopting an effective Fissile Missile Cutoff Treaty (FMCT); and
- Developing an international system to manage the nuclear fuel cycle. On this particular point there are a number of proposals to establish multinational centers for enrichment of uranium and a "fuel bank" under IAEA control. The purpose of such a system would be to provide for reliability of nuclear fuel, reserves of enriched uranium, infrastructure assistance, financing, and spent-fuel management, to ensure that the means to make nuclear weapons materials aren't spread around the globe.

The strengthening of the NPT is also made more urgent by the fact that the U.S.-India nuclear deal dealt a serious blow to the safeguards regime of the IAEA. As a non-signatory of the NPT and having nuclear weapons, India could not receive the technical assistance of NWS. These requirements were bent to accommodate the geopolitical and commercial interests of the United States. What's more alarming, the deal was approved unanimously by the Nuclear Suppliers Group, which makes decisions by consensus.

This controversial approval by the Nuclear Suppliers Group can only be understood by assuming that some of the participants foresaw themselves as someday being in the same position of India, and wanted to guarantee for themselves the same benefits and technical assistance India would get from the NWS (although India has a military program that will not be under IAEA safeguards). Others are betting that the nuclear energy renaissance will indeed take place, and see themselves as suppliers of raw materials or enriched uranium. This expectation is clearly one of the justifications for the Rezende plant in Brazil, since it is unlikely that the internal market will be large enough to justify large investment in facilities. From that perspective, it is clear that the expectation of a nuclear renaissance is already undermining the NPT.

ENDNOTES

1 Harold Brown, "New Nuclear Realities," *The Washington Quarterly* 31 (1) (Winter 2008/2009): 7 – 22.

2 José Goldemberg, "Lessons from the Denuclearization of Brazil and Argentina," *Arms Control Today* (April 2006): 41 – 43.

3 *Energy, Electricity, and Nuclear Power: Developments and Projections – 25 Years Past and Future* (Vienna, Austria: International Atomic Energy Agency, 2007).

4 Those 50 countries are Algeria, Bahrain, Bangladesh, Belarus, Bolivia, Chile, Croatia, Dominican Republic, Egypt, El Salvador, Estonia, Georgia, Ghana, Greece, Haiti, Indonesia, Israel, Jamaica, Jordan, Kazakhstan, Kenya, Kuwait, Latvia, Libya, Malaysia, Mongolia, Morocco, Myanmar (Burma), Namibia, Nigeria, Oman, Peru, Philippines, Poland, Qatar, Saudi Arabia, Senegal, Singapore, Sri Lanka, Sudan, Syria, Tanzania, Thailand, Tunisia, Turkey, United Arab Emirates, Uruguay, Venezuela, Vietnam, and Yemen; author's personal correspondence with H. H. Rogner of the IAEA, September 2008.

5 José Goldemberg, "The Limited Appeal of Nuclear Energy," *Scientific American* (June 2007).

6 "Lighting the Way: Toward a Sustainable Energy Future" (InterAcademy Council, 2007); www.interacademycouncil.net.

7 *World Energy Assessment: Energy and the Challenge of Sustainability*, ed. José Goldemberg (New York: United Nations Development Programme, 2000).

8 A measure of the work done by a machine or plant that separates uranium into streams with higher and lower fractions of U-235.

9 Ole Reistad and Styrkaar Hustveit, "HEU Fuel Cycle Inventories and Progress on Global Minimization," *The Nonproliferation Review* 15 (2) (2008): 265 – 282.

10 Zia Mian and Alexander Glaser, "A Frightening Nuclear Legacy," *Bulletin of the Atomic Scientists* (September/October 2008): 42 – 47.

11 Frank von Hippel, "Nuclear Fuel Recycling: More Trouble than It's Worth," *Scientific American* (April 2008).

12 George P. Shultz, William J. Perry, Henry A. Kissinger, and Sam Nunn, "Call for a World Free of Nuclear Weapons," *The Wall Street Journal*, January 4, 2007, and "Toward a Nuclear Free World," *The Wall Street Journal*, January 15, 2008.

John W. Rowe

Nuclear power in a carbon-constrained world

> History of science and technology has consistently taught us that scientific advances in basic understanding have sooner or later led to technical and industrial applications that have revolutionized our way of life. It seems to me improbable that this effort to get at the structure of matter should be an exception to this rule. What is less certain, and what we all fervently hope, is that man will soon grow sufficiently adult to make good use of the powers that he acquires over nature.
>
> – Enrico Fermi, in 1953, the year before his death

I have spent nearly four decades in the utility industry grappling with the effort to "make good use" of the power man has acquired in learning to split the atom. I cut my teeth in private practice licensing the fleet of Commonwealth Edison, one of the nation's most nuclear-intensive utility companies. In my first CEO position, I worked to recover Central Maine Power's economically disastrous investments in the Seabrook plant while fighting referenda to shut down the productive and economical Maine Yankee station. When I later returned to Illinois, this time as CEO of ComEd, I led a dedicated team of nuclear professionals who turned the country's worst-performing fleet into the nation's best. This year I celebrated my 25th year as a CEO in the electric industry. Exelon Corporation, a successor company to ComEd and PECO (another nuclear utility), is the largest commercial nuclear operator in the United States and the third largest in the world.

The politics and economics of nuclear energy represent a nearly complete circle: a burst of building in the late 1960s and 1970s; public concerns and rising costs aggravated by the Three Mile Island accident of 1979; deteriorating economics due to high inflation, poor operating performance, and low-priced natural gas in the 1980s and early 1990s; and now, as of early 2009, 17 license applications filed with the Nuclear Regulatory Commission (NRC) for the construction of as many as 26 new reactors, including Exelon's application to build a two-unit plant in Texas. Traditional considerations – the low production costs of nuclear power, volatility in electricity prices because of a growing reliance on natural gas, projected electricity demand outstripping supply (a "shrinking reserve margin," in utility parlance) – are driving these ambitious proposals and plans. Increasingly, however, concerns about climate change are also driving the so-called nuclear renaissance.

Dramatic economic growth and projected power demand in nations such as China and India have only accelerated the need for nuclear energy. Even more than in the United States, nuclear power is becoming a more attractive option globally. In a November 2008 survey of more than 10,000 respondents in 20 countries, Accenture found strong growing support for nuclear power as a way to reduce reliance on fossil fuels. Moreover, the strongest support came from respondents in India, China, the United States, and South Africa, in that order. Construction plans abroad are as bold as, and in many cases more real than, those in the United States. According to the International Atomic Energy Agency, 13 countries outside the United States are building 44 reactors, and an additional 108 are being planned. This is clearly a positive outcome from a climate change standpoint, but it raises concerns as well – not the least of which are about nuclear security and nonproliferation.

From my vantage point, this nation's energy and climate challenges pose three inconvenient truths (to borrow an already overworked phrase), rather than just one.

Inconvenient Truth #1: *Climate Change is Real*. Our planet is warming, at least in part due to human production of CO_2 and other greenhouse gases. The Intergovernmental Panel on Climate Change and the National Academy of Sciences have issued reports that persuade all but the most skeptical reader. Indeed, one must be almost obstinately skeptical to resist the weight of this analysis, the closest one gets to consensus among scientists.

These reports conclude that global temperatures are rising and that human activity – especially the burning of fossil fuels – is a major contributor to that warming. The reports are less sure about the long-term effects. Predicted outcomes range from comparative nuisance to complete catastrophe. However, our inability to predict the outcome must not be an excuse for inaction. Both governments and industry, including electric utilities, are obliged to make billion-dollar investment decisions in the absence of complete information. We must similarly deal with our climate challenge in a way that is both decisive and prudent.

Fortunately, President Obama and congressional leadership seem to agree there is a problem. As I write this in the spring of 2009, both branches of government are moving forward with proposals and legislation that will place a price on carbon emissions, either through a cap-and-trade system or a carbon tax, essential ingredients to encouraging low-carbon investments and discouraging high-carbon ones. We must ensure that this price signal is phased in gradually so as to avoid shocking a weak economy, to give it political stability, and to allow time for better technological solutions to develop. A predictable, economically sustainable price for greenhouse gas emissions is the *sine qua non* of addressing climate change. I believe that today we are closer to a comprehensive governmental policy on climate change than ever before.

Putting a price on carbon, however, creates another huge challenge. Because the essence of global energy policy has for years been founded on the consumption of low-cost fossil fuels, in a carbon-constrained world new sources and approaches to energy supply will be required.

Inconvenient Truth #2: *Energy Efficiency and Renewable Power Cannot Meet our Needs on Their Own.* The United States' appetite for electricity is projected to grow dramatically, even accounting for the impact of the current recession. Research by The Brattle Group based on the *Annual Energy Outlook* 2008, published by the Energy Information Administration (EIA) of the Department of Energy, concludes that the U.S. electric industry will need to build 214 gigawatts (GW) of new generating capacity in the next 20 years to meet projected demand.[1] This increase in generation is roughly 20 percent of the industry's current installed nameplate capacity. It is a stark reflection of the fact that as our nation has grown more prosperous and our standards of living have increased, so, too, have our power needs. Meeting these needs will be a stiff challenge for the utility industry, even absent the need to adapt ourselves to a low-carbon world.

Energy efficiency will be a critical – and in some ways the most creative – component of meeting that growing demand. Improved efficiency standards have been in vogue for years with policy-makers who have (wisely, in my view) passed laws requiring air conditioners that run on less power, toilets that flush with less water, and other similar measures. When Exelon renovated its headquarters in downtown Chicago, we designed our 10 floors of the 1970s-era building to meet LEED (Leadership in Energy and Environmental Design) Platinum standards. We changed our lighting, put advanced controls on our heating and cooling, and installed Energy Star-rated appliances. In doing so, we reduced our electricity consumption by 50 percent and achieved substantial cost savings. And efficiency is even penetrating the public consciousness. As electricity prices rose in recent years, consumers found themselves more willing to embrace the twists and curves of a compact fluorescent light bulb – even if it did not fit perfectly with their home decor.

Undoubtedly, efficiency is the best first step when it comes to meeting our future needs in the least carbon-intensive fashion. But how much of future demand can be mitigated by improved efficiency? The answer is not at all clear. Technology and the behavior of consumers are both too complicated to be characterized by a supply curve. The items that clearly pay for themselves, such as Exelon's office renovations, will be quickly adopted. Yet I believe that we are still far from the day when consumers will pay $20 for an LED bulb, even if it is more efficient than its compact fluorescent cousin. We must find a way to convince landlords to build the most efficient buildings possible when their tenants – not they – will pay the monthly bill. And we must realize that as our economy grows and our standards of living become ever higher, we will find new technologies, like mobile phones and flat-screen televisions, that will use more power, not less. We will not and cannot all live simpler lives consuming less and still providing for ourselves.

The Brattle Group study estimates that in the most realistic case, 38 percent of the projected growth in generating capacity can be eliminated through improved efficiency and conservation. In the best-case scenario – which assumes that we can (and will) change our behaviors and pay the still-unknown costs – 48 percent of projected growth in generating capacity could be eliminated. That is certainly meaningful progress toward meeting our needs in a low-carbon fashion, but assuming the best-case efficiency scenario, we still must build 111 GW of new generation over the next 20 years.

Renewable generation sources – primarily wind, which is the most mature of the alternatives – have also caught the imagination of the public and policy-makers. Subsidies and governmental mandates fueled a wind construction boom in recent years, aided by rising electricity prices (largely due to volatile natural gas supplies) and concerns about dependence on foreign energy sources. According to the American Wind Energy Association, over 5 GW of wind capacity were installed in 2007, and approximately 7.5 GW were projected for 2008. (The previous annual high-water mark for new installed wind capacity was in the neighborhood of 3 GW.) There is something appealing to the public about a form of electric generation that requires no fuel and passively harnesses nature.

But how much generating capacity can renewables achieve? The Brattle Group and the EIA conclude that we can expect to obtain roughly 39 GW of generating capacity from wind and other renewable sources. This amount is roughly the same in the reasonable and best-case scenarios, reflecting current knowledge about the technologies involved. These 39 GW come with a significant cost, though. Exelon's internal economic analysis places the unsubsidized cost of avoiding carbon emissions with wind at between $50 and $90 per metric ton.[2] A recent article in *The Economist* cites a study that places the cost of avoided carbon emissions with renewables at between $70 and $140 dollars per metric ton. This translates into wholesale power price increases between 3 and 14 cents per kilowatt-hour (depending upon the market), which could easily double a consumer's monthly bill. And these figures do not count the attendant investments that must come with renewable power. The most promising regions in the United States for wind development are in the Southwest and Great Plains, far from the population centers that would need the power the most and necessitating the construction of costly transmission lines. A February 2009 report by the Lawrence Berkeley National Laboratory summarizing more than 40 existing transmission studies estimates that the average additional cost for transmission – on top of the higher cost of wind energy – is between 1.5 and 2.5 cents per kilowatt-hour.

Moreover, renewable power sources are intermittent. According to a 2007 study by the engineering firm Black & Veatch, the newest and most efficient wind turbines have a 35 percent capacity factor (defined as the amount of energy produced over a given time divided by the unit's total energy potential). We would still need to build backup generation from traditional sources, most likely quick-starting natural gas facilities, to ensure reliability of the grid and that the lights come on whenever customers flip the switch, regardless of whether those wind resources are producing power. As for solar power, the same issues about transmission and reliability apply, but the technology is even less mature, and so the costs, according to Exelon's internal analysis, are as much as 10 times higher than the cost of wind.

We can and must invest in wind, solar, and other emerging technologies. But even in the most optimistic of scenarios, we face a shortfall of 75 to 100 GW of power. And it is critically important to remember that this is merely the generation required to meet projected demand. It does not address replacement of any part of the existing and aging carbon-intensive coal-generation infrastructure, which accounts for roughly 50 percent of power generated today and the vast majority of the industry's CO_2 emissions.

Inconvenient Truth #3: *We Need Low-Carbon Base Load Power, a Substantial Amount of Which Will Have to be Nuclear.* We have three options to fill the gap in our country's future power needs in a low-carbon fashion: natural gas, clean coal, and new nuclear plants. Each has disadvantages and complications.

More natural gas-fired generation is a certainty. The capital investments are manageable for companies the size of the average U.S. utility. It can be dispatched quickly, making it the ideal complement to intermittent renewables, and it is relatively attractive from the standpoint of carbon emissions. Current economic conditions, stresses on the ability of utilities to make large capital investments, and today's low commodity prices all but ensure another "dash to gas." In today's environment, natural gas is second only to energy efficiency as a way to provide electricity at the lowest avoided cost for carbon emissions. But we should be wary of the unintended consequences of such a dash. Most significantly, a further build-out of gas generation would lead to an increasingly undiversified generation portfolio. According to the energy data provider Ventyx, approximately 375 GW of nameplate generating capacity have been brought on line in the United States since 1990; more than 85 percent of that capacity is gas-fired. As the percentage of gas-fired generation increases, the volatility in its price will become an even larger problem. The potential volatility was perfectly illustrated in 2008: natural gas prices stood at $7 per MMBtu at the beginning of the year, rose to almost $14 per MMBtu in the summer, and fell to $5 per MMBtu at year's end. By early 2009, it had fallen even further, to less than $4 per MMBtu. Future oscillations in price will translate into power price volatility, and that volatility will become more pronounced as the dash to gas progresses. This outcome is good neither for power generators, whose revenues and cash flows will ride the peaks and troughs of the commodity cycle, nor the customers they serve, who will quickly become frustrated by the uncertainty about what their electricity bill will cost.

Nuclear power in a carbon-constrained world

Coal, which accounts for roughly 50 percent of the electricity generated in the United States, is a second option. We will not retire existing plants overnight, making coal-fired electricity a reality for many years to come, even in the unlikely event that we never build another new coal plant. Accordingly, we must pursue clean coal technology. Yet this, too, has limitations. Since my first day as a utility CEO, I have been told that the revolution in clean coal is imminent. While we have had success in removing the sulfur and nitrous oxides from the emissions, the challenge currently lies in confronting carbon emissions. Carbon capture and sequestration technology may work; however, it has not yet been proven on a large scale. The most significant project that would do so – the FutureGen project in downstate Illinois – has been in limbo due to tenuous governmental funding and industry support. The technology must be proven on a large scale and made available for both new plants and as retrofits to existing plants. We must understand the cost of coal with carbon capture, which Exelon's analysis estimates to be the most expensive of any base-load generating option, at roughly $150 per metric ton of CO_2 avoided. And the public must understand and become comfortable with the risks of sequestration. The process involves injecting a large amount of carbon dioxide into a geological repository, where it must stay for the duration of human existence. If those repositories burp, our planet will have a problem.

The third option is new nuclear power. Today, nuclear is the predominant low-carbon base-load generating source. The EIA estimates that in 2007 nuclear accounted for approximately 74 percent of the electricity derived from sources that emit no greenhouse gas. And as an industry, we have made progress on many of the concerns that reared their heads during the 1980s.

- *Improved safety and reliability.* We have made great progress since the partial meltdown at Three Mile Island Unit 2. According to the NRC, the number of "significant events" at U.S. plants has fallen from an average of 1 in 1989 to somewhere in the neighborhood of between 0.04 and 0.07 in recent years. Capacity factors across the industry are substantially improved as well. At the time of the Three Mile Island incident, the average nuclear reactor in the United States generated power at only 60 percent capacity; today that capacity factor is 91 percent. At Exelon we have had 6 straight years with capacity factors in excess of 93 percent.
- *Improved public support.* The public perception of nuclear power is improving, due in no small part to efforts by the industry to win back the public's trust through the safety and reliability improvements mentioned above, as well as an increasing recognition of the cost and environmental impacts of other fuel options. A poll by Bisconti Research commissioned by the Nuclear Energy Institute in March 2009 found that 70 percent of Americans supported nuclear power, up from roughly 50 percent in the early 1980s. Among those who view nuclear as a low-carbon option, the support level increases to 75 percent. Of those who have a plant within 10 miles of their home, 82 percent view nuclear power favorably. Lest one suspect some bias in the polling based on who commissioned it, an independent poll by Zogby International conducted in June 2008 shows that two-thirds of Americans favor the construction of new nuclear plants.
- *Plentiful, stable, and secure fuel source.* Nuclear power offers advantages over gas from the standpoint of fuel security. The Organisation for Economic Co-operation and Development (OECD) noted in its *Nuclear Energy Outlook*, published in October 2008, that identified uranium supplies could support an expansion of nuclear generating capacity until 2050 without the need for reprocessing; additional suspected reserves could provide enough supply for "several hundreds of years." Moreover, the OECD points out that uranium comes from diverse sources and regions, with the key suppliers operating in politically stable countries. The high energy density of uranium means that its transportation is less vulnerable to disruption, and the storage of reserves is easier. Finally, Goldman Sachs states in its January 2008 report, "Reacting to Climate Change: Considering Nuclear Options," that uranium costs represent only about 10 percent of the overall production cost. This compares to roughly 77 percent for coal and 93 percent for gas, according to data provided by Ventyx. This means that even when uranium prices become volatile, as was the case in the past several years, nuclear power is substantially less vul-

nerable to price shocks. In the United States, investments are beginning to be made in conversion, fabrication, enrichment, and other parts of the fuel cycle. This strengthened fuel supply chain will support new nuclear facilities as they come on line.

- *Spent fuel.* Sadly, we are not much closer to a consensus solution on spent fuel than we were when I first became a CEO. The government and the industry have spent approximately $9 billion and countless man-hours over a 20-year period on a permanent repository at Yucca Mountain, Nevada. The Nevada congressional delegation has exerted a comparable amount of effort to thwart it. Recent policy pronouncements indicate that the game is over, and Nevada has won. Nevertheless, current storage provisions at existing nuclear generating sites are safe. The NRC has certified on-site storage for the 60-year life of the plant plus another 30 years afterward during decommissioning, and the amounts of fuel are relatively compact in physical size. The nuclear industry has paid the federal government $20 billion since its plants entered operation to fund the government's obligation to take possession of spent fuel. Progress is beginning on alternatives to a permanent geological repository. Secretary of Energy Steven Chu plans to assemble a blue ribbon commission to determine the best options for managing spent fuel and the back end of the nuclear fuel cycle. I believe that the most likely outcome will be several regional, above-ground interim storage sites, which will serve as a bridge to further development of the technology and a national consensus on the solution. However, all options must be on the table, including developing advanced, safe reprocessing methods to close the fuel cycle.

- *Competitive economics.* Nuclear generation from existing sources enjoys the lowest production cost of any major form of base load generation in the United States. According to the EIA, production costs in 2007 amounted to 1.8 cents per kilowatt hour for nuclear generation, compared to 2.5 cents for coal, and 6.8 cents for natural gas. Exelon's 17 reactors had an average production cost of 1.5 cents, well below the national average. In terms of new-build economics in the long-term, nuclear is competitive with gas and coal even without a price on carbon emissions. Goldman Sachs estimates that the construction cost of new nuclear plants is roughly 6.3 cents per kilowatt hour, equal to that of natural gas and scrubbed coal.[3] Their analysis assumes a long-term natural gas price of $7 per MMBtu, a long-term coal price of $65 per ton, and a new-build cost for nuclear of $6,000 per kilowatt (in nominal dollars). It also ignores any production tax credit benefit nuclear would enjoy under the provisions of the Energy Policy Act of 2005. Were that to be included and were there to be a $20 per metric ton carbon cost, nuclear would be advantaged over natural gas and far more attractive than scrubbed coal. Other studies provide different conclusions in terms of absolute generating costs but not in relative ordering.

While nuclear is far from being "too cheap to meter," neither is it too expensive to contemplate.[4] At the same time, there are three important caveats to this economic analysis to bear in mind.

- *Construction risk remains.* The U.S. nuclear supply chain has atrophied, and no major project will proceed without significant engineering and construction support from French or Japanese partners. The industry and the NRC have designed processes to avoid many of the regulatory and design delays that plagued the last cycle of construction, but several projects will need to be completed on-time and on-budget to instill confidence that we truly have learned to avoid our past mistakes.

- *Financing risk is more acute than ever.* A two-unit nuclear plant is a massive capital investment, greater than the book equity of Exelon, the largest company in the industry. While oil companies can and do regularly undertake capital projects of this size, building a new nuclear plant may be a task too large for the U.S. electric industry in its current state. A few utilities in traditionally rate-based regulatory environments with cooperative state utility commissions might be able to build a plant with the costs and risks borne by their ratepayers through construction-work-in-progress (CWIP) rate increases, allowing them to recover the costs from their customers even before the plant is placed in service. The federal loan guarantee program is designed to provide additional assistance, offering attractive debt financing for up to 80 percent of the project's costs. For companies like Exelon that operate in competitive markets without the backstop of ratepayers, loan guarantees are essential. Congress, however, has underfunded the loan guarantee program. The allocated $18.5 billion cannot adequately support more than 5 or 6 of the 26 proposed units, which will dramatically curtail construction plans. Whether through CWIP or loan guarantees, ultimately all utilities will need some form of assistance until the construction risk diminishes in the minds of investors and a price on carbon translates into power prices that can support a project of this size.

- *Current economic conditions are unfavorable.* It takes serious courage, if not sheer audacity, to begin a project of this size in the midst of the worst economic downturn since the Great Depression. Electricity demand has fallen in the near term and reserve margins are not as tight, creating uncertainty about the revenues of a new project. More significant is the collapse in the price of natural gas. It has reduced the marginal price of electricity dramatically, and at $4 per MMBtu, gas-fired generation is by far the preferred low-carbon base load option. None of this addresses the concerns about energy security, price volatility, and diversity in generation, but the prospect of low gas prices for several years to come may be as powerful as the Sirens' call to Odysseus.

Finally, the U.S. nuclear industry has made progress on proliferation. Our plants have security plans and well-trained security forces in place. These in-depth security measures are designed both to protect public health and safety in the event of a terrorist attack and to safeguard fissile materials. We are confident in our ability to protect against either possibility.

In a larger sense, the industry is ready to contribute to crafting a policy response to concerns about proliferation, but we are only a small part of that response. When a rogue state contemplates building a nuclear weapon, spent fuel sitting in Clinton, Illinois, or Pottsville, Pennsylvania, probably doesn't occur to them as their first or best option. In addition to storage at generally remote locations, the plutonium is mixed with highly radioactive elements that make handling spent fuel dangerous and reprocessing complicated. Nevertheless, we need a comprehensive solution that covers the nuclear power industry and others with potential weapons-making capabilities. The solution needs to be led by public policy-makers who are cognizant of all the issues and competing interests. And the solution needs to be global, accounting for not only the U.S. sources of potentially fissionable material, but also those sources around the world. The American nuclear power community stands ready to contribute to the debate on that solution, and will work to ensure that the ultimate nonproliferation regime is effective.

Nuclear power is inescapably part of the answer to addressing climate change. We face a growing need for power; every available option to meet that demand has its limitations. Energy efficiency is valuable but too limited in its scope to meet all of our future needs without radically changing the way we live. Renewables are too expensive and too unreliable at the current or near-term state of technological advancement. Coal is too dirty, and carbon capture and sequestration is too hypothetical. Natural gas is too volatile. And nuclear, while significantly more attractive today than 20 years ago, still has unresolved issues related to construction, economics, and spent fuel. Nothing is perfect, and none of these solutions is compelling on its own. All of them taken together give us a realistic chance of meeting our future energy needs and adapting our current generation mix for a carbon-constrained world. But construction of new nuclear plants has to be on the table with all of the other options.

Which brings me to one final inconvenient truth: when this nuclear renaissance comes, it will come not only to the United States and Europe, but also to Asia, Africa, and the Middle East. Barring a breakthrough on carbon sequestration for coal, there is no other way to meet the needs of the world's fastest growing economies in a low-carbon fashion. This clearly creates new challenges for nonproliferation regimes. Despite past stumbles and a couple of near-calamities, the nuclear community in the United States, Europe, and Japan has by and large managed to be, in Fermi's words, "sufficiently adult to make good use" of the power to split the atom. The realities of a warming climate and growing energy needs now force us to address Fermi's challenge amid a new, larger international nuclear-generating community.

ENDNOTES

1 Other studies suggest different figures, but the Brattle and EIA scenario is a good enough approximation to illustrate the task before us.

2 Exelon conducted a comprehensive economic analysis of carbon abatement opportunities as part of *Exelon 2020 : A Low Carbon Roadmap*. *Exelon* 2020 is our plan to reduce, offset, or displace more than 15 million metric tons of greenhouse gas emissions (our 2001 carbon footprint) per year by 2020. The report, along with the supply curve showing the various costs of avoided emissions, can be found on our website, www.exeloncorp.com.

3 Production costs consist of operations and maintenance charges plus the cost of nuclear fuel. This is contrasted to construction costs, which include the capital expenditures and expenses incurred up to the point of a unit's commencement of commercial operations. In this context, construction costs are quoted in nominal dollars and include a substantial amount of interest incurred during the lengthy construction period.

4 "Too cheap to meter" is an old chestnut from Rear Admiral Lewis L. Strauss, the particularly controversial head of the Atomic Energy Commission from 1953 – 1958. All too often it has been attributed to a utility executive.

Anne Lauvergeon

The nuclear renaissance: an opportunity to enhance the culture of nonproliferation

President Obama gave a remarkable speech in Prague on April 5, 2009, in which he called for deep reductions in nuclear arms in the immediate future and, eventually, a world without nuclear weapons. He also proposed strengthened measures to prevent the spread of nuclear weapons. His words recall those of the German philosopher Hegel: "Human beings make history, but they are not aware of which history they are making." We should join President Obama in becoming aware of the history we should all strive to make – one that lays the groundwork for a safer, more prosperous world in which the planet's resources are more equitably distributed and the environment is safer and cleaner.

The *we* which I use here refers, first and foremost, to states, which have the responsibility to ensure a peaceful and prosperous world. But nongovernmental actors, such as laboratories, universities, think tanks, and corporations, must each play its individual part in helping to build and sustain this world. And now that the growing enthusiasm for nuclear energy that has been expressed by governments, utilities, and electro-intensive industries around the globe seems more than just a craze or a passing fashion, it is that much more necessary to involve all stakeholders.

Do we have to fear this nuclear renaissance? Several observers suggest that we do, arguing that the current nonproliferation system, the product of many decades of development, simply no longer works effectively or that it needs to be radically altered. I would suggest that, rather than fear a nuclear renaissance, we must seize it as a unique opportunity to enhance the culture of nonproliferation, in a way that involves all stakeholders in this renaissance.

Rational, well-grounded reasons underlie the nuclear renaissance. Governments and electricity utilities want to build new nuclear plants to address greenhouse gas emissions and to meet growing energy needs. Nuclear must do so while addressing three challenges that lie at the heart of any energy consideration: namely, sustainability, competitiveness, and security.

Few sources of energy can meet all three of these requirements. Fossil fuels, with their substantial greenhouse gas emissions, cannot meet the sustainability requirement. While we do need to develop renewable energy sources, most renewables provide only intermittent supplies of energy and therefore cannot by themselves ensure full security of supply. Moreover, they do not meet the competitiveness requirement, since, like all sources of energy at an early stage of development, they will require heavy subsidies in the United States, as well as in Europe.

Nuclear energy meets all three requirements. Indeed, nuclear energy is:

- Carbon free and sustainable, because it emits the lowest amount of carbon per kilowatt hour among all sources of energy;
- Competitive, even without a carbon pricing system. That is why it is the choice of countries with highly regulated economic systems (for example, China and India); partially deregulated ones, such as the United States; or totally deregulated economies, like in the United Kingdom; and
- Secure, because uranium is widely available around the world. Current major mines are in politically stable countries, such as Canada and Australia, and conventional resources account for 200 times the annual demand. In addition, the global nuclear fuel market is functioning effectively, and consumer states are able to obtain satisfactory assurances of enriched uranium fuel through long-term contracts. For example, AREVA has signed a 60-year contract with one customer.

Nuclear power's ability to meet these requirements explains the growing global interest in nuclear energy. However, the prospects for expanding nuclear energy also come with concerns in some quarters that the spread of this technology could contribute to the proliferation of nuclear weapons, either in additional states or among non-state actors, such as terrorist groups. As a result, some have advocated discouraging the development of nuclear power, particularly its spread to states that do not now have nuclear energy programs in operation. Over the last several years, some academic and media circles have taken a pessimistic view of the prospects of containing the spread of nuclear weapons. They have argued that the end of the Cold War has accelerated the risks of proliferation and that the current nonproliferation system, a decades-long development, is no longer effective and needs to be radically altered.

While a few countries have taken irresponsible actions in the nuclear field that threaten international and regional peace and security, the international nonproliferation system has, on the whole, been highly successful in limiting the spread of nuclear weapons. One hundred and eighty-seven states now adhere to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). Only three states have elected not to join the NPT, and some states, such as South Africa or, more recently, Libya, have abandoned or dismantled their nuclear weapons programs altogether. The non-nuclear-weapons states that are party to the NPT have pledged to forgo the manufacture or acquisition of nuclear weapons and have agreed to accept International Atomic Energy Agency (IAEA) safeguards on all of their nuclear activities. Nearly all have faithfully abided by that commitment.

Nevertheless, during the past few years, new threats have emerged to challenge the global nonproliferation regime. Over a 20-year period, Iran has clandestinely acquired uranium enrichment capabilities in a manner that constitutes a violation of its obligations under the IAEA safeguards agreement. In this action Iran has been supported by Pakistan, which itself has admitted that A.Q. Khan, the former head of the Khan Research Laboratory in Pakistan, transferred enrichment technology to North Korea, Iran, and Libya. The A.Q. Khan clandestine network also spread nuclear weapons technology to Iran and Libya. Thus far Iran has chosen to ignore several calls by the United Nations Security Council to suspend its enrichment activities. North Korea, which withdrew from the NPT and conducted nuclear tests, demonstrates another major challenge to the nonproliferation regime. While North Korea had begun dismantling its nuclear facilities, the 6-party talks with Pyongyang have stalled over disagreements about verification arrangements; as of this writing, North Korea had just expelled IAEA inspectors and announced its decision to restart its facilities.

Clearly the nonproliferation regime shows weaknesses and needs continuous strengthening. Responsible members of the international community must be ever vigilant, and must accelerate their efforts to strengthen international safeguards, nuclear export controls, physical protection, and other elements of the regime. The nonproliferation policy proposed by President Obama provides hope that the international community can take effective steps to close the loopholes in the nonproliferation regime.

However great the challenges we now face in preventing the spread of nuclear weapons, they do not cast doubt on the effectiveness of the nonproliferation system as a whole. Nor do they justify the conclusion that the growth of civil nuclear power programs means the spread of nuclear weapons. It is worth emphasizing that the few countries that have sought to acquire nuclear weapons in recent years have done so for reasons of national security, national power, or prestige: in other words, their basic motivations have been political. The nuclear programs of these countries – North Korea, Iraq, and Iran – have never used nuclear power to produce a single kilowatt hour of electricity.

The responsibility for preventing the spread of nuclear weapons rests first and foremost with governments. As President Obama has said, "Rules must be binding. Violations must be punished." States must ensure that countries comply with commitments they have made under the NPT, their IAEA safeguards agreements, and other elements of the regime. But we all share in the responsibility to prevent the proliferation of nuclear weapons. The nuclear industry, as well as the arms control and nonproliferation communities, must join governments in ensuring that the nuclear renaissance takes place under conditions that minimize the risk of proliferation.

An opportunity to enhance the culture of nonproliferation

The renewed interest in nuclear energy and the international growth of nuclear electricity generation do not equate – and should not be equated – with increasing proliferation risks. Indeed, the nuclear renaissance presents a unique opportunity to enhance the culture of nonproliferation. The nuclear industry must play a major role in strengthening this culture. AREVA's "Value Charter" establishes nonproliferation at the top of its operating principles. Among other things:

- AREVA manages all of its nuclear facilities and nuclear materials in full accord with all international nonproliferation treaties, norms, and national regulations.
- AREVA does not, and will never, cooperate with any customer from a coun-

try that does not adhere to international nonproliferation standards or is not compliant with its nonproliferation obligations.

- Even if a country satisfies the above criteria, AREVA reserves the right to assess the political stability and security situation of the country, and even the region, to consider possible risks associated with a given commercial transaction.

- AREVA strictly implements national and international rules and procedures governing export control for all end-user countries; it has also developed a special training and awareness program for all AREVA employees in charge of export control.

- AREVA is ready to supply countries with light water reactors, such as its EPR reactor, that by themselves do not present a proliferation risk, provided effective controls and conditions are accepted and implemented in these countries.

- AREVA is committed to exercising special care in considering the transfer of sensitive technologies, such as enrichment and reprocessing (or recycling) technologies, to other countries. We have transferred recycling technology to Japan, with the provision that Japan agree to refrain from retransferring the technology to any other country, and we have supported the implementation of IAEA safeguards in Japan. We are currently considering transferring recycling technology (without separation of pure plutonium) for peaceful purposes to China, and we are also prepared to transfer such technology to the United States, if the United States chooses to adopt recycling as part of its strategy to manage the back end of its fuel cycle. However, we have no plans to transfer such sensitive nuclear technology to other countries.

It also bears mentioning that the vast majority of potential AREVA customers have no aspiration to acquire enrichment or recycling facilities. On the contrary, most are interested only in the generation of clean and affordable power. We no longer live in the era when countries sought to master all aspects of the nuclear fuel cycle for reasons of prestige or demonstrating their technological prowess. Rather, most countries recognize that we have entered an era of realism and efficiency in meeting energy needs. Countries have an equation to solve: how to generate X thousand megawatts of electricity beginning in 2020 or 2025 on a competitive, sustainable, and responsible basis. Nuclear electricity generation is one of the solutions; but most countries do not believe that the development of their own sensitive nuclear technologies, such as highly sophisticated uranium enrichment or used-fuel treatment capability, will provide them with a sensible, economic, or competitive approach to help solve this equation. None of AREVA's customers has expressed a real interest in acquiring sensitive nuclear technology. At any rate, AREVA would not provide such technologies to countries where it would make no economic sense, or where it would present a risk of political instability or a danger of proliferation.

Beyond the care that AREVA exercises in its nuclear export policies, AREVA also seeks to contribute to nonproliferation in several other ways. AREVA actively participates in numerous international initiatives, committees, and institutions that are working to strengthen the nonproliferation regime. Such participation gives AREVA the opportunity to share its experience, to benefit from the expertise of others, and to improve its own export control practices, safeguards, and physical protection measures. For example, AREVA joined the IAEA's Committee 2020, established in 2008 by IAEA Director General Mohamed ElBaradei with the purpose of reflecting upon the nature and scope of the Agency's program up to 2020 and beyond and addressing the many challenges and opportunities the Agency will face in the coming years. That committee's report set out concrete recommendations, calling for a reinvigorated global nuclear order that reduces risks while allowing rapidly growing contributions from nuclear technologies to human well-being. AREVA is also working with the International Commission on Nuclear Nonproliferation and Disarmament, chaired by Garreth Evans and Yuriko Kawaguchi. The commission aims to revive the global debate on the need to prevent the further spread of nuclear weapons, as well as the need for nuclear disarmament; the commission also hopes to strengthen the NPT by seeking to shape a global consensus in the lead-up to the 2010 NPT Review Conference and beyond. A key issue that the commission will examine is how to ensure that expanded use of civil nuclear energy – most welcome in view of climate change and energy security concerns – does not result in an associated increase in proliferation risks.

AREVA does not participate in such endeavors to enhance its public image or to win a seal of good behavior for the nuclear industry. Rather, AREVA believes that being a responsible member of the international community means that the nuclear industry should partner with others, to learn from them and to share with them AREVA's considerable experience in safeguards, physical protection, and other technical aspects of nonproliferation.

An opportunity to enhance the culture of nonproliferation

In considering the global nuclear renaissance, we need to pay special heed to the interests that developing countries have expressed in acquiring civil nuclear programs. Some observers have expressed concern that the expansion of civil nuclear power to such countries will only increase the risk of nuclear weapons proliferation. However, we should view these countries' interest in nuclear energy as good news, for at least three reasons.

First, we need to do everything we can to put an end to today's global energy imbalance. Two billion people currently live without access to electricity, and not having electricity shortens life expectancy to 35 or 40 years. We know that many countries without sufficient energy now will face serious power shortages in the future as their populations continue to grow. We should not – cannot – allow this situation to continue.

Second, the effects of climate change will not be limited to industrialized countries. Developing countries will be hit particularly hard by global warming. Many of them are now turning to nuclear power as a source of energy that is carbon free. Far from trying to dissuade this, we should applaud and support their efforts.

Third, objecting to nuclear energy in the developing world on nonproliferation grounds is politically, legally, and ethically unacceptable. Article IV of the NPT[1] is part of the basic bargain of the international nonproliferation regime. As President Obama stated in his speech in Prague:

> The basic bargain is sound: Countries with nuclear weapons will move towards

disarmament, countries without nuclear weapons will not acquire them, and all countries can access peaceful nuclear energy. To strengthen the treaty, we should embrace several principles. We need more resources and authority to strengthen international inspections. We need real and immediate consequences for countries caught breaking the rules or trying to leave the treaty without cause.

And we should build a new framework for civil nuclear cooperation, including an international fuel bank, so that countries can access peaceful power without increasing the risks of proliferation. That must be the right of every nation that renounces nuclear weapons, especially developing countries embarking on peaceful programs. And no approach will succeed if it's based on the denial of rights to nations that play by the rules. We must harness the power of nuclear energy on behalf of our efforts to combat climate change, and to advance peace opportunity for all people.

Opposing the expansion of civil nuclear power to developing countries by claiming that it will lead to the spread of nuclear weapons is to deny these states' right to peaceful nuclear energy. Any effort to deny the benefits of civil nuclear power programs to developing countries risks overturning the fundamental balance of the NPT and jeopardizes the very foundation of the nonproliferation system. Nuclear energy is not just a privilege for rich countries.

This does not mean that it makes sense for all developing countries to choose the nuclear power option. Nuclear energy will not be appropriate for some countries in the world because they lack the required political stability and secure environment, the industrial infrastructure, and the human and financial resources to purchase, operate, and maintain nuclear power plants in the long run. However, for those countries for which nuclear power provides a sensible economic and technical means of meeting energy needs, AREVA believes that the rules for selling nuclear reactors and fuel should be fair, nondiscriminatory, and universal. Once a country commits to comply with international nonproliferation norms and obligations, we must apply the same rules, whether that country is America or Finland, China or South Africa. India has represented an important development in this respect. The reopening of nuclear trade relations with India over the last years has been based on the necessary peaceful-use guarantees and international inspections in the country.

The past several years have seen a number of proposals to minimize the risks associated with the spread of sensitive nuclear technologies. The Nuclear Suppliers Group is working to develop new criteria for the transfer of enrichment and reprocessing technology. France, Germany, The Netherlands, Russia, the United Kingdom, and the United States, at the June 2006 meeting of the IAEA Board of Governors, offered improved fuel assurances in order to discourage countries from developing enrichment and reprocessing facilities of their own. The proposal from that meeting, "Concept for a Multilateral Mechanism for Reliable Access to Nuclear Fuel," outlines a reliable supply mechanism, backed up by reserves of enriched uranium, that would support expansion of nuclear energy while at the same time obviating the need for investments in additional enrichment and reprocessing facilities.[2] The United States announced in September 2005 that it would commit 17.4 tons of highly enriched uranium to be blended down to low enriched uranium "to support assurance of reliable fuel supplies for states that forgo enrichment and reprocessing."[3]

In addition, the Nuclear Threat Initiative (NTI), an American nongovernmental organization, pledged $50 million for the establishment of an international fuel bank under the auspices of the IAEA, provided that one or more member states contribute either an additional $100 million in funding or an equivalent value of low enriched uranium to jump-start the reserve. The United States, the European Union, Norway, the United Arab Emirates, and Kuwait have pledged the necessary funds to establish this bank; the IAEA now needs to define the proper mechanism to implement such a bank.

In June 2007, Russia offered to set aside 120 tons of low enriched uranium, to be released upon request by the IAEA for use by member states of the Agency.[4] These initiatives show that the international community is prepared to take concrete and meaningful steps to provide nuclear fuel assurances to countries that suffer disruptions of supply unrelated to their fulfilment of nonproliferation obligations.

The nuclear industry itself can play an important role in making the acquisition of national enrichment and recycling facilities unnecessary and uneconomic. A well-functioning fuel cycle market, with suppliers like AREVA providing enrichment and used-fuel recycling services at competitive prices, makes it unnecessary for newcomers to nuclear energy to acquire sensitive nuclear technologies. It is worth pointing out that developed countries such as Belgium and Switzerland have enjoyed the benefits of nuclear energy for 40 years without perceiving any need to acquire sensitive capabilities, despite their having the technical and financial means to do so. They have purchased nuclear fuel as part of long-term contracts with enrichment suppliers, covered by export licenses. To make sure its products and services remain reliable in the long term, the nuclear industry has already committed to major investments in new capacity.

An opportunity to enhance the culture of nonproliferation

However, we cannot restrict our attention to assurances of supply of nuclear fuel. We also have to decide how to manage the used nuclear fuel once it has been discharged from reactors. There has been a long-standing debate about the merits of recycling and the management of the back end of the fuel cycle. On one side of the debate is the once-through approach historically endorsed by the United States, which involves disposing of used nuclear fuel as a waste. On the other side is the recycling approach adopted by France, Japan, Belgium, Germany, the United Kingdom, The Netherlands, and under consideration by China and India; this approach entails recycling used fuel and recovering both plutonium and uranium to produce recycled fuel for peaceful use in nuclear reactors.

Concerns about the proliferation risks associated with recycling have been at the heart of U.S. policy, which was originally established on an interim basis by President Ford and was extended by President Carter. The Bush administration showed a new willingness to reconsider America's once-through used-fuel management strategy and to examine the merits of developing advanced reprocessing and recycling technologies. We do not yet know what policy the Obama administration will adopt on recycling, but Secretary of Energy Steven Chu has expressed interest in continued research and development in the area of recycling technologies.

AREVA believes that the closed fuel cycle approach is an industrial solution available today, and that under the appropriate nonproliferation controls and conditions, it offers a sensible path in the future for some countries. In such cases, AREVA's experience shows that treatment and recycling can provide a very good fuel-cycle option at a competitive cost, and is an economically, environmentally, and socially responsible approach to the management of used nuclear fuel. AREVA has treated more than 20,000 tons of used nuclear fuel from seven countries on a commercial basis. AREVA takes the used fuel produced by our customers back to La Hague and treats it there to recycle 96 percent of its contents. The recycled materials are then manufactured into mixed-oxide fuel (MOX) in our MELOX facility. Waste from recycling (which is exempt from IAEA safeguards) is returned to the country that enjoyed the benefit of the energy delivered. Recycled uranium can be reenriched and sent back on the global market. Plutonium, the most sensitive material, shall be recycled in selected countries, dependent on technical, economic, security, and nonproliferation considerations and subject to international arrangements. With such a model, most countries could enjoy the full benefits of nuclear energy without having either to master or develop locally any sensitive technologies, significantly contributing to stabilizing the world's geopolitics.

AREVA believes that treating used nuclear fuel and fabricating MOX fuel for countries under effective international safeguards and physical protection measures do not present a proliferation risk and will not contribute to the weakening of the nonproliferation regime. On the contrary, AREVA is contributing both to reducing proliferation risks and to protecting the environment by removing used fuel, recycling reusable material, and reducing the volume and radiotoxicity of waste. In this respect, AREVA is prepared to consider treating used fuel from countries that would not necessarily be interested in or be in a technical or political position to recover the recycled fuels themselves. Some utilities that already recycle their own fuels, as well as utilities located in the G8 countries, for instance, could be encouraged to facilitate such operations.

In addition to its industrial reprocessing and recycling programs, AREVA is contributing to nuclear arms control and disarmament by helping to eliminate excess weapons-grade plutonium from the United States in connection with the U.S.-Russian Plutonium Management and Disposition Agreement of 2000. Securing and reducing global inventories of nuclear weapons and materials must be an integral part of any effort to prevent them from falling into the hands of terrorists. The United States and Russia have already declared a significant fraction of their plutonium as in excess of their defense needs. Much larger amounts could be removed as they reduce their arsenals to somewhere in the range of 1,700 to 2,200 operationally deployed strategic nuclear warheads by 2012, as agreed under the Strategic Offensive Reductions Treaty (SORT). And U.S. President Obama and Russian President Medvedev have agreed to pursue new and verifiable reductions in strategic offensive arsenals. Such reductions could result in additional quantities of excess plutonium from dismantled weapons.

AREVA is building a MOX fuel fabrication facility in Savannah River, South Carolina, based on its MELOX facility. This new U.S. facility will enable the

United States to convert 34 metric tons of surplus weapons-grade plutonium into MOX fuel and to produce electricity for peaceful use in nuclear plants. President Obama has urged the nuclear-weapons states to reduce their nuclear weapons arsenals. AREVA, already part of several U.S.-led initiatives aimed at reducing the risks of unused highly enriched uranium, is ready to deepen its partnership with the U.S. government to support this goal. It is important to stress that using MOX fuel for peaceful purposes in nuclear reactors is the only solution available in the short term to reduce the surplus of weapons-usable plutonium and civil plutonium.

We have entered a world where the nuclear industry cannot be part of the problem; it must be an active part of the solution. It must help create a world where countries must replace the alleged prestige and status of possessing nuclear weapons or sensitive nuclear technologies with new emphasis on the efficiency and pragmatism of producing electricity for peaceful purposes.

An opportunity to enhance the culture of nonproliferation

The ongoing nuclear renaissance presents a tremendous opportunity to meet the energy, economic, and environmental needs of both developed and developing countries for the lifetime of our children and beyond. However, governments, industry, and the nonproliferation community must cooperate closely to ensure that the growth of nuclear power does not increase the risk of nuclear weapons. We must make use of this nuclear renaissance as a unique opportunity to enhance the culture of nonproliferation among all stakeholders in the renaissance.

ENDNOTES

1 Paragraph 1 of Article IV of the NPT provides that "Nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination and in conformity with articles I and II of this Treaty." Paragraph 2 of Article IV provides that "All the Parties to the Treaty undertake to facilitate, and have the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy. Parties to the Treaty in a position to do so shall also cooperate in contributing alone or together with other States or international organizations to the further development of the applications of nuclear energy for peaceful purposes, especially in the territories of non-nuclear-weapon States Party to the Treaty, with due consideration for the needs of the developing areas of the world."

2 Cf. IAEA document GOV/INF/2006/10, June 2006.

3 See IAEA document INFCIRC/659, September 2005.

4 Cf. IAEA document INFCIRC/708, June 2007.

Richard A. Meserve

The global nuclear safety regime

Today, there are approximately 440 nuclear power plants (NPPs) around the globe contributing roughly 16 percent of the world's total supply of electrical energy, and the contribution from nuclear power is likely to grow in the years ahead.[1] Energy is an essential underpinning for economic growth, and as the developing world advances, its demand for energy is projected to grow significantly. At the same time, the carbon-intensive energy sources the world now relies on – chiefly coal, petroleum, and natural gas – pose a grave threat because the growing concentrations of carbon dioxide in the atmosphere are bringing about climate change and ocean acidification. As a result, the world needs to turn to energy sources that are substantially carbon free. Nuclear power, by far the most significant current source of greenhouse-gas-free energy, must play an important part in the world's response to the increasing concentrations of greenhouse gases in the atmosphere. In addition, volatile fossil fuel prices, coupled with concerns about the security of oil and gas supplies, enhance interest in energy sources that do not pose the same costs and risks. Nuclear technology is attractive in this regard, too, because fuel costs are only a slight component to the costs of nuclear energy (most of the costs arise from the amortization of the plant) and because supplies of uranium are abundant and secure.

The current widespread interest in nuclear technology has been described as a "nuclear renaissance." Construction of new plants is under way or is contemplated around the globe. Some Asian countries have steadily pursued nuclear construction over the past few decades, and several are significantly accelerating their efforts. Many European countries that had turned away from nuclear power in the aftermath of the Chernobyl accident are reconsidering their positions and are either undertaking or exploring new construction. Although no generating company in the United States has placed an order for a new plant for more than 30 years, the Nuclear Regulatory Commission (NRC) has received 17 applications for combined construction-and-operating licenses for 26 plants, and it expects several more applications in the years ahead. Perhaps most important, many countries that do not currently have NPPs have expressed interest in acquiring one. (These countries are the so-called new entrants.) The International Atomic Energy Agency (IAEA) has reported that some 60 such countries have explored nuclear power in recent years, and that as many as 20 are seriously interested in proceeding with NPPs.

No doubt, the current worldwide economic decline will slow major projects of all kinds. Nuclear power is a capital intensive activity, and therefore financing a new plant will be a difficult undertaking until the economy recovers. Nonetheless, the pressures that created interest in nuclear power persist, and we should anticipate that significant new construction probably will occur around the world over the next decade or two.

The growth of nuclear power presents challenges. One, of course, is the concern that the spread of nuclear technology could enable more countries to pursue nuclear weapons. Reactors are not the principal concern in this regard; rather, expansion of nuclear power might result in new countries undertaking fuel-cycle activities that present proliferation threats. The need for an assured fuel supply could cause more countries to develop their own uranium enrichment capacity. (Most commercial NPPs require fuel enriched in the isotope uranium-235 to a level of 4 to 5 percent; natural uranium has 0.7 percent uranium-235.) Although commercial nuclear fuel is not usable in a weapon, the technology to enrich uranium to the level needed for fuel could be applied to produce highly enriched uranium (above 20 percent uranium-235) – a weapons-usable material. Moreover, the used fuel from NPP operations can be chemically reprocessed to recover plutonium, another weapons-usable material. Because the principal barrier to the construction of a nuclear weapon is the challenge of obtaining the necessary weapons-usable material, expanded enrichment or reprocessing capacity heightens the proliferation risk, a significant concern that is discussed by other contributors in this volume.

The public also has particular concerns about the safety and security risks that attend nuclear power. We must heed these concerns not only because the public who might be affected by an accidental release from a NPP must be protected, but also because the prospects for nuclear power everywhere would be influenced by the public clamor following a serious nuclear event anywhere.

The history of nuclear power reinforces the need to pay special attention to safety. In 1979, operators at the Three Mile Island Plant in Pennsylvania failed to respond appropriately to a pressure relief valve on a reactor that was stuck in the open position, resulting in the venting of coolant. There was extensive melting of fuel, and, in effect, the reactor was destroyed. But no radioactive materials in excess of regulatory limits were emitted into the environment because the containment structure that surrounded the reactor prevented uncontrolled releases. The Russian RBMK reactor at the Chernobyl Power Plant in the Ukraine did not have a containment system, with the result that, in 1986, a runaway reactor not only destroyed the reactor, but also released extensive radioactive materials into the environment, spreading radioactive materials across Europe. Understandably, these events dampened enthusiasm for nuclear power in the United States and Europe in subsequent years.

Events such as these reinforce the obligation of all those associated with nuclear power – operators, regulators, vendors, and contractors – to be ever-vigilant. Fortunately, the recent safety record has, in the main, been good. Plant-based safety indicators (for example, measures of such things as actuation of reactor safety equipment, availability of safety-related equipment, releases of radiation, worker exposure, and unplanned shutdowns) have shown reasonably steady improvement for more than a decade. These improvements, attributable to greater attention to operations, maintenance, training, advances in diagnostic and assessment technology, and system upgrades, are impressive and, as a general matter, reassuring.

Recent experience also shows that strong economic performance correlates with strong safety performance. In the United States, for example, the improvement in safety indicators coincided with a significant improvement in capacity factors (a measure of the energy production actually achieved weighed against the theoretical maximum from continuous full-power operation). This correlation isn't accidental: the attention to detail that improves safety also leads to plant availability and stronger economic performance.[2]

Nevertheless, noteworthy safety lapses continue to occur at NPPs around the globe, including at reactors in countries with extensive operational experience and strong regulatory capabilities. None of the recent events has resulted in a substantial off-site release of radioactivity,[3] but these events reinforce the reality that assuring safety is hard work. It must be embedded in the management and cultural practices of both operators and regulators; it is an obligation that demands constant attention.

One lesson from years of operations is that the operator must assume the primary obligation for assuring safety. The operator controls what happens in the plant and, as a result, can best assure continuing safe performance. The operator must have the engineering, financial, and management capability to ensure not only that the plant is built and operated in a safe fashion, but also that it operates with safety as the highest priority. In turn, a national nuclear safety regulator undertakes the reinforcement and policing of the operator, defining the operator's responsibilities and seeking to ensure that those responsibilities are being met. The regulator should be independent, capable, and sufficiently staffed and funded to perform its functions. Every regulator should aspire to be tough, but fair, to fulfill its obligations and to meet public expectations.

Although operators and national regulators play the essential roles, there is an important backstop to the licensee and regulator: the global nuclear safety regime. The regime is a collective international enterprise that sets a level of performance expected of all operators and regulators, monitors that performance, and builds competence and capability among both operators and national regulators. This global nuclear safety regime will be increasingly important as the nuclear renaissance takes full flower.

Ad hoc in nature, the regime has grown and developed over many years. It is made up of several components:

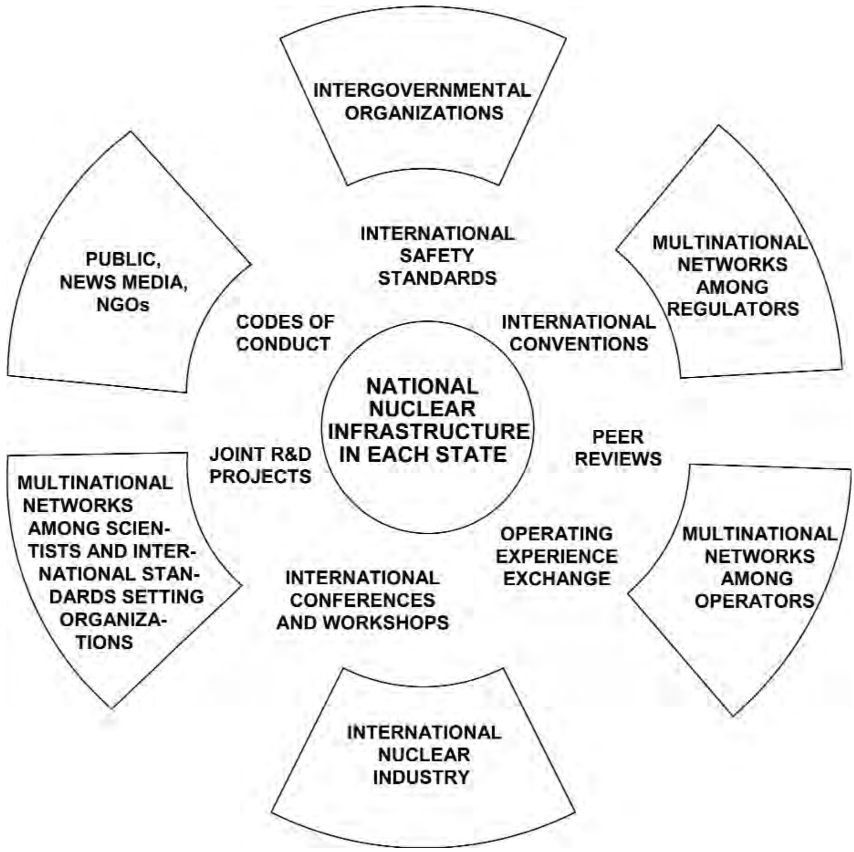
- Intergovernmental organizations such as the IAEA and the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD). The IAEA is a UN organization with responsibilities for nonproliferation, the safety and security of nuclear facilities, and the peaceful application of nuclear technology. In the safety and security arena, it provides standards and, at the request of a member country, inspections and advice on nuclear activities. The NEA is involved in international cooperative safety research and in the study of safety and regulatory issues. The IAEA and NEA jointly operate an international system for the exchange of operating experience.

- Multinational networks among regulators, including the International Nuclear Regulators Association and the Western European Nuclear Regulators Association. These networks encourage regulators to exchange views and information and coordinate activities.
- Multinational networks among operators, the most important of which is the World Association of Nuclear Operators (WANO). Among other activities, WANO provides peer reviews of plant operations and serves as a clearinghouse for the exchange of operating information between operators. WANO assessments and advice are held confidential. The World Institute for Nuclear Security (WINS) was recently created to serve a similar function on security-related matters at nuclear facilities.
- Stakeholders in the international nuclear industry. The vendors that design and sell NPPs are international businesses that market their products throughout the world. Similarly, the architect-engineering firms and the suppliers of equipment and services are worldwide enterprises. These enterprises provide a means for transferring knowledge from country to country.
- Multinational networks among scientists and engineers. Scientific and engineering societies encourage communication among experts in many nations.
- Standard development organizations – for example, the American Society of Mechanical Engineers (ASME), IEEE (formerly known as the Institute of Electrical and Electronics Engineers), and the American Nuclear Society (ANS) – and their interfaces with the International Organization for Standardization (ISO). Parts and components may originate in many different countries, and thus compliance with detailed standards is an important means of assuring appropriate quality.
- Nongovernmental organizations and the international press. Nuclear activities attract attention and interest around the globe, including from NGOs and the press. This attention provides an important stimulus for change.

A framework of international conventions, international safety standards, codes of conduct, joint projects, and international conferences and workshops holds the system together. These elements together provide the context in which every national nuclear program operates. (See Figure 1.)

Several overlapping factors serve to make the examination and revitalization of the global nuclear safety regime a pressing obligation. First, every nation's reliance on nuclear power is to some extent hostage to safety performance elsewhere in the world; a nuclear accident anywhere will have significant consequences everywhere, if only through an indirect impact on public opinion. Thus each country currently using or contemplating nuclear power has an interest in ensuring that there is attention to nuclear safety everywhere. The overall global improvement in safety performance does not tell the whole, or even the most crucial element of the

Figure 1
Global Nuclear Safety Regime



Source: IAEA, *Strengthening the Global Nuclear Safety Regime* (INSAG 21), 2006. Reprinted with permission from the International Atomic Energy Agency.

story. The web of nuclear safety is no stronger than its weakest link: all are vulnerable to the capabilities of the weakest performers. It is in the interest of all to identify and help those most in need of strengthening their safety performance.

The need for such international assistance is growing. As noted above, there is the prospect of substantial numbers of new entrants and of increasing numbers of NPPs around the globe. Many of the new entrants, by definition, have limited experience with nuclear energy, and nearly all lack the extensive national infrastructure common in most countries currently with NPPs. Constructing and operating these new NPPs in a safe fashion demands a strengthened international backstop.

Moreover, many currently operating plants were built years ago and are nearing the end of their originally anticipated lifetime of 40 years or so. The plants have had the benefit of detailed surveillance, maintenance, and replacement of components over those years, and many of them are running reliably and economically. As a result, operators in several countries are seeking to extend operations to 60 years and some are raising the prospect of operation for as long as 80 years. But aging plants present unique safety challenges because plants and equipment can deteriorate over time through mechanisms that may not yet be fully understood (for example, stress corrosion cracking); because spare parts may be difficult to find; and because older plants may not have all of the safety features of more modern designs. The continuing operation of older plants thus requires careful attention to aging mechanisms, with heightened attention over time to surveillance, preventive maintenance, and component replacement. Here again, the international system should help ensure that the safety margins of aging plants are maintained.

Second, the construction and servicing of NPPs has become a global enterprise, with vendors and contractors engaged around the world. Consequently, efficiencies and safety advantages have arisen from avoiding needless country-specific differences that require custom design modifications or that present unique operational challenges. Nuclear power must compete in the economic marketplace with other sources of energy, and the legal regime should further, rather than retard, economic efficiency, while simultaneously ensuring adequate safety. The global safety regime should reflect and respond to the changing structure of the industry by encouraging greater international harmonization.

Finally, there is also the simple reality that we have much to learn from each other. One of the most important ways to anticipate and prevent possible problems is to analyze and learn from the relevant experience of others, and to put in place anticipatory or corrective measures to forestall an accident. We now have about 13,000 reactor-years of experience around the world, and we benefit from putting systems in place to share the knowledge arising from that experience. Moreover, benefits are obtained by coordinating research activities and sharing research results, thereby reducing the cost of research to each participant and helping to ensure that all benefit from the growth in knowledge. The global safety regime should encourage the sharing of knowledge and nurture its expansion.

Any one of these reasons is sufficient by itself to justify the careful scrutiny of the global safety regime. Taken together, they offer a compelling argument for review. But what should change?

As noted above, the existing legal regime is founded on the fundamental obligation of operators to ensure safety, subject to rigorous oversight by a *national* regulatory entity exercising sovereign authority to protect the public health and safety. The national programs are augmented by an overlay of assistance provided by and through a variety of international organizations, chief among them the IAEA, the NEA, and WANO. But the decisions of each nation-state largely determine the extent and scope of international engagement.

One might imagine a different regime in which an international regulator with sweeping transnational authority ensures the adequacy of licensees' safety performance. Such an approach might be seen as a way both to ensure that all nuclear activities, regardless of location, conform to safety standards as well as to facilitate the harnessing of safety capabilities around the globe in an efficient and effective manner. It is very unlikely, however, that such a regime will soon be established, at least not in an extreme form, in which an international regulator displaces national regulators. Certainly, the population in the vicinity of a nuclear facility needs to be assured that its safety is guaranteed by a politically responsive body, rather than a distant and unaccountable international regulator. And the strategic importance of energy supply makes it doubtful that any nation would willingly surrender its authority over the continued operation of critical energy infrastructure, such as a NPP. Moreover, the safety system must operate within each nation's legal, economic, and social culture; adaptations of regulatory systems to fit local conditions are probably necessary in any event.

Accordingly, a global safety regime premised on a single and strong international regulator is implausible, perhaps even undesirable. This is not to deny, however, that we should encourage regional networks among regulators to share resources and capabilities, or that in the long term we should seek to establish the capacity of the IAEA to inspect and police the performance of the national safety systems, to ensure that at least minimum safety standards are achieved. The IAEA would then have strengthened capacity to ensure that the national systems were functioning appropriately.

At the moment, the IAEA does not have the power to undertake independent safety inspections absent the invitation of the member state, or the authority even to recommend sanctions for poor performance. Given safety's importance, the objective over time should be to enhance the IAEA's power to assure safety by giving the IAEA powers in the safety arena that are analogous to its powers on safeguards matters under the Additional Protocol – that is, the power to inspect nuclear facilities at a time of its choosing and to establish and seek compliance with standards. Because the national regulator will continue to have ongoing regulatory responsibilities, the focus of IAEA's increased role would be to monitor and assess the adequacy of the national regulator's efforts. An amendment of the Convention on Nuclear Safety (CNS) (discussed below) would provide the logical vehicle for the institution of these powers.

Establishing such strengthened inspection and enforcement authority would likely take many years of difficult negotiation and an arduous and time-consuming process to bring an amendment of the CNS into force. The difficulty of establishing the widespread implementation of the Additional Protocol in the safeguards arena illustrates the challenge that should be expected. In the meantime, however, the existing system can and should be reinforced and expanded in various ways. We must proceed now to augment national systems with a stronger overlay of international cooperation and engagement.

First, the safety services offered by the IAEA need to be enhanced. These services, which include voluntary inspections of nuclear facilities and of regulatory systems, currently receive only about 8 percent of the IAEA's regular budget. Given the need to assist the new entrants in establishing and maintaining appropriate national safety systems, the IAEA effort should grow significantly. There is an immediate need to provide training facilities for the staff of the operating companies and the regulatory organizations that will carry the primary responsibility for assuring safety at these new facilities. The IAEA (among others) has a very important role to play in making certain that the new entrants have the capacity and knowledge to fulfill their responsibilities.

Second, international security-related services need to be strengthened and coordinated with safety. Safety is focused on accidental events whereas, in the case of NPPs, security is aimed principally at preventing acts of sabotage that could result in releases of radioactive materials.[4] (Security at fuel-cycle facilities also focuses on the prevention of the theft of nuclear materials.) The security of NPPs has appropriately received greatly increased attention in the aftermath of the 9/11 attacks.

The security challenge will grow with the advent of more NPPs and more fuel-cycle facilities in more places. But the international network of security-related services, still in development, has not achieved the maturity that surrounds safety. Because of the need to keep security-related information confidential, there are challenges in designing and implementing international programs. This should be given high priority.

Safety and security are linked to each other. Common principles apply to both safety and security, such as a philosophy of defense in depth. The two objectives can reinforce each other: the massive structures of reinforced concrete and steel, for example, serve both safety and security objectives. But occasionally, plant features and operational practices that result from safety considerations conflict with those that serve security purposes. Access controls that are imposed for security reasons can inhibit safety, limiting access for emergency response or maintenance or for egress in the event of a fire or explosion. Similarly, if there were an attack, safety considerations may require access to an area at exactly the time that the security forces might seek to deny access. In short, the synergy and the antagonism between safety and security require careful evaluation.

This reality has national and international implications. At the national level, although the evaluation of security threats might appropriately be the responsibility of an intelligence or police organization, authority to determine the actions necessary to ensure both safety and security should be vested in a single body, so that safety and security are weighed at the same time and an appropriate balance is found. At the international level, the guidance and assistance that are now commonplace in the safety arena should be expanded to cover security, in a way that integrates security and safety advice. Both the IAEA and WINS should play a role in assuring that appropriate integration occurs.

Third, a universal, effective, and open network for sharing operating experience should be established to promote communication about near misses, design deficiencies, and even low-level operational events. Analysis of such occurrences can indicate ways of avoiding a serious accident. Currently, regulators and operators report safety-related information through existing global systems. The IAEA and NEA jointly operate an Incident Reporting System (IRS) that is available to the world's regulators; operators have access to operating information, on a private and confidential basis, from WANO. But not all relevant events and observations are reported, particularly to IRS. Moreover, there are inadequate mechanisms to sort and analyze the information, to distill and prioritize the lessons that should be learned, and to propagate those lessons widely in a user-friendly fashion. There is a need to find the means to preserve and facilitate access to the accumulated knowledge from operational experience in order to further the common interest in avoiding events that could lead to accidents. Access to such information is particularly important for the new entrant countries, so that they do not have to repeat the hard-learned lessons of their predecessors in the nuclear enterprise.

Fourth, to enhance the assurance of safety, national safety regulations should be harmonized, so that minimum requirements are met everywhere and greater compatibility is facilitated. The IAEA has developed three layers of documents – Safety Fundamentals, Safety Requirements, and Safety Guides – that provide a widely accepted foundation for nuclear safety and now serve as key references for national requirements. Safety Fundamentals establish the foundation that must be met without exceptions. Safety Requirements set mandates for new facilities and new activities, while setting a compliance target for existing facilities and activities to be met over time, if it is reasonable to do so. Safety Guides provide practical guidance on the state of the art in nuclear safety, but acknowledge that different means of providing equivalent safety are acceptable. While rigid application of IAEA safety standards may not be possible, particularly for existing facilities, IAEA standards do provide a common approach to which nations should be encouraged to conform, to the extent practical. The IAEA should pursue full awareness of and competence in the application of these standards.

At the same time, IAEA safety standards should be encouraged to evolve in two different directions. On the one hand, we should seek a global consensus on fundamental principles – how safe is safe enough – to guide the articulation of general safety goals, the expectations for new plants, and the requirements for safety improvements in older plants. This effort would seek to establish enduring fundamental goals, thereby serving the overall objectives of transparency, adequacy, stability, and harmonization. Compatibility can never be achieved unless there is common agreement on the fundamental goals.

On the other hand, the standards should be made sufficiently concrete, providing unambiguous guidance on the accepted and best practices in the multitude of areas in need of regulatory guidance. Again, compatibility can only be expected if the practical implications of the requirements are spelled out. However, safety standards must evolve to accommodate innovative new reactor designs. The existing standards, understandably, were written with current light water reactors in mind, and many of the requirements may not be appropriate, at least in their current form, for some of the new reactor designs being contemplated. (For example, the Safety Requirements document on design explicitly states in its introduction that it applies primarily to water-cooled reactors; similar statements are found in several of the supporting safety guides.) While the key elements of requirements can certainly be applied by analogy in some cases to different types of reactors, it would be beneficial to define a deeper set of principles so that the regulatory system can more readily accommodate, even encourage, designs that offer improved safety and other advantages.

Fifth, certain essential characteristics that extend beyond standards, but that are the foundation for success in achieving safety, must be encouraged. Prime among these is encouragement of an appropriate "safety culture": the cluster of organizational and individual elements that are fundamental to the achievement of safety. Organizational elements include the recognition by management that safety is the highest priority, as well as a commitment by management to organizational effectiveness, successful communications, a capacity to learn and adapt, and a workplace culture that encourages the identification of safety issues. Individual elements include personal accountability, a questioning attitude, and procedural adherence. These elements are difficult to define crisply and, hence, to regulate effectively. But they are foundational to safe operations, and the global nuclear safety regime should encourage their propagation everywhere. Similarly, the safety regime should encourage transparency, stability, practicality, and competence. Greater efforts must be undertaken to build these characteristics into regulatory and operator organizations around the world.

Sixth, while pursuing the amendment of the CNS along the lines described above, its current processes could be augmented without a formal amendment. The CNS calls for a meeting of parties at three-year intervals in which each state provides a report on its compliance with the various commitments set out in the Convention. Each national report is subject to peer review by the other parties, often resulting in recommendations for further improvement. The Convention offers no enforcement mechanism beyond the obligation to endure possible criticism from others in the review meeting.

Although the CNS has furthered its original purpose of promoting upgrades in national safety systems, the process still needs to be strengthened and refined. The review process could be more probing, perhaps by focusing on the most important safety issues, rather than by emphasizing a wide (and necessarily superficial) survey that is today's norm. The IAEA now reports to the meeting of the parties on conclusions drawn from its safety review missions and services, but the IAEA could contribute more centrally. The IAEA's report might, for example, provide more detail and be given more focused attention by the parties, perhaps by requiring affected nations to respond to the IAEA's observations. Perhaps most fundamentally, the perspective of the parties should change: rather than seeking to prove its own excellence in the review process, each country should instead welcome productive criticism and thereby collect useful ideas and lessons for safety enhancements. The questioning and open attitude that regulators expect of their licensees might also become the expected behavior of the parties in the review meetings.

Seventh, multinational design evaluation programs should be encouraged. As noted previously, the nuclear industry has become more concentrated, with the result that a small group of vendors seeks to construct NPPs around the globe. A group of countries is coordinating the evaluation of the designs, with the NEA serving as the secretariat for the group. Each national regulator retains its autonomous licensing authority, but can obtain guidance and information from the international evaluation process. This effort should be encouraged and expanded, with the aim to facilitate the construction of a given design in more than one country with only necessary modifications to accommodate local circumstances.[5] The multinational process facilitates the coordination of safety assessments, perhaps enabling more complete and thorough assessments than any one country could accomplish. It would also promote international trade, by bringing cost savings to the parties involved in licensing the plants and in constructing them. And it would further the general goal of advancing greater international consistency, thereby avoiding questions that may reasonably arise if significant differences in design were to be required from country to country.

Of course, because each country will retain its licensing authority, the final licensing actions must be taken at a national level. The coordination of design evaluation thus should not be seen to challenge the sovereign authority of national regulators. Clearly, site- or country-specific issues must be taken into account separately in connection with each construction application – issues such as site-related risk factors (for example, earthquake risk), reliability of off-site power, and the licensee's capability to build, operate, and maintain the plant. Indeed, the national regulator must be fully engaged in the details of design, construction, and operation if it is to be effective in the oversight of the plant. Nonetheless, a coordinated international design evaluation would streamline and strengthen the process, augmenting the capacities that any particular regulator could bring to bear.

At the same time, because the nuclear industry is part of a world economy in which production capabilities are globally interconnected, parts and components for nuclear plants may come from many areas of the world. The quality-assurance standards for nuclear plants are high, but no one regulator, vendor, or operator can readily have scrutiny over the quality of all these parts and components. As a result, there is a need for careful coordination among regulators around the globe to develop global standards and to ensure that those standards are being met.

Finally, increased efforts should be undertaken to advance international cooperation on research and development related to the safety performance of NPPs. Many existing plants were licensed in the years before there was extensive experience with nuclear power. Licensing decisions were guided by conservative engineering judgment and the application of fundamental design principles (such as defense in depth) to assure a robust capacity to mitigate or prevent accidents. But much has been learned over the years, and the resulting insights should be applied more effectively than is currently the case in many countries. For example, the insights from both probabilistic and deterministic analyses should be brought together and applied so as to assure focused attention on safety in all important areas. An international consensus on the application of these tools should be developed, to facilitate common understandings and standardized approaches. Moreover, coordinated research programs to increase knowledge bearing on advanced designs will ensure that necessary information is in place in time to facilitate decision-making.

There are opportunities for other international research activities that will benefit all. For example, aging phenomena that will affect performance of NPPs are not well understood at a fundamental level and, absent research, it is not clear that these issues will be dealt with properly. Further advances in nondestructive monitoring techniques will enhance the capacity to assess aging facilities. And although digital instrumentation and control offers great opportunities for safety improvements, there is a need for research to understand more deeply the safety implications of the increased reliance on digital systems. Many other such research opportunities present themselves.

The global nuclear safety regime provides an important and largely unrecognized means for helping to assure the safety of existing and future NPPs. It will have growing importance in the coming years, and there are opportunities for its significant improvement. These opportunities should be pursued in order to ensure that nuclear technology can be appropriately harnessed for the benefit of all humankind.

ENDNOTES

[1] Many of the matters explored in this paper are discussed in an International Atomic Energy Agency (IAEA) document prepared by the International Nuclear Safety Group (INSAG); IAEA, *Strengthening the Global Nuclear Safety Regime* (INSAG 21), 2006.

[2] See Statement by IAEA Director General Mohamed ElBaradei, *Nuclear Safety: A Maturing Discipline* (October 14, 2003), http://www.iaea.or.at/PrinterFriendly/NewsCenter/Statements/2003/ebsp2003n022.html.

[3] The most serious recent event in the United States can be characterized as a near miss. In 2002, it was discovered that corrosion arising from a boric acid leak at the Davis-Besse Plant in Ohio had completely penetrated 6 inches of steel in the head of the reactor pressure vessel, leaving a pineapple-sized hole. The pressure boundary was preserved only by the stainless-steel cladding on the inner surface of the head – cladding that was not intended to provide pressure integrity. There had been clear clues of a significant problem – for example, containment filters clogged with corrosion products – that were ignored by the licensee and by the NRC inspectors, presumably in part because of falsified inspection reports by licensee staff.

[4] Some reactors are fueled with mixed oxide (MOX) fuel, which includes both plutonium and uranium fissile materials. Fresh MOX fuel also needs to be protected from theft or diversion at power reactors.

[5] Unfortunately, substantial modifications from country to country may be necessary in some circumstances. Consider, for example, the consequences of the differing national standards for electricity between the United States (60 Hz, 120 V) and Europe (50 Hz, 220 V). Frequency differences in particular can drive substantial design changes because they affect the sizes of motors and the buildings in which they are installed, which in turn affect seismic analyses and cooling requirements. Substantial design changes result directly from different national standards for electricity.

Matthew Bunn

Reducing the greatest risks of nuclear theft & terrorism

In April 2009, President Obama warned that there was still a real danger that terrorists might get and use a nuclear bomb, calling that possibility "the most immediate and extreme threat to global security." He announced "a new international effort to secure all vulnerable nuclear material around the world within four years."

Keeping nuclear weapons and the difficult-to-manufacture materials needed to make them out of terrorist hands is critical to U.S. and world security – and to the future of nuclear energy as well. In the aftermath of a terrorist nuclear attack, there would be no chance of convincing governments, utilities, and publics to build nuclear reactors on the scale required for nuclear energy to make any significant contribution to coping with climate change.

But Obama's four-year goal will not be easy to achieve. At sites in dozens of countries around the world, the security measures in place for plutonium or highly enriched uranium (HEU) – the essential ingredients of nuclear weapons – are dangerously inadequate, amounting in some cases to no more than a night watchman and a chain-link fence. Changing that in four years will take sustained White House leadership, broad international cooperation, a comprehensive plan, and adequate resources.[1] The fundamental key to success will be convincing policy-makers and nuclear managers around the world that nuclear terrorism is a real threat to *their* countries' security, worthy of new investments of their time and resources to reduce the risks – something many of them do *not* believe today.

Resources for this mission are not infinite, and choices will have to be made. Clearly there is little prospect of arranging for every building that has some plutonium or HEU to have a division of armed troops to guard it. It is critical to focus resources on reducing the most serious risks. But how can we judge where those most serious risks lie?

There remains a very real danger that terrorists could get and use a nuclear bomb, turning the heart of a major city into a smoldering radioactive ruin. Tens or hundreds of thousands of people would be killed, and devastating economic shock waves would reverberate throughout the world, creating a second death toll in the developing world from the ensuing increase in global poverty, as then UN Secretary-General Kofi

Annan warned in 2005. The horror of such an event, were it ever to occur, would change America and the world forever.

The al Qaeda terrorist network has been seeking nuclear weapons for years. Osama bin Laden has said that he feels a "religious duty" to acquire nuclear and chemical weapons, and al Qaeda operatives have made repeated attempts to buy stolen nuclear material in order to make a nuclear bomb. They have tried to recruit nuclear weapon scientists to help them, including, but not limited to, the two extremist Pakistani nuclear weapon scientists who met with bin Laden and Ayman al-Zawahiri shortly before the 9/11 attacks to discuss nuclear weapons. Documents recovered in Afghanistan reveal a significant al Qaeda research effort focused on nuclear weapons. This effort included preliminary tests with conventional explosives in the Afghan desert. Long after the removal of al Qaeda's Afghanistan sanctuary, bin Laden sought and received a religious ruling, or *fatwa*, from a radical Saudi cleric authorizing the use of nuclear weapons against American civilians. In the 1990s, the Aum Shinrikyo terror cult, which launched the nerve gas attack in the Tokyo subways, also sought nuclear weapons. Russian officials have confirmed two cases of terrorist teams, presumably Chechens, carrying out reconnaissance at secret Russian nuclear weapon storage sites. With at least two groups pursuing nuclear weapons in the last 15 years, we must expect that others will, too, in the future.

Repeated government studies in the United States and in other countries have concluded that if a technically sophisticated terrorist group could get the HEU or plutonium they need, they might well be able to make at least a crude nuclear bomb. Making a bomb does not take a Manhattan project: more than 90 percent of that 1940s-era effort was devoted to making the nuclear material, not making the bomb; and that was before the basic principles of nuclear bombs were widely known, as they are today. One study by the now-defunct congressional Office of Technology Assessment summarized the threat: "A small group of people, none of whom have [*sic*] ever had access to the classified literature, could possibly design and build a crude nuclear explosive device.... Only modest machine-shop facilities that could be contracted for without arousing suspicion would be required."

Theft of potential nuclear bomb materials is not just a hypothetical worry; it is an ongoing reality, highlighting the inadequacy of the nuclear security measures in place today: the International Atomic Energy Agency (IAEA) has documented some 18 cases of theft or loss of plutonium or HEU confirmed by the states concerned (and there are more cases that the relevant states have so far been unwilling to confirm, despite the conviction of some of the participants). In virtually all of the known cases, no one had ever noticed the stolen material was missing until it was seized, suggesting that other thefts may have gone undetected.

Fortunately, there is no convincing evidence that any terrorist group has yet gotten the nuclear material or the expertise needed to make a bomb (though we cannot know what capabilities they may have succeeded in keeping secret). Also fortunately, hostile states are highly unlikely to choose to provide nuclear weapons or the materials needed to make them to terrorist groups, because of the possibility that this would be traced back to them and that overwhelming, regime-destroying retaliation would follow. Moreover, making plutonium or HEU on their own is beyond the plausible capabilities of any terrorist group today. Hence, if the world's stockpiles of nuclear weapons, plutonium, and HEU can be kept under tight state control, nuclear terrorism can be prevented.

A multilayer defense against nuclear terrorism is certainly needed, including efforts to stymie terrorist nuclear plots and interdict nuclear smuggling; but the greatest policy leverage on reducing the risk is in the first layer, in preventing nuclear weapons and materials from being stolen in the first place. The plutonium or HEU needed for a bomb would fit easily in a suitcase, and is not radioactive enough to make it dangerous for nuclear smugglers to transport or easy for border officials to detect. Thus, once someone succeeds in getting these materials out of the facility where they are supposed to be, they could be anywhere, and the problem of finding and recovering them multiplies a thousandfold. In short, insecure nuclear material anywhere is a threat to everyone, everywhere – and that threat must be addressed by a fast-paced global campaign to ensure that all nuclear weapons and all of the materials needed to make them are secure and accounted for.

Terrorists seeking a nuclear bomb or the materials to make one – or thieves seeking to supply them – will steal wherever they think they have the best chance of success in meeting their objectives. This means not only that the theft itself has to be successful, but that the terrorists have to be able to set off a nuclear bomb with what they get. The risk of nuclear theft from any particular facility or transport operation depends on:

- The quantity and quality of the material available to be stolen (that is, how difficult it would be to use it to make a nuclear bomb);
- The security measures in place (that is, what kind of insider and outsider thieves could the security measures protect against, with what probability); and
- The threats those security measures must protect against (that is, the probability of different levels of insider or outsider capabilities being brought to bear in a theft attempt).

The overall risk of nuclear theft depends on the balance among these factors. The few sites where the tails of two distributions intersect – sites or transport routes with particularly weak security measures facing adversaries with particularly effective capabilities – dominate the global risk of nuclear theft, both because terrorists are more likely to target them and because they are more likely to succeed if they do.

Because these factors interact, a one-size-fits-all approach to nuclear security will not work. A security system effective enough to reduce the risk to a low level in a country like Canada, where it is highly unlikely that nuclear facilities would be attacked by dozens of well-armed outsiders or have to cope with conspiracies of al-Qaeda-linked insiders, might not be remotely sufficient for a site located in Pakistan, where both outsider and insider threats are dangerously high. (However, as will be discussed later, in a world of terrorists with global reach, at least a minimum level of security must be maintained for stockpiles of nuclear weapons and the materials needed to make them, even in the safest countries.) Unfortunately, the approaches in use today are not providing accurate and nuanced global assessments of any of these three critical parameters, leaving dangerous uncertainties over where nuclear security efforts should be targeted.

Assessing which nuclear sites and transport routes have the weakest security is not easy. Most countries regard the specific measures they have in place to protect nuclear weapons or nuclear materials from theft as closely guarded secrets, and any test or assessment that revealed particularly urgent vulnerabilities would be especially closely held. In Pakistan, to take one urgent example, U.S.-Pakistani nuclear security cooperation has been greatly constrained by Pakistan's fear that the United States might be tempted to snatch Pakistan's nuclear weapons if it could. As a result, U.S. experts are not allowed to visit the Pakistani nuclear sites to assess what problems need to be fixed, or even to know where the sites are. Thus cooperation focuses on offering advice to Pakistan on how best to assess such vulnerabilities and design security systems to fix them, and on helping Pakistan buy and install security equipment. (The Pakistanis generally regard U.S.-provided equipment with suspicion, fearing it might somehow be bugged.) Even in Russia, where the United States has invested billions of dollars in nuclear security and achieved dramatic improvements as a result, it remains illegal for Russian experts to give their American counterparts the results of detailed assessments of remaining vulnerabilities at Russian sites.

As a result, no country or institution in the world has a comprehensive global database assessing the effectiveness of the security measures for each nuclear site and transport route handling nuclear weapons or weapons-usable materials. Despite these obstacles, however, much more can be done to collect and assess information about key indicators of nuclear security effectiveness in countries around the world, as the U.S. intelligence community's Nuclear Materials Information Program (NMIP), launched in 2006, is now beginning to do. Information to inform such assessments can be gleaned from published nuclear security regulations; from a wide variety of "open source" literature (journalistic accounts, legislative hearings, papers presented at conferences, and the like); from confidential exchanges of information among particular countries; from visits to nuclear sites; from international nuclear security reviews, such as those organized by the IAEA for the small fraction of the key sites with weapons-usable materials where such reviews have been conducted;[2] and from intelligence information.

Ultimately, a combined all-source analysis is needed, drawing on the partial information available about each particular site or transport route and making judgments about what types of threats the security measures there could protect against effectively. Today, by contrast, the assessments guiding some key U.S. programs are based on simple yes/no estimates of whether sites comply with a particular rule or not; some of the assessments simply exclude all sites in advanced developed countries from any possibility of posing urgent issues.

While we live in a world with terrorists with global reach, and organized thieves are present in every country, there is no doubt that the threat is higher in some countries than in others. How can we assess what outsider and insider capabilities nuclear security systems should be designed to protect against?

Such an assessment should start from experience – from the kinds of capabilities and tactics terrorists and thieves have actually used against high-value guarded targets in recent years (whether nuclear or non-nuclear). In some countries, these include large, well-planned forcible attacks; the use of multiple coordinated teams (such as the four teams that struck on 9/11); sophisticated covert attacks that defeat alarm and detection systems; the use of unusual routes (such as tunneling into bank vaults); deception attacks (for example, using real-looking uniforms, identification, and paperwork to get through the security system); and the use of sophisticated weapons such as armor-piercing rocket-propelled grenades and platter charges to blow through security doors.

Most importantly, perhaps, such crimes and attacks frequently have insiders as participants. All but one of the documented cases of theft of HEU or plutonium appear to have been perpetrated by insiders (and the exception involved insider help to an outsider).[3] Security managers who believe that all of *their* personnel are trustworthy should remember that insiders may be coerced: in a 2004 case, for example, thieves apparently linked to a splinter faction of the Provisional Irish Republican Army (IRA) made off with £26 million from the Northern Bank after kidnapping the families of two of the bank's managers to force the managers to use their keys together to open the vault.

A wide variety of indicators can be used to judge how likely it is that outsiders or insiders could bring particular types of capabilities to bear in different countries or regions of countries. (Al Qaeda clearly can bring more force to bear in the mountainous regions near Pakistan's Afghan border than in the rest of the country, though the militants' ability to strike throughout the country is clearly greater than it was three years ago; it is a good bet that none of Pakistan's nuclear assets is located in this conflict zone.) The most important indicators would be the kinds of capabilities terrorists and thieves have demonstrated in that country (or similar neighboring countries) in recent times, from the number of people involved to the tactics and weapons used. The frequency of terrorist incidents and of crimes involving theft of valuable items from heavily guarded facilities or transports would be additional important indicators, as would the level of insider corruption and theft in the country.[4] The level of pay and morale among nuclear staff and guards, and the procedures in place to screen and monitor individuals before giving them access to nuclear materials or roles in protecting them, are also critical factors that should be examined in considering the scale of insider threat. In integrating assessments of these factors, governments can work with insurance companies, which have already had to assess risks of theft in different countries to determine how much they should charge to insure against bank robbery, for example.

Unfortunately, despite the creation of NMIP, much of this kind of information is not being systematically collected and analyzed, though in many cases it is not difficult to get. Some years ago, for example, two researchers then at American University documented key elements of insider corruption, organized crime presence, and the potential for Islamic extremism among some insiders worshipping at recently established nearby Wahabbi mosques in one of Russia's closed nuclear cities that stores and processes enough plutonium and HEU for thousands of nuclear weapons.[5] Prior to this study, the U.S. government was unaware of these circumstances. Similar in-depth studies of other facilities around the world have not been done, despite the modest level of effort required.

A building with nuclear material that terrorists could readily make into a nuclear bomb needs more security than a building with lower-quality material that would be very difficult for adversaries to use to make a bomb. But this sensible "graded safeguards" approach, used in national regulations and international recommendations around the world, must avoid slipping into what might be called "cliffed safeguards," in which security falls off catastrophically if nuclear material is beyond some arbitrary threshold that has little relation to real risk. For example, under current Nuclear Regulatory Commission (NRC) rules in the United States, nuclear material that would normally require security measures costing millions of dollars a year requires none of that if it is radioactive enough to cause a radiation dose of one Sievert per hour at one meter – a level considered radioactive enough to make the material "self-protecting." But studies at the national laboratories have shown that at this level of radiation, thieves who carried the material out to a waiting truck with their bare hands would not even receive a big enough dose of radiation to make them feel sick. In a world of suicidal terrorists, these rules – and similar, though less extreme, international rules – urgently need to be revised.

More broadly, in-depth assessments of how different chemical, physical, isotopic, and radiological properties of a material affect the odds that adversaries would succeed in making a bomb from it should be used to determine how much security can be relaxed for particular types of material while keeping overall risks low. In making these assessments, it is important to remember that HEU at enrichment levels far below the 90 percent U-235 level considered "weapons grade" can still readily be used in a bomb, at the cost of using somewhat more material. So past policies that have focused cooperative security upgrades only on sites whose HEU is at least 80 percent U-235 should certainly be revised. Similarly, while weapons designers prefer weapons-grade plutonium, produced specifically to contain 90 percent or more Pu-239, the "reactor grade" plutonium produced in the spent fuel from typical power reactors can also be used to make fearsome explosives, despite the extra neutrons, heat, and radiation generated by the less desirable plutonium isotopes it contains. Indeed, repeated government studies have concluded that any state or group capable of making a bomb from weapons-grade plutonium would also be able to make a bomb from reactor-grade plutonium.[6]

Based on the limited data publicly available about these factors, three categories of facilities stand out as posing the highest risks of nuclear theft: facilities in Russia, facilities in Pakistan, and research reactors fueled with HEU in dozens of countries.[7]

Russia still has the world's largest stocks of nuclear weapons and weapons-usable nuclear materials, stored in the world's largest number of buildings and bunkers. The egregious security weaknesses of the 1990s – gaping holes in fences, lack of any detectors to set off an alarm if someone was carrying plutonium out in a briefcase – have, in general, been fixed, but important security weaknesses remain. And the threats these facilities must protect against – not only possible large-scale terrorist assaults, but widespread insider corruption and theft – are substantial. In 2008, for example, a colonel in the Ministry of Interior troops that guard Russia's nuclear sites was reportedly arrested for soliciting thousands of dollars in bribes to overlook violations of security rules in the closed nuclear city of Snezhinsk. Earlier, the chief of security at Seversk, a huge plutonium and HEU processing facility, described a stunning array of weaknesses in his site's guard forces, from patrolling with no ammunition in their guns to widespread corruption, calling the guards "the most dangerous internal adversaries."[8]

By contrast, Pakistan has a small nuclear stockpile, in a small number of locations. Pakistan's stockpile is believed to be heavily guarded, but it faces immense threats, from possible attacks by huge numbers of well-armed extremists to insiders with extremist sympathies. At least two Pakistani nuclear weapon scientists sat down with Osama bin Laden to discuss nuclear weapons, and while General Pervez Musharraf was president, at least two near-miss assassination attempts involved serving Pakistani military personnel in league with al Qaeda. If the people guarding the president cannot be trusted, how much confidence can one have in the people guarding the nuclear weapons?

Finally, there are some 130 research reactors around the world that still use HEU as their fuel, and many of these have only the most minimal security measures in place. Many of these do not have enough material for a bomb at one site, but some do; and the 1998 embassy bombings as well as the 9/11 attacks are painful reminders of terrorists' ability to strike in more than one place at the same time.

In each of these cases, and in others throughout the world, urgent actions are needed to improve security, constrain the plausible threats (through actions that make it more difficult to put together large outsider attacks or to infiltrate insiders without detection), and remove weapons-usable nuclear material entirely (such as by converting research reactors to fuels that cannot be used in a nuclear bomb, or shutting down little-used reactors entirely).

In the last 15 years, the United States and other countries have put together a patchwork quilt of programs and initiatives to address these issues. The Nunn-Lugar Cooperative Threat Reduction program and related efforts have dramatically improved security at scores of sites in the former Soviet Union and elsewhere, and removed the potential bomb material entirely at dozens more. New treaties have been negotiated, such as the Convention on the Suppression of Acts of Nuclear Terrorism and the amendment to the Convention on Physical Protection of Nuclear Materials and Facilities. The UN Security Council unanimously approved Resolution 1540, which legally requires all states to pass legislation making it a grave crime to help non-state actors with nuclear, chemical, or biological weapons, and also requires all states to provide "appropriate effective" security for any stockpiles of nuclear weapons or related materials they may have. In 2006, the United States and Russia announced the launch of the Global Initiative to Combat Nuclear Terrorism, providing a new forum for discussion and capacity-building among like-minded states.

Nevertheless, global nuclear security institutions and standards remain far weaker than the task demands – and certainly far weaker than global *safety* institutions. Nuclear security has never had a

Three Mile Island or a Chernobyl to focus the world's attention, and as a result, complacency is widespread, with many policy-makers and nuclear managers around the world dismissing the danger of nuclear terrorism or assuming that existing security measures are more than sufficient. Unlike safety, where information can be widely shared, nuclear security measures are shrouded in secrecy, inhibiting international cooperation. (As one French official put it: "In safety, transparency is an obligation. In security, it is an offense.") And secretive nuclear security establishments are simply not in the habit of cooperating with each other.

Hence, while there are established mechanisms for reporting and analyzing nuclear *safety* incidents around the world and ensuring that reactor operators act on their lessons, and there is an industry organization to which all power reactors belong that reviews the *safety* of these plants, nothing comparable exists for nuclear security. The IAEA Office of Nuclear Security makes recommendations (which states can choose to adopt or ignore) and only organizes nuclear security reviews when states request them (which most states have not done). An independent organization to exchange best practices among operators, the World Institute for Nuclear Security (WINS), was only established in 2008.

Remarkably, years after the 9/11 attacks, with overwhelming evidence that terrorists are seeking stolen nuclear weapons material, the world has still been unable to agree on any specific and binding minimum standards for how well nuclear weapons or the materials to make them should be secured. Despite the danger that insecure plutonium or HEU in any state poses to all other states, security for these stockpiles is left almost entirely to the discretion of each country where these weapons and materials exist. Even more remarkably, no effort to put specific and binding global standards in place is now under way.

The nuclear Non-Proliferation Treaty (NPT) does not contain any provisions requiring states to secure nuclear material from theft. Similarly, IAEA "safeguards" are only inspections to ensure that nuclear material is still in civil use, and do not involve any form of international guarding or even international review of the quality of security. No one has yet defined what essential elements must be in place for a nuclear security and accounting system to meet the "appropriate effective" requirement of UNSCR 1540. Neither the new nuclear terrorism convention nor the amended physical protection convention includes any specific requirements for how secure nuclear material should be; the amended physical protection treaty requires every party with nuclear facilities to enact and enforce a national rule on that subject, but it does not specify what that rule should say. IAEA recommendations on nuclear security are more specific, but still quite vague: they specify, for example, that significant amounts of weapons-usable nuclear material should be stored in a place with a fence and intrusion detectors, but they say nothing about how strong the fence should be or how difficult to defeat the intrusion detectors should be. More fundamentally, they say nothing about what level of threat nuclear weapons and the materials needed to make them should be protected against.

These international approaches need urgent steps to strengthen them. All nuclear weapons and all stocks of the materials needed to make them, whether at fixed sites or during transport, should be effectively protected against the kinds of threats that terrorists and criminals have demonstrated they can pose in the countries where those stocks exist.

While terrorist and criminal capabilities vary from one country to the next, in an age of global terrorism, there are no countries so safe that substantial security measures are not needed when handling materials that could be used to make a nuclear bomb. Every facility or transport route anywhere in the world where there is a nuclear weapon or a stash of plutonium or HEU should be protected against a family of potential types of theft attempts, including attempts by insiders with authorized access to a facility, forcible outsider attack, or a variety of other outsider scenarios, such as attempts to enter the facility covertly (such as by tunneling into a vault, as often occurs in bank robberies), or attempts to deceive the facility security forces with fake uniforms, forged documents, and the like. At a minimum, such facilities and transport routes must be well protected against one well-placed insider; two small teams of well-armed, well-trained outsiders; or both working together. This corresponds to the threat revealed in the attack on the Pelindaba site in South Africa in November 2007, when two armed teams attacked from opposite sides of the site. One of the teams got through a 10,000-volt security fence, disabled intrusion detectors without detection (apparently with insider knowledge of the security system), proceeded to the emergency control center (where they shot a site worker in the chest), and spent 45 minutes inside the guarded perimeter without ever being engaged by site security forces. As far as is known, they never entered the area of the site where hundreds of kilograms of weapons-grade HEU are stored; but nevertheless, this is the kind of lapse that simply should not be allowed to occur at sites handling the essential ingredients of nuclear weapons.

Today, there are many facilities with plutonium or HEU that are *not* effectively protected against this level of threat. Gaining agreement that all states with nuclear weapons or enough plutonium or HEU to provide a substantial fraction of the material needed for a bomb will protect these stocks, at least against such a minimum level of threat, should be a high priority for the Obama administration. Such an accord, if followed through, would lead to major improvements at the world's most vulnerable nuclear sites, greatly reducing the risk of nuclear theft and terrorism. Of course, in countries where adversaries can pose more capable threats, additional protection should be provided. In Pakistan, in particular, the most stringent attainable security measures against both outsider and insider threats are clearly required.

A strong argument can be made that UNSCR 1540's requirement for "appropriate effective" security already obligates states to provide something like this level of security. If the words "appropriate effective" mean anything, they should mean that nuclear security systems would effectively protect against the threats that terrorists and criminals have shown they can pose.

While effective security for nuclear stockpiles is the most important step to reduce the danger of nuclear terrorism, a multilayered defense is needed – not least because some weapons-usable material may already have been stolen, but may not yet be in the hands of terrorists or proliferating states.

First, counterterrorist measures focused on detecting and disrupting those groups with the skills and ambitions to attempt nuclear terrorism should be greatly strengthened, and new steps should be taken to make raising funds and recruiting nuclear experts more difficult (including addressing some sources of radical Islamic violence and hatred and challenging the moral legitimacy of the mass slaughter of civilians – already a matter of debate even among violent Islamic jihadists).

Second, a broad system of measures to detect and disrupt nuclear smuggling and terrorist nuclear-bomb-acquisition efforts should be put in place, including expanded international police and intelligence cooperation, increased emphasis on intelligence operations such as stings (that is, intelligence agents posing as buyers or sellers of nuclear material or nuclear expertise), and targeted efforts to encourage participants in such conspiracies to blow the whistle.

Radiation detectors such as those now being installed at ports and border crossings in the United States and dozens of other countries have a role to play in this effort, but there is a limit to what can be done with large, readily observable detectors that adversaries can easily bypass by taking other routes. (And it is important to understand that neither the detectors now being installed nor the proposed Advanced Spectroscopic Portals would have any significant chance of detecting HEU metal with even modest shielding.) Congress would be well advised to abandon the current legislated requirement that 100 percent of cargo containers be scanned for radiation before entering the United States, focusing instead on requiring the administration to develop an integrated approach that places as many barriers in the path of an intelligent adversary trying to get nuclear material into the United States on *any* pathway as can be done at reasonable cost.

Third, while the danger of conscious state decisions to transfer nuclear weapons or materials to terrorists is only a small part of the overall risk of nuclear terrorism, more can be done to reduce that danger. This is yet another motivation for putting together international strategies that can convince the governments of North Korea and Iran that it is in their own national interests to constrain their nuclear ambitions in a verifiable way. And the United States should make one "red line" clear: any transfer to terrorists of nuclear weapons or the materials to make them would provoke a swift and sure response.

Fourth, while the focus must be on preventing nuclear terrorism from ever occurring, there is also much to be done to prepare for the ghastly aftermath should these efforts fail, from better preparations to keep the government and the economy functioning to a strengthened ability to treat tens or hundreds of thousands of injured people, including making use of the military's capabilities.[9] Many of the needed steps would help respond to any catastrophe, natural or man-made, and would pay off even if efforts to prevent a terrorist nuclear attack succeeded.

Fortunately, there is good news in this story as well. The initial overthrow of the Taliban government in Afghanistan and the death or capture of many of al Qaeda's top leaders have made it more difficult for al Qaeda to carry out the large, complex operation of getting and using a nuclear bomb. As noted earlier, at scores of sites that once posed particular dangers of nuclear theft, security has been dramatically upgraded or the dangerous nuclear material removed, as a result of cooperative threat reduction programs and countries' own efforts.

Moreover, the expected growth and spread of nuclear energy need not increase the chance that terrorists could get their hands on the material for a nuclear bomb. Today, most nuclear power reactors run on low-enriched uranium fuel that cannot be used in a nuclear bomb without further enrichment, which is beyond plausible terrorist capabilities. These reactors produce plutonium in their spent fuel, but that plutonium is 1 percent by weight in massive, intensely radioactive spent-fuel assemblies that would be extraordinarily difficult for terrorists to steal and process into material for a bomb. In some countries, the plutonium is removed from the spent fuel (an approach known as "reprocessing") for recycling into new fuel; that process requires extraordinary security measures to ensure against terrorist access to the separated plutonium. Fortunately, economics and counterterrorism point in the same direction in this case: because reprocessing is much more expensive than simply storing spent fuel pending disposal, few countries that do not already reprocess their fuel are interested in starting, and some of the existing plants are running far below capacity or will soon be shut down.

Many more nuclear power reactors in many more countries *would* mean more potential targets for terrorist sabotage – and more chances that some reactor's security would be weak enough that a terrorist attack would succeed. Sabotage would not cause the kind of massive, instantaneous destruction a nuclear bomb would cause, but in the worst case, successful sabotage might cause a massive radiation release – a "security Chernobyl." Such an event would be a catastrophe for the country where it occurred, and for its downwind neighbors; but unlike readily transported nuclear weapons or materials, it would not pose a threat to countries thousands of kilometers away. It would, however, pose a threat to the global nuclear power industry, for the public reaction to such an event would almost surely doom any prospect for nuclear growth on the scale needed to play a significant role in mitigating the threat of climate change.

The bottom line: nuclear terrorism remains a real and urgent threat. The way to respond is through international cooperation, not confrontation and war. Immediate action is needed around the world to improve security for nuclear weapons and the materials needed to make them, focusing on those sites and transport routes that pose the highest risks. The job is big and complex, but finite and doable. With sufficient high-level leadership and political will, the world can meet the four-year target for achieving effective nuclear security that President Obama has laid out. The clock is ticking.

ENDNOTES

1 For comprehensive recommendations for meeting this objective, see Matthew Bunn, *Securing the Bomb 2008* (Cambridge, Mass.: Project on Managing the Atom, Harvard University, and Nuclear Threat Initiative, November 2008), and Matthew Bunn and Andrew Newman, "Preventing Nuclear Terrorism: An Agenda for the Next President" (Cambridge, Mass.: Project on Managing the Atom, Harvard University, and Nuclear Threat Initiative, November 2008); http://www.nti.org/securingthebomb.

2 It is important to understand that IAEA "safeguards," which cover all nuclear material in non-nuclear-weapons states, involve inspectors visiting every few weeks or months to

check that nuclear material is where the state says it is; they do not protect the material from theft. The IAEA only reviews a state's arrangements for protecting against theft if the state in question asks for such a review, and the states with nuclear weapons and most of the world's weapons-usable nuclear materials have not asked for such reviews.

3 The exception was a 1993 case at a Russian naval base in which the perpetrator was an outsider who was informed of how to steal the nuclear material by a relative who worked at the base. See Oleg Bukharin and William Potter, "Potatoes Were Guarded Better," *Bulletin of the Atomic Scientists* 51 (3) (May/June 1995): 46–50.

4 See Matthew Bunn, "Corruption and Nuclear Proliferation," in *Corruption, Global Security, and World Order*, ed. Robert I. Rotberg (Washington. D.C.: Brookings Institution Press, 2009).

5 For a summary of part of their results, see Robert Orttung and Louise Shelley, "Linkages Between Terrorist and Organized Crime Groups in Nuclear Smuggling: A Case Study of Chelyabinsk Oblast," PONARS Policy Memo No. 392 (Washington, D.C.: Program on New Approaches to Russian Security, Center for Strategic and International Studies, December 2005).

6 For the most detailed authoritative, unclassified statement on this point, see *Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Excess Plutonium Disposition Alternatives*, DOE/NN-0007 (Washington, D.C.: Department of Energy, January 1997), 37–39.

7 For a more detailed assessment, see Bunn, *Securing the Bomb* 2008, 7–10, 21–44.

8 Report of the Snezhinsk incident is from "An Employee of the Department of Classified Facilities of the MVD Was Arrested in Snezhinsk: What Incriminates the 'Silovic,'" trans. Jane Vayman; reported on www.ura.ru, May 29, 2008. The Seversk description is from Igor Goloskokov, "Refomirovanie Voisk MVD Po Okhrane Yadernikh Obektov Rossii (Reforming MVD Troops to Guard Russian Nuclear Facilities)," trans. Foreign Broadcast Information Service, *Yaderny Kontrol* 9 (4) (Winter 2003).

9 For an especially useful recent discussion, see Ashton B. Carter, Michael M. May, and William J. Perry, *The Day After: Action in the 24 Hours Following a Nuclear Blast in an American City* (Cambridge, Mass.: Preventive Defense Project, Harvard and Stanford Universities, May 2007); http://belfercenter.ksg.harvard.edu/files/dayafterworkshopreport_may2007.pdf (accessed May 29, 2009).

Thomas C. Schelling

A world without nuclear weapons?

A new and popular disarmament movement was provoked by a completely unexpected combination of Henry A. Kissinger, William J. Perry, Sam Nunn, and George P. Shultz with their op-ed pieces in *The Wall Street Journal* from January 4, 2007, and January 15, 2008. For the first time since the demise of General and Complete Disarmament (GCD) in the 1960s, there is a serious discussion of the possibility of utterly removing nuclear weapons from the planet Earth. Furthermore, the discussion is taking place among nuclear policy professionals, the people who publish in *Foreign Affairs*, *International Security*, and other serious journals.

The International Institute for Strategic Studies, founded in London in 1958 and notable for its Adelphi papers, published in August 2008, Paper 396, *Abolishing Nuclear Weapons*, by George Perkovich and James Acton of the Carnegie Endowment for International Peace. It was central to a conference at the Carnegie Endowment that produced 17 response papers from around the world. Other meetings similarly motivated have been occurring, many under the sponsorship of the Nuclear Threat Initiative (NTI). The Stanley Foundation convened 25 officials, including diplomats from UN institutions, U.S. and foreign experts, and officials from other nations "to examine the first steps toward a world free of nuclear weapons." The rapporteur of that meeting noted, "Participants were in general agreement that complete and eventual disarmament, or global zero, is the objective."

The American Academy of Arts and Sciences, which publishes *Dædalus*, awarded the Rumford Prize to Perry, Nunn, Shultz, Kissinger, and Sidney Drell at its 1929th Stated Meeting in October 2008, for "their contribution to nuclear abolition." President Obama's April 2009 Prague speech, in which he stated "clearly and with conviction America's commitment to seek the peace and security of a world without nuclear weapons," was a sign that the disarmament debate was now a serious enterprise.

Some of the motivation, among the diverse respondents on the issue, is to fulfill, or appear to fulfill, the "commitment" undertaken by the official nuclear-weapons states in the Non-Proliferation Treaty (NPT) "to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control." The underlying motive would be to renew and strengthen the Treaty itself, by removing an objection often voiced by non-nuclear governments about unacceptable discrimination. Some of the motivation is evidently to spur an overdue drastic reduction in Russian and American nuclear warheads, especially those on high alert.

But hardly any of the analyses or policy statements that I have come across question overtly the ultimate goal of total nuclear disarmament.[1] Nearly all adduce the unequivocal language of *The Wall Street Journal* quadrumvirate.

None explicitly addresses the question, why should we expect a world without nuclear weapons to be safer than one with (some) nuclear weapons? That drastic reductions make sense, and that some measures to reduce alert status do, too, may require no extensive analysis. But considering how much intellectual effort in the past half-century went into the study of the "stability" of a nuclear-deterrence world, it ought to be worthwhile to examine contingencies in a nuclear-free world to verify that it is superior to a world with (some) nuclear weapons.

I have not come across any mention of what would happen in the event of a major war. One might hope that major war could not happen in a world without nuclear weapons, but it always did. One can propose that another war on the scale of the 1940s is less to worry about than anything nuclear. But it might give pause to reflect that the world of 1939 was utterly free of nuclear weapons, yet they were not only produced, they were invented, during war itself and used with devastating effect. Why not expect that they could be produced – they've already been invented – and possibly used in some fashion?

In 1976, I published an article, "Who Will Have the Bomb?" in which I asked, "Does India have the bomb?"[2] India had exploded a nuclear device a couple of years earlier. I pursued the question, what do we mean by "having the bomb?" I alleged that we didn't mean, or perhaps didn't even care, whether India actually possessed in inventory a nuclear explosive device, or an actual nuclear weapon. We meant, I argued, that India "had" the potential: it had the expertise, the personnel, the laboratories and equipment to produce a weapon if it decided to. (At the time, India pretended that its only interest was in "Peaceful Nuclear Explosives" [PNEs].) I proposed an analogy: does Switzerland have an army? I answered, not really, but it could have one tomorrow if it decided today.

The answer to the relevant question about nuclear weapons must be a schedule showing how many weapons (of what yield) a government could mobilize on what time schedule.

It took the United States about five years to build two weapons. It might take India – now that it has already produced nuclear weapons – a few weeks, or less, depending on how ready it kept its personnel and supplies for mobilization. If a "world without nuclear weapons" means no mobilization bases, there can be no such world. Even starting in 1940 the mobilization base was built. And would minimizing mobilization potential serve the purpose? To answer this requires working through various scenarios involving the expectation of war, the outbreak of war, and the conduct of war. That is the kind of analysis I haven't seen.

A crucial question is whether a government could hide weapons-grade fissile material from any possible inspection-verification. Considering that enough plutonium to make a bomb could be hidden in the freezing compartment of my refrigerator, or to evade radiation detection could be hidden at the bottom of the water in a well, I think only the fear of a whistle-blower could possibly make success at all questionable. I believe that a "responsible" government would make sure that fissile material would be available in an international crisis or war itself. A responsible government must at least assume that other responsible governments will do so.

We are so used to thinking in terms of thousands, or at least hundreds, of nuclear warheads that a few dozen may offer a sense of relief. But if, at the outset of what appears to be a major war, or the imminent possibility of major war, every responsible government must consider that other responsible governments will mobilize their nuclear weapons base as soon as war erupts, or as soon as war appears likely, there will be at least covert frantic efforts, or perhaps purposely conspicuous efforts, to acquire deliverable nuclear weapons as rapidly as possible. And what then?

I see a few possibilities. One is that the first to acquire weapons will use them, as best it knows how, to disrupt its enemy's or enemies' nuclear mobilization bases, while itself continuing its frantic nuclear rearmament, along with a surrender demand backed up by its growing stockpile. Another possibility is to demand, under threat of nuclear attack, abandonment of any nuclear mobilization, with unopposed "inspectors" or "saboteurs" searching out the mobilization base of people, laboratories, fissile material stashes, or anything else threatening. A third possibility would be a "decapitation" nuclear attack along with the surrender demand. And I can think of worse. All of these, of course, would be in the interest of self-defense.

Still another strategy might, just might, be to propose a crash "rearmament agreement," by which both sides (all sides) would develop "minimum deterrent" arsenals, subject to all the inspection-verification procedures that had already been in place for "disarmament."

An interesting question is whether "former nuclear powers" – I use quotation marks because they will still be latent nuclear powers – would seek ways to make it known that, despite "disarmament," they had the potential for a rapid buildup. It has been suggested that Saddam Hussein may have wanted it believed that he had nuclear weapons, and Israel has made its nuclear capability a publicized secret. "Mutual nuclear deterrence" could take the form of letting it be known that any evidence of nuclear rearmament would be promptly reciprocated. Reciprocation could take the form of hastening to have a weapon to use against the nuclear facilities of the "enemy."

But war is what I find most worrisome. In World War II there was some fear in the U.S. nuclear weapons community that Germany might acquire a nuclear capability and use it. There is still speculation whether, if Germany had not already surrendered, one of the bombs should have been used on Berlin, with a demand that inspection teams be admitted to locate and destroy the nuclear establishment. Would a government lose a war without resorting to nuclear weapons? Would a war include a race to produce weapons capable of coercing victory?

Could a major nation maintain "conventional" forces ready for every contingency, without maintaining a nuclear backup? Just as today's intelligence agencies and their clandestine operators are devoted to discovering the location of terrorist organizations and their leaders, in a non-nuclear world the highest priority would attach to knowing the exact locations and readiness of enemy nuclear mobilization bases.

Would a political party, in the United States or anywhere else, be able to campaign for the abandonment of the zero-nuclears treaty, and what would be the response in other nations?

I hope there are favorable answers to these questions. I'm uncertain who in government or academia is working on them.[3]

One can take the position that substantial nuclear disarmament makes sense, and that the abstract goal of a world without nuclear weapons helps motivate reduction as well as presents an appearance of fulfilling the NPT commitment. Maybe some leaders of the movement have no more than that in mind. But even as a purely intellectual enterprise the "role of deterrence in total disarmament," to use the title of an article I published 47 years ago, deserves just as thoughtful analysis as mutual nuclear deterrence ever received.[4]

In summary, a "world without nuclear weapons" would be a world in which the United States, Russia, Israel, China, and half a dozen or a dozen other countries would have hair-trigger mobilization plans to rebuild nuclear weapons and mobilize or commandeer delivery systems, and would have prepared targets to preempt other nations' nuclear facilities, all in a high-alert status, with practice drills and secure emergency communications. Every crisis would be a nuclear crisis, any war could become a nuclear war. The urge to preempt would dominate; whoever gets the first few weapons will coerce or preempt. It would be a nervous world.

It took a couple of decades for the United States to work out a satisfactory theory of "strategic readiness," of how to configure strategic nuclear forces to provide reasonably comfortable assurance against surprise or preemption, with appropriate command and control. Nothing is perfect: we never did solve the MX missile basing problem; we apotheosized a "triad" that didn't really exist; we missed the early opportunity to restrain multiple independently targetable reentry vehicles (MIRV); we never had an agreed understanding of "flexible response" or "no-cities" and its relation to counterforce targeting; and we let a president carry us away with an expensive dream of active defense of the population. Still, we got away from soft, exposed, unready bombers and missiles; we avoided the troubles that rival anti-ballistic-missile (ABM) systems would have brought; and we understood the MX problem, if we couldn't solve it.

There are now many proposals for radically reconfiguring the strategic offensive force. Possible reductions in numbers get plenty of attention. The composition of the force – undersea, airborne, and fixed; gravity, ballistic, and cruise; air and naval – gets less attention, but will receive it intensely when service rivalries become aroused. The proposals that to me sound hasty and in need of more thought than I can detect behind them are those that would drastically change the readiness status of the strategic force. These involve various proposals for reduced alert status. In particular, some propose physically separating warheads and vehicles. An extreme case is the idea of "strategic escrow," warheads removed from vehicles, presumably at quite some distances, and stored under international supervision. I have heard proposals for keeping warheads nearby but separate from the bombers or the missiles themselves. There are also proposals, which I'm not able to judge, for electronic de-alert or fail-safe retargeting.

What I think took those couple of decades I mentioned was really getting "vulnerability" under control. It began seriously with the Gaither Committee in 1957, got incorporated into the surprise-attack negotiations in 1958, led to airborne alert for bombers and abandonment of Atlas and Titan, and gave the navy a strategic lease on life. One key to reduced vulnerability was dispersal. Minuteman was spread out so that no single enemy weapon could destroy more than one. (Decoys for the same purpose were considered during the MX predicament.)

What has me worried is a new kind of "dispersal," a perverse kind: offering multiple disabling points for an enemy to target. If a missile or bomber can be rendered inactive by, alternatively, destroying it, destroying its warhead, or destroying the means of locomotion from warhead storage to vehicle, vulnerability has increased. If removed warheads are stored centrally, or in clusters, "dispersal" has been reversed. (Subjecting warhead storage to inspection eliminates the possibility of keeping locations secret from potential targeting.) If there are limited transport routes by which warheads can join their vehicles, vulnerability is increased. And maybe not just vulnerability to strategic attack but to disruption or sabotage as well.

Another theme of strategic readiness that took pretty good hold during those decades was "crisis stability." The concept involved a couple of potentially contradictory ideas: that any urgent efforts to enhance readiness in a crisis should be unnoticeable, lest they alarm the enemy, and that any efforts should be so visible that, if they were not being taken, the enemy could see they were not! On balance I think the consensus was that the dynamics of mobilization should be minimized; that, of course, could depend on what kinds of actions we are talking about. And the actions depend on just what mode of de-alert or separation of components is being considered.

I worry that the necessary scenario analyses to find the strengths and weaknesses, especially the weaknesses, of these proposals have not been done. I do not want to see many years – more than half a century now – of painfully acquired understanding of the requirements of "safe readiness" be lost or ignored in a hurried effort to invent new configurations of readiness-unreadiness. In particular, just what can be done on what time schedule and with what visibility to the public or to the enemy (or to international referees) in various kinds of crises needs to be thoroughly worked out; the logistics need to be carefully simulated; and the range of choices needs to be identified.

I do not perceive that this analysis is being done before proposals are launched that would produce highly unfamiliar strategic-readiness situations. What we have developed and become acquainted with should be dismantled only when we are sure we understand what we may be getting into.

We have gone, as I write this, more than 63 years without any use of nuclear weapons in warfare. We have experienced, depending on how you count, some eight wars during that time in which one party to the war possessed nuclear weapons: United States vs.

North Korea, United States vs. People's Republic of China, United States vs. Viet Cong, United States vs. North Vietnam, United States vs. Iraq twice, United States vs. Taliban in Afghanistan, Israel vs. Syria and Egypt, United Kingdom vs. Argentina, and USSR vs. Afghanistan. In no case was nuclear weapons introduced, probably not seriously considered.

The "taboo," to use the term of Secretary of State John Foster Dulles in 1963 – he deplored the taboo – has apparently been powerful. The ability of the United States and the Soviet Union to collaborate, sometimes tacitly, sometimes explicitly, to "stabilize" mutual deterrence despite crises over Berlin and Cuba, for the entire postwar era prior to the dissolution of the USSR, would not have been countenanced by experts or strategists during the first two decades after 1945.

These are two different phenomena, the taboo and mutual deterrence. We can hope that mutual deterrence will subdue Indian-Pakistani hostility; we can hope that the taboo will continue to caution Israel, and that it will affect other possessors of nuclear weapons, either through their apprehension of the curse on nuclear weapons or their recognition of the universal abhorrence of nuclear use.[5]

There is no sign that any kind of nuclear arms race is in the offing – not, anyway, among the current nuclear powers. Prospects are good for substantial reduction of nuclear arms among the two largest arsenals, Russian and American. That should contribute to nuclear quiescence.

Concern over North Korea, Iran, or possible non-state violent entities is justified, but denuclearization of Russia, the United States, China, France, and the United Kingdom is pretty tangential to those prospects. Except for some "rogue" threats, there is little that could disturb the quiet nuclear relations among the recognized nuclear nations. This nuclear quiet should not be traded away for a world in which a brief race to reacquire nuclear weapons could become every former nuclear state's overriding preoccupation.

ENDNOTES

[1] For exceptions, see Harold Brown and John Deutch, "The Nuclear Disarmament Fantasy," *The Wall Street Journal*, November 19, 2007, and Charles L. Glaser, "The Instability of Small Numbers Revisited," in *Rebuilding the NPT Consensus*, ed. Michael May (Stanford, Calif.: Center for International Security and Cooperation, Stanford University, October 2008), http://iis-db.stanford.edu/pubs/22218/RebuildNPTConsensus.pdf.

[2] Thomas C. Schelling, "Who Will Have the Bomb?" *International Security* 1 (Summer 1976): 77–91.

[3] See Sverre Lodgaard's and Scott Sagan's essays in this issue of *Dædalus* for expert analyses of the problem of stability without nuclear weapons.

[4] Thomas C. Schelling, "The Role of Deterrence in Total Disarmament," *Foreign Affairs* 40 (1962): 392–406.

[5] T. V. Paul, *The Tradition of the Non-Use of Nuclear Weapons* (Stanford. Calif.: Stanford University Press, 2008); Nina Tannenwald, *The Nuclear Taboo* (Cambridge: Cambridge University Press, 2007); and Thomas C. Schelling, "The Legacy of Hiroshima," in Schelling, *Strategies of Commitment and Other Essays* (Cambridge, Mass.: Harvard University Press, 2006).

Paul Doty

The minimum deterrent & beyond

The first 40 years of the nuclear age, dominated by the Cold War, witnessed the staggering buildup of nuclear weapons in U.S. and Russian arsenals. In 1987 the arsenals reached a combined total of about 70,000. U.S. weapons peaked at 32,000 in 1966; Soviet weapons peaked somewhere between 40,000 and 50,000 in 1986. Equally remarkable has been the decline from those heights: both countries, having reduced their stockpiles to 10,000 by 2002, agreed to cut the number of "operationally deployed strategic warheads" to 2,200 by 2012. The United States has already reached this limit, but retains 700 tactical weapons and a reserve of 2,500 active and inactive weapons, not treaty-limited, making for a grand total of 5,200. While comparable data are not available from Russia, it is likely that their stockpile will soon approach a similar level, representing the lowest number of weapons between the United States and Russia since the early days of the buildup, around 1959.

A massive exchange between U.S. and Soviet nuclear arsenals during any part of the past half-century would have risked near or total destruction of the world's civilization. That this did not happen was mainly due to the fear that resorting to use of such weapons by one side would quickly lead to an escalation, since each side would seek to destroy the other's not-yet-used forces, as well as to retaliate in response to destruction already under way. The level of devastation that would have occurred is unimaginable, but several models have attempted to describe some of the consequences. One model, for example, concluded that to destroy 25 percent of the population of Russia, the United States, Britain, France, and Germany would need fewer than 250 large weapons. Millions more fatalities and further disruption of transportation, energy supply, communications, food supplies, and medical aid, as well as the breakdown of government, commerce, trade, social order, and civil life, would follow, while delayed fatalities and illnesses from radioactive fallout would peak and then subside only slowly over centuries.[1]

Alas, the potential for this level of destruction still remains, despite the seven-fold reduction in U.S. and Russian weapons that has occurred. Therefore a primary goal in the next decades must be to remove this risk of near global self-destruction by drastically reducing nuclear forces to a level where this outcome is not possible, but where a deterrent value is preserved – in other words, to a level of minimum deterrence. This conception was widely discussed in the early years of the nuclear era, but it drowned in the Cold War flood of weaponry. No matter how remote the risk of civilization collapse may seem now – despite its being so vivid only a few decades ago – the elimination of this risk, for this century and centuries to come, must be a primary driver for radical reductions in nuclear weapons.

As the Cold War risks of catastrophic damage receded, the risk of destruction at the other end of the scale – attacks on single cities – sharply increased. These attacks might come either from new, hostile nuclear-weapons states or from nuclear terrorists stealing or buying a weapon or acquiring enough fissile material to make a primitive weapon themselves. Since the mid-1990s, vigorous efforts have been made through negotiations and sanctions, so far unsuccessful, to block North Korea and Iran from going nuclear; bombing from Israel attempted to block Syria from going nuclear. Nuclear terrorists have focused mostly on stealing or buying enriched uranium through the underground from Russia: the International Atomic Energy Agency (IAEA) lists 18 confirmed attempts.[2] The security of Russia's fissile materials has improved substantially over the last 15 years, but much remains to be done since Russia has the world's largest stockpiles of nuclear weapons and fissile materials, spread over hundreds of sites.

Not only have these accelerated risks helped restimulate long-standing opposition to nuclear weapons, from "ban the bomb" groups that originated in the 1960s, for example, but they have also increased advocacy of "a nuclear-free world" from new groups, including former governmental officials and others well acquainted with nuclear matters. (Google lists 234 million references to "nuclear-free.")

The vision of a nuclear-free world caught hold at the governmental level more than 40 years ago, most notably through the 1968 Non-Proliferation Treaty (NPT), which required that "[e]ach of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament." Eighteen years later, in 1986, the Reykjavik Summit gave further hope for government action toward total nuclear disarmament, even hope for a new treaty. At the Summit, Gorbachev suddenly proposed the elimination of all nuclear weapons if space-based defenses would be abandoned as well; Reagan, however, could not agree to this condition, and hopes for a new treaty failed.

Although very major reductions in nuclear arsenals did follow the end of the Cold War, there is no evidence that the major nuclear states are moving toward complete divestiture. Nevertheless, urging radical reductions in nuclear arsenals and, ultimately, their elimination grew. Perhaps the most detailed, early proposal by experts was that of the Australian government-sponsored Canberra Commission on the Elimination of Nuclear Weapons.[3] In 1999, Paul Nitze, long an advocate of a hard line nuclear posture, questioned the deterrent itself, saying, "I can think of no circumstances under which it would be wise for the United States to use nuclear weapons, even in retaliation for their prior use against us." Then in 2007 four highly placed former government leaders – George Shultz, William Perry, Henry Kissinger, and Sam Nunn – furthered Nitze's conviction and proposed "the goal of a world free of nuclear weapons," specifying a number of steps to be taken in that direction. Many leading former officials of both parties along with qualified others have added their support to the group's 2007 statement or to a supplementary statement from 2008.[4] Importantly, this later statement reemphasized that a nuclear-free world is a distant goal rather than a state certain to be accomplished within a given time.

Four former defense ministers and four former foreign ministers of Britain joined this call in 2008, and Prime Minister Gordon Brown went on record proposing concrete steps that states could take jointly to help create the conditions necessary for the abolition of nuclear weapons. Most recently, President Obama added his endorsement, in his April 5, 2009, speech in Prague: "I state clearly and with conviction America's commitment to seek the peace and security of a world without nuclear weapons. I am not naive. This goal will not be reached quickly – perhaps not in my lifetime. It will take patience and persistence. But now we, too, must ignore the voices that tell us that the world cannot change." Numerous endorsements followed, for example by German Foreign Minister Steinmeier, who noted that Helmut Schmidt and three other foreign policy leaders had affirmed this position.[5]

Thus, the goal of a world free of nuclear weapons has become the second principal driver toward radical weapons reduction. Reflecting on the path that might lead to this twin goal – ending the risk of civilization collapse and preparing for the zero option – makes clear that any such course must involve the committed cooperation of Russia and the United States in three stages. First, the two nations must see that it is to their advantage to take the lead together in undertaking drastic reductions in their nuclear arsenals, which account for 96 percent of the world's weaponry. To prepare for these reductions, the United States and Russia should first adjust their arsenals to a common level; provide accurate inventories of all nuclear weapons; and establish new means of enhancing transparency, inspection, and verification to monitor accurately the progress of reductions. Second, once sufficient reductions have been made to demonstrate their own commitment, the United States and Russia should lead in seeking a treaty that would embrace the other three original nuclear states (Britain, France, and China) and the other states with significant arsenals (at present, India, Israel, and Pakistan); the treaty would incorporate scheduled reductions aimed at reaching the very low level constitutive of a minimum deterrent. The third phase would consist of reducing weapons to the designated levels of a minimum deterrent. Without reductions on this scale, neither can the long-term risk of worldwide destruction be eliminated, nor can advances toward a nuclear-free world be realized.

Completing these three phases would certainly take time – at least two decades or more. Yet taking this time to reach levels of minimum deterrent is necessary, because only then can the real problems of going on to zero be addressed. Can complete global participation be attained? If not, how can one deal with nuclear states unwilling to join? How can the risk of hidden weapons or the resort to rebuilding weapons, especially by countries facing defeat in wartime, be dealt with? Can inspection and verification systems be devised that will ensure perpetual compliance and be affordable? Can allies and friends long dependent on the United States' deterrent capability adjust to the disappearance of that capability? It is futile to try to answer such questions now because the political world order will have been changed so much if a minimum deterrent level is achieved; no one can now foresee how stresses and tensions, old and new, will reshape the world a few decades hence. Finding answers to these questions will be a task not for this generation, but for the next.[6]

What follows is a brief examination of one path for reaching a minimum deterrent in this generation. The aim is not to advocate this particular example, but rather to illustrate in concrete terms the magnitude of the steps needed and some of the impediments that will be met.

The destructive power of nuclear arsenals is measured commonly in terms of *numbers* of weapons. When levels remain in the many thousands this metric is convenient and adequate. But if weapons are radically reduced to only those needed for a minimum deterrent or less, then the number of weapons cannot be the only factor: the *yield* of weapons must be considered as well. Maintaining a balance by numbers would only be a formality, not real progress, and would favor the retention of higher-yield weapons.

Alternatively, explosive yield could be used as the primary metric to reduce (but not eliminate) uncertainty. The most convenient measure of explosive yield is the weight in tons of the explosive TNT required to produce the explosive force of a given warhead. The yield of individual weapons is measured in thousands of tons (KT) or millions of tons (MT) of TNT. The U.S. stockpile is at least 500 MT[7]; Russia's stockpile may be greater. It is unlikely that either side would specify the exact yield assigned to various weapons, but agreement might be reached in assigning ranges to weapon yield – weapons with a yield below 10 KT, say, or between 10 and 30 KT. Furthermore, arrangements allowing inspectors access to fissile material removed from dismantled weapons would provide a rough estimate of total yield, based on comparisons between yield from dismantled weapons and previously declared total yield. These and other measures would greatly reduce the uncertainty about destructiveness when relying on numbers alone. Even so, were the levels of a minimum deterrent reached, some limitation of numbers, even for the lowest-yield weapons, would be necessary since 20 weapons of 5 KT yield, for example, would in many circumstances be more damaging than one 100 KT weapon.

Initially, a very ambitious preliminary step would be necessary to bring Russian and U.S. nuclear arsenals to the same approximate levels and prepare for accurate monitoring of subsequent reductions. Two changes would need to be introduced in concert with what the Strategic Offensive Reduction Treaty (SORT) now in operation requires. One, all nuclear weapons, strategic and tactical, active and inactive – in effect, any that is not dismantled, not just those that are operationally deployed strategic warheads – would need to be included. Two, as explained above, the total explosive yield of the remaining nuclear arsenals would need to be used as the primary metric, rather than the number of weapons.

In tabulating necessary reductions for each step, we have chosen 512 MT as the beginning yield in order to keep the numbers simple. (The exact megaton yield to assume for a minimum deterrent is somewhat open to question, depending on what actions are to be deterred.) As will be discussed later, we have assumed that with balanced reductions of nuclear arsenals to less than 1 percent of current values, deterrence would be restricted to a single mission – that is, to deter the use of nuclear weapons or, if that fails, to be capable of retaliation in kind. We have also assumed that damage resulting from forbidden first use or in retaliation would not exceed that of larger past wars. The explosive power used in each of the world wars and the Vietnam War is estimated to be just under 2 MT. Hence, we have chosen 2 MT as the minimum deterrent, although 1 MT might be more appropriate, as damage from nuclear weapons would surely be compressed in time relative to a conventional war, thereby allowing much less time for partial recuperation. If the time came when this choice had to be made, input from an analysis of what was thought to be necessary to cover the reduced deterrence needs as then envisioned would be required.

The period of time needed for Russia and the United States to agree on this framework and adjust their inventories to the 512 MT limit (or some other agreed upon number) is unpredictable; we have optimistically chosen five years and called this Step 0. During this period, the inventory of all nuclear weapons existing in 2010 would be established as an essential guide to what is destroyed and what remains at each step of the reduction schedule.

It would be necessary to work out how the successor to the present Strategic Arms Reduction Treaty (START) would relate to seeking equal levels of total yield in Step 0. And further, agreement would have to be reached on the state in the dismantlement process at which a weapon is no longer a weapon, and which components, other than fissile material, must be rendered unavailable for weapons use.

A series of five-year steps, paced by reductions in total yield, would follow Step 0. However, an equal reduction in each of the four steps is not practical, since it would mean large reductions in all steps followed by a precipitous fall at the end. Instead, we have proposed an inverted progressive approach, reducing yield in each step by a factor of three-quarters of the limit reached in the previous step. This schedule, in terms of megaton yield, is shown in Table 1. The goal of reaching 2 MT by 2035 assumes that Step 1 begins in 2015 and that each subsequent step takes five years. Following this hypothetical schedule, the explosive yield of the United States and Russia would be reduced by 94 percent by the end of 2025, at which point further reductions would depend on the introduction of a comprehensive treaty that includes all, or nearly all, nuclear states.

Since dismantling weapons is very time consuming (one U.S. gravity bomb contains nearly 7,000 parts) and requires specially constructed facilities to convert plutonium pits to scrap, additional time (perhaps 10 years) may be needed to complete the dismantlement.[8] While the megaton limit does not specify the numbers of weapons, it is of interest to see what the numbers would be if all weapons were, say, 15 KT each (the yield of the Hiroshima weapon) or 100 KT; we have shown these numbers at the end of Step 4 (133 and 20, respectively) in the two columns at the right of the table. We have shown one further step in reductions if a lower minimum deterrent level were chosen.[9]

The other seven nuclear states are currently estimated to have about 1,000

Table 1
A Schedule for Reductions to a Minimum Deterrent by Russia and the United States

Step	Duration	Yield in MT	If Weapons Were 15 KT	If Weapons Were 100 KT
0	2010 – 2015	512		
Adjustment Reductions Begin 1	2015 – 2020	128	8,533	1,280
2	2020 – 2025	32	2,133	320
All Nuclear States Join 3	2025 – 2030	8	533	80
4	2030 – 2035	2	133	20
Further Reductions? 5	2035 – 2040	0.5	33	5

weapons. Consequently, the success of this plan necessarily requires these states' participation no later than by the end of Step 2. However, the question of what constitutes appropriate reduction goals for these states is trickier. Since this illustrative proposal assumes a 40-fold reduction in numbers and a 250-fold reduction in yield from the two dominant powers, it is arguable that the others should accept much lower limits, scaled by size of their arsenals at that time. Or the reduction rates used above might be applied to only the five original nuclear powers, with negotiated lower levels for the others. If no consensus on customized solutions such as these can be reached, it may be preferable to agree on the same reduction schedule (three-quarters elimination at each step) for all nuclear states, rather than to abandon the whole process, since the vast experience and the many nuclear tests of the five original nuclear states give them an inherent technical advantage, even if the same rules apply to all.

Although the impediments to negotiating and implementing a minimum deterrent treaty are intimidating, they are not unlike those faced by arms control efforts in the past, or by the introduction of those treaties already in force or being negotiated now. For example, concentrating most of the weapons reductions (perhaps 10,000) in the first 10 years (Steps 0 and 1) may seem too ambitious. However, Russia and the United States eliminated nearly 50,000 weapons in the 20-year period, 1988 to 2008. And SORT currently envisions a two-third reduction of deployed operational strategic weapons (from 6,000 to approximately 2,000) in 10 years; the follow-on to SORT is expected to call for additional reduction by one-third to one-half. Further, the oft-forgotten Intermediate-Range Nuclear Forces Treaty of 1988 saw 2,692 nuclear-armed missiles removed from Europe and Russia in three years.

Two existing treaties, the NPT along with the Comprehensive Test Ban Treaty

(CTBT), have contributed much to create an environment that makes radical reductions and the goal of a minimum deterrent treaty possible; yet the future of these two treaties is troubled. However, if Russia and the United States were to commit to a reduction program such as the one outlined here, some of this trouble could be avoided.

Although the CTBT of 1996 is not yet in force, many of its functions are in place because the Treaty's Preparatory Commission created a CTBT Organization. This organization has greatly improved the network of monitoring stations to detect nuclear tests, and has created a worldwide data center and an onsite inspection capability. Its operating budget is based on annual contributions of signatories. Thus, the Treaty now operates largely on a voluntary basis, no doubt in part because of its broad popular support – judged to be near 80 percent. However, that 10 of the 44 states that need to ratify the Treaty to bring it into force haven't done so[10] threatens its chance of becoming a much-needed, established part of the arms control environment. It is unfortunate and unwise that the United States failed to ratify the Treaty in 1999, but President Obama is now leading a renewed effort to do so. Such support seems vital to persuading some of the other non-ratifying states to ratify, and to sustaining the voluntary operation that so far has maintained nearly complete compliance until means can be found to bring the Treaty into force.

Whether or not the United States ratifies the CTBT within the coming year has become crucial to the advancement of a draw-down both in physical weapons and in the role of nuclear weapons in national security policy. Only by ratifying the Treaty can the United States signal that it is prepared to move into a new era of a nearly nuclear-free world. Without such confirmation, President Obama would be denied the leadership role that is essential to the redirection of arms control on the scale envisioned here.

The NPT, entered into force in 1970, is the central means by which the spread of nuclear weapons can be contained. This Treaty has led nine states to abandon their intention to become nuclear-armed states. However, the four de facto nuclear states (India, Israel, North Korea, and Pakistan) are not party to the NPT. Moreover, of the 189 signatories of the NPT, 66 have not ratified the 1997 Additional Protocol, which gives IAEA inspectors greater authority to visit declared and undeclared nuclear sites. Here, too, the United States has a leadership role to play in winning over signatories to the Additional Protocol and strengthening the Treaty at its Five Year Review Conference in 2010.

If the treaty expected to follow on from the original START, which was ratified in 1991, is secured, that, too, would greatly ease what must be done in Step 0 of the minimum deterrent treaty outlined here. The same is true if a fissile materials cutoff treaty were to be developed. Of the several treaties that collectively aim to control and reduce nuclear weapons, central is the one that radically reduces nuclear arsenals to a minimum deterrent level or beyond. This treaty would best provide the strategic framework to coordinate all the others and diminish the role of nuclear weapons in the security policies of the nuclear states – and to deter non-nuclear states from believing that nuclear weapons are a shortcut to power and prestige.

Clearly, there are other impediments to overcome and initiatives to undertake. These include negotiating treaties dealing with a fissile material production cutoff; introducing a regime to secure and reduce the large stocks of fissile materials and to monitor the flow of fissile materials through the reactor fuel cycle in the hundreds of power reactors worldwide; providing services for nuclear fuel and the disposal of used fuel from nuclear power reactors of non-nuclear states; expanding the IAEA; improving inspection and verification techniques; and finding effective ways to share intelligence, ensure enforcement, and deal with possible violations.[11]

General Kevin Clinton, who heads the U.S. Strategic Command, recently pointed out that the 2,200 operationally deployed strategic warheads now permitted by SORT are needed to carry out the missions developed under presidential guidance and policy directives. Such guidance is apparently based on the 2006 National Security Strategy, which continues wide-scale targeting of Russia's offensive strategic forces and command centers (that is, counterforce targeting along with targeted attacks on infrastructure such as transportation hubs, major industries, and communications centers). Numerous non-Russian targets are also included in various strike options developed by the Department of Defense. In April 2009, General Clinton noted that he cannot reduce the number of needed warheads without revised White House guidance.

Reducing weapons to a minimum deterrent level means substantially reducing nuclear missions, including counterforce targeting, which, at any rate, struggles with diverse demands and redundancy, a consequence of incomplete intelligence. Furthermore, counterforce targeting may not reach submarine-based, mobile land-based, or other well-hidden weapons. Abandoning counterforce targeting would take away the United States' first-strike capability, aimed at preempting attacks by Russia's nuclear forces. However, while current U.S. declaratory policy maintains that it is necessary to threaten the first use of nuclear weapons for the sake of deterrence in a number of scenarios, including deterrence of attacks by chemical and biological weapons and by large-scale, conventional military force, some experts have begun to argue convincingly that movement to a no-first-use doctrine would be in the best interests of the United States.[12] For these reasons, the missions for which U.S. nuclear forces could justifiably be used should contract to a single one: to retaliate after a nuclear attack on the U.S. or its allies. The minimum deterrent must be determined for this single mission alone, not for obsolete missions or those better left to conventional forces.

At present the United States extends protection by nuclear forces to 28 members of NATO, as well as to Israel, Japan, South Korea, and Australia. According to the NATO Treaty, "The Parties agree that an armed attack against one or more of them in Europe or North America shall be considered an attack against all . . . and to assist the Party or Parties so attacked by taking . . . such action as it deems necessary, including the use of armed force, to restore and maintain the security of the North Atlantic area." On this basis the United States can deem necessary the use of its nuclear forces in support of armed attack – nuclear or non-nuclear – against any member state. The NATO Treaty is of course 1949 language, with which the United States aimed to deter Soviet attacks in Europe. But now the Treaty justifies the United States' continuing to deny making a no-first-use nuclear pledge, even against non-nuclear attacks, in a NATO that now includes the Baltic states and most of the Balkans (and that would include, if some had their way, Georgia and Ukraine). Absurd as such possibilities may be, the move toward a minimum deterrent should be the occasion for clarifying that retaliation after a nuclear attack is the only mission for U.S. nuclear forces. This should apply as well to those non-NATO countries that the United States has expressed a similar commitment to protect.

Of course, constriction on extended nuclear deterrence should be discussed in advance with the states affected. Already there are indications that allies' reactions to dramatic reductions will vary. The German Foreign Minister has just called for the United States to remove its tactical nuclear weapons in Germany, and polls show this to be a popular view throughout Western Europe. By contrast, the Japanese Ministry of Defense has expressed opposition to deep cuts and has insisted, for example, that a U.S. nuclear weapon system in Japan that the United States would prefer to terminate be retained, no doubt in part because of uncertainties about the future of nuclear forces and growth in other Asian countries, including China. Yet it is quite likely that Russian-U.S. reductions would make the enlargement of Chinese nuclear forces unnecessary, and if Steps 3 and 4 were reached, would reduce Chinese nuclear forces.

The foregoing proposals, or alternative ways to the same goal, would have seemed fanciful at any earlier stage. It is only through the arrival of a new U.S. administration, with unprecedented goals in arms control combined with strong Russian interests in the same direction, and through the backing of so many experienced and responsible experts here and abroad that a serious debate on such matters may be near. The key will be what is decided at two critical points: will Russia and the United States join in taking down their own enormous arsenals, and will other nuclear states join with them in proceeding to a minimum deterrent level and possibly beyond? If India, Israel, Pakistan, or any newer nuclear state does not join in this transforming effort, will means be found to restrain that state from undoing the effort? In short, will the window that a rare confluence of events has opened be used to marginalize the role of nuclear weapons in the global search for a safer, more stable, and more secure world and to create the environment in which the elimination of nuclear weapons could become possible?

ENDNOTES

[1] Matthew McKinzie et al., *The U.S. War Plan: A Time for Change* (Washington, D.C.: National Resources Defense Council, June 2001), 126. More succinctly, the commander of the Strategic Air Command (SAC) once told the author, in answer to the question of what would be the difference if only half of the nuclear arsenals were used in an exchange, that "the difference would be between sand and gravel."

[2] Matthew Bunn, *Securing the Bomb 2008* (Cambridge, Mass.: Project on Managing the Atom, Harvard University, and Nuclear Threat Initiative, November 2008), 9; www.nti.org.

[3] http://www.dfat.gov.au/cc/index.html.

4 George Shultz, William Perry, Henry Kissinger, and Sam Nunn, "A World Free of Nuclear Weapons," *The Wall Street Journal*, January 4, 2007, and "Toward A Nuclear-Free World," *The Wall Street Journal*, January 15, 2008.

5 See www.auswaertiges-amt.de/diploen/Infoservice ; also, Helmut Schmidt, Richard von Weizacker, Egon Bahr, and Hans-Dietrich Genschler, "Toward a Nuclear-Free World," *International Herald Tribune*, January 9, 2009.

6 A detailed and objective study of these problems can be found in George Perkovich and James Acton, *Abolishing Nuclear Weapons*, Adelphi Paper No. 396 (London : International Institute for Strategic Studies, 2008).

7 The 500 MT number being assigned for both sides is lower than estimates of current force yields because the total number of warheads and their yields are not publicly known for both sides. Moreover, there is another uncertainty : as a current compilation of U.S. nuclear forces shows, most of the 14 weapon types now deployed by the United States have a broad range of selectable yields, often more than a hundredfold ; see Robert Norris and Hans Kristensen, *Bulletin of the Atomic Scientists* (July/August 2009) : 72 – 80. If these weapons could be reliably converted to the lower yield range, then the total force yield would be greatly reduced. If not, the use of the highest yield would perhaps double the force yield. Clearly, dealing with this would be a difficult negotiators' problem as the reductions proceeded. Our choice of 500 MT force yield remains a reasonable level to reach before serious parallel reductions begin, but it may involve large and uneven reductions for both sides to reach such a common level. The further reduction proceeds the more necessary it will be to take into account both numbers and yields.

8 Presently the United States is dismantling plutonium pits at a rate of 350 per year ; at this rate, the backlog of currently retired warheads would not be dismantled until 10 years after the treaty deadline, that is, 2022, unless facilities are expanded.

9 See the recent, very extensive analysis of this problem in Hans M. Kristensen, Robert E. Norris, and Ivan Oelrich, *From Counterforce to Minimal Deterrence* (Federation of American Scientists/Natural Resources Defense Council, April 2009) ; www.fas.org. They conclude that 500 warheads reached by 2025 would constitute a minimum deterrent for the United States, with submarine deployment ending in 2020. However, their conclusions do not assume any parallel Russian reductions and therefore are not comparable to ours.

10 These 10 countries are China, Egypt, India, Indonesia, Iran, Iraq, Israel, North Korea, Pakistan, and the United States.

11 The details of such initiatives are examined in the papers prepared for the conference that led to the proclamations of George Shultz and colleagues in *The Wall Street Journal*. These are now available in *Reykjavik Revisited : Steps Toward a World Free of Nuclear Weapons*, ed. George Shultz, Sidney Drell, and James Goodby (Stanford, Calif. : Hoover Institution Press, 2008).

12 Scott D. Sagan, "The Case for No First Use," *Survival* 51 (3) (2009) : 163 – 182.

Sverre Lodgaard

Toward a nuclear-weapons-free world

In a speech in Prague on April 5, 2009, President Obama reconfirmed his intention to seek a nuclear-weapons-free world (NWFW): "today, I state clearly and with conviction America's commitment to seek the peace and security of a world without nuclear weapons."[1] In Cairo two months later, he defused the charge of double standards that has been leveled at the nuclear-weapons states (NWS) throughout the 40-year history of the nuclear Non-Proliferation Treaty (NPT): "No nation should pick and choose which nation holds nuclear weapons. That's why I strongly reaffirmed America's commitment to seek a world in which no nations hold nuclear weapons."[2] By seizing the high ground he is set to win important debates. However, there are numerous obstacles in the way.

What might a NWFW look like? The term is used in a variety of ways, some of which appear more stable and satisfactory than others. Certain principles, prerequisites, and transitional issues, as well as political order requirements, must be considered on the way to such a world. On the whole, growing international interdependence is helpful, but for nuclear disarmament to succeed, interdependence must be turned into cooperative security practices between the big powers, with a view to more effective collective security mechanisms in the hands of the world organization (currently the United Nations).

In their *Wall Street Journal* article of January 4, 2007, George Shultz, William Perry, Henry Kissinger, and Sam Nunn emphasized the interrelationship between the vision of a NWFW and measures to that end: "without the bold vision, the actions will not be perceived as fair or urgent. Without the actions, the vision will not be perceived as realistic or possible."[3]

To achieve a dynamic, interactive relationship between vision and measures, one has to be serious about both. To be serious about the vision means that a convincing rationale for a NWFW has to be spelled out; that the broadest possible agreement must be sought; and that the advantages of such a world should weigh in the assessment of specific steps to be taken. If not, the advantages and disadvantages of each step will instead be weighed within the framework of the existing international system, with little or no regard for the gains that a NWFW offers, leaving the steps hostage to the obstacles that will surely be raised along the way. The "four horsemen" are therefore right in their emphasis on vision: if the vision is not persistently invoked in the discussions of how best to promote disarmament and nonproliferation, efforts in this direction may not lead very far. The dynamism will be missing.

One part of the rationale relates to the terrorist threat: terrorists seek nuclear weapons in order to use them. Another part emanates from the state paradigm. In an increasingly multicentric world with more NWS, nuclear weapons are likely to interact with interstate conflicts in more regions and in new ways. A NWFW would also be safer for nuclear energy. This is not among the major factors in the case for such a world – the overriding objective is to prevent nuclear weapons from being used – but for proponents of nuclear power it is another attraction. Others emphasize that a NWFW would be far more sustainable as part of a double abolition: an end to both nuclear weapons and nuclear energy. However, much like the compromise between the "no" to nuclear weapons and the "yes" to nuclear power built into the NPT, a NWFW would probably entail the same compromise. If and when a NWFW comes into being, the energy situation will certainly be a lot different from what it is today; but this is what full implementation of the NPT implies.

As of mid-2009, the call for a NWFW remains primarily a Western one. In other regions of the world, nuclear- and non-nuclear-weapons states are waiting to see what comes of the call. Will it fizzle out? Will the domestic interests in nuclear weapons hit back and reaffirm the continued relevance of nuclear arms? Abolition has been proposed three times before – the Baruch plan in 1946, the McCloy-Zorin proposal of 1961, and the Reagan-Gorbachev attempt in 1986 – and those initiatives were short-lived.

Others have more fundamental doubts. They are concerned that the call is part of a double agenda, the real purpose of which is to sustain and enhance Western unilateral advantage. The synergies of disarmament and nonproliferation may stop smaller and weaker states from acquiring "the great equalizer" – nuclear weapons – thus minimizing those states' ability to counter the vast U.S. conventional superiority. So why should North Korea, Iran, and other states that are at odds with the United States willingly expose themselves to threats and humiliation? In a world without nuclear weapons, U.S. forces may be even more superior than they are today; moreover, at low levels of offensive forces an advanced ballistic missile defense system may give the United States a first-strike capability vis-à-vis other NWS. Seen in one or more of these ways, nuclear disarmament is not a hallmark of progressive politics, but a conservative goal: change meant to preserve the dominance of the United States and the West.

In the NWS, the call for a NWFW raises strong concerns of a different nature. There is the view that nuclear weapons make major war very unlikely, if not impossible; that they provide unique and irreplaceable security benefits; that a world of zero would be highly unstable; and that approaching zero might spur proliferation by making it possible for very small arsenals to have large strategic implications not neutralized by the much bigger arsenals of the major NWS. Then there are the less legitimate, but still very real, unilateral advantages that nuclear weapons are seen to offer: they can be used to threaten and humiliate others, and in some cases they confer a status on their possessors that is thought to be generally useful in the pursuit of national interests.

It is critically important, therefore, to convince states – nuclear and non-nuclear – that disarmament will be pursued in the universal interest. It is a matter neither of unilateral advantage nor of national sacrifice, but of seeking abolition as a common, public good. The objective is to prevent nuclear weapons from being used ever again. The task is to turn fundamental moral considerations – preventing mass slaughter; preserving human civilization – into realpolitik.

To begin in earnest, the United States must lead and Russia must cooperate. If Russia is not ready for major cuts, the disarmament ambition will not go far. Next in the line of importance is China, because of its geopolitical significance. Together, these states most affect the security dynamics in regions of proliferation concern: Northeast Asia, South Asia, and to a smaller extent, the Middle East. As veto-wielding members of the UN Security Council, they also determine whether confidence will be built in the enforcement of disarmament commitments.[4] If they cannot stabilize their own strategic relations and put the nuclear order on a path to disarmament, proliferation may continue and the risk of nuclear weapon use may increase.

Words like *zero*, *elimination*, and *abolition* all have in common the idea of no nuclear weapons. However, *zero* can be conceived of in a variety of ways, and not everyone means the same thing when referring to it. It may be taken to mean no deployed weapons; no stockpiled weapons; no assembled weapons; no nuclear weapons in the hands of the military (but possible under civilian governmental control as an insurance premium); or no national nuclear weapons (but possibly nuclear weapons controlled by an international body).

Beyond the various meanings of *zero*, the vision of a NWFW also comes in several other forms, one of which imagines a world where all ready-made weapons have been eliminated, but where states maintain a mobilization base for rapid reintroduction of them. It might include fissile materials in stock, able nuclear weapons engineers and manufacturing equipment on hand, and delivery vehicles ready for use. For the NWS this would be a form of deep de-alerting, approaching the status of Japan today. The purpose of such a base would be to deter others from breaking out of the agreement and to be able to confront violators if deterrence breaks down.

This is a bad idea,[5] first and foremost because it sustains the mentality that nuclear war is possible at any time. Many states, suspecting that others may be cheating, may come to think that hedging is prudent, with the result of a hedging race: vertically toward capabilities that can be turned faster and faster from virtual to real; horizontally to involve more states. The trust on which abolition was achieved would then evaporate. Second, virtual arsenals need arsenal keepers, who are never disinterested experts, but sociopolitical actors legitimizing their activities in terms of threats to be met and demanding more resources to counter them. In effect, the arsenal keepers are likely to push for a hedging race, and would quite possibly prefer real arsenals to virtual ones. Such an end state would therefore contain the seeds of its own destruction. Third, it is a particularly bad idea because in the breakout scenarios, first-strike capabilities are more likely to emerge than in current nuclear constellations.

It would be better to go "below zero" to eliminate the fissile materials that have been dedicated to nuclear explosive uses; to institute strict international control of all remaining materials; to dismantle the nuclear weapons infrastructure; and to redirect the workforce to other sectors. Even more, nuclear materials that can be used to build weapons should be banned from civilian use as well. Highly enriched uranium (HEU) is not the most important issue here – there is little HEU left in the civilian sector and what remains is being phased out – but plutonium continues to pose a problem. Technical fixes may or may not solve the problem; if not, a compromise would have to be struck to accommodate the civilian industry. Dual-capability production facilities for civilian use would remain, possibly based on proliferation-resistant technologies and subject to international control. This would be a more stable NWFW than a world where virtual arsenals are allowed. However, going below zero is a matter of more or less, so this image of a NWFW comes in several variations.

A third version relies on joint capabilities to intercept a nuclear attack before the weapons reach their targets – the idea that Reagan presented to Gorbachev in Reykjavik. An effective shield could be traded against milder restrictions on nuclear infrastructure and modified requirements of international control. Twenty-five years and $150 billion after the Strategic Defense Initiative (SDI) was born, ballistic missile defense remains an unproven technology with no certainty of success. Countermeasures seem to be simpler and cheaper. Furthermore, to convert the program into a global asset for the benefit of all may be impossible, for it takes a much more cooperative world to overcome the formidable political problems involved. Still, in a world that has come close to elimination, missile defense is likely to be seen through other lenses. If the road to a NWFW results in, say, 100 or 200 weapons for each NWS, further steps will be considered in an environment much different from where the journey started. The path-dependence of the disarmament process must always be kept in mind, so the option should not be ruled out.

Can a shield be developed as an option for a NWFW while nuclear disarmament is taking place? It is conceivable that research and development of defensive technologies could continue if deployment limitations are agreed upon. But would this be enough? China and others not only are concerned about the specific missile defense applications of the U.S. program, but also are worried that someday there may be a technological breakthrough in another related area that leaves them at a significant disadvantage. The trust-consuming effect of such an R&D program should therefore not be underestimated.

Scaling down missile defense is another way to reduce the overall concerns surrounding it. In the years ahead, the United States is likely to do so, as missile defense was always more of a Republican program than a Democratic one. Additionally, there are strong financial pressures for cuts. Yet another option is a cooperative venture with Russia. This may facilitate negotiations toward deep cuts, but would send a dubious signal to China and others. To enhance U.S.-Russian security at the expense of the security of others is not in the spirit of global public good, and not the way to pursue the long-term ambition of a NWFW.

This builds up to an argument for deployment limitations on a slimmer

U.S. missile defense program. Deployment limitations mean reinstating the Anti-Ballistic Missile (ABM) Treaty or negotiating an updated version of it; a slimmer program is the likely outcome of U.S. politics anyhow. Whether the stability of a NWFW would best be enhanced by erecting a shield will be a matter for consideration in a world much different than ours now.

Two measures from the classical arms control agenda are uppermost on the priority list of many states: the ratification and entry into force of the Comprehensive Test Ban Treaty (CTBT) and negotiation of a Fissile Material Cutoff Treaty (FMCT). The United States and China have not ratified the CTBT, while the other P5 countries (France, Russia, and the United Kingdom) have. The United States has conducted 1,000 tests and Russia 700; the others, far fewer. There is the concern, moreover, that sooner or later, simulation techniques will allow the United States to make new types of weapons without live testing. To stem these inequalities and avoid qualitative improvements in the face of a test ban, the NWS should be asked to join the CTBT *and* undertake not to develop and deploy qualitatively new types of weapons. China is ready to ratify the CTBT at any time, provided the United States goes first.

China is not prepared, though, to declare a cut in the production of weapons-grade materials. Like the other P5, China seems to have stopped production of fissile materials for weapons; but unlike the others, China has made no statement or formal commitment in this respect. In view of the uncertainties surrounding missile defense and the future of U.S. forces, China is not confident that it has enough fissile materials in stock. India and Pakistan, which are building up their forces, are not ready for a cutoff either. Therefore, an FMCT does not seem to be near at hand.

A CTBT and an FMCT are important because nuclear infrastructures would be closed down, notably nuclear test sites and fissile material production facilities. (France has done so already.) There may be consequences for personnel as well. The treaty measures would signal that there will be less of a future for nuclear weapons work, which may lead experts in other directions, unless they are absorbed by stewardship programs for the weapons that remain.

The ongoing U.S.-Russian negotiation of an agreement to succeed START I (the Strategic Arms Reduction Treaty) is a relatively simple task. The anticipated follow-on negotiation of deep cuts – often said to aim at no more than 1,000 deployed strategic weapons – faces higher hurdles. During that negotiation, the issues of missile defense and tactical nuclear weapons will come into full play. Iran may also complicate the talks. If Iran's nuclear and missile programs continue unchecked, it will be harder for the United States to forgo a missile shield in Eastern Europe, which is a cardinal Russian demand.

Mutual deterrence is far from being an ideal basis for international security. The risks of breakdown are too great, and the policy is counterintuitive, suggesting that we are best protected when we are naked. But missile defense makes an untenable situation even worse, for by stimulating competitive acquisitions of offensive and defensive capabilities it stands in the way of nuclear disarmament. What may be a problem for Russia in the future is already a problem for China. Deep cuts may take deployment limitations on a slimmer program, as argued above.

Primo 2009, the United States had 500 operational tactical weapons, 200 of them in Europe. On the basis of the number of available delivery platforms, it is estimated that Russia has approximately 2,100 weapons in this category. Including these weapons in an overall count is an increasingly legitimate U.S. demand: the lower the level of strategic arms, the higher the stock of unregulated tactical weapons would loom. Agreed reductions of operationally deployed strategic weapons to the level of 1,000 or below, leaving aside the 2,000 Russian sub-strategic weapons, are hard to imagine. To prepare for the inclusion of sub-strategic weapons, Russia might do more of what the United States is planning for, that is, assigning long-range weapons to regional roles. Freedom to mix strategic and tactical weapons under common ceilings can also facilitate inclusion of them.

The United States holds 2,500 weapons in reserve for strategic and tactical use.[6] The corresponding Russian figure is not known, but it may be higher.[7] In the U.S. Congress, the bipartisan McGovern-Lungren resolution brings reserves into the deep-cut framework, proposing to limit U.S. and Russian arsenals to no more than 1,000 weapons deployed and no more than 3,000 weapons in all, reserves included, and with a freedom to mix.

How deep do U.S. and Russian cuts have to be to engage France, China, and the United Kingdom in disarmament negotiations? The three countries used to say that the superpowers would have to match their level in the low hundreds. Recently, the United Kingdom has shown flexibility in this respect. Maybe the United States and Russia need not come down to the same level as the smaller P5 powers *before* multilateral negotiations can begin. If the United States and Russia agree to cut their forces to three-digit figures while stating their readiness to head toward common P5 ceilings at about the current level of the United Kingdom, France, and China, this may suffice. With such an approach, reductions to 1,000 weapons may also be enough. But if the United States and Russia were to approach the other P5 countries with proportional reductions in mind, such that the United States and Russia would retain larger arsenals than the others, it might go nowhere. Today, France has a somewhat larger arsenal than the United Kingdom and China: 348 operational weapons compared to 185 for the United Kingdom and 179 for China.[8]

Should the multilateral phase be limited to the P5 at first and widened to include others thereafter, or should all NWS be included right away? Two of the four outliers – Israel and North Korea – can best be addressed separately. The Israel problem is a regional one that can only be solved as part of a peace settlement in the Middle East, and North Korea may be willing to trade its arsenal for economic assistance and normalization with the United States and the rest of the world. For the other two – India and Pakistan – the ambition must be to draw them into global negotiations together with the P5. India's nuclear posture has global ramifications, like those of the P5, and Pakistan's weapons are a function of India's. If a criteria-based approach is adopted in relation to the outliers, asking all three to abide by the commitments that India has undertaken and raising the bar for *de jure* recognition by demanding accession to the CTBT and a moratorium on fissile material production, only India may be able to live up to these requirements. In that case, the table would be enlarged from P5 to P6.

Article VI of the NPT was always about hardware *and* software, about both the weapons and the roles assigned to them. For half a century, calls have been made to reduce the role of nuclear weapons in international affairs. NNWS are more vulnerable to use and threats of use than NWS. Where mutually assured destruction applies, resort to nuclear weapons is an ordained act of suicide; while in relation to NNWS, the aggressor may get away with it. No wonder, then, that most of the threats that have been made have been addressed to NNWS. In some instances they seem to have worked.

Non-aligned states have therefore called for an international convention committing the NWS not to use or threaten to use nuclear weapons against those NNWS that are party to the NPT, no qualifications added. No-first-use doctrines, limiting the role of nuclear weapons to that of deterring others from using theirs, would meet the same concerns and, in addition, would reduce the role of nuclear weapons in inter-NWS affairs to deterring the others from using theirs. Such doctrines have an intriguing disarmament corollary: nobody would need them if nobody had them. In pursuit of a NWFW, this proposition is more relevant than extension of non-use assurances to NNWS.

The Geneva Protocol of 1925 prohibited the use of chemical and biological weapons, which were considered inhumane. Later, possession of them was outlawed as well: biological weapons by the Biological Weapons Convention (BWC) of 1972; chemical weapons by the Chemical Weapons Convention (CWC) of 1992. The CWC set a timeline for destruction of the arsenals, and agreement was reached on a comprehensive verification system. In the 1990s, a verification protocol was negotiated for the BWC, too, but the recent Bush administration turned it down. Stressing that any use of nuclear weapons must be compatible with international humanitarian law, the International Court of Justice (ICJ) Advisory Opinion of 1996 came close to a no-use position. The effects of nuclear weapons are such that it is hard to imagine circumstances in which they could be used in compliance with humanitarian law, although a reservation was made for situations in which national survival is at stake (as in the case of Israel).

A protocol banning the use of nuclear weapons, on the model of the Geneva Protocol, would convey the same message: that the effects of nuclear weapons are such that no civilized state or sane leader should or would use them. An international legal instrument declaring their use to be a crime against humanity would send an even stronger message and be a better deterrent against use.

In effect, the Geneva Protocol was a no-first-use agreement. An agreement banning the use of nuclear weapons would similarly allow for nuclear retaliation, that is, it would be a no-first-use agreement. It may include provisions branding the use of nuclear weapons a crime against humanity. Alternatively, the Security Council could be invited to issue such a declaration.

Given its conventional preponderance, the United States could more easily convert to no-first-use than could Russia. However, if the United States seizes the initiative and Russia is willing to generalize the bilateral Russia-China no-first-use commitment, the P5 would end up with such a doctrine, for it is hard to imagine that the United

Kingdom and France would not follow the U.S. lead, especially when reinforced by Russia. (China always had a policy of no-first-use.) The United States would have to stop issuing nuclear weapons threats, and its alliance commitments and nuclear umbrellas would have to be changed accordingly. Its allies would have to be reassured in other ways.

One or more NWS may find that they can move to the low hundreds, but no further unless their security concerns have been much alleviated and the military and political role of nuclear weapons has been much diminished. Russia may be a case in point. Others may be ready to push for proposals beyond a call for low hundreds: China to follow up on its no-first-use posture; India to promote its long-standing proposal for a nuclear weapons convention; NNWS to press their case for a NWFW whether they are brought into the negotiations or not. Most important, the United States should remain committed to the course initiated by President Obama. All of this is uncertain, however.

Ceilings in the low hundreds will presumably be set on the basis of some notion of minimum deterrence. In terms of hardware, minimum deterrence is a function of the vulnerability of the weapons, their ability to penetrate enemy defenses, and the possibility that some of them will malfunction and fail to arrive on target for that reason. In terms of software, it is a function of the efficiency of the C3I system (Communications, Command, Control, and Intelligence) and the perceived political will to follow through on deterrence doctrines. Today, the powers that subscribe to minimum deterrence keep arsenals ranging from 180 weapons (China and the United Kingdom) to 350 (France). India and Pakistan are probably heading for forces in about the same range, and Israel may already be there.

It may be assumed that multilateral negotiations will seek ceilings in the lower end of this range, compatible with notions of minimum deterrence but not allowing significant increases in any of the forces. Substantial additions would run against the declared aim of the exercise, which will be framed in disarmament terms. How could one go on from there? What approach would minimize the risks on the way to a NWFW and maximize the advantages that it offers? The prize is high, but so may be the risks.

From this point on, the continuation is hard to foresee. Indeed, it would be presumptuous to claim to know much about it. However, political-order issues aside, some force constellations are known to be more dangerous than others. A few parameters, therefore, may be established to steer the process away from some of the greatest risks in the final approach to the goal – in particular, the worlds immediately above and immediately below zero. The dangers of a world immediately below (virtual arsenals) have been spelled out above. Similar dangers would exist in a world immediately above. At the level of, say, 30 nuclear weapons, the retaliatory capabilities may be in doubt. Some weapons may be destroyed by the enemy, others may be intercepted, and yet others may not function as planned. As a result, first-strike propensities may be too great for comfort. It may lead to surprise attacks, hitting the enemy when his guard is down, or to inadvertent escalation when decision-makers begin to believe that war can no longer be avoided. However flexible the notion of minimum deterrence, force levels in the low hundreds may have been chosen for good reason.

It may therefore be wise to skip those transitional phases immediately above and below zero and go from the low hundreds directly to a NWFW significantly below zero. That can be done by eliminating weapons-grade materials, dismantling dedicated nuclear infrastructure, and trimming the nuclear weapons workforce to a minimum *before* eliminating the remaining weapons. In other words, the stability of minimum deterrence postures would be maintained until the stability of a NWFW has been ensured. Then, and only then, would it be time to move from the one to the other.

It is hard to imagine a NWFW where the ground rules are different for different categories of states. Forty years of discontent with the NPT's division of the world into nuclear- and non-nuclear-weapons states, and persistent complaints over the slow implementation of Article VI, which was supposed to have ended that division, have led many NNWS to insist on equal rules for all. Thus new measures must be equitable and capability differences increasingly reduced as the process unfolds. Regardless of the exact roadmap followed, the principle of equity will be important throughout the disarmament process.

The NPT was meant to be the regulatory mechanism for nonproliferation, disarmament, and peaceful uses on the path toward zero. The parties may wish to reinterpret some of its provisions, but may see fit to keep the Treaty until it has been implemented – that is, until all weapons have been eliminated. At that point, however, the equity that it prescribes stops. The NPT goes to zero, but never pretended to guide moves below zero. Therefore, a new convention outlining the ground rules of a NWFW has to be written before reaching that point. A convention well ahead of zero may also be desirable because the NPT is no more than a skeleton agreement; new rules guiding the final approaches to zero will be needed in any case. To be agreeable, those rules must be informed by the principle of equity and lead to a NWFW where the rules are the same for all.

Measures to enhance the proliferation resistance of nuclear power must also be the same for all. For instance, proposals to internationalize the fuel cycle must apply to *all* existing and future facilities, including those in the NWS. If not, the critical cases are unlikely to be covered. Deep cuts and measures blocking qualitative developments of nuclear arsenals may improve the prospects for internationalization by making the implementation of the NPT more balanced. Even so, studies have shown that the problems are formidable. Will proliferation resistance be more urgent as disarmament progresses, or will it be less important? To what extent will civilian uses of nuclear energy have to be circumscribed by technological and organizational constraints in a NWFW?

The main driver – the concerns about weapons proliferation in a world where nuclear power is spreading – would seem stronger today than in a world that is set on the course of nuclear disarmament. Reductions to 1,000 U.S. and Russian weapons with no promise of going further would hardly impress would-be proliferators; but if disarmament becomes an established trend pointing toward a NWFW, it will be more costly to defy that trend. In that setting, proliferation resistance will still be desirable, but arguably less urgent.

Today, the incentives to acquire nuclear capabilities and nuclear weapons are strong, while the mechanisms to enforce the commitments undertaken by NPT members are weak. In a NWFW, on the other hand, the further below zero one goes, the stronger the inhibitions against remilitarization will be and the lesser the concerns about the shape of the civilian sector. In a world of virtual arsenals this will be different: civilian facilities may become part of a hedging race, so proliferation resistance and international safeguards will be of the essence. The nuclear industry would therefore be well served by a sustained disarmament process and by a NWFW below zero.

On the way to a NWFW, the differences between the NWS will diminish. Still, their capabilities will remain different in many respects, especially qualitative ones. The principle of equity should inform the process, but how agreeable is it and how will it be practiced? Would China use the opportunity to go for equal status with the United States and Russia in as many respects as possible and as soon as possible? Would India reach out for the same? So far, China has refrained from arms racing, saying enough is enough. But will it continue to do so in the face of a real chance to obtain equal status? Why should the United States and Russia give up their nuclear superiority and accept equal status with the much smaller nuclear powers any sooner than is absolutely necessary? Would they ask for proportional reductions when they come to the multilateral table? Even if the United States maintains its commitment to a NWFW, why should it yield to the others any more or any sooner than is required?

If the commitments to a NWFW are firm and the expectations that it will be achieved are strong, equal or unequal terms some steps earlier will not necessarily matter very much. The end result would be the same for everybody. In a *process* perspective, there would be more leeway in the negotiation of transitional steps than in a *static* perspective, where each stage stands on its own and the future is open-ended. For instance, if a multilateral deal is struck in a static perspective – this far, but no promise of going further – the NWS are likely to be more sensitive to competitive edges and seek unilateral advantages. The leading powers cannot then be expected to relinquish their lead generously. More than in a process perspective that is pursued in the name of global public good, old-fashioned power politics would be the name of the game.

A static perspective, which regards disarmament not as a process but as a state of affairs, presents a problem similar to a well-known question in integration theory. Integration is also seen variously as a process or a state of affairs. In the European Union, which has inspired integration theory more than any other empirical setting, there is the recurrent question whether integration can stop and remain at some point without unravelling. Is there such a point of stability, or will stagnation be the beginning of reversal? The same question is pertinent to the field of disarmament. If the United States and Russia stay content after having reduced their forces to 1,000 weapons all in all, losing sight of the objective of a NWFW, what will others do? Will emerging powers go for equal numbers? Maybe not. Will more states take an active interest in the nuclear weapon option? Maybe yes. Proliferation is more likely in a static context, where the NWS continue to demonstrate the significance that they attach to nuclear arms, than in a process perspective, where proliferators would confront an overwhelming majority of states set on the course of continued disarmament. It is always more costly to act against an existing trend. Stagnation may therefore lead to proliferation, which in turn may lead more states to rearm.

The first stage of the disarmament process – U.S.-Russian cuts and missile defense limitations in advance of multilateral talks – does not presuppose any change of world order, but it implies a distinct shift from antagonistic to cooperative behavior. Subsequent stages require more of the same, gradually transforming the current security system based on nuclear deterrence into a system based on cooperation and mutual restraint. Arms control and disarmament can assume the role of *catalyst and amplifier* of such a change. It has had that role before: starting in 1986 with the Stockholm agreement on confidence and security-building measures, it helped to move the world out of the Cold War.[9] If it is widely recognized as a high-priority global public good, it may even become a *driver* of systemic change.

When multilateral reductions to the low hundreds have been agreed, further steps will depend on fundamental world-order changes, for it is from that point on that the question of how to live without nuclear deterrence becomes pressing. Some are likely to stick to the view that it is safer to keep the weapons than to take the risk of disarming, so a better system must be developed to substitute for it. Disarmament and world order become twins – two sides of the same coin. Would all NWS be ready to engage in that endeavor? Would they proceed to discuss what version of a NWFW they should go for and how best to reach it? How conditional or categorical would they be about it?

In thinking about how to sustain nuclear disarmament and enhance international security, parallels have been drawn to the so-called European concert after the Napoleonic Wars, when the European powers undertook to respect each other's vital interests and exercise restraint in a system characterized by balance of power. Henry Kissinger, an authority on concert diplomacy, describes it as a system in which "the great powers work together to enforce international norms.... Common action grows out of shared convictions. Power emerges from a sense of community and is exercised by an allocation of responsibilities related to a country's resources. It is a kind of world order either without a dominating power or in which the potentially dominating power leads through self-restraint." Believing that the Obama administration favors some kind of concert diplomacy, he argues that American leadership will "result from the willingness to listen and to provide inspirational affirmations (of norms)."[10]

A great-power concert may be predicated on equilibrium between the participating states or it may be based on consensus. Generally, the former has been considered less demanding than the latter, although there are few examples of sustained operation of any version of power concerts. Today, however, when power is shifting so rapidly, a lasting equilibrium is dead on arrival. Better then to focus on norms – norms of mutual respect and self-restraint embedded in a growing body of international law, with a view to building a platform for effective enforcement action.

The organizing framework in the nuclear field, the NPT, suffers very much from the lack of well-functioning enforcement mechanisms. Not only is it difficult to forge consensus between the P5, but the UN Security Council has long been out of tune with the distribution of power in the international system. Progress toward a NWFW requires *cooperative security* between the big powers with a view to more effective *collective security* mechanisms in the hands of the world organization.

Globalization encourages development along these lines. Interdependence is growing by the day and necessitates broad-based international cooperation on regulatory measures. The current economic crisis does the same. It absorbs the energies of all the major powers, so they need respite from international confrontation. This is a period of opportunity for international security cooperation.

In East Asia, rapidly growing economic interdependence is a brake on security dynamics in the region. Use of force will come at tremendous costs to all involved. However, economic cooperation and security policies are conducted along different trajectories. Economic cooperation means interdependence, but it is pursued by sovereign states and does not translate into political integration.

Europe is different in this respect. Starting from the interdependence of the Coal and Steel Union, integration has been going on for more than 50 years. When the Cold War ended, the European Union and Russia became strategic partners. Still, Russia and the Western nuclear powers threaten to be the first to use nuclear weapons against each other, and U.S. tactical nuclear weapons remain deployed in Europe. There is no reasonable connection between the political sphere and existing nuclear doctrines. Many elements of the nuclear postures have become anachronistic.

The danger of nuclear weapons use is probably highest in South Asia and the Middle East. These are volatile areas that call for combinations of regional measures and global initiatives. The political requirements of nuclear disarmament are therefore different for different parts of the world. The nuclear arsenals evolved under different historical circumstances and have different political meanings and utilities for their owners. Because the starting points are so different and because long-term disarmament is path-dependent, attempts to envisage how the process might unfold are easily overblown.

Thinking beyond multilateral talks about arsenals in the low hundreds, the path-dependence of nuclear deterrence blurs the picture. This paper nevertheless advances one specific proposition about disarmament below that stage. Since stability concerns and bickering over numbers are likely to become more of a problem at very low levels, and since virtual arsenals are likely to be unstable, it may be wise to stay at minimum deterrence levels until nuclear weapons infrastructure and weapons-grade materials have been eliminated, and then go straight to a world below zero.

For political leaders to act on complex realities, the realities have to be simplified. Heuristic assumptions to that effect may be flawed, but they are necessary to keep the debate about the feasibility and desirability of a NWFW alive.

ENDNOTES

1 http://www.huffingtonpost.com/2009/04/05/obama-prague-speech-on-nu_n_183219.html.

2 http://www.usatoday.com/news/world/2009-06-04-Obama-text_N.htm.

3 See also the second Shultz et al. op-ed in *The Wall Street Journal*, January 15, 2008. A number of high-level statements have been made in support of this initiative, including the statement by German leaders (Bahr, Schmidt, Genscher, von Weizsacker); the statement by British leaders (Rifkind, Hurd, Owen, Robertson); the statement by Norwegian leaders (Bondevik, Brundtland, Nordli, Stoltenberg, Willoch); the statement by Australian leaders (Fraser, Gration, Sanderson); the statement by Polish leaders (Kwasnievski, Walesa, Mazowiecki); the statement by Italian leaders (D'Alema, Fini, La Malfa, Parisi); the joint statement by Presidents Obama and Medvedev; the joint statement by Carter, Gorbachev, Beckett, Rocard, et al. (Global Zero); and the joint statement by Norwegian Foreign Minister Støre and German Foreign Minister Steinmeier. These and other statements by a great many individual leaders show that the interest in reviving the objective of a NWFW has spread to the political mainstream also in countries that had not been very vocal on this matter in the past.

Of the many academic contributions to the debate, this paper draws, in particular, on George Perkovich and James Acton, eds., *Abolishing Nuclear Weapons: A Debate* (Washington, D.C.: Carnegie Endowment for International Peace, February 2009). Perkovich and Acton's own contribution to that volume was first published as an Adelphi Paper in September 2008.

4 George Perkovich, "Principles for Reforming the Nuclear Order," Proliferation Papers, IFRI Security Studies Center, Fall 2008.

5 Harald Muller, "The Importance of Framework Conditions," in *Abolishing Nuclear Weapons*, ed. Perkovich and Acton.

6 Weapons loaded on heavy bombers or stored in weapons storage areas at heavy bomber bases are counted as operational strategic weapons.

7 It is estimated that about 8,800 weapons are held in reserve or have been slated for dismantlement.

8 As of 2008; Stockholm International Peace Research Institute (SIPRI), *SIPRI Yearbook 2008* (Oxford: Oxford University Press, 2008).

9 Harald Muller, "The Future of Nuclear Weapons in an Interdependent World," *The Washington Quarterly* (Spring 2008).

10 Henry Kissinger, "Obama's Foreign Policy Challenge," *The Washington Post*, April 22, 2009.

Sam Nunn

Taking steps toward a world free of nuclear weapons

Secretary of State Dean Acheson was once asked to define foreign policy.[1] He thought a moment and replied, "Foreign policy is one damn thing after another." I realized at a relatively young age that nuclear weapons were not just another thing, but that indeed they held hostage the future of mankind. I was a 24-year-old lawyer for the House Armed Services Committee on a three-week air force trip to Europe when the Cuban Missile Crisis broke out. During that period, while the world held its breath, our delegation met at Ramstein Air Base in Germany with the head of the U.S. Air Forces in Europe. The general explained that in the event of war, he had only a couple of minutes to launch all of what were known as quick-reaction aircraft, or they would be destroyed. These planes and forward bases were the first targets for the Soviets because they would deliver the first nuclear weapons to strike the Soviet Union, or at least that is what the Soviet Union anticipated. The fact that the fate of mankind rested on the shoulders of only a few people on each side who had only a few moments to decide whether to launch nuclear weapons made a lasting impression on me. I pledged to myself then that if I ever had a chance to work on the problem, I was going to tackle it.

Today the Cold War is over, but we face new nuclear dangers. I believe that the greatest danger we face is the possibility of a catastrophic nuclear attack by a terrorist group that does not have a return address and therefore is unlikely to be deterred. The accelerating spread of nuclear weapons, nuclear materials, and nuclear know-how has brought us to a nuclear tipping point. Indeed, we are in a race between cooperation and catastrophe. If we are to continue to avoid a catastrophe, all nuclear powers will have to be highly capable, careful, competent, rational – and if things go wrong, lucky – every single time. India and Pakistan have already had more than one close call, and their nuclear age has just begun.

I frequently ask myself two questions: the day after a nuclear attack on one of the cities of the world, what would we wish we had done to prevent it? And why aren't we doing it now?

We do have important efforts under way as well as some important successes, including the Nunn-Lugar Cooperative Threat Reduction program, the Global Threat Reduction Initiative, the Proliferation Security Initiative, and the Global

Initiative to Combat Nuclear Terrorism. These programs mark progress and potential, but the risk of a nuclear weapon being used today is growing, not receding. The storm clouds are gathering:

- Terrorists are seeking nuclear weapons, and there can be little doubt that if they acquire a weapon they will use it.
- There are nuclear weapons materials, some secured by nothing more than a chain-link fence, in more than 40 countries; at the current pace, it will be decades before this material is adequately secured or eliminated globally.
- The expertise to build nuclear weapons is far more available today because of an explosion of information and commerce throughout the world.
- The number of nuclear-weapons states is increasing. A world with 12 or 20 nuclear-weapons states will be immeasurably more dangerous than today's world and will make it more likely that weapons or materials to make them will fall into the hands of terrorists with no return address. Developments in cyberterrorism pose new threats that could have disastrous consequences if the command-and-control systems of any nuclear-weapons state are compromised.
- With the growing interest in nuclear energy, a number of countries are considering developing the capacity to enrich uranium to use as fuel for nuclear energy; but this would also give them the capacity to move quickly to a nuclear weapons program if they chose to do so.
- Meanwhile, the United States and Russia continue to deploy thousands of nuclear weapons on ballistic missiles that can hit their targets in less than 30 minutes, encouraging both sides to continue a prompt-launch capability that carries with it an increasingly unacceptable risk of an accidental, mistaken, or unauthorized launch.

The bottom line: the world is heading in a very dangerous direction.

With these growing dangers in mind, former U.S. Secretaries of State George Shultz and Henry Kissinger, former U.S. Secretary of Defense William Perry, and I published an op-ed in *The Wall Street Journal* in January 2007[2] and a follow-up piece in January 2008[3] that called for a different direction in our global nuclear policy. We proposed steps that would lay the groundwork for a world free of nuclear threat. We called for building a solid consensus for reversing reliance on nuclear weapons globally.

We are all keenly aware that the quest for a world free of nuclear weapons is fraught with many practical challenges. We have taken aim at those challenges by laying out a number of steps, which I believe are doable even though they are very difficult. We cannot reduce nuclear dangers without taking these steps. We cannot take these steps without the cooperation of other nations. We cannot get the cooperation of other nations without the shared vision of eradicating these weapons and their threat to the world. Indeed, even a quick glance at the steps we proposed in our two *Wall Street Journal* essays reveals that none of the steps can be accomplished by the United States and our close allies alone:

- Changing nuclear force postures in the United States and Russia to greatly increase warning time and ease our fingers away from the nuclear trigger;
- Reducing substantially the nuclear forces in all states that possess them;

- Moving toward developing cooperative multilateral ballistic-missile defense and early warning systems, which will reduce tensions over defensive systems and enhance the possibility of progress in other areas;
- Eliminating short-range "tactical" nuclear weapons, beginning with accountability and transparency among the United States, NATO, and Russia;
- Working to bring the Comprehensive Test Ban Treaty into force, in the United States and in other key states;
- Securing nuclear weapons and materials around the world to the highest standards;
- Developing a multinational approach to civil nuclear fuel production, phasing out the use of highly enriched uranium in civil commerce, and halting the production of fissile material for weapons;
- Enhancing verification and enforcement capabilities – and our political will to do both;
- Building an international consensus behind ways to deter and, when necessary, strongly and effectively respond to countries that breach their commitments.

Many people's reaction to the vision of a world without nuclear weapons comes in two parts. On the one hand, most people say, "Boy, that would be great"; on the other, "We simply can't get there from here." But there is hope. In the 1990s, under Bill Perry's capable leadership as the Secretary of Defense, we made a deal to buy highly enriched uranium from Russian warheads that were aimed at the United States, blend it down, make it into nuclear fuel, and use it in our power plants. Today, after a number of years working on that program, we have made tremendous progress. If you think about it, approximately 20 percent of the electricity in the United States is supplied by nuclear power; 50 percent of the nuclear fuel that goes into that nuclear power is supplied by highly enriched uranium that has been blended into low-enriched uranium and made into nuclear fuel that 20 or 25 years ago was in warheads aimed at the United States. So when you look at the lights in any room in America, theoretically 10 percent of those light bulbs are fueled by material that was in the form of weapons aimed at America in the 1970s and the 1980s. Swords to plowshares: we have hope.

Taking steps toward a world free of nuclear weapons

When I think about the goal of a world free of nuclear weapons, to me it is like a very tall mountain. It is tempting and easy to say we can't get there from here. It is true that today our troubled world cannot even see the top of the mountain. But we can see that we are heading down, not up; we can see that we must turn around, that we must take paths leading to higher ground, and that we must get others to move with us. It is urgent for the survival of humanity that we stop our descent and find paths up the mountain toward a world free of nuclear weapons.

ENDNOTES

1 This essay is based on remarks made by Senator Nunn at the American Academy of Arts and Sciences in Cambridge, Massachusetts, on October 12, 2008, and at the American Academy in Berlin, Germany, on June 12, 2008.

2 George P. Shultz, William J. Perry, Henry A. Kissinger, and Sam Nunn, "A World Free of Nuclear Weapons," *The Wall Street Journal*, January 4, 2007.

3 George P. Shultz, William J. Perry, Henry A. Kissinger, and Sam Nunn, "Toward a Nuclear-Free World," *The Wall Street Journal*, January 15, 2008.

Scott D. Sagan

Shared responsibilities for nuclear disarmament

Interest in nuclear disarmament has grown rapidly in recent years. Starting with the 2007 *Wall Street Journal* article by four former U.S. statesmen – George Shultz, Henry Kissinger, William Perry, and Sam Nunn – and followed by endorsements from similar sets of former leaders from the United Kingdom, Germany, Poland, Australia, and Italy, the support for global nuclear disarmament has spread.[1] The Japanese and Australian governments announced the creation of the International Commission on Nuclear Non-Proliferation and Disarmament in June 2008. Both Senators John McCain and Barack Obama explicitly supported the vision of a world free of nuclear weapons during the 2008 election campaign. In April 2009, at the London Summit, President Barack Obama and President Dmitri Medvedev called for pragmatic U.S. and Russian steps toward nuclear disarmament, and President Obama then dramatically reaffirmed "clearly and with conviction America's commitment to seek the peace and security of a world without nuclear weapons" in his speech in Prague.

There is a simple explanation for these statements supporting nuclear disarmament: all states that have joined the Nuclear Non-Proliferation Treaty (NPT) are committed "to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament." In the United States, moreover, under Clause 2 of Article 6 of the Constitution, a treaty commitment is "the supreme Law of the Land." To affirm the U.S. commitment to seek a world without nuclear weapons is therefore simply promising that the U.S. government will follow U.S. law.

A closer reading of these various declarations, however, reveals both the complexity of motives and the multiplicity of fears behind the current surge in support of nuclear disarmament. Some declarations emphasize concerns that the current behavior of nuclear-weapons states (NWS) signals to non-nuclear-weapons states (NNWS) that they, too, will need nuclear weapons in the future to meet their national security requirements. Other disarmament advocates stress the growth of global terrorism and the need to reduce the number of weapons and the amount of fissile material that could be stolen or sold to terrorist groups. Some argue that the risk of nuclear weapons accidents or launching nuclear missiles on false warning cannot be entirely eliminated, despite sustained efforts to do so, and thus believe that nuclear deterrence will inevitably fail over time, especially if large arsenals are maintained and new nuclear states, with weak command-and-control systems, emerge.

Perhaps the most widespread motivation for disarmament is the belief that future progress by the NWS to disarm will strongly influence the future willingness of the NNWS to stay within the NPT. If this is true, then the choice we face for the future is *not* between the current nuclear order of eight or nine NWS and a nuclear-weapons-free world. Rather, the choice we face is between moving toward a nuclear-weapons-free world or, to borrow Henry Rowen's phrase, "moving toward life in a nuclear armed crowd."[2]

There are, of course, many critics of the nuclear disarmament vision. Some critics focus on the problems of how to prevent nuclear weapons "breakout" scenarios in a future world in which many more countries are "latent" NWS because of the spread of uranium enrichment and plutonium reprocessing capabilities to meet the global demand for fuel for nuclear power reactors. Others have expressed fears that deep nuclear arms reductions will inadvertently lead to nuclear proliferation by encouraging U.S. allies currently living under "the U.S. nuclear umbrella" of extended deterrence to pursue their own nuclear weapons for national security reasons. Other critics worry about the "instability of small numbers" problem, fearing that conventional wars would break out in a nuclear disarmed world, and that this risks a rapid nuclear rearmament race by former NWS that would lead to nuclear first use and victory by the more prepared government.

Some critics of disarmament falsely complain about nonexistent proposals for U.S. *unilateral* disarmament. Frank Gaffney, for example, asserts that there has been "a 17-year-long unilateral U.S. nuclear freeze" and claims that President Obama "stands to transform the 'world's only superpower' into a nuclear impotent."[3] More serious critics focus on those problems – the growth and potential breakout of latent NWS, the future of extended deterrence, the enforcement of disarmament, and the potential instability of small numbers – that concern *mutual* nuclear disarmament. These legitimate concerns must be addressed in a credible manner if significant progress is to be made toward the goal of a nuclear-weapons-free world.

To address these problems adequately, the current nuclear disarmament effort must be transformed from a debate among leaders in the NWS to a coordinated global effort of shared responsibilities between NWS and NNWS. This essay outlines a new conceptual framework that is needed to encourage NWS and NNWS to share responsibilities for designing a future nuclear-fuel-cycle regime, rethinking extended deterrence, and addressing nuclear breakout dangers while simultaneously contributing to the eventual elimination of nuclear weapons.

The NPT is often described as a grand bargain between NWS and NNWS. The NNWS, it is said, agreed not to acquire nuclear weapons in exchange for the "inalienable right," under Article IV of the Treaty, to acquire civilian nuclear power technology under international nonproliferation safeguards and the promise by the NWS, under Article VI of the Treaty, to work in good faith to eliminate eventually all of their nuclear weapons. Wolfgang Panofsky, for example, argued:

> Non-nuclear Weapons States were enjoined from acquiring nuclear weapons and Nuclear Weapons States were forbidden to transfer nuclear weapons and the wherewithal to make them to an NNWS. To compensate for this obvious discriminatory division of the world's nations, NNWS were assured that they had an "inalienable right" to the peaceful application of nuclear energy, and the NWS obligated themselves in Article VI of the treaty to work in good faith toward nuclear disarmament.[4]

In his 2009 Prague speech, President Obama similarly maintained that "the basic bargain is sound: Countries with nuclear weapons will move towards disarmament, countries without nuclear weapons will not acquire them, and all countries can access peaceful nuclear energy."

These statements correctly highlight the important linkage between nuclear disarmament and nuclear nonproliferation. But framing the linkage in this way – with NWS seen as responsible for disarmament and NNWS responsible for accepting nonproliferation safeguards on their nuclear power programs – is historically inaccurate and politically unfortunate. It is historically inaccurate because both Article IV and Article VI were written to apply *to both* the NWS and the NNWS. This common description of the Treaty is unfortunate because it limits the prospects for crafting a more comprehensive and more equitable implementation of the basic NPT bargains, based on shared responsibilities between NWS and NNWS, in the future.

Shared responsibilities for nuclear disarmament

Article IV of the NPT simply states, "Nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination and in conformity with Articles I and II of this Treaty." The expected global expansion of nuclear power, however, will lead to increasing demand for enriched uranium and reprocessed plutonium around the globe; a crucial question for future security therefore is whether the spread of nuclear power will lead to the spread of enrichment and plutonium fuel-production facilities. Mohamed ElBaradei has been particularly forceful in warning of the security risks inherent in such a world of multiple "virtual nuclear weapons states," arguing for "a new international or multinational approach to the fuel cycle so as to avoid ending up with not just nine nuclear weapon States but another 20 or 30 States which have the capacity to develop nuclear weapons in a very short span of time."[5] George Perkovich and James Acton agree, noting that the NWS are unlikely to take the final steps toward complete disarmament if there are many states that could quickly get nuclear weapons material from their own national uranium or plutonium production facilities. "If no acceptable form of regulation can be established for the proliferation-sensitive activities that many states which today promote disarmament are seeking to conduct," they argue, "the abolition of nuclear weapons may not prove possible."[6]

Many proposals exist for different forms of multinational fuel-cycle facilities (plants owned and operated by multiple states) or international facilities (plants owned and operated by an international organization). Governments of many NNWS, however, as well as some nuclear technology exporters, argue that creating any constraints on the national production of nuclear fuels would violate the "inalienable right" mentioned in Article IV. As Albert Wohlstetter once noted, it is as if some diplomats believe that all states have "a new natural right to Life, Liberty, and the Pursuit of Plutonium."[7]

Three important points about Article IV become clearer if one probes a little more deeply. First, this "inalienable right" is in reality a conditional right, dependent upon the state in question being "in conformity" with Articles I and II of the NPT. It is too often forgotten in the debate over the Iranian nuclear program, for example, that a state that is not behaving "in conformity" with its Article II commitment "not to seek or receive any assistance in the manufacture of nuclear weapons" has at least temporarily sacrificed its rights to acquire civilian nuclear technology under Article IV. The Board of Governors of the International Atomic Energy Agency (IAEA) decides whether or not a state is in compliance with its specific safeguards commitments. But the IAEA does not determine the appropriate response to a safeguards violation that is not remedied in a timely fashion; instead, it reports any such case of noncompliance to the UN Security Council and the General Assembly – as it did in 2004 with respect to Libya and in 2006 with respect to Iran – and then the Security Council must decide on appropriate responses.[8]

Second, Article IV refers to "*all the Parties to the Treaty*," not just the NNWS. This should lead to increased opportunities to share responsibility for nonproliferation and disarmament, for it suggests that as part of their Article IV commitment, the NWS should reaffirm that international safeguards can eventually be placed on all of *their* nuclear power plants and enrichment and reprocessing facilities. Indeed, such an agreement in principle, with an exception for facilities with "direct national security significance," was in fact made by President Lyndon Johnson in 1967, as a major compromise during the NPT negotiations.[9] Reaffirming this commitment, as a responsibility under Article IV, should be easy to accept in principle; after all, if NWS are committed to working in good faith toward nuclear disarmament, at some point they would become, to coin an acronym, FNWS (former nuclear-weapons states), and the safeguard exceptions they currently maintain would no longer apply.

In practice, it would be helpful for NWS to go beyond reaffirmations and expressions of principle and pick one or more model facilities to place under advanced safeguards, to demonstrate future intentions and help create best practices. Strict safeguards on existing nuclear-fuel production facilities in the NWS are not really necessary *today* to ensure that the materials from the plants are not diverted for nuclear weapons, since NWS already have sufficient fissile materials from their military nuclear production programs. But placing new facilities under IAEA safeguards would signal equitable treatment and a long-term commitment to disarmament. Similar safeguards will also be needed if a Fissile Material Cutoff Treaty (FMCT), ending the production of materials for weapons, is successfully negotiated, though in this case the verification and safeguarding functions would be best handled (at least initially) by a new organization of inspectors from NWS, rather than the IAEA, so as to limit access into sensitive former weapons-material production facilities.

Third, responsibilities for sharing the financial support of IAEA international safeguards can be improved. Today, each

IAEA member state pays into a regular budget of the Agency, from which the Safeguards Division draws funds for its inspection programs; but the Agency is strapped for funds to deal with the current level of inspections, and will be much more so if nuclear power continues to expand as expected and if the more intrusive regime required by the Agreed Protocol, which calls for advanced inspections, comes into force. One approach that has been advocated is to have states pay more into the IAEA safeguards budget in proportion to the number and kinds of facilities they have on their soil that are subject to inspection. This approach, however, places the financial burden only on the state that benefits from the nuclear power plant or fuel facility in question and ignores that the nonproliferation benefits of the safeguards are shared by all states. A better approach would be to have all governments – both NWS and NNWS, and both states with nuclear power programs and those without nuclear power – substantially increase their funding support for the IAEA, to enhance its future safeguards capabilities. Indeed, it would be possible to have private industry and even philanthropic organizations interested in promoting more safe and secure use of nuclear power also contribute to the IAEA safeguards budget.[10]

Shared responsibilities for nuclear disarmament

Article VI of the NPT states in full, "Each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control." Many diplomats from NNWS have complained at virtually every NPT review conference that the NWS have not done enough to meet their disarmament commitments, and the May 2009 NPT Preparatory Committee meeting was not unusual in that regard. The NNWS complaints are not without some merit, for the recent Bush administration did not follow through on some of the disarmament-related commitments (most specifically, seeking ratification of the Comprehensive Test Ban Treaty) that previous administrations had made at NPT review conferences.[11] In addition, some former U.S. government officials have unhelpfully claimed that the United States never really intended to keep its Article VI commitments. Former CIA Director John Deutch, for example, asserted in *Foreign Affairs* in 2005 that Washington was "unwise" "to commit under Article 6 of the Nonproliferation Treaty [NPT] 'to pursue good-faith negotiations' toward complete disarmament, a goal it has no intention of pursuing."[12] The Bush administration's 2001 U.S. Nuclear Posture Review was also widely interpreted to signal movement away from the NPT commitment to nuclear disarmament because the document declared that U.S. nuclear weapons "possess unique capabilities ... to hold at risk targets [that are] important to achieve strategic and political objectives"; it called for the development of new nuclear warheads; and it outlined a strategy of "dissuasion," the policy of maintaining such a large advantage in military forces, including nuclear, that other states would be dissuaded from even considering entering into a military arms competition with the United States.

Many diplomats and scholars have spoken about the specific arms-control and disarmament steps the United States and other NWS could take to demonstrate that they are pursuing their Article VI commitments more seriously. Missing from this debate is a discussion of what the NNWS can do to help in the disarmament process. Looking at shared responsibilities points to two specific ways in which the NNWS can better honor their Article VI commitments.

First, just as NWS and NNWS should share responsibilities for funding the increasingly advanced international safeguards necessary for nuclear power facilities, the NWS and NNWS should both contribute significantly to funding the necessary major research and development effort for improved monitoring and verification technologies that will be needed if nuclear disarmament is to progress to very low numbers of weapons. In October 2008, the British government invited the governments of the other NPT-recognized nuclear states – the United States, Russia, France, and China – to participate in a major technical conference examining future verification challenges and opportunities. Even more importantly, the British government recognized that R&D for disarmament verification must not occur in "splendid isolation," and so jointly sponsored test programs with the Norwegian government laboratories to identify promising technologies that would permit Norway and other NNWS to be more directly involved in implementing and monitoring future global nuclear disarmament.[13]

Second, focusing on shared responsibilities helps identify a more direct and stronger linkage between Article VI and Article IV of the NPT. Because NWS will be less likely to accept deep reductions to zero (or close to zero) if there are more and more states with latent nuclear-weapons capability because of the spread of uranium enrichment and plutonium reprocessing technologies, NNWS have both an individual interest and a collective responsibility to make sure that constraints are placed on sensitive fuel-cycle facilities. In short, the NNWS should recognize that entering into negotiations about international control of the nuclear fuel cycle is an essential part of *their* Article VI commitment "to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race."

A third common criticism of the disarmament goal is that nuclear force reductions might backfire, inadvertently encouraging nuclear proliferation, by undercutting U.S. extended deterrent commitments. In September 2008, for example, Secretary of Energy Samuel Bodman and Secretary of Defense Robert Gates declared that "the United States will need to maintain a nuclear force . . . for the foreseeable future," basing this position in part on the need to protect U.S. non-nuclear allies:

> The role nuclear forces play in the deterrence of attack against allies remains an essential instrument of U.S. nonproliferation policy by significantly reducing the incentives for a number of allied countries to acquire nuclear weapons for their own. . . . In the absence of this "nuclear umbrella," some non-nuclear allies might perceive a need to develop and deploy their own nuclear capability.[14]

The term "nuclear umbrella," however, should be deleted from the strategic lexicon used by government officials and scholars alike. It connotes a defensive, passive strategy – as if Japan, South Korea, and NATO countries were protected by some kind of missile defense shield – rather than the threat of retaliation with nuclear weapons against a state that attacks a U.S. ally. Even more importantly, the nuclear umbrella term does not differentiate between two very different kinds of extended deterrence policies: a U.S. commitment to use nuclear weapons first, if necessary, to defend an ally if it is attacked by an enemy who uses conventional forces, biological or chemical weapons, or nuclear weapons; and a more tailored U.S. commitment to use U.S. nuclear weapons in retaliation against *only* a nuclear attack on an ally. The first form of extended deterrence was the U.S. Cold War policy in NATO and in East Asia and remains largely intact today despite the end of the Cold War.

Adopting the second form of extended deterrence – maintaining commitments to joint defense but limiting the threat of nuclear weapons use to retaliation against nuclear attacks on allies – would not necessarily lead to the nuclear proliferation cascade that Gates and Bodman seem to fear. Indeed, a more targeted U.S. nuclear guarantee, if implemented properly after alliance consultation, could have a number of positive strategic effects. First, such a change might be welcomed by those allies who continue to value allied conventional military commitments, but feel that first-use nuclear threats encourage nuclear proliferation elsewhere in the world. A more targeted nuclear guarantee would also make U.S. nuclear weapons doctrine consistent with Negative Security Assurances (NSAs) – commitments not to use nuclear weapons against NNWS – which all five NPT-recognized NWS have made at past NPT review conferences and at the UN Security Council in 1995. In addition, abandoning U.S. threats to use nuclear weapons in response to another state using chemical or biological weapons against the United States or our allies could be followed by more credible deterrent threats to respond with devastating conventional military retaliation, and with a commitment to isolate and overthrow any leader who uses outlawed chemical or biological weapons. Finally, limiting the role of U.S. nuclear weapons to deterrence of other states' use of nuclear weapons would signal strong support for the eventual elimination of all nuclear weapons, for if such a no-first-use nuclear doctrine became universally accepted, the existing NWS could more easily coordinate moving in tandem to lower and equal levels of nuclear weapons on the road to zero.

Shared responsibilities for nuclear disarmament

Such a change in U.S. and other powers' nuclear doctrine will not be easily accepted by all allies, nor will it be easy to implement within military establishments. NATO official doctrine, for example, which has not been revised since 1999, continues to assert (though it does not prove) that nuclear weapons remain critical for a variety of threat scenarios: "[T]he Alliance's conventional forces alone cannot ensure credible deterrence. Nuclear weapons make a unique contribution in rendering the risks of aggression against the Alliance incalculable and unacceptable. Thus, they remain essential to preserve peace."[15] Interest in maintaining an expansive form of extended deterrence remains strong in East Asia as well. Ambassador Yukio Satoh, for example, correctly notes that the Japanese government's official "Defense Program Outline" states only that "to protect its territory and people against the threat of nuclear weapons, Japan will continue to rely on the U.S. nuclear deterrent"; but Satoh has also recommended that the United States should now threaten to retaliate with nuclear weapons if North Korea uses chemical or biological weapons in any future conflict.[16]

The major responsibility for reducing the roles and missions that nuclear weapons play in the doctrines of the nuclear powers clearly falls on the governments of those nations. President Obama called for precisely such doctrinal change in his 2009 Prague speech, promising that "to put an end to Cold War thinking, we will reduce the role of nuclear weapons in our national security strategy." This will require that U.S. politicians and military officers stop leaning on the crutch of nuclear weapons to shore up deterrence, even in situations in which the credibility of such threats is vanishingly thin. During the 2008 U.S. election primary campaign, for example, Senators Hillary Clinton and Christopher Dodd both criticized then Senator Obama for saying that he would not consider using U.S. nuclear weapons to attack al Qaeda targets inside Pakistan (a U.S. ally), arguing, in Clinton's words, "I don't believe that any president should make any blanket statements with respect to the use or non use of nuclear weapons."[17] In May 2009, General Kevin Chilton, the commander of the U.S. Strategic Command, took the "all options are on the table" argument to a new level, threatening U.S. nuclear retaliation in response to cyber attacks: "I think you don't take any response options off the table from an attack on the United States of America.... And I don't see any reason to treat cyber any differently. I mean, why would we tie the president's hands?"[18]

While the United States and other NWS should take the first steps to reduce their reliance on nuclear weapons, there is much that NNWS can do to encourage and enable new nuclear doctrines to be adopted, in the spirit of shared responsibilities for nuclear disarmament. First, NNWS that are members of U.S. alliances can stop asking to be reassured about noncredible military options. This is not a new problem. Indeed, although the global strategic context is different, Henry Kissinger alluded to a similar dynamic when he admonished the NATO alliance back in 1979:

> We must face the fact that it is absurd to base the strategy of the West on the credibility of the threat of mutual suicide.... Don't you Europeans keep asking us to multiply assurances that we cannot possibly mean; and that if we mean them, we should not want to execute; and that if we execute, we'll destroy civilization. That is our strategic dilemma, into which we have built ourselves by our own theory and by the encouragement of our allies.[19]

Second, it would be helpful if the NNWS that are not members of U.S. alliances would spend as much time condemning states that are caught violating their commitments not to develop chemical or biological weapons as they do complaining that the NSAs offered at the NPT review conferences should be legally binding. Finally, those U.S. allies that remain concerned about conventional or chemical and biological threats to their national security should, as part of their Article VI disarmament commitment, help to develop the conventional forces and defensive systems that could wean themselves away from excessive reliance on U.S. nuclear weapons for extended deterrence.[20]

The final argument against nuclear disarmament concerns breakout scenarios and the challenge of enforcement. Harold Brown and John Deutch, for example, have argued that "[p]roliferating states, even if they abandoned these devices under resolute international pressure, would still be able to clandestinely retain a few of their existing weapons – or maintain a standby, break-out capability to acquire a few weapons quick-

Shared responsibilities for nuclear disarmament

ly, if needed."[21] The breakout problem, however, applies to both new potential proliferators and former NWS that have disarmed in a nuclear-free world. Thomas Schelling and Charles Glaser have made similar arguments about "the instability of small numbers," fearing nuclear use would be more likely at the final stages of disarmament or after nuclear disarmament occurs, because states would engage in arms races to get nuclear weapons in any subsequent crisis and the winner in any such arms race would use its nuclear weapons with less fear of nuclear retaliation.[22]

These are legitimate concerns, and addressing the challenges of verification and enforcement of disarmament should be a high priority for future disarmament efforts. How can a vision of shared responsibility between the NWS and NNWS help address these vexing problems? First, NWS and NNWS should work together to punish the violators of currently existing nonproliferation agreements. North Korea violated its NPT commitments by secretly taking nuclear material out of the Yongbyon reactor complex in the 1990s and by covertly starting a uranium enrichment program with the assistance of Pakistan. Iran similarly was caught in violation of its NPT safeguards agreement in 2002, when the covert Natanz enrichment facility was discovered and evidence of nuclear weapons-related research was later released by the U.S. intelligence community. Finally, Syria was caught violating its NPT commitments in 2007, when Israeli intelligence discovered a covert nuclear reactor under construction. More consistent pressure by all five permanent members of the UN Security Council (the P5 are the United States, Russia, China, France, and the United Kingdom) should be matched by more uniform support by the NNWS at the IAEA and in the UN Security Council to create stronger resolutions condemning these violations and imposing sanctions on the violators. Such a display of shared responsibilities would both help resolve these proliferation crises and set better precedents for future challenges.

Second, the NNWS and NWS need to work together more effectively to reduce the risks of nuclear weapons breakout in the future. To help deter withdrawal from the NPT, the UN Security Council could adopt a binding resolution stating that it would consider any case in which a state withdraws from the NPT, after being found to be in noncompliance with its safeguards agreements, to constitute a threat to international peace and security under the UN charter. The Nuclear Suppliers Group and the IAEA could also discourage future withdrawals from the NPT by making all future sales of sensitive nuclear facilities subject to safeguards agreements that do not lapse if a state withdraws from the NPT and including a "return to sender" clause in which the recipient state would be required to close down the facilities and return the sensitive technology and nuclear materials to the country of origin as soon as possible.[23]

It is often forgotten, however, that there is a logical link between Article VI and Article X of the NPT. It will be difficult for the existing NWS to take the final steps of nuclear disarmament without more confidence that NNWS will not withdraw from the Treaty in the future. It will also be difficult for the NNWS to accept constraints on their Article X rights without more confidence that the existing nuclear powers will actually implement disarmament in ways that are difficult for them to reverse. At future NPT review conferences, the NWS and NNWS should therefore address how best to promote increased verification and transparency and to reduce incentives for NPT withdrawal and disarmament reversal as part of their joint responsibilities to work in good faith toward a nuclear-free world.

Efforts to prevent cheating on NPT commitments or future disarmament agreements may fail, of course, and stronger enforcement mechanisms therefore need to be considered. There are, fortunately, strong logical reasons to be optimistic about the prospects for enforcement in a nuclear-free world: in such a world, the major powers, which would include both traditional NNWS and new former NWS, would take violations more seriously because small-scale cheating would pose an even greater risk to their security than is the case now. Today, the existence of large arsenals in the United States and Russia, and arguably in other NWS as well, encourages some leaders to be complacent about the spread of nuclear weapons to new nations. Faith in the strength of nuclear deterrence leads some policy-makers to believe that North Korea or Iran, for example, will be deterred from ever using their nuclear weapons if the current negotiations fail. In a nuclear-free world, however, such deterrence optimism would be far less likely, and all major powers would share deeper fears of the emergence of new nuclear states.[24] The temptation for buck-passing would remain, but the faith that nuclear deterrence would constrain a violator would not, and new institutional arrangements for coordinating decision-making on sanctions and conventional military operations, perhaps through the UN Security Council, could help produce more effective enforcement of nonproliferation and disarmament.

Finally, it should be noted that in a nuclear-weapons-free world, former NWS will retain the option of withdrawing from any disarmament agreement. The possibility of rearmament, however, is both a potential problem for stability, if a conventional war or deep crisis occurs between two latent nuclear states, and a potential source of stability, for each latent nuclear state will know that if it rushes to rearm, others may do so as well. "Irreversibility" is often cited as a key objective in any nuclear disarmament agreement (for example, this goal was cited in the 13 Practical Steps agreed to at the 2000 NPT Review Conference). Yet in a world without nuclear weapons, the former NWS would be "more latent" than others who did not have their technological expertise or operational experience, and an objective in the final negotiations in the global disarmament process must be to create stronger verification and monitoring capabilities to provide confidence that one state could not start the rearmament process without others observing such actions. Nuclear deterrence would still exist in a nuclear-weapons-free world, but it would be of a much more recessed and latent form than exists today.

Some are pessimistic about the prospects for latent nuclear deterrence, believing that it is inherently less stable than the current form of active nuclear deterrence. Sir Michael Quinlan, for example, argued that "it is sometimes suggested that the very fact of this reconstitution risk would serve as a deterrent to war – weaponless deterrence, it has been called, a sort of deterrence at one remove. But that implies a worldwide and long-sighted wisdom on which it would surely be imprudent to count."[25] Quinlan was certainly correct to remain skeptical about the degree we can ensure that "worldwide and long-sighted wisdom" will exist in the future world without nuclear weapons. But surely the same argument holds true, and in spades, for a future world with many states holding nuclear arsenals. We cannot design an international system in which wisdom and prudence are guaranteed. A nuclear-free world would, however, reduce the consequences of individual failures of wisdom and prudence.

The technical and political challenges that confront proponents of nuclear disarmament are complex and serious. It is therefore by no means clear that the NWS will be able to overcome these challenges to achieve the goal of complete nuclear disarmament. What *is* clear, though, is that the existing NWS cannot reach the summit of a nuclear-free world without the active partnership of the current NNWS. The NWS and NNWS have a shared responsibility for nuclear disarmament in the future, and will share a common fate if they fail to cooperate more effectively.

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ENDNOTES

1 George P. Shultz, William J. Perry, Henry A. Kissinger, and Sam Nunn, "A World Free of Nuclear Weapons," *The Wall Street Journal*, January 4, 2007, and "Toward a Nuclear-Free World," *The Wall Street Journal*, January 15, 2008; Douglas Hurd, Malcolm Rifkind, David Owen, and George Robinson, "Stop Worrying and Learn to Ditch the Bomb," *The Times* (London), June 30, 2008; Alexander Kwasnewski, Tadeusz Mazowieki, and Lech Walesa, "The Vanishing Bomb," *The Moscow Times*, April 7, 2009; Helmut Schmidt, Richard von Weizsacher, Egon Bahr, and Hans-Dietrich Genscher, "Toward a Nuclear-Free World: A German View," *International Herald Tribune*, January 9, 2009; Massimo D'Alema, Gianfranco Fini, Giorgio La Malfa, Arturo Parisi, and Francesco Calogero, "A World Free of Nuclear Weapons," *Corriere Della Sera*, July 24, 2008; Malcolm Fraser, Gustav Nossal, Barry Jones, Peter Gration, John Sanderson, and Tilman Ruff, "Imagine There's No Bomb," *The Age*, April 8, 2009.

2 See Albert Wohlstetter, Thomas A. Brown, Gregory Jones, David McGarvey, Henry Rowen, Vincent Taylor, and Roberta Wohlstetter, "Moving Toward Life in a Nuclear Armed Crowd?" *Report for the Arms Control and Disarmament Agency*, April 22, 1976; http://www.npec-web.org/Frameset.asp?PageType=Single&PDFFile=19751204-AW-EtAl-MovingTowardsLifeNuclearArmedCrowd&PDFFolder=Essays.

3 Frank Gaffney, Jr., "Peace Through Weakness," February 16, 2009; http://www.centerforsecuritypolicy.org/p17891.xml?cat_id=120.

4 Wolfgang K. H. Panofsky, "The Nonproliferation Regime under Siege," *Bulletin of the Atomic Scientists* (August 5, 2007); http://www.thebulletin.org/web-edition/op-eds/the-nonproliferation-regime-under-siege.

5 Mohamed ElBaradei, "Addressing Verification Challenges," Statements of the Director General: Symposium on International Safeguards, October 16, 2006; http://www.iaea.org/NewsCenter/Statements/2006/ebsp2006n018.html.

6 George Perkovich and James M. Acton, "Abolishing Nuclear Weapons," Adelphi Paper 396 (London: International Institute for Strategic Studies, 2008), 93.

7 Albert Wohlstetter, "Spreading the Bomb without Quite Breaking the Rules," *Foreign Policy* (Winter 1976/1977).

8 Pierre Goldschmidt, "Exposing Nuclear Non-Compliance," *Survival* 51 (1) (2009): 143–164.

9 See George Bunn, *Arms Control by Committee* (Stanford, Calif.: Stanford University Press, 1992), 101.

10 For creative ideas on increasing the size and diversity of IAEA contributions, see Thomas Shea, "Financing IAEA Verification of the NPT," November 2006; http://www.npec-web.org/Essays/20061113-Shea-FinancingIAEAVerification.pdf.

11 For differing views on this, see Christopher A. Ford, "Debating Disarmament: Interpreting Article VI of the Treaty on the Non-Proliferation of Nuclear Weapons," *The Nonproliferation Review* 14 (3) (2007): 402–428, and Scott D. Sagan, "Good Faith and Nuclear Disarmament Negotiations," in *Abolishing Nuclear Weapons: A Debate*, ed. George Perkovich and James M. Acton (Washington, D.C.: Carnegie Endowment for International Peace, 2009), 203–212.

12 John Deutch, "A Nuclear Posture for Today," *Foreign Affairs* (January–February 2005): 51.

13 Des Brown, "Laying the Foundation for Multilateral Disarmament," February 5, 2008; http://www.reachingcriticalwill.org/political/cd/speeches08/1session/Feb5UKDefSecDesBrown.pdf.

14 Samuel W. Bodman and Robert M. Gates, "National Security and Nuclear Weapons in the 21st Century," September 2008; http://www.defenselink.mil/news/nuclearweaponspolicy.pdf.

15 "The Alliance's Strategic Concept" (NATO, April 1999); http://www.nato.int/docu/pr/1999/p99-065e.htm.

16 See "Are the Requirements for Extended Deterrence Changing?" Carnegie Endowment for International Peace Conference, April 6, 2009; transcript available at http://www.carnegieendowment.org/events/?fa=eventDetail&id=1299.

17 Reuters, "Obama, Clinton in New Flap over Nuclear Weapons," August 2, 2007; http://www.alertnet.org/thenews/newsdesk/N02381100.htm.

18 Elaine M. Grossman, "U.S. General Reserves Right to Use Force, Even Nuclear, in Response to Cyber Attack," Global Security Newswire, May 12, 2009; http://gsn.nti.org/gsn/nw_20090512_4977.php.

19 "Kissinger on NATO," *Time*, September 17, 1979; http://www.time.com/time/magazine/article/0,9171,920653,00.html.

20 George Perkovich, "Extended Deterrence," Draft Paper Prepared for the Evans-Kawaguchi Commission, May 2009.

21 Harold Brown and John Deutch, "The Nuclear Disarmament Fantasy," *The Wall Street Journal*, November 19, 2007.

22 See Thomas C. Schelling's essay in this issue of *Dædalus*, as well as Schelling, "The Role of Deterrence in Total Disarmament," *Foreign Affairs* (April 1962). See also, Charles Glaser, "The Instability of Small Numbers Revisited," in *Rebuilding the NPT Consensus*, ed. Michael May (Stanford, Calif.: Center for International Security and Cooperation, 2008); http://iis-db.stanford.edu/pubs/22218/RebuildNPTConsensus.pdf.

23 See Pierre Goldschmidt, "Concrete Steps to Improve the Nonproliferation Regime," Nonproliferation Program Paper 100 (Washington, D.C.: Carnegie Endowment for International Peace, April 2009).

24 This argument was first made by Charles L. Glaser, "The Flawed Case for Nuclear Disarmament," *Survival* 40 (1) (Spring 1998).

25 Michael Quinlan, "Abolishing Nuclear Armouries: Policy or Pipedream?" *Survival* 49 (2) (Winter 2007–2008): 12.

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