Nuclear Energy

Balancing Benefits and Risks

Charles D. Ferguson

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FOREWORD

Increased concern over energy security and global climate change has led many people to take a fresh look at the benefits and risks of nuclear power for the United States and other countries. The debate surrounding nuclear energy also intersects with critical U.S. foreign policy issues such as nuclear proliferation and terrorism. This Council Special Report, produced in partnership with Washington and Lee University and written by the Council's Fellow for Science and Technology Charles D. Ferguson, provides the factual and analytical background to inform this debate.

Nuclear Energy: Balancing Benefits and Risks is a sobering and authoritative look at nuclear power. Dr. Ferguson argues that nuclear energy, despite its attributes, is unlikely to play a major role in the coming decades in strengthening energy security or in countering the harmful effects of climate change. In particular, the rapid rate of nuclear reactor expansion required to make even a modest reduction in global warming would drive up construction costs and create shortages in building materials, trained personnel, and safety controls. There are also lingering questions over nuclear waste, as well as continued political opposition to siting new plants. Nonetheless, the report points out steps the United States could take—such as imposing a fee on greenhouse gas emissions—to level the economic playing field for all energy sectors, which over the long run would encourage the construction of new nuclear reactors (if only to replace existing ones that will need to be retired) and help reduce global warming.

Dr. Ferguson has written a fair and balanced report that brings the nuclear energy debate down from one of preferences and ideologies to one of reality. *Nuclear Energy: Balancing Benefits and Risks* is useful to anyone who wants to understand both the potential and the limits of nuclear power to enhance energy security and slow climate change.

Richard N. Haass
President
Council on Foreign Relations
April 2007

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Charles D. Ferguson

ACRONYMS

DBT	design-basis-threat
GNEP	Global Nuclear Energy Partnership
HEU	highly enriched uranium
IAEA	International Atomic Energy Agency
IEER	Institute for Energy and Environmental Research
kWh	kilowatt-hour
NAM	Nonaligned Movement
NEPA	National Environmental Policy Act
NPT	Nuclear Nonproliferation Treaty
NRC	Nuclear Regulatory Commission
NSG	Nuclear Suppliers Group
WANO	World Association of Nuclear Operators

COUNCIL SPECIAL REPORT

NUCLEAR ENERGY AT A CROSSROADS

According to a prevailing belief, humanity confronts two stark risks: catastrophes caused by climate change and annihilation by nuclear war. The conventional wisdom also believes that the former danger appears far more certain than the latter. This assessment has recently led an increasing number of policymakers, pundits, businesspeople, and environmentalists to advocate a major expansion of nuclear energy, which emits very few greenhouse gases into the atmosphere.[1] While acknowledging the connection between nuclear fuel making and nuclear bomb building, nuclear power proponents suggest that nuclear proliferation and terrorism risks are readily manageable. Consequently, some of these advocates favor the use of subsidies to stimulate substantial growth of nuclear power.

This conventional wisdom possesses some truth, but it oversells the contribution nuclear energy can make to reduce global warming and strengthen energy security while downplaying the dangers associated with this energy source. To realistically address global warming, the nuclear industry would have to expand at such a rapid rate as to pose serious concerns for how the industry would ensure an adequate supply of reasonably inexpensive reactor-grade construction materials, well-trained technicians, and rigorous safety and security measures. Furthermore, some argue that a significant growth of nuclear reactors and fuel making in politically unstable regions would substantially increase the risks of nuclear terrorism and proliferation. Conversely, others decry the hypocrisy of this double standard in which only certain countries are allowed access to the full suite of nuclear technologies. Thus, the United States faces a fundamental policy dilemma: Is it possible to encourage growth of nuclear energy and fuel making in some regions and countries while denying or significantly limiting it in other places?

To reduce the deleterious effects of climate change, the world will need to dramatically increase the use of low- and no-carbon emission energy sources as well as

[1] Because fossil fuels are used to mine and enrich uranium, the nuclear fuel cycle releases carbon dioxide and other greenhouse gases. However, nuclear reactors themselves do not emit greenhouse gases while generating electricity. Summing up the total energy use associated with nuclear power production, only a small fraction of the energy expended results in greenhouse gas emissions.

promote far greater use of energy efficiencies. Nuclear will undoubtedly be part of this mix, but the policy question is: How much can and should it contribute to energy needs? This benefit needs to be weighed against the entire costs and risks of nuclear power production.

In addition to substantial capital costs for construction of power plants, nuclear energy includes significant external costs: applying safeguards to sensitive activities such as fuel making, securing nuclear facilities against terrorist attacks, decommissioning reactors, storing highly radioactive waste, and paying for insurance to cover the costs of an accident. Another important policy question is: How much of these external costs should be paid for by the industry versus governments? A related question is: If all energy sectors identified and paid for most, if not all, of their external costs, including greenhouse gas emissions, how would the nuclear sector fare on this level playing field that refrained from further government subsidies?

To better inform the debate that is under way in the United States about nuclear energy use, this Council Special Report provides a clear examination of the benefits and risks and then lays out a set of recommendations for U.S. nuclear energy policy, distinguishing between domestic and international use. The United States has considerably more leverage influencing domestic nuclear energy production than international use; however, the United States can help shape nuclear policies abroad through leading by example and through making use of existing bilateral partnerships and multilateral institutions, including the International Atomic Energy Agency, the International Energy Agency, and the Nuclear Suppliers Group. An effective policy needs to address climate change, energy security, safety and security of nuclear power plants and radioactive waste storage, and proliferation of nuclear technologies that can produce nuclear bombs.

THE ROAD AHEAD

Where and how do countries use nuclear energy? What contribution can nuclear energy make to strengthen energy security and reduce global warming? Regardless of whether nuclear energy experiences a major expansion domestically or internationally, what steps should the United States, other governments, multilateral institutions, and the nuclear industry take to ensure safe and secure use of this energy source?

NUCLEAR ENERGY'S ROLE IN STRENGTHENING U.S. ENERGY SECURITY

Nuclear power can provide greater energy security by reducing reliance on fossil fuels acquired from unstable regions. In recent years, the United States imported about two-thirds of its oil and one-fifth of its natural gas.[2] Most of the oil the United States uses fuels transportation needs with only a small portion (about 3 percent) used for generating electricity. Electricity generation from all sources comprises about 40 percent of total U.S. energy consumption. Of this total, nuclear comprises only about 8 percent. Currently, nuclear power, which solely generates electricity, offers some relief in use of foreign sources of oil and natural gas and could, over the long term (many decades), power cars and trucks through production of hydrogen for fuel cells or electricity for plug-in hybrid vehicles. But at least over the next few decades, a substantial growth in nuclear energy use will not wean the United States off foreign sources of oil.

Unlike oil, natural gas provides a significant portion (16 percent) of U.S. electricity production as well as heating for homes and businesses. Rising natural gas prices, however, have sparked recent corporate interest in nuclear power. If natural gas prices remain at the currently high levels for many years, nuclear power could offer a more favorable business investment. But historically, natural gas prices have fluctuated, and the presently high prices could fall, undermining support for a growth of nuclear energy.

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[2] International Energy Agency, *Key World Energy Statistics,* 2006.

In the electricity production sector, nuclear power plants' operating costs compete favorably with coal, natural gas, hydro, oil, geothermal, wind, and solar energy sources, but its capital costs have difficulty competing against them. Presently, according to the Energy Information Administration, the United States produces 52 percent of its electricity from coal-fired plants, 21 percent from nuclear power plants, 16 percent from natural gas, 7 percent from hydro, 3 percent from oil, and 1 percent from geothermal, wind, and solar combined.[3] Thus, the vast majority of U.S. electricity comes from three sources: coal, nuclear, and natural gas. Tables 1 and 2, based on two recent authoritative studies, show the estimated costs of these electricity sources. Coal remains a relatively cheap fuel, and capital costs for coal-fired plants are considerably less than for nuclear plants. The United States is the Saudi Arabia of coal reserves; thus, the use of coal helps reduce dependence on foreign sources of oil and natural gas in the electricity production sector. Without restrictions imposed on greenhouse gas emissions, coal wins out over nuclear in terms of financial costs.

Economics is a major factor influencing the growth of nuclear energy. As an industry official recently said, "Nuclear energy is a business, not a religion." Despite the passions both for and against continued or expanded use of this energy source, business decisions will mainly determine whether use of nuclear-generated electricity will rise or fall.

The long lead time for, and large uncertainties in, nuclear reactor construction and licensing have stymied growth in the industry in the United States. American utilities have not ordered a nuclear reactor since 1978, and that order was subsequently canceled. The last completed reactor in the United States was the Tennessee Valley Authority's Watts Bar 1, which was ordered in 1970 and began operation in 1996.

Despite the lack of reactor orders, the contribution of nuclear-generated electricity has increased in recent years in the United States. During the past decade, average operating costs have decreased, and time needed for refueling outages has shortened, allowing nuclear power plants to operate longer at full capacity or, in industry terms, "increasing the load factor." (The load factor in the United States increased from 65

[3] Energy Information Agency, "Country Analysis Brief: United States, Electricity," November 2005. http://www.eia.doe.gov/emeu/cabs/Usa/Electricity.html.

percent in the 1980s to 90 percent by 2002.) Moreover, several nuclear plants have received licenses to increase their power ratings, again permitting production of more electricity.

Table 1: Cost of Electricity Estimated by the MIT and University of Chicago Studies

	MIT Report (2003)	University of Chicago Report (2004)
Electricity Generation Type	*Cost (cents per kWh)*	
Coal	4.2	3.3 to 4.1
Natural Gas (Combined Cycle Gas Technology)	3.8 to 5.6	3.5 to 4.5
Nuclear	6.7	6.2

Table 2: Comparison of Assumptions in the MIT and University of Chicago Studies

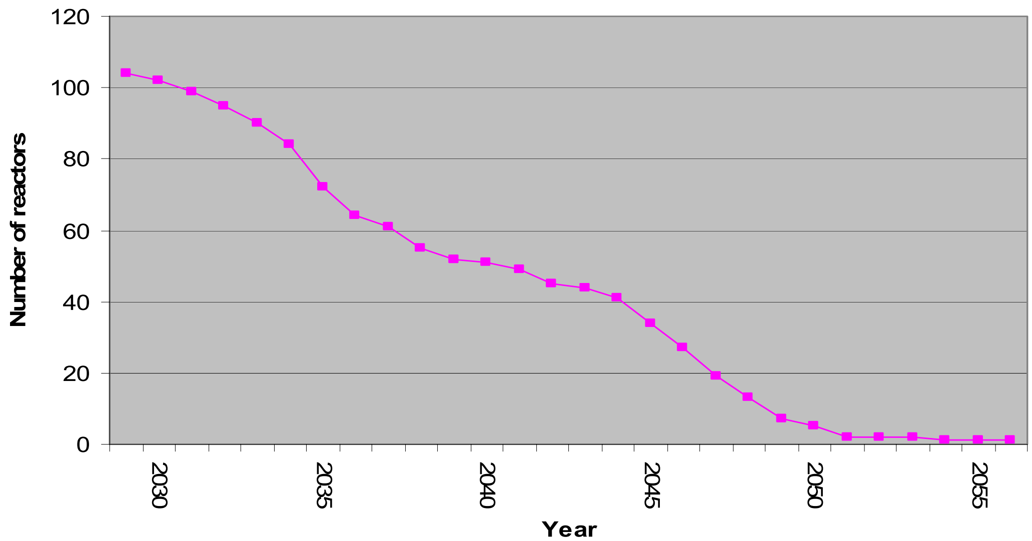
	MIT Report (2003)			University of Chicago Report (2004)		
Electricity Generation Type	*Overnight Capital Cost ($ per kW)*	*Lead Time for Construction (years)*	*Effective Interest Rate*	*Overnight Capital Cost ($ per kW)*	*Lead Time for Construction (years)*	*Effective Interest Rate*
Coal	1,300	4	9.6	1,182 to 1,430	4	9.5
Natural Gas	500	2	9.6	500 to 700	3	9.5
Nuclear	2,000	5	11.5	1,200 to 1,800	7	12.5

Sources: These tables are adapted from Brice Smith, "Insurmountable Risks: Can Nuclear Power Solve the Global Warming Problem?" *Science for Democratic Action*, August 2006, p. 7.

While the industry has yet to order any new domestic reactors, changes in U.S. law have helped renew interest among several companies in applying for reactor licenses. The Energy Policy Act of 1992 began a reform of the licensing process to allow combining construction and operating licenses in one application. In principle, a combined license should help streamline the application process. Yet, large uncertainties in construction costs continue to impede investors. To try to jump-start the nuclear industry, which was already receiving more subsidies than any other no- and low-carbon energy sources, the Energy Policy Act of 2005 provided billions of additional dollars' worth of incentives to nuclear and smaller amounts of incentives to other no- and low-carbon energy sources. (See the Appendix for an analysis of this act.) Nonetheless, the process of new nuclear reactor licensing and construction is estimated to take ten to fifteen years. Even if their license applications are approved, the utilities have still not committed to building the reactors.

In the coming decades, the U.S. nuclear industry will have to run faster on the treadmill of impending nuclear power plant retirements to replace the aging fleet of reactors. Initially, commercial reactors received forty-year licenses. While a number of reactors never reached their forty-year nominal life spans before being decommissioned, much of the current fleet of reactors has, in recent years, received twenty-year license renewals. As of the end of 2006, more than forty reactors have obtained twenty-year license extensions and about a dozen more have applied for renewal. Figure 1 shows that even assuming all 103 currently operating reactors receive twenty-year license renewals and no new reactors are constructed, the U.S. fleet will cease operations by 2056.

Figure 1: U.S. Nuclear Reactor Fleet with Twenty-Year License Renewal and No New Reactor Construction



Source: Data from the Energy Information Administration, http://www.eia.doe.gov/cneaf/nuclear/page/nuc_reactors/operational.xls.

Without new reactor construction, a precipitous falloff will begin about twenty years from now. While Nuclear Regulatory Commission (NRC) Chairman Dale E. Klein has recently discussed considering license renewals for up to eighty total years for a selected number of reactors, prudent planning would suggest counting on replacing practically all of the current reactors within the coming decades. The replacement rate would be on the order of one new reactor every four to five months over the next forty years. Based on the periods of the 1960s and 1970s, when most of the current fleet was built, this construction rate appears feasible. However, based on the past thirty years, in which reactor orders and construction ground to a halt, this replacement rate faces daunting challenges. For this reason alone, nuclear energy is not a major part of the solution to U.S. energy insecurity for at least the next fifty years.

U.S. Nuclear Energy as a Contribution to Reducing Global Warming

As the damaging consequences of climate change increase, more and more countries, including the United States, will consider financially supporting the expansion of nuclear energy use, which emits very few greenhouse gases into the atmosphere. The 1992 Framework Convention on Climate Change commits the United States and other countries to reduce greenhouse gases, such as carbon dioxide, in the atmosphere to prevent "dangerous anthropogenic interference with the climate system." In February 2007, the Intergovernmental Panel on Climate Change, which includes about 2,500 of the world's top climate scientists, assessed a "very high confidence that the globally averaged net effect of human activities since 1750 has been one of warming."[4] While there are large uncertainties regarding the predicted amounts of warming and the severity of the climatic effects by the end of the century, there is no doubt that the massive amounts of greenhouse gases already in the atmosphere will continue to alter the climate across the globe for many decades to come.

To date, the Bush administration has opposed mandatory greenhouse gas reduction programs. Nonetheless, in the 2007 State of the Union address, President George W. Bush acknowledged the need to confront the "serious challenge of global climate change." In recent years, some senators and representatives have proposed legislation that would implement greenhouse gas reduction programs. But the proposals have yet to pass either house of Congress. In 2003, the first proposal failed by a 55 to 43 vote in the Senate. In 2005, during debate on the Energy Policy Act, another proposal was defeated in the Senate by 60 to 38 votes. Both proposals would have enacted a tradable permit program.

An alternative approach is a carbon tax, which many economists favor. While many representatives and senators have opposed taxing carbon emissions, such a tax might win over enough political support if it were revenue neutral. Proceeds from the tax could be used to alleviate the financial burden on poor citizens and to stimulate research in innovative energy technologies.

Despite the failed efforts to pass the emission reduction legislation, in 2005 the Senate passed a Sense of the Senate resolution on climate change. The resolution finds that (1) greenhouse gases are increasing and raising average global temperatures, (2) a mounting scientific consensus concludes that human activity has significantly caused the

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[4] Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis*, Fourth Assessment Report, February 2007.

increase in greenhouse gases, and (3) mandatory steps will be needed to slow or stop the growth in greenhouse gas emissions. The resolution calls on Congress to enact a comprehensive national program using market-based mechanisms to slow, stop, and reverse the growth of greenhouse gas emissions. Moreover, the resolution expresses the view that such a program should not significantly harm the American economy and should encourage comparable efforts by other countries that contribute to global emissions and are major trading partners of the United States.

The particular price set for carbon emissions would signal to the market whether a specific no- or low-carbon-emitting energy source is favored with respect to high-carbon-emitting energy sources. A high initial carbon price could hurt the coal industry, which would lobby against such an initiative. On the other hand, gradually ramping up the price in a predictable way over several years could provide long-term incentive for development of coal-fired power plants that employ carbon sequestration as well as for nuclear power plants.

The United States would not stand alone if it imposed costs on greenhouse gas emissions. In the past two years, the European Union started a carbon trading scheme and plans to continue developing it. California has indicated interest in joining the European carbon trading system. Several other U.S. states are also exploring ways to reduce greenhouse gas emissions. Conceivably, the United States could use the North American Free Trade Agreement to bring Canada and Mexico into a regional system to control carbon emissions. Concerned that a complicated patchwork is emerging, an increasing number of leading national and multinational corporations have expressed interest in the federal government creating a regulatory standard for controlling these emissions.

To reduce the deleterious effects of climate change, the United States will need to increase use of all low- and no-carbon emission energy sources as well as promote greater use of energy efficiency. But given the current U.S. energy sources and patterns of use, nuclear energy alone does not provide a solution for at least the next few decades for significantly reducing the U.S. contribution to global warming. However, setting a price on carbon emissions through a cap-and-trade system or a carbon tax could make nuclear energy economically competitive with coal and natural gas, potentially stimulating some growth in nuclear reactor construction.

Nuclear energy provides about 16 percent of the globe's electricity. In comparison, fossil fuels, which contribute to global warming through emissions of greenhouse gases, generate about 66 percent of the world's electricity. Global electricity demand is projected to double by 2030 and triple by 2050, based on business-as-usual usage. Much of this demand growth will occur in the developing world. Decisions leaders make today about where to invest in various energy sources will have a lasting effect because the life of most power plants extends beyond forty years.

How much could global nuclear energy consumption grow over the next four decades? A 2003 Massachusetts Institute of Technology study posited a base growth scenario of one thousand gigawatts of nuclear capacity by 2050.[5] (A one-gigawatt nuclear reactor can power a U.S. city containing about a half-million people, comparable to the size of Washington, DC.) In comparison, today the world has about 370 gigawatts of installed nuclear capacity. The almost threefold increase in nuclear power by 2050 would only increase the global proportion of nuclear energy use from 16 percent to about 20 percent because of the projected increased demands for electricity. As a consequence, this modest increase in contribution from nuclear energy alone would not decrease the emissions of greenhouse gases. In the absence of regulating carbon, reducing energy demand, and expanding no- and low-carbon energy sources, those emissions would increase because of greater use of fossil fuels to meet the projected demand for electricity as well as heating and transportation fuels.

How much nuclear energy would be needed to maintain global carbon dioxide emissions at the year 2000 level? Reaching this goal might head off many of the damaging consequences of climate change. The Institute for Energy and Environmental Research (IEER) has recently estimated that this scenario would require between 1,900 and 3,300 gigawatts of nuclear capacity depending on differing projections of alternative energy usage and adoption of energy efficiencies.[6] Under this very ambitious scenario, each new reactor would have to come online at a rate of less than one per week over the

[5] "The Future of Nuclear Power," Massachusetts Institute of Technology, 2003.

[6] Brice Smith, *Insurmountable Risks: The Dangers of Using Nuclear Power to Combat Global Climate Change* (IEER Press, 2006).

next four decades. As a practical matter, building reactors at this rapid pace would initially tend to drive up unit costs and, thus, scare off investors. For example, there are currently only a few companies in the world that can make reactor-quality steel, concrete, and other vital parts. Moreover, a rush to build would aggravate existing shortages of skilled workers to construct the reactors, qualified engineers to run the power plants, and inspectors to ensure safe operations.

In contrast to the IEER study, Stephen W. Pacala and Robert Socolow of Princeton University have proposed a more realistic, but still ambitious, plan for stabilizing greenhouse gas emissions.[7] They have identified fourteen energy technology wedges. (They used the term "wedge" because of the wedge or triangular shape of the reduction in greenhouse gas emissions plotted over time.) Each wedge technology, if fully employed, would reduce carbon emissions by a million tons per year by 2050. According to the Princeton study, employing seven of these wedges in equal proportions would stabilize greenhouse gas emissions at the current level. Each wedge would contribute a relatively modest contribution to reducing greenhouse gas emissions. Although Pacala and Socolow's study remains neutral about the growth of nuclear energy, they include it as an option among their fourteen energy wedges. The nuclear wedge would include seven hundred gigawatts or about seven hundred large commercial reactors in addition to the current nuclear-generated electricity. Adding this amount to the 370 gigawatts presently used would roughly equal the MIT base growth scenario. Because almost all of the current reactor fleet would require replacement by mid-century, the Princeton and MIT growth scenarios would require about two new reactors to come online every month over the next forty years. Thus, these growth scenarios would pose quite significant challenges.

Many countries, especially in parts of Europe and Asia, have proposed ambitious plans for a substantial expansion of nuclear power production. Globally, about thirty reactors are under construction or have been ordered to be built. But it remains uncertain how many of these reactors will be built and whether many more will be constructed to

[7] S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technology," *Science*, 305, August 13, 2004, pp. 968–72, as quoted in William Sweet, *Kicking the Carbon Habit: Global Warming and the Case for Renewable and Nuclear Energy* (New York: Columbia University Press, 2006), pp. 150–51.

replace an aging fleet. Today, about thirty countries are harnessing nuclear energy in about 440 commercial reactors. While the United States leads the world in the number of operating reactors at 103, it does not lead in the proportion of electricity generated by nuclear energy.

With fifty-nine reactors, France produces about 78 percent of its electricity from nuclear power, a larger proportional amount than any other country. Even in France, however, nuclear energy has not ensured energy independence. Use of nuclear energy has nevertheless allowed France to eliminate oil use in electricity production. Even so, the transportation sector consumes large amounts of oil. France's greenhouse gas emissions have not leveled off, but the rate of increase is less than it would have been without nuclear energy.

Other European countries are looking to expand or at least maintain their current use of nuclear energy. In the United Kingdom, twenty-three commercial nuclear reactors are operating, and Prime Minister Tony Blair's government has recently signaled interest in building new reactors. However, in late November 2006, a British government official cautioned that the United Kingdom will likely not have a new nuclear unit built before 2020. Because the fleet of British nuclear plants is rapidly nearing retirement, the United Kingdom will probably experience a deficit of nuclear-generated electricity prior to operation of new reactors. In contrast, Finland has already begun to build a new reactor to add to its four existing reactors that produce about 25 percent of its electricity, though the new reactor project has experienced significant delays. In neighboring Russia, President Vladimir V. Putin has set his sights on a major growth of nuclear energy. Russia presently has thirty commercial nuclear reactors producing 16 percent of its electricity. Full implementation of Putin's proposal would increase that share to 25 percent within the next twenty years. As another sign of potential renewal, some European countries that had committed to phasing out use of nuclear energy, such as Germany and Sweden, have been reconsidering those decisions.

In contrast, Italy and Spain remain opposed to new nuclear reactors. In 1987, Italy passed a law against new nuclear plants after the Chernobyl accident. In January, Spanish President José Luis Rodríguez Zapatero said, "Nuclear energy keeps on producing serious problems," and ruled out plans to expand nuclear power production. He called for a European energy policy to develop renewable energy sources.

While a few countries in Asia rely significantly on nuclear-generated electricity, most of the continent derives its electricity needs primarily from fossil fuels. With fifty-four reactors, Japan leads Asia in use of nuclear energy, which generates about one-third of Japan's electricity. South Korea and Taiwan have used nuclear power for decades to meet a significant portion (presently about 40 percent and 15 percent, respectively) of their electricity needs.

China and India, the world's two most populous countries, have employed nuclear power for many years, but they have yet to meet more than a small fraction (2 to 3 percent) of their electricity production from this source. While Beijing and New Delhi have announced plans for building several nuclear power plants in the coming years, these governments are still not planning for nuclear energy to meet more than a relatively small fraction of their electricity needs. For example, by 2020, China is aiming for about a doubling of the contribution that nuclear makes to its electricity sector or roughly 4 percent of its total electricity generation. Both Beijing and New Delhi are planning for a far greater use of coal-fired power plants because coal provides an indigenous, abundant, and cheap fuel. Over the next ten years, China and India are expected to build as many as 560 and 210 coal-fired plants, respectively.[8] Coal-fired plants now provide about 80 percent of China's and 70 percent of India's electricity needs. These percentages would likely grow under Beijing and New Delhi's current plans. Thus, in the absence of efforts to build more efficient coal-fired plants and to capture greenhouse gases from these plants, China and India will significantly exacerbate global warming. Nuclear power plant construction cannot occur rapidly enough in the next ten years in those countries to replace the planned coal-fired plants. While state-owned nuclear enterprises such as those in China, France, India, and Russia can have greater control over nuclear power plant construction than privately owned companies such as those in the United States, such control does not necessarily mean that more plants will be built.

In the foreseeable future, nuclear energy is not a major part of the solution to further countering global warming or energy insecurity. Expanding nuclear energy use to

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[8] Mark Clayton, "New Coal Plants Bury 'Kyoto'," *Christian Science Monitor*, December 23, 2004.

make a relatively modest contribution to combating climate change would require constructing nuclear plants at a rate so rapid as to create shortages in building materials, trained personnel, and safety controls. Furthermore, while the nuclear industry is only structured to produce electricity, the existing abundant and cheap fossil fuels provide readily usable energy for electricity, heating, and transportation needs.

PROLIFERATION CONCERNS

Regardless of whether nuclear energy use expands, the United States and its partners face the daunting challenge of preventing the diversion of nuclear explosive materials into weapons programs and controlling the spread of potentially dangerous nuclear fuel-making technologies and materials. Fuel-making technologies are dual use: either for creating fuel for peaceful reactors or for producing explosive material for nuclear weapons. Thus, a commercial fuel-making facility represents a latent nuclear bomb factory.

Fuel making involves two processes: uranium enrichment and plutonium reprocessing. Enrichment increases the concentration of uranium-235, a uranium isotope that can easily fission inside a reactor or a bomb. Natural uranium has too low a concentration of uranium-235 to fuel most commercial reactors. These reactors require low-enriched uranium for fuel. Low-enriched uranium has too low a concentration of uranium-235 to power nuclear weapons. But weapons-grade uranium can be produced by the same enrichment plant that made low-enriched uranium. Weapons-grade uranium is a special type of highly enriched uranium (HEU) with a concentration of uranium-235 greater than 90 percent. Any type of HEU is considered weapons usable, although the greater the concentration or enrichment of uranium-235, the better the material is for making bombs.

Plutonium reprocessing is a technique that extracts plutonium from spent nuclear fuel to create new fuel for reactors. Reactor-grade plutonium can also power nuclear bombs. Currently, Britain, France, India, Japan, and Russia are operating plutonium reprocessing facilities. These facilities have separated out from spent nuclear fuel about

250 metric tons of plutonium, enough material to make thousands of nuclear bombs. (Spent nuclear fuel provides a highly radioactive, and thus lethal, barrier against theft of plutonium. Separated plutonium does not have that protective barrier.) This amount of civilian plutonium is comparable to the amount of military plutonium and is increasing. The rate of reprocessing plutonium exceeds the rate of consumption as reactor fuel and is projected to continue to do so at the rate of about five metric tons per year over the next four years. Thus, by the end of 2010, the stockpile of civilian plutonium could increase to more than 270 metric tons, enough material to make thousands of nuclear weapons.[9]

The current nuclear fuel suppliers can more than meet present demand for fuel. But under many envisioned growth scenarios, global nuclear fuel capacity would have to increase from two to six times from the present to 2050. But only 1 percent of these projected capacities could fuel hundreds of nuclear weapons annually. To date, the International Atomic Energy Agency (IAEA) has not applied inspections that are thorough enough to detect diversion of this small fraction of nuclear material from a commercial-scale uranium enrichment or plutonium reprocessing facility. Also, the safeguards system does not provide timely warning of a clandestine effort to use diverted material in nuclear explosives. For example, according to the IAEA, only seven to ten days would be needed to convert separated plutonium into bombs. But the IAEA goal for inspection frequency of a plutonium reprocessing plant is only one month, and even that goal has not been met.

The nuclear material currently unaccounted for at plutonium reprocessing facilities could make many bombs. For example, Japan cannot account for more than two hundred kilograms of plutonium at the Tokai-mura plant. In Britain, the Sellafield plant cannot account for about thirty kilograms of plutonium. According to the IAEA, only eight kilograms of plutonium are needed to make a bomb. But even less than that was used in the Nagasaki bomb, which employed six kilograms. More advanced designs could use as little as one to three kilograms.[10]

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[9] David Albright and Kimberly Kramer, "Separated Civil Plutonium Inventories: Current Status and Future Directions," *Global Stocks of Nuclear Explosive Materials*, Institute for Science and International Security, revised July 8, 2005.
[10] Thomas B. Cochran and Christopher E. Paine, "The Amount of Plutonium and Highly Enriched Uranium Needed for Pure Fission Nuclear Weapons," Natural Resources Defense Council, revised April 13, 1995.

The current limitations of nuclear safeguards and the potential for greatly increased use of nuclear energy underscore two urgent and interconnected security matters: how to strengthen safeguards and how to limit the spread of fuel-making technologies. To address the former concern, near-real-time monitoring of an enrichment facility or reprocessing plant would raise the barrier to diversion of nuclear materials but would not guarantee prevention of diversion. For example, continuously monitoring the enrichment level of individual centrifuge units in an enrichment plant is possible, but this has not been applied. A near-real-time inspection system could sound an alarm if it detected the production of HEU in any part of the plant. An enrichment plant that produces low-enriched uranium for peaceful purposes could not be lawfully used to produce HEU for nuclear weapons. But making HEU is not outlawed by the Nuclear Nonproliferation Treaty (NPT) if it is slated for non-weapons applications such as fueling research or naval reactors.[11] Although the United States and other countries are working to phase out HEU in certain applications, they have not pushed for a complete ban of this weapons-usable material.[12] Such a ban could improve the ability to catch cheaters by using a near-real-time inspection system.

Establishing a near-real-time monitoring system confronts financial and political hurdles, however. The International Atomic Energy Agency is strapped for funds to pay for inspectors and near-real-time surveillance capabilities for all of the current nuclear facilities. While IAEA member states have made voluntary contributions to fill some funding shortfalls, they have not committed to placing the IAEA on a more secure financial footing. As nuclear energy demand rises, the budget of the IAEA would have to match that rise to increase the probability of detecting diversion of weapons-usable nuclear materials. (The current IAEA safeguards budget is approximately $100 million, comparable to the payroll of the Washington Redskins football team.) A nuclear safeguards expert has argued that greater use of proliferation-resistant technologies can help hold down the inspectors' costs.[13] Nonetheless, someone or some countries will have

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[11] James Clay Moltz, "Closing the NPT Loophole on Exports of Naval Propulsion Reactors," *The Nonproliferation Review*, Fall 1998.

[12] Charles D. Ferguson, "Preventing Catastrophic Nuclear Terrorism," Council on Foreign Relations Council Special Report No. 11, March 2006.

[13] Thomas Shea, "Financing IAEA Verification of the NPT" (paper presented at the NPEC/FRS Conference, November 12–13, 2006).

to pay for the increased costs for the inspectors and the development of the technologies. Those countries that have benefited the most and want to continue to benefit from nuclear power should have the responsibility to pay their fair share and would gain the most by ensuring that the IAEA is adequately funded and resourced.[14]

The other major problem of limiting the spread of fuel-making technologies runs into the dilemma of dividing the world into "good guys" and "bad guys." In this view, there are two classes of countries: those that can be trusted with these technologies and those that cannot. One problem with this view is that today's good guy can become tomorrow's bad guy and vice versa. Another problem is that even some of the good guys or trusted countries cannot account for all of their nuclear materials. As noted earlier, Japan and the United Kingdom, for example, cannot account for several bombs' worth of plutonium. This type of problem could grow worse in a world in which fuel making increases two to six times faster than present demands. While the security in most trusted countries is arguably better than in potentially unstable countries, greater fuel-making activities in any country could raise the risk of an insider threat, leading to possible diversion of nuclear materials to terrorists.

Several well-intentioned proposals in recent years have tried to head off fuel making in politically unstable regions by offering fuel assurances to countries wanting to use nuclear energy. Countries would receive guarantees of nuclear fuel as long as they are members in good standing with the NPT; that is, they are not making nuclear explosives and are maintaining safeguards on their peaceful nuclear programs. The Nonaligned Movement (NAM) countries, in particular, have raised concern that these proposals are discriminatory and are trying to deny them their "right" to acquire uranium enrichment and plutonium reprocessing technologies. (The NAM is an international organization of more than one hundred developing states that are not formally aligned with any major power bloc.) In September 2006 at the NAM summit in Havana, these countries expressed strong support for exercising this right.

Still, fuel assurance proposals have merit in helping to expose underlying and unstated intentions of some countries. For instance, Iran has cited its right under the NPT to pursue nuclear fuel making, while the West suspects that this activity provides a cover

[14] Ibid.

for a nuclear weapons program. But fuel making only makes economic sense if a country has about ten or more commercial reactors. Iran has yet to begin operating even the one reactor at Bushehr being built by Russia. In addition, Iran has very limited known supplies of indigenous uranium, further undermining Tehran's rationale and urgency in building a nuclear fuel facility for a peaceful reactor program. Responding in part to Iran's steps toward acquiring a latent nuclear bomb capacity, numerous Arab countries have recently expressed interest in nuclear power programs, which might eventually include enrichment facilities. While Iran is not interested in fuel assurance proposals, these proposals might appeal to other countries.

But before proceeding with any of these proposals, the United States and its international partners need to assess whether the proposals would unintentionally spur demand for fuel-making technologies in the future in countries now entering into or considering nuclear power production. For instance, a country could take advantage of a fuel assurance initiative to launch a nuclear power program, reasoning that buying fuel is initially cheaper than making its own fuel. However, once that country's nuclear power program crosses the threshold of about ten large commercial reactors, building a nuclear fuel plant would become more economically favorable. If the fuel assurance proposal were voluntary and did not require a country to forsake fuel making, it could have the unintended effect of stimulating development of this activity in more countries. Thus, the United States and its partners need to be aware of potential unintended consequences of fuel assurance proposals.

As a complement to these assurances, the United States could pursue another policy strategy: properly interpret the NPT's right to peaceful nuclear technologies, develop and apply country-neutral rules, and offer a broad portfolio of energy choices to all countries based on sound economic analysis of their energy needs. While the NPT acknowledges that countries have the right to research and develop peaceful nuclear energy, it does not specifically mention nuclear fuel-making facilities as part of that right.[15] This right also comes with the responsibility to maintain adequate safeguards on the peaceful program. A country-neutral rule could be that any country not in compliance

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[15] Robert Zarate, "The NPT, IAEA Safeguards, and Peaceful Nuclear Energy: An 'Inalienable Right,' But Precisely to What?" Nonproliferation Policy Education Center, January 2007.

with its safeguards commitments must suspend the suspect activity until the compliance problem is resolved.[16]

The IAEA would make the determination of noncompliance, but it lacks enforcement authority. Enforcement could follow from a resolution by the UN Security Council. But as the recent experiences of Iran and North Korea demonstrate, obtaining effective UN Security Council action can be difficult and convincing the suspect countries to obey the resolution can be challenging. Approaches outside of the Security Council could gain more traction. For example, the six-party talks with North Korea involving China, Japan, Russia, South Korea, and the United States might eventually bring North Korea back into compliance with its safeguards commitments by verifiably dismantling its nuclear weapons programs. Of course, it would have been far more preferable to counter these programs years ago when concerns about North Korea's lack of compliance, in particular, with the suspected uranium enrichment program, arose. While the Security Council is the logical forum to address enforcement of compliance problems, competing national interests among permanent and revolving members of the Council could stymie passage of a country-neutral rule requiring suspension of suspect nuclear activities.

As a minimum near-term practical step toward a long-term potential Security Council resolution neutral on compliance, the IAEA Board of Governors could pass a rule to suspend technical assistance to countries that are in noncompliance. Recently, the IAEA Board of Governors voted to halt technical assistance to Iran's nuclear power program while maintaining assistance related to humanitarian projects such as nuclear medicine.

The Nuclear Suppliers Group (NSG), the forty-five member group of countries that coordinate nuclear export controls to contribute to nonproliferation, could also enforce a rule to halt exports that would aide a country in noncompliance with its safeguards commitments. While such an initiative could run into roadblocks, the NSG already has rules about not aiding countries that are not maintaining safeguards or are out of compliance with their safeguards commitments. Still, more assertive efforts by the

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[16] Pierre Goldschmidt, "Priority Steps to Strengthen the Nonproliferation Regime," Policy Outlook, Carnegie Endowment for International Peace, February 2007.

NSG are necessary but not sufficient, as the clandestine Khan nuclear network underscores. For decades until his house arrest in 2004, Dr. Abdul Qadeer Khan, the so-called father of Pakistan's nuclear bomb, supplied uranium enrichment and other bomb-usable technologies to Iran, Libya, and North Korea. This network involved several companies and individuals in more than a dozen countries, including some member states of the NSG. Although the United States and its partners are working to tighten export controls and prevent Khan-like networks from developing, the potential remains for future clandestine networks.

Also, all countries with nuclear programs could implement near-real-time monitoring of nuclear activities that could contribute to a potential weapons program. To encourage buy-in to this neutral rule, the United States and other countries currently in the fuel-making business could take the lead in implementing this more rigorous surveillance. To support this initiative, the NSG could pass a consensus rule that all fuel-making states should put in place near-real-time surveillance. But it should be stressed that this type of surveillance may still not be enough to prevent diversion of fuel-making capacity into a weapons program. For example, an alarm could sound to alert the IAEA to the presence of HEU in an enrichment plant, but due to the months that could easily elapse before the IAEA Board of Governors and the UN Security Council could act to intervene, a proliferator could have sufficient time—a matter of weeks—to make a bomb from the nuclear explosive material diverted from a fuel-making facility. Thus, the United States and the IAEA should clearly distinguish between those activities that can be rigorously safeguarded and those that cannot.

Another neutral rule could be that any country should ideally demonstrate the economic soundness of any proposed fuel-making facility before proceeding to build one.[17] The problem is, who would decide whether a country's nuclear power program makes economic sense? Realistically, countries would resist having an economic determination imposed on them. Nonetheless, faced with problems such as global warming and nuclear proliferation that transcend sovereignty, all countries should be encouraged to make wise energy investment decisions that factor in all benefits and risks.

[17] Henry Sokolski, "Does Nuclear Nonproliferation Have a Future?: Market-Based Atomic Power," *Harvard International Review*, February 2007.

In general, countries should have a wide selection of energy choices available to them. Like a salesperson offering only one investment choice, the IAEA only has the mandate to promote nuclear energy. The IAEA should work together with the International Energy Agency, which has expertise in a broad suite of energy choices, to provide comprehensive assessments that would factor in all internal and external costs of energy options available to a country.[18] This approach would offer a broad portfolio of energy investment choices. If the United States and its partners applied these integrated, country-neutral rules, they would move toward a nuclear energy and nonproliferation strategy that is less discriminatory and, thus, more likely to be accepted by many countries.

Presently, the Bush administration is advocating a discriminatory approach to limiting the spread of fuel-making technologies. In February 2006, the administration proposed the Global Nuclear Energy Partnership (GNEP). GNEP is partly intended to offer fuel services to countries wanting to use nuclear energy and to develop proliferation-resistant methods of plutonium reprocessing. GNEP's fuel services proposal would divide the world into two classes: fuel supplier states and fuel client states. The supplier states would provide fuel and perhaps other services such as spent fuel reprocessing and waste disposal to the client states so that the latter would not have to do any activities that could readily power weapons programs.

In part in response to the GNEP proposal as well as to similar fuel assurance proposals, a number of countries, including Argentina, Australia, South Africa, and Ukraine, expressed interest in building commercial enrichment facilities. Even before the launch of GNEP, Brazil was constructing such a facility. Brazil and several countries that have begun or expressed interest in fuel making want to ensure that they are members of the fuel supplier class.

The other fundamental part of GNEP is to develop plutonium reprocessing methods that are more impervious to use in nuclear bombs and that could help reduce the burden of highly radioactive waste storage. Since the Ford administration, the United States has opposed separation of plutonium from spent fuel because of proliferation concerns and because plutonium reprocessing was too expensive compared to using fresh

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[18] Author's conversation with Lawrence Scheinman of the Monterey Institute's Center for Nonproliferation Studies, January 10, 2007.

uranium as fuel. Reprocessing plutonium into reactor fuel (closed fuel cycle) is still far more expensive than enriching and making uranium into fuel (once-through fuel cycle). On economic grounds alone, it makes sense to refrain from plutonium reprocessing. A country-neutral rule that required countries doing this practice to factor in all of the environmental, safety, and security costs might convince many of them to abandon reprocessing. However, some have argued that a plutonium economy makes sense if nuclear energy use undergoes a major expansion, leading to shortages of uranium. Based on the current demand for uranium at 68,000 metric tons per year and the known recoverable resources at 4,743,000 metric tons, the world would have enough uranium at current prices for the next seventy years.[19] But as the demand for uranium increases, incentives for increased uranium mining and prospecting would increase, leading to increased supplies. Nonetheless, GNEP proponents foresee the need for using plutonium as fuel.

Unlike traditional methods of reprocessing, the GNEP methods do not completely separate plutonium from other radioactive materials. Nonetheless, GNEP-produced plutonium would not meet the spent fuel protective standards endorsed by the U.S. National Academy of Sciences.[20] If terrorists obtained access to the types of plutonium mixtures currently being studied by GNEP, they could easily carry and use these materials in a radiological dispersal device (one type of which is commonly known as a "dirty bomb"), or perhaps a crude nuclear bomb, without killing themselves in the process of handling the plutonium mixture. Because of this situation, GNEP would limit participation in its plutonium reprocessing methods to a select list of trusted fuel-supplier states such as Japan, Russia, Britain, and France. Many independent scientists and analysts, however, have questioned the government's claim that these methods are proliferation resistant and have expressed concern about the administration's interest in possibly sharing these technologies with countries that have had nuclear weapons programs.[21]

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[19] Nuclear Energy Agency, *Uranium 2005: Resources, Production, and Demand*, Organization of Economic Cooperation and Development, 2005. This estimate is based on a price of $130 per kilogram of uranium.

[20] *Management and Disposition of Excess Weapons: Plutonium*, National Academy of Sciences, 1994.

[21] See, for example, Frank von Hippel, "GNEP and the U.S. Spent Fuel Problem," Congressional Staff Briefing, March 10, 2006; Matthew Bunn, "The Case Against a Near-Term Decision to Reprocess Spent

GNEP also envisions using up to two hundred fast neutron reactors to burn up long-lived fission products and thus, in principle, help reduce the storage burden on permanent radioactive waste disposal repositories. But to be adequately consumed, the fission products would have to undergo multiple passes through fast reactors; this processing could take several decades for each batch of material. To date, industry has shown a lack of interest in funding the construction of the fast reactors. Projected costs are at least $200 billion.

Based on current and likely demand for nuclear fuel for the next several decades, known and projected uranium resources are sufficient for the once-through (open) fuel cycle. There is no urgent need to rush ahead with developing plutonium reprocessing under GNEP or another closed-fuel cycle initiative. GNEP's plutonium reprocessing should remain as a research program. The United States should refrain from sharing the fruits of this research with other countries until it is assured that the program meets rigorous standards of proliferation and theft resistance.

To address proliferation concerns, greater efforts are needed to strengthen safeguards and to limit the spread of fuel-making technologies. Both of these initiatives should, as much as possible, be based on country-neutral rules in which all countries would phase out enrichment of uranium to HEU and implement near-real-time surveillance on sensitive nuclear facilities. Countries that benefit the most from nuclear energy should pay the most to improve safeguards. All countries wanting to use nuclear energy or practice fuel making should be encouraged to demonstrate the economic soundness of these endeavors. Any country found in noncompliance with safeguards commitments by the IAEA should suspend the suspect activity until the problem is resolved. While these efforts would not guarantee prevention of misuse of nuclear materials or fuel making, they would move toward an equitable system that would have greater cooperation from more countries than proposals that practice or appear to practice discrimination.

Nuclear Fuel in the United States," Testimony to the Subcommittee on Energy, Committee on Science, U.S. House of Representatives, June 10, 2005.

According to a nuclear safety aphorism, "An accident anywhere is an accident everywhere." As with the 1979 Three Mile Island accident and the 1986 Chernobyl accident, a future major nuclear power plant accident could have a chilling effect on the growth of the industry or sustained operation of the current fleet of reactors. Similarly, a terrorist attack on any reactor could have a stifling effect on continued use or potential growth of nuclear energy in many countries. Thus, regardless of nuclear expansion in America, the United States has a vested interest in working bilaterally and multilaterally to strengthen international nuclear safety and security standards.

Whether the United States builds new commercial nuclear reactors, many countries are already doing so. The location of these reactors matters. Countries with mature power programs would tend to operate reactors in a safer and more secure manner than countries with little or no experience in commercial nuclear energy. However, even in nuclear-experienced countries, safety and security risks could increase if reactors are extended beyond their design life or if operators became complacent about providing for adequate security to account for terrorist attacks.[22] Still, the greatest safety risks stem from countries that have little or no nuclear regulatory experience. Without increased attention to creating and strengthening nuclear safety cultures in these countries, nuclear power programs in the United States and other countries could be held hostage to an accident involving inexperienced nuclear programs.

Safety as well as reliable and cost-effective consumer access to electricity depends on the electrical distribution grid. The grid in the United States and other countries is not well equipped to meet growing demand for electricity.[23] Even if the United States had no nuclear plants, it would benefit from investing in revitalized electrical grids. Such an investment would also enhance reactor safety by ensuring more reliable access to outside sources of power in the event of a forced shutdown of or an accident at a nuclear power plant.

[22] Scott D. Sagan, "The Problem of Redundancy Problem: Why More Nuclear Security Forces May Produce Less Nuclear Security," *Risk Analysis: An International Journal*, August 2004, pp. 935–46.
[23] David Cay Johnston, "Grid Limitations Increase Prices for Electricity," *New York Times*, December 13, 2006.

The United States has been a leader in improving the safety of nuclear plant operations. For instance, U.S. nuclear engineers, working with their counterparts in other countries, created the World Association of Nuclear Operators (WANO) after the 1986 Chernobyl accident. Headquartered in Atlanta, WANO serves as a nongovernmental organization that conducts confidential peer reviews of nuclear power plant safety around the world. The Nuclear Regulatory Commission's Office of International Programs has provided regulatory assistance to several countries. Also, the U.S. Department of Energy and the State Department have drawn on their technical talent to assist reactor safety programs in Eastern Europe and the former Soviet Union. The International Atomic Energy Agency also has programs to improve the safety and security of nuclear facilities, but it lacks adequate resources to educate regulatory officials and nuclear plant operators in the numerous countries that may develop nuclear power programs.

The United States has taken steps to improve the security of nuclear power plants against terrorist attack or sabotage. Soon after the September 11, 2001, terrorist attacks, the U.S. Nuclear Regulatory Commission launched a top-to-bottom review of security procedures and requirements. Despite these updated security requirements, some independent groups continue to express concern about security vulnerabilities at U.S. nuclear power plants.

In part to address such concerns, Congress placed statutory requirements for nuclear plant security in the Energy Policy Act of 2005. In particular, the act requires that each nuclear plant conduct force-on-force exercises at least once every three years, which is the NRC's current policy. The act also calls for the exercises to simulate threats in the design-basis-threat (DBT) and for the NRC "to mitigate any potential conflict of interest that could influence the results of a force-on-force exercise, as the Commission determines to be necessary and appropriate." In addition, the act requires the NRC to revise the DBT at least every eighteen months, factoring in all conceivable modes of attack, including use of multiple teams of attackers, several plant employees aiding the attackers, and large explosives. The new law also includes requirements to fingerprint and conduct background checks of plant personnel and for the NRC to consult with the Department of Homeland Security about the vulnerability of proposed nuclear facilities to terrorist attack.

Until June 2006, private citizens and nongovernmental organizations were stymied in post-9/11 attempts to challenge the government and industry about security concerns at U.S. nuclear power plants. At that time, the Ninth Circuit Court of Appeals ruled that the NRC violated the National Environmental Policy Act (NEPA) by not reviewing the vulnerability of a proposed spent nuclear fuel facility at the Diablo Canyon nuclear plant in California. The NRC rejected the security review under NEPA in part because it believed that security is already carefully evaluated outside of environmental legal requirements. In January, the U.S. Supreme Court declined to hear an appeal by the owner of the California power plant. The outcome of this legal case could affect investment decisions for building American nuclear power plants in the future.

The nuclear industry has a vested interest in ensuring the safe and secure operation of nuclear power plants. It should devote a commensurate amount of safety and security resources to meet the projected growing demands for nuclear energy and should fund efforts to develop the best regulatory practices throughout the world. This proposed initiative for industry would draw on the precedent established by WANO in improving safety. The nuclear industry should factor these safety and security costs into the total operational costs of nuclear power plants. Because the electrical distribution grid connects a variety of electricity production sources, including nuclear, the U.S. government should invest adequate resources to ensure an effective grid similar to government's role in investing in the development of the superhighway system and the Internet.

Radioactive Waste Disposal

More than fifty years of commercial nuclear energy use has left the world with a legacy of tens of thousands of tons of highly radioactive waste that will last for tens of thousands of years. If nuclear power production expands substantially in the coming decades, the amount of waste requiring safe and secure disposal will also significantly increase. Although several countries are exploring various long-term disposal options, no country has begun to store waste from commercial power plants in permanent repositories.

Industry officials generally believe that further growth of nuclear energy depends on establishing these repositories.

Countries that have derived benefits from nuclear-generated electricity have an obligation to future generations to safely and securely dispose of nuclear waste. In the United States, the government is legally bound to remove this waste from reactor sites and store it in permanent repositories. Delays in storing spent nuclear fuel in a permanent repository have already resulted in lawsuits with financial penalties.

Yucca Mountain in Nevada, the site slated for a permanent geologic repository, has not received approval to store this waste. Even if the license application is approved within the next few years, the Department of Energy does not anticipate starting to store waste there until 2017, and, more realistically, not before 2020. Meanwhile, spent fuel is accumulating in pools at nuclear power plants, increasing the risk of radioactive release from sabotage or attack at these facilities. A recent U.S. National Academy of Sciences study has concluded that "successful terrorist attacks on spent fuel pools, though difficult, are possible." Zirconium cladding provides a protective barrier around the spent fuel, but the cladding could catch fire under some attack scenarios. According to the National Academy study, "If an attack leads to a propagating zirconium cladding fire, it could result in the release of large amounts of radioactive materials." In considering alternative storage options, the study assessed, "Dry cask storage has inherent security advantages over spent fuel storage, but it can only be used to store older spent fuel."[24] Removal of older spent fuel would also relieve overcrowded conditions in many spent fuel pools, thus decreasing safety and security risks of the remaining spent fuel in the pools. While some plants have begun using dry cask storage on-site to relieve the storage burden on spent fuel pools, most plants have not.

Hardened on-site storage of dry spent fuel casks would reduce the risk of attack or sabotage. Spent fuel could be moved to dry cask storage after cooling for five years in pools. Estimates are that dry cask storage can safely and securely store spent fuel for up to one hundred years. Although a lack of a permanent repository in the coming years would not derail the potential for a major expansion of nuclear energy in the United

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[24] Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, National Research Council, *Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report* (Washington, DC: National Academy of Sciences Press, 2006), p. 3.

States, financial and legal commitments argue for proceeding as soon as possible with opening up a permanent repository.

Assuming that Yucca Mountain is eventually approved for waste storage, continued spent fuel production in the next few years will exceed the current storage limits based on current legal restrictions. According to some technical analyses, the current legislative limit of 77,000 metric tons appears arbitrary. For example, Secretary of Energy Samuel W. Bodman has requested that the allowed storage capacity be determined by the physical capacity of the mountain, estimated to exceed 120,000 metric tons of waste. In addition, according to an Electric Power Research Institute study, Yucca Mountain could hold at least four times the legislative limit and possibly nine times that limit, allowing that site to store "all the waste from the existing U.S. nuclear power plants, but also waste produced from a significantly expanded U.S. nuclear power plant fleet for at least several decades."[25] But opposition to using or expanding use of the proposed repository in Nevada, a state that has never had a commercial nuclear power plant, could well demand that the United States establish more than one repository.

The waste storage problem in the United States is manageable. The United States should pursue a dual-track approach: commit to developing a consensus and then opening up a permanent repository and in parallel store as much spent fuel as possible in dry casks that are hardened against attack at existing reactor sites. The combination of interim storage and commitment to a permanent repository would provide the assurances needed by the public and the investment community for continued use of nuclear power.

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[25] "Program on Technology Innovation: Room at the Mountain," Electric Power Research Institute, May 2006.

RECOMMENDATIONS

Nuclear energy produces one-fifth of U.S. electricity and one-sixth of global electricity; thus, the United States and its partners have a vested interest in ensuring safe and secure operation of the world's nuclear industry. But the future of domestic and international commercial nuclear energy use faces large uncertainties in financial competitiveness and in external costs such as proliferation risks of the nuclear fuel cycle, safe and secure operation of nuclear power plants, and long-term disposal of highly radioactive waste. Generating electricity from any energy source comes with external costs. Traditionally, the U.S. government and many other governments have relied on subsidies to pick winners and losers among energy sectors. But providing subsidies to mature industries such as nuclear power have hidden the external costs. Governments should strive to identify and factor in as many of the external costs as possible into the price of energy sources.

One of the biggest external costs is environmental damage from greenhouse gas emissions. The United States must work urgently to achieve the objective of substantially reducing global warming as fast as possible and thus should shift from providing subsidies to holding all energy sectors equally accountable for their external costs. Currently, the costs incurred through carbon pollution are a debt unpaid; therefore, governments should begin by collecting these costs through a mechanism such as imposing a fee on greenhouse gas emissions. In other words, the polluter pays. This step would act to level the economic playing field among high-carbon emitters such as traditional coal-fired plants and no- and low-carbon emitters such as highly efficient natural gas plants, nuclear plants, and wind- and solar-generated electricity. No single energy source is a technical panacea for combating global warming. Also, there are too many uncertainties in having governments pick the correct mix of energy sources to achieve the goal of countering the worst effects of climate change. However, a price, in some form, imposed on carbon emissions would stimulate the market to work toward an appropriate mix. Nuclear power will remain part of this mix for the foreseeable future.

While nuclear energy will continue to play a role in meeting the world's energy needs, it will not solve the immediate problems of climate change. To effectively counter climate change, the United States and its partners must move quickly forward to advance the use of all low- and no-carbon forms of energy, to use energy more efficiently, and to develop methods of capturing and storing carbon emissions. Over the long term, an economically competitive nuclear industry could experience modest growth domestically and internationally. The United States and its partners should welcome such growth provided they can successfully manage nuclear energy's risks: safety, security, waste disposal, and proliferation. What follows are major recommendations for factoring in external costs and managing the risks.

Require Energy Sectors to Cover Entire Costs of Energy Production

Level the playing field for all energy sectors by holding each sector accountable, as much as possible, to its own costs, including environmental, safety, and security costs. While the United States should refrain from further subsidies to developed energy industries, it should help to cover research expenses to foster new technological development and to ensure needed improvements in the electrical distribution grid, which is shared by all sectors. In particular, to account for each sector's costs:

- The United States should impose a fee on greenhouse gas emissions to leverage market forces in order to counter global warming.
- Industry should devote adequate resources to cover safety and security costs.
- To complement the safety assessments done by the World Association of Nuclear Operators, the nuclear industry in all advanced countries should set up a fund that would support developing best regulatory practices for both safety and security in all countries that use or want to use nuclear power.
- To further improve security, the nuclear industry should transfer as much spent fuel as possible into dry storage casks that are hardened against attack while the United States moves forward with development of a permanent nuclear waste repository.

Apply Country-Neutral Rules to Reduce Proliferation, Safety, and Security Risks

Countries that benefit the most from nuclear energy should contribute the most funding and safeguards support to the International Atomic Energy Agency. If demand for nuclear energy rises, so should the resources available to the IAEA. Regardless of an increase in demand, the United States should take the lead in working with IAEA member states and the Nuclear Suppliers Group to develop country-neutral rules for limiting the spread of nuclear fuel-making facilities and for reducing the likelihood of misuse of existing fuel facilities and power plants. While the United States would likely face a roadblock in the near term in convincing the UN Security Council to pass resolutions on country-neutral rules that are binding on all UN members, a more practical approach would be to begin by asking the IAEA Board of Governors and the NSG to apply the authorities they already have to limit or cut off technical assistance and bomb-usable exports to countries in noncompliance with their safeguards commitments. The NSG and IAEA Board of Governors should also refrain from assisting development of nuclear programs that were acquired by countries prior to their withdrawal from the NPT. Withdrawal should not absolve countries from their responsibilities to maintain safeguards on nuclear technologies obtained while members of the NPT.

Over the long term, the United States should work with partner governments to develop and implement rules that would apply equally to all countries and, thus, would move toward a less discriminatory nonproliferation system. Such rules could include:

- Requiring any country in noncompliance with safeguards commitments to suspend suspect activities until the problem is resolved.
- Encouraging any country seeking a nuclear fuel facility to consider the economic soundness of this activity before building the facility. An economic test would be whether the proposed nuclear project could secure financing by private capital.
- Urging any country wanting to develop nuclear power programs to factor in all environmental, safety, and security costs as compared to other energy sources; to support these assessments, the IAEA and the International Energy Agency could work together to provide comprehensive energy analysis for any country, including all costs for each energy source.

- Offering assured access to nuclear fuel based on competitive market prices as long as a country meets rigorous safeguards criteria and can secure private financial support for its civilian nuclear program.

APPENDIX

ANALYSIS OF THE ENERGY POLICY ACT OF 2005 AND NUCLEAR POWER PRODUCTION

The Energy Policy Act of 2005 offered a number of incentives to spur growth in nuclear energy use as well as other low- or no-carbon emission energy sources. As a direct incentive, the act provided for a tax credit of 1.8 cents per kilowatt-hour for up to six thousand megawatts of new nuclear capacity for the first eight years of operation. (A commercial reactor is typically rated at about one thousand megawatts of electrical power production.) This credit equates to $125 million annually per one thousand megawatts or a total eight-year credit of up to $6 billion for six thousand megawatts. To be eligible for the tax credit, a utility would have to apply for a combined construction and operating license by December 31, 2008, begin reactor construction prior to January 1, 2014, and obtain Department of Energy certification as meeting eligibility requirements. If more than six thousand megawatts of eligible reactor applications are received by December 31, 2008, the tax credit would be distributed proportionally among the eligible reactors. If less than six thousand megawatts of eligible reactor applications are received by that date, the deadline would extend until the six thousand megawatt limit is reached. While the end-of-2008 deadline provides an incentive for applicants to file early, if applications significantly exceeded the six thousand-megawatt limit, the credit for each individual reactor could shrink to a level where there would not be a sufficient construction incentive. Moreover, even if a utility received the tax credit for 100 percent of a new reactor's power production, it would not necessarily stand to benefit from receiving a tax credit for subsequent reactor construction. Presently, at least three different companies are vying for the tax credit. Under that scenario, each company would likely build one or two reactors and not have any further incentive from the tax credit to build additional reactors.[26] By itself, the tax credit could stimulate construction of a handful of new

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[26] Larry Parker and Mark Holt, "Nuclear Power: Outlook for New U.S. Reactors," CRS Report for Congress, May 31, 2006, pp. 9–10.

reactors but would not provide the long-term sustainable conditions for large-scale construction.

The 2005 Energy Policy Act also provides for regulatory risk insurance, which is the only incentive in the act uniquely tailored to nuclear energy. This insurance, called "standby support," would cover the principal and interest on debt and other costs incurred in buying replacement power as a result of licensing delays caused by the Nuclear Regulatory Commission or licensing-related litigation in state, federal, or tribal courts. If these delays ensue, the first two new reactors licensed by the NRC could receive up to $500 million each, and the next four licensed reactors could receive a 50 percent reimbursement of up to $250 million each. In total, standby support could cost American taxpayers up to $2 billion. The intention behind this risk insurance is to reduce uncertainty about the combined construction and licensing process.

In addition, the Energy Policy Act makes new nuclear plants eligible for federal loan guarantees. These guarantees cover energy projects that reduce harmful air emissions and could pay up to 80 percent of a plant's estimated cost. In the event of a loan default, the Department of Energy would pay off the loan and could choose to complete or dispose of the project or could reach an agreement with the borrower to finish the project. To guard against default, the law allows the department to make loan payments, which are contingent on appropriations and an agreement by the borrower to reimburse these expenditures. Because the federal government, i.e., U.S. taxpayers, would bear the financial risk, these loan guarantees could make investment in the first handful of new reactors more appealing from the standpoint of Wall Street. However, as with the tax credit, such guarantees could offer at best a short-term fix and might not create a long-term sustainable platform for growth in the domestic nuclear industry.

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