Proliferation Papers

Potential Strategic Consequences of the Nuclear Energy Revival

In collaboration with the Atomic Energy Commission (CEA)

Charles D. Ferguson

Summer 2010

Security Studies Center

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Though it has long been a concern for security experts, proliferation has truly become an important political issue with the last decade, marked simultaneously by the nuclearization of South Asia, the weakening of international regimes and the discovery of frauds and traffics, the number and gravity of which have surprised observers and analysts alike (Iraq in 1991, Libya until 2004, North Korean and Iranian programs or the A. Q. Khan networks today).

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Introduction: Overview of the Benefits and Risks of Nuclear Energy

Many people have projected their hopes and fears onto nuclear power. Nuclear energy has both benefits and risks, and disagreement persists about whether this energy source is, on balance, more of an asset than a liability. This debate involves a complicated set of factors that are difficult to assess, let alone fully resolve because of the differing interests in various countries' use and pursuit of nuclear power. Renewed interest throughout the globe in harnessing this energy source has stoked this perennial debate and raised concern about security threats from states and non-state actors while holding out the promise of more electricity for more people.

While the motivations for nuclear energy vary among states, the two primary public goods this energy source offers are countering human-induced climate change and providing for greater energy security. An operating nuclear power plant does not emit greenhouse gases, and the nuclear fuel cycle as a whole releases very few of these gases relative to almost all other energy sources, especially fossil fuels. Although views on how to achieve energy security differ, the essential aspect for nuclear energy is that for several countries, especially those with scarce indigenous energy sources from fossil fuels, investing in nuclear power plants diversifies electricity production portfolios and helps reduce dependence on foreign sources of energy. It is beyond the scope of this paper to examine these benefits in depth. Nonetheless, it is worth highlighting these motivations.

Instead, the focus here is on assessing the potential security consequences of increased use of nuclear power in the existing nuclear power states and most importantly in many more states that have in recent years expressed interest in this power source. The risks of nuclear power include possible reactor accidents, release of radioactive waste to the environment, attacks on or sabotage of nuclear facilities, and misuse of peaceful nuclear technologies to make nuclear weapons. While safety of nuclear plants and disposal of radioactive waste are important issues, this paper analyzes the latter two issues. In addition, it addresses two under-examined risks: military attacks on nuclear facilities and the effects on security alliances and conventional arms buildups as more countries seek to acquire nuclear power infrastructures.

Even if the total number of operating reactors does not substantially increase worldwide, the security threats may increase because of more countries acquiring nuclear power plants or at least developing a nuclear infrastructure. This infrastructure could provide a portal for states to acquire knowledge of nuclear weapons design and manufacture by offering a convenient political and commercial cover for this transaction and could provide a means to acquire the types of research reactors that are optimized for production of weapons-usable fissile material.[1] Once a state has a significant number – typically ten or more – of nuclear power plants, it may then have an economic rationale to argue for developing a uranium enrichment plant to provide for its own nuclear fuel, but before that threshold number is crossed, economics argue against building an indigenous enrichment plant.[2]

The latent proliferation threat revolves mainly around where many of these countries are located. In particular, the Middle East is a politically volatile region and includes numerous states that have recently expressed interest in acquiring nuclear power plants. The Arab states that have expressed interest in these plants are not monolithic in their view on this energy source, and they are not all major petroleum and natural gas producing states. Of course, the backdrop for these recent pronouncements is the growth of Iran's acquisition of a latent nuclear weapons capability. In addition, some of the petroleum and gas producing states have stated that they want to free up more of these resources for export and not use as much for electricity production and seawater desalination. Moreover, the states lacking these resources such as Jordan are seeking ways to reduce dependency on oil and gas imports. They see nuclear energy as helping to do that. In the long term, solar power – especially in the sunny Middle East – would likely provide a sustainable solution without the risk of proliferation. But solar energy is not as powerful politically as nuclear energy. New nuclear power entrant states have heard the message from major suppliers that nuclear power is prestigious.[3] This received wisdom has been a strong motivator.

The major supplier states also have powerful economic and alliance motivations to pursue peaceful nuclear cooperation agreements. Large nuclear reactors cost several billion dollars or euros and thus mean big business. These sales may be a relatively small fraction of other lucrative commercial and military transactions. For instance, the chamber of commerce or the equivalent business group tries to leverage major government-to-government nuclear agreements to promote non-nuclear sales to recipient states. Increased military sales or stronger military

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[1] Matthew Kroenig, "Importing the Bomb: Sensitive Nuclear Assistance and Nuclear Proliferation", *Journal of Conflict Resolution,* Vol. 53, No. 2, April 2009; Matthew Fuhrmann, "Spreading Temptation: Proliferation and Peaceful Nuclear Cooperation Agreements", *International Security*, Vol. 34, No. 1, Summer 2009.

[2] Thomas W. Wood, Matthew D. Miazzo, Barbara A. Reichmuth, and Jeffrey Bedell, "The Economics of Energy Independence for Iran", *The Nonproliferation Review*, Vol. 14, No. 1, March 2007.

[3] Sharon Squassoni, *Nuclear Energy: Rebirth or Resuscitation?*, Washington, Carnegie Endowment for International Peace, 2009.

alliances can be associated with nuclear deals.[4] More acquisition of conventional arms by nuclear recipient states may stimulate such sales to neighboring states, thereby potentially spurring or exacerbating regional arms races.[5] As a result, developing states would channel more scarce resources from productive pursuits in the civilian economy to the military. Major suppliers may want to connect nuclear deals to construction of military bases in and joint military exercises with recipient states.[6] Nuclear deals might come as a first step, or sometimes as a second or third one. Neighbors will tend to look for protection from major powers to counter perceived security threats from states that develop a nuclear infrastructure that has a latent nuclear weapons capability. Some states under threat may ask for formal nuclear extended deterrence and other security assurances from nuclear-armed states. As the world becomes more globalized and more multi-polar, it is urgent to examine seriously what risk reduction measures are needed as the world appears on the verge of a nuclear energy revival.

[4] For example, increased U.S. arms sales to India followed the conclusion of the U.S.-India nuclear deal. Jim Wolf, "U.S. OKs Record $2.1 Billion Arms Sale to India", *Reuters*, 16 March 16 2009. In 2008, when the United Arab Emirates expressed strong interest in moving forward with a nuclear agreement with the United States, the UAE request for arms from the United States soared to more than $9 billion that year, and more than half of the $75 billion governmental requests for U.S. arms were from the Middle East; at the same time, many U.S. allies in the region were expressing interest in commercial nuclear deals. Jeff Abramson, "U.S. Arms Notifications Spike in 2008", *Arms Control Today*, March 2009.

[5] Joby Warrick, "U.S. Steps Up Arms Sales to Persian Gulf States", *Washington Post*, January 31, 2010; Julian E. Barnes, "Pentagon Chief Defends Arms Sales to India, Pakistan", *Los Angeles Times*, 23 January 2010; Saibal Dasgupta, "Arms Sales to Pak Justified as India Buys from US: Chinese Official", *The Times of India*, 22 December 2009.

[6] Molly Moore, "France Announces Base in Persian Gulf: Deal with U.A.E. Seen as Warning to Iran", *Washington Post*, 16 January 2008; Riad Kahwaji, "French Base in UAE Signals Regional Strategic Shift", *Defense News*, 28 January 2008.

The Potential for a Nuclear Energy Revival

Many uncertainties cloud forecasts for the future of nuclear power and the possible concomitant evolution or revolution of global security. Estimates for nuclear power in the coming decades, for example, range widely from a decrease in the number of reactors to a major increase in deployment. The variance results from differing projections of capital construction costs, sustained demand for electricity, capacities to provide for major reactor parts and highly skilled personnel, life extensions of existing reactors, the global effort to combat climate change, the likelihood of nuclear accidents, and the effect of proliferation.

To understand whether nuclear power will experience substantial growth in the coming decades, it is necessary to establish a baseline of where nuclear power is being used. Nuclear energy generates about 15 to 16 percent of the world's electricity. Thirty countries plus Taiwan use commercial nuclear power. Worldwide as of mid-2009, there are 436 commercial reactors with a combined capacity of about 370 Gigawatts electrical power.[7] The distribution of nuclear power by geopolitical region is very heterogeneous. Europe, East Asia, and North America dominate. But some European states and the United States may experience a decline in nuclear power's proportional use over the next couple of decades mainly due to decommissions of older reactors and political decisions to shut down reactors as well as difficulties of financing construction. In East Asia, China, Japan, and South Korea will almost assuredly keep building new reactors. In particular, China has launched a grand reactor construction spree. If this is sustainable, China may have more than 100 commercial reactors deployed by 2030 and may surpass the United States as the country with the most commercial reactors, especially if U.S. nuclear plant construction remains stymied.

Outside of these regions, relatively few power reactors are deployed. In South Asia, for example, India has about a dozen power reactors, mostly of relatively modest power ratings, and Pakistan has only two power reactors with a third under construction. But India has ambitious plans for major construction especially following the conclusion of the 2008 U.S.-India nuclear cooperation deal, which opened up India to the commercial nuclear market after more than 30 years of sanctions. While

[7] For the latest updates on nuclear reactors' status, see the International Atomic Energy Agency's Power Reactor Information System, available at: http://www.iaea.org/programmes/a2/.

Africa, the Middle East, and Southeast Asia lag far behind the aforementioned regions in nuclear power use, in recent years, several states, particularly in the Muslim world, have expressed interest in acquiring their first nuclear power plants.

Hopes are running high in the industry and among many governments for a nuclear energy revival. But nuclear power, on a worldwide basis, has been stuck on a plateau for the past decade and has experienced only relatively modest growth as averaged over the past twenty years. In 1989, there were 423 operating commercial reactors with a combined capacity of 328 GWe, and in mid-2009, there were 436 reactors with a total capacity of 370 GWe, according to the International Atomic Energy Agency. The peak year for reactor deployment was 2002 with 444 reactors. However, peak generating capacity was reached by the end of 2007 with almost 372 GWe. In 2008, for the first time in commercial nuclear power history, no new reactor was connected to the electrical grid. Three reactors were shut down in 2008 resulting in the total installed capacity being reduced by about 1,600MWe, equivalent to an EPR (European Pressurized Water Reactor) as under construction in Finland and France.

New reactors are being built, however. In 2008, 35 reactors were listed as under construction, but by mid-2009, this list had surged to 53 reactors. More than two-thirds of these are in China, India, Russia, and South Korea. (China accounts for the lion’s share of the surge in 18 reactors from 2008 to 2009.) But a caveat is that at least one-fourth of the 53 have had the “under construction” status for over twenty years. Mainly, the new reactors are using Russian or Chinese designs although the prevalent Chinese design is derived from a technology transfer agreement from a French design. China may eventually position itself to become a major nuclear power plant exporter.

Despite the doldrums in reactor deployment, the industry has increased generation capacity through increases in plants’ power ratings and capacity factors. By making improvements in plant efficiencies such as through more effective turbines, many plant operators have received permission from regulatory agencies to increase the power rating of their plants by as much as several percent. By paying greater attention to safety and preventive maintenance and by lowering plant downtime, operators have increased capacity factors – the proportional amount of time that a plant operates at full power – to greater than 90 percent for many plants.[8]

A country’s use of nuclear power has much to do with government intervention such as streamlined regulations, loan guarantees, tax credits, and additional incentives including regulatory risk insurance and caps on operators’ contribution to liability coverage. Although these incentives appear enticing, utility executives may still be reluctant to take a big

[8] E. Michael Blake, “U.S. Capacity Factors: A Small Gain to an Already Large Number”, *Nuclear News*, May 2007; Mycle Schneider and Antony Froggatt, “The World Nuclear Industry Status Report 2007”, Report Commissioned by the Greens-EFA Group in the European Parliament, January 2008.

financial risk on expensive nuclear plants. In the United States, utilities typically have relatively small market capitalization of at most a couple of tens of billions of dollars. Consequently, a reactor that costs five to nine billion dollars would risk well over ten percent of a company's market capitalization – a level that is usually deemed exceedingly risky for a single project.[9] In other countries with strong government ownership of electric utilities such as China, France, Russia, and the United Arab Emirates, there tends to be greater tolerance for investing in big nuclear power projects.

Nuclear power construction also depends significantly on fossil fuel availability and pricing. Capital costs for coal and gas power plants are significantly lower than for nuclear plants. There is an inverse relationship for fuel costs. France and Japan, in particular, have very little indigenous fossil fuel resources and have thus gravitated toward nuclear power to compensate for this lack. On the other hand, the United States has an abundance of coal with estimates of 200 or more years of relatively ready resources; it generates about half of its electricity from coal. The recent major discoveries of large reserves of natural gas in the United States as well as low natural gas prices have further depressed the financial incentives to build new reactors.[10]

Other government policies on greenhouse gas emissions through carbon taxes or cap-and-trade schemes could further favor nuclear power by raising the costs of fossil fuel power plants as compared to nuclear power plants and renewable energy sources such as solar and wind. Carbon price stability and high enough prices are essential to send the market signals that would favor nuclear, solar, and wind power production. For example, the European Union has a relatively new scheme that experienced tremendous price fluctuations in its first year. The U.S. Congress has taken steps toward enacting cap-and-trade legislation, but even if enacted, the scheme would not begin to take effect until 2012. The Congressional Budget Office has estimated that a price of at least $25 per ton of CO2 would be needed to make nuclear energy look cost competitive with coal plants that do not use carbon capture and storage or with high natural gas prices.[11]

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[9] Stephen Maloney, "Financial Issues Confronting Nuclear Construction", Presentation to Conference at the Carnegie Endowment for International Peace, Washington, 13 November 2008.

[10] Matthew L. Wald, "Nuclear Power Renaissance?", *Technology Review*, November/December 2009; David Rotman, "Natural Gas Changes the Energy Map", *Technology Review*, November/December 2009.

[11] Congressional Budget Office, "Nuclear Power's Role in Generating Electricity", Washington, May 2008; John M. Deutch et al., "Update of the MIT 2003 Future of Nuclear Power Report", *Massachusetts Institute of Technology Interdisciplinary Studies Report*, May 2009.

Proliferation Risks of Nuclear Energy Programs

With all the attention focused on the push for a nuclear power revival, it is worth emphasizing that the line between commercial nuclear power programs and nuclear weapons production has been blurry. While almost all commercial reactors have not been used to make fissile material for nuclear weapons, some nuclear-armed states have connected plutonium-production and other weapons-material-production reactors to the commercial electricity grid. The United States, for example, has recently been using a commercial reactor to produce tritium for nuclear weapons.[12]

States that have acquired nuclear weapons can be sorted into two categories: those that developed a dedicated nuclear weapons program and detonated a nuclear explosive prior to the Non-Proliferation Treaty's cutoff date of 1 January 1967 and those that developed nuclear weapons having never signed the NPT, doing so prior to joining the NPT, or after leaving the treaty. The first category includes the officially recognized nuclear weapon states of China, France, Russia, the United Kingdom, and the United States. The second category includes India, Israel, and Pakistan, the three states that have never signed the treaty, North Korea, which had joined the NPT but left in 2003, and South Africa, which built nuclear weapons during the apartheid regime in the 1970s and 1980s, but then dismantled these weapons as the government was transitioning from apartheid. South Africa joined the NPT after this dismantlement. States in the second category used either research reactors to produce weapons-grade plutonium or uranium enrichment plants solely or largely dedicated to weapons production.[13] The vast majority of states – more than 180 – have acceded to the NPT as non-nuclear weapon states. Thus, if any of them want to develop a nuclear weapons program, they would have to withdraw from the treaty to start a dedicated program, use the cover of a peaceful nuclear program to acquire a latent weapons capability, or start a clandestine weapons program.

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[12] For a more in-depth discussion of this blurring between civilian and military applications, see endnote 9 of Henry Sokolski, *Controlling the Further Spread of Nuclear Weapons*, Working Paper, Council on Foreign Relations, April 2010.

[13] Because South Africa could not keep its uranium enrichment program secret, it publicly announced in 1970 that it was building the Y-Plant and created a separate state corporation to run the program. While the program did provide enriched uranium for some commercial and scientific applications, it was the source for highly enriched uranium for South Africa's gun-type nuclear bombs. David Albright, "South Africa and the Affordable Bomb", *Bulletin of the Atomic Scientists*, July/August 1994.

The Various Civil Paths to Nuclear Proliferation

Acquiring a nuclear weapons capability can occur through indigenous development, open purchase of the requisite weapons-production technologies, or clandestine access via black markets. A state could use a combination of these methods. Traditionally, nuclear weapons acquisition has involved two pathways: uranium enrichment or plutonium production.[14] Uranium enrichment can employ a variety of techniques, but the most likely technique is gaseous centrifugation because it is relatively easy to hide a small but proliferation-prone centrifuge plant and because of the proven ability of black markets to make this technology relatively accessible. Laser enrichment, if it is proven technologically, may become a greater proliferation problem than centrifuge enrichment due to the relative ease of concealment.[15] Plutonium production requires at a minimum a reactor of about 20 Megawatt thermal power rating and a reprocessing facility. This power rating level would allow the production of about one bomb's worth of plutonium annually assuming at least an 80 percent capacity factor. The reprocessing facility would chemically extract the plutonium from the spent reactor fuel.

Non-nuclear weapon states are not prohibited by treaty from indigenous development or open purchase of uranium enrichment or plutonium production technologies. In fact, article IV of the NPT has been interpreted by some states such as Brazil, Iran, and Japan to allow acquisition of such technologies. But it is important to stress that this article does not explicitly mention these particular technologies, and the NPT requires applying adequate safeguards on peaceful nuclear programs and upholding the commitment by non-nuclear weapon states not to acquire nuclear explosives. A norm against transferring such technologies has been emerging, but certain states have carved out exceptions. In particular, the Nuclear Suppliers Group (NSG), which was formed after India tested a nuclear device in 1974 using plutonium produced from a research reactor, has endeavored to restrict the sales of enrichment and reprocessing technologies and to require full scope safeguards as a condition of nuclear technology sales. However, this code of conduct was not uniformly applied among participating states. The 2008 deal with India has carved out an exception to the NSG guidelines. Nonetheless, for non-nuclear weapon state signatories to the NPT, open acquisition of enrichment or reprocessing technologies is becoming exceedingly difficult. While a code of conduct may play a significant role in creating a norm of behavior, supplier states may be most strongly motivated to stem sales of these technologies in order not to stimulate more economic competition in the fuel market and not to jeopardize their security interests by shipping these dual-use technologies to less politically secure regions.

[14] Other pathways that have not been exploited include making uranium-233, neptunium, americium, and fissile isotopes other than the preferred isotopes of uranium-235 and plutonium-239. But these routes have technical challenges that make them far less likely than the two traditional routes.

[15] Jack Boureston and Charles D. Ferguson, "Laser Enrichment: Separation Anxiety?", *Bulletin of the Atomic Scientists*, March/April 2005.

Indigenous development has been tried by a few non-nuclear weapon states.[16] Japan, for instance, developed an enrichment plant, but it experienced significant technical problems over the course of more than two decades. (Japan received significant assistance from France in building a reprocessing plant at Rokkasho-mura, which has experienced technical problems and has been struggling in the start up phase.) Brazil began an ambitious enrichment program exploring different techniques during the 1970s through the 1980s when it was considering possible nuclear weapons production. The current Brazilian centrifuge program was derived from the Brazilian navy's enrichment program. Brazil is suspected to have had significant assistance from external sources.

In 1975, the West German firm Kraftwerk Union shocked the world with an agreement to supply Brazil with the major ingredients of the nuclear fuel cycle including uranium mining capabilities, uranium enrichment using the Becker jet nozzle technology, fuel fabrication, spent fuel reprocessing, and construction of nuclear power reactors. This agreement has been called "the deal of the century." The accord fell apart because of domestic and international pressure. Inside Brazil, many scientists opposed this official deal as overly ambitious and as taking away from efforts for indigenous development. The Brazilian military proposed an alternative nuclear program that would not rely on West German assistance. The United States was able to apply effective diplomacy to thwart much of the technology transfer.[17]

External assistance has aided numerous nuclear weapons programs including the Indian, Iranian, Israeli, North Korean, Pakistani, and South African programs.[18] Much of this assistance occurred outside the constraints of the NPT. Iran is the one state in that group that stands out as having joined the NPT (being one of the first states in 1970) and ostensibly expressing interest in remaining a member. The Iranian nuclear program was put on hold from 1979 to 1985 because of Supreme Leader Ayatollah Khomeini's initial opposition to nuclear power.[19] But it was revived with assistance from A.Q. Khan's black market, which provided centrifuge technology.[20] Iran has been using the political cover of a nuclear power program centered on Bushehr, where Russia is helping to complete a nuclear power plant that was begun by West Germany in the 1970s.

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[16] M.D. Zentner, G.L. Coles, and R.J. Talbert, "Nuclear Proliferation Technology Trends Analysis", *Pacific Northwest National Laboratory*, September 2005.

[17] Michael Barletta, "The Military Nuclear Program in Brazil", *Center for International Security and Arms Control*, Stanford University, August 1997.

[18] Mitchell Reiss, *Bridled Ambition: Why Countries Constrain Their Nuclear Capabilities*, Washington, Woodrow Wilson Center Press 1995; Joseph Cirincione, Jon B. Wolfsthal, and Miriam Rajkumar, *Deadly Arsenals: Nuclear Biological, and Chemical Threats*, Washington, Carnegie Endowment, 2005 (2nd ed.).

[19] Ray Takeyh, *Hidden Iran: Power and Paradox in the Islamic Republic*, New York, Times Books, 2009.

[20] Gordon Corera, *Shopping for Bombs: Nuclear Proliferation, Global Insecurity, and the Rise and Fall of the A.Q. Khan Network*, New York, Oxford University Press, 2006; Douglas Frantz and Catherine Collins, *The Man from Pakistan: The True Story of the World's Most Dangerous Nuclear Smuggler*, New York, Twelve Publishers, 2009.

Other states may try to follow Iran's lead down this path. But they may worry about drawing attention to themselves by immediately starting up enrichment or reprocessing programs. Instead, they would likely want to appear as responsible members of the NPT as much as possible. For example, the United Arab Emirates has sought in its recent peaceful nuclear cooperation agreement with the United States to adhere to the highest nonproliferation standards for its nascent nuclear power program. In particular, it has signed the Additional Protocol to its safeguards agreement in order to give the IAEA more access and to allow the IAEA to make an assessment about whether the UAE has any undeclared nuclear facilities or materials. Moreover, it has agreed to not acquire enrichment or reprocessing facilities. Furthermore, in light of concerns about use of Dubai as a trading hub for Iran's acquisition of nuclear technologies, the UAE has been working toward improving its export controls. But other states in the region may not adopt such a stance. For instance, Jordan has recently discovered significant uranium deposits and has expressed some interest in perhaps "adding value" to this uranium via enrichment.[21] Egypt has been opposed to joining the Additional Protocol because it has been reluctant to take on more nonproliferation responsibilities while Israel maintains nuclear weapons. Egypt has consistently called for a nuclear weapon free zone in the Middle East.[22] Thus, a one-size-fits-all peaceful nuclear cooperation agreement appears elusive.

Even if states renounce enrichment and reprocessing facilities, nuclear power programs may still serve as portals for weapons programs although it may take many years for weapons capabilities to emerge. For instance, a state may reason that it needs research reactors to train personnel for power programs. Many of these reactors would not be suitable for production of significant quantities of plutonium. But they could still provide valuable training especially if personnel gain access to computer codes useful for both safety analysis and weapons design. If a state decides to use these reactors for isotope production, it would likely seek to build hot cells, which would give valuable experience in chemical techniques applicable to reprocessing. These hot cells would likely be far too small to reprocess spent reactor fuel to extract significant quantities of plutonium, however. A possible route to acquiring this plutonium could involve a nuclear power program. If the spent fuel is stored in this state, it may be susceptible to being diverted to a weapons program. It is important to underscore that this spent fuel will be subject to IAEA safeguards. A state would have to withdraw from the NPT and seize the spent fuel or find a means to divert portions of the stored spent fuel. This state would also have to build a clandestine reprocessing plant if it had not withdrawn from the NPT. While estimates vary as to whether a state could do this, a few U.S. studies since the late 1970s have indicated that "a quick and simple"

[21] Author interviews with Jordanian officials, April 2009.

[22] Claudia Baumgart and Harald Müller, "A Nuclear Weapons-Free Zone in the Middle East: A Pie in the Sky?", *The Washington Quarterly*, Vol. 28, No. 1, Winter 2004-05.

reprocessing plant is within the capability of most states with some industrial capability and might be built within a year.[23]

The Limits of Safeguards

Such activities may escape detection due to limitations in safeguarding and monitoring states' nuclear activities. The purpose of safeguards is to prevent "diversion of nuclear energy from peaceful uses to nuclear weapons or other nuclear explosive devices," according to Article III.1 of the NPT. A failure to comply with safeguards is a violation of the NPT, which could jeopardize international peace and security. The International Atomic Energy Agency is charged with applying safeguards to states' nuclear power programs. There are significant differences in safeguards among the nuclear weapon states, non-nuclear weapon states, and non-NPT signatory states. In particular, the nuclear weapon states are not required to apply safeguards but could accept voluntary safeguards on part or all of their civilian programs. The non-NPT signatories can apply INFCIRC/66 safeguards on specific civilian facilities but not on their entire programs. The NPT non-nuclear weapon states are required to apply comprehensive safeguards under INFIRC/153. According to INFCIRC/153, the objective of IAEA safeguards "is the timely detection of diversion of significant quantities of nuclear material from peaceful activities to the manufacture of nuclear weapons or of other explosive devices or for purposes unknown and deterrence of such diversion by the risk of early detection." A significant quantity is the approximate amount of nuclear material needed for a nuclear explosive and takes into account unavoidable losses of material due to conversion and manufacturing processes. A significant quantity is somewhat greater than the critical mass for a nuclear weapon. For direct use material, a significant quantity is 8 kg of Pu, 8 kg of U-233, or 25 kg of U-235 in highly enriched uranium (U-235 > 20%). For indirect use material, a significant quantity is 75 kg of U-235 in low enriched uranium (U-235 < 20%), 20 tonnes of natural or depleted uranium or 20 tonnes of thorium. According to calculations by Thomas Cochran and Christopher Paine, the values for direct use material are too large.[24] Table 1 lists the revised values recommended by Cochran and Paine. It is already hard enough to have confidence in the IAEA detecting a diversion of a significant quantity of direct use material; these revised values by Cochran and Paine point to the even greater challenge in detection.

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[23] Albert Wohlstetter et al., *Swords from Ploughshares: The Military Potential of Civilian Nuclear Energy*, Chicago, University of Chicago Press, 1979; Victor Gilinsky, Marvin Miller, and Harmon Hubbard, "A Fresh Examination of the Proliferation Dangers of Light Water Reactors", *Nonproliferation Policy Education Center*, October 2004.

[24] 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 13 April 1995.

YIELD	TECHNICAL CAPABILITY (PLUTONIUM KG)			TECHNICAL CAPABILITY (HEU KG)		
KILOTONS	Low	Medium	High	Low	Medium	High
1	3	1.5	1	8	4	2.5
5	4	2.5	2.5	11	6	3.5
10	5	3	2	13	7	4
20	6	3.5	3	16	9	5

Table 1: Revised Values for Significant Quantities for Pu and HEU Nuclear Bombs

Detection time is "the maximum time that may elapse between diversion of a given amount of nuclear material and detection of that diversion by IAEA safeguards."[25] Where there is no additional protocol to safeguards in force or where the IAEA has not made a conclusion about the absence of undeclared material and activities, it is assumed that

- The state has clandestinely acquired the facilities needed to convert materials into components of a nuclear explosive;
- It has tested bomb components using surrogate materials;
- It has made, assembled, and tested nonnuclear components of a bomb.

Under these conditions detection time is approximately the conversion time, which is the time required to transform material of a given form into a weapons component. Longer detection times may be acceptable in states that have undergone complete assessment by the IAEA of the absence of undeclared material or activities.

[25] Thomas B. Cochran, "Adequacy of IAEA's Safeguards for Achieving Timely Detection", in Henry D. Sokolski, (ed.), *Falling Behind: International Scrutiny of the Peaceful Atom*, Strategic Studies Institute, U.S. Army War College, February 2008.

BEGINNING MATERIAL FORM	CONVERSION TIME
Pu, HEU, or U-233 metals	Order of days (7-10)
PuO2, Pu(NO3)4, or other pure Pu compounds; HEU or U-233 oxide or other pure U compounds; MOX or other non-irradiated pure mixtures; Pu, HEU, and/or U-233 scrap or other impure compounds*	Order of weeks (1-3)
Pu, HEU, or U-233 in irradiated fuel	Order of months (1-3)
U enriched <20% U-235 or U-233; Th + depleted uranium	Order of months (3-12)
*This range is not determined by any single factor but the pure Pu and U compounds will tend to be at the lower end and the mixtures of scrap at the higher end	

Table 2: Estimated conversion times by the IAEA[26]

A significant problem is that the IAEA's timeliness detection goals are typically longer than the conversion times. These goals are used to determine frequency of inspections to verify no abrupt diversion has taken place. The goals depend on the type of material and are one month for un-irradiated direct use material, three months for irradiated direct use material, and one year for indirect use material. Because the IAEA is resource limited, the actual inspection frequencies are lower than these goals. Thomas Cochran has further raised concern about the inadequacy of IAEA's inspections by evaluating whether the IAEA's conversion times are justified and then assessing the implications for detection goals. His analysis shows:

– For un-irradiated direct use material in metal form, conversion times (7 to 10 days) appear adequate but the timeliness detection goal (one month) is too lax.

– For un-irradiated direct use material in chemical compounds and mixtures, the low end of the conversion time (one week) is adequate but upper end (3 weeks) appears too long and the timeliness detection goal (one month) is too lax.

– For irradiated fuel, the conversion time (1-3 months) is adequate, but the timeliness detection goal is somewhat too lax, especially if a state has a pilot-scale reprocessing plant that can be used to divert SQs of fissile material.

[26] *Ibid*.

– For indirect use material, e.g. LEU, the upper end of the conversion time (3-12 months) can be too generous especially if there is a clandestine enrichment plant. Detection goal of one year is too lax.

Because of the short conversion times and laxness in detection goals, he concludes that non-nuclear weapon states should not possess un-irradiated direct use material and should not acquire enrichment or reprocessing facilities.[27] Even if the IAEA had more resources to match the frequency of inspections to the timeliness detection goals, the conversion times for direct use material are too short to allow enforcement. Based on past efforts at enforcement, even several months notice may be too short. For example, the international community has resisted levying substantial penalties on Iran's violation of safeguards for several years. It is important to differentiate between being unable to verify nuclear materials are not diverted for military uses and being unable to impose sanctions on non-compliant states. But these technical and political challenges are main aspects of the common endeavor to enforce the NPT signatories' obligations.

[27] *Ibid*.

Terrorism and Military Attacks on Nuclear Facilities and Protection of Commercial Nuclear Materials

A nuclear energy revival runs the risk of having more facilities that can be targeted by terrorists or militaries. However, there have been relatively few attacks or threats of attack against nuclear power plants or other nuclear facilities. Most of the attacks have originated from states, as discussed at the end of this section. Concerning terrorist organizations, most, if not all, terrorists refrain from attacking hardened targets. Nuclear power plants typically project vigorous security. The terrorist group's psychological and cultural constraints have profound influences on its choice of targets.[28] For example, religiously motivated terrorists do not want to disappoint their god or higher power by failing in an attack. National separatist terrorists may feel constrained in using methods that could cause massive harm through exposing their constituents to ionizing radiation. In contrast, other politically motivated terrorists such as al Qaeda may feel that such attacks are justified because they seek to cause massive social, psychological, and economic damage.

Individual members of political causes may decide to attack a nuclear power plant before it begins operations and thus before the attack has the potential to release radiation. For example, in December 1982, Rodney Wilkinson, a young white South African, who had joined the African National Congress, detonated four bombs at South Africa's Koeberg nuclear power station while the plant was under construction.[29] Radical environmentalists may despise nuclear power plants as symbols of humans' harming the environment through production of radioactive waste, for example. In January 1982, the Pacifist Ecological Committee fired five anti-tank rockets at the Superphénix breeder reactor near Lyon, France, while the reactor was still under construction.[30] In sum, the motivations of

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[28] Jerrold M. Post, "Differentiating the Threat of Radiological/Nuclear Terrorism: Motivations and Constraints", Paper for the International Atomic Energy Agency, September 2001; Jessica Stern, *The Ultimate Terrorists*, Cambridge, Harvard University Press, 2001.

[29] Joseph Lelyveld, "Bombs Damage Atom Plant Site in South Africa", *New York Times*, 20 December 1982, p. A1; David Beresford, "Man Who Spiked Apartheid's Bomb", *The Guardian*, 2 January 1996, p. 9

[30] Center for Nonproliferation Studies (CNS) Terrorism Database; for information on accessing this database, available at: http://cns.miis.edu/research/terror.htm#db

attackers or saboteurs can vary significantly. In addition to non-state actors who may have motivation to attack nuclear facilities, a state may use military forces to attack an enemy's nuclear facilities. This possibility is considered along with other modes of attack.

Modes of Attack

An attacker or saboteur can choose among a variety of attack modes: airplane crashes, truck bombs, commando attacks by land, waterborne attacks, cyber attacks, insider assistance, and military attacks. The ability of a nuclear plant to withstand any of these attacks depends on the plant's design, the robustness of security perimeters, the training of the operators and on-site guards, the responsiveness of emergency responders and external security forces, and, in the case of airplane crashes, the capabilities of airport and airline security personnel.

Airplane Crashes

The terrorist attacks on September 11, 2001, against the World Trade Center in New York and the Pentagon in Washington, DC, demonstrated weaknesses in U.S. airport and airline security and showed that terrorists can adapt and combine two well-proven techniques to cause massive damage. Four cells of attackers wielded simple box cutters as weapons to overpower the airline crews and then crash three of four large fuel-laden jets into the World Trade Center and the Pentagon. According to the 9/11 Commission report, Mohamed Atta, one of the leaders of the 9/11 terrorists, considered crashing an airplane into a U.S. nuclear power plant but thought preparing for such an attack would be difficult because of the restricted airspace around nuclear facilities.[31]

Many nuclear facilities are, however, typically not hardened to withstand a crash of a large airplane. Although the nuclear industry is quick to point out that all U.S. and other modern nuclear power plants use strong containment structures around nuclear reactors as the last line of defense to prevent a release of radiation in the event of an accident, containments were typically not designed to prevent breaching in case of a premeditated attack, such as suicidal terrorists piloting a large airliner such as a 757. Nonetheless, smashing a fast-moving large commercial airplane into a containment building is extremely challenging. Assuming that terrorists could in a post-9/11 world seize control of such a plane, they would need the ability to direct the plane onto a relatively small area to try to breach a containment structure. Independent experts have cautioned that airplane crashes might not damage containment structures but could harm auxiliary

[31] *The 9/11 Commission Report: Final Report of the National Commission on Terrorist Attacks Upon the United States*, New York: W. W. Norton, authorized edition, 2004, p. 245.

buildings, thereby causing considerable financial damage even if no radioactive material is released into the environment.[32]

Could air defenses stop an airplane attack on a nuclear facility? Should such defenses be employed? Who would decide to fire the defensive missiles? While at first glance air defenses appear necessary for defense of a nuclear facility, as the preceding questions indicate, these defenses are fraught with difficult decisions. Very little time would be available to make the decision to fire defensive missiles. If a pilot had strayed innocently off course, a misuse of missile interceptors could doom hundreds of people to death. While French authorities did place missile air defenses outside of some of their nuclear facilities for a period of time after 9/11, U.S. authorities decided against such action. Instead, the U.S. response relied on strengthening security at airports through better screening of passengers, on hardening cockpit doors, and on stationing federal police officers onboard random flights as a deterrent. In early 2009, the U.S. Nuclear Regulatory Commission passed a ruling that requires any new nuclear power plants in the United States to be designed to withstand a large commercial aircraft impact.

Truck Bombs

Truck bombs have caused devastating effects on non-nuclear targets. The 1983 truck bomb attacks in Lebanon spurred the U.S. Nuclear Regulatory Commission to investigate the potential effects of such bombs against nuclear power plants. But despite research indicating significant damage at some plants, the NRC decided against a regulation change. Not until the 1993 truck bomb detonation at the World Trade Center did the NRC include this mode of attack in its design basis threat. Ramzi Yousef, who had ties to al Qaeda, masterminded this attack. Nevertheless, U.S. nuclear power plants did not fully install vehicular barriers until 1996: a year after domestic American terrorists exploded a powerful truck bomb in April 1995 at a federal building in Oklahoma City.[33]

Commando Attacks by Land

A commando type attack has been included in the U.S. NRC's design basis threat (DBT) for many years. However, some non-NRC people who have knowledge of the DBT have expressed concern that the revised post-9/11 DBT does not adequately account for the potential for a relatively large sophisticated group of attackers. While the details of the DBTs remain classified, it is believed that the latest DBT does not factor in an attacking force as large as the 19 well-trained men involved in the 9/11 attack.[34]

[32] Daniel Hirsch, "The NRC: 'What Me Worry?'", *Bulletin of the Atomic Scientists*, January/February 2002; John H. Large, "The Implications of 11 September for the Nuclear Industry", *Disarmament Forum*, May 2003.

[33] Letter from Shirley Ann Jackson, Chairman, U.S. Nuclear Regulatory Commission, to Paul Leventhal, President, Nuclear Control Institute, 20 December 1995, available at: http://www.nci.org/l/l122095a.htm.

[34] U.S. Government Accountability Office, *Nuclear Power Plants: Efforts Made to Upgrade Security, but the Nuclear Regulatory Commission's Design Basis Threat Process Should be Improved,* Washington, Report GAO-06-388, March 2006.

Similar to the 9/11 attackers, these attackers could form independent teams to launch near simultaneous attacks on the nuclear facility. Increased numbers of security guards may provide better security. But raising the number of guards increases security costs. More importantly, more guards may not mean better security. In a paper that challenges conventional wisdom, Scott Sagan expressed concern that more guards could lead to social shirking in which a guard may not work as hard if he knows that more guards will cover for him.[35] However, more guards may also demonstrate stronger security to potential attackers, thereby dissuading them from attacking. Also, Sagan said that the appearance of greater security may lead the plant operators to take greater risks. In sum, he cautions about an enhanced security measure that would just involve hiring more guards. Layered access points and two-man rules are important means to protect against unauthorized access. Also, making sure that the nuclear plant has redundant safety systems can help mitigate the effects of an attack.[36]

Waterborne Attacks

Nuclear power plants need external cooling water to ensure safe operation. Blocking cooling water to the plant could lead to reactor damage but would likely not do so because of backup safety systems. But forcing the plant to shut down for an appreciable period of time could have serious economic and power production consequences. Plants vary in the sources of external cooling water, which could come from oceans, rivers, or natural or manmade lakes. Some of these water systems would be easier to access than others. For instance, a waterborne commando crew could try to sneak toward the cooling water intake by a surreptitious sea route. Although this mode of attack was reportedly not included in the NRC's pre-9/11 DBT, it has reportedly been added to the post-9/11 DBT.[37]

Cyber Attacks

As nuclear power plants move toward more digital control systems, they may become more vulnerable to cyber attacks. Older plants usually have employed analog control systems, which are less vulnerable to external hacking although they could be susceptible to insider sabotage. In 1992, a technician at the Ignalina Nuclear Power Plant in Lithuania launched a computer virus into auxiliary control systems. He allegedly did this to draw attention to security weaknesses and expected to be rewarded for his efforts. Instead, he was arrested.[38] In January 2003, the slammer computer virus penetrated the network at the Davis Besse Nuclear Power Plant in Ohio. Fortunately, the plant was shut down at that time. The plant was susceptible to intrusion because technicians had not installed a Microsoft

[35] Scott Sagan, "The Problem of Redundancy Problem: Why More Nuclear Security Forces May Produce Less Nuclear Security", *Risk Analysis*, Vol. 24, No. 4, August 2004, pp. 935-946.
[36] Charles D. Ferguson and William C. Potter with Amy Sands, Leonard S. Spector, and Fred L. Wehling, *The Four Faces of Nuclear Terrorism*, New York, Routledge, 2005.
[37] U.S. Government Accountability Office, *Nuclear Power Plants*, *op. cit.*
[38] William Potter, "Less Well-Known Cases of Nuclear Terrorism and Nuclear Diversion in the Former Soviet Union", Report for Center for Nonproliferation Studies, August 1997.

security patch.[39] In 2002, the NRC began a research program to identify ways to protect nuclear plants against cyber attacks.

Separating power plants from the Internet can provide protection against cyber attacks. But the trend in many countries has been to introduce more and more Supervisory Control and Data Acquisition Systems (SCADA) to control pumps, generators, transformers, valves, and other components of electrical power systems. While connecting SCADA software to the Internet is not required, increasingly utilities, especially in the United States, are making use of the ubiquitous Internet to send SCADA instructions to the power plants and the electrical grid. As governments push toward development and deployment of "smart" grid technologies, power plants and the grid itself would likely become more vulnerable to Internet cyber attacks unless serious efforts are made to erect cyber firewalls and encrypt SCADA instructions.[40]

Insiders

Personnel working at a plant have special knowledge about the facility's operations. If attackers could recruit insiders, they might gain the edge they need to launch a damaging attack. Insiders can help accelerate the attack and would likely not raise undue suspicion until possibly it is too late to prevent major damage. Means to recruit insiders include finding those sympathetic to the attackers' cause, blackmailing, and paying enough money to convince the insider to help with the attack. Insiders can identify vulnerable equipment or can take a more active role by actually disabling safety equipment. Disgruntled employees or those motivated by a political cause could also become lone actors. For example, Rodney Wilkinson who had attacked the Koeberg plant in South Africa had access to the plant because of his job and thus could place limpet mines while minimizing his chance of being stopped. To reduce the risk of insiders assisting attackers, background security checks can try to spot those people who may be susceptible to recruitment. Prior to 9/11, the NRC required background checks of those personnel who would have access to sensitive parts of a nuclear plant. But due to concerns that these checks may not have been sufficient, the U.S. Congress required more rigorous background checks when it enacted the Energy Policy Act of 2005.[41]

Military Attacks

Nuclear facilities have been targets of military attacks. Military motivations to target such facilities can be fourfold: damage the electrical power system of an enemy, destroy a major status symbol, degrade the capability for an opponent to make fissile material for nuclear weapons, or cause radioactive

[39] Daniel Horner, "Cyber-Security Lapse at Davis-Besse Prompts Markey Letter to NRC", *Nucleonics Week*, 28 August 2003.

[40] Richard A. Clarke and Robert K. Knake, *Cyber War: The Next Threat to National Security and What to Do About It*, New York, HarperCollins, 2010.

[41] Mark Holt and Anthony Andrews, "Nuclear Power Plants: Vulnerability to Terrorist Attack", CRS Report for Congress, *Congressional Research Service*, 4 October 2006.

contamination of an enemy's territory.[42] There have been few incidents of such attacks. The first attack on a reactor occurred on September 30, 1980, when Iran's air force bombed a French-supplied, 40-Megawatt thermal nuclear research reactor under construction in Iraq. While this attack did not destroy the facility, on June 7, 1981, the Israeli air strike against the Osirak reactor did destroy it. Prior to this attack, Israel had employed diplomacy, coercion, and sabotage to try to stop Iraq from obtaining the capability to make plutonium for nuclear weapons. During the Iran-Iraq War in the 1980s, Iraq bombed the commercial nuclear power plant under construction at Bushehr, Iran. More recently, in September 2007, Israel bombed a suspected nuclear reactor site in Syria. The U.S. government reported that Syria was building a research reactor of the same or similar design to the North Korean reactor at Yongbyon, which has produced weapons-grade plutonium. North Korean technicians were also reportedly seen at the Syrian site. Concerns about possible military attacks on civilian nuclear facilities prompted India and Pakistan to agree in 1988 to exchange annually lists of facilities that put them off limits to the military. While this confidence building measure can help establish a norm against military attacks, states may decide to protect their nuclear facilities with air defenses and hardened burial, as Iran has done with its uranium enrichment plant at Natanz and the newer facility at Qum.

The choice of weapons used during military attacks on nuclear facilities can have dramatically different effects. Also, the types of target will require certain types of weapons to achieve the desired effect. If the attackers seek, for example, to destroy buried and hardened facilities, "bunker buster" bombs will be the weapon of choice. Concerns have been raised about possible U.S. nuclear bunker busters being used to destroy Iranian nuclear facilities, especially the buried and hardened enrichment plant at Natanz; the radioactive and political fallout from employing such weapons would erect high barriers for any U.S. president to order their use.[43] Instead, the preferred weapon would be "smart" conventional bunker busting bombs such as BLU-110, -117, and -192 bombs, which a March 2010 press story reports that the United States has shipped to a U.S. base in Diego Garcia, which is within striking range of Iran.[44] A military attack that dispersed uranium, but no other radioactive materials, would not result in significant contamination of radioactive materials because uranium is weakly radioactive. Such an attack could be on an enrichment plant. But an attack that caused a meltdown of an operating commercial reactor might lead to massive radioactive contamination if the containment building were penetrated and other safety systems were not able to contain the highly radioactive fission products. An incendiary weapon might ignite spent nuclear fuel stored in pools if the pools were breached and drained. A spent fuel fire might result in significant contamination.[45] An attacker that just

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[42] Bennett Ramberg, *Nuclear Power Plants as Weapons for the Enemy: An Unrecognized Military Peril*, Berkeley, University of California Press, 1984

[43] Seymour Hersh, "The Iran Plans", *The New Yorker*, 17 April 2006.

[44] "U.S. Ships 'Bunker Busters' for Possible Iran Strike", CBNNews.com, 18 March 2010.

[45] Board on Radioactive Waste Management, U.S. National Research Council, *Safety and Security of Commercial Spent Nuclear Fuel: Public Report*, Washington, National Academies Press, April 2005.

wanted to disable the nuclear plant could select weapons that minimize the potential for causing radioactive contamination.

Protection of Commercial Nuclear Materials

In addition to ensuring that facilities are well protected, nuclear materials in use at facilities and in domestic and international transit require strong security measures. Many metric tons of plutonium and highly enriched uranium are used and transported annually in several countries.[46] In particular, those countries such as Britain, China, France, India, Japan, and Russia with commercial reprocessing plants or plans to acquire these facilities need to make sure those shipments to and from the reprocessing plants are well guarded. As a testimony to the tight security, to date no plutonium has been seized from these shipments, but of course, security must continue to evolve to address the dynamic threat environment. In addition, a few countries still use highly enriched uranium as fuel and target material to produce radioisotopes for medical and other commercial and scientific research applications. Canada, the Netherlands, Russia, and South Africa, in particular, still use significant amounts of HEU in their isotope production reactors.[47] The United States has been leading international efforts to phase out HEU in civilian applications but technical and commercial hurdles remain. Namely, some types of reactors are waiting on development of alternative non-weapons usable fuels. Commercially, there has been resistance to giving up HEU in this sector because companies do not want to potentially place themselves at an economic disadvantage. A U.S. National Academy of Sciences report concluded that there are no major technical hurdles to reactor conversion and that this conversion can be done at reasonable cost.[48] Regarding continued use and domestic and international transit of civilian nuclear materials, the amended Convention of Physical Protection of Nuclear Materials requires parties to implement rigorous security, but some analysts are concerned that the security requirements are not adequate and that it could take many years before this amendment has entered into force because of the number of signatories needed.[49] A new initiative called the World Institute for Nuclear Security is seeking to develop and implement best security practices among companies in this sector.[50]

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[46] International Panel on Fissile Materials, *Global Fissile Material Report 2009*, Princeton University, Program on Science and Global Security, October 2009.

[47] At the April Nuclear Security Summit, Canada "agreed to transfer inventories of HEU to the United States from the Chalk River Laboratories in Ontario." Sarah J. Diehl and Paula Humphrey, "The April 2010 Nuclear Security Summit: One More Step Toward the Mountaintop", NTI Issue Brief, 20 April 2010.

[48] National Research Council, *Medical Isotope Production Without Highly Enriched Uranium*, Washington, National Academies Press, 2009.

[49] Matthew Bunn, *Securing the Bomb 2008*, Washington, Nuclear Threat Initiative, November 2008, p. 60.

[50] See http://www.wins.org/ for WINS' activities and statement of principles.

Security Alliances, Arms Sales, and Peaceful Nuclear Energy Cooperation

The Nexus Between Security Cooperation and Nuclear Energy

Security alliances and nuclear energy cooperation often go hand-in-hand, but not always. Nonetheless, even when a security alliance is not the objective, a state may pursue nuclear energy deals along with non-nuclear commerce. Russia, for example, does not seek a security alliance with Iran through its nuclear energy cooperation in building the Bushehr Nuclear Power Plant. But Russia companies and government-affiliated firms have pushed for more business dealings with Iran, including military sales. Although Moscow has generally been supportive of stopping Iran from developing nuclear weapons, in early May 2010, Russia negotiated an exemption to the most recent round of a UN Security Council resolution that would impose sanctions on Iran. The draft resolution includes "a loophole that would exempt a 2005 Russian deal, valued at hundreds of millions of dollars, to sell Tehran five S-300 surface-to-air missile systems capable of intercepting ballistic missiles and aircraft" although Russia has yet to transfer these systems.[51] This example illustrates that nuclear energy commerce may not be just about selling peaceful nuclear technologies and may be associated with a supplier state's interest in also selling military hardware.

The correlation among nuclear power producing states and states in security alliances with the United States is remarkable. Table 3 lists the states and other entities that have peaceful nuclear cooperation agreements, noting the military ties with the United States as well as special rights an entity may have in its nuclear cooperation agreement. For instance, Japan and Euratom have the special right of reprocessing under their agreements. Of the 30 non-U.S. states using commercial nuclear power, 22 of them are U.S. allies. This strong correlation has arisen because of the large deployment of nuclear power plants in Europe, a relatively rich region that could afford construction of these plants.

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[51] Colum Lynch and Glenn Kessler, "Gains for Moscow in Iran Deal", The Washington Post, 23 May 2010. Having come under diplomatic pressure over the potential for the missiles' sale to go forward, Russia's Prime Minister Vladimir Putin assured French President Nicolas Sarkozy on 11 June that Russia had decided to "freeze the delivery of the S-300 missiles." Lynn Berry, "Russia now says Iran sanctions ban S-300 missiles", *Associated Press*, 11 June 2010.

Moreover, the United States provides extended nuclear deterrence guarantees to about 30 states, including NATO members, Australia, Japan, and South Korea. Of the 28 NATO members, exactly half have commercial nuclear plants.

State or entity	Allied status with U.S.	Significant aspect of nuclear agreement or expertise
Argentina	Major ally	Has enrichment expertise
Australia	Major ally	No commercial nuclear power but major uranium supplier
Bangladesh		No commercial nuclear power
Brazil		Has enrichment plant
Canada	NATO member	Expressed interest in possible enrichment plant
China	Strategic competitor	Legally recognized nuclear weapon state with enrichment and reprocessing expertise
Colombia	Close military ties	No commercial nuclear power
Egypt	Major recipient of U.S. military aid	No commercial nuclear power
Euratom	Contains many NATO members	Reprocessing rights
India	Major recent recipient of U.S. military aid	Recently secured reprocessing rights
Indonesia	Developing closer military ties post East Timor crackdown in early 1990s	Expressed interest in nuclear power
IAEA	Neutral/International organization	
Japan	Major non-NATO ally	Reprocessing rights
Kazakhstan	Partnership for Peace state	Major uranium supplier
Republic of Korea	Major non-NATO ally	Wants to secure reprocessing rights in renewed agreement
Morocco	Non-NATO ally	Expressed interest in nuclear power
Norway	NATO member	Has vast thorium deposits
South Africa		Has enrichment experience
Switzerland	Partnership for Peace state	Uses MOX fuel

TAIWAN	Major ally	Had explored nuclear weapons development
THAILAND	Close military ties	Expressed interest in nuclear power
TURKEY	NATO member	Expressed interest in nuclear power
UKRAINE	Partnership for Peace state (would like to join NATO)	
UAE	Major recipient of U.S. military aid	Agreed to strong nonproliferation stance

Table 3: States or Entities with Peaceful Nuclear Energy Cooperation Agreements with the United States, Noting Allied or Military Ties

While these correlations among existing nuclear power producers and U.S. alliances may be largely historical artifacts, a more interesting development is the emerging nuclear cooperation agreements with Arab states. None of these states presently have nuclear power plants. The United Arab Emirates appears the nearest to making this acquisition. It has close military ties with the United States. Moreover, it has been forging a close military and commercial relationship with France. President Nicolas Sarkozy signed a nuclear cooperation deal with the UAE almost at the same time as he obtained agreement to build a French military base there. Consequently, France and the United States will be the only two Western states with military bases in the Persian Gulf region. Until late 2009, French-based nuclear industrial giant Areva appeared to be in the lead for constructing the UAE's first nuclear power plants but lost to a consortium led by Korea Electric Power Corp. Areva CEO Anne Lauvergeon said that enhanced safety systems in the French reactor design was a major contributing factor to increasing the cost of Areva's bid.[52]

Nonetheless, both France and the United States have gained tremendous political will with the UAE in their shepherding of nuclear power to this Arab state. The French and American strategic plan is to boost the military strength in the UAE so that it can help serve as a check on Iranian power. Similarly, both France and the United States have sought to show that they support peaceful nuclear development in other Arab states while encouraging these states to stand up to Iran and supplying more conventional military capabilities to these states. For example, the United States has provided substantial military aid to Egypt, Jordan, Qatar, and

[52] Ann Maclachlan, "Lauvergeon: French Lost UAE Bid Because of Expensive EPR Safety Features", *Nucleonics Week*, 14 January 2010.

Saudi Arabia, which have all expressed strong interest in nuclear power.[53] Moreover, President Sarkozy recently visited Saudi King Abdullah to discuss nuclear energy. Since 2007, when he entered the presidency, President Sarkozy and Ms. Lauvergeon have travelled the Arab world promoting peaceful nuclear energy. Positively for nonproliferation, Ms. Lauvergeon has pledged that her company does not plan to transfer sensitive (proliferation-prone) technology to non-nuclear weapon states other than the assistance that Areva had already provided to Japan. Areva has also formed a "Value Charter" that places nonproliferation as a top priority in its business.[54]

The U.S. government has also leveraged nuclear diplomacy through the previous Bush administration's Global Nuclear Energy Partnership (GNEP). While GNEP fell somewhat flat because it was initially perceived as restricting states' "rights" to enrichment and reprocessing, it has been undergoing a transformation in the Obama administration to the International Nuclear Energy Framework, which has been seeking a broader agenda for many countries to discuss what is needed to embark on nuclear power programs. It is highly uncertain that all developing states will resist acquiring enrichment and reprocessing facilities. In July 2009 at the IAEA Board of Governors meeting to discuss fuel assurance proposals, for instance, many of these states reacted strongly against perceived restraints that they thought the major powers were trying to impose through these proposals.[55]

Future Perspectives

While the past is far from a perfect guide as to future behavior, it might be prologue and offer lessons. Table 4 shows the seven developing states that presently have nuclear power programs.[56] Only one (Mexico) of the seven has not developed enrichment and reprocessing facilities and has not had a nuclear weapons program. Mexico does not face external security threats in that it has generally friendly relations with the United States and Central American states. Moreover, Mexico does not have strong desire for great power status. South Africa developed nuclear weapons and an enrichment plant during the apartheid regime, which fed Pretoria's perception of external threats. Another relevant point among the other states is the pairings of regional rivalries: China vs. India, India vs. Pakistan, and Argentina vs. Brazil. While Argentina and Brazil have renounced their weapons programs, they remain latent nuclear weapons states because of their expertise in enrichment. Brazil, in particular, has continued to support its now commercial enrichment program, which stemmed from its navy's

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[53] Richard F. Grimmett, "Conventional Arms Transfers to Developing Nations, 2001-2008", CRS Report for Congress, *Congressional Research Service*, 4 September 2009.

[54] Anne Lauvergeon, "The Nuclear Renaissance: An Opportunity to Enhance the Culture of Nonproliferation", *Daedalus*, Vol. 138, No. 4, Fall 2009.

[55] Ann Maclachlan and Randy Woods, "IAEA Fails to Endorse Fuel Bank Proposals, Contnues Fine-Tuning", *Nuclear Fuel*, July 27, 2009.

[56] The information in this table is adapted from José Goldemberg, "Nuclear Energy in Developing Countries", *Daedalus*, Vol. 138, No. 4, Fall 2009.

program, because of its strong national interest in energy independence. For example, Brazil has invested heavily in indigenous ethanol production and offshore oil production to ensure this independence.[57] While many nonproliferation analysts often argue that the cost of building enrichment facilities does not make economic sense unless a state has eight to ten large commercial reactors, national prestige and a policy of energy independence may bypass this economic argument.[58]

Developing State	Nuclear Weapons Status	Enrichment	Reprocessing
China	Officially recognized NPT nuclear weapon state	Yes	Yes
India	Nuclear-armed and never joined NPT	Yes	Yes
South Africa	Non-nuclear and dismantled weapons	Had developed	No
Brazil	Non-nuclear, but had program	Yes	No
Argentina	Non-nuclear, but had program	Had developed	No
Mexico	Non-nuclear	No	No
Pakistan	Nuclear-armed and never joined NPT	Yes	Yes

Table 4: Developing States with Nuclear Power Programs and Nuclear Weapons Capabilities

Developing states may also cite the recent U.S.-India nuclear deal as providing a rationale to hold out for an agreement preserving their rights to pursue enrichment or reprocessing. India has linked commercial nuclear reactor purchases with GE-Hitachi and Toshiba-Westinghouse (American-Japanese nuclear power companies) to the U.S. government giving India consent to reprocess spent fuel of U.S. origin.[59] In late March 2010, India received permission from the United States to reprocess U.S.-origin spent fuel.[60] French and Russian nuclear companies have an edge in the Indian market because their governments are not as concerned with the particular type of liability agreement signed by New Delhi. The U.S. government, on the other hand, is insisting on India joining the Convention on

[57] "Critical Issues in Brazil's Energy Sector" Report Issued by The James A. Baker III Institute for Public Policy, Rice University, March 2004; "Brazil: Country Analysis Brief", *U.S. Energy Information Administration*, September 2009.
[58] Charles D. Ferguson, "Nuclear Energy: Balancing Benefits and Risks", Council on Foreign Relations, *Council Special Report*, April 2007; Sharon Squassoni, *Nuclear Energy: Rebirth or Resuscitation?*, Washington, Carnegie Endowment for International Peace, 2009.
[59] Randy Woods, "Progress in Reprocessing Talks Deemed Key to US-India Trade Agreement", *Nuclear Fuel*, 16 November 2009.
[60] Rama Lakshmi and Steven Mufson, "U.S., India Reach Agreement on Nuclear Fuel Reprocessing", *The Washington Post*, 30 March 2010.

Supplementary Compensation to provide adequate liability coverage for U.S. vendors. In May 2010, the Indian Parliament took steps to pass the requisite nuclear liability legislation.[61] Russia is already building power reactors at Kudankulam, India, under a grandfather clause to the NSG guidelines. New foreign-supplied reactors will be under safeguards. But there are no serious constraints on India's weapons program.[62] Critics of the deal have made the following arguments. First, providing foreign-supplied uranium would free up scarce indigenous uranium for potential use in making more plutonium. Second, leaving the breeder reactors outside of safeguards would allow India to make large amounts of weapons-grade plutonium. Third, giving nuclear power a higher priority would bias India away from more effective energy technologies. Fourth, not clearly specifying in the deal that tough sanctions would follow future Indian nuclear explosive tests would weaken international efforts to ban testing.[63] While these consequences may or may not occur, in the wake of the deal, China has revived nuclear energy cooperation with Pakistan. In May 2010, it was revealed that Beijing has agreed to build two more commercial reactors in Pakistan, the state that served as the hub of the A.Q. Khan nuclear black market.[64] Proponents have argued that India needed greater use of peaceful nuclear power and thus should be given access to the international nuclear market. Moreover, India has shown restraint in its plutonium production prior to the deal and would likely to continue to do so after the agreement is reached.[65]

Concerning non-nuclear strategic consequences, the U.S.-India nuclear deal may not net U.S. nuclear companies much business, but it has opened the door wide for major arms purchases. One of the not-so-hidden aspects of the Bush administration's eagerness for the nuclear deal was to strengthen India's military and political capabilities to balance a rising China.[66] China and India had fought a border war in 1962. India lost that

[61] Rama Lakshmi, "India Introduces Controversial Legislation on Compensation for Nuclear Accidents", *The Washington Post*, 8 May 2010.
[62] Sharon Squassoni, "U.S. Nuclear Cooperation with India: Issues for Congress", *CRS Report for Congress*, 29 July 2005.
[63] Jayshree Bajoria and Esther Pan, "The U.S.-India Nuclear Deal", Council on Foreign Relations, *Backgrounder*, Updated November 20, 2009.
[64] Agence France Presse, "China to Build Two Nuclear Reactors in Pakistan," April 29, 2010.
[65] Ashley Tellis, "Atoms for War? U.S.-Indian Civilian Nuclear Cooperation and India's Nuclear Arsenal", Report for Carnegie Endowment for International Peace, June 2006.
[66] Rahul Bedi and Richard Spencer, "US-India Defence Deal 'to counter' China", *Telegraph*, 26 February 2008. In an online debate between Teresita Schaffer and Henry Sokolski, Ambassador Schaffer argued that "the rise of China and India is transforming Asia. Even with a policy of friendly engagement with China, the United States needs to build strong relations with other Asian powers, especially India. "The U.S.-India Nuclear Deal: The Right Approach?", Online debate, Council on Foreign Relations (www.cfr.org), 22-26 May 2006. Also, Ashley Tellis, one of the leading architects of the deal, assessed that the deal "preserves New Delhi's right to produce those nuclear weapons judged to be essential for Indian security in the face of threats emanating from a rising China and a revanchist Pakistan." Prepared Testimony by Ashley Tellis, House Committee on International Relations, "The U.S.-India 'Global Partnership': Legislative Options", 11 May 2006. He gave a

war, and still faces border disputes with China. New Delhi has launched an ambitious expansion of its military with major investments in its navy and air force. Boeing and other U.S. defense companies have been garnering major deals to supply advanced aircraft and other arms to India.[67] As India builds up both its conventional and nuclear forces, Pakistan will confront an even more acute lack of strategic depth. In response, Pakistan has sought to buy advanced conventional arms and has been constructing another plutonium production reactor.[68] Pakistan's military is caught between a tug-of-war in guarding against India's growing strength and fighting terrorists and other extremists who are trying to undermine Islamabad. While the architects of the U.S.-India nuclear deal may not have intended to stoke this regional conventional and nuclear arms race, the deal has not done anything to stop it.

In the coming decades, China may emerge as a major nuclear power supplier. It has already proven adept at building so-called replication reactors – the CPR-1000 series – based on a French technology transfer agreement. To feed its growing need for uranium, Beijing has forged deals with Kazakhstan and several African states. Beijing has been selling conventional weapons to many African states.[69] Also, China has other significant commercial ties with these states. Such ties may form the basis of future nuclear deals. Chinese nuclear vendors may argue that they can build reactors faster and cheaper than Western, Japanese, and Korean vendors. Notably, Beijing would have to receive permission from Paris in order to export the French-derived Chinese reactors. As long as China, which is a newer member of the NSG, supports the highest standards of safety, security, and safeguards for these deals, such developments may be welcome news for electricity production for these states. But in the larger strategic context, China may leverage these ties similar to the way the United States and other major nuclear suppliers have leveraged their deals to sell conventional arms and bind states into security alliances. If this comes to pass, Africa and other developing regions could move down a path of more conventional arms races and potential latent nuclear proliferation.

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more toned down view a few weeks earlier by stating that "containing China is neither feasible nor necessary for the United States at this point in time. Further, it is not at all obvious that India, currently, has any interest in becoming part of any coalition aimed at containing China." Prepared testimony of Ashley Tellis, Senate Foreign Relations Committee, "U.S.-India Atomic Energy Cooperation: Strategic and Nonproliferation Implications", 26 April 2006. One year earlier, however, he advocated an alliance between the United States and India to "buttress [India's] potential utility as a hedge against a rising China." Ashley Tellis, *India as a New Global Power: An Action Agenda for the United States*, Carnegie Endowment for International Peace, 2005, p. 27.

[67] Emily Wax, "U.S. Eyes Bigger Slice of Indian Defense Pie", *Washington Post*, 26 September 2009.

[68] Joby Warrick, "Pakistan Expanding Nuclear Program", *Washington Post*, 24 July 2006; Saibal Dasgupta, "Arms Sales to Pak Justified as India Buys from US: Chinese Official", *The Times of India*, 22 December 2009.

[69] "Chinese Weapon Sales to Africa Raise Fresh Concerns", *VOANews.com*, 3 May 2007.

Risk Reduction Measures

Preventing Proliferation

The probability of further proliferation cannot be reduced to zero. There is no proliferation-proof nuclear technology. While proliferation-resistance can be further improved, stopping proliferation is primarily a political issue.[70] In this regard, governments as well as energy industries have significant power if they want to wield it for promoting nonproliferation.

- Properly interpret the NPT's "right" to peaceful nuclear technologies to make sure that it is contingent on the responsibility to refrain from obtaining nuclear explosive devices and to maintain rigorous safeguards on civilian nuclear programs.[71]

- Make implementation of the Additional Protocol or an equivalent rigorous inspections system a requirement for each state's safeguards agreement. This should also be a condition of sale under the Nuclear Suppliers Group's guidelines.

- Be honest about what activities can and cannot be safeguarded. Develop and implement near-real-time monitoring of weapons-usable activities and materials.[72]

- Ensure that the IAEA fully uses its available authorities, especially the authority under its statute to request special inspections of suspect activities such as those that have recently taken place in Iran and Syria.

- Urge the UN Security Council to require any country found in noncompliance with its safeguards agreement by the IAEA's Board of Governors to suspend the suspect activity until the compliance

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[70] James M. Acton, "The Myth of Proliferation-Resistant Technology", *Bulletin of the Atomic Scientists*, November/December 2009.
[71] Robert Zarate, "The NPT, IAEA Safeguards and Peaceful Nuclear Energy: An 'Inalienable Right', But Precisely to What?", Nonproliferation Policy Education Center, Revised September 2007.
[72] Henry D. Sokolski, "Assessing the IAEA's Ability to Verify the NPT", in *Falling Behind: International Scrutiny of the Peaceful Atom*, *op. cit.*

problem is resolved although enforcing this resolution would be difficult.[73]

- Encourage development of multinational fuel cycle facilities under rigorous multilateral control. These facilities should restrict access to designs of enrichment and other proliferation-sensitive equipment as well as implement personnel reliability programs to reduce the insider threat.

Increasing Security of Nuclear Facilities and Commercial Nuclear Materials

In a world of more nuclear power plants and related facilities, more and more governments have a vested interest in implementing the highest security standards of these facilities. Risk reduction measures in this area include:

- Integrate improved security features, including enhanced protection against large aircraft crashes, into new nuclear plant designs and to fully implement these design features. To facilitate this enhancement, security assessment teams should work side-by-side with engineering teams who are designing the plant. Plants should have greater protection against all modes of attack.

- Encourage safety and security teams to work closely together to develop and implement protections against the design basis threat. They also need to consult regularly with intelligence agencies to obtain the latest information about possible attackers in order to continually update the design basis threat. It is vitally important to instill a security culture among all workers at nuclear facilities.

- Conduct effective background checks of plant personnel to reduce the likelihood of an insider threat.

- Protect against cyber attacks, especially as the newer plants use more digital control systems.

- Develop and implement rigorous international security standards – but national authorities are still responsible for security at their facilities.

- Ratify the amended Convention on Physical Protection of Nuclear Material

[73] For recommendations in this issue area, see Pierre Goldschmidt, “The Urgent Need to Strengthen the Nuclear Non-Proliferation Regime”, Policy Outlook, Carnegie Endowment for International Peace, January 2006.

– Urge states to cooperate in information sharing of potential threats. An attack on a nuclear plant anywhere could affect the continued operation of nuclear plants everywhere.

Addressing States' Security Concerns

A world with more countries seeking nuclear power plants will likely experience changes in security alliances. Major supplier states almost assuredly try to leverage their nuclear sales to promote additional commercial and military sales. Governments of these suppliers need to assess the conventional military impact on the region where such sales may take place. Client states need to consider the consequences of buying nuclear technologies. For instance, they and their neighbors may feel compelled to purchase more conventional arms to protect nuclear facilities, in particular, and to provide their people's greater assurances of security, in general. The result could very well be more resources diverted from the civilian economy. Other risk reduction measures in this area include:

– Encourage nuclear weapon states to adhere to their responsibility to pursue nuclear disarmament. All states should work seriously toward general and complete disarmament. Practically, serious steps toward nuclear disarmament are contingent on addressing the security concerns of states that perceive the need for preserving nuclear deterrence. This includes the United States that has responsibilities to extend nuclear deterrence to allies, especially those in East Asia. Have nuclear weapon states commit to not threatening non-nuclear weapon states with use of nuclear weapons as long as the non-nuclear weapon state is not aligned with a nuclear weapon state. This is the so-called "negative security assurance." The Obama administration's Nuclear Posture Review has modified the previous assurance by "declaring that the United States will not use or threaten to use nuclear weapons against non-nuclear weapons states that are party to the NPT and in compliance with their nuclear non-proliferation obligations."[74]

– Urge nuclear weapon states to further strengthen positive security assurances to allied states, promising to come to their defense in the event of a nuclear threat. These defense measures do not necessarily mean that nuclear weapons need to be the preferred response.

[74] U.S. Department of Defense, *Nuclear Posture Review Report*, April 2010, p. viii.

Conclusion: Responsibilities of Government and Industry

Continued and possible greatly expanded use of nuclear energy globally does not have to result in a more dangerous world. The proposed risk recommendation measures above, if implemented, would help put the world in the path toward better security. But they are not sufficient. Both government and industry must make a serious commitment to responsible use of nuclear energy. The responsibilities are integrated.

One responsibility is to uphold the highest standards of safety in nuclear plant operations. The nuclear industry has recognized since the 1979 Three Mile Island and 1986 Chernobyl nuclear accidents that we are all "hostages of each other."[75] That is, a major nuclear accident anywhere would likely halt significant expansion of nuclear energy across the globe. While this responsibility is generally well accepted, an emerging responsibility is to ensure that commercial nuclear facilities have adequate protection against attack or sabotage and commercial nuclear materials have adequate security against diversion or seizure. In effect, countries are hostages of each other in nuclear security. A damaging terrorist attack, for example, on a nuclear plant would likely affect the prospects for more growth of nuclear energy. Industry obviously has a major role in ensuring safety and security of facilities and materials. But in nonproliferation, industry has traditionally looked to government to ensure adequate safeguards. Yet, as described in this paper, the technical measures that have been implemented by the IAEA to safeguard facilities and materials have fallen short. Governments have also failed to give the IAEA enough resources and authorities and have failed to enforce compliance. If governments want to continue to benefit from peaceful nuclear energy, they must bear the responsibility to prevent further proliferation.

Industry, however, can and should implement self-governance efforts and provide governments with information on imports and exports of nuclear technologies, for example, to limit the further spread of weapons-usable technologies to countries that do not already have such capabilities.[76] Industry can and should also implement additional means of

[75] Joseph V. Rees, *Hostages of Each Other: The Transformation of Nuclear Safety Since Three Mile Island*, Chicago and London, University of Chicago Press, 1994.

[76] For an in-depth examination of the implementation of industry self-governance and greater partnership with governments, see G. Hund and A. Seward, *Broadening Industry Governance to Include Nonproliferation*, Report for Pacific Northwest National Laboratory, November 2008.

security on these potentially weapons-usable activities no matter where they take place. This will require industry coordination and a code of conduct that upholds these principles. Continued viability of nuclear energy for peaceful purposes depends on government and industry acting on these responsibilities.

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