BROOKINGS

SECURITY IMPLICATIONS OF THE EXPANSION OF NUCLEAR ENERGY

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The energy world is abuzz with talk of a nuclear renaissance. With an increasingly resource-hungry planet desperate for a source of reliable, emissions-free power and the disaster at Chernobyl and the accident at Three Mile Island receding into distant memory, the idea of an expansion in atomic energy is enjoying a comeback in policymaking and industry circles. Following a decades-long lull in the rate of construction of nuclear power stations, a new generation of politicians faced with rising concerns over energy security and carbon emissions is taking a fresh look at a revamped nuclear industry, itself replete with a new generation of reactors and a new-found sense of confidence. While the rhetoric of a new nuclear dawn increases, the reality lags a little behind. Dogged by an ageing nuclear fleet based on cold war-era technology, intractable waste-management issues, formidable regulatory challenges, and a charged geopolitical climate, the nuclear industry has plenty of issues to concern itself with, even before it considers the daunting financial, regulatory, and logistical challenges involved in a major commercial expansion.

This paper addresses the security concerns associated with an expansion of nuclear power. After examining the validity of the concept of a nuclear renaissance and the energy context in which any such phenomenon will take place, we address the leading technical, institutional, and geopolitical challenges facing an expanded nuclear industry in the twenty-first century[1].

[1] While we have divided the paper into sections on reactors, fuel-cycles, and international institutions, each of these constituents of the civilian nuclear sector are necessarily interrelated.

I. GLOBAL ENERGY CONTEXT

As the earth's hydrocarbons diminish at an accelerating rate and global warming presents an ever-more urgent challenge, scientists are racking their brains to develop secure, low-carbon sources of power. As a result, innovations in the exploration, production, and use of existing fuels as well as advances in the development of new ones have been gathering pace. On the former, the use of new techniques to unlock previously inaccessible "unconventional" natural-gas resources have changed the hydrocarbon landscape as gas promises to play an increasing role as an "energy bridge" to a lower-carbon future. The development of technologies such as carbon capture and sequestration (CCS), while still commercially unproven, may extend coal's dominance as an energy source long into the future of a carbon-constrained economy. Advances in the technology and economics of solar and wind power and the development of advanced biofuels and distributed generation on the supply side, as well as the redesign of existing infrastructure including developments in the "smart grid" and the electrification of the vehicle fleet on the demand side will have a significant impact on the power sector worldwide. Efforts to improve energy efficiency in the commercial and domestic sectors will further change aggregate demand and energy usage patterns, putting additional pressure on high-cost supply options.

In the United States, the world's largest energy consumer, the changes in the energy landscape have prompted some senior policymakers to rethink the role of traditional power sources. In April 2009 Jon Welighoff, the Chairman of the Federal Energy Regulatory Commission said that, in light of the growing prominence of renewable energy, there may be no further need for the construction of new coal or nuclear power facilities[2]. Given the virtual inevitability of a carbon tax-mechanism in the United States, which will significantly alter the price of coal-fired power, and the formidable financial and regulatory obstacles to building new nuclear power stations, sentiments such as those expressed by Mr Wellinghoff have some plausible economic and logistical underpinnings. In a recent update of its seminal 2003 report on the future of the nuclear industry, the Massachusetts Institute of Technology (MIT) concluded that "since 2003 construction costs for all types of large-scale [nuclear] engineered projects have escalated dramatically"[3]. According to MIT's calculations, the cost of constructing a new nuclear plant has been increasing at 15 percent per year[4]. These figures are more than underscored by the experience of one of the few new nuclear plants to have been built in recent years: Finland's

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[2] New York Times, "Energy Regulatory Chief Says New Coal, Nuclear Plants May Be Unnecessary", April 22, 2009

[3] J. Deutch et al, "Update of the 2003 The Future of Nuclear Power: An Interdisciplinary MIT Study. Cambridge, Mass.: Report for Massachusetts Institute of Technology", 2009

[4] Ibid

Olkiluto 3 plant is now expected to be three years late and $2 billion over budget[5]. Plans by Luminant, a U.S. merchant power company, to build two 1700 MW power stations at an estimated cost of $15 billion dollars indicate the sheer scale of the financial challenges the industry faces[6]. Against such cautionary tales and the strengthening prospects of alternative energy sources, the promise of a nuclear renaissance seems far from certain.

Tempting as it may be for opponents of nuclear power to write off the nuclear renaissance in favor of a renewable *deus ex machina*, however, a closer examination of the realities of global energy demand and supply suggest a different scenario. Despite the rapid advances in renewable technologies such as solar photovoltaic cells, concentrated solar, and wind turbines, the contribution of non-hydropower sources of renewable energy is expected to contribute just 1.5 trillion kwh to the total net global electricity generation increase of 13.8 trillion kwh between 2006 and 2030[7]. For renewable sources other than wind and hydropower, the U.S. Energy Information Agency concludes that most "are not economically competitive with fossil fuels over the projection period" to 2030[8]. On the other hand, the same report finds that higher fossil fuel prices will enable nuclear power to become economically competitive with coal, natural gas, and liquid hydrocarbons for electricity generation[9].

The strongest case for a nuclear renaissance is the growing body of circumstantial evidence around the world. After a period of 30 years in which no construction permits have been issued for new nuclear power plants, the United States' Department of Energy has shortlisted four proposed nuclear facilities for a final round of evaluation for eligibility for $18.5 billion in federal loans. (Many U.S. industry officials at believe that this number needs to be raised to over $100 billion over the next decade to cope with the projected increase in capacity[10].) In Europe countries that had turned their backs on the idea of nuclear power are doing an about-face: in February Italy announced that it was going to restart nuclear production after banning it in the wake of the Chernobyl disaster; this year the Spanish government granted an extension to its oldest civilian nuclear plant despite committing to a phase out nuclear power 2006; and Sweden has overturned its moratorium on new nuclear power stations and has even offered to provide a nuclear-waste repository for the rest of the world. In Germany, Chancellor Angela Merkel

5 BBC, "Nuclear Dawn Delayed in Finland", July 8, 2009
6 Presentation by David Campbell CEO, Luminant at the Howard Baker Forum, September 2009, Washington DC
7 US Energy Information Administration , "International Energy Outlook 2009", May 2009
8 Ibid
9 Ibid
10 Address by Alex Flint, SVP Nuclear Energy Institute, Howard Baker Forum, OpCit

has campaigned on behalf of restarting the nuclear industry, much to the chagrin of the influential Green Party, while the British Government has made a major commitment to the expansion of commercial nuclear power.

Faced with soaring energy demand, developing countries are in the forefront of a new wave of nuclear-reactor construction. According to the World Nuclear Association, China has eleven nuclear power reactors in commercial operation, 14 under construction, and at least ten more slated to start construction in 2009. By 2020, China plans to increase its nuclear generated capacity fourfold to 40 gigawatts (GW), an addition equivalent to half the entire nuclear capacity of France. Elsewhere, India, Korea, Russia and the UAE are embarking on nuclear-reactor construction projects. It is not only countries with existing civilian nuclear programs that are rethinking their stance: over the next ten years the number of countries pursuing nuclear power is predicted by the British government to grow from the current thirty to fifty[11]. All this adds up to a compelling set of indicators that support the idea of a resurgence in the civilian nuclear sector. Absent a dramatic breakthrough in renewable energy technology or another nuclear accident in the near future, it appears that atomic power is indeed due for a comeback.

[11] UK Cabinet Office, "The Road to 2010: Addressing the nuclear question in the twenty first century", July 2009

II. REACTORS

Existing fleet

Before addressing the implications of the projected increase in global nuclear power, it is worthwhile to take stock of the situation with regard to the current reactor fleet. Today there are 435 nuclear reactors in operation in 30 countries. The average age of these operating reactors is around 25 years; for reactors with the largest generation capacity the average age is slightly higher. The oldest and--according to industry consensus--least safe nuclear reactors currently in operation are the handful of so-called "generation I" reactors. These include the three remaining VVR-440 230 reactors (two in Russia, one in Armenia), which lack emergency operating procedures and fall far short of internationally accepted safety standards; and the British Magnox-design reactors, which have no secondary containment systems and incorporate components that are particularly subject to corrosion[12]. The remaining Magnox reactors are scheduled for retirement by 2010. Also of concern among the existing fleet are the dozen or so RBMK reactors, which gained enduring notoriety during the Chernobyl disaster in 1986. While immediate upgrades were made to the remaining RBMK reactors in the wake of the accident, the design still suffers from fundamental safety flaws, including the lack of full containment structures, and a "positive void coefficient", a tendency for an increase in power output during a loss-of-coolant accident.

The vast majority of the remainder of the nuclear-reactor fleet is based on the pressurized water reactor (PWR) design developed in the 1960s. Most reactors in operation today rely on a once-through, low-enriched uranium (LEU) fuel cycle. The existing security implications of the once-through fuel cycle—concerns about the proliferation of enrichment capabilities, treatment of spent fuel, and disposal of nuclear radioactive waste—are well documented. Expansion of the PWR fleet, especially to countries not hitherto equipped with commercial nuclear power, magnifies these risks, particularly the prospect of the involvement of new countries in enrichment and reprocessing activities. (For a detailed discussion of the security implications of the development fuel cycle, see Fuel Cycle section below.)

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[12] National Academy of Science, "Management and Disposal of Excess Weapons Plutonium: Reactor-related Options, National Academy Press", 1995

Future expansion

The PWR is set to dominate the near-term expansion of the nuclear power sector with the design comprising 42 of the 52 reactors currently under construction. Despite the dozens of reactors currently being constructed and the license extensions of dozens of existing plants (particularly in the United States), the nuclear industry is facing a "retirement cliff" over the coming years as long-serving reactors are eventually decommissioned[13]. If it is to replace the outgoing reactors and meet the new generation-requirements that a nuclear renaissance suggests, the industry must undergo a period of rapid and sustained construction. According to Princeton's Robert Socolow, for nuclear power to displace one seventh of the projected increase in carbon emissions over the next 50 years, nuclear power plants need to be constructed at a rate of 14 one-GW plants per year for the next 50 years[14]. This is a rate of growth that has not been witnessed since the rapid period of civilian nuclear expansion in the 1980s and only then for less than a decade. According to a report by the Keystone Nuclear Center, an expansion on the scale envisioned by Dr Socolow would also entail a massive expansion in associated production and storage capacity with the addition of 11 to 22 large enrichment plants, 18 fuel fabrication plants, and ten nuclear repositories the size of the aborted Yucca Mountain storage facility[15].

In the medium term, the reactor-related security implications of an expanded global nuclear power sector hinge on next-generation reactor designs. So-called "generation III" and "generation III+" designs build on the fundamental principles of generation II light water reactors (LWRs) while aiming to increase safety through the use of simplified reactor designs, and passive safety features. The most notable generation III designs are the Advanced Boiling Water Reactor (ABWR), a collaboration between America's General Electric and Hitachi currently operational in Japan; and Mitsubishi Heavy Industries' Advanced Pressurized Water Reactors (APWR), scheduled to enter service in Japan in 2016/17.

13 Of the 104 operating reactors in the United States, for example, 51 have had their licenses extended with another 21 under review and 24 getting ready to make extension submissions to the Nuclear Regulatory Commission. With US reactors having improved there operating efficiencies to 92 percent in 2008, these technical improvements combined with life extension of their licenses bodes well for an industry that just a few years ago believed that many existing reactors would have to be mothballed over the next decade.

14 S. Pacala and R. Socolow, "Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies," Science, August 2004

15 C. Morris et al "Nuclear Power Joint Fact-Finding", The Keystone Center, June 2007

The leading generation III+ reactors include the European Pressurized Water Reactor (EPR) developed by Areva, General Electric's Economic Simplified Boiling Water Reactor (ESBWR), and Westinghouse's AP-1000. There are currently two EPR reactors under construction in Europe (including the overdue and over-budget Olinko 3 development in Finland), plans to build two EPRs in China, and interest in the design from a range of other countries. Construction on two AP-1000s has begun in China.
While advanced reactors such as the EPR and AP-1000 are generally accepted to demonstrate greater operational safety than current generation II reactors (according to French governmental officials, the EPR is ten times safer[16]), concerns have arisen over the increased radioactivity of these advanced reactors' spent fuel relative to existing LWR fuel. In order to achieve greater efficiency and to reduce waste volume, some generation III reactors employ higher rates of fuel "burn-up" than their predecessors. According to the IAEA, higher burn up of fuel has a significant impact on the storage systems required for spent fuel due to the latter's increased decay heat[17]. While the level of risk associated with higher-burn-up spent fuel is the matter of considerable debate, it is clear that additional safeguards will be needed to cope with handling and storage (both temporary and permanent) of such material. The second major concern around the deployment of generation III+ reactors is their ability to operate on recycled, mixed-oxide (MOx) fuel. Both the EPR and the AP-1000 can accept a complete (100 percent) core loading of MOx if necessary. The security implications of MOx are dealt with in the Fuel Cycle section below.

Further out, the so-called "generation IV" set of reactor designs present a new combination of operational advances and potential security concerns. Among these is the resurrection of the fast-reactor design, which underpins at least three of the six generation IV concepts shortlisted by the Generation IV International Forum (GIF), an international consortium. With their ability to use reprocessed spent fuel as an input and to "burn up" long-lived nuclear waste, fast reactors have long been recognized as a potential solution to extracting better efficiency from the fission process and as a means of reducing existing stockpiles of spent fuel. However, aside from the serious questions of their economic viability, fast reactors present a number of operational and fuel-cycle related security considerations. To attain criticality, fast reactors need to be fueled with either highly enriched uranium or with plutonium. The civilian use of both of these elements has serious additional proliferation

[16] Presentation by A Bugat, "'Energy Policy and the Role of Nuclear Power Generation in France", at The 38th JAIF Annual Conference: "After fifty Years of Nuclear Power, a new Stage for Safety and trust" France, April 2005

[17] IAEA, "TechDoc-1558: Selection of Away-From-Reactor Facilities for Spent Fuel Storage. A Guidebook," 2007

implications relative to the LEU inputs used with existing LWR reactors. The second security-related aspect of the adoption of fast reactors is their inherent dual use capabilities: while the reactors can be used in "burner" mode to break down long-lived actinides in spent fuel, they can conceivably be reconfigured to breed plutonium using a fertile blanket of depleted uranium. While the reference designs for fast reactors do not include breeder capabilities others in the civilian nuclear sector—notably India's Department of Atomic Energy—are anticipating an expansion of FBRs as an integral part of the nuclear renaissance. (The adoption of FBRs is seen by India as a key step in the development of the thorium fuel cycle, which would enable the country to use its vast reserves of natural thorium as a fertile reactor fuel.)

III. FUEL CYCLE

Enrichment

A primary consideration for any large-scale increase in the global fleet of once-through LWRs is the increased demand for LEU fuel. To satisfy this demand, existing uranium enrichment centers will need to expand their output significantly. Large scale enrichment plants are currently in place in France, Germany, the Netherlands, the United Kingdom, the United States, and Russia. Smaller scale enrichment operations are in place in Japan, China, Brazil, India and—famously—Iran. North Korea also claims that it is in the final stages of uranium enrichment, while Israel is widely believed to be in possession of enrichment capabilities. In addition there are currently four new enrichment plants under construction in the United States. Any increase in output from existing large-scale enrichment facilities will lead to the presence of more LEU and a proportionate increase in the risk of diversion or misuse of this material. Moreover, while the Nuclear Energy Agency estimates that reserves of natural uranium are sufficient to supply the world for a century[18], many countries with civil nuclear sectors are not so sanguine. Increased existing and anticipated demand is driving a new wave of uranium exploration. In the past few months, a slew of uranium mining contracts have been signed, including a joint-venture uranium mining deal between France and the Democratic Republic of Congo and a flurry of activity from India, which has used its newly obtained nuclear-import freedom to strike fuel deals with Russia, France, Namibia, Kazakhstan and Mongolia. India alone is reported to be allocating up to $1.2 billion for equity stakes in overseas uranium mines[19]. China and Japan have also been active in buying stakes in uranium-mining companies, principally in uranium-rich Australia but also in Central Asia. Elsewhere, South Africa, Brazil, and Jordan are also very interested in an expanded role in the market for commercial enrichment activities. While the prospects for "uranium wars" may still be dim, a substantial increase in the number of reactors worldwide coupled with a delay in the development of spent-fuel recycling could lead to heightened competition for a valuable--and limited--resource.

An equally important implication of the nuclear renaissance is the possibility of new state actors entering the enrichment process. As new countries invest in nuclear power facilities to provide part of their energy mix, they will naturally seek a reliable source of fuel supplies. While bilateral and multilateral agreements between current enrichment producers and new nuclear-power states guaranteeing LEU supply from the former in exchange for an agreement by the latter to forswear their own enrichment

[18] NEA "Uranium resources sufficient to meet projected nuclear energy requirements long into the future", June 2008
[19] Bloomberg, "India, Mongolia Sign Civil Nuclear Agreement for Uranium Supply" 14 September, 2009

facilities may be a logical solution to this problem (see Institutions section below), the *realpolitik* of energy security suggests that states will be reluctant to rely on outsiders for vital power-sector inputs if there is a domestic alternative. The *de facto* linkages between enrichment capabilities and the potential to develop weapons bolster the attractiveness of domestic uranium enrichment programs. Renewed interest in enrichment by Argentina, Australia, and South Africa (among others) in recent years suggests that emerging civil-nuclear nations are likely to keep the option of domestic enrichment on the table. In addition to security considerations, changing economics in the uranium-enrichment sector may also lead to the entry of new players looking to capitalize on export opportunities. As recognized in a recent study by Geoffrey Rothwell and Chaim Braun of Stanford University[20], nuclear fuel companies are facing a change in the enrichment industry landscape over the coming years as obsolete, inefficient diffusion technology plants are retired and the cost of enrichment comes down. The authors posit that this development could lead either to a fall in the price of enrichment services to competitive levels (whereby existing enrichment players will have less of an economic incentive resulting in a fall in global enrichment capacity) or the maintenance of artificially high enrichment prices (through the formation of a cartel), which could provide economic incentive for new players to enter the market.

The adoption of new technology will also provide an added challenge to the non-proliferation regime in the form of laser enrichment. Known also by its specific technical titles of Separation of Isotopes by Laser Excitation (SILEX), Molecular laser isotope separation (MLIS), and Atomic Vapor Laser Isotope Separation (AVLIS), laser enrichment provides an economically attractive alternative to gas diffusion or centrifuge based enrichment. However, owing to the compact physical footprint of laser-diffusion facilities, plants that employ laser separation techniques are far harder to detect than those using older technologies. This situation presents a significant challenge to international inspectors looking for evidence of illicit enrichment programs and therefore adds to the risk of proliferation of fissile material.

[20] G. Rothwell and C. Braun, "The Cost Structure of International Uranium Enrichment Service Supply", May 2008

Reprocessing

Many proponents of the nuclear renaissance talk about "proliferation-resistant" fuel cycles and technologies. The majority of these ideas are predicated on the concept of recycling spent nuclear fuel into mixed oxide (MOx) fuel or by "closing" the fuel cycle through the use of fast reactors. One of the key debates concerning the expansion of nuclear power centers on the subject of the reprocessing of spent nuclear fuel from LWRs. In the continued absence of a long-term storage solution, increasing amounts of spent fuel are sitting either in temporary cooling pools or in indefinite on-site dry-cask storage. With the planned increase in the nuclear fleet, this spent fuel inventory is set to grow. The concept of reusing this spent fuel through reprocessing---also known by its more palatable "recycling" is well established. By separating the plutonium dioxide from the spent LWR spent fuel (about 1 percent of the total spent-fuel volume) and combining it with uranium oxide, nuclear-plant operators can create a mixed oxide fuel (MOx) that can then be reused as a fuel in its own right. Some 30 European reactors in operation toady use MOx fuel, the majority being in France, where it is used in about one third of the reactors.

Aside from the questionable economics of MOx fuel use relative to the once-through cycle[21], the reprocessing of spent fuel presents several serious security considerations. The first of these is that the separation of plutonium from the other spent fuel isolates one of the key elements needed to create a nuclear weapon. While the plutonium created in civilian reactors would require further reprocessing to become "weapons grade", the initial act of separating the raw material makes the job of diverting supplies to a would-be bomb maker significantly easier. In testimony before the US House of Representatives committee on Science and Technology earlier this year, Charles Ferguson of the Council on Foreign Relations, stated that any reprocessed fuel failed to meet the "spent-fuel standard" of proliferation resistance owing to the separation of highly radioactive fission products from the plutonium and uranium. Citing a study by Oak Ridge National Laboratory, Dr Ferguson said that

[21] See "The Economics of Reprocessing vs. Direct Disposal of Spent Nuclear Fuel", Belfer Center for Science and International Affairs, Harvard Kennedy School, December 2003 and "Economic Assessment of Used Nuclear Fuel Management in the United States", Boston Consulting Group, July 2006 for two divergent analyses of the economics of reprocessing

radiation emission from reprocessed products is one hundred times less than the "spent fuel standard", thus lowering the danger of radiation exposure to potential thieves[22].

The second concern related to the current practice of reprocessing is the disposal of the spent MOx fuel. Having been reused in the reactor core, spent MOx fuel presents its own storage and disposal problems. While the MOx fuel inputs are accepted to be more self-protecting than the uranium oxide fuel elements used in once-through reactor cycles, spent MOx fuel emits significantly more residual decay heat than that from uranium oxide spent fuel[23]. Consequently, spent MOx fuel needs to be stored above ground for considerably longer than other spent fuel before further conditioning can begin.

Currently, commercial reprocessing is conducted by five countries: France, Russia, the United Kingdom, and India—all declared nuclear weapons states—as well as Japan. The United States, which indefinitely deferred domestic civilian reprocessing under the Carter administration, resurrected the idea under the George W. Bush administration's Global Nuclear Energy Partnership only to abandon it in 2009 under the Obama Administration. China, which already has a pilot reprocessing plant based on the PUREX concept (see below), is planning a large commercial reprocessing plant based on its own technology, scheduled to begin operations in 2020. The nuclear renaissance has serious implications for the future of reprocessing. With the addition of up to 20 new states to the list of those with civilian nuclear power facilities and the development of MOx-compatible- and advanced fast reactors, the demand for reprocessing technology will escalate. Given the close relationship between reprocessing technology and nuclear weapons production capabilities—again evidenced by the world's consternation at Iran's actions—any such expansion has serious proliferation implications.

An important consideration in assessing the security implications of reprocessing is the range of spent-fuel treatment technologies currently under consideration. The vast majority of reprocessing currently relies on an aqueous separation process known as Plutonium and Uranium Extraction (PUREX), through which the two reusable elements are separated from other fission products. In addition to increasing the volume of radioactive material, the PUREX process raises significant proliferation concerns through its isolation of a pure stream of plutonium.

[22]E.D. Collins, Oak Ridge National Laboratory, "Closing the Fuel Cycle Can Extend the Lifetime of the High-Level Waste Repository," American Nuclear Society 2005 Winter Meeting, November 2005
[23] Presentation by R. Garwin "GNEP: Leap before looking," at the American Chemical Society annual meeting, Chicago, Illinois, March 2007

In recent years, several alternative reprocessing techniques have been developed in anticipation of the increased prevalence of MOx-compatible- and fast reactors. Chief among these separation techniques are UREX+, COEX, and NUEX, all of which are designed to prevent the isolation of plutonium in the extraction process. While this is a welcome development from a proliferation perspective, the perception that these new techniques make reprocessing inherently safe presents its own security challenge. A large scale expansion of reprocessing activity predicated on the assumption that the proliferation threat had been completely overcome through new techniques could prove to be a greater threat to security than current limited level of PUREX reprocessing.

A further cause for concern on the back end of the fuel cycle is the potential disconnect between new treatment techniques and existing agreements and regulatory regimes. A prime example of this is the issue of pyroprocessing, a multi-stage process for breaking down spent fuel without the isolation of plutonium that is being actively pursued by South Korea. Under the 1992 Inter-Korean Declaration of Denuclearization of the Korean Peninsula, Seoul pledged not to posses nuclear reprocessing facilities. South Korea, which is due to renegotiate a bilateral nuclear agreement with the United States that expires in 2014, is expected to make the case that pyroprocessing does not constitute reprocessing; many experts in the United States disagree. The resolution of such a nuance is likely to be monitored closely by existing and aspiring nuclear-power states around the world. As with uranium enrichment, a key factor in assessing the reprocessing-related security threats from an expanded global nuclear-power industry will rest on the design of new international regimes and institutions.

IV. INSTITUTIONS

Regulatory frameworks

Any expansion of the civilian nuclear sector poses additional challenges to an international regulatory regime already struggling to cope with current proliferation and safety concerns. As Hannelore Hoppe, the director of the UN's Office for Disarmament Affairs, said in November 2008, "[t]he simultaneity of higher energy demands and proliferation concerns has created both political and economic obligations to address the question pertaining to the peaceful uses in a more concrete and urgent manner[24]". As the foundation of current international efforts to ensure nuclear non-proliferation and nuclear energy concerns, the Treaty on the Non Proliferation of Nuclear Weapons (NPT) has had a mixed record. While the withdrawal of North Korea from the Treaty, the discovery of the A.Q. Khan network, the nuclear tests in South Asia, and continued non-compliance by Iran have proven the NPT to be far from a panacea, the "cascade of proliferation" that many pessimists were predicting has failed to materialize. The fact that so few state actors have joined the nuclear club is a testament to the ideological strength of the NPT and the appeal of a collective solution to nuclear disarmament. That no instances of *non-state* actors acquiring nuclear weapons to date have been recorded is owing more to the regime's practical enforcement.

In a world of expanded nuclear-energy demand, both the ideological and practical aspects of the NPT (and other international non-proliferation regimes) face new challenges. The clearest example of the former is the controversial U.S.-India nuclear deal, through which the United States pushed for and obtained an exception to the Nuclear Suppliers Group-ban on trade with non-NPT signatories in order to provide assistance to India's civilian nuclear sector. While many commentators, including IAEA Director General Mohammed El Baradei, see the deal as a positive way to bring India into the nonproliferation regime, others see the precedent of Indian exception as undermining the spirit of international agreements through selective application.

[24] Presentation by H. Huppe, "Nuclear Renaissance and the NPT: Reinforcing the Three Pillars of the NPT" at the Seventh United Nations-Republic of Korea Joint Conference on Disarmament and Non-Proliferation Issues, November 2008

The weakness of the practical element of current institutional non-proliferation safeguards—particularly with regard to preventing the diversion of fissile material—is arguably even more problematic. As the Commission on Weapons of Mass Destruction Proliferation and Terrorism warned last year, the threat from nuclear-armed non-state actors is grave, with a nuclear terrorist attack "more likely than not" somewhere in the world by 2013"[25]. The nuclear renaissance provides two additional challenges to an already shaky non-proliferation regime: as the use of existing civilian nuclear technology increases, so does the risk of its diversion and weaponization; and the adoption of new technologies such as spent-fuel recycling and fast (breeder) reactors provide new potential sources of proliferation.

The NPT review conference of 2010 will seek to address some of the growing and changing challenges of proliferation in the 21st century. Among the points for discussion is the specific language of a number of the existing articles of the Treaty, including:

- Article 1: The current language prohibits the transfer of "nuclear weapons or other nuclear explosive devices or control over such weapons or explosive devices directly, or indirectly". To strengthen the non-proliferation regime, it has been suggested that this article be broadened to include enrichment and reprocessing devices and technology.
- Article 4: One of the key components of the NPT, this article enshrines the right of members to develop, research, and produce nuclear energy and makes provision for the "fullest possible exchange" of equipment, materials and technology between members for peaceful energy uses. It has been suggested that the language of the article should be changed in order not to apply to enrichment and reprocessing devices and technology, and that provision should be made for the guarantee of fuel supplies.
- Article 10: It has been suggested that this article, which makes provision for withdrawal from the Treaty, should include a new clause that ensures that all nuclear facilities acquired by the withdrawing member remain under IAEA safeguards.

[25] B Graham et al, "WORLD AT RISK The Report of the Commission on the Prevention of WMD Proliferation and Terrorism", First Vintage Books Edition, December 2008

The inadequacies of non-proliferation institutions are mirrored in the current agreements for nuclear-liability issues. The two existing nuclear-liability frameworks (the 1960 Paris Convention and the 1963 Vienna Convention) have been found seriously to underestimate the potential costs of compensation in the event of a civil nuclear accident, even taking into account more recent revisions[26]. Moreover, it has been calculated that more than half of the worldwide installed nuclear capacity is located in countries that operate outside the existing nuclear compensation regimes[27]. With such a threadbare international liability regime for the existing nuclear fleet, the issue of upgrading or supplanting existing liability protocols must be at the forefront of any discussion regarding a nuclear renaissance.

Multilateral Regimes

Aside from the issues being considered under the abovementioned existing frameworks, a number of new multilateral initiatives are being considered to address the security concerns of the growing nuclear-energy sector. Most notable among these is the concept of an IAEA-controlled international nuclear fuel bank. Funding for the fuel-bank concept, which would guarantee a supply of LEU fuel and reactor services to approved states, has been provided by the United States, the European Union, Norway and the United Arab Emirates (UAE). The terms of compliance for membership of such a fuel bank arrangement are a matter of some dispute: while some advocate an approach that requires participants to forswear domestic enrichment and reprocessing activities altogether, other proposals see such conditions as running counter to the abovementioned Article IV of the NPT treaty, which states that all parties have the right to develop and produce nuclear energy. For some states, the price of discontinuing indigenous enrichment and all its concomitant prestige and security implications may be too high; for others, a multinational regime that proscribes domestic enrichment is seen as a means of further dividing the world into nuclear "haves" and "have nots". The resolution of this single issue will have a fundamental bearing on the security of any fuel-bank regime.

Some nuclear-industry observers see cause for hope in the proposed "123" agreement between the United States and the United Arab Emirates (UAE). According to the conditions of the agreement, which has the support of the Obama Administration but still has to be ratified by the U.S. Congress, the UAE agrees to forgo sensitive elements of the nuclear fuel cycle, including enrichment and reprocessing,

[26] M Schneider, S. Thomas, A Froggart, D Koplow, "World Nuclear Industry Status Report 2009", August 2009

[27] Quoted in Schneider et al Ibid

in exchange for the transfer of nuclear technology and components between the two countries. Proponents say that in making the UAE reliant on approved international suppliers for the supply and disposal of its (spent) nuclear fuel, the agreement will widen access to peaceful nuclear power while minimizing risks of proliferation. However, while this argument has certain merit, there are reasons to be wary of the universal applicability of the 123 model for expansion of nuclear power to new countries. Even if parties to such a regime agree to forgo domestic enrichment and reprocessing, the issues of compliance with and defection from such a regime will be as challenging as those faced by the NPT.

Assuming that the institutional challenges can be overcome, an international fuel-bank regime presents a formidable set of logistical hurdles. Given the enormous strategic and energy-security implications of reliance on a fuel bank, agreement on the siting, operation, and oversight of such a facility presents a potential political hornets' nest. The offer from Kazakhstan, one of the world's biggest natural uranium exporters, to host a fuel bank has been met with an initially upbeat reaction in the international community, but the reality may prove to be more problematic. Moreover, while a multinational approach to the nuclear fuel cycle will likely improve security with regard to enrichment facilities themselves, it will also lead to the increased international transhipment of fissile and waste materials. Questions regarding oversight of the safe passage of these dangerous materials and the rights and responsibilities of the global community to board ships believed to contain illicit cargo will need to be addressed.

Other multilateral nuclear approaches (MNAs) proposed by the IAEA, including the conversion of existing state-controlled facilities to multilateral ones; regional cooperation on new facilities; and the development of a multilateral fuel cycle face similar institutional and practical challenges[28].

[28] Multilateral Approaches to the Nuclear Fuel Cycle: Expert Group Report submitted to the Director General of the International Atomic Energy Agency, IAEA, 2005

CONCLUSION

Given the projected increase in global energy demand over the coming decades and the continued focus on low-emissions power solutions, the prospects for a nuclear renaissance look realistic. With the impending retirement of much of the existing worldwide nuclear reactor fleet (reactor-license extensions notwithstanding) and the adoption of civilian nuclear programs by new countries, such a resurgence will require a rapid and sustained increase in construction levels for new nuclear reactors.

Even in the presence of a satisfactory nuclear waste-management solution and adequate regulatory protocols, a large-scale expansion of the civil nuclear sector will present significant security challenge. In the absence of either the global community faces serious questions regarding its ability to cope with many more states having access to sensitive nuclear technology. The prospect of a nuclear revival is further complicated by a new generation of nuclear technology that presents its own advances and security challenges. The adaptation of the fuel cycle to incorporate reprocessed spent nuclear-fuel presents perhaps the most serious concern owing to the inherent relationship between reprocessing and nuclear proliferation. Despite exhortations to the contrary, there is still no such thing as a "proliferation-proof" fuel cycle, particularly in a geopolitical climate in which small diversions of fissile material to non-state actors represents a growing threat.

Of equal concern is the inadequacy of existing international regimes to deal with civilian-nuclear related issues in the 21st century. Serious question marks hang over some of the most fundamental aspects of nuclear sector regulation, including non-proliferation enforcement, fuel provision, and accident liability. In the absence of an overhaul of existing international and multilateral regimes, the projected expansion of worldwide civil nuclear sector promises to put increased strain on an already outdated and inadequate regulatory system.

Nuclear power likely has a significant role to play in the powering the global economy in the coming decades. However, while it promises to address the very real concerns of climate change and hydrocarbon scarcity, an expanded nuclear energy sector comes with many of its own security-related challenges. Issues of reactor safety, fuel cycle management, and regulatory oversight all need to be closely evaluated if the nuclear renaissance is to deliver on its promise of secure, reliable energy.