Re-igniting the Atom: The Political Consequences of the Global Nuclear Revival

by Duane Bratt

A global nuclear revival is taking place. This can be seen in the building and planning of new nuclear reactors, efforts to extend the life of existing reactors, and increased public support for nuclear power. This revival is due to the collision of three vectors: (1) the substantial rise in the global demand for electricity; (2) the increased attention placed on the problem of greenhouse gases (GHGs) contributing to climate change; and (3) the need to diversify electricity supply away from fossil fuels. Accompanying this revival are some important political consequences, notably in the areas of international trade, nuclear non-proliferation, and nuclear safety. These issues have always existed, but what impact will the increase in nuclear power have on them?

Measuring the Revival

There are 436 nuclear power plants generating approximately 370 gigawatt-electric (GWe) of electricity in operation around the world. These 436 reactors contribute around 14 percent of the world's electricity. More than 80 percent of these reactors were built during the 1970s. After several decades of relative stagnation, it is evident that the world has now entered a second "golden age." There are 53 reactors currently under construction, being built by 14 countries, capable of generating 47.2 GWe that (see Table 1).

In addition to the reactors under construction, there are many more in various stages of planning. The International Atomic Energy Agency (IAEA) has created a number of scenarios for the future of nuclear power generation. Its low projection sees no new reactors—outside of those already under construction or firmly planned—coming on-stream and old reactors being retired on schedule. Under this scenario, nuclear power plants would generate 511 GWe of electricity. The high

Duane Bratt is an Associate Professor in the Department of Policy Studies at Mount Royal University in Calgary, Alberta, Canada.

TABLE 1

NUCLEAR REACTORS WORLDWIDE
(as of November 2009)

COUNTRY	IN OPERATION	NUCLEAR SHARE OF ELECTRICITY GENERATION	UNDER CONSTRUCTION
United States	104	19.66%	1
France	59	76.18%	1
Japan	53	24.93%	2
Russia	31	16.86%	9
South Korea	20	35.62%	6
United Kingdom	19	13.45%	0
Canada	18	14.80%	0
Germany	17	28.29%	0
India	17	2.03%	6
Ukraine	15	47.4%	2
China	11	2.15%	16
Sweden	10	42.04%	0
Spain	8	18.27%	0
Belgium	7	53.76%	0
Czech Republic	6	32.45%	0
Others	41		10
Total	436		53

Source: Reactors in operation was taken from IAEA, "Number of Reactors in Operation Worldwide." Nuclear Share of Electricity Generation was taken from IAEA, "Nuclear Share in Electricity Generation in 2008." Reactors under construction was taken from IAEA, "Number of Reactors under construction Worldwide." Accessed on 4 November 2009 at http://www.iaea.org/NewsCenter/Focus/NuclearPower/

projection estimates additional reasonably planned and proposed reactors being built combined with some life extension of older reactors. Under this scenario, nuclear power plants would generate 807 GWe. This would require between 75 and 300 new reactors being built by 2030. The IAEA predicts that the overall share of electricity production from nuclear plants would be between 12.6 and 15.9 percent, not far from the current 14 percent.[1] The Organisation for Economic Co-operation and Development's (OECD) Nuclear Energy Agency estimates that by 2050, nuclear power would generate between 580 and 1, 400 GWe of electricity. Nuclear power's share of electricity production would range between 9 and 22 percent. To achieve this goal, there would have to be between 23 and 54 new reactors built every year between 2030 and 2050.[2]

The International Energy Agency's World Energy Outlook also put forward a range of scenarios. Its reference scenario, assuming unchanged current policies, projects a slightly increased generating capacity of 415 GWe by 2030. Its alternative scenario, which assumes that the world adopts additional measures to prevent GHG emissions, projects an increase to 519 GWe.[3]

The question now is: where will, these new reactors be built? The market for nuclear reactors, as Miller and Sagan put forward, can be distinguished between "a potential *growth* in the production of nuclear energy in states that currently have nuclear power facilities and the potential *spread* of nuclear power plants and related facilities to states that are new entrants to the 'nuclear energy club.'"[4] Therefore the market for nuclear reactors can be divided into four categories ranked in descending order of the number of new builds: (1) China and India; (2) Western industrialized countries; (3) developing countries with pre-existing nuclear power; and (4) new entrants.

International Trade

Trade protectionism has been a historic problem in the sale of nuclear reactors. In this respect, the reactor business is not that much different from other facets of economic activity, especially large industrial products like automobiles and planes. Since the 1970s, largely through the work of the World Trade Organization and various regional trade agreements, there have been significant efforts at liberalizing trade. Trade liberalization has also occurred in several parts of the nuclear fuel cycle, but it has not been extended to nuclear reactors. There are still some barriers to the trade of uranium and nuclear components, but this is on the export side, not the import side. The reason for export controls of nuclear materials is due to security concerns, not trade protectionism. Since its creation in the aftermath of the 1974 Indian nuclear test, the Nuclear Suppliers Group (NSG) has tried to standardize nuclear export controls among its members. This issue will be dealt with in more detail in the following section on non-proliferation.

The degree of openness of reactor markets is not the same around the world. In the past, countries with domestic nuclear industries were closed off to foreign competition. The only open markets were in countries without a domestic industry, largely in the developing world. Today, not much has changed. France (Areva), Russia (Rosatom), and Japan (Toshiba, Hitachi, and Mitsubishi) possess some of the largest markets for nuclear power; they are also the most protected because of the existence of a national champion(s). Even the US market, which advertises itself as being the most open, shows signs of protectionism. Its current fleet of 103 reactors were all designed by either Westinghouse or General Electric. Today, the only change in their market composition is the likely arrival of Areva. However, as will be shown below, Areva had to make significant US investments in order to penetrate the market, leaving the developing world—especially China and India—as the most open markets for reactor sales. Even South Korea, which in the past bought technology from Westinghouse, Framatome (now Areva), and Atomic Energy of Canada Limited (AECL), is now a closed market. This is because Korea Hydro & Nuclear

Power Co Ltd (KHNP) has created its own reactor design, the Optimised Power Reactor (OPR-1000), which is now being built in South Korea and marketed in Indonesia and Vietnam.

What is new is that protectionism in the trade of nuclear reactors has become more sophisticated.[5] Two methods in particular stand out. First, is the use of regulatory standards. In theory regulators are technology-neutral, but in reality national regulators tend to possess expertise in the local reactor design. This makes it difficult for different reactor designs to gain regulatory approval without a lot of additional time and money being spent and represents a significant barrier to entry. A second method is the growing partnerships, even including some cross-ownership, between reactor companies and electricity utilities. This means that when the utility decides to build a new reactor, it will choose its designated reactor vendor, and not conduct an open bid process.

The situation in France is a good illustration of the "new" trade protectionism in nuclear reactors. There is a "Team France" approach that combines Areva, Total (an oil and gas firm), EDF, and GdF-Suez. In all four, the French government has a significant ownership stake. Beyond the joint partnerships in specific nuclear projects, there are also cross-ownerships between the companies, with Total owning one percent of Areva, and Areva owning one percent of GdF-Suez. France is obviously an inaccessible market for any competing nuclear firm, but Team France is trying to extend its protected market to the rest of the EU. According to nuclear insiders, EDF and GdF-Suez, "by buying up utilities," the French have "cornered the European market."[6] When EDF and GdF-Suez look to expand electricity capacity, their focus will be on nuclear power, and it will not be an open bid process; they are likely to select Areva's Evolutionary Power Reactor (EPR). Beyond the partnerships with EDF and GdF-Suez, Areva has other major advantages in Europe. It is a local company with intimate knowledge of the market and access to politicians, and it is in the EURO currency zone. Team France is seeking to enhance these inherent advantages by attempting to standardize nuclear regulations in the European Union (EU), but based on EPR technology. This factor will make it difficult for competing nuclear firms to access the entire EU market.[7]

WHAT IS NEW IS THAT PROTECTIONISM IN THE TRADE OF NUCLEAR REACTORS HAS BECOME MORE SOPHISTICATED.

Team France talks like the US is an open market for nuclear reactors, but its actions show that they perceive the US to be as closed as France. This is why they have pursued the same strategy in the US as in Europe; using EDF and GdF-Suez to buy up electricity utilities to build EPRs without a competitive bid process. For example, EDF's purchase of almost half of Constellation Energy paved the way for building four new nuclear reactors in the US starting with a new nuclear unit at Calvert Cliffs, Maryland. These units will obviously be EPRs.[8] Areva even changed the name of its new reactor from a European Power Reactor to an Evolutionary

Power Reactor in order to make it more appealing to the American audience.

The high percentage of state-owned reactor companies, such as Rosatom, Areva, AECL, and KHNP, is a simple, but powerful, symbol of the state of trade protectionism in the nuclear reactors arena. The question is why does protectionism in the nuclear reactor trade still linger? First, despite some recent efforts at deregulation (largely in North America and Britain), electricity is still regarded in most jurisdictions as a natural monopoly. This means that it is often treated as a public good and not solely in the domain of market forces. Second, electricity generation is often viewed by states as an instrument of economic and industrial development. Third, nuclear power has a very high economies of scale, with large amounts of both up-front costs and electricity production. Fourth, there are important aspects of public policy—namely national security, safety, and the environment—strongly associated with nuclear power. For example, Ipsos Reid, in a survey of Canadians, reported that "nuclear energy is simply too important an element of public infrastructure and too expensive with too long term a pay-off to expect the private sector to adequately support it, ensure its safety or consider the national security implications of its proliferation."[9] Fifth, public opinion supports economic nationalism when it comes to the nuclear sector. For example, 84 percent of Canadians said that it was "important that the nuclear technology used in Canada be retained in companies owned and controlled by Canadians."[10]

The high percentage of state-owned reactor companies, such as Rosatom, Areva, AECL, and KHNP, is a simple, but powerful, symbol of the state of trade protectionism in the nuclear reactors arena.

Nuclear Non-Proliferation

Sharon Squassoni has noted that "a defining feature of nuclear energy, in contrast to other electricity sources, is the risk that fissile material, equipment, facilities, and expertise can be misused to develop nuclear weapons. No other type of electricity-generating plant requires international inspections to detect diversion of material."[11] Therefore, the question is whether the global nuclear revival will increase the proliferation of nuclear weapons? For some, the issue has already been decided. Jose Goldemberg has determined that the "nuclear renaissance is already undermining the NPT."[12] On the other hand, John Ritch, Director General of the World Nuclear Association has responded that,

> *the global non-proliferation and safeguards system—one of the greatest achievements in diplomatic history—effectively curtails any link between civil and military programmes, and actually helps to detect and deter illicit nuclear activity....Most fundamentally, whatever proliferation risk we face would be unaffected even by a 20-fold increase in the global use of safeguarded nuclear*

reactors to produce clean energy.[13]

Regardless, it is clear that "the expansion of nuclear power, the future of nuclear weapons disarmament, and the future of the NPT and related parts of the nuclear control regime are so intertwined."[14]

There are several arguments that link nuclear proliferation with the global nuclear revival. Despite elaborate safeguards by the IAEA, the proliferation of nuclear weapons is tied into civilian programs in two respects: people and technology. An expansion of the civilian side creates a cadre of technically sophisticated scientists and engineers who, with some extra effort, have the potential of migrating to the military side. On the technology side, there are concerns that the revival will increase the amount of plutonium and highly enriched uranium (HEU), the essential ingredients of nuclear weapons. The cause of this increase is a reliance on spent fuel reprocessing and enrichment technology. After going through a reactor, spent fuel—also called nuclear waste—still retains about 96 percent uranium.

Reprocessing is a chemical process to recover usable uranium from spent fuel. This process occurs by separating the uranium from the other by-products of the fission process (plutonium and other minor actinides). Unfortunately, the process also separates the plutonium from the rest of the waste. The benefits of reprocessing are as a hedge against a uranium shortage, more efficient use of uranium, and the reduction of nuclear waste. The fear of reprocessing is that it increases the availability of plutonium. That being said, there is a major distinction between weapons-grade plutonium and reactor-grade plutonium. Weapons-grade plutonium, specifically designed for use in nuclear bombs, is 93 percent P_u-239. Reactor-grade plutonium, found in a reactor's spent fuel, is 60 to 70 percent P_u-239. Reactor-grade plutonium can be used as the fissile material for a nuclear weapon, but it requires "sufficient ingenuity, expertise, expense, personal health risk, and luck."[15] Countries that have reprocessing technology include France, India, Japan, and Russia. China has a pilot program, but the UK is on the verge of abandoning reprocessing. The US has not reprocessed since President Carter issued a 1978 moratorium precisely because of proliferation risks.

Enrichment involves increasing the amount of U-235 (0.72 percent) that naturally occurs in uranium: light water reactors use slightly enriched uranium (U-235 that is enriched between 3 to 5 percent), research reactors require more highly enriched uranium (U-235 that is enriched to more than 20 percent), and nuclear weapons require very highly enriched uranium (U-235 that is enriched to over 90 percent). Uranium is enriched either by gaseous diffusion or centrifuge technology. Both of these processes work on the principle of separating the lighter U-235 from the heavier U-238 when in the form of uranium hexafluoride gas. Uranium enrichment is a very complex process and acquiring the sufficient expertise is not an easy proposition.

The issue is ensuring that countries have access to nuclear fuel—enriched uranium—but are prevented from developing an enrichment capability. Obtaining an enrichment facility would allow a country, albeit with some technical difficulty, to go from low enriched uranium, used for power production, to highly enriched uranium, used for weapons production. Countries that currently have some form of enrichment technology include: Argentina, Brazil, China, France, Germany, India, Iran, Japan, the Netherlands, Pakistan, Russia, the United Kingdom, and the United States. To help prevent proliferation, the G-8 established a 2006 moratorium on countries with enrichment technologies. There have been initiatives by both the IAEA and the Global Nuclear Energy Partnership (GNEP) to have multilateral control of the entire nuclear fuel cycle including enrichment technology.[16] At this moment, these efforts have been unsuccessful because they would contradict the principle of Article IV of the NPT that allows all Parties to the Treaty "the right to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy." As a result, the biggest deterrent for states seeking an enrichment capability is the technological sophistication and associated costs required. It is simply cheaper and easier to purchase nuclear fuel from an existing enrichment facility.

URANIUM ENRICHMENT IS A VERY COMPLEX PROCESS AND ACQUIRING THE SUFFICIENT EXPERTISE IS NOT AN EASY PROPOSITION.

A related concern is that sensitive dual-use items, like reprocessing and enrichment technology, will proliferate due to black market networks based on those assembled by A.Q. Khan.[17] The non-proliferation system that the IAEA and NSG put in place was designed to prevent the spread of dual-use nuclear technology from Western states to developing world countries. Since that time, a wider array of countries has developed nuclear technology; therefore, it has become much harder to stop these countries from exporting their nuclear know-how to others. Aspiring weapons states can simply buy, share, and sell technology amongst themselves rather than starting programs from scratch, importing materials, or stealing plans from the West as Khan and Pakistan were forced to do. Even the exposure of the Khan network is unlikely to put a stop to the growth of these activities. Secondary proliferation is a major worry, particularly when states like North Korea, Syria, and Iran are involved. It has the capacity to shatter the existing non-proliferation system.

Critics also worry that nuclear facilities, which would naturally increase as part of the global nuclear revival, are prime targets for terrorist attacks. Graham Allison, a prominent international relations expert at Harvard, has written about the different ways that nuclear terrorism could occur. The ones that are relevant to nuclear power plants—as opposed to the security of nuclear weapons—include: planes hitting the containment domes or the storage site for spent fuel rods; starting fires at a nuclear power plant to disperse radiation; using conventional explosives wrapped around radioactive material to produce a "dirty bomb;" and stealing spent fuel waste that could be separated to make a nuclear weapon.[18]

The terrorist fears that Allison describes are indeed scary, especially regarding the theft of nuclear weapons; however, in the case of nuclear power facilities, he has greatly exaggerated the threat. If spent fuel from a reactor was stolen, it would also require elaborate separation technology to convert it to the plutonium that is needed for a nuclear bomb. A further deterrent to theft is the fact that a terrorist group would have to steal many spent fuel bundles to acquire enough reactor-grade plutonium to convert into a bomb and deal somehow with the deadly irradiation field surrounding the bundles. As Jeremy Whitlock has pointed out,

> *[T]his would require 100 spent fuel bundles, weighing two tonnes without shielding. Not only would the theft be extremely difficult, but since it would also be easily and quickly detected, it would be followed by the necessary evasion of a top-priority manhunt employing most likely the full resources of the country's security infrastructure.*[19]

Fears about terrorist attacks also ignore the fact that there are stringent safeguards enforced by the IAEA on nuclear facilities. Even prior to 9/11, "nuclear plants represent hardened targets and already had strong security forces in place." The containment structure, part of the defense-in-depth strategy for reactor safety, is simultaneously also a very effective defense against sabotage or terrorism. In the 1980s, Ontario Hydro determined that even in the extremely unlikely event that a 747 jumbo jet was able to successfully hit a CANDU plant, there would be no significant damage because of the facility's very thick reinforced concrete and steel roofs and walls. The pool water that immerses the spent fuel rods would act as an additional security barrier from falling debris. Finally, all reactors are designed to automatically shut down in the event of a physical attack.[20]

After 9/11, the IAEA and domestic nuclear regulatory agencies increased their already tough guidelines related to the security of nuclear facilities. In March 2002, the IAEA's Board of Governors, in cooperation with its member states, approved an action plan designed to prevent nuclear terrorism that emphasized physical protection of nuclear materials.[21] As part of this action plan, the 1980 Convention on the Physical Protection of Nuclear Material (CPPNM) was amended in 2005, although it has yet to come into force. An additional treaty, the International Convention for the Suppression of Acts of Nuclear Terrorism, came into force in 2007.

National regulatory bodies followed suit by strengthening their own regulations. For example, the Canadian Nuclear Safety Commission (CNSC) amended its Nuclear Security Regulations to include the following provisions: better threat and risk assessment; a permanent on-site armed response force at major nuclear facilities; enhanced security screening of employees and contractors; enhanced access control to nuclear facilities, including reactors, uranium refineries, and fuel fabricators; development of basic threat analysis for nuclear facilities; uninterrupted power supplies in place for alarm systems; and contingency planning involving drills and exercises. The CNSC also monitors its licensees to ensure that they are compliant with these new enhanced security regulations.[22] In short, if the possibility of major radioactivity or weapons proliferation because of a terrorist act against a nuclear power facility was remote prior to 9/11, the steps taken by the world's nuclear community in the last few years have made it even more remote.

What about the new entrants to the global nuclear revival? It has been suggested that there are particular vulnerabilities for many of the aspiring nuclear power states. There is a clear link between stable democracy and nuclear non-proliferation. Many developing countries, which make up the vast majority of the aspiring nuclear power states list, lack "domestic 'good governance' characteristics that will encourage proper nuclear operations and management." These include low degrees of corruption, high degrees of political stability, high government effectiveness scores, and a strong degree of regulatory competence.[23] There is also a concern about their willingness and ability to accept IAEA safeguards. IAEA safeguards are the principle mechanism by which the legally binding obligations contained in the NPT are monitored. Unfortunately, as Miller and Sagan point out, "each known or strongly suspected case of a government starting a secret nuclear weapons program was undertaken by a non-democratic government."[24] Consider the record of Iraq, Iran, and North Korea. Prior to the democratization process in Brazil, Argentina, South Korea, and South Africa, those countries also pursued a nuclear weapons program. Examining the list of aspiring nuclear power states identifies many non-democratic countries: Algeria, Belarus, Egypt, Indonesia, Kazakhstan, Kenya, Malaysia, Philippines, Saudi Arabia, Thailand, United Arab Emirates, and Venezuela.

Ultimately, these concerns all have the same solution: maintaining and strengthening the nuclear non-proliferation regime. In particular, the IAEA safeguards system needs to be enhanced in order to respond to the global nuclear revival. International safeguards place technical barriers and political disincentives on states and groups that seek nuclear weapons. As the situations in Iran and North Korea have shown, the IAEA cannot enforce nuclear non-proliferation, but it has been more than capable at sounding the alarm. There are some proposals for strengthening the nuclear non-proliferation regime. First, more states should ratify the IAEA's additional protocol. The additional protocol will enhance safeguards by allowing the IAEA to conduct surprise inspections of nuclear facilities, inspect both declared and undeclared facilities, rely on IAEA member states' intelligence information, take environmental samples, and other measures designed to reveal illicit nuclear activities.[25] The following are existing and aspiring nuclear power countries where, as of November 2009, the IAEA's additional protocol is not yet in force: Argentina, Albania, Algeria, Bahrain, Belarus, Brazil, Egypt, India, Iran, Kenya, Malaysia, Mexico, Pakistan, Philippines, Thailand, United Arab Emirates, Vietnam, and Venezuela.[26] The Nuclear Suppliers Group should add support for the further ratification of the Additional Protocol by making it a condition for any nuclear transfers.

Second, the IAEA needs to be able to better utilize its scarce resources by allowing it to prioritize its inspections. Why should the IAEA divert resources from suspect states like North Korea and Iran so that it can monitor Canada and Sweden? The challenge is to balance the issues of sovereignty and non-discrimination with the realization that some states are more likely to try to violate their non-proliferation commitments.

The IAEA took a step forward when it adopted the concept of Integrated Safeguards in 2002. Integrated Safeguards gives the IAEA more flexibility to optimize safeguards implementation on a state-by-state basis for states that have both a Comprehensive Safeguards Agreement and its Additional Protocol in force. For example, Canada is now under Integrated Safeguards, "which means that the IAEA has concluded that we have not diverted anywhere in our infrastructure (a conclusion they have to renew annually) and therefore the inspection frequency can be relaxed—making use of less frequent, unannounced inspections, and lengthening the time between verification requirements."[27] In this way, Integrated Safeguards provides for the implementation of IAEA inspections to be consistent across countries. It is a rigorous process for qualifying and implementing Integrated Safeguards. By January 2010, there were close to 50 states under Integrated Safeguards and several of them were non-nuclear weapons states with large civilian nuclear programs, such as Canada, Germany, and Japan.[28] The Integrated Safeguards system has cleared up some resources for the IAEA to inspect other, more problematic, countries. A 2007 study on Integrated Safeguards found the program has increased the IAEA's efficiency and effectiveness. In particular, the program has been beneficial in three ways:

> *(1) they are helping to reduce the overall verification burden on the IAEA Secretariat and its member states;*
>
> *(2) they are increasing the national verification capacity of participating countries; and*
>
> *(3) they are strengthening the Agency's ability to carry out its verification mission.*[29]

Third, the IAEA must receive substantially more financial and human resources in order to handle the global nuclear revival. According to Jeremy Whitlock, AECL's international safeguards representative,

> *the IAEA will be seriously challenged if its resources stay effectively flat. It has found ways to 'work smarter' with safeguards, but with the predicted increase in not only the numbers of reactors, but the types, its safeguards regime will need to become much more efficient. Fortunately there has been an increase in states helping the IAEA in this regard. Canada has consistently contributed to improvements in efficiency (and effectiveness) over the years. The U.S. Next Generation Safeguards Initiative (NGSI) is a major recent entry to this effort.*[30]

Fourth, the Nuclear Suppliers Group needs to increase its membership to include India. India has become important in the international nuclear sector and its exports will only increase with the global nuclear revival. Therefore it only makes sense that India adheres to the export controls established by the NSG. India has been strongly opposed to the NSG, seeing it as a cartel designed to keep nuclear materials out of Indian hands. This impression was not unreasonable given that the NSG was created explicitly after India's 1974 nuclear weapons test; however, Indian and NSG attitudes have recently changed because in September 2008, the NSG passed a waiver allowing its members to transfer nuclear materials to India, even though it had not signed the NPT. The decision to grant the waiver should make it easier for India to join the NSG.

Nuclear Safety

It is essential that any spread of civilian nuclear technology accompanying the global nuclear revival is safe and secure. The safety record of nuclear power worldwide has been very high, but there are concerns, primarily related to the accidents at Chernobyl and Three Mile Island, that continue to haunt the industry. In the case of Three Mile Island in 1979, the reactor's safety features kicked in and shut down the reactor and its containment structure prevented the emission of large doses of radiation into the environment. Nobody died or was injured. Chernobyl, in 1986, was much more serious as it led to the death of 31 people within hours and radiation was spread across thousands of kilometres. The most authoritative study of Chernobyl, undertaken by eight UN agencies and the governments of Russia, Belarus, and Ukraine has indicated that 4,000 thyroid cancer cases will likely be attributed to the accident.[31] However, the Chernobyl disaster was primarily caused by the political and social culture in the former Soviet Union that did not emphasize safety. A sense of the uniqueness of the Chernobyl disaster is provided by the fact that the facility, incredibly, lacked a fully capable containment structure and the steam explosions occurred during a test where the reactor's safety system was turned off. It must be stated that these two nuclear accidents occurred over two decades ago. In contrast, coal mine disasters and pipeline explosions continue to occur at a rate of more than one per year. Experts in the United States, using Probabilistic Risk Assessment, have estimated that reactor core damage is likely to occur less than once in 10,000 reactor-years.[32]

The safety record of nuclear power worldwide has been very high, but there are concerns, primarily related to the accidents at Chernobyl and Three Mile Island, that continue to haunt the industry.

Nuclear reactor safety is the responsibility of designers, operators, and regulators. Designers need to include extensive safety features in their reactors. There are built in safety redundancies—known as the suspenders and belt approach—to ensure that the reactor is automatically shut down in the case of an accident. This includes passive devices that do not require an operator to shut down a reactor in case of danger. In addition, a major feature of all reactors is the containment dome which is designed to prevent the release of radiation. New Generation III+ reactors that are being built as part of the revival have even more enhanced safety features.

Operators need to be vigilant in ensuring that the reactor operates as intended and that there are no accidents. To assist nuclear operators in the dedication to safety, a peer review system led by two industry association has been established. The Institute of Nuclear Power Operators (INPO) was formed by US nuclear operators in 1979, after the Three Mile Island accident. The World Association of Nuclear Operators (WANO) was formed in 1989, by international nuclear operators after the Chernobyl accident. These peer groups will be essential resources for aspiring nuclear power states.

Regulators independently monitor the safety performance of operators. In fact, nuclear power, more so than any other energy source, is heavily regulated to prevent and mitigate accidents. There are international efforts, led by the IAEA, to ensure reactor safety. For example, the 1996 Convention on Nuclear Safety established international safety standards which were maintained through a peer review system. Since 1982, the IAEA also offers a peer review service called the Operational Safety Review Teams (OSART). Regulators also have formed their own associations. The International Nuclear Regulatory Association (INRA) was formed in 1997, by Canada, France, Germany, Japan, Spain, Sweden, the United Kingdom, and the United States. INRA's purpose is to influence and enhance nuclear safety, from the regulatory perspective, among its members.

The Nuclear Energy Agency (NEA), part of the OECD, is another association with some regulatory responsibilities. The NEA has 28 members, among which are many of the leading nuclear power countries in the world. The NEA's Multinational Design Evaluation Programme (MDEP) is a multinational initiative taken by national safety authorities to develop innovative approaches to leverage the resources and knowledge of the national regulatory authorities who will be tasked with the review of new reactor power plant designs; its aim is to harmonize safety goals. The MDEP incorporates a broad range of activities including: enhanced multilateral cooperation within existing regulatory frameworks; multinational convergence of codes, standards and safety goals; and the implementation of MDEP products to facilitate licensing of new reactors, including those being developed by the Generation IV International Forum.[33] Both the INRA and the NEA operate the same way for regulators as WANO does for operators. There has also been greater coordination between national regulators. According to a CNSC official,

> *this is relatively new. While the regulatory network has always existed, the scale and volume of the interactions has substantially increased. This has occurred in response to the nuclear renaissance.*[34]

The result of efforts by designers, operators, and regulators, is that nuclear power has a safety record that is better than any other major energy source (see Table 2). WANO has been tracking reactor safety for almost two decades. In 1990, there were 5.2 accidents per 200,000 hours worked, but this had declined to 0.92 by 2008. There has also been a noticeable decline in radiation exposure across all types of nuclear reactors.

Another way of illustrating the increased safety of nuclear reactors, both their design and their operation, is by highlighting the dramatic improvement in the capacity factor of the world's reactors. According to WANO,

> *[unit capability factor]is the percentage of maximum energy generation that a plant is capable of supplying to the electrical grid, limited only by factors within [the] control of plant management. A high unit capability factor indicates effective plant programmes and practices to minimise unplanned energy losses and to optimize planned outages.*[35]

Although capacity factor measures the efficiency of a reactor, it is also a good proxy for measuring safety because the more efficient a reactor is the safer it is. In

TABLE 2

COMPARING FATAL ACCIDENTS ACROSS ENERGY SOURCES (1969–2000)

Energy Source	Accidents	Direct Fatalities
Coal	1 221	25 107
Oil	397	20 283
Natural Gas	125	1 978
Liquefied Petroleum Gas	105	3 921
Hydro	11	29 938
Nuclear Reactor	1	31

Source: Australia, Department of the Prime Minister and Cabinet, Uranium Mining, Processing and Nuclear Energy Review, "Uranium Mining, Processing and Nuclear Energy – Opportunities for Australia" (2006), 77.

1990, the global unit capability factor was 77.2 percent, but by 2008, this number had climbed to 86.3 percent.[36]

The biggest improvement has been in the US. In the 1970s and early 1980s, measures were under 60 percent, but today they have surpassed the 90 percent mark. This improvement has been due to a number of factors that are directly related to the global nuclear revival. First, the consolidation of reactor operators has been a factor because, simply put, the current roster of operators is better. The US nuclear industry has gradually,

> *overhaul[ed] (and standardiz[ed]) reactor control systems for existing plants, with*

> *the aim of simplifying operator training and reducing operator error. This approach, together with extensive preventive maintenance programs, has led the U.S. nuclear industry over the past two decades to outstanding performance in both human safety and reactor availability (presently averaging well over 90 percent).*[37]

Second, INPO and WANO have played a role through the uniform application of best practices.[38] The global nuclear revival has been in place for the last couple of years through both new reactor construction and life extension projects. Yet, contrary to those who predicted a decline in safety, the statistics for industrial accidents, radiation exposure, and capacity factor continues to improve.

Meserve identifies two potential safety dangers associated with the global nuclear revival. First, new entrants "have limited experience with nuclear energy, and nearly all lack the extensive national infrastructure common in most countries currently with NPPs." Second, many existing reactors are having their life extended to 60 or 80 years; however, "the continuing operation of older plants thus requires careful attention to aging mechanisms, with heightened attention over time to surveillance, preventive maintenance, and component replacement."[39] In both cases, the peer support network provided by WANO, IAEA, NEA, and the INRA will be crucial.

Conclusion

The global nuclear revival, measured in new builds both under construction and planned, life extension, and increased public support is real; however, there are many international political implications stemming from the revival. On the economic side, despite the revival, the international trade of nuclear reactors remains far from free. An interesting twist is the use of national regulators, who are there to ensure reactor safety, as a barrier to the entry of new reactor firms in markets. Things are better on the security side. It is true that there are significant concerns on the future of the NPT and the spread of nuclear weapons, largely due to activities in Iran and North Korea; however, the global nuclear revival has not made the security situation worse, and it could be argued that it has, in fact, made it better. In preparing for the revival, the IAEA has adopted new policies and procedures, such as the Additional Protocol and the Integrated Safeguards system that will allow it to better monitor the commitment to peaceful nuclear energy. In addition, bringing the Indians back into the nuclear family, despite criticism, will have a positive effect on nuclear non-proliferation. Finally, the international cooperative efforts, at maintaining nuclear safety— through WANO, for example— will be extended to the expansion of nuclear power. The nuclear industry realizes that a nuclear accident anywhere in the world could bring the revival to a crashing halt. Therefore the industry has a stake in ensuring nuclear safety in all countries, either existing or aspiring, developed or developing. In sum, the global nuclear revival will have either a neutral (trade) effect or a positive (security and safety) effect on the traditional concerns surrounding nuclear power.

Notes

[1] International Atomic Energy Agency, "Energy, Electricity and Nuclear Power Estimates for the Period up to 2030," *Reference Data Series,* No. 1 2009 Edition, IAEA Vienna 2009.
[2] Organization of Economic Cooperation and Development, Nuclear Energy Agency, "Nuclear Energy Outlook 2008," OECD: Brussels, 2008.
[3] International Energy Agency, "Nuclear Power," *IEA Energy Technology Essentials*, OECD: March 2007, http://www.iea.org/techno/essentials4.pdf.
[4] Steven E. Miller and Scott D. Sagan, "Nuclear power without nuclear proliferation?" *Daedalus* 138.4 (Fall 2009) 9-10. See Figure 1.
[5] Telephone interview with Duane Bratt (Mississauga), 30 October 2009.
[6] Telephone interview with Duane Bratt (Mississauga), 30 October 2009 and Telephone interview with Duane Bratt (Mississauga), 29 October 2009.
[7] Keith Bradley, interview with Duane Bratt, 29 October 2009; Telephone interview with Duane Bratt (Mississauga), 29 October 2009; and Telephone interview with Duane Bratt (Mississauga), 30 October 2009.
[8] EDF Development Inc., "Constellation Energy and EDF Group Enter Definitive Investment Agreement," December 17, 2008 http://presse.edf.com/fichiers/fckeditor/File/press/cp_2008/cp_20081217_va.pdf
[9] Ipsos Reid, "Public Opinion Research on Nuclear Energy" *Ipsos Reid,* February 23, 2009: 4.
[10] Ibid, 19.
[11] Sharon Squassoni, *Nuclear Energy: Rebirth or Resuscitation?* (Washington: Carnegie Endowment for International Peace, 2009), 39-40.
[12] Jose Goldemberg, "Nuclear energy in developing countries," *Daedalus* 138.4 (Fall 2009) 79.
[13] John Ritch, "Crucial Role for Government and Industry," Round Table Presentation. *International Ministerial Conference: 'Nuclear Power for the 21st Century,'* Paris, March 21-22, 2005. http://www.world-nuclear.org/John_Ritch_speeches/John_Ritch_paris210305.html.
[14] Miller and Sagan, "Nuclear power without nuclear proliferation?" 9.
[15] Jeremy Whitlock, "Security and Non-Proliferation," *The Canadian Nuclear FAQ* 2009. Accessed on June 3, 2008 at http://www.nuclearfaq.ca/cnf_sectionF.htm#x2.
[16] The GNEP, which has subsequently seen its funding cut by the United States, was also viewed suspiciously by many countries because it was designed to "ensure that existing suppliers would remain in control, with spent fuel being returned to suppliers for reprocessing." Trevor Findlay, e-mail message to author, February 24, 2010.
[17] For a good account of the A. Q. Khan story see Gordon Corera, *Shopping For Bombs: Nuclear Proliferation, Global Insecurity, and the Rise and Fall of the A.Q. Khan Network* (Scribe Publications: Victoria, Australia 2006).
[18] Graham Allison, *Nuclear Terrorism: The Ultimate Preventable Catastrophe* (New York: Owl Books, 2005).
[19] Whitlock, "Security and Non-Proliferation."
[20] Dave Rossin, "Nuclear Facilities and Terrorism," 2005. http://www.euronuclear.org/reflections/nuclear-facilities.htm.
[21] International Atomic Energy Agency. "IAEA Action Plan to Combat Nuclear Terrorism," *Press Release* (19 March 2002). http://www.iaea.org/NewsCenter/PressReleases/2002/prn0204.shtml.
[22] See Canada, Department of Justice, Nuclear Security Regulations SOR/2000-209 (31 May 2000). http://laws.justice.gc.ca/eng/sor-2000-209/page-1.html.
[23] Miller and Sagan, "Nuclear power without nuclear proliferation?" 9-10.
[24] Ibid, 11.
[25] International Atomic Energy Agency, *Model Protocol Additional to the Agreement(s) between State(s) and the International Atomic Energy Agency for the Application of Safeguards.* INFCIRC /54 0 (Corr.) (May 1997). http://www.iaea.org/Publications/Documents/Infcircs/1997/infcirc540c.pdf.
[26] International Atomic Energy Agency, "Strengthened Safeguards System: Status of Additional Protocols," (26 November 2009). http://www.iaea.org/OurWork/SV/Safeguards/sg_protocol.html.
[27] Jeremy Whitlock, email message to author, 8 December 2009.
[28] International Atomic Energy Agency, *Safeguards Statement for 2008 and Background to the Safeguards Statement* (2009). http://www.iaea.org/OurWork/SV/Safeguards/es2008.html#ftn26. The EU reached an agreement with the IAEA in January 2010 making all their members eligible for integrated safeguards. IAEA, "Agreement Reached on Integrated Safeguards in European Union," *Press Release* (January 8, 2010). http://www.iaea.org/NewsCenter/PressReleases/2010/prn201001.html.
[29] Jack Boureston and Yana Feldman, "Integrated nuclear safeguards: development, implementation, future

challenges," *Compliance Chronicles*.4 (January 2007): 19.
[30] Jeremy Whitlock, interview by Duane Bratt 18 November 2009.
[31] International Atomic Energy Agency, "Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts," *The Chernobyl Forum: 2003-2005*. (2005).
[32] Massachusetts Institute of Technology, *The Future of Nuclear Power: An Interdisciplinary MIT Study* (MIT: Cambridge, MA, USA, 2003): 48.
33 Telephone interview with Duane Bratt (Ottawa), 23 September 2009.
34 Confidential interview with CNSC official.
35 World Association of Nuclear Operators, *2008 Performance Indicators* (2009), http://www.wano.org.uk/PerformanceIndicators/PI_Trifold/PI_2008_TriFold.pdf.
36 Ibid.
[37] Richard K. Lester and Robert Rosner, "The growth of nuclear power: drivers and constraints," *Daedalus* 138, no. 4 (Fall 2009): 26.
38 Keith Bradley, interview with Duane Bratt, October 29, 2009.
[39]Richard A. Meserve, "The global nuclear safety regime," *Daedalus* 138 no. 4 (Fall 2009): 104-105.