# THE FUTURE OF NUCLEAR ENERGY TO 2030 AND ITS IMPLICATIONS FOR SAFETY, SECURITY AND NONPROLIFERATION

Overview



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CIGI
The Centre for International Governance Innovation
Centre pour l'innovation dans la gouvernance internationale

Addressing International Governance Challenges

# The Future of Nuclear Energy to 2030 and its Implications for Safety, Security and Nonproliferation

## Overview

Trevor Findlay

## Nuclear Energy Futures Project

CIGI's Nuclear Energy Futures Project is conducted in partnership with the Canadian Centre for Treaty Compliance (CCTC) at the Norman Paterson School of International Affairs, Carleton University, Ottawa. The project is chaired by CIGI Distinguished Fellow Louise Fréchette and directed by CIGI Senior Fellow Trevor Findlay, director of CCTC. CIGI gratefully acknowledges the Government of Ontario's contribution to this project.

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# Technical Glossary

**Units**

BTU British thermal unit

g gram

kWh kilowatt hour – a unit of electrical energy equal to the work done by one kilowatt acting for one hour

SWU separative work unit – a measure of work done by a machine or plant in separating uranium into higher or lower fractions of U-235

t tonne

We watt (electric)

Wth watt (thermal)

**Elements and Compounds**

C carbon

CO2 carbon dioxide

Pu plutonium

U uranium

UF6 uranium hexafluoride

**Metric Prefixes**

k kilo $10^3$

M mega $10^6$

G giga $10^9$

T tera $10^{12}$

# Acknowledgements

This report culminates three-and-a-half years' work on the Nuclear Energy Futures (NEF) project. An enterprise of this length and scale would not have come to fruition without the backing of several key organizations and the support of many individuals.

Special thanks must go first to those individuals who had the foresight to conceive of the project, shape its beginnings and provide the funding and resources to permit it to proceed: John English, former CIGI executive director; Louise Fréchette, chair of the project and CIGI Distinguished Fellow; CIGI Distinguished Fellow Paul Heinbecker; Daniel Schwanen of CIGI; and Fen Hampson, director of the Norman Paterson School of International Affairs (NPSIA) at Carleton University.

One of the project's first acts was to commission a series of research studies that provided the basic data and "feedstock" for the project's analytical work. Some of these studies were published as NEF Papers. I am grateful to the following authors and contributors: Justin Alger, John Cadham, Ian Davis, Kenneth Dormuth, David Jackson, Nathaniel Lowbeer-Lewis, David McLellan, Miles Pomper, M.V. Ramana, Heather Ray, Mycle Schneider, Aaron Shull, Sharon Squassoni, Christine Wing and Yun Zhou.

To track the progress of countries seeking civilian nuclear power, the NEF project developed a unique database that is now accessible to the public as the Survey of Emerging Nuclear Energy States (SENES). Several NPSIA masters students at the Canadian Centre for Treaty Compliance (CCTC) worked on designing, compiling, formatting and updating SENES and creating it as an ongoing feature of CIGI's website in cooperation with CIGI's IT and design experts. Thanks go to Ray Froklage for the initial concept and layout and to Justin Alger, Derek de Jong, Alex Sales, Jonathan Miller and Paul Davis for their input at various stages. At CIGI, Som Tsoi provided indispensable technical advice.

Project staff convened workshops and consulted with an extensive range of stakeholders over the course of the project. We began with a one-day nuclear-themed contribution to CIGI's annual conference CIGI '07 in Waterloo. This was followed in December 2007 by a roundtable with Canadian government and industry representatives organized with the Department of Foreign Affairs and International Trade (DFAIT) in Ottawa. We are grateful to DFAIT for its assistance in organizing this event. In April 2008 the project organized a conference on nuclear affairs in the Asia-Pacific region in Sydney, Australia, in close collaboration with the Lowy Institute for Public Policy. Our thanks go to Lowy's Deputy Director Martine Letts and Orietta Melfi for their efforts in making this event so successful. A second conference held at CIGI in November 2008 considered various other regions of the world. CIGI's events team, led by Colleen Fitzpatrick, and its media and public affairs staff, led by Neve Peric, helped make this a watershed event in the life of the project. In January 2009 a consultation with Canadian nuclear stakeholders was held at Carleton University organized by John Cadham, to whom we are most grateful. Informal consultations with experts and officials included meetings with the Canadian Nuclear Safety Commission in Ottawa, the US Department of Energy and US Department of State in Washington DC, the International Atomic Energy Agency (IAEA) in Vienna and the Preparatory Commission for the Comprehensive Nuclear Test Ban Treaty Organization, also in Vienna. We are thankful to all of these organizations and those individuals who helped arrange our appointments. We are especially indebted to Peter Rickwood, formerly of the IAEA's media department, for his assistance above and beyond the call of duty in arranging appointments and transport in Vienna, including an enlightening visit to the IAEA Safeguards Analytical Laboratory at Seibersdorf. In addition, the IAEA's Tariq Rauf was his usual helpful and hospitable self. The project also appreciated the opportunity provided by Christine Wing of New York University to participate in her own workshop on the nuclear energy revival at Blue Mountain in upstate New York in June 2008, and to Peter Jones of the University of Ottawa for the opportunity to take part in a workshop on the nuclear issue in Iran that he organized in April 2008.

Many CIGI staff members have been tireless in their enthusiasm and support for the project. In addition to those already mentioned, I would like to thank Anne Blayney, Karen Daniel, Peggy Dix, Briton Dowhaniuk, Matt Eason, Colleen Fitzpatrick, Jackie Hatherly-Martin, Tammy McCausland, Juanita Metzger, Neve Peric, Becky Porlier, Sandy Rung, Mary-Lou Schagena, Stephanie Woodburn and Tamara Zur for their respective contributions. The CIGI publications team, led by Max Brem with the strong support of Jessica Hanson, deserves particular mention for managing an ever-growing series of NEF reports and the sizeable final project publications all expertly edited and presented. Other members of the publication team include designer Steve Cross and editors Matthew Bunch and Tammy McCausland. I am particularly indebted to Max Brem for his unwavering support and quiet encouragement throughout the project as well as his deft editorial hand.

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In addition, the following individuals provided their time, information, support or advice during the project's life and I thank them all: Joonhong Ahn, Mir Md Akramuzaman, Robert Alvarez, Sulfikar Amir, Gabriel Barceló, Colin Bradford, Duane Bratt, Jason Cameron, John Carlson, Alvin Chew, Young-Myung Choi, Stuart Coke, Jill Cooley, Katherine Croft, Azhar Djaloeis, Elizabeth Dowdeswell, Hal Feiveson, Carlos da Silva Feu Alvim, Brian Finlay, Mark Fitzpatrick, Brian Gracie, Viacheslav Gutkov, Mark Gwozdecky, Allan Gyngell, Anne Harrington, Olli Heinonen, Mark Hibbs, Laura Holgate, Paul Hough, Philippe Jamet, Togzhan Kassenova, Darryl Kimball, Gary Kodman, Richard Leaver, Nicolas Lesieur, Xiaoping Li, Miroslav Lipar, Jacqueline Littlewood, Rafael Martincic, Peggy Mason, Julie Mecke, Doug Miller, Bob Morrison, Kaoru Naito, Jatin Nathwani, Anita Nilsson, Andrew O'Neill, David Pumphrey, Christopher Reberger, Christian Schmitzer, Mohamed Shaker, Adam Sheinman, John Simpson, Mark Smith, Dick Stratford, Ziggy Switkowski, Andrew Symon, Matti Tarvainen, Ken Wagstaff, David Waller, Julian Whichello, Jeremy Whitlock, Isabelle Williams and Reudiger Christoph Zettel. I apologize to anyone I have overlooked but I am grateful to you nonetheless.

Finally, this project could not have been executed without the enthusiastic involvement of a team of NPSIA masters degree students at the CCTC who provided research and administrative support. In addition to those who worked on SENES, Muneeba Omar and CCTC administrator and researcher Scott Lofquist-Morgan provided vital support in the early stages of the project. I am especially indebted to Justin Alger, CCTC administrator and researcher for the past year, and to Derek de Jong, research assistant, for their crucial support and dedication in the closing stages of the final report preparation as deadlines loomed. Louise Fréchette, my project chair, was crucial in providing wise policy guidance and high-level support throughout the project.

Notwithstanding the contributions of all of the above, the opinions expressed and conclusions reached in this report, along with any mistakes and infelicities, are my responsibility alone.

**Trevor Findlay**

Director, Canadian Centre for Treaty Compliance

Carleton University

Ottawa

# Foreword
## By Louise Fréchette

2010 will be a pivotal year for nuclear issues. In April, President Obama will host a special summit on nuclear security. In May, parties to the Nuclear Nonproliferation Treaty will gather in New York for a review conference and in June, at the G8 Summit hosted by Canada, nuclear proliferation issues will occupy a prominent place on the agenda. New challenges to the nuclear nonproliferation regime by countries such as North Korea and Iran and growing concerns about the possible appropriation of nuclear material by terrorist groups arise at a time when there is much talk about a major increase in the use of nuclear energy for civilian purposes.

This so-called "nuclear renaissance" was the starting point of the Nuclear Energy Futures project which was initiated in May 2006. The purpose of this project was three-fold:

- to investigate the likely size, shape and nature of the purported nuclear energy revival to 2030 – not to make a judgement on the merits of nuclear energy, but rather to predict its future;
- to consider the implications for global governance in the areas of nuclear safety, security and nonproliferation; and
- to make recommendations to policy makers in Canada and abroad on ways to strengthen global governance in these areas.

The project commissioned more than a dozen research papers, most of which have been published in CIGI's Nuclear Energy Futures Papers series; held several workshops, consultations and interviews with key Canadian and foreign stakeholders, including industry, government, academia and non-governmental organizations; convened two international conferences, one in Sydney, Australia, and one in Waterloo, Ontario; and participated in conferences and workshops held by others. The project has assembled what is probably the most comprehensive and up-to-date information on possible additions to the list of countries that have nuclear power plants for civilian purposes. Along with this Survey of Emerging Nuclear Energy States (SENES), the project has produced a compendium of all the nuclear global governance instruments in existence today which will, I believe, prove to be a valuable reference tool for researchers and practioners alike.

The project was generously funded and supported by The Centre for International Governance Innovation and was carried out in partnership with the Canadian Centre for Treaty Compliance (CCTC) at Carleton University, Ottawa. I was very fortunate to have found in Dr. Trevor Findlay, director of the CCTC, the perfect person to oversee this ambitious project. I am very grateful to him and his small team of masters students at the Norman Paterson School of International Affairs, especially Justin Alger, Derek de Jong, Ray Froklage and Scott Lofquist-Morgan, for their hard work and dedication.

The full report, written by Dr. Findlay, will be available online at www.cigionline.org (along with the Action Plan, commissioned papers and SENES). This overview presents the main findings and key recommendations.

Nuclear issues are quintessential global issues. Their effective management requires the collaboration of a broad range of actors. Canada, with its special expertise in nuclear technology and its long history of engagement in the construction of effective global governance in this area, is particularly well placed to help deal with the new challenges on the horizon. My colleagues and I hope that the findings and recommendations of the Nuclear Energy Futures Project will be of use to policy makers as they prepare for the important meetings which will be held later this year.

**Louise Fréchette**
Chair of the Nuclear Energy Futures Project
Distinguished Fellow,
The Centre for International Governance Innovation

# Introduction

There are signs of life in the nuclear power industry that have not been seen since the 1980s, driven by concerns about energy security and climate change and by a growing demand for electricity worldwide. Scores of states, including developing countries, have expressed interest in nuclear energy and some have announced plans to acquire it. Several existing nuclear energy states, notably in Asia, are already building new reactors, while others are studying the possibilities. There is certainly a revival of interest.

This study concludes, however, that on balance, a significant expansion of nuclear energy worldwide to 2030 faces constraints that, while not insurmountable, are likely to outweigh the drivers of nuclear energy. Globally, while the gross amount of nuclear-generated electricity may rise, the percentage of electricity contributed by nuclear power is likely to fall as other cheaper, more quickly deployed alternatives come online. An increase as high as a doubling of the existing reactor fleet as envisaged in some official scenarios seems especially implausible, given that it can take a decade of planning, regulatory processes, construction and testing before a reactor can produce electricity. While the numbers of nuclear reactors will probably rise from the current number, the addition of new reactors is likely to be offset by the retirement of older plants, notwithstanding upgrades and life extensions to some older facilities.

The economics are profoundly unfavourable and are getting worse. This will persist unless governments provide greater incentives, including subsidies for first entrants, and establish carbon prices high enough to offset the advantages of coal and to a lesser extent natural gas. Nuclear is not nimble enough to meet the threat of climate change in the short term. Demand for energy efficiency is leading to a fundamental rethinking of how electricity is generated and distributed that will not be favourable to nuclear. The nuclear waste issue, unresolved almost 60 years after commercial nuclear electricity was first generated, remains in the public consciousness as a lingering concern. Fears about safety, security and nuclear weapons proliferation also act as dampeners of a nuclear revival. In short, despite some powerful drivers and clear advantages, a revival of nuclear energy faces too many barriers compared to other means of generating electricity for it to capture a growing market share to 2030.

This might appear to imply that there should be no concerns about global governance of nuclear energy. Nothing could be further from the truth. The second major finding of this study is that the various regimes for nuclear safety, security and nonproliferation, despite improvements in recent years, are still inadequate in meeting existing challenges, much less new ones. They have all emerged in fits and starts across the decades, reacting to, rather than anticipating, threats and crises like Chernobyl, the dangers of nuclear terrorism post-9/11 and attempts to acquire nuclear weapons by Iraq, North Korea and Iran. The regimes are all under-funded, under-resourced, un-integrated and too often lacking in transparency and openness. The civilian nuclear industry tends to keep a wary distance from the regimes, while governments and international organizations often fail to consult and involve industrial and other stakeholders, including civil society. A revival of the nuclear industry on even a modest scale, even if limited to the existing nuclear energy states and a handful of inexperienced new ones, poses risks that should be anticipated and prepared for. In order to avoid mistakes made at the outset of the nuclear age, some of which led to disastrous results, steps must be taken now to strengthen global governance. One more major nuclear accident, one more state that develops nuclear weapons under the guise of generating electricity, or one more 9/11 but with nuclear weapons this time, is one catastrophe too many.

This Overview highlights the key findings of *The Future of Nuclear Energy to 2030 and its Implications for Safety, Security and Nonproliferation*. For the research, analysis, data and references that support the findings sketched in this Overview, see the full report at www.cigionline.org.

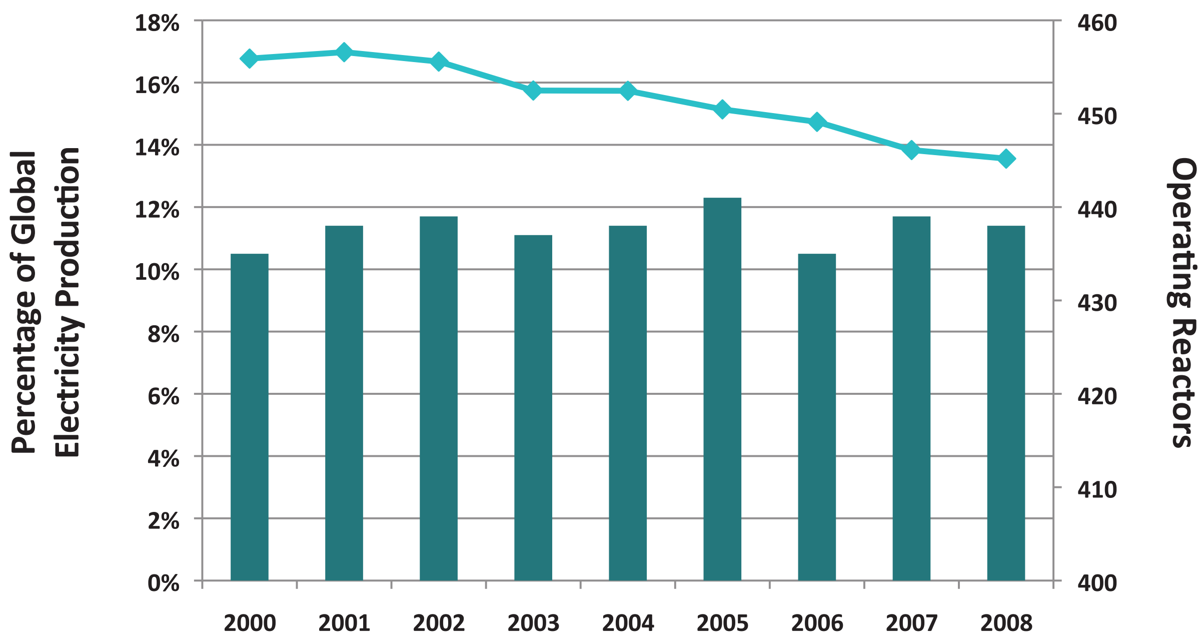
# The Future of Nuclear Energy to 2030

## The Revival so Far

If one dates the revival of interest in nuclear energy from 2000, it is clear a decade later that progress has been slow. Several countries, notably in East Asia, have begun building new reactors as part of ambitious nuclear energy programs, but many others have only announced intentions or plans, are studying the possibilities or are simply floating ideas. There has been, in fact, a decline in the contribution of nuclear power to world electricity production from 16.7 percent in 2000 to 13.5 percent in 2008. This level was only sustained due to capacity factor improvements in the existing fleet and extended operating licences, mostly in the United States. The International Atomic Energy Agency (IAEA) figure of 436 reactors as of December 2009 is eight units less than the historical peak of 444 in 2002. Five nuclear power reactors remain in long-term shutdown. Since commercial nuclear energy began in the mid-1950s, 2008 was the first year that no new nuclear plant was connected to the grid, although two were connected in 2009.

The industry is struggling to quickly reverse a profound stagnation that has occurred since the boom years of the 1970s and 1980s. The accidents at Three Mile Island in 1979 and Chernobyl in 1986 led to tightening of regulations and more prolonged and expensive approval processes that deterred investment and led to numerous cancelled orders. Cheaper oil and gas prices, along with perennially cheap coal, also played against the economics of nuclear power. The average age of operational nuclear power plants worldwide is now 25.5 years. Current

**Nuclear Reactor Numbers and Share of Global Electricity Production since 2000**




Source: Power Reactor Information System (PRIS), International Atomic Energy Agency. Accessed 3 December 2009. 'Electricity Generation' and 'Nuclear Energy – Consumption' in Statistical Review of World Energy 2009: Historical data, BP, June 2009.

reactors employ vintage technology and the sector until recently has exhibited poor industrial learning rates. Static growth has led to a low turnover of personnel and an ageing workforce that is now nearing mass retirement. There has been declining investment in nuclear education, training, and research and development in most countries and fewer nuclear science and engineering graduates worldwide.

At present, 52 reactors are under construction, but several are orders from previous eras; some are partially completed mothballed reactors on which work has resumed (like Argentina's); some are quite small and experimental (like Russia's floating reactors); and some have been on the IAEA's "under construction" list for years (especially in India and Russia). Reactor projects in Eastern Europe are essentially replacing old Soviet reactors shut down due to safety concerns. Most of the current activity — 30 reactors — is taking place in just four countries: China, India, Russia and South Korea. Only one country, Iran, is currently building its first power reactor, but construction began decades ago.

The reactors currently being built are mostly old-generation models. The only reactors in operation that are marketed as being "evolutionary" Generation III+ models are four General Electric/Hitachi Advanced Boiling Water Reactors (ABWR) in Japan that went online between 1996 and 2005. Two more of these are under construction in Taiwan and one in Japan.

Two additional types are under construction: two Areva Evolutionary Power Reactors (EPR), one in Finland and one in France; and the first Westinghouse Advanced Passive 1000 (AP-1000) reactor, construction of which commenced in China in 2009. No new Advanced CANDU (Canadian Deuterium-Uranium) Reactors (ACRs) have been ordered.

## Nuclear Power Plants Currently Under Construction

| Country | # of units | New nuclear capacity (MWe) | Existing units | % of Total Capacity |
|---|---|---|---|---|
| Argentina | *1 | 692 | 2 | 3.5% |
| Bulgaria | *2 | 1906 | 2 | 19.6% |
| China | 19 | 19920 | 11 | 1.3% |
| Finland | 1 | 1600 | 4 | 16.0% |
| France | 1 | 1600 | 59 | 54.4% |
| India | 6 | 2708 | 18 | 2.6% |
| Iran | *1 | 915 | 0 | 0.0% |
| Japan | 1 | 1325 | 54 | 17.7% |
| Pakistan | 1 | 300 | 2 | 2.4% |
| Russia | *9 | 6894 | 31 | 10.5% |
| Slovakia | *2 | 810 | 4 | 29.9% |
| South Korea | 6 | 6520 | 20 | 24.1% |
| Taiwan | *2 | 2600 | 6 | 12.6% |
| Ukraine | *2 | 1900 | 15 | 25.7% |
| United States | *1 | 1165 | 104 | 10.1% |
| **Total** | **55** | **50855** | | |

* Denotes construction on previously suspended projects.
Source: PRIS Database, IAEA. Last updated 12 January 2010.

## The Outlook to 2030

Plans for real "new build" have been announced by 19 of the 31 countries that already have nuclear power. Especially extensive are the intentions of China, India, Japan, Russia, South Korea, the UK and the US. However, close examination of each country's preparations and progress to date elicits caution. The national case studies commissioned by this project on major existing nuclear energy states (Canada, China, France, India, Russia, the UK and the US) expressed skepticism about their ambitious visions for expansion.

China has the most extensive plan of any country and is the only one likely to come close to fulfilling it. But it is starting from a very low base: even its most ambitious projections envisage an increase to just five percent of its electricity by 2020. Already there are concerns about costs, financing, and labour and material shortages, especially given the boom in building other types of power plants in China, notably for coal. India, now free of import constraints, may advance faster than in the past, but has never come anywhere near its previous outlandish targets. Even in the United States, seen as a bellwether of the nuclear revival following the launch of its Nuclear Power 2010 program in 2002, construction has not started on a single new reactor, despite loan guarantees and other subsidies for early entrants. Industry promoters predict that only four to eight new reactors will come online in the US by 2015 and then only if even bigger government loan guarantees materialize. Canada's plans for new build have so far come to naught, with cancellations by Ontario and hesitation in Alberta and Saskatchewan. France, already so well supplied with nuclear electricity that it exports it, is building just one new reactor. However, French companies Areva and Electricité de France are gearing up to export and operate reactors abroad. Russia has elaborate domestic and export schemes but faces significant barriers in realizing all of these. South Korea envisages relatively steady expansion of an already sizeable fleet of reactors and has export intentions that have already been realized with a sale to the United Arab Emirates (UAE).

Many existing nuclear energy states have no plans for expansion. Currently, of the European states that decided to phase out nuclear power after Chernobyl, only Italy has completely reversed its position, while Sweden has partly done so. With the electorate deeply divided, the current government in Germany plans only to extend the existing phase-out. South Africa has cancelled its expansion plans due to its financial situation. Australia, despite huge uranium deposits, continues to reject nuclear electricity.

A small number of new entrants may succeed in acquiring their first nuclear reactors by 2030, among them two European countries — Poland and Turkey. A handful of developing states, those with oil wealth and/or command economies, or special support from other countries, may be able to embark on a modest program of one or two reactors. The most likely candidates appear to be Algeria, Egypt, Indonesia, Jordan, Kazakhstan, the UAE and Vietnam, although some of these have envisaged acquiring nuclear reactors for decades and all face significant challenges in doing so now.

It is thus likely that expansion in nuclear energy to 2030 will be confined largely to the existing nuclear energy producers, plus a handful of newcomers. For the vast majority of states, nuclear energy will remain as elusive as ever.

## Technology Trends to 2030

Most "new build" to 2030 is likely to be Generation III+ light-water reactors, of 1,000 megawatt (MW) capacity and above, in order to achieve economies of scale. Three individual brands (Areva, Westinghouse/Toshiba and General Electric/Hitachi) are poised to dominate the global export market. Construction consortia, sometimes assembled by utilities like Electricité de France or new entrants like South Korea, are required, as no single company can currently build a nuclear power plant single-handedly. It is not clear whether Canada, India or Russia will succeed in exporting new reactor types.

New generation reactor technology promises to be more efficient, safer and more proliferation-resistant, but this remains to be demonstrated. Nuclear power will continue to prove most useful for baseload electricity in countries with extensive, established grids. Lifetime extensions and renovation will continue to prolong the life of existing reactors to 2030 and in some cases beyond: they are proving profitable since construction costs have long been written off and running costs, including for fuel, are low.

Large nuclear plants will continue to be infeasible for most developing states and other states with small or fragile electricity systems. Small reactors are still in the research and development stage and are unlikely to be widespread by 2030. A couple of pilot Generation IV reactors may be deployed by 2030, but nuclear fusion will remain completely elusive.

Uranium is unlikely to be in short supply and current cost advantages compared with coal and natural gas are likely to persist or increase (for nuclear power fuel is cheap but the plant expensive, the opposite for coal and natural gas). Price rises are likely to trigger more exploration and development of uranium resources, with Australia, Canada and Kazakhstan well placed to remain the major suppliers.

The "once through" fuel cycle will predominate, as will continuing interim storage of spent fuel and nuclear waste at reactor sites or in some cases at centralized storage facilities. No additional plutonium reprocessing capacity is likely to be necessary: the number of international customers for existing plants in France, Russia and the UK has been dwindling for years. Uranium enrichment will increase modestly to cater for some increased demand, but new entrants are likely to be deterred: enrichment plants are expensive, existing enrichers can simply add additional centrifuges to meet demand, and tightening export controls will likely amount to a permanent moratorium on exports of the technology.

Given the relative cheapness of uranium and the expense of reprocessing, advanced fuel cycles involving fast or breeder reactors will be rare, confined even by 2030 to a few states, probably only India, Japan and Russia. Even then, deployment will depend on resolving persistent difficulties with the technology. Such reactors are unlikely as in the past, to generate much electricity. Mixed oxide (uranium and plutonium) fuel, known as MOX, will continue to be used to take advantage of plutonium already reprocessed, but will not expand greatly, partly due to cost, but also to proliferation and security concerns. The thorium fuel cycle will not be viable by 2030.

# Assessing the Drivers and Constraints

Assessing the likelihood of a nuclear revival involves the tricky business of attempting to predict the collective and cumulative impact of scores of decision makers in various guises. These include governments and their constituents, electricity utilities, the nuclear industry, private and institutional investors, and international, regional and non-governmental organizations.

There is no scientific method for precisely predicting the outcome of such a complex process. This report is thus skeptical about linear projections of increased nuclear energy based on population increases, economic growth rates or electricity demand, sometimes combined with unquestioning extrapolations of governments' announced plans. These methods invariably ignore or discount political, financial and societal factors. Governments tend to exaggerate their nuclear energy expansion plans for political purposes, yet all face political, economic, technological and/or environmental challenges to their ambitions, sometimes including outright anti-nuclear sentiment, that need to be factored into any assessment.

The methodology adopted by this study has involved considering the balance of the main drivers and constraints (listed on page 14) on the various stakeholders. This summary report focuses on only the most powerful constraints since they are what make the crucial difference. For a more complete analysis, consult the main report.

### Nuclear Energy Drivers and Constraints

**Drivers**

- The urgent need to "decarbonize" the world's energy supply to deal with global warming using relatively carbon-free nuclear power
- The energy demands of China, India and other emerging economies and projected increased electricity demand in most countries
- The search for energy security or diversity: to avoid recurrent spikes in oil and natural gas prices and fears about availability over the long term, compared with readily available, comparatively cheap uranium
- The newly profitable, but rapidly ageing existing nuclear reactor fleet
- The promise of new reactor technologies: Generation III, III+ and IV and small and medium-size reactors
- Promotion of a revival by industry, government and international organizations
- Rising public support in some countries
- Political motivations: national prestige, a desire to demonstrate technological prowess; a predisposition towards high-profile, large-scale projects; competition with other states
- Nuclear weapons "hedging"

**Constraints**

- Economics:
  - Rising overnight costs of nuclear power plants
  - Effects of deregulated electricity markets on competitiveness
  - Unfavourable or highly uncertain levelized electricity cost comparisons with other baseload sources: coal and natural gas
  - Unfavourable "carbon cost" comparisons with alternative energy sources: conservation, efficiency and renewables
  - Construction delays and cost overruns
  - Mixed or uncertain impact of carbon pricing and subsidies
  - Cost of nuclear waste management and decommissioning
- Industrial bottlenecks/personnel constraints
- Nuclear waste management and disposition
- Public and expert concern about safety, security and weapons proliferation
- Additional constraints on aspiring developing countries: governance, infrastructure, finance, and technology export controls.

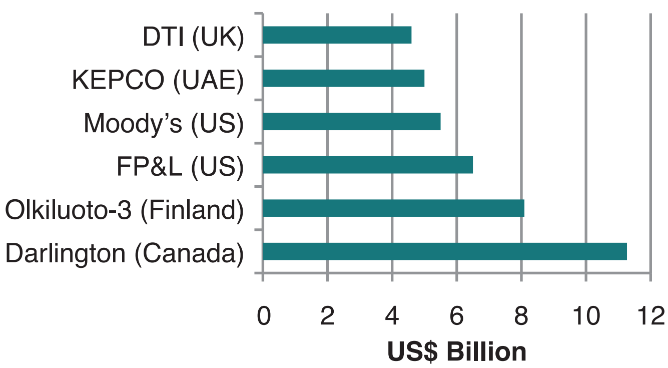
# Nuclear Economics

Most promoters and critics agree that the economics of nuclear power is the single most important constraint on nuclear expansion. Nuclear power plants are large construction projects with dauntingly high up-front costs. The cost of capital is also steep due to the risk involved. The economics are worsening rather than improving, especially as a result of the recent global financial and economic turmoil.

## Rising construction costs

Since 2003, construction costs for all types of large-scale engineering projects have escalated dramatically due to increased prices for materials (iron, steel, aluminum and copper), rising energy costs, tight manufacturing capacity and increases in labour costs. But the costs of nuclear plants have been rising disproportionately. While some costs may currently be falling again due to the global economic downturn, they are likely to rebound as demand from China, India, Japan and others begins to increase once more. Some price rises are unique to nuclear power due to shortages of reactor components, notably large forgings for nuclear reactor vessels.

### Cost Estimates of Recent Nuclear Build (per unit)




Sources: 'Olkiluoto 3 losses to reach €1.7 billion', World Nuclear News, 26 February 2009. NEA, Nuclear Energy Outlook 2008, 80. '26B cost killed nuclear bid', Toronto Star, 28 July 2009. Moody's Corporate finance, Special Comment, October 2007. Joe Romm, 'The Self-Limiting Future of Nuclear Power', Center for American Progress Action Fund, Washington DC, June 2008.

## EFFECTS OF DEREGULATION

Unlike the 1970s and 1980s, most developed countries and several developing ones now have deregulated or partially deregulated electricity markets. Utilities can no longer secure guaranteed high prices or pass cost increases onto customers. Private investors and electricity utilities must now base investment decisions on projected levelized costs and likely rates of return compared to other alternatives. No new nuclear power plant has yet been built and operated in a liberalized electricity market, although Finland is attempting the first. Even in non-competitive markets like China, where it might be thought that public funding is assured, the economics are considered important.

## COMPARISONS WITH TRADITIONAL BASELOAD POWER ALTERNATIVES

Competitive energy markets tend to heighten the disadvantages of nuclear compared to its traditional baseload power competitors. Coal and natural gas plants are cheaper and quicker to build, they win regulatory approval more easily, are more flexible electricity generators (they can be turned on and off easily) and can be of almost any size. Nuclear plants take up to a decade to plan, win regulatory approval and build, their up-front costs are huge and they are inflexible generators that need to be large and kept operating at full power to be economic. A 2003 study by the Massachusetts Institute of Technology (MIT), the most sophisticated and widely cited study on the future of nuclear power, updated in 2009, concluded that nuclear is not an economically competitive choice. It is more expensive than coal and Combined Cycle Gas Turbine (CCGT) generation, even at high natural gas prices. Since the 2009 update, natural gas prices have plummeted due to newly accessible reserves in shale, an indication of the energy volatility that nuclear power has to cope with.

### Costs of Electric Generation Alternatives

| | Over-night Cost | Fuel Cost | Base Case | With carbon charge $25/ton $CO_2$ | With same cost of capital as coal/gas |
|---|---|---|---|---|---|
| | $/kW | $/million BTU | ¢/kWh | ¢/kWh | ¢/kWh |
| **2003** (2002 USD) | | | | | |
| Nuclear | 2,000 | 0.47 | 6.7 | n/a | 5.5 |
| Coal | 1,300 | 1.20 | 4.3 | 6.4 | n/a |
| Gas | 500 | 3.5 | 4.1 | 5.1 | n/a |
| **2009** (2007 USD) | | | | | |
| Nuclear | 4,000 | 0.67 | 8.4 | n/a | 6.6 |
| Coal | 2,300 | 2.60 | 6.2 | 8.3 | n/a |
| Gas | 850 | 7.00 | 6.5 | 7.4 | n/a |

Source: Adapted from "Update of the MIT 2003 Future of Nuclear Power Study", Massachusetts Institute of Technology, 2009, p. 3. See source for original assumptions on which the calculations are based.

To be truly economic (without subsidies or other market distortions), nuclear power projects need to attract a discount rate (the cost of capital) below 10 percent. But it can rise as high as 15 percent due to the risk involved compared with other energy technologies. Even accounting for currency conversion distortions, the range of cost estimates is enormous, further illustrating the complexity of the decisions facing potential investors in nuclear energy.

### Results of Recent Studies on the Cost of Nuclear Power

| Study | Year | Original Currency | Cost of Capital | Overnight Cost (per kW) | | Generating Cost (per MWh) | |
|---|---|---|---|---|---|---|---|
| | | | | Original | 2000 USD | Original | 2000 USD |
| Massachusetts Institute of Technology (MIT) | 2003 | USD | 11.5% | 2000 | 1869 | 67 | 63 |
| Tarjamme and Luostarinen | 2003 | EUR | 5.0% | 1900 | 1923 | 24 | 25 |
| Canadian Energy Research Institute | 2004 | CAD | 8.0% | 2347 | 1376 | 53 | 31 |
| General Directorate for Energy and Raw Materials, France | 2004 | EUR | 8.0% | 1280 | 1298 | 28 | 28 |
| Royal Academy of Engineering | 2004 | GBP | 7.5% | 1150 | 725 | 23 | 15 |
| University of Chicago | 2004 | USD | 12.5% | 1500 | 1362 | 51 | 46 |
| IEA/NEA (High) | 2005 | USD | 10.0% | 3432 | 3006 | 50 | 41 |
| IEA/NEA (Low) | 2005 | USD | 10.0% | 1089 | 954 | 30 | 25 |
| Department of Trade and Industry (DTI), (UK) | 2007 | GBP | 10.0% | 1250 | 565 | 38 | 18 |
| Keystone Center (High) | 2007 | USD | 11.5% | 4000 | 3316 | 95 | 89 |
| Keystone Center (Low) | 2007 | USD | 11.5% | 3600 | 2984 | 68 | 63 |
| MIT Study Update | 2009 | USD | 11.5% | 4000 | 3228 | 84 | 78 |

Source: Adapted from Table 8.1, 'Results of recent studies on the cost of nuclear power', *Energy Technology Perspectives 2008*, International Energy Agency, OECD Publishing, Paris, 2008, p. 290. Historical exchange rates adopted from Table B-110, 'Foreign exchange rates, 1985-2008', Economic Report of the President, US Government Printing Office, Washington DC, 2009. GDP deflator figures adopted from Table 10.1, 'Gross Domestic Product and Deflators Used in the Historical Tables: 1940–2014', Budget of the United States Government (FY 2010), US Government Printing Office, Washington DC, 2009.

## Construction Delays and Cost Overruns

While most major engineering and construction mega projects like bridges, tunnels and Olympic stadiums take longer to build and cost more than originally estimated, nuclear reactor construction delays and cost overruns are legion. The average nuclear plant construction time increased from 66 months in the mid-1970s to 116 months (nearly 10 years) between 1995 and 2000. Since 2000, there has been a decline, with faster construction times in Asia, but average construction time remains at seven years. Because the cost of capital for nuclear power plants is so high, delays can have huge effects on investor return and profitability — which are less tolerated in a competitive electricity market. The Areva EPR currently being built in Finland, the first of its kind, is over three years behind schedule and more than 50 percent over budget.

## The "first-of-a-kind" (FOAK) Dilemma and Government Assistance

While trumpeting the "new economics" of third-generation nuclear reactors, the nuclear industry in many countries is seeking government assistance or preferential treatment for first-of-a-kind plants in the hope that they will lead to a flood of orders and production-line techniques that will produce economies of scale. The

MIT study advocated government subsidies for FOAK (along with carbon pricing) as the only way to make nuclear economic. Most governments, burned by past experience, constrained by deregulated markets, facing demands for a level playing field for different energy technologies and strapped for cash in the current economic downturn, are reluctant to provide subsidies.

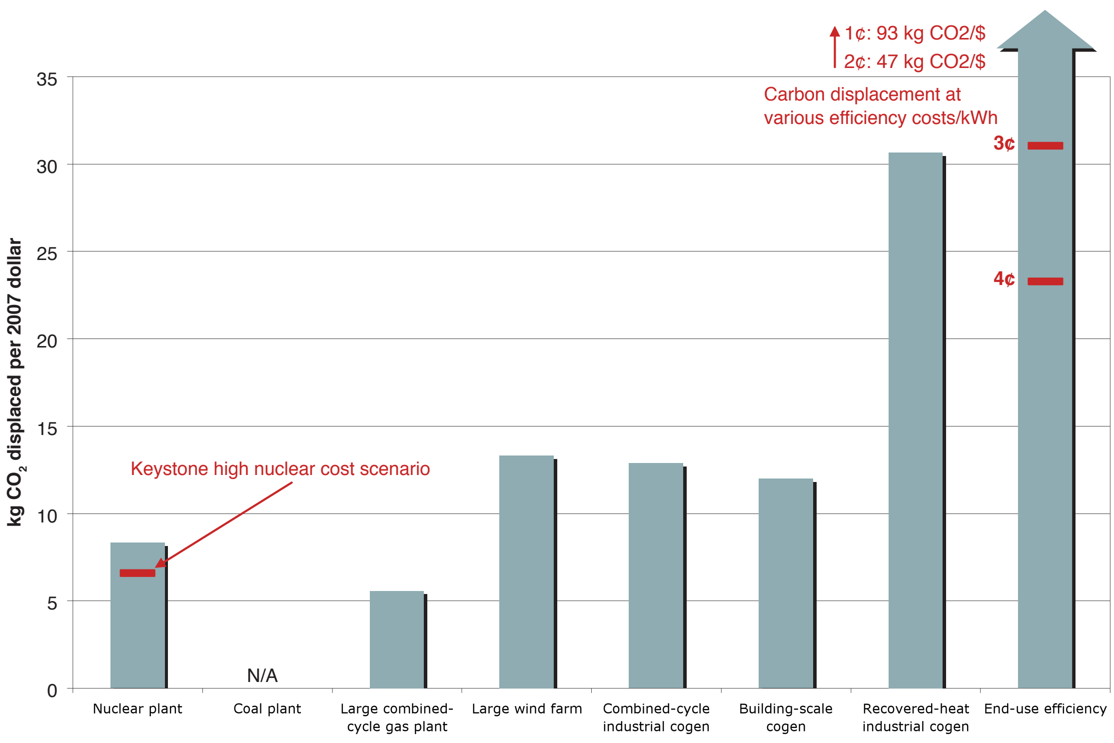
## Cost Comparisons with Non-traditional Alternatives

One of the arguments used for increasing the use of nuclear energy is that there are no other relatively carbon-free alternatives for providing reliable baseload power, especially for large urban areas. Yet some alternatives, such as conservation and efficiency, reduce demand for baseload power altogether, as has happened in California and Ontario. Others, such as solar, wind and biofuels, seek to replace baseload power, but face problems that include intermittency of supply (wind and solar); the need for enormous tracts of land (wind, solar, biofuels) and energy storage (battery technology is currently inadequate). Other technologies, such as "clean coal" and carbon capture and storage (CCS) are unproven. However, research and development is proceeding at such a pace for most of these alternatives that improvements in performance and cost will likely arrive faster than for nuclear technology — which has traditionally demonstrated poor learning rates and slow deployment. Moreover, traditional electricity grids with large centralized generating plants that favour nuclear are being increasingly viewed as an outmoded twentieth century model that will be superseded by "smart grids," with greater use of "distributed generation" from smaller plants closer to consumers.

## Tackling Climate Change

One of the seemingly plausible arguments in favour of a crash program of nuclear energy is that climate change is

**Coal-fired CO2 Emissions Displaced per dollar Spent on Electrical Services**




Source: Reprinted (with permission) from Amory Lovins and Imran Sheikh, "The Nuclear Illusion", 27 May 2009, http://www.rmi.org/cms/Download.aspx?id=1366&file=E08-01_AmbioNucIllusion.pdf.

so potentially catastrophic that every means possible, including relatively carbon-free nuclear energy, should be deployed, regardless of cost. Yet it would take decades for nuclear to make significant inroads into carbon emissions even in the best of circumstances. Since resources for tackling climate change are not unlimited, choices must be made based on efficacy and cost, especially if government subsidies are being sought. According to research by Amory Lovins (see chart on page 17) , nuclear is more expensive than any technology except traditional gas-fired plants (operating at high gas prices) in terms of displaced carbon emissions from coal plants.

The pricing of carbon through taxes and/or a cap-and–trade mechanism would improve the economics of new nuclear build compared with coal and gas, but it will also favour such alternatives as conservation, efficiency, carbon sequestration and renewables. As the December 2009 Copenhagen Climate Change Summit demonstrated, a global climate change regime that puts a predictable, stable price on carbon is years away, although governments and regions may implement their own mechanisms.

### Industrial Bottlenecks and Personnel Constraints

Compounding the economic challenges of nuclear energy is a lack of industrial capacity and personnel constraints. The rate at which countries can ramp up a nuclear energy program will vary. The US has a particularly flexible economy that responds quickly to market opportunities, while semi-command economies, like those of China and Russia, may be able to direct resources where needed. In between these extremes lie other countries that will prove less nimble. Over the medium term, the industry itself will undoubtedly ramp up in response to clear demand. Yet it faces a classic investment catch-22: it will have to be convinced of the likelihood of a major revival before investing in the necessary specialized and expensive production capacity to make one possible. The other uncertainties surrounding the future of nuclear electricity make this a tricky balancing act.

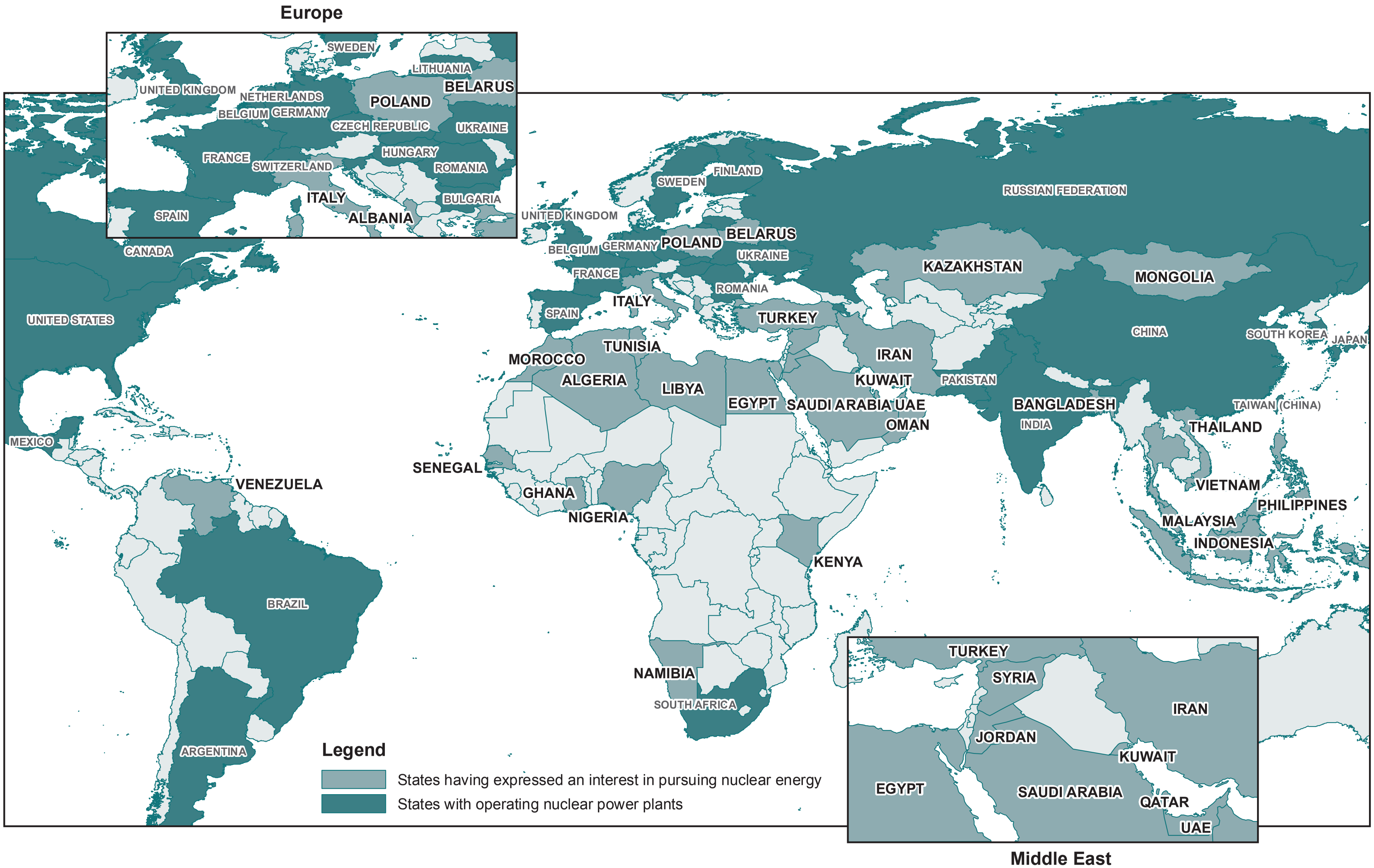
## Nuclear Waste

The final major constraint on a global expansion of nuclear energy is the abiding controversy over high-level nuclear waste disposal. The principal proposed long-term solution, which attracts close to scientific consensus, is deep geological burial. Almost six decades after commercial nuclear energy was first generated, not a single government has succeeded in opening such a repository for civilian high-level nuclear waste. Plans for a site at Yucca Mountain in Nevada have run aground due to persistent political opposition. Currently, only Finland and Sweden are well advanced and could have their repositories operating by 2020, followed by other European countries in the 2030s and 2040s. For new entrants in the nuclear power business, with just one or two reactors, establishing their own nuclear waste repositories is likely to be prohibitive on grounds of cost and capacity.

The lack of disposal options for waste that may last thousands of years could spur opposition to nuclear energy in new entrants, as it still does in some existing nuclear energy states. To deal with the waste problem, international cooperation will be necessary in the form of regional repositories or nuclear waste "take back" schemes. But there is great sensitivity in all countries, with the apparent exception of Russia, about becoming a nuclear waste dump. An evolving approach, pioneered by Canada and Sweden, is a comprehensive national consultation aimed at reaching consensus on a long-term nuclear waste management strategy. Canada's three-year process of citizen engagement resulted in an agreed plan for "adaptive phased management" that could be a model for others.

## Current and Aspiring Nuclear Energy States

(Aspiring Nuclear Energy States in Bold)




Source: Survey of Emerging Nuclear Energy States (SENES), Centre for International Governance Innovation, http://cigionline.org/senes. Power Reactor Information System, International Atomic Energy Agency (IAEA). Accessed 24 November 2009.

# Special Barriers for Aspiring Nuclear Energy States

New entrants to the nuclear energy business face particular barriers to entry that reinforce skepticism about the likelihood of a significant nuclear energy expansion by 2030. This project's *Survey of Emerging Nuclear Energy States* (SENES) (www.cigionline.org/senes) tracks progress made by aspirant states from the first official announcement of interest to the connection of a nuclear power plant to the country's electricity grid.

SENES reveals that 33 states, plus the members of the Gulf Cooperation Council (GCC) collectively, have announced a "consideration" or "reconsideration" of nuclear energy at a credible ministerial level since 2000. Only three, Italy, Poland and Turkey, are considered developed countries. The first two have good prospects of succeeding in their acquisition plans, Turkey less so. Of the remainder, which are almost all developing countries, several are wealthy enough due to oil income to be able to afford a nuclear reactor on a turnkey basis, including Algeria, Indonesia, Libya, Nigeria, Venezuela and the Gulf States, notably Saudi Arabia and the UAE. But all SENES developing countries, with the sole exception of Iran, lack an indigenous capacity at present to even operate, regulate and maintain a single nuclear reactor, much less construct one. The Philippines has a partially completed reactor in a seismically-active area which it may resume work on. Among the SENES developing states, as of January 2010 only Egypt, Turkey and the UAE are known to have invited bids for a plant. The UAE has just accepted a bid from a South Korean consortium, while Turkey has recently cancelled the initial bid and restarted the process.

Many SENES states have taken some preliminary steps towards acquiring nuclear energy, such as consulting the IAEA and establishing an atomic energy commission and/or nuclear regulatory authority. But these are the easiest steps and imply nothing about actual capability. Such countries would need to make unprecedented progress in their governance, infrastructure and economic situation before nuclear power becomes a feasible option, as revealed by several measurable indicators researched as part of this study.

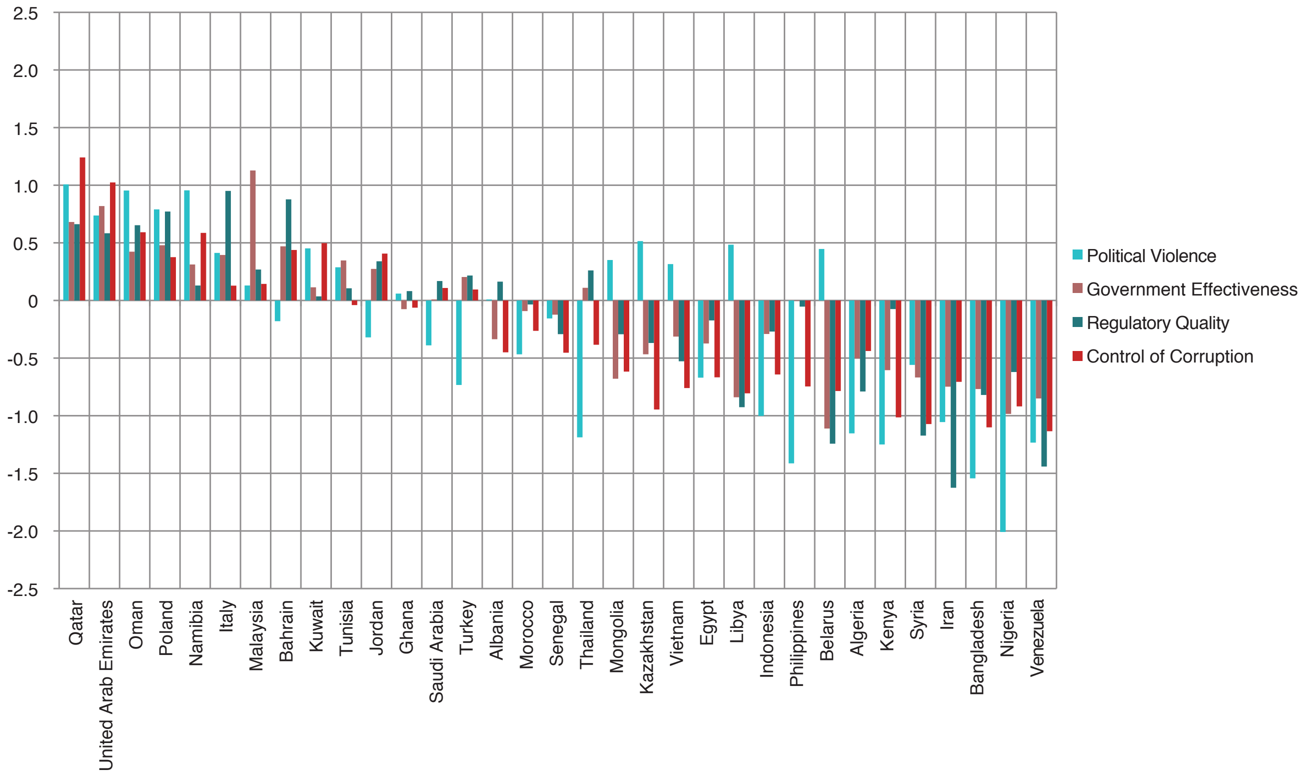
## Governance

A country's ability to run a nuclear power program safely and securely is dependent on its capacity to successfully and sustainably manage a large and complex project stretching over decades — from planning to decommissioning. This includes nuclear waste management, essentially in perpetuity. Vital requirements are an effective nuclear regulatory infrastructure and a good safety and security culture. These are not built overnight. Many aspiring nuclear energy states struggle with poor governance, corruption, the threat of terrorism and civil unrest. While one alternative is to buy an entire nuclear infrastructure, including operators and regulators, only the wealthy oil-rich states like the UAE will be able to afford this route.

## Infrastructure

A second major barrier is having the physical infrastructure to support a nuclear power plant. The IAEA's *Milestones in the Development of a National Infrastructure for Nuclear Power* lists hundreds of infrastructure targets — including physical infrastructure — that aspiring nuclear states should meet before even considering whether to commission a nuclear plant. These include roads, transportation, a safe and secure site, supporting power generators, a large water supply and waste management facilities. Reaching just a fraction of these

## Governance Indicators for SENES States, 2008




Source: Ratings from 'Worldwide Governance Indicators: 1996-2008', World Bank, 2009, http://info.worldbank.org/governance/wgi/index.asp.

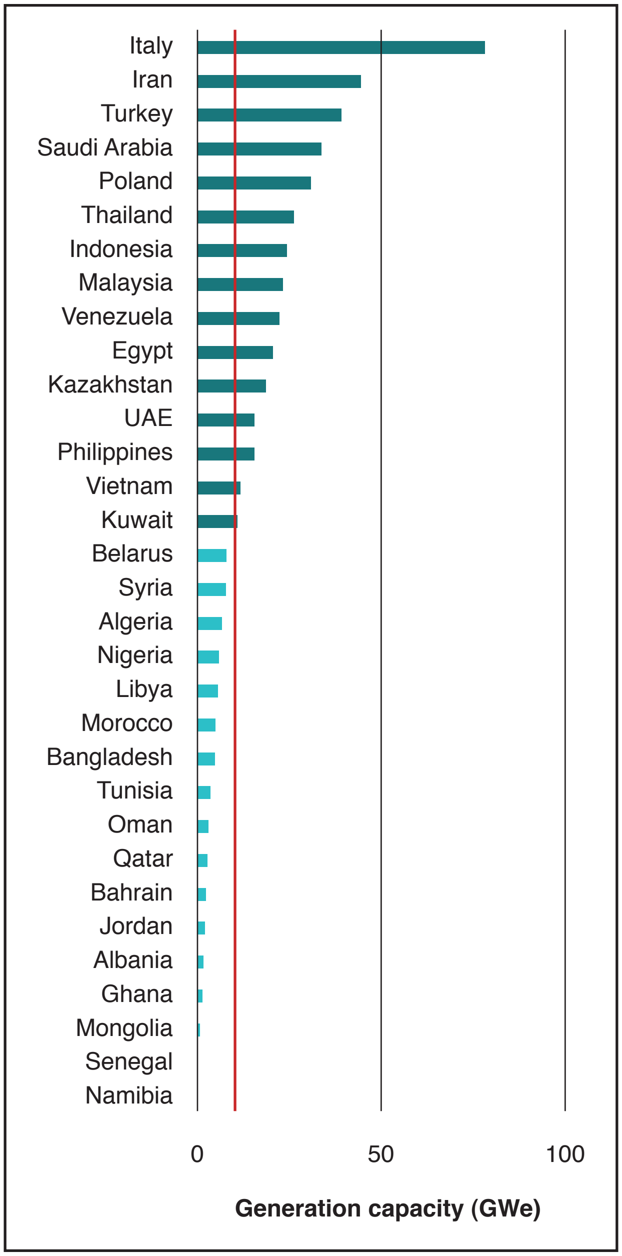
milestones, requiring them to invest billions of dollars on infrastructure upgrades for several years, will be impossible for most SENES states.

One telling measure of a country's preparedness for nuclear power is the size of its existing electricity generating capacity. The IAEA recommends that a single nuclear power plant should represent no more than 10 percent of the total installed national generating capacity. This is to ensure that stability of the grid is not jeopardized. For a 1,000 MW nuclear power plant, a state would have to have an existing capacity of 9,000 MW. Only 15 of the 33 SENES states currently have such capacity.

## Economic Situation

A third significant barrier that impedes a state from realizing its nuclear plans is finance. The possibility that a single nuclear reactor could cost up to US$10 billion illustrates the problem. There is no precise way to measure whether a country can afford a nuclear power plant, especially since decisions may be driven by politics rather than financial analysis or rational energy strategy. Where private capital is unwilling to invest, governments may do so. States with a low Gross Domestic Product (GDP) and a poor credit rating (or none at all) are unlikely to be able to raise a commercial loan for nuclear power. Development banks currently refuse to provide loans for such purposes and foreign aid is unlikely to be available. The only developing countries that may be able to ignore such constraints are those with oil-based wealth.

## Installed Electricity Generation Capacity for SENES Countries (2005)




Source: US Energy Information Administration, International Energy Statistics, http://www.eia.doe.gov/ (accessed 22 July 2009).

## SENES States' GDP and Credit Ratings

| State | 2007 GDP (billion USD) | Credit Rating |
|---|---|---|
| Italy | 1,834.00 | A+ |
| Turkey | 893.10 | BB- |
| Indonesia | 863.10 | BB- |
| Iran | 790.60 | |
| Poland | 636.90 | A- |
| Saudi Arabia | 553.50 | AA- |
| Thailand | 533.70 | BBB+ |
| Egypt | 414.10 | BB+ |
| Malaysia | 367.80 | |
| Venezuela | 357.90 | BB- |
| Nigeria | 318.70 | BB- |
| Philippines | 306.50 | BB- |
| Algeria | 228.60 | |
| Vietnam | 227.70 | BB |
| Bangladesh | 213.60 | |
| Kazakhstan | 171.70 | BBB- |
| UAE | 171.40 | AA |
| Kuwait | 137.40 | AA- |
| Morocco | 129.70 | BB+ |
| Belarus | 104.50 | B+ |
| Syria | 90.99 | |
| Libya | 83.59 | |
| Tunisia | 78.21 | BBB |
| Qatar | 76.75 | AA- |
| Oman | 62.97 | A |
| Ghana | 32.02 | B+ |
| Jordan | 29.07 | BB |
| Bahrain | 25.17 | A |
| Senegal | 20.92 | B+ |
| Albania | 20.57 | |
| Namibia | 10.87 | |
| Mongolia | 8.70 | |

Sources: GDP figures from Central Intelligence Agency, *World Factbook 2007*, Washington DC, 2007; credit ratings from Standard and Poor's, New York, December 2009.

# Implications for Global Governance

The implications for global nuclear governance of the less-than-dramatic increase in nuclear energy projected by this report are obviously not as alarming as they would be if a full-bore revival were imminent. Nonetheless, they are sufficiently serious to warrant attention now, especially as many aspects of the nuclear regime are today not optimally effective or are under threat. Indeed, the slow pace of nuclear energy expansion gives the international community breathing space to put in place the necessary reform of global governance arrangements. The following are the critical questions:

- **Safety:** How can we commit all current and aspiring nuclear energy states to the highest nuclear safety standards?
- **Security:** How can we ensure nuclear material and equipment are secure everywhere and not accessible by terrorists or subject to terrorist attack?
- **Nonproliferation:** How can we prevent a nuclear revival contributing to proliferation of nuclear weapons, especially through the spread of sensitive technologies?

# Nuclear Safety

Nuclear safety standards have markedly improved since the wake-up call of the 1986 Chernobyl accident and its dramatic demonstration of radioactive cross-boundary effects. Old Chernobyl-style reactors have been closed, other Soviet types retrofitted for better safety, international conventions negotiated and international standards clarified and promoted. Industry itself has become more safety conscious, aware that a major nuclear accident anywhere is a major accident everywhere and could kill prospects for a revival. Reactor designers are seeking inherently safe designs (which require no human intervention in case of a malfunction) for new-generation reactors and considering strengthening them against aircraft crashes, for instance.

Still, alarming incidents continue to occur even in a well-regulated industry like that of the US. A lack of transparency prevents outsiders from knowing the true state of many countries' civil nuclear installations. The danger is that new entrants will be unaware of and unprepared for their safety responsibilities, have no safety culture and be too poorly governed to enforce safety regulations.

Global and national nuclear safety thus needs to be a permanent work in progress, and complacency and regression avoided.

The current global governance regime for nuclear safety is complex, sprawling and based on a variety of treaties and implementation mechanisms that have arisen in different eras to meet particular needs. It does, however, now seem to have all of the necessary components in place, with the exception of legally binding safety agreements for fuel cycle facilities (and research reactors).

To cope with increased use of nuclear energy, the nuclear safety regime does not need wholesale reform or major additions, but rather universal adherence to existing treaties; enhancement and rationalization of existing mechanisms; and increased human and financial resources, including for regulatory purposes.

### Main Elements of the Nuclear Safety Regime

- 1994 Convention on Nuclear Safety and its review meetings
- 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste and its review meetings
- 1986 Convention on Early Notification of a Nuclear Accident
- 1986 Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency
- The International Nuclear Accident Liability Regime (various conventions and protocols)
- International Atomic Energy Agency (IAEA) Safety Standards and Technical Assistance and Services, especially:
    - Operational Safety Review Teams (OSART)
    - Peer Review of the Effectiveness of the Operational Safety Performance Experience Review (PROSPER)
    - Integrated Regulatory Review Service
- International Nuclear Safety Group (INSAG)
- International Commission on Radiological Protection
- World Association of Nuclear Operators (WANO) and its peer-review process
- Regional networked databases in Asia and Latin America
- Other industry bodies, notably the US Institute for Nuclear Power Operations (INPO) and its peer review process
- Nuclear Energy Agency (NEA)/IAEA Multinational Design Evaluation Program (MDEP)
- International Nuclear Regulators Association (INRA)

## Increasing Adherence to and Entry into Force of the International Conventions

While most existing nuclear energy states are party to the main safety conventions, there are yawning gaps in adherence by aspirant states that need to be filled before they acquire nuclear power plants. Worryingly, four SENES states — Bahrain, Kenya, Namibia and Venezuela — are party to none of them.

The nuclear liability regimes — two competing ones originating, respectively, in the IAEA in Vienna and the Organisation for Economic Co-operation and Development (OECD) in Paris — are in particularly poor shape despite attempts at rationalizing and integrating them. They have so few parties that some protocols have not yet entered into force years after they were negotiated and the international funds they purport to set aside are alarmingly inadequate for a major nuclear accident. These regimes should be repaired and further integrated urgently.

## Making the Regime More Legally Binding and Subject to Verification

The international nuclear safety conventions currently set out general legally binding undertakings and general safety principles. Implementation of IAEA standards derived from such generalities are left up to each state. The question arises whether such standards should be made legally binding and compliance with them verified by international inspectors as in the case of nuclear safeguards.

While superficially appealing and logical, it is not clear that making standards legally binding would help, even if it were politically possible. They are arrived at through a consultative process among states and are increasingly recognized as essential, so there is peer pressure to comply. They are also subject to periodic revision based on experience; they are not all applicable to all types of existing, let alone future reactors; and they often are open to legitimate interpretation in their application. Each country's safety regime must fit its own national legal, economic and cultural circumstances if it is to be truly effective and must primarily be the responsibility of the national regulator. Moreover, it is unlikely that compliance would be any greater without the addition of an enforcement mechanism, which states would likely oppose. Finally, an egregious safety record is less likely to be due to willful intent than a lack of government attention to the problem, poor national governance generally, substandard technical or institutional capacity and insufficient funds. All of these challenges are better solved with international technical assistance than international enforcement.

As for verification, the nuclear safety regime relies on a different model — peer review — which appears to work surprisingly well. It includes review meetings for the main treaties and peer-review services offered by the IAEA, the World Association of Nuclear Operators (WANO) and national bodies like the US Institute for Nuclear Power Operations (INPO). States are under considerable pressure during these processes to demonstrate a good safety record to their peers. Compliance is high and improvements are being made. Constant reinforcement of the regime should occur to emphasize to newcomers that peer reviews and IAEA review services are essential, if not mandatory. This could be done through politically binding decisions of the parties to the various conventions and IAEA counseling of new entrants as to their responsibilities.

## Closer Cooperation between the IAEA, Industry and other Stakeholders

As in other areas of global nuclear governance, there is a distance between the IAEA and industry that needs closing. There are, for instance, two separate nuclear plant peer-review systems and two separate incident notification systems, run by the IAEA and WANO, respectively. The lack of integration between them creates duplication of effort, unnecessary expense and lost opportunities. Consideration should be given to increasing cooperation between the peer-review systems and integration of the notification systems in order to strengthen nuclear learning overall. One particularly effective example of government/industry cooperation appears to be the Multinational Design Evaluation Program that is seeking harmonization of regulatory approaches to new reactor designs. This work deserves continued support from all relevant stakeholders.

The existing international processes for sharing lessons learned and positive experiences are inadequate, do not involve all states and all other stakeholders and suffer from a lack of transparency and openness. There are numerous players which either act independently of, or only in partial cooperation with, the IAEA, such as various "clubs" of regulators. Differences in safety philosophy, which may be one barrier, should not be permitted to stand in the way of cooperation, but should be used to increase mutual understanding of different approaches and, potentially, produce harmonization. All stakeholders need to be drawn more closely into collaborating in the international regime.

## Strengthening the Role of the IAEA

The Agency's role as the global "hub" of nuclear safety has been steadily enhanced and become paramount since Chernobyl. In addition to acting as the Secretariat for all of the new safety-related conventions, its key activities are: setting and promoting safety standards; safety advisory missions; managing a peer-review system and providing technical assistance in nuclear safety. It manages an extraordinary number of programs, measures and arrangements to guide, advise and assist states. The prospects of a nuclear revival, even one restricted to the existing nuclear energy states, plus a few new entrants, will place added responsibilities and burdens on the IAEA that it will not be able to cope with unless furnished with additional resources — technical, financial and human. A flood of new entrants to nuclear energy could overwhelm the Agency and jeopardize nuclear safety worldwide.

### Select Recommendations

- Establish an IAEA program to promote the earliest possible accession by potential new nuclear energy states to all nuclear safety-related international conventions and protocols.
- Negotiate new legal instruments dealing with the safety of fuel cycle facilities and research reactors to fill a lacuna in the current legal regime.
- Strengthen implementation of the Convention on Nuclear Safety, including by increasing IAEA involvement in peer-review processes and making them more transparent to the public; broadening the scope of national reports; and defining the requirements for regulatory independence.
- Create momentum for peer and IAEA reviews to become mandatory by politically binding decisions of the CNS and Joint Convention parties at their next review conferences.
- Fix the currently inadequate international feedback/lessons learned process for nuclear safety, by establishing a Global Nuclear Safety Network, led by the IAEA, involving reactor vendors, operators, regulators and all other stakeholders in nuclear safety; this should be more than just a web-based network and involve strengthening the IAEA's role as an information hub.
- Establish an international nuclear regulators' organization with universal membership to supplement or replace the current self-appointed "clubs."
- Continue to pursue the harmonization of safety standards for new reactor designs, especially through the MDEP process.
- Mount a joint campaign by the IAEA and the OECD/NEA to increase accessions to their nuclear liability instruments to enable them to enter into force and trigger the provision of the necessary international funding; the two organizations should work together to decrease fragmentation of the regime.

## Nuclear Security

Since the terrorist attacks of September 11, 2001, there has been heightened concern that nuclear power plants or other facilities may make tempting targets for saboteurs, or that nuclear materials may be purloined for use in nuclear weapons or radiological weapons (also known as radiological dispersal devices (RDDs)).

One difficulty in dealing with such threats through global governance is that nuclear security is considered the exclusive preserve of sovereign states in a way that nuclear safety is not. As nuclear security and radiological protection measures necessarily involve key national functions such as law enforcement and control over access to information, states are understandably reluctant to expose their security and law enforcement practices to external scrutiny, let alone anything resembling external regulation.

The international nuclear security regime, if it can even be so described, is not yet ready for any form of nuclear revival that goes much beyond the existing nuclear energy states. It is newer and much less developed than those for safety and nonproliferation (although related to and mutually reinforcing of both). As in the case of nuclear safety, many (although not all) existing nuclear energy states are well practised at ensuring security for their nuclear materials and facilities. Incidents have been rare.

### Main Elements of the Global Nuclear Security Regime

- 1980 Convention on the Physical Protection of Nuclear Material (CPPNM)
- 2005 Amendment to the CPPNM
- 2007 International Convention for the Suppression of Acts of Nuclear Terrorism
- Security Council Resolution 1540 (April 2004)
- IAEA role:
  - Nuclear security standards, recommendations and advisory services
  - Three-Year Plan of Activities to Protect Against Nuclear Terrorism
  - Nuclear Security Fund
  - IAEA Illicit Trafficking Database
- Global Initiative to Combat Global Terrorism
- World Institute of Nuclear Security (WINS)

New entrants will, however, lack the necessary security capability and experience, including legislative and regulatory framework, customs and border security, security culture and enforcement capacity, including rapid response. Poor governance generally, and corruption and crime in particular, will be barriers to quickly meeting these requirements. A sizeable nuclear energy expansion risks catastrophe unless governance, both national and international, deals with nuclear security threats competently and effectively.

## Ensuring Implementation of Security Conventions

The international conventions in this field are not remotely universal in adherence and application. Significant numbers of SENES states are not party to them. The main pillar of the regime is the Convention on the Physical Protection of Nuclear Material. An Amendment to this Convention is a vital new measure, since it will oblige states to implement physical protection measures domestically, not just during international transport as the existing Convention requires. But the Amendment is not yet in force. The most recent treaty, the International Convention for the Suppression of Acts of Nuclear Terrorism, is a useful addition to international law in this field by seeking to criminalize individual acts and ensure a degree of uniformity internationally.

All of the nuclear security treaties, while legally binding with respect to their broad provisions, unfortunately leave detailed implementation up to each state party. Verification of compliance and penalties for non-compliance are absent and even the peer-review processes common in the nuclear safety area are missing. This deficit in global governance needs to be rectified.

## Enhancing the Security Council's Relatively Ineffective Involvement

As part of its response to the terrorist attacks of 9/11, the UN Security Council adopted Resolution 1540 in April 2004 to require states to establish national implementation measures to ensure that terrorists do not acquire so-called weapons of mass destruction. The Resolution is legally binding and states must report to the Council on the steps they have taken to implement it. To date, compliance has been far from universal and as a transparency measure it has proved of limited value. Additional capacity building is required for states unable to comply. In the nuclear area, the IAEA is attempting to meet this need. But since the Resolution focuses on a much wider problem than nuclear materials or reactors, it is not well targeted to deal with nuclear security issues specifically. It could be redirected to do so.

## Increasing Support for IAEA's Vital but Undernourished Role

The IAEA, as in the nuclear safety area, now provides a huge range of services to member states to advise, guide and assist them. The Agency's Three-Year Plans, inaugurated in the wake of 9/11, have been useful in integrating the various activities and in funding them through a special Nuclear Security Fund (NSF). However, funding is still insufficient and too many conditions are attached by donors. The IAEA's Illicit Trafficking Database is another useful service, but suffers from insufficient participation by states.

## Finding the Right Balance between Secrecy and Transparency

Because of the secrecy that surrounds nuclear security (much of it for understandable reasons), international transparency is constrained and IAEA involvement less welcome. The Nuclear Energy Agency recommends a sensible "need to know" concept with two levels of disclosure: release of "generic" information on policies and practices to provide a measure of transparency, while limiting public release of specific information on facilities, transportation routes and other technical and operational details to avoid compromising security. This could form the basis for rethinking the balance between the conflicting values of confidentiality and transparency that may improve global governance instruments in this field, making peer review, for instance, more feasible.

## Fashioning a Universal Nuclear Security Regime

As in the case of nuclear safety, there needs to be greater cooperation among the various stakeholders involved in nuclear security. Industry seems largely content to leave matters to governments, as it does in the case of nonproliferation issues. However, a major security incident at a nuclear power plant would threaten the nuclear revival in a similar fashion to a major nuclear reactor accident. In designing new generation reactors, vendors need to consider security in the same way that they consider safety, while regulators need to consider how to apply security regulations to new facilities. New entrants need to develop security practices and acquire a sustainable security culture quickly. Cooperation seems axiomatic.

There is a need for a truly international, universal nuclear security regime that encompasses all interested parties — international organizations, governments, regulators and industry. The US/Russia Global Initiative to Combat Nuclear Terrorism and the World Institute of Nuclear Security (WINS) are both excellent initiatives that deserve support from all stakeholders worldwide. Whether they are the beginnings of such a global regime, or whether it needs to be constructed afresh, are questions that require urgent attention.

## Select Recommendations

- All states, but especially those seeking nuclear energy for the first time, should be strongly urged to accede to the CPPNM and sign and ratify the Amendment to help bring it into force as soon as possible; a campaign should be mounted by the IAEA and supportive states to achieve this.
- The UN Security Council's 1540 Committee should adopt objective criteria to identify sectors and countries, like nuclear security in developing states that seek nuclear energy, where implementation is a high priority; it should cooperate more closely with the IAEA in coordinating assistance to states in this area.
- States should make increased financial contributions to the regular IAEA budget that funds nuclear security and to the voluntary Nuclear Security Fund; states' restrictions on NSF funding should be dropped.
- The April 2010 Nuclear Security Summit should address the security of the civilian nuclear power sector and adopt measures specifically targeted at this issue, including, where appropriate, those outlined above.
- Above all, a true global security community for the nuclear energy sector needs to be established involving all stakeholders.

# Nuclear Nonproliferation

The link between civilian nuclear energy and nuclear weapons proliferation has been an abiding one since the dawn of the nuclear age. An international nonproliferation regime, based on the IAEA, its nuclear safeguards system and the 1968 Nuclear Nonproliferation Treaty (NPT) has prevented the spread of nuclear weapons to scores of states, but has not prevented proliferation entirely. India, Israel and Pakistan remain outside the NPT, and there have been several cases of non-compliance with the treaty. The IAEA safeguards system that verifies compliance has been considerably bolstered since the early 1990s, notably via the Additional Protocol, following revelations that Iraq had come close to acquiring nuclear weapons undetected. Several other multilateral initiatives have been taken to bolster the regime, especially in response to the discovery of the A.Q. Khan nuclear smuggling network.

The regime presently faces serious challenges, notably continuing non-compliance by Iran and North Korea, non-cooperation from Syria and the spectre of nuclear smuggling. Concessions made to nuclear-armed India by the Nuclear Suppliers Group have weakened the incentives built into the regime. Not all NPT parties have safeguards in force despite their legal obligation to do so and many are still resisting the Additional Protocol. The IAEA is underfunded and under-resourced in the safeguards area, and faces critical personnel shortages, deteriorating infrastructure and progressively outdated technology. The discontent of the non-nuclear weapon states with the perceived inequities of the regime risks disrupting yet another NPT Review Conference, in 2010. The international community has still not resolved the central contradiction of the NPT: that some states have accorded themselves the right to retain nuclear weapons apparently in perpetuity, while all others are legally bound never to acquire them. Such threats to the regime will only be made worse by a careless nuclear energy revival that fails to act on the nonproliferation lessons learned from the original spread of peaceful nuclear technology.

### Main Elements of the Global Nonproliferation Regime

- 1968 Nuclear Nonproliferation Treaty
- Nuclear weapon-free zones
- IAEA nuclear safeguards, including Comprehensive Safeguards Agreements (CSA), the Additional Protocol and other verification and monitoring capacities, including nuclear trade and technology analysis
- Bilateral and regional safeguards arrangements, including the Argentine-Brazilian Agency for Accounting and Control (ABACC)
- Zangger Committee and Nuclear Suppliers Group (NSG)
- Proliferation Security Initiative (PSI)
- US Next Generation Safeguards Initiative (NGSI)

## Challenges Posed by a Nuclear Revival

Renewed enthusiasm for nuclear electricity generation is raising fears of "nuclear hedging" — whereby states seek the peaceful nuclear fuel cycle to facilitate eventual acquisition of nuclear weapons. The proliferation risk of civilian nuclear energy is difficult to calibrate precisely and easy to exaggerate. A state with no previous exposure to nuclear science and technology that acquires and operates a once-through nuclear power reactor (run on imported low-enriched uranium and with storage or return of spent fuel) would gain only the beginnings of the scientific and technological expertise experience needed to learn how to build a nuclear device. If the state buys a turnkey plant operated by foreigners under contract, it will gain even less. However, if a state has existing nuclear expertise and facilities, such as a research reactor, a nuclear power plant gives it additional, useful nuclear expertise and experience. Yet even when a state fully owns and operates a civilian nuclear power plant, it would need much more nuclear knowledge and of a different kind, to proceed to design and construct a nuclear explosive device, much less weaponize it. The successful illicit diversion of nuclear material from any type of civilian nuclear power plant or waste storage facility is highly unlikely, as is the construction of secret enrichment and reprocessing facilities or production reactors, but such risks cannot be entirely discounted.

On the positive side, all non-nuclear weapon states are required to operate all of their nuclear facilities under strengthened nuclear safeguards, and newcomers to nuclear energy will be under strong pressure to adopt an Additional Protocol. The IAEA's monitoring and verification capabilities have been significantly enhanced. The vast majority of states will seek civilian nuclear energy for legitimate purposes. Nonetheless, there is a possibility that a tiny number of states may seek nuclear energy as a form of nuclear weapons hedging against a threatening neighbour with nuclear ambitions or to deter a nuclear weapon state. The most troubling region in this respect is the Middle East, where several states fear Iran's nuclear intentions.

The main proliferation threat from a nuclear revival comes not from the spread of nuclear power reactors by themselves, but the possibility that increasing numbers of states, lured by the dream of energy self-sufficiency and security, will seek a complete nuclear fuel cycle — from uranium mining to the enrichment of uranium and the reprocessing of spent fuel. This would give them a way of acquiring weapons-grade material that could be diverted secretly to build a bomb or be used openly for such purposes after withdrawal from the NPT on three months' notice. An equally worrying proliferation threat emerges from the possibility of terrorists stealing weapons-grade nuclear material from a civilian nuclear facility or in transit. A nuclear revival would increase the amounts of nuclear material produced and transported, and put pressure on the export control regime by increasing the volume and frequency of nuclear-related trade.

## Strengthening Safeguards

In response, there is an urgent need for universalizing the Additional Protocol, crafting further refinements (an Additional Protocol-plus) and providing the IAEA with advanced technology, modern facilities, the highest possible levels of expertise and clarified mandates with respect to its verification powers and compliance determinations. All aspiring nuclear energy states need to be drawn fully into the regime as soon as possible.

## Multilateralizing the Fuel Cycle

Controls on so-called sensitive parts of the fuel cycle — uranium enrichment and the reprocessing of spent fuel to produce plutonium — should be strengthened to prevent additional states acquiring such technology for weapons purposes. Fuel banks to provide assurances of nuclear fuel supply are a useful start in convincing all states without such technology to forego it, but serious work must commence on complete multilateralization of the fuel cycle.

## Ensuring Compliance

The least developed parts of the nonproliferation regime are those dealing with compliance. Both North Korea and Iran have abused the current system by failing to cooperate with the IAEA and ignoring the will of the international community as expressed in Security Council resolutions. This undermines the whole nonproliferation enterprise and jeopardizes the future of nuclear energy. Clearer determinations of non-compliance by the IAEA would help address this problem, as would legally-binding penalties on states that violate the NPT and then try to withdraw from it with impunity.

## Fulfilling all Parts of the Nonproliferation Bargain

The tougher safeguards and other measures required to prevent a nuclear revival from increasing the risk of weapons proliferation will not be politically feasible unless the advanced nuclear energy states and those that have nuclear weapons are prepared to forego options that they ask others to forego — the right to the full nuclear fuel cycle and the retention of nuclear weapons in perpetuity. Encouragingly, there is a new wave of support and proposals for moving faster towards nuclear disarmament ("getting to zero"). This may help break the deadlock between states arguing for ever tighter nonproliferation controls and those resisting on the grounds that the nuclear weapon states need to move faster to disarm as part of the nonproliferation grand bargain.

## Select Recommendations

### Safeguards

- The Additional Protocol should be made the "gold standard" for nuclear safeguards, including as a condition of all supply of nuclear material and technology.
- Any state seeking nuclear power plants should be expected to immediately negotiate an Additional Protocol.
- The US, Canada and other safeguards supporters should initiate further strengthening of IAEA safeguards through an Additional Protocol-plus process.
- To this end, the US Next Generation Safeguards Initiative could be multilateralized, including by other safeguards champions like Canada establishing their own versions of the Initiative.
- The IAEA Director General should request special inspections in serious cases of suspected safeguards violations and non-cooperation.
- The IAEA Board of Governors should confirm the authority of the Agency to monitor weaponization research and development activities.
- More states should provide information to the IAEA's Trade and Technology Analysis Unit to help unravel nuclear smuggling networks.

### Nuclear Fuel Cycle

- Efforts must continue to establish an IAEA Fuel Bank.
- The existing nuclear energy states should commit themselves to eventual international ownership and oversight of all enrichment, reprocessing and other sensitive fuel cycle facilities.
- Although not used in nuclear power reactors, in the interests of nonproliferation all highly enriched uranium should be removed from all civilian use.

### Increased Cooperation among Various Stakeholders

- The IAEA Secretariat should work more closely with industry, research institutes and non-governmental organizations to take advantage of their capacities and perspectives.
- The nuclear industry, especially reactor vendors, needs to take nuclear nonproliferation more seriously and ramp up involvement with the IAEA, the NEA and WINS.

### Nuclear Disarmament

- This report endorses the recommendations of the 2009 *Report of the International Commission on Nuclear Nonproliferation and Disarmament* for ensuring a successful 2010 NPT Review Conference, and for getting to a nuclear weapons "minimization point" by 2025 in preparation for the challenge of achieving complete nuclear disarmament.

# Final Recommendations and Conclusions

In addition to the recommendations made for safety, security and nonproliferation specifically, several overarching recommendations flow from this report.

## Safety, Security and Nonproliferation Should be Integrated

While this study has itself largely dealt separately with nuclear safety, security and nonproliferation, since this is the way the international regimes are organized, the three are intrinsically linked. They need to be deliberately integrated in considering the implications of a nuclear energy revival. Reactor design, the implementation of safeguards and other activities of the IAEA and national regulatory processes are just some of the areas that would be improved by pursuing such an integrated outlook. The guidance and assistance provided bilaterally and multilaterally to new entrants in the areas of safety and security should be increasingly integrated where appropriate.

## Increasing the Capacities of the International Atomic Energy Agency

This study has revealed the increasing centrality of the IAEA to the entire global governance regime. Always considered paramount in nuclear safeguards, the Agency has proved increasingly vital in nuclear safety, following Chernobyl, and in nuclear security, following 9/11. States which have previously been lukewarm to the Agency in any of these areas need to recognize that, while not perfect, the IAEA has the greatest legitimacy, and the highest levels of experience and capacity of any international body in the nuclear field. Considering that nothing short of international peace and security is at stake, the IAEA is a veritable security bargain. It deserves increasing support along the following lines:

- The IAEA budget, as recommended by the 2008 Commission of Eminent Persons on the Future of the Agency, should be doubled by 2020 to cope with safety, security and safeguards demands as a result of the increased use of nuclear energy; proportionate increases should be made to 2030.
- In order that advice, guidance and assistance to aspirant states can be levered to produce the best possible outcomes for safety, security and nonproliferation, the following should be considered:
    - Nuclear safety and security programs should be funded from the IAEA regular budget rather than relying on voluntary contributions.
    - Technical cooperation specifically for new nuclear electricity programs should be pegged to the recipient's safety, security and nonproliferation record and commitments; the Agency should cooperate closely with reactor supplier states and vendors in this endeavour.
    - The IAEA should be mandated to coordinate international assistance to new nuclear energy states aimed at improving their institutional capacities, especially legislative and regulatory ones, in advance of acquiring nuclear reactors; this would include assistance offered by other international bodies, governments and reactor vendors.
- The IAEA should be funded to undertake a crash program to upgrade its Seibersdorf facilities to incorporate the latest technology and supportive infrastructure and to bring it up to the highest safety and security standards; the financing plan for the Major Capital Investment Fund is inadequate and needs to be boosted with the US$ 50 million one-off injection

of funds recommended by former Director General Mohamed ElBaradei.

- The IAEA must be permitted to expand and renew its personnel resources, including by being exempted from constraining UN system rules.

## Enhancing the Role of the Nuclear Industry

While governments rightly retain the right to approve or reject the export of nuclear reactors or nuclear materials and other technologies by companies under their jurisdiction, industry cannot absolve itself of responsibilities by pretending that nuclear safety, security and nonproliferation are issues of "high politics" that are entirely the responsibility of governments. Industry has a strong self-interest in working more closely with the IAEA and other international bodies in ensuring that any nuclear revival does not rebound on its fortunes as a result of a serious accident, terrorist incident or nuclear weapons breakout. This suggests the following recommendations:

- An international forum should be convened or an existing one (such as the former Global Nuclear Energy Partnership) adapted to bring together all states and companies (including vendors and utilities) involved in international nuclear power reactor sales in order to harmonize the criteria for proceeding with such sales.
- Such a forum could consider an industry code of conduct for nuclear reactor sales that restricts them to states which:
    - Are in full compliance with IAEA safeguards and an Additional Protocol;
    - Are party to all safety and security conventions;
    - Accept and implement high safety and security standards, including by participating in peer reviews;
    - Have established an appropriate national regulatory system; and
    - Comply with UN Security Council Resolution 1540's reporting requirements.
- Additional factors that should be taken into account include: governmental stability, the quality of governance; regional security and a willingness to voluntarily renounce sensitive nuclear technologies.

## Concluding Comments

Global governance in the nuclear realm is already facing significant challenges even without the prospect of a nuclear energy revival. The international community, governments, the nuclear industry and other stakeholders are obligated to do everything possible to ensure that a rise in the use of nuclear-generated electricity does not jeopardize current efforts being made to strengthen nuclear safety, security and nonproliferation. Indeed, the desire of states for the perceived benefits of nuclear energy should be levered to further reinforce the various global governance arrangements.

The deal for aspiring states should be: if you want civilian nuclear power, you have to agree to the highest international standards for avoiding nuclear accidents, nuclear terrorism and diversion of materials to nuclear weapons. The deal for existing advanced nuclear states should be: if you want the newcomers to comply with a newly strengthened global regime that was not in place when you first acquired nuclear energy, you have to multilateralize the fuel cycle and disarm yourselves of nuclear weapons.

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Louise Fréchette (chair), Trevor Findlay (director), *Nuclear Energy Futures Project Report*
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# Acronyms and Abbreviations

| | |
|---|---|
| ABACC | Argentine-Brazilian Agency for Accounting and Control |
| ABWR | Advanced Boiling Water Reactor |
| ACR | Advanced CANDU Reactor |
| ADB | Asian Development Bank |
| AECL | Atomic Energy of Canada Limited |
| AFCI | Advanced Fuel Cycle Initiative (GNEP) |
| AFCONE | African Commission on Nuclear Energy |
| AFNI | L'Agence France Nucléaire International (France) |
| AIP | Advance Information Package (OSART) |
| ALARA | as low as reasonably achievable |
| ANDRA | Agence nationale pour la gestion des déchets radioactifs/ National Agency for the Management of Radioactive Waste (France) |
| ANWFZ | African Nuclear Weapon-Free Zone Treaty |
| AP | Additional Protocol (IAEA) |
| ASE | AtomsTroyExport (Russia) |
| ASME | American Society of Mechanical Engineers |
| ASN | Nuclear Safety Authority (France) |
| AU | African Union |
| BADEA | Arab Bank for Economic Development in Africa |
| BMWG | Border Monitoring Working Group (IAEA) |
| BNFL | British Nuclear Fuels Limited |
| BOG | Board of Governors (IAEA) |
| BSS | Basic Safety Standards (IAEA) |
| BWR | boiling water reactor |
| CACNARE | Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency |
| CANDU | Canada Deuterium Uranium reactor |
| CBO | Congressional Budget Office (US) |
| CCGT | combined cycle gas turbine |
| CCPNM | Convention on the Physical Protection of Nuclear Material |
| CCS | carbon capture and storage |
| CD | Conference on Disarmament (UN) |
| CDM | clean development mechanism |
| CEA | Commissariat à l'Énergie Atomique/ Atomic Energy Commission (France) |
| CEC | Commission of the European Communities (now EC) |
| CENNA | Convention on Early Notification of a Nuclear Accident |
| CFDT | Confédération Français Démocratique du Travail/ French Democratic Confederation of Workers |
| CHP | combined heat and power |
| CIA | Central Intelligence Agency (US) |
| CIRUS | Canada India Research US reactor |
| CISAC | Committee on International Security and Arms Control |
| CNRA | Committee on Nuclear Regulatory Activities (OECD/NEA) |
| CNS | Convention on Nuclear Safety |
| CNSC | Canadian Nuclear Safety Commission (Canada) |
| COGEMA | Compagnie Général des Matièrere nucléaire/ General Company for Nuclear Materials (France) |
| CORDEL | Working Group on Cooperation in Reactor Design Evaluation and Licensing (WNA) |
| CSA | Comprehensive Safeguards Agreement (IAEA) |
| CSS | Commission on Safety Standards (IAEA) |
| CTBT | Comprehensive Nuclear Test Ban Treaty |
| CTR | Cooperative Threat Reduction |
| DBT | design basis threat |
| DOE | Department of Energy (US) |
| DTI | Department of Trade and Industry (UK) |
| DUPIC | direct use of spent PWR fuel in CANDU |
| EC | European Commission |
| EDF | Electricité de France |
| EIA | Energy Information Agency (DOE) |
| ENAC | Early Notification and Assistance Conventions |
| ENATOM | Emergency Notification and Assistance Technical Operations Manual |
| ENEN | European Nuclear Education Network |
| ENSREG | European Nuclear Safety Regulators Group |
| EPAct | US Energy Policy Act (2005) |
| EPR | Evolutionary Power Reactor (formerly European Power Reactor) |
| EPREV | Emergency Preparedness Review Teams (IAEA) |
| EPRI | Electric Power Research Institute |
| ERBD | European Bank for Reconstruction and Development (EC) |
| ERNM | Emergency Response Network Manual |
| EUP | enriched uranium product |
| Euratom | European Atomic Energy Community (EC) |
| FAO | Food and Agricultural Organization of the United Nations |
| FBR | fast breeder reactor |
| FMCT | Fissile Material Cut-Off Treaty |
| FMT | Fissile Material Treaty |
| FOAK | first-of-a-kind |
| FP&L | Florida Power and Light |
| G8 | Group of Eight |
| GAO | Government Accountability Office (US) |
| GCC | Gulf Cooperation Council |
| GCR | gas-cooled reactors |
| GDF | Gaz de France |
| GDP | gross domestic product |
| GHG | greenhouse gases |
| GIF | Generation IV International Forum |
| GNEP | Global Nuclear Energy Partnership |
| GPP | Global Partnership Program (G8) |
| GTCC | gas turbine combined cycle |
| HEU | highly enriched uranium |
| IACRNA | Inter-Agency Committee on Response to Nuclear Accidents |
| IAEA | International Atomic Energy Agency |
| IATA | International Air Transport Association |
| ICAO | International Civil Aviation Organization |
| ICJ | International Court of Justice |
| ICNND | International Commission on Nuclear Nonproliferation and Disarmament |
| ICRP | International Commission on Radiological Protection |
| ICSANT | International Convention for the Suppression of Acts of Nuclear Terrorism |
| IDB | Inter-American Development Bank |
| IEA | International Energy Agency (OECD) |
| IEC | Incident and Emergency Centre |
| ILO | International Labor Organization |
| IMO | International Maritime Organization |
| INES | International Nuclear and Radiological Event Scale |
| INF | irradiated nuclear fuel |
| INFA | International Nuclear Fuel Agency |
| INIR | Integrated Nuclear Infrastructure Review (IAEA) |
| INLEX | International Expert Group on Nuclear Liability |
| INMM | Institute of Nuclear Materials Management |
| INPO | Institute of Nuclear Power Operations (US) |
| INPRO | International Project on Innovative Nuclear Reactors and Fuel Cycles |
| INRA | International Nuclear Regulators Association |
| INSAG | International Nuclear Safety Group (IAEA) |
| INSServ | International Nuclear Security Advisory Service (IAEA) |
| INSSP | Integrated Nuclear Security Support Plan (IAEA) |
| INTERPOL | International Criminal Police Organization |

| | |
|---|---|
| IPCC | Intergovernmental Panel on Climate Change |
| IPFM | International Panel on Fissile Materials |
| IPPAS | International Physical Protection Advisory Service (IAEA) |
| IRRS | Integrated Regulatory Review Service |
| IRS | Incident Reporting System (IAEA/NEA) |
| IsDB | Islamic Development Bank |
| ISIS | Institute for Science and International Security |
| ISSAS | International SSAC Advisory Service (IAEA) |
| ISSC | International Seismic Safety Centre |
| ITDB | Illicit Trafficking Database (IAEA) |
| ITE | International Team of Experts (IAEA) |
| ITER | International Thermonuclear Experimental Reactor |
| JREMPIO | Joint Radiation Emergency Management Plan of the International Organizations |
| JSW | Japan Steel Works |
| KEPCO | Korea Electric Power Corporation |
| KINS | Korea Institute of Nuclear Safety |
| LEU | low enriched uranium |
| LIS | laser-isotope separation |
| LNG | Liquid Natural Gas |
| LWGR | light water-cooled graphite-moderated reactor |
| LWR | light water reactor |
| MCIF | Major Capital Investment Fund (IAEA) |
| MDEP | Multinational Design Evaluation Program |
| MESP | Multilateral Enrichment Sanctuary Project |
| MIT | Massachusetts Institute of Technology |
| MOI | Ministry of Industry (Vietnam) |
| MOST | Ministry of Science and Technology (Vietnam) |
| MOX | Mixed Oxide Fuel |
| NAS | National Academy of Sciences (US) |
| NASA | National Aeronautics and Space Administration (US) |
| NATO | North Atlantic Treaty Organization |
| NCACG | National Competent Authorities' Coordinating Group |
| NEA | Nuclear Energy Agency (OECD) |
| NEF | Nuclear Energy Futures |
| NEI | Nuclear Energy Institute |
| NEPIO | Nuclear Energy Programme Implementing Organization |
| NERC | North American Electric Reliability Corporation |
| NERS | Network of Regulators of Countries with Small Nuclear Programmes |
| NESA | Nuclear Energy System Assessment |
| NEWS | Nuclear Events Web-based System |
| NGO | non-governmental organization |
| NGSI | Next Generation Safeguards Initiative |
| NIA | Nuclear Industry Association (UK) |
| NIF | National Ignition Facility (US) |
| NII | Nuclear Installations Inspectorate (UK) |
| NJFF | Nuclear Power Joint Fact Finding (Keystone Center) |
| NNWS | non-nuclear weapon state (NPT) |
| NPT | Nuclear Nonproliferation Treaty |
| NRC | Nuclear Regulatory Commission (US) |
| NRU | National Research Universal reactor (Canada) |
| NSEL | Nuclear Security Equipment Laboratory (IAEA) |
| NSF | Nuclear Security Fund (IAEA) |
| NSG | Nuclear Suppliers Group |
| NSSG | Nuclear Safety and Security Group (IAEA) |
| NTI | Nuclear Threat Initiative |
| NTM | National Technical Means |
| NUSS | Nuclear Safety Standards (IAEA) |
| NWFZ | nuclear-weapon-free zone |
| NWMO | Nuclear Waste Management Organization (Canada) |
| NWPA | US Nuclear Waste Policy Act (1982) |
| NWS | nuclear weapon state (NPT) |
| O&M | operation and maintenance |
| OECD | Organisation for Economic Co-operation and Development |
| OEF | operating experience feedback |
| OER | Operating Experience Reports |
| OSART | Operational Safety Review Teams (IAEA) |
| PBMR | Pebble Bed Modular Reactor |
| PHWR | pressurized heavy water reactor |
| PIU | Performance and Innovation Unit (UK Cabinet Office) |
| POC | Point of Contact |
| PRA | Probabilistic Risk Assessment |
| PRIS | Power Reactor Information System |
| PROSPER | Peer Review of the effectiveness of the Operational Safety Performance Experience Review |
| PSI | Proliferation Security Initiative |
| PSR | Periodic Safety Review |
| PUREX | Plutonium Uranium Extraction |
| PWR | pressurized water reactor |
| RADWASS | Radioactive Waste Safety Standards (IAEA) |
| RANET | Response Assistance Network |
| RBMK | Reaktor Bolshoy Moshchnosti Kanalniy (High Power Channel-Type Reactor) |
| RDD | radiological dispersal device |
| REPLIE | Response Plan for Incidents and Emergencies (IAEA) |
| RWC | Radiological Weapons Convention |
| SAG | Senior Advisory Group (IAEA) |
| SAGSI | Standing Advisory Group on Safeguards Implementation (IAEA) |
| SAGSTRAM | Standing Advisory Group on the Safe Transport of Radioactive Materials (IAEA) |
| SAL | Safeguards Analytical Laboratory (IAEA) |
| SEDO | Safety Evaluation During Operation of Fuel Cycle Facilities (IAEA) |
| SENES | Survey of Emerging Nuclear Energy States |
| SILEX | separation of isotopes by laser excitation |
| SMR | small- and medium-sized reactor |
| SOARCA | State-of-the-Art Reactor Consequences Analysis |
| SOER | Significant Operating Experience Reports |
| SOLAS | International Convention for the Safety of Life at Sea |
| SQP | Small Quantities Protocol (IAEA) |
| SSAC | State System of Accounting and Control |
| STUK | Säteilyturvakeskus (Radiation and Nuclear Safety Authority, Finland) |
| SWU | separative work unit |
| TCP | Technical Cooperation Programme (IAEA) |
| TRC | Technical Review Committee (IAEA) |
| TTA | Nuclear Trade and Technology Analysis unit (IAEA) |
| TVO | Teollisuuden Voima Oyj (Finland) |
| UAE | United Arab Emirates |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UNSCEAR | United Nations Scientific Committee on the Effects of Atomic Radiation |
| URENCO | Uranium Enrichment Company |
| USSPC | ultra-supercritical pulverized coal |
| VARANSAC | Vietnam Agency for Radiation Protection and Nuclear Safety Control |
| VERTIC | Verification Research, Training and Information Centre |
| VVER | Vodo-Vodyanoi Energetichesky Reactor (Russia) |
| WANO | World Association of Nuclear Operators |
| WENRA | Western European Nuclear Regulators Association |
| WGRNR | Working Group on Regulation of New Reactors (CNRA) |
| WHO | World Health Organization (UN) |
| WINS | World Institute of Nuclear Security |
| WMD | weapons of mass destruction |
| WMO | World Meteorological Organization |
| WNA | World Nuclear Association |
| WNTI | World Nuclear Transport Institute |
| WNU | World Nuclear University (WNA) |

# About CIGI

The Centre for International Governance Innovation is an independent, nonpartisan think tank that addresses international governance challenges. Led by a group of experienced practitioners and distinguished academics, CIGI supports research, forms networks, advances policy debate, builds capacity, and generates ideas for multilateral governance improvements. Conducting an active agenda of research, events, and publications, CIGI's interdisciplinary work includes collaboration with policy, business and academic communities around the world.

CIGI conducts in-depth research and engages experts and partners worldwide from its extensive networks to craft policy proposals and recommendations that promote change in international public policy. Current research interests focus on international economic and financial governance both for the long-term and in the wake of the 2008-2009 financial crisis; the role of the G20 and the newly emerging powers in the evolution of global diplomacy; Africa and climate change, and other issues related to food and human security.

CIGI was founded in 2002 by Jim Balsillie, co-CEO of RIM (Research In Motion) and collaborates with and gratefully acknowledges support from a number of strategic partners, in particular the Government of Canada and the Government of Ontario. CIGI gratefully acknowledges the contribution of the Government of Canada to its endowment fund. Support from the Government of Ontario includes a major financial contribution to the Nuclear Energy Futures project.

Le CIGI a été fondé en 2002 par Jim Balsillie, co-chef de la direction de RIM (Research In Motion). Il collabore avec de nombreux partenaires stratégiques et leur exprime toute sa reconnaissance pour leur soutien. Il remercie tout particulièrement le gouvernement du Canada pour sa contribution à son Fonds de dotation, de même que le gouvernement de l'Ontario, dont l'appui comprend une aide financière majeure au projet Perspectives de l'énergie nucléaire.

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