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Questioning a Nuclear Renaissance

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Dr. Sovacool has worked as a researcher, professor, and consultant on issues pertaining to energy policy, the environment, and science and technology policy. A frequent contributor to *Electricity Journal* and *Energy Policy*, he has also appeared on the *BBC World News*, *Bloomberg Live!*, and *Channel News Asia* and been interviewed by *Newsweek International*, *Associated Press*, *United Press International*, and *Nature*. He has served in advisory and research capacities at the U.S. National Science Foundation's Electric Power Networks Efficiency and Security Program, Virginia Tech Consortium on Energy Restructuring, Virginia Center for Coal and Energy Research, New York State Energy Research and Development Authority, Oak Ridge National Laboratory, Semiconductor Materials and Equipment International, U.S. Department of Energy's Climate Change Technology Program, and the International Institute for Applied Systems and Analysis near Vienna, Austria.

Dr. Sovacool has published more than 90 academic articles and presented at 42 international conferences and symposia in the past few years. He is the co-editor of *Energy and American Society: Thirteen Myths* (Springer, 2007) and the author or co-author of *The Dirty Energy Dilemma: What's Blocking Clean Power in the United States* (Praeger, 2008), *Powering the Green Economy: The Feed-In Tariff Handbook* (2009, Earthscan), and *Climate Change and Energy Security: An Overview of Global Technology and Policy Options* (MIT Press, forthcoming 2010).

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1. *Introduction*

An ironic moment in history occurred on March 31, 1979. That evening, then U.S. Secretary of Energy James Schlesinger was testifying before the American Congress on ways to expedite the licensing process for nuclear reactors, arguing that onerous requirements were no longer needed given the inherent safety of new designs. At precisely the same time Nuclear Regulatory Commission (NRC) Chairman Joe Hendrie was transmitting evacuation orders to Governor Thornburgh in Pennsylvania over the accident at Three Mile Island (TMI). Unknown to Schlesinger, the NRC had long suspected an accident would occur at TMI, previously ordering the shutdown of five similarly designed nuclear power plants based on errors discovered in a computer program used to assess the stresses on power plant pipes and cooling systems during an earthquake. A few days before the accident in March 1979, NRC inspectors even warned the Commissioner that the TMI design was unsafe and should be shut down immediately. NRC was in the process of considering what to do when the accident occurred.[1]

The story doesn't end there. Rather than admit to the inherent flaws with their reactor designs, the nuclear industry ran a sleek public relations campaign a few months after the accident featuring the physicist Edward Teller in newspaper and televisions advertisements. Teller solemnly told viewers (or in newspaper versions, expressed in very large bold-faced type) that *"I was the only victim of Three Mile Island."* Even though Teller was nowhere near Pennsylvania at the time of the accident, he claimed he suffered a heart attack a few weeks later because he had been working around the clock to refute senseless anti-nuclear propaganda.[2]

The lessons from this story are numerous and possibly prophetic. The anecdote reveals that various organizations promoting nuclear power do not always share information and can make mistakes (as in the Secretary of Energy believing designs to be safe when the NRC did not). It shows that some scientists and engineers involved in the industry, such as Teller, have optimistic views about atomic energy and intolerance for skepticism. It demonstrates that nuclear reactors are extremely dangerous when they malfunction. And it implies that the nuclear industry will utilize public opinion and savvy media techniques to insulate itself from criticism.

When one peaks behind the current industry rhetoric about a nuclear renaissance, what are the current risks involved with modern commercial nuclear power plants? As an answer, this policy paper takes a critical review of modern nuclear energy facilities. By "critical" it does not fully weigh the costs and benefits of nuclear energy; it instead identifies only key challenges. By "review" the author relied not only on information from politics and economics sources but also literature from the disciplines of ecology, energy policy, public policy, natural resource management, and law. The article finds that modern nuclear power plants suffer from at least five limitations related to cost, safety and accidents, fuel scarcity, environmental insults (to water, air, and land), and insecurity

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[1] Peter A. Bradford, "Three Mile Island: Thirty Years of Lessons Learned," *Testimony Before the Senate Committee on Environment and Public Works* (March 24, 2009).

[2] Ibid.

and weapons proliferation. In aggregate, the article concludes that these challenges present possibly insurmountable obstacles to a true global nuclear renaissance.

2. Cost

Although historically the cost of producing electricity from commercial nuclear reactors is relatively low in the United States, this is because those plants have been operating quite a long time and their stranded costs written off, they relied on the highest grades of uranium for fuel (which have already been exhausted), and many of social and environmental costs (such as subsidies and the cost of accidents) have been excluded. Decisions to build new nuclear power plants should therefore be based on current estimates, and how well they compare to other sources of electricity supply.

A far better metric than historic costs are marginal costs, or the price for building a new nuclear power plant on the margin. Assessments from the Keystone Centre, an independent think tank that surveyed 27 nuclear power companies and contractors, have found that the operating costs for new nuclear power plants are high: 30¢/kWh for the first 13 years followed by 18¢/kWh. Table 1 depicts that this makes nuclear power the second most expensive source of electricity on the market today after solar photovoltaics.[3] One assessment of nuclear energy in the United States noted that the cost of building 100 new reactors, rather than pursuing cheaper methods such as energy efficiency, would amount to an extra $1.9 to $4.4 trillion over the life of the reactors.[4]

Table 1: Levelized Cost of Electricity (LCOE) for New Renewable and Nuclear Power Plants[5]

Source of Electricity	Nominal LCOE ($2007 U.S. ¢/kWh)
Hydroelectric	3 to 7 ¢/kWh
Geothermal	4 to 7 ¢/kWh
Wind	5 to 12 ¢/kWh
Bioelectric	5 to 12 ¢/kWh
Solar Thermal	12 to 18 ¢/kWh
Nuclear	18 to 30 ¢/kWh
Solar PV	20 to 80 ¢/kWh

What makes nuclear energy so expensive? Part of the explanation lies in their capital intensive nature. Nuclear power plants are more like cathedrals than cellular telephones: they must be individually sited and built on a site-by-site basis. The approval process before construction even begins in places like the United States takes about 42 months.[6] Once approved, Table 2 shows that the average construction time for all global nuclear power plants built from 1976 to 2007 has been greater than seven years.

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[3] Pam Radtke Russell, Prices Are Rising: Nuclear Cost Estimates Under Pressure, *EnergyBiz Insider*, May-June 2008, at 22.

[4] Mark Cooper, *The Economics of Nuclear Reactors: Renaissance or Relapse?* (Montpellier, VT: Institute for Energy and the Environment, June 2009).

[5] Renewable energy figures taken from Renewable Energy Policy Network for the 21st Century, *Renewables 2007: Global Status Report* (Washington, DC: REN21, 2008). Nuclear power figures taken from Russell.

[6] Tom Doggett, "NRC Expects Requests for 7 New Nuclear Reactors," Reuters News Service, March 19, 2009.

Table 2: Average Global Construction Time for Nuclear Reactors, 1976-2009[7]

Period	Number of Reactors	Average Construction Time (Months)
1965-1970	48	60
1971-1976	112	66
1977-1982	109	80
1983-1988	151	98
1995-2000	28	116
2001-2005	18	82
2005-2009	6	77

These long construction times place nuclear power plants at great risk to unforeseen changes in electricity demand, interest rates, availability of materials, severe weather, labor strikes—which all contribute to severe cost overruns. Now, to be fair, all large infrastructure projects from dams and dikes to opera houses and airports suffer the risk of overruns due to their capital intensity, complexity, involvement of hundreds of contractors, and long lead times. Even some large-scale wind farms in Europe have seen actual costs exceed quoted costs. But nuclear power plants seem especially acute to cost overruns, largely because economies of scale are close to impossible and every single plant is what one nuclear power executive called a "premier."[8] Because of the unique site characteristics for each plant, one study estimated nuclear power plant construction costs from 1966 to 1977, when most light water reactors in the U.S. were built, and found that in every case plants cost *twice as much* as expected or more.[9] The results of that study are presented in Table 3. The quoted cost for these 75 plants was $89.1 billion, but the real cost was a monumental $283.3 billion.[10] These numbers paint only a partial picture as they refer to only those plants that were actually built; another 130 reactors had billions of dollars funneled into them before they were abandoned in the 1970s and 1980s.[11]

Table 3: Estimated and Actual Costs of 75 Nuclear Power Plants in the United States

Plant	Estimated Costs at Start of Construction (Millions of 1990$)	Realized Cost (Millions of 1990$)	Plant	Estimated Costs at Start of Construction (Millions of 1990$)	Realized Cost (Millions of 1990$)
Arkansas Nuclear 1	$375	$624	McGuire 1	$414	$1,299
Arkansas Nuclear 2	$460	$1,081	McGuire 2	$472	$1,269
Beaver Valley 1	$513	$1,176	Millstone 2	$474	$936
Beaver Valley 2	$913	$4,099	Millstone 3	$1,046	$3,998

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[7] Source: M.V. Ramana, "Nuclear Power: Economic, Safety, Health, and Environmental Issues of Near-Term Technologies," *Annual Review of Environment and Resources* 34 (2009), pp. 127-152; updated by Antony Froggatt, personal communication, March 23, 2010.

[8] Wolfgang Dirschauer, personal communication, March 11, 2010.

[9] Ramana 2009.

[10] U.S. Congressional Budget Office, *Nuclear Power's Role in Generating Electricity* (Washington, DC: CBO, May, 2008).

[11] Michael T. Hatch, "Nuclear Power and Postindustrial Politics in the West," In John Byrne and Steven M. Hoffman (Eds.) *Governing the Atom: The Politics of Risk* (London: Transaction Publishers, 1996), p. 238.

Braidwood	$762	$2,723	Nine Mile Point 2	$1,008	$5,281
Browns Ferry 1	$303	$876	North Anna 1	$515	$1,555
Browns Ferry 2	$227	$657	North Anna 2	$445	$932
Browns Ferry 3	$227	$657	Palisades	$294	$422
Brunswick 1	$430	$718	Palo Verde 1	$1,234	$4,185
Brunswick 2	$352	$933	Palo Verde 2	$920	$2,291
Byron 1	$741	$2,518	Peach Bottom 2	$532	$1,418
Byron 2	$552	$2,072	Peach Bottom 3	$423	$560
Callaway	$1,136	$2,999	Perry 1	$981	$3,729
Calvert Cliffs 1	$357	$1,142	Rancho Seco	$389	$876
Calvert Cliffs 2	$287	$765	River Bend 1	$718	$4,091
Catawba 1	$559	$2,074	Salem 1	$462	$1,829
Clinton	$710	$4,058	Salem 2	$378	$1,497
Cooper	$378	$1,053	San Onofre	$1,134	$3,343
Crystal River 3	$362	$948	San Onofre 3	$1,056	$2,078
Davis-Besse 1	$484	$1,359	Sequoyah 1	$524	$1,560
Diablo Canyon 1	$445	$3,750	Sequoyah 2	$429	$1,276
Diablo Canyon 2	$459	$2,333	Shoreham	$300	$4,139
Donald C. Cook 1	$657	$1,303	St. Lucie 1	$365	$1,130
Duane Arnold	$340	$716	St. Lucie 2	$893	$1,876
Edwin I. Hatch 1	$417	$951	Surry 1	$419	$761
Edwin I. Hatch 2	$653	$922	Surry 2	$329	$437
Fermi 2	$596	$3,783	Susquehanna 1	$1,320	$2,654
Fort Calhoun 1	$222	$520	Susquehanna 2	$753	$2,274
Grand Gulf 1	$1,105	$3,473	Three Mile Island 1	$323	$1,008
Harris 1	$898	$3,999	Three Mile Island 2	$668	$1,287
Hope Creek	$1,592	$4,598	Trojan	$582	$1,145
Indian Point	$477	$859	Virgil Summer 1	$630	$1,707
Joseph M. Farley 1	$387	$1,463	Waterford 3	$617	$3,303
Joseph M. Farley 2	$406	$1,228	Wolf Creek 1	$1,143	$2,835
Kewaunee	$297	$559	WPSS 2	$786	$4,008
LaSalle 1	$715	$1,918	Zion 1	$593	$768
LaSalle 2	$532	$1,255	Zion 2	$430	$752
Limerick 1	$921	$3,980			
			Total	**$45,247**	**$144,650**

One peer-reviewed study looked at the economic and financial risks for advanced nuclear power plants utilizing a three-decade historical database of delivered costs from each of 99 conventional nuclear reactors operating in the U.S.[12] They noted that the newest plants would be most dependent on operational learning, a feature ill suited to rapidly changing technology and market environments. They also argued that the difficulty in standardizing new nuclear units makes them impossible to mass produce, further adding to unexpected costs. The authors posited that these often invisible costs could explain why investors have been reluctant to invest in the newest generation of nuclear reactors, although the recent push by Stephen Chu and Bill Gates for smaller-scale, modular nuclear power plants could mitigate some of these risks if reactors could become more standardized and pass produced.

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[12] Nathan E. Hultman, Jonathan G. Koomey, Daniel M. Kammen, "What History Can Teach Us About the Future Costs of U.S. Nuclear Power," *Environmental Science & Technology* (April 1, 2007), pp. 2088-2099.

The trend appears to hold for the construction of recent European reactors as well. The completion of a European Pressurized Water Reactor in Olkiluoto, Finland, called the "flagship" of the next generation of designs, has seen major delays and cost overruns. The Finnish nuclear safety watchdog STUK reported 2,100 quality defects in the plant so far and the project is $2.4 billion over budget and three years behind schedule.[13] In Flamanville, France, a "clone" of the Finnish reactor now under construction is also behind schedule and over-budget. There, nuclear safety inspectors discovered cracks in the concrete base and steel reinforcements in the wrong places and warned Électricité de France that welders working on the steel container were not properly qualified.[14]

Perhaps because of their military origin, as well as their capital intensity, proclivity to cost overruns, and exposure to risk, new nuclear power plants are completely dependent on government subsidies. The United States is one of the best examples. There, from 1947 to 1999 federal subsidies for nuclear power in amounted to $145.4 billion, more than 96 times the cumulative spending on wind and solar (although to be fair substantial solar and wind research did not really begun until the 1970s).[15] One interesting comparison is to look at subsidies for wind, solar, and nuclear power for their respective first 15 years of operation. Nuclear power in the U.S. received subsidies worth $15.30 per kWh between 1947 and 1961, which compares with subsidies worth only $7.19 per kWh for solar and 46 cents per kWh for wind between 1975 and 1989. In its first 15 years, nuclear and wind produced about the same amount of energy—2.6 billion kWh for nuclear and 1.9 billion kWh for wind—but nuclear subsidies outweighed wind subsidies by more than a factor of 40, receiving $39.4 billion compared to wind's $900 million over the 15 year period.[16] (And, amazingly, these figures underestimate subsidies for nuclear power because they exclude price guarantees, discovery and production bonuses for uranium miners, accelerated depreciation, tax exemptions for industrial development bonds, investment tax credits, and all non-DOE R&D on fusion, high energy physics, and metallurgy).

Subsequent legislation in the U.S. has only sweetened the deal. The Energy Policy Act of 1992 promised $100 million in new funding for reactor designs, limits on utility payments for decommissioning, and delegated authority to set waste disposal standards with the National Academy of Science rather than public participation—and failed to incentivize *anyone* to build a new nuclear power plant.[17] The Energy Policy Act of 2005 sweetened the deal with $13 billion worth of loan guarantees, $3 billion in R&D, $2 billion of public insurance against delays, $1.3 billion in tax breaks, an extra 1.8 ¢/kWh in operating subsidies, and limited liability for accidents—and *still* wasn't enough.[18] Government

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[13] Greenpeace, *Nuclear Power: A Dangerous Waste of Time* (Amsterdam: Greenpeace International, 2009), p. 11.

[14] Ibid.

[15] Janet L. Sawin, *The Role of Government in the Development and Diffusion of Renewable Energy Technologies: Wind Power in the United States, California, Denmark, and Germany, 1970-2000* (Tufts University: 2001), p. 115.

[16] Marshall Goldberg, Federal Energy Subsidies: Not All Technologies are Created Equal (Washington, DC: Renewable Energy Policy Project, Report No. 11, July, 2000).

[17] Byrne, John and Steven M. Hoffman, "The Ideology of Progress and the Globalisation of Nuclear Power," In John Byrne and Steven M. Hoffman (Eds.) *Governing the Atom: The Politics of Risk* (London: Transaction Publishers, 1996), pp. 17-18.

[18] Amory B. Lovins, "Energy Myth Nine—Energy Efficiency Improvements Have Already Reached Their Potential," In Benjamin K. Sovacool and Marilyn A. Brown (Eds.) *Energy and American Society—Thirteen Myths* (New York:

subsidies in the United States therefore covered about 80 percent of the cost of building a new nuclear power plant for most of the past decade, yet still successfully convinced the Obama Administration to give them *more* subsidies in 2010, including loan guarantees exceeding $54 billion in the 2011 national budget.[19] Despite all of these subsidies, momentum still favored investments in coal, natural gas, and wind in 2009 and 2010.

3. Safety and Accidents

Although the accidents at TMI and Chernobyl have been widely publicized, nuclear power facilities around the world continue to suffer accidents, incidents, and unplanned outages every year. A survey of major energy accidents from 1907 to 2007 found that nuclear plants ranked first in economic cost among all energy accidents, accounting for 41 percent of energy accident related property damage (or $16.6 billion), although nuclear power plants didn't even start operating until the 1950s.[20]

The risk of incidents and accidents is not confined to the past. Using probabilistic risk assessment, an interdisciplinary team at MIT identified possible reactor failures in the U.S. and predicted that the best estimate of core damage frequency was about one every 10,000 reactor years. Although this estimate applies only to current reactors, and the MIT researchers noted that the risks could be reduced through improvements in safety culture and technology, the risk of a serious accident can never be eliminated. In terms of the expected growth scenario for nuclear power from 2005 to 2055, the MIT team estimated that at least 4 serious core damage accidents would occur. Such a probability of accidents provoked the team to conclude that "both the historical and probabilistic risk assessment data show an unacceptable accident frequency."[21]

Another assessment conducted by the Commissariat à l'Énergie Atomique in France concluded that in no way will technological improvements eliminate the risk of human-caused mistakes at nuclear facilities. Two types of mistakes were found to be most egregious and recurring: errors committed during field operations, such as maintenance and testing, that can cause an accident, and human miscalculations that make small accidents into larger ones.[22]

Interestingly, it is the *newest* reactors that are often most prone to accidents and serious incidents, due to a combination of unproven designs and plant operators lacking familiarity with procedures and equipment. Historically, almost all severe nuclear accidents occurred with nuclear power plants only a few years old. For example, the July 26, 1959, Sodium Research Experiment reactor in California experienced a partial meltdown 14 months after opening. The January 3, 1961, Sl-1 Reactor in Idaho was slightly more than

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Springer, 2007),pp. 259-260; and Dan Watkiss, "Ready to Emerge from the Middle Ages of Our Energy Policy?," *Electric Light & Power* (May/June, 2008), forthcoming.

[19] Stephanie Kirchgaessner and Sheila McNulty, "Obama offers nuclear plant loan guarantee," *Financial Times*, February 13, 2010.

[20] Benjamin K. Sovacool, "The Costs of Failure: A Preliminary Assessment of Major Energy Accidents, 1907 to 2007," *Energy Policy* 36(5) (May, 2008), pp. 1802-1820.

[21] Beckjord et al., *Future of Nuclear Power* p. 48.

[22] Bernard Papin and Patrick Quellien, "The Operational Complexity Index: A New Method for the Global Assessment of the Human Factor Impact on the Safety of Advanced Reactor Concepts," *Nuclear Engineering and Design* 236 (2006), pp. 1113-1121.

two years old before a fatal accident killed everyone at the site. The Fermi Unit 1 reactor began commercial operation in August 1966, but had a partial meltdown two months after opening. The St. Laurent des Eaux A1 Reactor in France started in June 1969, but an online refueling machine malfunctioned and melted 400 pounds of fuel four months later. The Browns Ferry Unit 1 reactor in Alabama began commercial operation in August 1974, and experienced a fire severely damaging control equipment six months later. Three Mile Island Unit 2 began commercial operation in December 1978 but had a partial meltdown three months after it started. Chernobyl Unit 4 started up in August 1984, and suffered the worst nuclear disaster in history on April 26, 1986 before its two-year birthday. These accidents have been attributed to previously unrecognized vulnerabilities, manufacturing defects, material imperfections, and shoddy construction.[23]

Indeed, six factors seem to increase the risk of future accidents and possibly offset improvements in safety culture. First, the global nuclear industry lacks qualified and experienced staff, especially in the United States. There, the Department of Energy has warned that the lack of growth has gradually eroded important infrastructural elements such as experienced personnel, qualified suppliers, and organizational support.[24] The situation seems even more severe in developing countries. In Indonesia, the National Atomic Energy Agency (BATAB) had to train than 3,500 personnel (including 110 researchers with doctorates and 295 with advanced degrees) just to research the construction of one new power plant.[25]

Second, in the early days of the industry, nuclear power plants were sited more remotely for safety reasons, meaning an accident would affect less people. How, however, many are located closer to population centers.[26] Sites that had once been remote when reactors started have become more populated over time; regions in which nuclear power is most attractive tend to be urban and have a limited number of remote locations; and substantial losses and costs are associated with remote transmission of nuclear power, creating an incentive to situate plants closer to points of electricity consumption.

Third, the industry has been trying to scale up reactor sizes and promote designs that operators have little experience with. These larger reactors tend to use more fuel and create more heat, meaning they have bigger cores containing larger quantities of dangerous fissionable materials, increasing the magnitude of any accident that could occur.[27] They can also add to core instability, one of the problems that lead to the Chernobyl accident in 1986.

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[23] David Lochbaum, *U.S. Nuclear Plants in the 21st Century: The Risk of a Lifetime* (Washington, DC: Union of Concerned Scientists, 2004).

[24] U.S. Department of Energy, *A Roadmap to Deploy New Nuclear Power Plants in the U.S. by 2010* (2001).

[25] Vijay Sakhuja, "Securing the Nuclear Energy Supply Chain: The Maritime Dimension," *Paper Presented to the Emerging Challenges to Energy Security in the Asia Pacific International Seminar* (Chennai, India: Center for Security Analysis, March 16 and 17 2009).

[26] Greenberg 1996.

[27] See Gail H. Marcus, "Considering the Next Generation of Nuclear Power Plants," *Progress in Nuclear Energy* 37 (2000), pp. 5-10; K.L. Murty and I. Charit, "Structural Materials for Gen-IV Nuclear Reactors: Challenges and Opportunities," *Journal of Nuclear Materials* (2007), and T.A. Lennox, D. N. Millington, and R.E. Sunderland, "Plutonium Management and Generation IV Systems," *Progress in Nuclear Energy* 49 (2007), pp. 590-593.

Fourth, the restructuring of electricity sectors around the world has motivated some nuclear operators to place profits before safety. Undue solicitude for profits of the licensee has played a large role in explaining the mishaps that have occurred at nuclear power plants. Put another way, nuclear power is least safe in environments where complacency and pressure to maximize profits are the greatest, yet the global trend appears headed in that direction.[28]

Fifth, some of the key anthropological work on nuclear power safety culture has revealed a tendency to see incidents not as accidents, but instead as new sources of information about how a nuclear system functions. Perhaps perversely, some operators may even welcome and see value in accidents and incidents as they contribute to new knowledge about reactor and human performance.[29] This can create a norm at a particular plant that a reactor is "safest when running," contributing to pressure to keep plants online and delay maintenance, and also to consider production of electricity first and safety second. To these operators, nuclear work is supposed to be fast and efficient, not "slowed down" by frivolous safety concerns.[30]

Sixth, if there is a substantial increase in nuclear power worldwide, new countries (Indonesia, Myanmar, and Zimbabwe are all on that list) may elect to build reactors even though they do not have the necessary regulatory oversight, technical support, and safety culture to properly operate those facilities.

These six factors present serious challenges given the severity of what a single accident can do. The most *conservative* estimate, accepted by the industry, is that a meltdown of a single 500 MW reactor located 30 miles from a single city would cause the immediate death of between 3,400 to 45,000 people, injure roughly another 50,000, induce $7 billion in property damage, and contaminate an area the size of Pennsylvania with unsafe levels of radiation [31] Other studies have projected economic damages from a single nuclear accident to be greater than $1 trillion[32], to say nothing of the consequences to human health and the environment.

4. Fuel Scarcity

Almost all commercial nuclear reactors, even those that utilize reprocessed fuel, need fresh uranium ore to operate. The world nuclear fleet at present needs 160 million pounds of uranium per year, but uranium mines produce only 100 million pounds. The shortfall in supply is made up by stockpiles of mined uranium, unused fuel from decommissioned plants, and reprocessing from nuclear weapons.[33] However, these reserves

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[28] Bradford 2009.

[29] Constance Perin, "Operating as Experimenting: Synthesizing Engineering and Scientific Values in Nuclear Power Production," *Science, Technology, & Human Values* 23(1) (Winter, 1998), pp. 98-128.

[30] Perin 1998.

[31] Zachary Smith, *The Environmental Policy Paradox* (Upper Saddle River: Prentice Hall, 2009), p. 181.

[32] Mark S. Winfield, "Nuclear Power No Solution to Oil Sands," *Edmonton Journal*, January 24, 2007, quoting that "It has been estimated that the economic damages from a major accident at the Darlington Ontario nuclear plant east of Toronto would be in the range of $1 trillion."

[33] Paul Wenske, Uranium Supply Questions: Finding Fuel for an Expanded Fleet, ENERGY BIZ INSIDER, Sept./Oct. 2008, at 16, available at http://energycentral.fileburst.com/EnergyBizOnline/2008-5-sep-oct/Financial_Front_Uranium.pdf.

are being rapidly depleted. One assessment from the International Atomic Energy Agency, hardly an organization against nuclear power, concluded that enough high-grade uranium ore existed to supply the needs of the current fleet for only forty to fifty years.[34]

A mismatch between uranium supply and demand is thus emerging, with dependence on secondary sources of uranium generally believed to completely run out by 2015. Such a bleak outlook was recently confirmed by a peer-reviewed study on available uranium resources at ninety-three deposits and fields located in Argentina, Australia, Brazil, Canada, Central African Republic, France, Kazakhstan, Malawi, Mongolia, Namibia, Niger, Russia, South Africa, United States and Zambia. [35] The study documented that the quality of mined uranium peaked during the nuclear weapons programs of the 1940s and 1950s, when the highest grade deposits were depleted. No "world class" discoveries of uranium have occurred since the 1980s, and since then all increases in uranium mining and milling between 1988 and 2005 have resulted from increased drilling and new assessments at known deposits. The study noted that uranium miners are having to go deeper and use more energy and water to extract uranium resources as the overall quality of ore declines.

Further complicating matters, finding and developing new deposits and fields requires large amounts of time and significant capital, as new mines and enrichment facilities often take longer than a decade to bring online, and can be delayed (like nuclear reactors) by unforeseen events. For example, a single cyclone stopped production of the Australian Ranger open-pit uranium mine in 2007 for more than a year, and the completion of the Cigar Lake uranium mine in Canada was delayed for three years by a flash flood.[36]

Researchers at the Oxford Research Group suggest that declining ore grades will eventually yield a negative net energy loss before the end of this century.[37] They posit that the energy required in enriching ores of less than 0.02% U_3O_8 exceeds the total energy the uranium can produce. The global average for ore grade currently stands at 0.15%, though the range varies tremendously from high-grade locations like Canada's McArthur River (>21%)[38] to Australia's Lake Maitland (0.04%).[39] Although reserves today are comfortably above the 0.02% threshold, as high-grade reserves are exhausted, production will shift to low-grade sources at a higher cost. While technological advances may enable

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[34] Ibid.

[35] Gavin M. Mudd & Mark Disendorf, Sustainability of Uranium Mining and Milling: Toward Quantifying Resources and Eco-Efficiency, 42 ENVTL. SCI. & TECH. 2624, 2626,

2629 (2008).

[36] Edward D. Kee, "Nuclear Fuel: A New Market Dynamic," *Electricity Journal* 20(10) (December, 2007), pp. 54-64.

[37] Oxford Research Group. 2006. "Energy Security and Uranium Reserves." Secure Energy: Options for a Safer World Factsheet 4.

(http://www.oxfordresearchgroup.org.uk/publications/briefing_papers/energy_security_and_uranium_reserves_secure_energy_factsheet_4)

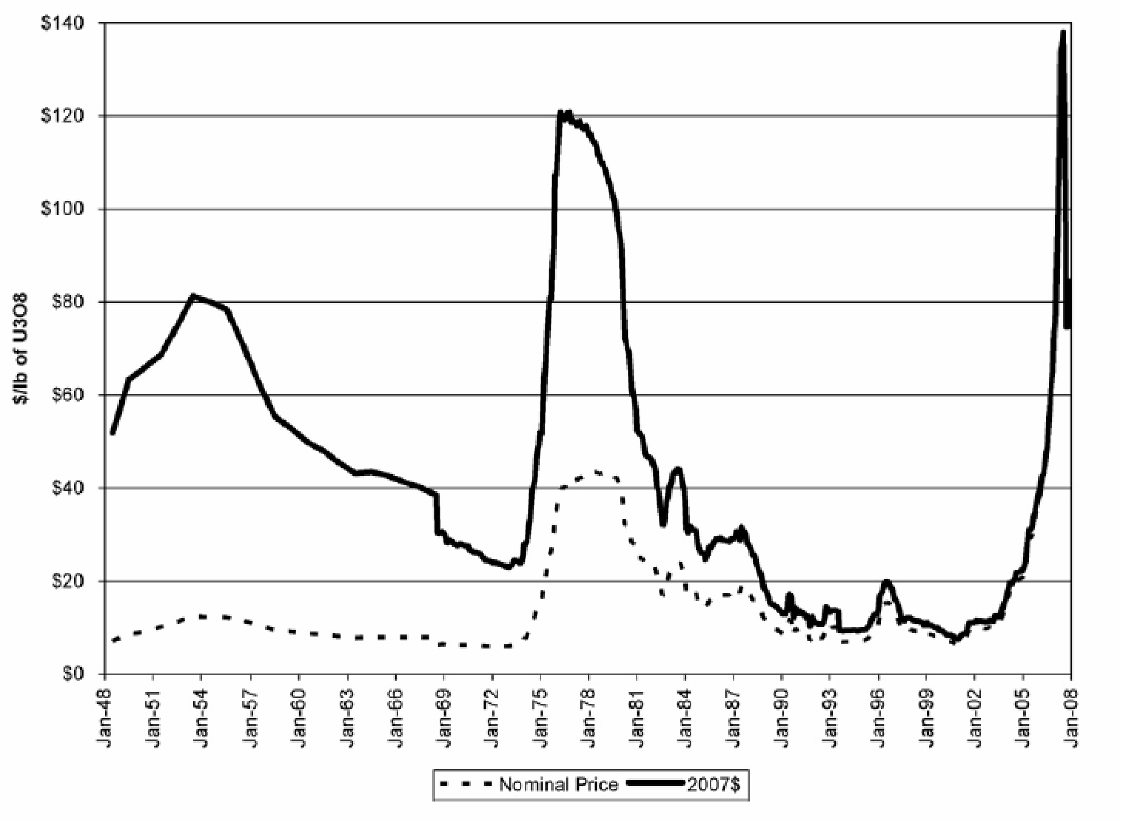
[38] McKay, A.D. and Miezitis, Y. 2007. "Australia's Uranium Resources, Geology and Development of Deposits." AGSO Geoscience Australia - Mineral Resource Report 1.

[39] Canadian Nuclear FAQ. 2010. "Uranium." Access date: 24 Feb 2010, Online at: http://www.nuclearfaq.ca/cnf_sectionG.htm.

profitable access to these resources, doing so will inevitably need more energy and thus a larger carbon footprint.

Expected shortfalls in available fuel not only threaten future plants; they contribute to the volatility of uranium prices at existing plants. Although they account for less than 20 percent of a nuclear power plant's total cost, uranium prices have shown recent escalation and volatility, which negatively impact nuclear project economics, making them riskier than alternatives. For example, Figure 1 depicts uranium spot prices from 1948 to 2007 and reveals at least three astronomical spikes: one in the 1960s and 1970s resulting from a rush of countries trying to develop weapons and exhausting easily accessible reserves, a second one in the 1970s and 1980s as a large number of commercial nuclear power plants began operation, and a third one post-2004 caused by an expected renaissance and constraints in supply.

Figure 1: Uranium Spot Prices, 1948 to 2007[40]



5. Environmental Impacts

Writing about the environmental consequences of nuclear power could fill a library, but the most pernicious seem to relate to water, climate, and land.

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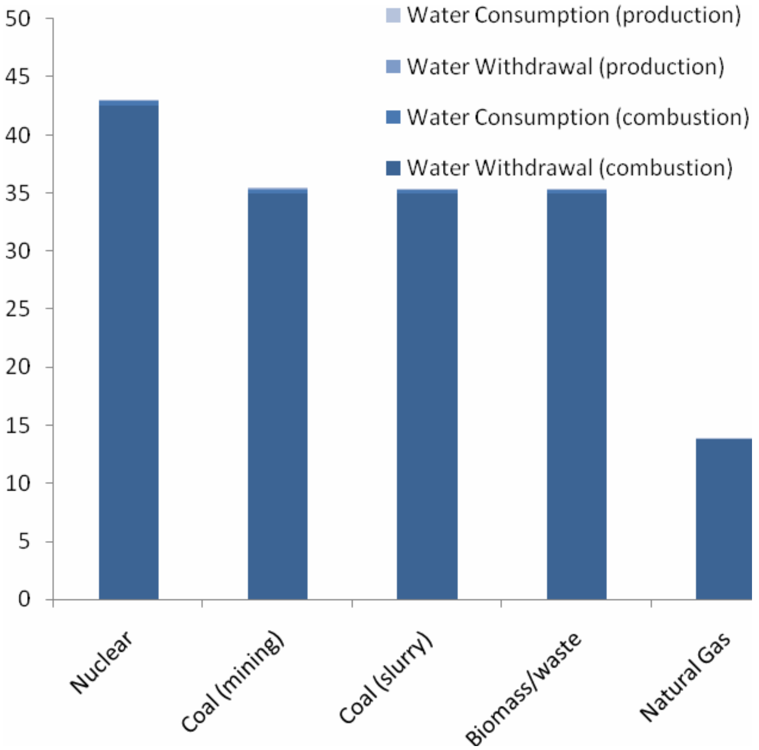
[40] Source: Kee 2007.

Water

Nuclear reactors require massive supplies of water to cool reactor cores and spent nuclear fuel rods. Although all thermoelectric power plants—those that combust fuel or fission atoms—have heavy water needs, Figure 2 shows that nuclear units consume and withdraw the most water compared to all other power stations: about 43 gallons of water for every kWh generated. Put another way, nuclear plants demand up to 50% more water per unit electricity generated than a fossil-fueled plant with equivalent cooling system.[41]

Figure 2: Total Water Use for Thermoelectric Generators (Gallons/kWh)[42]



Droughts and extended periods of high temperatures can subsequently cripple nuclear power generation and it is often during these times when electricity demand is highest because of air-conditioning and refrigeration loads and diminished hydroelectric capacity. This disconnect was poignantly felt in European heatwaves, such as in 2003 when France had to cut back 6 GW of capacity and several German reactors operated at 40%

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[41] Electric Power Research Institute. "Water & Sustainability (Volume 3): U.S. Water Consumption for Power Production - The Next Half Century." Technical Report 1006786. March 2002. (http://mydocs.epri.com/docs/public/000000000001006786.pdf).

[42] Source: U.S. Department of Energy, *Energy Demands on Water Resources: Report to Congress on the Interdependence of Energy and Water* (Washington, DC: U.S. Department of Energy, December, 2006, pp 38- 39.

capacity.[43] A more recent episode occurred in 2007 in the Southwest of the United States where nuclear plants were shutdown due to lack of water.[44]

Nuclear plants don't just use water—they also contaminate it at multiple points of the cooling cycle: at the point of intake, at the point of discharge, and during unexpected accidents.

At the point of intake, nuclear plants bring water into cooling cycle through intake structures. Riparian or marine organisms are frequently killed as they are trapped against the screens in a process known as *impingement*. Organisms small enough to pass through the screens can be swept up in the water flow where they are subject to mechanical, thermal and toxic stress in a process known as *entrainment*.[45] Smaller fish, fish larvae, spawn, and a tremendous volume of other marine organisms are frequently pulverized by reactor condenser systems. One study estimated that more than 90 percent are scalded and discharged back into the water as lifeless sediment that clouds the water around the discharge area, blocking light from the ocean or river floor which further kills plant and animal life by curtailing light and oxygen.[46] The annual damages alone to fisheries have been estimated in the millions of dollars in various locations including the Hudson River, the Delaware Estuary Watershed, the Floridian coast, and the Californian coast.[47]

At the point of discharge, nuclear plant operators often treat cooling water with chemical agents to limit the growth of mineral and microbial deposits that interfere with equipment. These chemicals, along with significant temperature differences between intake and discharge waters (temperature deltas) can contribute to destruction of vegetation, increased algae growth, oxygen depletion and strain the temperature range tolerance of organisms. Impacts can be multiple and widespread, affecting numerous species and habitats.[48]

Most insidiously, some nuclear power plants can contaminate water supplies with radioactive tritium and other toxic substances. In December 2005, for example, Exelon Corporation reported to authorities that its Braidwood reactor in Illinois had since 1996 released millions of gallons of tritium-contaminated waste water into the local watershed, prompting the company to distribute bottled water to surrounding communities while local drinking water wells were tested for the pollutant.[49] Similarly, in New York, Entergy's Indian Point Nuclear Plant (on the Hudson River) emptied thousands of gallons

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[43] Colover, Gala. 2003. "Summer 2003: A lesson for the future?" EU Energy Issue 65. 12 September; Reuters. 2003. "Heatwave halves output at some German n-plants." 5 Aug.

[44] Weiss, Mitch. 2008. "Southern US drought could dry up coolant water and force nuclear plants to shut down." Associated Press, 24 January.

[45] See Clear Air Task Force and Land and Water Fund of the Rockies, *The Last Straw: Water Use by Power Plants in the Arid West* (Washington, DC: The Hewlett Foundation, April, 2003), available at http://www.catf.us/publications/reports/The_Last_Straw.pdf; Ellen Baum, *Wounded Waters: The Hidden Side of Power Plant Pollution* (Washington, DC: Clean Air Task Force, February, 2004). Many of the following case studies come from these two original sources.

[46] Linda Gunter, Paul Gunter, Scott Cullen, and Nancy Burton, *Licensed to Kill: How the Nuclear Power Industry Destroys Endangered Marine Wildlife and Ocean Habitat to Save Money* (Grace Foundation and Norcross Foundation, February, 2001).

[47] Sovacool, BK and Sovacool KE. Preventing National Electricity-Water Crisis Areas in the United States," *Columbia Journal of Environmental Law* 34(2) (July, 2009), pp. 333-393.

[48] Sovacool and Sovacool 2009.

[49] Sovacool and Sovacool 2009.

of radioactive waste into underground lakes from 1974 to 2005. Such examples are not isolated and have not been chosen selectively: as of February 2010, 27 of the 104 reactors operating in the United States have been documented leaking radioactive tritium into the watershed.[50]

Air and Climate

It may seem counter intuitive that nuclear power contributes to air pollution or climate change, given that nuclear plants burn no coal, gas, or oil. But reprocessing and enriching uranium requires a substantial amount of electricity, often generated from fossil fuel-fired power plants, and uranium milling, mining, leaching, plant construction, and decommissioning are all greenhouse gas intensive. Consequently, when one considers the carbon-equivalent emissions associated with the entire nuclear lifecycle, nuclear plants do contribute meaningfully to climate change. The average CO_2 emissions over the typical lifetime of a plant are around 66 grams for every kWh, or the equivalent of some 183 million metric tons of CO_2 in 2005.[51] If the global nuclear industry were taxed at a rate of $24 per ton for the carbon equivalent emissions associated with its lifecycle, the cost of nuclear power would increase by about $4.4 billion per year.[52]

Furthermore, the carbon equivalent emissions of the nuclear lifecycle will only get worse, not better, since over time reprocessed fuel is depleted necessitating a shift to fresh ore, and reactors must utilize lower quality ores as higher quality ones are depleted. While they may be overstating their case, analysts at the Oxford Research Group calculated that if the percentage of world nuclear capacity remains what it is today, by 2050 nuclear power would generate as much carbon dioxide per kWh as comparable gas-fired power stations.[53] If true, this bears repeating: nuclear plants will be *equivalent* in terms of their greenhouse gas emissions to some fossil fuel plants by 2050.

Land and Nuclear Waste

About 85 percent of global reactors operate on the open fuel cycle, meaning they do not reprocess or recycle their fuel, and they produce 10,000 tons of spent nuclear fuel *each year*.[54] Nuclear power plants thus have at least five waste streams that contaminate and degrade land. They create spent nuclear fuel at the reactor site; produce tailings and uranium mines and mills; routinely release small amounts of radioactive isotopes during

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[50] Associated Press, "Leaks Spotlight Aging Nuclear Plants," February 1, 2010.

[51] Benjamin K. Sovacool, "Valuing the Greenhouse Gas Emissions from Nuclear Power: A Critical Survey," *Energy Policy* 36 (8) (August, 2008), pp. 2940-2953.

[52] The calculation works like this. In 2005, 435 nuclear plants supplied 16 percent of the world's power, constituting 368 GW of installed capacity generating 2,768 TWh of electricity. With every TWh of nuclear electricity having carbon-equivalent lifecycle emissions of 66,000 tons of CO_2, these plants emitted a total of some 182.7 million tons. If each ton cost $24, the grand total would be about $4.4 billion every year.

[53] Barnaby and Kemp, *Secure Energy?*

[54] T.S. Gopi Retinaraj, "Nuclear Breeders in Japan and India: Policy Options," *Faculty Seminar at the Lee Kuan Yew School of Public Policy*, April 25, 2008, p. 17.

operation; can catastrophically release large quantities of pollution during accidents; and create plutonium waste when fuel is reprocessed.[55]

The issue of nuclear waste could be why physicist Alvin M. Weinberg compared nuclear power to a "Faustian bargain," since it creates an unbreakable commitment where society receives electricity only in exchange for yielding political power to a small cadre of technocrats and national security agencies.[56] Some of the fission products from nuclear power are incredibly long lived. Plutonium-239 has a half-life greater than 24,000 years and Iodine-129 has a half-life of 15.7 *million* years. Nuclear waste will thus remain dangerously radioactive for hundreds of thousands of years—longer than our civilization has practiced Catholicism, or cultivated agriculture. In the United States, the GAO has projected that building a repository to dispose of 153,000 metric tons would cost $41 billion to $67 billion over a 143-year period.[57] And that's if construction proceeds as anticipated, when the facility could be prone to cost overruns and delays.

Perhaps because of their cost, as well as public opposition to having nuclear waste sites located near them, not a single country has yet to successfully build a centralized spent fuel repository. The United States cancelled its Yucca Mountain facility in early 2010 after spending twenty years and billions of dollars and now has nowhere to place 60,000 tons of spent fuel other than on-site at power plants. The facility itself was not the only problem. Transportation of waste to Yucca Mountain would have necessitated 15,000 to 80,000 separate shipments with no less than 50 million Americans living within a half-mile of the railways and interstates likely to serve as transportation routes crisscrossing 43 states. Many of these communities protested and banned the possibility of these shipments.[58] France is running out of storage space and existing sites will likely be full by 2015. A 1991 law requiring the creation of a geologic storage facility underground was never sited due to public opposition.[59] A South Korean underground repository for permanent disposal of spent nuclear fuel will not be ready by 2041, but onsite storage pools will likely reach maximum capacity between 2016 and 2024.[60]

What about reprocessing, some knowledgeable readers may wonder? Current reprocessing techniques suffer from at least four drawbacks.[61] First, they are more expensive than direct disposal of spent fuel. The National Academy of Sciences in the U.S. projected in

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[55] David Fleming, *The Lean Guide to Nuclear Energy: A Lifecycle in Trouble* (London: The Lean Economy Connection, 2007).

[56] Alvin M. Weinberg, "Nuclear Energy: A Faustian Bargain?" In *Energy and the Way We Live: Article Booklet* (San Francisco: Boyd & Fraser Publishing Company, 1980), pp. 31-33.

[57] U.S. Government Accountability Office, Nuclear Waste Management: Key Attributes, Challenges, and Costs for the Yucca Mountain Repository and Two Potential Alternatives (Washington, DC: U.S. GAO-10-48, November, 2009).

[58] Zachary Smith, The Environmental Policy Paradox (Upper Saddle River: Prentice Hall, 2009), pp. 165-166.

[59] Yves Marignac, Benjamin Dessus, Helene Gassin, and Bernard Laponche, Nuclear Power: The Great Illusion (Paris: Global Chance, October, 2008).

[60] The 2016 date comes from personal correspondence with Sharon Squassoni from the Center for Strategic and International Studies in Washington, DC. The other date comes from Lee, Chang Min and KunJai Lee. 2007. "A Study on Operation Time Periods of Spent Fuel Interim Storage Facilities in South Korea," Progress in Nuclear Energy 49 (2007), pp. 323-333.

[61] This paragraph draws entirely from Frank von Hippel, "Managing Spent Fuel in the United States: The Illogic of Reprocessing," In Henry D. Sokolski (Ed.) Falling Behind: International Scrutiny of the Peaceful Atom (Washington, DC: Nonproliferation Education Center, 2008), pp. 159-219.

1996 that extra cost of separation and transmutation of wastes would cost $100 billion *more* than simply storing it in a repository. The U.S. government contracted with Areva to build a test Mixed Oxide fuel fabrication plant to reprocess 34 tons of plutonium, but its cost has ballooned from $1 billion to $3.5 billion and is more than five years behind schedule. Second, reprocessing creates its own waste, including Cesium-137 and Strontium-290 in liquid form, isotopes difficult to handle and store. Third, there simply is not enough reprocessed fuel to go around. Worldwide, about half of the plutonium being separated is simply being stockpiled at reprocessing plants. As of 2005, this global stockpile of separated plutonium exceeded 250 tons, or enough to make more than 30,000 nuclear weapons. Interestingly, while the stockpile is enough to make tons of weapons, it could only fuel the world's fleet of nuclear reactors in 2008 for less than one year. Fourth, reprocessing is increases the risk of weapons proliferation significantly. The IAEA has been unable to reduce statistical measurement uncertainties over how much plutonium is produced below 1 percent for PUREX reprocessing. This means there will always be uncertainty about how much pure plutonium is actually produced. For these reasons, reprocessing has been abandoned by a handful of other countries. Since 1977, when Japan started operating its Tokaimura pilot plant, no state without nuclear weapons has begun civilian reprocessing. Argentina, Brazil, and Italy shut down their plants during this period, and South Korea and Taiwan abandoned laboratory research.

6. Security

The negative security implications of nuclear power facilities are almost as daunting as its environmental costs. Nuclear plants and reactor cores themselves offer lucrative targets for terrorism, and the fissile material produced from nuclear reactions can be used to make radioactive weapons of mass destruction.

The Nobel Prize winning nuclear physicist Hannes Alven once said that "the military atom and the civil atom are Siamese twins." Because slightly less than 20 pounds (9.07 kilograms) of plutonium is needed to make a nuclear weapon,[62] every ton of separated plutonium waste has enough material for 110 nuclear weapons. In the European Union alone, 2,500 tons of spent fuel produced annually, containing about 25 tons of separated plutonium (along with 3.5 tons of minor actinides such as neptunium, americium, and curium and 3 tons of long-lived fission products)[63]—enough fissile material for 2,750 new nuclear weapons every year. The four countries with the largest reprocessing fleets—Belgium, France, Germany, and UK—declared more than 190 tons of separated plutonium in 2007, mostly stored in plutonium dioxide powder at above ground sites and fuel manufacturing complexes[64]—enough for 20,900 nuclear weapons. Put another way, the typical nuclear reactor produces enough plutonium for a nuclear weapon every

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[62] Union of Concerned Scientists, *Nuclear Reprocessing: Dangerous, Dirty, and Expensive* (January, 2006), available at http://www.ucsusa.org/global_security/nuclear_terrorism/extracting-plutonium-from-nuclear-reactor-spent-fuel.html.

[63] M. Salvatores, "Nuclear Fuel Cycle Strategies Including Partitioning and Transmutation," *Nuclear Engineering and Design* 235 (2005), pp. 805-806.

[64] D. Haas and D. J. Hamilton, "Fuel Cycle Strategies and Plutonium Management in Europe," *Progress in Nuclear Energy* 49 (2007), p. 576.

2 months.[65] Taken as a whole, commercial nuclear reactors already create an amount of plutonium equal to the global military stockpile every four years.[66]

There is no shortage of terrorist groups eager to acquire the nuclear waste or fissile material needed to make a crude nuclear device or a dirty bomb, and the risks are not confined to the reactor-site. All stages of the nuclear fuel cycle are vulnerable, including:

- Stealing or otherwise acquiring fissile material at uranium mines;
- Attacking a nuclear power reactor directly;
- Assaulting spent fuel storage facilities;
- Infiltrating plutonium stores or processing facilities;
- Intercepting nuclear materials in transit;
- Creating a dirty bomb from radioactive tailings.[67]

Since the collapse of the Soviet Union in 1991, authorities have documented hundreds of incidents of nuclear smuggling in Europe and the Middle East.[68] As one senior diplomat at the IAEA confided to the author, "in some cases nuclear facilities are guarded only by chicken wire."

Further complicating matters, global norms and controls against the proliferation of nuclear weapons seem to be eroding at precisely the same time interest in using nuclear reactors to produce weapons remains strong. Israel, India, and Pakistan have at various stages after 1968 attained nuclear power status despite not signing the nuclear Non-Proliferation Treaty. Among parties to the treaty, North Korea withdrew in 2003, and has embarked on its own ambitious nuclear program, spurring some in neighboring Japan to advocate going nuclear as deterrence against a threatening North Korea. Meanwhile, Iran, another signatory, has been exercising its right under the NPT to develop "peaceful" nuclear technologies. Even Myanmar is constructing a 10 MW thermal research reactor with training and equipment from Russia that could form the basis of a nuclear weapons program.

A transition to newer reactors could (perhaps oddly) *exacerbate* many of these security risks. The most favored designs for Generation IV reactors tend to improve economics, trying to earn operators greater revenue, but do so at the risk of weaker controls on proliferation and fuel efficiency. Fast neutron and breeder reactors would use plutonium as their primary fuel, and if breeders are ever able to produce more plutonium than they consume, they could produce a virtually inexhaustible supply of weapons grade material. The same problem occurs with thorium. A thorium fuel cycle produces highly radioac-

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[65] Federation of American Scientists, *Special Weapons Primer: Plutonium Production* (June 20, 2000), available at http://www.fas.org/nuke/intro/nuke/plutonium.htm.

[66] Arjun Makhijani and Scott Saleska, "The Nuclear Power Deception." *Report to the Institute of Energy and Environmental Research* (1996).

[67] Frank Barnaby and James Kemp, *Secure Energy? Civil Nuclear Power, Security, and Global Warming* (Oxford: Oxford Research Group, March, 2007).

[68] Rensselaer Lee, "Nuclear Smuggling and International Terrorism: Implications for U.S. Policy," *CRS Report for Congress* (October 22, 2002), p. 8, and U.S. Government Accountability Office, "Combating Nuclear Smuggling," *GAO Report to the Department of Homeland Security* (June 21, 2005).

tive Th-228, and neutron bombardment of thorium produces uranium 233, another fissile material that can be used for nuclear weapons.[69]

Even the best intentioned governments can sometimes make bungling security mistakes. In 2009, for example, the U.S. federal government mistakenly released a "highly confidential" and "sensitive" 266 page report detailing location of civilian nuclear reactors, weapons laboratories, fuel facilities, and stockpiles of uranium and plutonium. The document provided maps, addresses, pictures, images, and locations of fuel vaults, diagrams of reactors, and updates on quantity and type of fuel being stored. The document was what one analyst called a "one-stop-shop" for information on U.S. nuclear technology for "thieves or terrorists."[70]

7. Conclusion

So where does this leave us? About the only uncontroversial aspect of the world's current energy and climate challenges is that they are serious, and therefore require serious solutions. The industry has done an exceptional job of portraying nuclear energy as clean, carbon-free, and cheap. But when cost, safety and accidents, fuel scarcity, environmental insults, and insecurity are taken into consideration, it becomes close to impossible to build a credible case for nuclear energy in a carbon constrained, post-Copenhagen world.

New nuclear plants are excessively capital intensive, take years to build, are prone to cost overruns, and are economically competitive only when significantly subsidized. The history of operating performance shows an unacceptable rate of serious incidents that will grow in proportion with greater nuclear power generation. Secondary reserves of uranium will likely be exhausted before the end of this decade and high quality reserves of primary uranium are hard to find, contributing to rising and volatile fuel prices. The consequences of the nuclear fuel cycle to global water supply and land are disastrous, and within a few decades the carbon footprint of nuclear plants will worsen to be equivalent to some fossil-fueled sources of electricity. Nuclear facilities are attractive targets for terrorism, and they produce hazardous and radioactive material that can be used to make weapons. Taken together, these challenges demand consideration for any country or community seriously considered a commitment to new nuclear power plants.

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[69] Jim Green, *Nuclear Power" Energy Science Coalition Factsheet* (London: Friends of the Earth, 2003).

[70] William J. Broad, "Secret Nuclear List Accidentally Released," *The New York Times* (June 3, 2009).

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The Global Energy Governance Project

"Common Goals – Different Approaches? Strengthening Transatlantic Cooperation on Global Energy Issues" is a two-year research and dialogue program jointly implemented by the Global Public Policy Institute (GPPi) and the Brookings Institution and funded by the European Commission.

The project focuses on the role of markets and institutions in fostering global energy security. Rather than adopting a traditional security lens to studying energy security, this project will assess ways in which global energy governance can be strengthened by creating and deepening markets, and adapting the "rules of the game". The project combines policy research with constructive and forward-looking transatlantic dialogue among researchers, industry experts and policymakers.

While the global dimension of energy challenges is unambiguous, the international community generally, and the transatlantic alliance in particular, has so far failed to supply the effective governance mechanisms that would form the basis of an effective multilateralism. The substantive focus of the project will build upon our previous work on global energy governance and will address a whole new set of pressing policy challenges.

- Governance of global carbon emissions (post-Copenhagen strategy).
- Managing the resurgence of resource nationalism.
- Governing the global market for oil in the context of rising demand and dwindling low-cost reserves.

While each of the issue clusters deals with different dimensions of the global energy governance puzzle, the proposed work will zoom in on each of the clusters to explore the potential for more effective transatlantic leadership in global energy governance providing the framework for:

- An exchange over substantive transatlantic policy differences
- A dialogue on the utility (and potential complementarily) of different policy strategies, and finally
- Discussions about potential ways and means to engage new powers, and specifically China, into efforts to organize effective global energy governance.

More information can be found at www.globalenergygovernance.net.