The Externalities of Nuclear Power: First, Assume We Have a Can Opener...

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INTRODUCTION

The nuclear power industry has latched on to global warming as an argument for its renaissance. Although even industry proponents acknowledge that the problem of disposing of spent nuclear fuel remains unsolved, the industry routinely assumes this problem will be solved in the future. Unfortunately, this is the same assumption made by nuclear energy proponents at the beginning of the nuclear industry fifty years ago. We haven't solved the nuclear waste problem in the past half century, and there is no reason to think we will be more likely to do so in the next one. Like the shipwrecked economist in the old joke, the nuclear industry continues to postulate that we should "assume we have a can opener" for the nuclear waste problem.[1]

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1. *See* Profession Jokes—Economists, http://www.workjoke.com/projoke44.htm (last visited Jan. 22, 2008).

While the impacts of global warming are described as "intergenerational," the impacts of the nuclear waste cycle are better described as inter-civilizational.[2] Nuclear fuel wastes remain hazardous for hundreds of thousands to as much as a million years.[3] By contrast, recorded human history goes back only about 5,000 years, and human civilization is only about 10,000 years old. Globally, none of the generators of nuclear fuel waste have successfully implemented any permanent disposal option for nuclear waste, leaving this externality of nuclear energy production as a problem for future generations, or, more likely, for future civilizations. Put simply, the nuclear industry, with government complicity, has transferred and deferred the most expensive part of the cost of the nuclear fuel cycle to future generations and civilizations unknown.

Nor are the environmental and public health costs of nuclear waste the only ones that nuclear energy generation has externalized. Nuclear generation also poses a risk externality — the economic and social harms that the public has assumed in the event of a radiation release, for which the generating industry has limited liability. This risk externality arises not only from the risk of accidental reactor meltdown and release of radioactivity, but also from the proliferation and terrorism risks that are inseparable from any scheme of nuclear energy production and waste disposal.

These twin externalities, waste and risk, make any nuclear renaissance an unsatisfactory substitute for fossil fuel power generation. As horrendous as the impacts of global warming will be — millions of people displaced and dead — the likely long-term impacts of increased nuclear energy production are comparable, and longer lasting.

I. THE EXTERNALITIES OF THE NUCLEAR FUEL CYCLE

The "spent" fuel resulting from nuclear energy production consists of 97% uranium and 3% other isotopes created by the fission process.[4] These isotopes include Cesium-137, Iodine-129, Cesium-137, and

2. *See* Karl S. Coplan, *The Intercivilizational Inequities of Nuclear Power Weighed Against the Intergenerational Inequities of Carbon Based Energy*, 17 FORDHAM ENVTL. L. REV. 227 (2006). This essay is adapted from the article in the Fordham Environmental Law Review and the author's presentation at the Fordham Environmental Law Review Symposium on Climate Change in March, 2006.

3. *See* Comm'n on Technical Bases for Yucca Mountain Standards, Nat'l Res. Council, TECHNICAL BASES FOR YUCCA MOUNTAIN STANDARDS 18-19 (1995) (hereinafter NAT'L. RES. COUNCIL YUCCA MOUNTAIN REPORT), *available at* http://newton.nap.edu/books/0309052890/html/2.html.

4. U.S. Dep't of Energy, Office of Nuclear Energy, Science, and Technology, *Report to Congress On Advanced Fuel Cycle Initiative: The Future Path for Advanced Spent Fuel Treatment and Transmutation Research* II-2 and Figure II-1 (2003), *available at* http://nuclear.gov/pdfFiles/AFCI_CongRpt2003.pdf.

Plutonium-239.[5] Some of these isotopes have half lives running into the millions of years, such as Iodine-129, which has a half life of 17 million years. Plutonimum-239 has a half life of 24,360 years.[6] Dangerous human exposure can occur by proximity to the spent fuel or by release of the constituents into the biosphere, resulting in human exposure through ingestion or respiration. It can also occur by simple proximity to places where these radionuclides collect.

Currently, there are 55,000 metric tons of spent nuclear fuel in the United States.[7] The majority of this fuel is stored in spent fuel pools at currently operating or decommissioned nuclear power plants. These spent fuel pools were originally designed to hold spent nuclear fuel only until it cooled sufficiently to be transported to a permanent disposal site or reprocessing facility. As no permanent disposal site has opened and no commercial reprocessing industry has ever developed, these spent fuel pools store most of the spent fuel generated during the entire history of nuclear power generation on-site. Several nuclear power plants across the country, including the Indian Point plant north of New York City, now experience leaks from these spent fuel pools, releasing dangerous tritium, cesium, and strontium isotopes into groundwater and the environment.[8]

As these spent fuel pools become full even at higher density configurations, power plant owners have begun to move spent fuel rods into "dry cask" storage. These "dry cask" storage containers consist of concrete and steel cylinders. According to Nuclear Regulatory Commission (NRC) regulations, the required design life of these dry cask storage units is only twenty years.[9]

Dry cask storage represents a sort of limbo for spent nuclear fuel. Unfortunately, neither deep geological burial nor reprocessing appear to be likely solutions to the waste disposal problems, and both pose serious risks.

5. NAT'L RES. COUNCIL YUCCA MOUNTAIN REPORT, *supra* note 3, at 18-19.

6. *Id.*

7. Lisbeth Gronlund et al., NUCLEAR POWER IN A WARMING WORLD 46 (2007), *available at* http://www.ucsusa.org/global_warming/solutions/jump.jsp?itemID=35069259. Although the author disagrees with the report's conclusion that the expansion of nuclear energy production is appropriate in the absence of proven solutions to the nuclear waste problem, the report is an excellent up-to-date summary of the unsolved externalities and risks posed by the nuclear fuel cycle.

8. Greg Clary, *Indian Pt. Leak Sources Found*, THE JOURNAL NEWS (WESTCHESTER COUNTY, N.Y.), Nov. 4, 2005, at 1A.

9. 10 C.F.R. § 72.236(g) (2007); *see also* U.S. NUCLEAR REG. COMM'N, STANDARD REVIEW PLAN FOR DRY CASK STORAGE SYSTEMS, FINAL REPORT (1997), *available at* http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1536/.

II. THE GEOLOGICAL REPOSITORY NON-SOLUTION

The Nuclear Waste Policy Act of 1982 directed the Department of Energy (DOE) to develop, construct, and operate a deep burial geological waste repository for high level civilian and military nuclear wastes.[10] In 1987, Congress amended the Act to direct the DOE to focus on one site: Yucca Mountain in the Nevada desert.[11] Three years ago, the United States Court of Appeals for the D.C. Circuit undercut the regulatory basis underlying the Yucca Mountain licensing procedure when it struck down regulations governing public exposure from the nuclear waste repository.[12] These regulations only accounted for hazards associated with waste disposal during the first 10,000 years. The Court held that the United States Environmental Protection Agency (EPA) should have followed the National Academy of Sciences's recommendation to consider risks up to one million years after disposal. While the DOE currently predicts a 2017 opening for the Yucca Mountain facility, standards requiring isolation of wastes for a million-year time frame may preclude the Yucca Mountain site from ever opening, or at least delay it substantially.

Even if it opens, however, Yucca Mountain will barely have the capacity to accept all of the civilian nuclear waste that has been generated and now sits in limbo at nuclear power plant sites, and it will have no reserve capacity. Based on current rates of nuclear power generation, the entire civilian nuclear waste capacity of Yucca Mountain will soon be exceeded.[13] Yucca Mountain is thus not a solution to continued nuclear energy generation in the United States. Yucca Mountain further provides no capacity for the expansion of United States nuclear energy production as an alternative to fossil fuel energy production. Deputy Energy Secretary Clay Sell has testified that the United States would require nine repositories the size of Yucca Mountain if nuclear power generation in this country is to achieve a six-fold increase as a substitute for fossil fuel power generation.[14]

Nor is the United States unique in its political inability to site a long-term geological waste repository. Switzerland and Sweden, which have also nominally chosen long-term geological waste repositories as the solution to the nuclear waste problem, have similarly been unable to site such facilities.[15]

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10. 42 U.S.C. §§ 10101-270 (2000).
11. Nuclear Waste Policy Amendments Act of 1987, Pub. L. No. 100-203, 101 Stat. 1330-227.
12. See Nuclear Energy Inst., Inc. v. U.S. Envtl. Prot. Agency, 373 F.3d 1251 (D.C. Cir. 2004) (per curiam).
13. *See* Gronland, *supra* note 13, at 46.
14. *Id.* at 71-72.
15. *Id.* at 45; see also James Kanter, *Radioactive Nimby: No One Wants Nuclear Waste*, N.Y. TIMES, Nov. 7, 2007, at H2.

III. THE REPROCESSING NON-SOLUTION

In theory, the 97% of spent nuclear fuel that consists of uranium isotopes could be reprocessed, separating the uranium from the plutonium. The uranium could then be re-enriched and burned again to generate electricity. Commercially viable reprocessing always has been, and always will be, the Holy Grail of the nuclear energy industry. Indeed, commercial reprocessing was the “can opener” that the industry and governmental regulators assumed we would have at the dawn of the nuclear energy industry.

Reprocessing poses its own set of political and moral risks and corresponding externalities. Reprocessing isolates plutonium. Plutonium is much more poisonous than uranium. Plutonium is also the ideal fuel for atomic bomb construction; just a few pounds of it in the wrong hands would allow the construction of a crude atomic weapon. The only commercial fuel reprocessing facility ever to operate in the United States, constructed in West Valley, New York, by Getty Oil Company, never achieved profitability. Instead, it left behind a $1 billion cleanup bill, borne by the public, after it closed.[16]

India’s use of plutonium from nuclear waste reprocessing to build a nuclear weapon in the 1970’s and the weapons proliferation risk led Presidents Jimmy Carter and Gerald Ford to ban the reprocessing of spent nuclear fuel into plutonium.[17] This ban has subsequently been lifted, reinstated, and lifted again.

Current administration policy is to seek the implementation of reprocessing facilities combined with dedicated plutonium-burning reactors in order to reduce the amount of nuclear waste requiring long-term disposal while minimizing the proliferation and terrorism risks associated with separation of plutonium.[18] Fifty years after the dawn of nuclear energy production, this latest initiative is barely commencing the research and development phase. There is no proposal to actually site and construct even one such facility, much less the seventy-five reactors spread over twenty sites that would be necessary to reprocess waste from the nation’s existing 104 nuclear power plants.[19] We can expect that siting even one such facility, meant to accept and reprocess wastes from multiple nuclear power plants, will prove every bit as politically problematic as siting a geologic waste repository. Even if such a reprocessing facility moves from nuclear engineers’ brainstorming sessions to reality, the DOE has calculated that it would take 100 years of reprocessing to reduce the amount of transuranic waste requiring disposal

16. *See* Matthew L. Wald, *Big Question Marks on Nuclear Waste Facility*, N.Y. TIMES, Feb. 14, 2006, at C4.
17. *See* Gronland, *supra* note 7, at 39.
18. *See id.* at 39, 68–74.
19. *Id.* at 50.

by 50%, at a dollar cost more than twice that of direct disposal of unreprocessed waste.[20]

Nuclear proponents often point to France as an example of a nation that has "solved" its nuclear waste disposal problem through reprocessing. On closer examination, however, while France has been successful in reprocessing nuclear waste, it has not found a means of recycling either the reprocessed uranium or the separated plutonium resulting from reprocessing. As a result, France has an inventory of thousands of tons of reprocessed uranium for which there is no commercial use, and 50 tons of separated plutonium.[21] The plutonium stockpile poses the quintessential problem of reprocessing: just nine pounds of separated plutonium is sufficient to make a crude nuclear bomb.[22]

The unseparated nuclear waste is not suitable bomb-making material, and is sufficiently radioactive to make it impossible to handle without highly specialized reprocessing facilities (unshielded, fresh spent fuel will cause a lethal exposure within an hour).[23] Once separated, however, the plutonium is sufficiently less radioactive that a terrorist willing to risk long-term health impacts could fashion a crude nuclear weapon with no more protection than a dust mask to prevent inhalation of plutonium dust.[24] Diversion of just one ten-thousandth of France's fifty-ton plutonium stockpile would allow terrorists to fashion a portable nuclear weapon. Keeping plutonium out of the wrong hands assumes perfect security and accounting for the separated plutonium indefinitely.

Fifty years into the nuclear era, neither reprocessing nor geologic disposal have overcome the basic engineering, economic, security and political obstacles to their implementation. Yet the nuclear energy industry enjoys the economic advantage of collecting electricity rates while shifting the entire economic uncertainty of the as yet unsolved problem of waste disposal to the federal government. Pursuant to the Nuclear Waste Policy Act of 1982, nuclear power producers were assessed a tax of 0.1 cents per kilowatt hour of electricity generated, and in exchange, the DOE was obligated to accept and dispose of all nuclear waste generated by these plants.[25] Several nuclear generators have successfully sued DOE for failing to take nuclear wastes by 1998 as

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20. *Id.* at 73, nn.185–97 (citing Matthew Crozat, *Evaluating the Economics of GNEP Deployment*, DOE, pre-decisional draft (January 8, 2007)).

21. Gronland, *supra* note 7, at 51.

22. *See* Global Security: Nuclear Terrorism, http://www.ucsusa.org/global_security/nuclear_terrorism/ (last visited Jan. 22, 2008).

23. Gronland, *supra* note 7, at 43.

24. *Id.* at 44.

25. Nuclear Waste Policy Act, Pub. L. 97-425, 96 Stat. 2201 (1982).

contemplated.[26] Thus, for a minimal payment, the economic cost of waste disposal has been externalized by the industry.

IV. THE NUCLEAR RISK EXTERNALITY

As with the costs of waste disposal, the costs and consequences of the risk of catastrophic nuclear accident or terrorist attack have been shifted from the industry to the public. Under the Price-Anderson Act, individual power plant liability for a nuclear mishap is limited to $300 million, while the joint liability of the industry is limited to a total of $10 billion.[27] This liability limit falls far short of the potential damages associated with a severe reactor accident. A 2004 study commissioned by the Riverkeeper organization estimated that damages caused by a severe reactor or spent fuel accident at the Indian Point nuclear power plant, 35 miles north of New York City, would exceed $2 trillion in property damage, in addition to 44,000 short-term fatalities and 518,000 latent long-term fatalities.[28] The NRC itself, in a 1982 report, similarly estimated the consequences of a severe reactor accident to include 46,000 early fatalities, 13,000 cancer deaths, and $274 billion in property damage (in 1982 dollars).[29]

This risk externality has three components: the risk of release of radioactivity due to an accident or malfunction at nuclear power plant, the risk of a release of radioactivity due to terrorist attack, and the risk of nuclear weapons proliferation unavoidably associated with the nuclear fuel enrichment and reprocessing cycle. The value of this "risk subsidy" to the nuclear industry has been estimated as high as thirty cents per kilowatt hour.[30]

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26. *See, e.g.*, PSEG Nuclear, L.L.C. v. United States, 465 F.3d 1343 (Fed. Cir. 2006); Maine Yankee Atomic Power Co. v. United States, 225 F.3d 1336, 1337-40 (Fed. Cir. 2000); Wisconsin Elec. Power Co. v. U.S. Dep't of Energy, 211 F.3d 646 (D.C. Cir. 2000); Indiana Mich. Power Co. v. US. Dep't of Energy, 88 F.3d 1232 (D.C. Cir. 1996); *see also DOE Backs Interim Storage Without Wavering On Yucca's Future*, ENERGYWASHINGTON WEEK, Dec. 13, 2006 (reporting that DOE's potential liability in lawsuits exceeds the amount available in the Nuclear Waste Fund).

27. 42 U.S.C. § 2210(e) (2000); *see also* U.S. Nuclear Reg. Comm'n, *Fact Sheet on Nuclear Insurance and Disaster Relief Funds,* http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/funds-fs.html (last visited Jan. 15, 2007).

28. EDWIN S. LYMAN, RIVERKEEPER, INC., CHERNOBYL ON THE HUDSON? THE HEALTH AND ECONOMIC IMPACTS OF A TERRORIST ATTACK AT THE INDIAN POINT NUCLEAR POWER PLANT (2004), *available at* http://riverkeeper.org/document.php/317/Chernobyl_on_th.pdf.

29. Data from Sandia Labs and U.S. Nuclear Regulatory Commission's 1982 "Calculation of Reactor Accident Consequences" report (commonly referred to as the "CRAC-2 Report") are reprinted at Mothersalert, Impact of a Meltdown at Nuclear Plant, http://www.geocities.com/mothersalert/crac.html (last visited Mar. 30, 2008).

30. Anthony Heyes, *Determining the Price of Price-Anderson,* REGULATION, Winter 2003, at 26, *available at* http://www.cato.org/pubs/regulation/regv25n4/v25n4-8.pdf.

A. Accident Risk

As the incidents at Chernobyl and Three Mile Island have demonstrated, the operation of nuclear power plants entails a risk of malfunctions that could potentially lead to core meltdown and atmospheric release of radioactivity These two incidents are comfortably in the past, but as recently as 2002, undiscovered deterioration of the reactor vessel head at the Davis-Besse nuclear power plant in Ohio brought that facility within weeks of a core meltdown event,[31] and this past year, an earthquake ruptured pipes and led to the release of radioactive contamination at Japan's Kashiwazaki plant.[32]

As it turns out, even based on industry reliability estimates, the operation of hundreds of nuclear power plants domestically and thousands of nuclear power plants internationally is statistically certain to result in more severe accidents in the mid-term. According to industry estimates, a severe nuclear power accident can be expected to occur less frequently than once every 10,000 reactor-years.[33] While this number sounds comfortably large, this translates into one severe accident every one hundred years for the 104 currently operating nuclear power plants in the United States, or one severe accident every twenty-five years if the number of operating reactors is quadrupled to reduce the global warming impacts of electricity generation. Since the NRC has not required the next generation of nuclear power plants to be any safer than the existing power plants,[34] the expected accident rate is not likely to change. Even in the mid-term, a severe nuclear accident is a likelihood if we increase nuclear power production enough to make a substantial dent in our greenhouse gas emissions.

B. Terrorism Risk

The industry's 1-in-10,000 reactor-years estimate of the likelihood of severe reactor incidents is based only on the likelihood of accidental mechanical or operational mishap. It does not take into account the probability of a successful terrorist attack on an operating nuclear power plant or its spent fuel pools. Following the September 11 attacks, the

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31. *See* Gronlund, *supra* note 7, at 17.

32. Martin Fackler, *Japan Nuclear Site Damage Worse than Reported*, N.Y. TIMES, July 19, 2007, at A8.

33. MARK HOLT, CRS ISSUE BRIEF FOR CONGRESS: NUCLEAR ENERGY POLICY, 7 (Updated Oct. 26, 2004), *available at* http://www.iags.org/CRS_IB88090.pdf. The NRC refers to a "severe accident" as "beyond the substantial coverage of design basis events," and one that "constitute[s] the major risk to the public associated with radioactive releases from nuclear power plant accidents." Nuclear Regulatory Commission, Policy Statement on Severe Reactor Accidents Regarding Future Designs and Existing Plants, 50 Fed. Reg. 32138 (Aug. 8, 1985) (to be codified at 10 C.F.R. pt. 50).

34. Gronland, *supra* note 7, at 53–54, Regulation of Advanced Nuclear Power Plants: Statement of Policy, 51 FR 24643 (July 8, 1986).

National Academy of Sciences assessed the nation's vulnerabilities and concluded that "the potential for a September 11th-style surprise attack in the near term using U.S. assets, such as airplanes, appears to be high."[35] Remarkably, the NRC takes no account of these risks in licensing and other regulatory decisions concerning nuclear power plants.[36] NRC regulations specifically provide that a licensee "is not required to provide for design features or other measures for the specific purpose of protection against the effects of . . . attacks and destructive acts, including sabotage, directed against the facility by an enemy of the United States, whether a foreign government or other person . . . ."[37] NRC has reaffirmed this position repeatedly since the September 11 attacks,[38] most recently when it announced that it would not follow a Ninth Circuit decision requiring it to consider the potential of terrorist attacks during environmental review of nuclear facility licenses and renewals under the National Environmental Policy Act.[39]

While nuclear proponents claim that nuclear containment structures are robust structures that might survive a September 11-style aircraft impact, this argument ignores the fact that spent fuel pools—which contain a larger radioactive inventory than the active reactor core—are outside of the containment structure. This spent fuel is susceptible to a zirconium cladding fire in the event the pools were drained rapidly, an event that the NRC considered to be a likely consequence of a crash of a commercial jetliner into a spent fuel pool structure.[40] Similarly, there are other critical operational structures located outside the containment dome, destruction of which would cause loss of reactor control.[41]

Like the risk of accidental radioactive release, the risk of a sabotage or terrorist induced core meltdown at a nuclear power plant is one that is

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35. COMM. ON SCI. AND TECH. FOR COUNTERING TERRORISM, NAT'L RES. COUNCIL, MAKING THE NATION SAFER: THE ROLE OF SCIENCE AND TECHNOLOGY IN COUNTERING TERRORISM 50 (2002), *available at* http://www.nap.edu/html/stct/index.html.

36. *See* Limerick Ecology Action, Inc. v. Nuclear Regulatory Comm'n, 869 F.2d 719 (3d Cir. 1989); *see also* City of New York v. U.S. Dep't of Transp., 715 F.2d 732 (2d Cir. 1983); Final Rule, Physical Protection for Spent Nuclear Fuel and High-Level Radioactive Waste, 63 Fed. Reg. 26955, 955-56 (May 15, 1998).

37. 10 C.F.R. § 50.13 (2008).

38. *See* Private Fuel Storage, L.L.C., 56 N.R.C. 340 (2002); *see also* Duke Energy Corp., 56 N.R.C. 358 (2002).

39. Amergen Energy Co., LLC, 65 N.R.C. 124 (2007) (declining to follow San Luis Obispo Mothers for Peace v. NRC, 449 F.3d 1016 (9th Cir. 2006), *cert denied sub nom.* PG&E v. San Luis Obispo Mothers for Peace, 127 S. Ct. 1124, 166 L. Ed. 2d 891 (2007)). Although the NRC revised the "Design Basis Threat" that nuclear power plants are required to plan for, ostensibly to respond to the heightened threat environment since September 11, this new design basis threat (details of which remain classified) still fails to reflect the level of force and coordination reflected in the September 11 attacks themselves. *See* Gronland, supra note 7, at 4.

40. Gronland, *supra* note 7, at 34; *see also* NATI'L RES. COUNCIL, TECHNICAL STUDY OF SPENT FUEL POOL ACCIDENT RISK AT DECOMMISSIONING NUCLEAR POWER PLANTS 3–23 (2000).

41. Gronland, *supra* note 7, at 34.

borne by the public and one for which the nuclear generating industry has no responsibility either to defend against or to compensate for beyond the minimal limits of Price-Anderson.

C. Proliferation Risk

The nuclear fuel cycle poses two nuclear weapons proliferation risks: enrichment technology and plutonium production. First, the technology and facilities needed to enrich uranium fuel to make it suitable for energy production are identical to the technology and facilities that can be used further to enrich uranium to the point that it is suitable bomb-making material. This means that spreading nuclear fuel generation technology also spreads nuclear weapons technology. While the nuclear non-proliferation treaty prohibits signatories other than the United States, the United Kingdom, France, Russia, and China from converting nuclear energy technologies to weapons use, a nation that withdraws from the treaty can rapidly convert the technology to bomb production.

Second, and perhaps more hazardous in the short term, is the amount of weapons-grade plutonium necessarily created by reprocessing nuclear waste. As noted above, keeping this material out of the hands of terrorist organizations assumes perfect security and accounting for this plutonium, while diversion of just a few kilograms is sufficient to fashion a nuclear bomb.[42]

If nuclear power is to be a permanent replacement for fossil fuels, then diversion of technology or plutonium to hostile use is likely in the long run. Ironically, the political upheavals and geopolitical tensions that are likely to result from global warming may actually make nuclear weapons proliferation from expanded nuclear energy generation and hostile use of nuclear weapons more likely.[43]

V. OTHER NUCLEAR POWER EXTERNALITIES

While I have focused this discussion on the two largest and least conventional externalities of nuclear power generation, nuclear power generation involves other environmental externalities as well. The most significant of these are the aquatic impacts associated with cooling water withdrawals and heat discharges common to most steam electric generating facilities. According to the EPA, aquatic impacts from even one facility can be staggering: "impingement and entrainment at individual facilities may result in appreciable losses of early life stages of

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42. *Id.* at 42.

43. In his acceptance speech for the Nobel Peace Prize on behalf of the Intergovernmental Panel on Climate Change, Chairman R.K. Pachauiri warned that international conflict is one likely consequence of global warming. *See* R. K. Pachauri, Chairman, Intergovernmental Panel on Climate Change (IPCC), Nobel Lecture at Oslo (Dec. 10, 2007) (*available at* http://nobelprize.org/nobel_prizes/peace/laureates/2007/ipcc-lecture_en.html).

fish and shellfish (e.g., three to four billion individuals annually . . . , serious reductions in forage species and recreational and commercial landings (e.g., 23 tons lost per year . . .), and extensive losses over relatively short intervals of time (e.g., one million fish lost during a three-week study period)."[44] These impacts can be largely eliminated through the implementation of closed cycle cooling systems.

Nor is the nuclear fuel cycle entirely without its own contribution to greenhouse gas emissions, as fossil fuel energy is used in the mining, transportation and enrichment phases of the nuclear fuel cycle. Nevertheless, these greenhouse gas emissions are relatively modest, comparable to the emissions associated with wind or hydroelectric power, and less than the emissions associated with construction of photovoltaic panels.[45]

VI. WHO WILL PAY FOR THESE EXTERNALITIES?

So, without any operating reprocessing cycle or geological repository, nuclear waste and its byproducts continue to pile up, primarily at the location of nuclear power generation facilities in this country, and at reprocessing facilities in other countries. In this country, this waste is being moved from spent fuel pools packed well beyond their original design capacity into dry cask storage units that, by regulation, have a design life of twenty years.[46] Yet there is no facility in the works that will be available in twenty years to accept these wastes for treatment or long-term geological disposal, just as there still is no facility to accept the waste generated from the past forty years of nuclear power generation.

Fiscal responsibility for nuclear wastes has been assumed by the federal government, but the bill is likely to come due at the same time as the global economic system grapples with the dislocations caused by several deferred costs of the unprecedented current global and national economic prosperity. These include the end of cheap transportation and energy provided by an unsustainable carbon fuel cycle in addition to the many other adaptations to climate change that will have to be made.

The fact is that no political or economic system can assure the security or integrity of waste for a period of time even remotely approaching the time period during which waste poses extreme health, environmental, terrorism, and nuclear proliferation risks. To put the 24,000 year half life of plutonium in context, keep in mind that recorded human history has lasted for only 5,000 years. China, the world's oldest

44. National Pollutant Discharge Elimination System: Regulations Addressing Cooling Water Intake Structures for New Facilities, Final Rule, 66 F.R. 65256-01 (Dec. 18, 2001) (to be codified at 40 C.F.R. 9, 122-125).

45. Gronland, *supra* note 7, at 11.

46. 10 C.F.R. § 72.236(g) (2008); *see also* U.S. NUCLEAR REG. COMM'N, STANDARD REVIEW PLAN FOR DRY CASK STORAGE SYSTEMS, FINAL REPORT (1997), *available at* http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1536/.

continuous civilization is 10,000 years old. Thirty thousand years ago, neanderthals still populated the European continent. In that time period, the continental glaciers of the Wisconsin age have advanced and retreated, covering and uncovering and grinding to dust many of the locations of currently operating nuclear power plants and their waste piles.

If the past is any prediction of the future, the nuclear waste we are now taking from storage pools and placing in casks will outlast our political system. Many of these disposal locations are located in major metropolitan areas: over 161 million people currently live within 75 miles of a nuclear power plant. Each spent fuel inventory contains enough radionuclides that if widely dispersed would render thousands of square miles uninhabitable.[47] Dispersal might occur by sea level rise inundating coastal locations, by spent fuel pool fires lofting aerosols, or by terrorist attack. The populations impacted by such dispersal—over ten million people in the New York metropolitan area potentially impacted by either the Indian Point nuclear power plants or by the Oyster Creek nuclear power plants in New Jersey—are comparable to the populations that will be impacted by global sea level rise. The city subject to a possible nuclear terrorist attack from unaccounted-for plutonium would be subject to casualties on a similar order of magnitude.

Nuclear power might nonetheless have a role to play in mitigating global climate change by displacing carbon cycle energy. If such a role is to be any less disastrous to future generations (and civilizations) than the carbon fuel cycle, then continuation and expansion of nuclear energy production should be contingent on the proven availability of existing facilities for geological disposal or a proven and commercially viable fuel reprocessing system. If we plan for the future of the planet to depend on canned goods, then we should first have an operable can opener.

47. *See* Declaration of 7 December 2001 by Dr. Gordon Thompson in Support of a Petition by Riverkeeper, Inc., Energy Corporation, 53 N.R.C. 488 (2001), *available at* http://riverkeeper.org/document.php/41/Thompson_Declar.doc.