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Environmental Critiques of Nuclear Energy

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Chapter 1: A New Energy Paradigm

The burning of hydrocarbons produces emissions of carbon-bearing gases. The overloading of our atmosphere with these emissions is held responsible for global warming leading to global climate change…it would seem prudent, whatever the case may be, to reduce our emissions of carbon gasses as rapidly as possible in order not to aggravate the situation further, and there is a strong case for a coherent international effort to achieve this.[1]

--Maxwell Irvine, *Nuclear Power: A Very Short Introduction*

Planet Earth, creation, the world in which civilization developed, the world with climate patterns that we know and stable shorelines, is in imminent peril. The urgency of the situation crystallized only in the past few years…The startling conclusion is that continued exploitation of all fossil fuels on Earth threatens not only the other millions of species on the planet but also the survival of humanity itself—and the timetable is shorter than we thought.[2]

--Dr. James Hansen, NASA climatologist

We need a new energy paradigm.

Despite the widely acknowledged dangers of climate change, we continue to act irresponsibly by relying on damaging and unsustainable energy sources: the production of electricity accounts for the largest percentage of national and international greenhouse gas (GHG) emissions compared to other sectors. In the U.S., about 33% of GHG emissions come from the electricity industry[3], and globally, electricity production accounts for about 26% of GHG emissions[4].

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[1] Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.
[2] Hansen, James E. *Storms of My Grandchildren: The Truth About the Coming Climate Catastrophe and Our Last Chance to Save Humanity*. New York: Bloomsbury USA, 2009. Print.
[3] *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009*. U.S. Environmental Protection Agency (EPA), 2011. Web. 24 Oct. 2011.
[4] *IPCC Fourth Assessment Report: Climate Change 2007*. Publication. Cambridge, UK: Cambridge UP, 2007. *Climate Change 2007: Mitigation of Climate Change*. Intergovernmental Panel on Climate Change, 2007. Web. 24 Oct. 2011.

The vast majority of these GHG emissions are produced when we burn hydrocarbons (or "fossil fuels"), such as petroleum, natural gas, or oil. In 2010, 68% of the U.S.'s electricity was provided via the burning of hydrocarbons[5], which closely matches the overall global percentage of electricity coming from these energy sources[6]. Various projections suggest that electricity use is increasing, will continue to rise, and—most importantly—use of these petroleum, natural gas, and coal as energy sources will also continue to increase[7].

If we continue with "business-as-usual greenhouse gas emissions, without any doubt, [we] will commit the planet to global warming of a magnitude that will lead eventually to an ice-free planet." The disintegration of the ice sheets will lead to a sea level rise of about 75 meters, rendering coastal cities "impractical to maintain" and making adaptation to continually changing sea levels "nearly impossible"[8].

Climate change of this magnitude will have lead to other disastrous consequences, including more extreme weather and a warmer and more acidic ocean. These new conditions will lead to substantial crop loss from drought or flooding, the destruction of vital infrastructure, mass extinctions and the loss of biodiversity, loss of freshwater, more disease, and on, and on[9].

We are marching towards an uncertain future in part because we can't figure out—or won't commit to—a better, more benign way to keep the lights on.

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[5] *Annual Energy Review 2010*. U.S. Energy Information Administration, Oct. 2011. Web. 23 Oct. 2011.
[6] *Key World Energy Statistics 2010*. Rep. International Energy Agency, 2010. Web. 23 Oct. 2011.
[7] *Annual Energy Outlook: Annual Projections to 2035*. Rep. U.S. Energy Information Administration, 15 Dec. 2010. Web. 24 Oct. 2011.
[8] Hansen 2009. Page 250.
[9] McKibben, Bill. *Eaarth: Making a Life on a Tough New Planet*. New York: Times, 2010. Print.

The purpose of this essay is not to convince anyone of the reality of climate change, nor to enumerate global warming's tragic consequences.

Instead, we will look at the future of electricity production coming from nuclear sources in this context of climate change and growing energy needs. The continued use of hydrocarbons for electricity is not viable, and it is not inevitable: indeed, more and more voices are calling for an immediate phase-out from fossil fuels to more sustainable energy sources, or for other emissions-curbing actions such as a carbon tax and strict regulatory measures.

As we shift away from hydrocarbons (voluntarily or out of necessity), we will turn to other methods to sustain our energy-producing capacity. Increased energy efficiency and conservation will help make up this deficit, but we will still need to supplement our electrical infrastructure in some way, especially as global energy demands increase.

Where will this new energy come from? Many people have suggested that we can satisfy our energy needs if we invest in and develop renewables, including wind power, hydropower, solar power, biomass or biofuel, and geothermal energy. On the whole, these energy sources emit very little GHG during operation, and are generally considered more environmentally friendly than other energy sources. But there are very real doubts about their capacity to provide sufficient energy on a global scale.

Experts and environmentalists such as Dr. James Hansen[10], Dr. James Lovelock[11], Steward Brand[12], and Gus Speth[13] have suggested that we should supplement renewables

[10] Dr. Hansen is a prominent NASA climatologist who has been writing about climate change since the 1970s.

with nuclear power. In 2010, about 13.4% of the world's electricity was provided by nuclear reactors, and in some countries, nuclear energy provides more than one-quarter of their total electricity[14]. If we simply committed to developing more reactors, some say, we could quickly move towards a new, carbon-free energy paradigm.

Proponents of nuclear energy say it's a cost-effective, long-term solution that is safe, reliable, and environmentally friendly, emits very little GHG during operation, and perhaps most importantly, can provide significantly more electricity than renewables.

Critics of nuclear power point out the economic costs of building and operating nuclear reactors, the risks associated with radioactive waste and a potential reactor meltdown, the environmental effects of uranium mining (and the GHG emissions associated with "life cycle" fuel management), the limited reserves of fuel material, and the possibility of nuclear weapons proliferation as strong reasons why we should relegate nuclear to the wastebasket.

Some of the most vocal supporters and detractors of nuclear energy are environmentalists. This essay will analyze nuclear power from an environmentalist's perspective: that is, how does nuclear power compare to other energy sources in terms of immediate environmental impacts, public health effects, and long-term sustainability? We will examine a variety of other environmental issues, such as waste management, uranium

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[11] Dr. Lovelock is a scientist and environmentalist who developed the Gaia hypothesis, which postulates that the biosphere is a self-regulating entity.
[12] Mr. Brand is the founder of the Whole Earth Catalogue.
[13] Mr. Speth was the dean of the Yale School of Forestry and Environmental Studies and is an environmental lawyer and advocate.
[14] "Nuclear Energy Around the World." *World Statistics*. Nuclear Energy Institute. Web. 24 Oct. 2011. <http://www.nei.org/resourcesandstats/nuclear_statistics/worldstatistics/>.

mining and enrichment, radiation and public health, environmental justice more broadly, and the potential impacts of a catastrophic meltdown. We will avoid questions of cost and political practicality—important as they are—in order to focus on concerns about public health and short- and long-term environmental damage. Our analysis will not be exhaustive: rather, I hope to provide a clear-eyed survey of these issues, and give readers a roadmap for further research and evaluation.

Focusing on an analysis of environmental concerns provides an especially compelling, useful structure for evaluating nuclear energy's potential because it recognizes the high stakes of climate change and a global energy crunch: if we are trying to provide energy to billions of people without rendering the Earth uninhabitable, the cost of energy production will be less important, and the politics are hypothetically straightforward. We have to provide energy for people, and we have to produce the energy without killing our planet, its ecosystems, and its organisms. In such dire circumstances, the decision of whether or not to pursue nuclear power hinges on real concerns about the environment and public health, rather than artificial concerns about dollars or policy. In the most tangible, immediate sense, can we afford nuclear energy?

In addition to analyzing the impacts of existing nuclear power, we will look at the emerging technologies in nuclear energy and determine whether any of these advancements could significantly impact the argument of the environmentalist. The goal is to synthesize and distill what environmentalists don't like about nuclear, and to determine whether new, "in the pipeline" nuclear technologies bypass some of these concerns.

Ultimately, we must decide if nuclear power will be a part of our response to climate change and rising global energy demand. The stakes are too high to dismiss a potential solution based on faulty information, misguided beliefs, or unexamined emotion. Conversely, we must decide if we are willing to invest the time, money, and effort that are necessary for nuclear energy to play a major role in the future.

In Chapter 2, I will provide an abridged history of global nuclear development, with special emphasis paid to the science behind nuclear fission and the three major disasters that have defined the nuclear age: Three Mile Island, Chernobyl, and Fukushima. In Chapter 3, we will examine and evaluate the anti-nuclear positions of some of the U.S.'s largest and most influential environmental groups. In Chapter 4, I will briefly discuss emerging nuclear technologies, and whether these advancements may be "game-changers" for anti-nuclear environmentalists. Finally, in Chapter 5, I will offer some final thoughts about this study, including my feelings about the ultimate role nuclear energy should play in the future.

Chapter 2: History of Nuclear Energy

Pre-1940: The foundations of nuclear physics

Some recent work by E. Fermi and L. Szilard…leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future…In the course of the last four months it has been made probable…that it may become possible to set up a nuclear chain reaction in a large mass of uranium, by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.[15]

--Letter from Albert Einstein to President Franklin Roosevelt

A series of exciting scientific breakthroughs in the early 1900s provided the foundation for nuclear physics: in 1909, the researcher Ernest Rutherford posited a model of the atom that included a positively charged mass as the nucleus, surrounded by electrons. In 1920, he proposed the theoretical existence of the neutron, and in 1932, Rutherford's colleague James Chadwick was able to discover this particle[16]. Shortly after this discovery, in 1934 Frédéric and Irène Joliot-Curie induced radioactivity by bombarding a stable material with radiation. The physicist Enrico Fermi built upon this research by using neutrons to increase the effectiveness of induced radioactivity, and in 1934, he announced that he had successfully transformed uranium into different elements. In 1938,

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[15] Einstein, Albert. "Letter from Albert Einstein to President Franklin Delano Roosevelt." Letter to Franklin Roosevelt. 2 Aug. 1939. Argonne National Laboratory. Web. 25 Oct. 2011.

[16] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.

was awarded the Nobel Prize in Physics for demonstrating the existence of new radioactive elements, and using neutrons to create nuclear reactions[17].

Meanwhile, German scientists Otto Hahn and Fritz Strassman continued to investigate induced radioactivity. In 1938, they discovered that Fermi's "new radioactive element" derived from uranium was not a transuranic: it was in fact barium, an element slightly less than half the size of uranium. They sent these findings to their Austrian colleague Lise Meitner, who realized that the uranium atom had split. Meitner and her colleague Otto Frisch used Albert Einstein's theory of the mass-energy equivalence to show that this process, which she called "atomic fission," must have released huge amounts of energy[18]. She relayed these findings to Niels Bohr, a Danish physicist who had won the Nobel Prize in Physics in 1922 for his work in the emerging field of quantum mechanics. Within a month, Bohr was on a ship bound for the United States to discuss these discoveries with Einstein.

It was now 1939. While he was in America, Bohr also met Fermi, and they discussed the possibility of a self-sustaining nuclear reaction. This same idea had occurred to the Hungarian scientist Leó Szilárd, who in 1933 had filed a patent on the concept of the neutron-induced nuclear chain reaction[19].

Many of the nuclear scientists were Jewish, and they were forced to flee from Europe as Nazi influence and power expanded. It was becoming clear to these scientists that this new technology could be used to create a powerful weapon, and so Szilárd and

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[17] Mahaffey, James. *Atomic Awakening: A New Look at the History and Future of Nuclear Power*. New York: Pegasus Books, 2009. Print.
[18] "The History of Nuclear Energy." U.S. Department of Energy. Web. 6 Nov. 2011.
[19] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.

other scientists contacted Einstein, in the hopes that his fame and reputation, combined with the petitions of other scientists, would persuade President Franklin Roosevelt to invest more resources into this technology. The appeal was successful, and the S-1 Uranium Committee (which would later evolve into the Manhattan Project), was established in 1939.

> **Layperson's aside:** By 1939, scientists around the world understood of the foundations of nuclear physics. Radiating uranium (bombarding it with neutrons) causes fission—the uranium nucleus splits into two fragments—releasing several more neutrons that can induce further fission[20]. If there is enough fissile material (in this case, uranium), this mass is said to be *critical*, which means the nuclear chain reaction is self-sustaining. This nuclear fission releases a large amount of energy. Although the potential for electricity generation was noted, scientists were far more concerned that this process could be used by the Nazis to create a powerful bomb.

[20] Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.

1940-1945: World War II and the Manhattan Project

If the radiance of a thousand suns were to burst into the sky, that would be like the splendor of the Mighty One—I am become Death, the shatterer of Worlds.[21]

--Translated passage from the *Bhagavad Gita*, a portion of which was quoted by J. Robert Oppenheimer while watching the Trinity nuclear test

With the new funding provided by the Uranium Committee, Fermi and Szilárd built the world's first man-made nuclear reactor, called the Chicago Pile-1 (CP-1). The reactor was literally a pile of uranium, and Fermi used cadmium-coated rods to increase or decrease the neutron activity within the pile, effectively controlling the chain reaction and therefore the amount of energy created. On December 2, 1942, CP-1 went critical[22].

Before CP-1, atomic and nuclear structure had been studied modestly and progress was steady. Following this success, research in the field of nuclear physics accelerated[23]. Most of the scientists went to Los Alamos, NM. Their new objective was to build a bomb.

In order to create a powerful bomb, the scientists needed to concentrate a much greater amount of fissionable material than was used in CP-1. Furthermore, this concentration of material had to happen very quickly; otherwise the chain reaction could fizzle out[24].

There were two technical challenges: 1) to slow down the neutrons in order to significantly improve the fission yields (energy created) and 2) to enrich naturally

[21] Jungk, Robert. *Brighter than a Thousand Suns: a Personal History of the Atomic Scientists*. New York: Harcourt Brace, 1958. Print.
[22] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.
[23] Mahaffey.
[24] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.

occurring uranium, which is 99.3% uranium-238 and 0.7% fissionable uranium-235. Separating the uranium with graphite blocks, which slowed the neurons enough to moderate and control the reaction, solved the first challenge[25].

Enriching uranium was more difficult. As part of the Manhattan Project, the United States Army Corps of Engineers acquired Oak Ridge, Tennessee in order to develop materials that would be used for weapons development[26]. Oak Ridge's primary purpose was to enrich enough uranium (enriching uranium entails separating the U-235 isotope). There were three methods for enriching the uranium: 1) gas diffusion, in which uranium fluoride gas was filtered through microscopic pinholes, 2) electromagnetic separation, in which the gas was shot through a magnetic field, and 3) thermal diffusion, in which the gas was heated. Enrichment was extremely difficult and tedious: it took the Oak Ridge site two years to produce enough U-235 for one bomb[27].

Scientists also built the X-10 Graphite Reactor, the first reactor designed for continuous operation. In 1941, UK scientists Frisch and Rudolf Peierls had shown that plutonium-239 was much more potent as fissile (bomb-making) material than uranium-235, and the X-10 reactor was used to manufacture the first significant amounts of plutonium through a process called "breeding." When U-238 absorbs a neutron, it transforms into Pu-239, which is even more effective bomb-making material than U-235. Soon, plutonium manufacturing moved to the B Reactor in Hanford, WA, another branch of the Manhattan Project.

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[25] Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.
[26] Johnson, Charles W., and Charles O. Jackson. *City behind a Fence: Oak Ridge, Tennessee, 1942-1946*. Knoxville: University of Tennessee, 1981. Print.
[27] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.

With Oak Ridge providing enriched uranium and Hanford providing plutonium, the first weapons were being assembled and tested in Los Alamos. On July 16, 1945, "Trinity"—the first atomic bomb—was detonated[28].

On August 6th, 1945, "Little Boy," an atomic bomb made with U-235, was dropped on Hiroshima, Japan. Three days later, on August 9th, "Fat Man," containing a core, or "pit," of plutonium, was dropped on Nagasaki. The estimated number of acute deaths at Hiroshima is 90,000-166,000 persons. The estimated number of acute deaths at Nagasaki is 60,000-80,000 persons[29]. On August 15th, Japanese Emperor Hirohito announced the surrender of Japan via radio, and the formal surrender ceremony was held September 2nd. There is considerable debate about whether the bombings of Hiroshima and Nagasaki were justified[30].

> **Layperson's aside:** In order to build an effective bomb, scientists needed extremely fissile material. At first, this came in the form of enriched uranium, where the U-235 isotope was separated and concentrated. Later, it was discovered that plutonium was much more potent than U-235, and scientists began using breeder reactors to manufacture plutonium. Breeder reactors generate more fissile material than they

[28] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.
[29] "Frequently Asked Questions - Radiation Effects Research Foundation." *The Radiation Effects Research Foundation Website*. The Radiation Effects Research Foundation, 2007. Web. 11 Nov. 2011.
[30] For an extended database of articles and books written on the subject, see: *Issues*. Alsos Digital Library for Nuclear Issues. Web. 10 Nov. 2011. <http://alsos.wlu.edu/qsearch.aspx?browse=issues/Decision+to+Use+the+Atomic+Bomb>.

consume[31]. Both of these breakthroughs—enriching uranium and employing breeder reactors—are still of fundamental importance today. Without the Manhattan Project and the exigencies of World War II, it is unlikely that commercial nuclear reactors would have been built in the 20th century[32].

[31] Waltar, Alan E., and Albert B. Reynolds. *Fast Breeder Reactors*. New York: Pergamon, 1981. Print.
[32] Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.

1950-1957: Nuclear technology and the beginning of the arms race

Heads or tails, the same thing is going to happen. Either the face of the earth is going to be changed by hydrogen bombs or the face of the earth is going to be changed by an unlimited source of power which is promised in fission and fusion reactors.[33]

--New York Times editorial, 1955

Following the war, expectations for atomic power were high: there was talk of a "240,000-mile rocket trip to the moon"[34] and energy "too cheap to meter"[35].

Before any of this could happen, Congress had to decide whether nuclear energy should be strictly contained within the military, or whether the technology should be available to, or controlled by, civilians. There were compelling arguments on both sides: those in favor of total military control cited weapons-grade plutonium production as a major reason to restrict the proliferation of nuclear technology, while Szilárd and others cited the potential for good and peaceful use as a reason to allow for civilian use. Ultimately, Congress passed the Atomic Energy Act of 1946, creating a civilian agency—the Atomic Energy Commission (AEC)—to oversee the usage of nuclear technology for military purposes and ending the government monopoly on nuclear research[36].

In 1949, traces of radioactive material were found in the atmosphere over Asia. The arms race had begun. Once the U.S. learned that the Soviets had detonated an atomic device

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[33] Plumb, Robert K. "Science in Review: Atomic Projects Hold the Promise of Both Vast Destruction and Unlimited Power." *New York Times* [New York] 20 Feb. 1955, Editorial sec. *ProQuest Historical Newspapers*. Web. 11 Nov. 2011.
[34] Dietz, David. *Atomic Energy in the Coming Era,*. New York: Dodd, Mead &, 1945. Print.
[35] "Too Cheap to Meter?" Canadian Nuclear Society, 20 Feb. 2009. Web. 11 Nov. 2011. <http://media.cns-snc.ca/media/toocheap/toocheap.html>.
[36] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.

of their own, there was a major fracturing within the scientific community as some pushed to develop an even more powerful hydrogen bomb, while others, notably including J. Robert Oppenheimer, the head of the secret weapons lab during the Manhattan Project, protested the increasing proliferation of such potent, apocalyptic weapons.

In 1953, President Dwight Eisenhower gave his famous "Atoms for Peace" speech at the newly-formed United Nations in response to an arms race with the Soviet Union that threatened to spiral out of control[37]. In the speech, he eschewed brinkmanship in an attempt to assure the world that the U.S. was committed to using nuclear technology for peaceful, enriching purposes, rather than for war.

> **Layperson's aside:** Nuclear energy and nuclear weapons are inextricably tied together. The rhetoric of the Cold War affected and continues to affect the way we understand nuclear technology's potential, limits, and danger.

[37] Eisenhower, Dwight D. "Address by Mr. Dwight D. Eisenhower, President of the United States of America, to the 470th Plenary Meeting of the United Nations General Assembly." Speech. New York City. 8 Dec. 1953. *Atoms for Peace*. World Nuclear University. Web.

1957-1979: The golden age of nuclear construction

Our monster cities, based historically on the need for mass labor, might now be humanized, broken into smaller communities, powered by nuclear energy, arranged according to community decision. These are but a fraction of the opportunities of the new era: serious study and deliberate experimentation, rooted in a desire for human fraternity, may now result in blueprints of civic paradise.[38]

--Manifesto written by Students for a Democratic Society, 1962

With government assistance (most notably the Price-Anderson Reactor Safety Act, which provided federal insurance for the first reactors[39]), Shippingport Atomic Power Station, the U.S.'s first commercial reactor, became operational in 1957[40]. All around the world, nuclear reactors were being connected to the electrical grid: the USSR developed the world's first nuclear power plant that was connected to the power grid in 1954; Calder Hall, the world's first commercial nuclear power station, was opened in 1956 in the UK; over 40 reactors had been connected to power grids worldwide by 1965[41].

These reactors were all Gen-I breeder reactors, meaning they had the dual purpose of producing electricity for the public and plutonium for the military. Because plutonium production was part of their function, these reactors were much less efficient and cost-effective at producing electricity. In addition to the inefficiencies associated with plutonium production, there were other design problems that made operating the plants dangerous

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[38] Students for a Democratic Society. *The Port Huron Statement of the Students for a Democratic Society*. 1962. Web.

[39] "Fact Sheet on Nuclear Insurance and Disaster Relief Funds." United States Nuclear Regulatory Commission, 9 June 2011. Web. 11 Nov. 2011.

[40] *Shippingport Atomic Power Station National Historic Mechanical Engineering Landmark*. 20 May 1980.

[41] *Nuclear Power Reactors in the World*. Rep. 26th ed. Vienna: International Atomic Energy Agency, 2005. Print. Ser. 2.

and expensive. Even with these flaws, many Gen-I plants operated safely well past their expected lifespans[42].

In the U.S., efforts were concentrated on developing pressurized water reactors (PWRs) and boiling water reactors (BWRs), which were designed exclusively for electricity production. PWRs, BWRs, and VVERs (the Russian version) are known as light water reactors (LWRs), and they represent Gen-II of nuclear reactors. LWRs are thermal reactors, meaning they use heat to generate electricity: fission heats water, and the resulting steam turns a turbine. Although much of this technology was developed in the 1960s, LWRs are still dominant among the world's reactors: the U.S. is currently operating over 100 LWRs, while Japan operates 63 LWRs, and France has 59 LWRs. Together, these three countries account for approximately 56% of the world's nuclear power[43].

The dangers associated with nuclear power began to garner more attention as more and more reactors were built. In 1964, the AEC commissioned a study to examine the worst-case scenario if a reactor were to meltdown near a population center. Despite technological improvements, the study found that fatalities could be as high as 45,000 persons. In 1969, MIT faculty and students formed the Union of Concerned Scientists (UCS), which challenged the AEC—especially in regards to reactor safety—and added to the growing chorus of voices speaking out against nuclear energy[44].

In 1974, the AEC was split into the Nuclear Regulatory Commission (NRC), and the Energy Research and Development Administration, both of which were incorporated into the newly formed Department of Energy.

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[42] Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.
[43] Ibid.
[44] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.

Layperson's aside: We have seen three different generations of nuclear reactors. Built in the 1950s, Gen-I reactors were breeder reactors, and they were fairly primitive and inefficient for electricity production. Gen-II LWRs were designed exclusively for electricity production, and they are still the dominant type of reactor used today despite being designed and constructed in the 1960s. Cheaper, safer, more efficient LWRs represent Gen-III reactors, developed in the 1990s.

Criticism of nuclear power grew with its prominence. Concerns about reactor safety, thermal pollution, cost, and other issues provided fertile ground for environmentalists, students, activists, and politicians who were skeptical that nuclear energy was as efficient, safe, and cheap as the industry claimed.

1979-1986: Nuclear accidents at Three Mile Island and Chernobyl

We have an emergency at Unit II and it's serious.[45]

--Call made to Ralph Desantis, security guard at Three Mile Island Nuclear Generating Station

There have been three significant nuclear accidents since 1979. In many ways, these accidents have provided a foundation for critics of nuclear energy, and they have certainly shaped the way we think and talk about nuclear power.

On March 28, 1979, the Three Mile Island Nuclear Generating Station near Harrisburg, Pennsylvania experienced a core meltdown. Following a cooling malfunction, human error and inadequate instrument design led to exposed fuel rods, causing them to melt[46]. Approximately 2.5 million curies of radioactive gases, and approximately 15 curies of iodine-131 were released into the atmosphere. According to the American Nuclear Society, the average radiation dose to people living within 10 miles of the plant was eight millirem, which is about equal to a chest X-ray[47].

Although there was no nuclear explosion (the U-235 content of reactor-grade fuel is 3%, which is insufficient to generate an explosion) and no immediate fatalities, it caused panic around the U.S. and provoked a renewed outcry against nuclear energy.

[45] Whitford, David. "Rethinking Three Mile Island." *CNN Money*. CNN, 31 July 2007. Web. 12 Nov. 2011.
[46] "Three Mile Island Accident." World Nuclear Association, 2010. Web. 11 Nov. 2011.
[47] "What Happened and What Didn't in the TMI-2 Accident." American Nuclear Society. Web. 12 Nov. 2011.

In the immediate aftermath of Three Mile Island, the NRC stepped up oversight and tightened down on regulations. In part because of the stringent regulations, construction of new reactors slowed or stopped altogether, because new, required safety features were being developed all the time, and the licensing process was long and tedious, all of which inflated costs. A law passed in 1982 required utility companies to develop evacuation plans, which gave local and nearby governments (responding to growing anti-nuclear sentiment) an easy way to delay the opening of new plants: they would simply refuse to participate in or submit a plan[48]. This new climate of regulation and public skepticism hobbled the budding nuclear industry.

In some ways, the long-term legacy of Three Mile Island seems to be somewhat positive: the president's special commission that investigated the accident suggested that there would be little or no adverse health effects due to the release of radiation[49], and several subsequent studies have supported this hypothesis[50]. Estimates suggest that the accident caused an additional one or two cancer deaths within 10 miles of the plant[51]. Furthermore, the accident was a sort of low-stakes meltdown test-run, and it provided important lessons about the physics of fuel melting. Finally, new regulations (especially

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[48] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.

[49] Kemeny, John G. *Report of The President's Commission on The Accident at Three Mile Island*. Rep. Washington, DC, 1979. Print.

[50] "Three-Mile Island Cancer Rates Probed." *BBC News World Edition*. BBC, 1 Nov. 2002. Web. 12 Nov. 2011.

[51] Mangano, Joseph. "Three Mile Island: Health Study Meltdown." *Bulletin of the Atomic Scientists* 60.5 (2004): 30-35. Print.

regarding better instrument design and increased operator training) decreased the probability that a similar accident would happen in the future[52].

On April 26, 1986, during an experimental test, a reactor at the Chernobyl Nuclear Power Plant in Ukraine suffered a catastrophic power increase, leading to explosions in the reactor core. The resulting fire created a cloud of radioactive fallout that spread throughout the region, shutting down certain industries (especially agricultural) and forcing at least 300,000 people throughout Europe to relocate[53]. Four hundred times more radioactive material was released during this explosion than the atomic bombing of Hiroshima, and an uninhabited “exclusion zone” some 4,300 square kilometers was created by contamination[54]. Some experts have estimated that the contamination extends over an area of about 100,000 square miles, or about the size of Kentucky[55].

Many historians, scientists, and analysts have suggested that the accident at Chernobyl was due more to the Soviet political and administrative system than to nuclear power itself. The reactor was designed without a containment building, and was fundamentally instable at low levels of operating power: rather than automatically shutting down when there is a problem, the RBMK reactors used at Chernobyl will occasionally run hotter and faster, which can lead to major problems. Furthermore, the operators at Chernobyl made deliberate decisions to bypass and disconnect safety systems and ignore

[52] Walker, J. Samuel. *Three Mile Island: a Nuclear Crisis in Historical Perspective*. Berkeley: University of California, 2004. Print.
[53] "Frequently Asked Chernobyl Questions." *Feature Stories*. International Atomic Energy Agency. Web. 12 Nov. 2011.
[54] "Ten Years after Chernobyl: What Do We Really Know?" International Atomic Energy Agency. Web. 12 Nov. 2011.
[55] Caldicott, Helen. *Nuclear Power Is Not the Answer*. New York: New York, 2006. Print.

(already insufficient) protocol, and communications between operational teams proved inadequate to deal with the crisis[56].

Because there were significant differences in reactor design and operating protocol in the Soviet Union and the U.S., the Chernobyl disaster did not prompt the same sort of policy-driven response like that of Three Mile Island. However, multiple European countries—including Austria, Sweden, Ireland, Poland, and Italy—voted in referendums to oppose or phase out nuclear energy[57]. Chernobyl also provided a dramatic manifestation of many of the fears people had about nuclear energy. These concerns have not gone away: there are ongoing studies about the human health effects as well as the environmental and economic effects of the Chernobyl disaster.

> **Layperson's aside:** The accidents at Three Mile Island and Chernobyl were very dissimilar in terms of severity: Three Mile Island was scary, and financially problematic for the plant owners, but it was not very dangerous. Chernobyl was a disaster that is directly accountable for 31 deaths, and anywhere from 30 to 985,000 more, with perhaps the most credible assessment suggesting about 4,000 deaths[58].

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[56] Rhodes, Richard. *Nuclear Renewal: Common Sense about Energy*. New York, N.Y., U.S.A.: Whittle in Association with Viking, 1993. Print.

[57] "50 Years of Nuclear Energy." International Atomic Energy Agency. Web. 11 Nov. 2011.

[58] The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) issued a report that suggested there were 64 confirmed deaths as of 2008. The World Health Organization said in 2011 that the death toll could reach 4,000 (not including cleanup worker casualties). Two UK scientists issued a study that suggested there could be 30,000 to 60,000 cancer deaths as a result of fallout, while a Greenpeace report said this figure could be above 200,000 deaths. Finally, a Russian publication (aptly named *Chernobyl*) concluded that 985,000 premature cancer deaths occurred worldwide between 1986 and 2004 as a result of the radioactive contamination from the accident. See *Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts Second Revised Edition*. Rep. The Chernobyl Forum, 2005. Web. 30 Nov. 2011.

In both cases, human error contributed to the accidents, but the plant at Three Mile Island employed fail-safe technology, whereas the plant at Chernobyl did not[59]. It was only when operators overrode these measures at Three Mile Island that problems arose—left untouched, the reactor would have shut itself down, as it was designed to do[60]. All nuclear plants are not created equal: differences in safety systems and instrument use, as well as operator training and protocol, can make some nuclear plants very safe, while other plants may be hazardous or unreliable (for example, the Chernobyl plant design would not have been certified in the U.S. Moreover, the accident at Chernobyl was the result of an experimental procedure, which would not have been allowed in the U.S.).

These nuclear accidents have shaped the political and regulatory climate of the nuclear industry, as well as public opinion about nuclear technologies. Following these accidents, efforts for more standardization, better operating practices and employee training, stricter safety protocol, and improved instruments and design made nuclear reactors considerably safer[61]. These efforts also arguably hindered the growth of the nuclear industry.

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[59] Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.
[60] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.
[61] "15 Years After Chernobyl, Nuclear Power Plant Safety Improved , but Strains on Health, Economy and Environment Remain." *Feature Stories*. International Atomic Energy Agency, 25 Apr. 2001. Web. 12 Nov. 2011.

1986-2011: The modern nuclear era

All the waste in a year from a nuclear power plant can be stored under a desk.[62]

--U.S. President Ronald Reagan

Despite public concern and smaller accidents than those described above, global nuclear capacity rose quickly from less than 1 gigawatt (GW) in 1960 to 300 GW in the 1980s. Post-Chernobyl, worldwide capacity has risen much more slowly, reaching about 366 GW in 2005[63]. This slowdown in growth can be attributed to a variety of different factors, including extremely high reactor construction and operating costs due to lack of standardization and regulatory changes, cheaper fossil fuels, increased energy conservation efforts, and more concerns about safety and radioactive waste[64]. In fact, more than two-thirds of nuclear plants ordered after 1970 were eventually canceled, including 63 nuclear units in the U.S. between 1975 and 1980[65]. Overall, 48% of the 253 plants originally ordered in the U.S. were canceled.

There has not been a new plant opened in the U.S. since 1996, and in 1998, the Department of Energy reduced its nuclear research budget to zero. Multiple sources

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[62] Dillon, Carrington. "Recycling Nuclear Fuel 101." Clean Energy Insight, 28 Aug. 2009. Web. 28 Nov. 2011. <http://www.cleanenergyinsight.org/tag/recycling/>.
[63] "50 Years of Nuclear Energy." International Atomic Energy Agency. Web. 11 Nov. 2011.
[64] Rüdig, Wolfgang. *Anti-nuclear Movements : a World Survey of Opposition to Nuclear Energy*. Essex, England: Longman Group, 1990. Print.
[65] *The Changing Structure of the Electric Power Industry: an Update.* Washington, DC: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels, U.S. Dept. of Energy, 1996. Print.

predicted that electrical deregulation and construction debt would lead to a decline in nuclear capacity as utilities closed plants that could no longer compete[66].

The nuclear industry responded by increasing internal efficiency through improving and enhancing the mechanical and electrical equipment that was prone to breaking down. Breakdowns caused long delays and safety outages during which the reactors were shut down or disconnected from the electrical grid. Out of the reactors in the U.S., 27% have experienced outages that have lasted a year or more[67]. The industry standard in the early 1990s was to run the reactors at about 45% of their generating capacity: by 2001, the fleet of American reactors was operating at 90% capacity. Furthermore, "scrams" (emergency shutdowns) and unplanned outages were reduced from 100 or more days per year to less than 50, and refueling times decreased from three months to less than 30 days. Since 1990, about one-third of electrical growth within the nuclear industry has been the result of this enhanced performance[68].

There were also technological advancements made in reactor design. Improvements and advances made for PWRs and BWRs represent Gen-III+ of nuclear reactors. These design changes are meant to decrease operating cost and increase reliability. In addition to improved safety systems (one reactor design is made to withstand a direct airplane crash), some of the Gen-III+ reactors utilize "passive" safety systems, which rely on gravity and

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[66] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.
[67] Lovins, Amory, Imran Sheikh, and Alex Markevich. "Nuclear Power: Climate Fix or Folly?" *Rocky Mountain Institute* (2009). Web. 12 Nov. 2011.
[68] Tucker, William. *Terrestrial Energy: How Nuclear Power Will Lead the Green Revolution and End America's Energy Odyssey.* Savage, Maryland: Bartleby Press, 2008. Print.

natural circulation rather than pumps. The first Gen-III+ reactors are expected to be operational in 2012, with plants opening in Finland, France, UK, India, and Italy[69].

[69] Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.

2011: Fukushima and the future of nuclear energy

There is talk of an apocalypse and I think the word is particularly well chosen. Practically everything is out of control.[70]

--European Commissioner for Energy Günther Oettinger, describing the nuclear disaster in Fukushima, 2011

On March 11, 2011, an earthquake measuring 9.0 on the Richter scale triggered a massive tsunami that devastated the eastern coast of Japan. The tsunami caused tens of thousands of deaths, and forced hundreds of thousands to relocate. Road, rail, water, and electricity systems were destroyed or disrupted. All told, the costs of the disaster are likely to exceed a trillion US dollars. The tsunami also led to the largest nuclear accident since Chernobyl[71].

A 50-foot wave flooded the Fukushima I Nuclear Power Plant (Fukushima-Daiichi plant), disrupting the plant's connection to the electrical grid and to its emergency generators. The reactors started to overheat, and within days, three reactors had experienced full meltdown[72].

> **Layperson's aside:** A meltdown (or "core melt accident") occurs when the heat generated by a nuclear reactor exceeds the heat removed by the cooling systems to the point where at least one nuclear fuel element exceeds its melting point. These

[70] Oettinger, Günther. "Japan Nuclear Plant Disaster: Warning of an 'apocalypse' as Fallout Hits Danger Levels." Interview by Martin Evans and Gordon Rayner. *The Telegraph* 16 Mar. 2011. Print.
[71] Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.
[72] CNN Wire Staff. "3 Nuclear Reactors Melted down after Quake, Japan Confirms" *CNN* 7 June 2011. Web. 20 Nov. 2011.

fuel elements can leach out into the coolant or destroy parts of the containment vessel. Meltdowns have the potential to release radioactive materials into the environment[73].

Explosions and fires further damaged the reactors, and cooling water leaked out of the damaged reactor vessels. In addition, spent fuel rods stored in pools began to overheat as water levels in the pool dropped. Due to the flooding and destruction, workers were unable to enter reactor buildings until May 5, nearly two months after the disaster.

In many ways, the meltdown at Fukushima-Daiichi represented the “worst-case scenario:” a core meltdown and hydrogen explosions were able to destroy an already weakened containment vessel, leaking radioactive materials into the atmosphere[74]. Japanese officials assessed the accident as Level 7 on the International Nuclear Event Scale, which is the maximum scale value, and the value assigned to the Chernobyl accident[75]. According to this scale, a Level 7 accident creates “widespread health and environmental effects” and involves the “external release of significant fractions” of the core[76].

Observations and analysis regarding Fukushima-Daiichi are ongoing[77]. It has been estimated that the total release of radioactivity is about one-tenth that from the Chernobyl

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[73] International Atomic Energy Agency. "IAEA Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection." June 2007. Web. 20 Nov. 2011.
[74] Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.
[75] Black, Richard. "Fukushima: As Bad as Chernobyl?" *BBC* 12 April 2011. Web. 20 Nov. 2011.
[76] International Atomic Energy Agency, and Nuclear Energy Agency. "The International Nuclear and Radiological Event Scale." Web. 20 Nov. 2011.
[77] NPR Staff. "Fukushima, Three Mile Island, Chernobyl: Putting It All In Perspective." *NPR* 15 Mar. 2011. Web. 21 Nov. 2011.

accident[78]. Tokyo's tap water was briefly contaminated[79], and food grown in the surrounding area has been banned from sale[80]. Although the Fukushima and Chernobyl disasters were both Level 7 accidents, it is unlikely that the accident at Fukushima will have comparable effects in terms of severity or scale[81]. So far, the only casualties have been two workers hospitalized for non-life threatening radiation burns, but the release of radioactive material could theoretically increase cancer rates in the surrounding areas over the next few decades.

It's important to note that other nuclear plants in Japan were also affected by the tsunami, but didn't suffer the disastrous meltdowns like those at the Fukushima-Daiichi plant. Part of this could be due to somewhat poor decision-making at Fukushima-Daiichi immediately following the tsunami[82]. Another station, the Fukushima II Nuclear Power Plant (Fukushima-Daini), automatically shut down following the earthquake, but the backup diesel engines and cooling systems were damaged following the tsunami. The core overheated, resulting in a Level 3 accident. Other nuclear plants were also compromised, but were shut down automatically and safely.

Layperson's aside: It is somewhat unsurprising that a 9.0 earthquake and subsequent tsunami would be able to destabilize a nuclear reactor. Few man-made

[78] Von Hippel, F. N. "The Radiological and Psychological Consequences of the Fukushima Daiichi Accident." *Bulletin of the Atomic Scientists* 67.5 (2011): 27-36. Print.
[79] McCurry, Justin. "Tokyo Water Unsafe for Infants after High Radiation Levels Detected." *The Guardian* 23 Mar. 2011. Web. 20 Nov. 2011.
[80] Dahl, Fredrik. "Japan Mulls Fukushima Food Sale Ban." *Reuters* 19 Mar. 2011. Web. 20 Nov. 2011.
[81] Sich, Alexander. "How Bad Is Fukushima Crisis?" *The Diplomat* 12 Apr. 2011. Web. 20 Nov. 2011.
[82] Harris, Richard. "What Went Wrong In Fukushima: The Human Factor." *NPR* 5 July 2011. Web. 21 Nov. 2011.

structures are designed to withstand such natural disasters. Still, these sorts of events must be considered if we intend to provide nuclear energy as safely as possible, especially given the potentially catastrophic and long-lasting effects of a total meltdown.

Due to significantly better reactor design (including fail-safe technology) and better-trained personnel, the accident at Fukushima was not as bad as the Chernobyl disaster, but the ultimate health effects of the meltdown remain to be seen[83].

One of the most enduring legacies of Fukushima may be the change it prompts in the world's energy paradigm[84]: in August, Japan approved a bill that will subsidize electricity from renewable sources, perhaps indicating a shift away from nuclear power[85]. Various countries ended or froze their nuclear programs: Germany has decided to phase out its nuclear program by 2022[86] following protests that drew hundreds of thousands of people; Venezuela has halted its nuclear development projects[87]; China suspended approvals of nuclear plants and froze construction plans[88] (although they may be resuming construction

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[83] Tsukimori, Osamu, and Nathan Layne. "Areas near Japan Nuclear Plant May Be off Limits for Decades." *Reuters* 27 Aug. 2011. Web. 21 Nov. 2011.
[84] Schneider, Mycle. "Fukushima Crisis: Can Japan Be at the Forefront of an Authentic Paradigm Shift?" *Bulletin of the Atomic Scientists* (2011). 9 Sept. 2011. Web. 21 Nov. 2011.
[85] Watanabe, Chisaki. "Japan Spurs Solar, Wind Energy With Subsidies for Renewables." *Bloomberg* [Tokyo] 26 Aug. 2011. Web. 21 Nov. 2011.
[86] Cole, Deborah. "Fukushima Fallout: Germany Abandons Nuclear Energy." *The Sydney Morning Herald*. 31 May 2011. Web. 23 Nov. 2011.
[87] Pons, Corina R. "Chavez Halts Venezuela Nuclear Plans After Japanese Crisis." *Bloomberg*. 15 Mar. 2011. Web.
[88] CNN Wire Staff. "China Freezes Nuclear Plant Approvals." *CNN*. 16 Mar. 2011. Web. 23 Nov. 2011.

of some of the plants[89]); Israel canceled the construction of its first civilian plant[90] and Prime Minister Benjamin Netanyahu indicated that the country would not be developing civilian nuclear energy[91]; Taiwan halted its nuclear expansion[92]; Italy has frozen construction of nuclear plants[93]; and Switzerland has announced that it will be decommissioning its current nuclear plants, with no plans to pursue future nuclear energy[94]. The EU[95] and India[96] have been rigorously reevaluating their nuclear programs, with special attention being paid to safety mechanisms[97].

The Fukushima disaster may signal the beginning of the end of the nuclear era, especially as the cost of renewable energy drops[98]. But nuclear power still plays a significant role in worldwide energy production, and reactors will continue to provide large amounts of electricity into the foreseeable future. Some experts and industry

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[89] Baizhen, Chua. "China May Resume Nuclear Plant Construction, Official Says." *BusinessWeek*. Bloomberg, 18 Nov. 2011. Web. 23 Nov. 2011.
[90] Xuequan, Mu, ed. "Israeli PM Cancels Plan to Build Nuclear Plant." *English News Global Edition*. Xinhua News, 18 Mar. 2011. Web. 23 Nov. 2011.
[91] Somfalvi, Attila. "Netanyahu: We'll Reconsider Nuclear Power Plans." Ynetnews.com, 17 Mar. 2011. Web. 23 Nov. 2011.
[92] Sun, Yu-huay. "Quake-Prone Taiwan Halts Nuclear Expansion as Japan Struggles at Fukushima." *Bloomberg*. 13 Apr. 2011. Web. 23 Nov. 2011.
[93] World Nuclear News. "Italy Announces Nuclear Moratorium." World Nuclear News, 24 Mar. 2011. Web. 23 Nov. 2011.
[94] Robinson, Francine. "Stepping Back from the Nuclear Brink." *The Gainesville Sun*. 17 Nov. 2011. Web. 23 Nov. 2011.
[95] World Nuclear News. "Ministers authorise nuclear 'stress tests.'" World Nuclear News, 23 Mar. 2011. Web. 23 Nov. 2011.
[96] Mehdudia, Sujay. "Indian Nuclear Plants 'safe' but No Room for Complacency." *The Hindu*. 14 Mar. 2011. Web. 23 Nov. 2011.
[97] PTI. "Govt to review safety at nuclear plants: Ramesh." *The Times of India*. 15 Mar. 2011. Web. 23 Nov. 2011.
[98] DB Climate Change Advisors. *The 2011 Inflection Point for Energy Markets: Health, Safety, Security and the Environment*. Rep. Deutsche Bank Group, 2 May 2011. Web. 23 Nov. 2011.

supporters have even suggested that we are on the brink of a nuclear renaissance, with promising new technology and a more agreeable political atmosphere.

In 2009, about 438 nuclear plants provided 5.8% of global energy supply, and about 13.4% of global electricity generation[99]. Power generation has actually been dropping since 2005 as plants are decommissioned or closed[100]. However, new orders for reactors in the U.S., Asian countries (most notably China and India), and Europe may lead to increased nuclear energy production[101]. In many European nations, nuclear plants already provide a significant percentage of some countries' energy, and in France (the "most nuclear" nation), 76% of the nation's electricity comes from nuclear reactors[102].

The U.S. is the world's largest producer of nuclear energy with 104 licensed and operating power reactors. These reactors generated about 798.9 TWH in 2009, which accounts for about one-fifth of U.S. electricity generation. In the same year, these commercial reactors operated at an average of 90.3% of their total capacity[103]. All of these plants were built in 1974 or earlier, but many have been relicensed, extending their lifetime past the original target of 40 years[104].

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[99] *Key World Energy Statistics 2011*. Rep. International Energy Agency, 2011. Web. 23 Nov. 2011.

[100] World Nuclear News. "Another drop in nuclear generation" World Nuclear News, 5 May. 2010. Web. 23 Nov. 2011.

[101] For a summary of nuclear plants under construction, see *Nuclear Power Reactors in the World*. Rep. 26th ed. Vienna: International Atomic Energy Agency, 2005. Print. Ser. 2.

[102] Diesendorf, Mark. *Economics of Nuclear and Renewable Electricity*. Issue brief no. 1. 2010. Print.

[103] *Annual Energy Review 2010*. U.S. Energy Information Administration, Oct. 2011. Web. 23 Oct. 2011.

[104] Donn, Jeff. "NRC, Nuclear Industry Rewrite History: AP Investigation." *Huffington Post*. 28 June 2011. Web. 23 Nov. 2011.

Layperson's aside: 2011 has been a time of rapid change and reassessment in the energy industry. Breakthroughs in renewable energy technology, as well as growing energy needs have changed (or will soon change) the way many of us get our energy. Anti-nuclear sentiment was already high (and growing) before Fukushima: the disaster provided activists, politicians, and citizens with a dramatic example of the risks associated with nuclear energy. Public support for nuclear eroded quickly following the accident, which will hinder or stop nuclear development around the world[105].

Still, nuclear power is too important to ignore or dismiss. Besides providing a significant portion of the world's electricity, it is a low GHG-emitting source of energy—a vital characteristic as scientists and governments seek an answer to climate change.

The future of nuclear energy is unclear. We can look at the backlash to the Fukushima disaster, growing anti-nuclear sentiment, and the slow pace of nuclear development (in countries with existing nuclear programs as well as countries without nuclear programs) and make a reasonable assertion that nuclear power is on its way out. Alternatively, we can look at renewed construction and government support for nuclear plants in the U.S. and Asian countries, as well as the intensifying search for non-GHG intensive energy sources, to conclude that the nuclear industry may be on the cusp of resurgence. The success of the industry depends on the price of oil and other fossil fuels,

[105] Cooper, Michael, and Dalia Sussman. "Nuclear Power Loses Support in New Poll." *The New York Times*. 22 Mar. 2011. Web. 24 Nov. 2011.

the affordability of renewables, and the industry's own ability to ensure that nuclear plants (and the byproducts of nuclear power generation) are safe and economical.

The future of nuclear development is influenced by economics and technology, but it is primarily a political issue. Different groups have an interest in preventing or promoting the use of the nuclear power, and the growth of the industry will hinge on the way these sides are able to mobilize themselves and recruit supporters from other populations[106].

[106] Stone, Deborah. *Policy Paradox: The Art of Political Decision Making, Revised Edition*. 2 ed. New York: W. W. Norton, 2001.

Chapter 3: The Environmentalist's Perspective

The Sierra Club remains unequivocally opposed to nuclear energy. Although nuclear plants have been in operation for less than 60 years, we now have seen three serious disasters. Tragically, it took a horrific disaster in Japan to remind the world that none of the fundamental problems with nuclear power have ever been addressed. Besides reactor safety, both nuclear proliferation and the required long-term storage of nuclear waste (which remains lethal for more than 100,000 years) make nuclear power a uniquely dangerous energy technology for humanity.[107]

--Statement on Sierra Club's website

In order to save the future of our planet, we must continue to fight the expansion of nuclear power and instead push for clean, renewable sources of energy. Over the next three years Greenpeace will continue to:
1. Debunk the myth that nuclear provides a "green" source of electricity and detail the threats posed by nuclear reactors and the radioactive wastes they produce.
2. Expose the abysmal economics of new nuclear power.
3. Advocate for the permanent closure of the old, leaky Vermont Yankee nuclear power plant in 2012.[108]

--Statement on Greenpeace's website

Environmentalists are some of the major political players in the nuclear energy fight. Within any given group of environmentalists, there are likely to be strong advocates for nuclear energy, as well as strong critics.

In this chapter, we will be focusing on the critics of nuclear energy. Our goal is to characterize and evaluate the concerns articulated by the "green community"[109]. In order to do this, we will examine the statements made by some of the largest and most influential environmental groups, organizations, and lobbies. We will support these critiques with

[107] "Nuclear Is Not the Answer." *Sierra Club Home Page*. Sierra Club. Web. 24 Nov. 2011. <http://www.sierraclub.org/nuclear/>.
[108] "Nuclear Power and Nuclear Energy Dangers." Greenpeace. Web. 24 Nov. 2011. <http://www.greenpeace.org/usa/en/campaigns/nuclear/>.
[109] This term will be used in reference to a loosely-defined population of environmentalists, environmental justice advocates, and environmentally-minded activists.

analyses made by various experts, scientists, and researchers. We are focusing on these large groups because they dominate the conversation about nuclear power: they have the visibility necessary to reach large portions of the general population, the budgets to lobby aggressively and effectively, and enough political clout to affect public policy.

This is not a comparative study. As much as possible, we will be evaluating nuclear power on it's own, as a viable energy source (not as the lesser-of-two-evils energy source). We want to determine whether the environmental risks associated with nuclear energy outweigh its benefits. It's also important to note that the positions of these large environmental organizations are not necessarily the "best" arguments. We may not find certain aspects of their critiques compelling. But remember: the goal is not to present the most forceful environmental critique of nuclear power. The goal is to characterize and evaluate the concerns *as they are*. Ultimately, we want to see how (mainstream) environmentalists articulate their criticisms, so that we can assess whether these concerns are valid, and identify the most productive ways to move forward in the debate about nuclear energy. Furthermore, we can use this analysis to provide a framework for evaluating new, emerging nuclear technologies.

As stated in Chapter 1, evaluating nuclear energy from an environmentalist's standpoint is particularly useful and salient if we are deciding whether we ought to pursue more nuclear development in the future. But it's important to note that there are other reasons why the development and proliferation of more nuclear energy may prove unpalatable or unfeasible.

Perhaps most significant are the economics of nuclear energy. Without massive government subsidies, the construction, operation, maintenance, and decommissioning of new nuclear reactors would (at present) be prohibitively expensive. These costs may decrease as the nuclear industry standardizes designs and continues to make technological advances, but the price of nuclear energy will likely remain a noteworthy concern.

Additionally, it would be naïve to suggest that the merits of nuclear energy alone (even if they were undeniable) are sufficient to spur new investment in and dedication to the technology. The politics of energy are not technocratic: the "best" type of energy is not always the type of energy we employ. A variety of political realities exist—such as the sway of special interests, the intractability of bureaucracies and established policy, or the will of the citizens (we do, after all, ostensibly live in a democracy)—that could prevent the government or the private sector from making a strong commitment to nuclear energy.

In order to determine the concerns of environmentalists, I gathered data from the websites and publications of various organizations[110]. **Table 1** below shows how each

[110] "Nuclear Power and Nuclear Energy Dangers." Greenpeace, 2010. Web. 26 Nov. 2011. <http://www.greenpeace.org/usa/en/campaigns/nuclear/>.
"Why Nuclear Power Doesn't Make Sense." Sierra Club, 2011. Web. 26 Nov. 2011. <http://www.sierraclub.org/nuclear/factsheet.aspx>.
Holstein, Elgie, and Lisa Moore. "An Inquiry: What Should the U.S. Do about Nuclear Power?" *Summer 2011 Talk Back*. Environmental Defense Fund, 12 July 2011. Web. 26 Nov. 2011. <http://solutions.edf.org/2011/07/12/summer-2011-talk-back/>.
"Facts about Nuclear Power." Friends of the Earth, 20 Apr. 2011. Web. 26 Nov. 2011. <http://www.foe.co.uk/campaigns/climate/issues/nuclear_index.html>.
"Energy Policy and Legislation." Defenders of Wildlife. Web. 26 Nov. 2011. <http://www.defenders.org/programs_and_policy/policy_and_legislation/energy/index.php>;
Cochran, Thomas B., Christopher E. Paine, Geoffrey Fettus, Robert S. Norris, and Matthew G. McKinzie. *Position Paper: Commercial Nuclear Power*. Publication. Natural Resources Defense Council, 2005. Print;

environmental organization addressed the nuclear issue. Their "Overall" stance reflects whether they believe nuclear power is redeemable—that is, if significant changes are made within the industry, whether nuclear power should be part of our energy paradigm. The rest of the table shows which aspects or characteristics of nuclear energy these organizations identified as problematic. An 'x' in any particular column indicates that the organization mentioned that problem as a reason to avoid nuclear development.

Table 1

	Overall	Economics	Uranium mining	Normal operation	Meltdown/ accident	Waste disposal	Weapons proliferation	Terrorist threat
Greenpeace	Firmly anti-nuclear	x	x	x	x	x	x	x
Sierra Club	Firmly anti-nuclear	x	x	x	x	x	x	x
Environmental Defense Fund	Neutral			x	x	x	x	
Friends of the Earth	Firmly anti-nuclear	x	x	x	x	x	x	x
Defenders of Wildlife	Somewhat anti-nuclear					x		
Natural Resources Defense Council	Somewhat anti-nuclear	x	x	x	x	x	x	x
The Nature Conservancy	Undecided					x		
WWF	Firmly anti-nuclear	x	x	x	x	x	x	
Union of Concerned Scientists	Neutral	x		x	x	x	x	x

Bendick, Robert. "Jobs, Cleaner Air, National Security Key to Obama's State of the Union Energy Goals."*Planet Change*. The Nature Conservancy, 26 Jan. 2011. Web. 26 Nov. 2011. <http://change.nature.org/tag/nuclear/>;
WWF. *WWF Position Statement: Nuclear Power*. 2003. Print;
Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

We can see that there are a few issues that were mentioned by almost every group: the economics of building and operating reactors; the effects of uranium mining; health and safety concerns associated with accidents as well as normal operations; unsafe disposal of radioactive waste; and the threat of terrorism and nuclear proliferation. We will discuss and evaluate each of these concerns in turn, leaving aside the issue of economics for the reasons stated earlier.

Concern #1: Uranium mining

Mining is like a search and destroy mission.[111]

--Stewart Udall, Former U.S. Secretary of the Interior

Environmentalists identify uranium mining as a problem for two broad reasons: the energy costs and GHG emissions associated with mining, and the health, safety, and environmental problems caused by mining.

In her book *Nuclear Power Is Not the Answer*, Helen Caldicott says that the energy costs associated with uranium mining mean that the life cycle (from mining to waste disposal) energy output of nuclear plants is much higher than we think. Significant amounts of energy must be expended to mine, crush, and then mill uranium ore; to enrich the uranium; to build the reactor; and to adequately store the waste. She cites a study by Jan Willem Storm Van Leeuwen and Philip Smith[112] that suggests that lower grade uranium ore requires such large energy expenditure to mine and process, that it is "energetically non-productive"[113]. Furthermore, to adequately dispose of and contain mill tailings requires huge amounts of energy, further decreasing energy efficiency. If the energetic costs of the entire fuel cycle are considered—without including the energy costs of storing and transporting radioactive waste—the "total energy debt comes to approximately 240

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[111] "New Dawn for Mining at the Seabed." Editorial. *New Scientist*. 29 June 2011. Web. 10 Dec. 2011.
[112] Storm Van Leeuwen, Jan Willem, and Philip Smith. *Nuclear Power–the Energy Balance*. Rep. 2007. Print.
[113] Caldicott, Helen. *Nuclear Power Is Not the Answer*. New York: New York, 2006. Print.

petajoules. The construction and implementation process involved in a gas-fired plant requires only one-tenth that amount…to produce the same electricity[114].”

It’s important to note that Storm Van Leeuwen’s report, upon which Caldicott relies, is heavily disputed. A few different industry sources question his methods for predicting the amount of energy used, and suggest that the actual measured energy costs are much lower than he reports[115]. In addition, the position paper published by the Union of Concerned Scientists contains information that contradicts multiple parts of Storm van Leeuwen’s study, including the energy costs and GHG emissions associated with the nuclear fuel cycle[116].

Caldicott and Storm Van Leeuwen are trying to get us to consider the entire life cycle energy inputs and outputs associated with nuclear power. Clearly, when the entire life cycle is considered, significant amounts of energy will go in to operating mining equipment, fabricating the actual reactors, etc. Often, this energy is supplied via the burning of hydrocarbons, which releases GHG. This is true of any power station—nuclear, renewable, or fossil fuel-based. A study completed by The University of Sydney (interestingly, drawing on Storm Van Leeuwen’s research) suggests that the overall energy intensity of a nuclear reactor increases with less pure uranium ore grades and decreased fuel recycling. Still, the

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[114] Ibid.

[115] See "Energy Analysis of Power Systems." World Nuclear Association, Jan. 2011. Web. 27 Nov. 2011. <http://www.world-nuclear.org/info/inf11.html>; Barton, Charles. "David Fleming and Jan Willem Storm Van Leeuwen." *Energy From Thorium*. 23 Mar. 2008. Web. 27 Nov. 2011. <http://energyfromthorium.com/2008/03/23/david-fleming-and-jan-willem-storm-van-leeuwen/>; Sevior, Martin. "Response from Martin Sevior to Rebuttal 2 from Jan Willem Storm Van Leeuwen." *Nuclear Power Education*. Nuclearinfo.net, 2 June 2006. Web. 27 Nov. 2011. <http://nuclearinfo.net/Nuclearpower/SeviorSLSRebutall>.

[116] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

energy use associated with nuclear power (throughout the entire fuel cycle) "is lower than that of any fossil-fuelled power technology"[117].

In addition to the energy costs associated with uranium mining and the nuclear fuel cycle, there is also significant environmental damage and human health risks associated with mining itself. Exploration for uranium can lead to the dispossession of indigenous peoples' land, and post-mining "rehabilitation" can be cosmetic, leaving the dangerous radioactivity of the area unchanged[118]. In the U.S., a significant portion of accessible uranium is on Navajo Nation land (some estimates suggest over 50% of ore deposits are on Navajo land), and many advocates and environmentalists feel that mining companies have exploited this already-marginalized population[119]. In the 1940s and 1950s, many Navajo people worked as miners, and were exposed to high levels of radioactivity. One 1959 report finding that miners endured radiation 90 times the acceptable limit[120]. Additionally, these miners inhaled radioactive gas that can irradiate cells in the lungs, causing them to become malignant. One study found that 133 out of 150 Navajo workers died of lung cancer or fibrosis within a decade of working at a mine in Shiprock, NM[121]. High rates of cancer in uranium miners have been found in other countries, including Germany and Russia[122].

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[117] Lenzen, M. "Life cycle energy and greenhouse gas emissions of nuclear energy: A review." *Energy Conversion and Management* 49 (2008): 2178-2199. Print.
[118] *Uranium Mining*. Publication. Reaching Critical Will. Web. 27 Nov. 2011. <http://www.reachingcriticalwill.org/resources/edkit/21uramine.pdf>.
[119] "Navajos "chop The Legs Off Uranium Monster"" WISE, 13 May 2005. Web. 27 Nov. 2011.
[120] Klauk, Erin. "Human Health Impacts on the Navajo Nation from Uranium Mining."*Science Educations Resource Center*. Carleton College, 27 Oct. 2011. Web. 27 Nov. 2011.
[121] Ali, Saleem H. *Mining, the Environment, and Indigenous Development Conflicts*. Tucson: University of Arizona, 2003. Print.
[122] Kahn, Patricia. "A Grisly Archive of Key Cancer Data." *Science* 259.5094 (1993): 448-51. Print.
For other studies regarding cancer rates for uranium miners, see Roscoe, Robert, Kyle Steenland, William Halperin, James Beaumont, and Richard Waxweiler. "Lung Cancer Mortality Among

Fears about radiation-induced sickness are not limited to the act of mining. Many environmentalists are concerned about the physical, radioactive waste generated during mining, and its potential health effects. Because uranium ore is typically found in very low concentrations, large amounts of dirt, rock, and other ores must be excavated to get to the uranium. The uranium ore is then crushed and chemically treated in a process called milling, which further separates it from the unwanted byproducts. The waste generated during excavation and milling is called tailings.

According to a study published in 2006, global mining of uranium has generated 938 $\times 10^6$ m^3 of mill tailings[123]. In the U.S., this waste is supposed to be transported to impoundments or storage facilities for containment or disposal[124]. These tailings can remain radioactive for thousands of years, and many of the mining and mill sites have not been adequately remediated, with the tailings "left lying in huge heaps adjacent to the mine, exposed to the air and the rain"[125]. These tailings can have the consistency of sand, and when left unattended can easily be blown by the wind or find their way into local aquifers. These tailings can also be inhaled. Hundreds of millions of tons of uranium and

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Nonsmoking Uranium Miners Exposed to Radon Daughters." *The Journal of the American Medical Association*262.5 (1989): 629-33. Print; "Medicine: Uranium Miners' Cancer." *Time Magazine* 26 Dec. 1960. Print; Roscoe, R. J., J. A. Deddens, A. Salvan, and T. M. Schnorr. "Mortality among Navajo Uranium Miners." *American Journal of Public Health* 85.4 (1995): 535-40. Print; Oncol, Ann. "Radon: A Likely Carcinogen at All Exposures." *Annals of Oncology* 12.10 (2001): 1341-351. Print; Pasternak, Judy. "A Peril That Dwelt among the Navajos." *Los Angeles Times* 19 Nov. 2006. Print.

[123] Abdelouas, A. "Uranium Mill Tailings: Geochemistry, Mineralogy, and Environmental Impact." *Elements* 2.6 (2006): 335-41. Print.

[124] "Uranium Mill Tailings." U.S. Nuclear Regulatory Commission, 12 Mar. 2011. Web. 26 Nov. 2011.

[125] Caldicott, Helen. *Nuclear Power Is Not the Answer*. New York: New York, 2006. Print.

mill tailings pollute the American Southwest, and they have contaminated water sources[126], soil, and crops, and caused health problems for livestock and humans[127].

A recent and ongoing battle over uranium mining involves some of these concerns. Virginia Uranium, Inc. is interested in mining an ore deposit in south central Virginia. They have assured residents and environmentalists that the tailings would be properly contained: by placing the tailings back in the mine and in underground, state-of-the-art holding compartments, the waste would be managed "in perpetuity." Environmentalists aren't convinced: they "fear the tailings will leach into groundwater or run off into surface rivers and streams." Although the company has engineered the facilities to withstand earthquakes and storms, opponents to the mining operation cite a poor record for adequately containing waste as a reason for skepticism. Nathan Lott, executive director of Virginia Conservation Network, said, "They're leaving behind tons and tons of waste that is toxic and radioactive. We have no confidence that Virginia or anyone else has the ability to keep this contamination contained for thousands of years. We're worried about a toxic legacy that will put peoples' lives and livelihoods at risk"[128]. [129]

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[126] Cochran, Thomas B., Christopher E. Paine, Geoffrey Fettus, Robert S. Norris, and Matthew G. McKinzie. *Position Paper: Commercial Nuclear Power*. Publication. Natural Resources Defense Council, 2005. Print.

[127] Long, Michael. "Half Life: The Lethal Legacy of America's Nuclear Waste." *National Geographic.* July 2002. Print.

[128] O'Connor, Rose. "Uranium Mining-The Virginia Battleground: Environmental Concerns vs. Corporate Interests Part Two." *DC Bureau*. Public Education Center, 23 Nov. 2011. Web. 26 Nov. 2011.

[129] An unrelated study conducted by The National Academy of Science titled "Uranium Minim in Virginia" is expected to be released in December 2011. For more information about the environmental affects of uranium mining, please see Gnugnoli, Giorgio, Michele Laraia, and Peter Stegnar. *Uranium Mining & Milling: Assessing Issues of Environmental Restoration*. Publication. International Atomic Energy Agency, 1996. Print; "Uranium Impact Assessment Program." Southwest Research and Information Center. Web. 27 Nov. 2011. <http://www.sric.org/uranium/>; "Environmental Aspects of Uranium Mining." World Nuclear

Evaluating Concern #1: Uranium Mining

It seems like there are three main problems with uranium mining: 1) the energy costs associated with uranium mining decrease the energy efficiency of nuclear power, 2) the health and safety risks taken on by miners, and 3) the health, safety, and environmental impacts associated with the mining itself (including the possibility of radioactive contamination).

In evaluating these concerns, we will leave aside Problem #1—the energy costs associated with uranium mining—because there isn't any definitive and undisputed research on the energy inputs associated with the entire fuel cycle. Suffice to say, in the unlikely event that nuclear power plants ultimately cost more energy to operate than they produce, we ought to immediately shut down all such reactors. In fact, if the energy ratio (output to input) of nuclear power is significantly lower than other energy sources, we should reconsider using reactors to provide significant amounts of energy.

In terms of the GHG emissions associated with the entire nuclear fuel cycle, a number of recent studies have suggested that the production of nuclear energy generates GHG at a rate comparable to renewables like solar, hydro, and wind power. These studies take into account the GHG emissions associated with mining, transportation, construction, decommissioning, etc.[130]. As one might expect, lifetime GHG emissions from nuclear plants are significantly lower than lifetime GHG emissions from fossil fuel technologies.

Association, Feb. 2011. Web. 27 Nov. 2011; "Nuclear Impacts." Altenergy.org. Web. 27 Nov. 2011. <http://www.altenergy.org/nonrenewables/nuclear_impacts.html>.

[130] See Lenzen, M. "Life Cycle Energy and Greenhouse Gas Emissions of Nuclear Energy: A Review." *Energy Conversion and Management* 49.8 (2008): 2178-199. Print; Weisser, D. "A Guide to Life-cycle Greenhouse Gas (GHG) Emissions from Electric Supply

Problem #2 is largely historical: improved technology and safety standards have drastically reduced the amount of radiation to which workers are exposed[131]. Furthermore, all uranium mines in the U.S. have been closed as of 1992[132] (although small in-situ leaching sites are still operating in a few states[133]). Most uranium ore now comes from mines in Kazakhstan, Canada, and Australia[134]. Still, we must ensure that mines in other countries are operated according to strict safety standards and procedural guidelines in order to ensure the safety of miners. According to the World Nuclear Association, "safety regulations today are among the most comprehensive and stringent in the world," resulting in "radiation doses…well within regulatory limits"[135]. Policies that would hold both the producer (the mining company) and the buyer (electrical utilities) culpable for worker accidents or illness due to radiation will help push the industry to police itself and develop safe, efficient extraction techniques.

Technologies." *Energy* 32.9 (2007): 1543-559. Print; Fthenakis, Vasilis M., and Hyung Chul Kim. "Greenhouse-gas Emissions from Solar Electric- and Nuclear Power: A Life-cycle Study." *Energy Policy* 35.4 (2007): 2549-557. Print; Sovacool, Benjamin K. "Valuing the Greenhouse Gas Emissions from Nuclear Power: A Critical Survey." *Energy Policy* 36.8 (2008): 2950-963. Print.

[131] See *Effects of Ionizing Radiation*. Rep. Vol. 1. United Nations Scientific Committee on the Effects of Atomic Radiation, 2006. Print; Ahmed, J. U. "Occupational Radiological Safety in Uranium Mines and Mills." *International Atomic Energy Agency Bulletin* 23.2 (1981): 29-32. Print.

[132] "Addressing Uranium Contamination in the Navajo Nation." US Environmental Protection Agency. Web. 27 Nov. 2011.

[133] In-situ leaching is a mining process that recovers minerals through boreholes drilled directly into the ore deposit. A leaching solution—usually acid or carbonate—is then pumped into the deposit, dissolving the metals without convention mining techniques. See *U.S. Uranium In-Situ-Leach Plants by Owner, Capacity, and Operating Status at End of the Year*. Rep. U.S. Energy Information Administration, 15 July 2010. Web. 30 Nov. 2011.

[134] *World Uranium Mining*. Rep. World Nuclear Association, Sept. 2011. Web. 30 Nov. 2011.

[135] *Occupational Safety in Uranium Mining.* Rep. World Nuclear Association, January 2011. Web. 30 Nov. 2011.

It is also of utmost importance that the issue of Navajo exploitation is dealt with swiftly and justly. Immediate actions should be taken to compensate Navajo Nation as best as possible, clean up abandoned mines and tailings, begin to decontaminate important water sources, and educate the local population and post signs to inform others of radiation. In 2007, the EPA developed a Five-Year Plan to address uranium contamination, which is a good first step towards environmental and social justice[136].

As illustrated in the fight over uranium mining in Virginia (as well as another debate over mining in Colorado[137]), Problem #3 is still very relevant. Despite improvements in mining technology and remediation techniques, as well as stricter, more environmentally conscious mining regulations, many environmentalists are still concerned with the destruction caused by mining. The mining industry—and the uranium mining industry in particular—has a poor track record of ensuring that negative environmental effects are contained, localized, and remediated after mining is complete. With uranium, the potential for radioactive contamination adds a new, more sinister dimension to inadequate and unsafe mining practices. Mines are (perhaps inherently) unsafe and somewhat unpredictable, and many environmentalists are unwilling to take these risks when the consequences can be long-lasting contamination to soil and water. Very recently, there have been concerns about the health effects associated with uranium mining in India, where the state-owned Uranium Corporation of India Limited is accused of dumping

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[136] Ibid.
[137] Finley, Bruce. "Judge Halts Uranium-mining Plans in Colorado over Environmental Issues." *The Denver Post*. 20 Oct. 2011. Web. 27 Nov. 2011.

radioactive waste into ponds. Environmentalists say the polluted groundwater is causing a rise in stillbirths, birth defects, cancer, kidney disease, and tuberculosis[138].

It should be pointed out that available uranium resources could last longer if the U.S. started to reprocess its spent nuclear fuel. Reprocessing is akin to (very expensive, very dangerous, and very complicated) recycling: it allows us to extract significantly more energy out of the same volume of fuel—the World Nuclear Association suggests it is possible to gain 25% more energy from the original uranium—and though it still results in radioactive byproducts[139], reprocessing reduces the volume of high-level waste[140]. Some of this waste would decay in a few hundred years (as opposed to tens of thousands of years without reprocessing), but reprocessing does not eliminate the need for waste repositories or long-term storage: it merely would increase the longevity of current fuel reserves without mining[141]. Some estimates suggest that the spent fuel currently available for reprocessing could run the U.S. reactor fleet for 30 years with no new uranium input[142]. However, reprocessing is also very complex and very expensive, and can be used to purify material necessary for nuclear weapons. The U.S. ended its reprocessing program in the 1970s due to proliferation concerns and relatively cheap uranium prices, but India, Japan,

[138] Kannampilly, Ammu. "India's Uranium Mines Cast a Health Shadow." *The West Australian*. AFP, 5 Dec. 2011. Web. 5 Dec. 2011.

[139] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

[140] Feiveson, Harold, Zia Mian, M. V. Ramana, and Frank Von Hippel. "Managing Nuclear Spent Fuel: Policy Lessons from a 10-country Study." *Bulletin of the Atomic Scientists* (2011). Print.

[141] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.

[142] "Processing of Used Nuclear Fuel." World Nuclear Association, 7 Nov. 2011. Web. 28 Nov. 2011.

France, Russia, and the UK have had long-lived reprocessing programs[143]. In 2009, U.S. President Barack Obama ended preliminary plans to explore restarting a domestic, commercial reprocessing program[144]. Reprocessing may not be a great option, but if policymakers are trying to expand nuclear fuel reserves without initiating new mining operations, it is a possibility[145].

World uranium prices have been rising, and there has been renewed interest in opening mines in the U.S[146]. However, the concerns we've examined about uranium mining are valid, even if some of the specific problems environmentalists raise are less relevant today. Until the waste and contamination caused by past mining operations is remediated, it is difficult to advocate for more uranium exploration and extraction.

If U.S. policymakers are interested in operating uranium mines, there are two steps they should take in order to ensure that new mines are environmentally friendly. First, they must ensure that existing regulatory policy is strict and effective, with an open and citizen-friendly grievance process, provisions for constant and continual oversight, and

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[143] Dillon, Carrington. "Recycling Nuclear Fuel 101." Clean Energy Insight, 28 Aug. 2009. Web. 28 Nov. 2011. <http://www.cleanenergyinsight.org/tag/recycling/>.

[144] Editorial. "Adieu to Nuclear Recycling." *Nature* 460.7252 (2009): 152. Print.

[145] For more information on nuclear reprocessing, see Andrews, Anthony. *CRS Report for Congress: Nuclear Fuel Reprocessing: U.S. Policy Development*. Rep. 2008. Print; Lee, Terence. "Assessment of Safety Culture at a Nuclear Reprocessing Plant." *Work & Stress* 12.3 (1998): 217-37. Print; Saito, Masaki, and Tetsuo Sawada. *Advanced Nuclear Energy Systems toward Zero Release of Radioactive Wastes*. Oxford, UK: Pergamon, 2002. Print; Ahmed, S. Basheer. *Nuclear Fuel and Energy Policy*. Lexington, MA: Lexington, 1979. Print; Long, Justin T. *Engineering for Nuclear Fuel Reprocessing*. La Grange Park: American Nuclear Society, 1978. Print; Lumetta, Gregg J. *Separations for the Nuclear Fuel Cycle in the 21st Century*. Washington, DC: American Chemical Society, 2006. Print.

[146] Mudd, Gavin M., and Mark Diesendorf. "Sustainability of Uranium Mining and Milling: Toward Quantifying Resources and Eco-Efficiency." *Environmental Science & Technology* 42.7 (2008): 2624-630. Print.

appropriate penalties for offenders. These regulations must require mining companies to clean up mine sites and adequately dispose of tailings and waste. Secondly, policymakers must ensure that these regulations are being implemented. That may entail a larger budget for the NRC, the EPA, and other agencies tasked with enforcement.

Finally, it should be noted that the concern about uranium mining arguably isn't a concern about nuclear power *per se*. These concerns, while valid, can theoretically be addressed without shutting down nuclear reactors, and it seems like this is a relevant distinction. Only if we believe—as some environmentalists do—that mining is *unavoidably* problematic and *inevitably* going to cause environmental and public health problems, are we forced to advocate for an end to uranium mining, which would also entail the shutdown of nuclear reactors.

But if policymakers were able to ensure that miners were safe, waste and radioactive materials would be contained and adequately treated, and mine sites would be remediated, anti-nuclear environmentalists are forced to criticize nuclear power on other merits. Bad uranium mining practices are not inevitable, and it's not clear that the best way to address bad uranium mining practices is by ending nuclear development (although ending nuclear development probably would end the bad mining practices, simply because it would drastically reduce the demand for uranium ore). Depending on our optimism, we might be able imagine a scenario in which uranium mines were operated responsibly, or where the production of nuclear power no longer depended on the extraction of new uranium ore. That is to say, *bad* uranium mining practices are not necessary for the production of nuclear energy.

It might seem like I'm splitting hairs here. An anti-nuclear environmentalist might say, "Of course if uranium mining wasn't a problem then we wouldn't complain about it! But it is a problem." I do believe that current uranium mining practices are problematic and must be addressed. But the purpose of this distinction is to relocate the locus of debate to the practices of the mining industry, and remind all parties that it may be more effective to focus on reforming mining regulations and enforcing environmental law, rather than on shutting down the nuclear power industry.

> **Summary:** Environmentalists are concerned about three aspects of uranium mining: 1) the energy use and GHG emissions associated with uranium mining and the nuclear "life cycle" more broadly, 2) the health effects uranium mining has on workers, and 3) the environmental damage—including potential radioactive contamination—caused by mining itself.
>
> The first two objections are not particularly powerful. Studies have shown that the GHG emissions associated with the entire nuclear fuel cycle are comparable to other renewable energy sources, and are significantly less than emissions from fossil fuel technology. In terms of mining, most of the evidence and facts cited by anti-nuclear activists is historical, and largely irrelevant to the contemporary debate. There are no open mines active in the U.S., and the mining done in other countries is safe and highly regulated.

However, the mining industry does have a long history of acting with disregard for the environmental effects or mining. Huge amounts of waste from uranium mining have been left in untreated heaps next to abandoned mines. If we are to allow future mining, the industry must be held liable for any damages. They must take adequate care and make a marked effort to minimize and contain the effects and byproducts associated with mining. The stakes are too high: long-term radioactive contamination in soil or local water systems could be devastating to the environment and local communities.

Concern #2: Radiation and meltdowns

Statistically speaking, an accidental meltdown is almost a certainty sooner or later in one of the 438 nuclear power plants located in thirty-three countries around the world. Human error, compromise, laziness, and greed are implicit in the affairs of men; when these attributes are applied to the generation of atomic energy, the results can be catastrophic.[147]

--Helen Caldicott, physician and author

The possibility of a nuclear meltdown or release of radiation is perhaps the most common fear about nuclear power. We have already seen the devastation caused by three nuclear accidents. Environmentalists are concerned that these accidents—which may be unavoidable—have the potential to cause major damage and endanger human and environmental health. Briefly, a nuclear accident could sicken and kill tens of thousands people via radiation poisoning or radiation-induced cancer[148]; permanent evacuations may be necessary (the psychological effects associated with the uncertainty of living near a nuclear plant or in the aftermath of a meltdown have barely been explored[149]); water and soil could be contaminated. Furthermore, the remediation and cleanup following an accident is likely to cost billions of dollars[150].

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[147] Caldicott, Helen. *Nuclear Power Is Not the Answer*. New York: New York, 2006. Print.
[148] Caldicott, Helen. *Nuclear Power Is Not the Answer*. New York: New York, 2006. Print.
[149] See Koscheyev, Victor S., Vladimir K. Martens, Alexander A. Kosenkov, Michael A. Lartzev, and Gloria R. Leon. "Psychological Status of Chernobyl Nuclear Power Plant Operators after the Nuclear Disaster." *Journal of Traumatic Stress* 6.4 (1993): 561-68. Print; Qian, Frank. "Effects of Nuclear Power on Public Health: From Three Mile Island to Fukushima." The Triple Helix Online, 2 Aug. 2011. Web. 28 Nov. 2011; Bromet, Evelyn. "Will Japan Face a Mental Health Crisis?" *CNN Opinion*. CNN, 16 Mar. 2011. Web. 28 Nov. 2011.
[150] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

In addition to the accidents that have occurred (and there have been numerous minor accidents besides the three major disasters discussed in this essay[151]), environmentalists point to recent "near-misses" that could have had serious consequences. In 1995, the Monju reactor in Japan had a coolant leak, starting a serious fire. Luckily the coolant was not radioactive, but if the fire had gone out of control, it could have led to a meltdown. In 2002, a hole in the reactor vessel was discovered at the Davis-Besse nuclear generating station in Ohio[152]. The reactor's outer layer of stainless steel—a mere one-half inch thick—was the only material preventing a loss-of-coolant accident that could have spread radioactive materials and led to a Three Mile Island-style core meltdown[153].

The near-miss at Davis-Besse also revealed an extremely worrying reality: the NRC, tasked with overseeing and regulating commercial reactors, had allowed the plant to continue operations despite reports of cracks and leaks that had been discovered in similar nuclear plants. Furthermore, after an inspection in 2001, NRC staff members were so concerned about the conditions at Davis-Besse that they ordered an immediate shut down in order to further inspect the parts they suspected could be damaged or compromised. Despite these warnings, NRC managers allowed the plant to continue operating, probably in order to protect the utility's financial interests[154]. "In other words," a UCS position paper

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[151] Rogers, Simon. "Nuclear Power Plant Accidents: Listed and Ranked since 1952." The Guardian, 18 Mar. 2011. Web. 29 Nov. 2011.

[152] Cochran, Thomas B., Christopher E. Paine, Geoffrey Fettus, Robert S. Norris, and Matthew G. McKinzie. *Position Paper: Commercial Nuclear Power*. Publication. Natural Resources Defense Council, 2005. Print.

[153] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

[154] NRC, Office of the Inspector General, "NRC's regulation of Davis-Besse regarding damage to the reactor vessel head," Case No. 02-03S (December 30, 2002). Print.

says, "the NRC had ample reason to suspect that disaster was looming at Davis-Besse," yet they did nothing[155].

Davis-Besse and the general frequency of shutdowns and minor accidents points to what the UCS calls a negligent "safety culture." In a scathing analysis of the Davis-Besse incident, the UCS says:

> The NRC's abysmal performance in this case is especially troubling because its staff will likely never assemble a stronger case for a pending disaster...If the warning signs at Davis-Besse were not compelling enough to spur prompt action to protect public health, it is difficult to envision warning signs that would.[156]

Although the NRC has since issued new rules and initiatives aimed at strengthening safety culture[157], environmentalists worry that regulation and oversight for nuclear plants is lax and inadequate. Ensuring nuclear safety is difficult and complex: operators must be highly-trained, there must be constant oversight and preventative maintenance performed on equipment, old reactors must be monitored and retrofitted with the best available safety systems, etc.[158] Making matters worse, environmentalists point out that the NRC is underfunded, understaffed, and more interested in protecting plant owners than the public. Furthermore, some critics have suggested that the NRC or *any* regulating agency—even if they were committed to responsible regulation and had the large budge and staff to do it—will eventually fall short of its duties. Humans are fallible: we make errors, poor judgments, and rash decisions all the time.

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[155] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.
[156] Ibid.
[157] "Safety Culture." NRC, 21 Sept. 2011. Web. 29 Nov. 2011.
[158] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.

But it's not just about operator error or lax regulation. There are also serious concerns about the mechanical and structural integrity of nuclear plants. There are various "weak points" in a reactor (including the fuel rods, reactor pressure vessel, steam generators, cooling systems, etc.), and the material used to fabricate these parts can corrode or become brittle over time[159]. The nuclear plants operating in the U.S. are relatively old. Originally licensed for a 40-year lifespan, half of American reactors are now over 30 years old, and most of the remaining reactors are over 20 years old[160]. Many plant operators are applying for 20-year license extensions. Some environmentalists worry that NRC relicensing inspections are lax and inadequate, and even NRC regulators and plant operators admit that more substantial oversight may be needed[161].

Old, broken-down plants simply add to the poor industry safety culture, inadequate regulation, and other safety problems surrounding nuclear power. With consequences as severe and long lasting as a potential nuclear meltdown, many environmentalists have suggested that nuclear power is simply a gamble we should not make[162].

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[159] Riccio, Jim, and Michael Grynberg. *A Roll of the Dice: NRC's Efforts to Renew Nuclear Reactor Licenses*. Rep. Public Citizen's Critical Mass Energy Project, 1995. Print.

[160] Hargreaves, Steven. "Half of U.S. Nuclear Reactors over 30 Years Old." *CNNMoney*. CNN, 15 Mar. 2011. Web. 30 Nov. 2011.

[161] Behr, Peter, and Climatewire. "Can Aging Nuclear Reactors Be Safe?" *Scientific American*. 9 Mar. 2010. Web. 30 Nov. 2011.

[162] See Caldicott, Helen. *Nuclear Power Is Not the Answer*. New York: New York, 2006. Print; "Accidents." Greenpeace. Web. 30 Nov. 2011. <http://www.greenpeace.org/usa/en/campaigns/nuclear/safety-and-security/accidents/>.

Evaluating Concern #2: Radiation and meltdowns

Before we really start analyzing the environmentalist's concern about potential accidents and meltdowns, it will help to know a bit more about radiation and its health effects.

We measure dose equivalent radiation with a unit called the Sievert (Sv). By measuring dose equivalent radiation, we can quantitatively evaluate the biological effects of the absorbed dose of radiation, as well as the effects of ionizing radiation (which can break chemical bonds and cause cancer[163]). Sudden exposure to 6 Sv will kill at least half of the people exposed. Sudden exposure to more than 10 Sv is 100% lethal[164]. It is very unlikely to ever be exposed to this much radiation at once. For our purposes, it is more useful to discuss gradual exposure to radiation—which can also be lethal (depending upon rate received)—using the millisieverts (mSv) as our unit of measurement.

According to the NRC, cancer risk increases when we receive more than 100 mSv per year[165]. To put that in perspective, consider the following facts:

- On average, the individual background radiation dose for Americans is 3 mSv per year. The average total radiation dose for Americans is 6.2 mSv per year[166].
- The dose from living within 50 miles of a nuclear power plant is about 0.0001-0.01 mSv per year[167]. Sleeping next to someone every night results in a dosage of about

[163] Roan, Shari. "Possible Health Effects of Nuclear Crisis." *Los Angeles Times*. 16 Mar. 2011. Web. 1 Dec. 2011.
[164] Fackler, Martin. "Fatal Radiation Level Found at Japanese Plant." *New York Times* 2 Aug. 2011. Print.
[165] U.S. Nuclear Regulatory Commission. *Fact Sheet on Biological Effects of Radiation*. 17 Oct. 2011. Web. 30 Nov. 2011.
[166] Ibid. Also see U.S. Environmental Protection Agency. Office of Air and Radiation, Office of Radiation and Indoor Air. *Radiation: Risks and Realities*. EPA, May 2007. Web. 30 Nov. 2011.

0.02 mSv per year, or roughly twice the dose received from living near a nuclear reactor[168].

- The dose from a full chest CT scan—the most radiologically intense medical procedure—is 6-18 mSv per procedure[169].
- Following the Three Mile Island accident, the average radiation dose received by people living within 10 miles of the reactor was about 0.08 mSv, according to the American Nuclear Society[170].
- In the aftermath of the Fukushima accident, radioactive "hotspots" were found, with radiation readings equivalent to about 11.32 mSv per year[171].
- A pack-a-day smoker (30 cigarettes a day) receives a dose of 60-160 mSv per year[172].

Worldwide support for nuclear power remains very low, driven in large part because of concerns regarding safety[173]. We associate nuclear power with radiation, and

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[167] See U.S. Nuclear Regulatory Commission. *Fact Sheet on Biological Effects of Radiation*. 17 Oct. 2011. Web. 30 Nov. 2011; PBS. *Facts about Radiation: Everyday Exposures to Radiation*. WGBH Educational Foundation. Web. 30 Nov. 2011.
[168] PBS. *Facts about Radiation: Everyday Exposures to Radiation*. WGBH Educational Foundation. Web. 30 Nov. 2011.
[169] Van Unnik, J. G., J. J. Broerse, J. Geleijns, J. T. Jansen, J. Zoetelief, and D. Zweers. "Survey of CT Techniques and Absorbed Dose in Various Dutch Hospitals." (1997). *PubMed.gov*. Web. 30 Nov. 2011.
[170] "What Happened and What Didn't in the TMI-2 Accident." American Nuclear Society. Web. 12 Nov. 2011.
[171] Watanabe, Chisaki. "Japan to Open Hotlines to Allay Public Concerns Over Radiation." *Bloomberg*. 19 Oct. 2011. Web. 30 Nov. 2011.
[172] See Watanabe, Chisaki. "Japan to Open Hotlines to Allay Public Concerns Over Radiation."*Bloomberg*. 19 Oct. 2011. Web. 30 Nov. 2011; "Typical Sources of Radiation Exposure." *Office of Research Services*. Web. 01 Dec. 2011. <http://www.ors.od.nih.gov/sr/drs/training/GRS/Pages/sectionf.aspx>.

radiation with cancer. But there is some evidence that suggests nuclear power—even major accidents—aren't quite as damaging to human health as most people think.

A study by the Scientific Research Society examined the effects of nuclear fallout from weapons testing on thyroid cancer and leukemia (two of the primary cancer risks from exposure to radioactive fallout) rates. They estimated that about 49,000 cases of thyroid cancer (not deaths), and 1,800 deaths from leukemia in the U.S. were caused by radiation from global fallout. These are big numbers. But it is important to consider the context: in the same population, they predicted about 400,000 cases of thyroid cancer and 1.5 million leukemia deaths would occur absent any fallout exposure. So fallout from nuclear weapons testing—which represents the vast majority of radioactive fallout, and is more dangerous than a worst-case nuclear power accident—caused about 11% of thyroid cancer cases, and 0.0012% of leukemia deaths in a population[174]. It's also important to note that the NRC requires state governments to consider using (and helps fund the purchase of) potassium iodide (KI) as part of a nuclear accident preparedness plan[175]. States can choose to distribute KI pills to citizens who live within 10 miles of a nuclear plant, and in the event of an accident, these pills would act as a thyroid-blocking agent, drastically reducing the probability of contracting thyroid cancer due to the uptake of radioactive molecules[176].

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[173] Carrington, Damian. "Citizens across World Oppose Nuclear Power, Poll Finds." *The Guardian*. 23 June 2011. Web. 1 Dec. 2011.

[174] Simon, Steven, André Bouville, and Charles Land. "Fallout from Nuclear Weapons Tests and Cancer Risks." *American Scientist* 94.1 (2006): 48. Print.

[175] U.S. Nuclear Regulatory Commission. *Frequently Asked Questions about Potassium Iodide*. 25 Apr. 2011. Web. 2 Dec. 2011.

[176] Food and Drug Administration, U.S. Department of Health and Human Services, and Center for Drug Evaluation and Research. *Guidance: Potassium Iodide as a Thyroid Blocking Agent in Radiation Emergencies*. Rep. 2001. Print.

Let's briefly revisit the effects of Chernobyl, by far the worst nuclear accident in history. We know that the accident exposed many individuals to high doses of radiation, and we know that this exposure increased the chances that they would subsequently develop certain types of cancer[177]. Although the estimates for cancer rates associated with the accident vary considerably, arguably the most credible study was conducted by a team of over 100 scientists from the World Health Organization. The study suggested that 4,000 people could die eventually from radiation exposure, and that as of 2005, fewer than 50 deaths had been directly attributed to radiation from the disaster[178]. Again, these are not insignificant numbers, but they don't seem to be a reason to panic either, especially when we consider the results of two studies that examined the effects of KI pills distributed following the accident. The first study, conducted by the NRC, found permissible iodine levels (indicating the KI had worked as a thyroid-blocking agent) in 97% of the evacuees who received it[179]. The second study examined the effectiveness of KI after 18 million doses were distributed to the Polish population (Poland is about 300 miles from Chernobyl), and found that there were no known cases of thyroid cancer among KI recipients[180]. So again, there is reason to believe not only that the ultimate effects of nuclear accidents are not as devastating as they may seem, but also that there are effective ways to prepare for these disasters and protect human health.

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[177] See National Cancer Institute. *Accidents at Nuclear Power Plants and Cancer Risk*. Web. 2 Dec. 2011. <http://www.cancer.gov/cancertopics/factsheet/Risk/nuclear-power-accidents#ques3>; Hatch, M. "The Chernobyl Disaster: Cancer following the Accident at the Chernobyl Nuclear Power Plant." *Epidemiologic Reviews* 27.1 (2005): 56-66. Print.

[178] World Health Organization. *Chernobyl: the True Scale of the Accident*. 5 Sept. 2005. Web. 2 Dec. 2011. <http://www.who.int/mediacentre/news/releases/2005/pr38/en/index.html>.

[179] U.S. Nuclear Regulatory Commission. *Report on the Accident at the Chernobyl Nuclear Power Station (NUREG-1250)*. Rep. 1987. Print.

[180] Nauman, Janusz, and Jan Wolff. "Iodide Prophylaxis in Poland after the Chernobyl Reactor Accident: Benefits and Risks." *The American Journal of Medicine* 94.5 (1993): 524-32. Print.

Another study by the National Cancer Institute (NCI) found no increased risk of death from cancer for people living near nuclear facilities[181]. Obviously, none of these facilities experienced a serious accident, but this study suggests that—absent a meltdown—nuclear plants can be operated safely, emitting only tiny amounts of ionizing radiation[182]. It should be noted that some scientists believe that any amount of ionizing radiation may be harmful[183]. Interestingly, there is some evidence to suggest that fly ash and other waste generated by coal plants is actually more radioactive than the radiation emitted by a normally functioning nuclear plant when producing the same amount of energy[184].

When we look at it this way, radiation from nuclear sources doesn't seem as scary. Nuclear accidents—though they have the potential to be devastating—haven't been as apocalyptic as many environmentalists suggest. Nuclear plants do have the potential to meltdown, and can contaminate huge areas with radioactive materials. But even if this happens, cancer rates may not be incredibly high, and there is strong evidence to suggest that at least some radiation-related cancer is preventable.

This is not to minimize the severity of nuclear accidents. Human casualties are only part of a meltdown's cost: in the cases of Chernobyl and Fukushima, there have been massive evacuations (and in Chernobyl, areas that are more or less permanently

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[181] Jablon, S., Z. Hrubec, and JD Boice. "Cancer in Populations Living near Nuclear Facilities. A Survey of Mortality Nationwide and Incidence in Two States." *Journal of the American Medical Association* 265.11 (1991): 1403-408. Print.

[182] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.

[183] National Academy of Sciences. *Low Levels of Ionizing Radiation May Cause Harm*. 29 June 2005. Web. 30 Nov. 2011.

[184] Hvistendahl, Mara. "Coal Ash Is More Radioactive than Nuclear Waste." *Scientific American*. 13 Dec. 2007. Web. 2 Dec. 2011.

uninhabitable) and significant contamination in food, water, and soil. Nuclear accidents have the potential to derail an area's infrastructure, and if a major meltdown were to occur simultaneously with another disaster, the spread of radiation could impede relief and cleanup efforts.

But even if the death tolls from a nuclear accident haven't yet been very high, there are still compelling reasons to question whether we ought to pursue nuclear development based on concerns about radiation and potential meltdowns. The most pressing reason is the lax regulation and poor safety culture of the NRC and the nuclear industry.

The NRC seeks to have the probability of major reactor-core damage (i.e. a meltdown) to be better than one in 10,000 years of reactor operations (or "reactor-years"). To provide some context, the cumulative number of operational years worldwide is about 14,000 reactor-years. There are about 100 reactors in the U.S. fleet, so this means that, according to NRC regulations, it is acceptable to have one major accident every hundred years[185]. Utilities supposedly work to keep the probability even better, aiming for one accident every 100,000 reactor-years[186]. If the NRC and utilities were effective and vigilant enough to preserve these probabilities, it seems like the probabilities should be favorable for most environmentalists[187].

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[185] 100 reactors times 100 years is equal to 10,000 cumulative reactor-years.

[186] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.

[187] However, one paper suggests that if we were to deploy 3,500 1000-megawatt large reactors to meet growing energy needs without releasing massive amounts of carbon into the atmosphere, the probability of a core melt accident would be one every six years. See Forsberg, C. W., and A. M. Weinberg. "Advanced Reactors, Passive Safety, and Acceptance of Nuclear Energy." *Annual Review of Energy* 15.1 (1990): 133-52. Print.

But the reality is that this sort of acceptable safety record is not attainable given the current regulatory environment:

> The poor safety culture at the NRC manifests itself in several ways. The agency has failed to implement its own findings on how to avoid safety problems at U.S. reactors. It has failed to enforce its own regulations, with the result that safety problems have remained unresolved for years at reactors that have continued to operate. And it has inappropriately emphasized adhering to schedules rather than ensuring safety. A significant number of NRC staff members have reported feeling unable to raise safety concerns without fear of retaliation, and a large percentage of those staff members say they have suffered harassment or intimidation.[188]

This sort of safety culture is not without consequences. In addition to the near misses described above, the NRC has reported four-dozen "abnormal occurrences" since 1986, and notified the International Atomic Energy Agency of 18 nuclear "events" since reporting began in 1992[189]. The UCS has asserted that at least some of these events were due to the NRC failing to enforce its own regulations, or tolerating known safety violations. Even when the NRC reprimands plant owners—as it did in Illinois after a plant repeatedly lowered the required minimum thickness of pipe walls as the walls corroded—the fines tend to be small and the punishment insignificant[190].

When we consider the inadequate oversight—and subsequent safety issues and mechanical breakdowns—that seems pervasive throughout U.S. regulatory efforts and the nuclear industry, the recent relicensing of aging nuclear plants is concerning[191]. As of July

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[188] For the full report, see Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.
[189] Ibid.
[190] Zeller, Tom Jr. "Nuclear Agency is Criticized as Too Close to Its Industry." *The New York Times.* 7 May 2011. Web. 2 Dec. 2011.
[191] Behr, Peter, and Climatewire. "Can Aging Nuclear Reactors Be Safe?" *Scientific American*. 9 Mar. 2010. Web. 30 Nov. 2011.

31st, 71 reactors had been granted 20-year renewals[192], and the NRC has not yet rejected an application to extend an original license since the agency granted its first renewal in 2000[193]. Earlier this year, the NRC approved the relicensing bid from the Vermont Yankee nuclear plant, despite its history of serious operational problems: the plant suffered a partial collapse of a cooling tower in 2007, and in 2010, it was discovered that underground piping systems (which the parent company assured state lawmakers didn't exist) were leaking radioactive tritium, contaminating nearby groundwater and soil. David Lochbaum, a member of UCS and a frequent critic of the NRC's safety practices, asked, "How does a place like that get a license renewal? Because they asked for one. Absent dead bodies, nothing seems to deter the NRC from sustaining reactor operation." Lochbaum went on to say that the NRC has to tolerate these violations, "Otherwise, nearly all the U.S. reactors would have to shut down"[194]. Critics have called the NRC's approach to relicensing "rubber-stamping," implying that very little individual attention is paid to the details of each application, too much of the decision relies on paperwork supplied by plant operators, and the process in general is more of a formality than a rigorous evaluation[195].

Perhaps part of the problem is that adding new safety systems, constantly inspecting and repairing plants, and conducting lengthy, complicated audits is expensive[196].

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192 Sforza, Teri. "Feds have never said no to nuclear plant relicensing." *The Orange County Register*. 31 Jul. 2011. Web. 30 Nov. 2011.
193 Zeller, Tom Jr. "Nuclear Regulatory Commission Changed Nuclear Relicensing Rules." *Huffington Post*. 9 May 2011. Web. 30 Nov. 2011.
194 Zeller, Tom Jr. "Nuclear Agency is Criticized as Too Close to Its Industry." *The New York Times.* 7 May 2011. Web. 2 Dec. 2011.
195 The Center for Media and Democracy. *NRC Rubber-Stamps Relicensing for Aging U.S. Nuclear plants*. 29 June 2011. Web. 30 Nov. 2011.
196 Asselstine, James K. "Testimony for the Record to the Committee on Science and Technology, United States House of Representatives." Address. Hearing on Opportunities and Challenges for Nuclear Power. 23 Apr. 2008. Web. 4 Dec. 2011.

As compared to coal plants, the output of nuclear reactors is not easy to change: as a result, nuclear plants are far more economical when they are run at near-capacity at all times. Plant owners thus have a strong incentive to produce as much power as they can, as long as they can, while minimizing shutdown time. This can translate into negligence, even though the long shutdowns required to fix major problems may cost more than the shorter shutdowns necessary for small upgrades and repairs. And considering many NRC officials have ties or go on to work in the private sector (not to mention the effect of the nuclear lobby in Congress, which dictates the budget for the NRC), it isn't difficult to imagine why the financials of plant owners and utility companies may be taking priority over truly safe operation[197].

The NRC isn't the only nuclear regulatory agency struggling with these problems: in the UK, the Nuclear Installations Inspectorate (NII) reported there were 1,767 safety incidents at British nuclear plants between 2001 and 2008. About 50% were serious enough to have had the potential to compromise the plant's safety systems[198]. In addition to a poor safety culture the and old, deteriorating mechanical parts, both the NRC and the NII have also had to deal with staff shortages and budget cuts, exacerbating the difficulties associated with effective regulation.

This sort of ineffective regulation is very difficult to change, especially when the NRC is tied so closely to the industry. One avenue for environmentalists concerned about the poor safety record of the nuclear industry is to work towards the repeal the Price-Anderson Act. First passed in 1957 and most recently renewed in 2005, the act establishes

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[197] Zeller, Tom Jr. "Nuclear Agency is Criticized as Too Close to Its Industry." *The New York Times.* 7 May 2011. Web. 2 Dec. 2011.

[198] Macalister, Terry, and Rob Edwards. "Revealed: Catalogue of Atomic Leaks." *The Guardian*. 20 June 2009. Web. 3 Dec. 2011.

an insurance system whereby the federal government will cover liability claims (above a certain point) from a nuclear incident[199]. The "deductible" covered by the nuclear insurance pools represents a very small fraction of the estimated cost of a serious accident[200], but so far, the nuclear insurance pools have paid out about $151 million for claims, as opposed to the $65 million paid out by the government[201].

The act was originally passed in order to stimulate private-sector growth, as utilities and suppliers were unwilling to build and operate plants unless there was a limitation on liability. Private insurance companies were loath to back nuclear technology, and so it fell to the government to indemnify the nuclear industry in the case of a major accident.

By repealing Price-Anderson, plant owners will be forced to seek insurance in the private sector, forcing them to adopt the stricter safety standards that would undoubtedly be required by insurance companies[202]. This could potentially bypass some of the problems regarding the poor oversight by the NRC: without federal insurance, the nuclear industry would probably be significantly more self-regulating. However, the repeal of the Price-Anderson Act could also potentially cripple nuclear development if insurance companies are unwilling to cover major accidents or the nuclear industry is unable to meet

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[199] "Fact Sheet on Nuclear Insurance and Disaster Relief Funds." United States Nuclear Regulatory Commission, 9 June 2011. Web. 11 Nov. 2011.

[200] "Price-Anderson Act: The Billion Dollar Bailout for Nuclear Power Mishaps." Public Citizen, Sept. 2004. Web. 2 Dec. 2011.

[201] "The Price-Anderson Act." American Nuclear Society, Nov. 2005. Web. 2 Dec. 2011.

[202] Brownstein, Barry. *The Price-Anderson Act: Is It Consistent with a Sound Energy Policy?* Rep. The Cato Institute, 17 Apr. 1984. Web. 4 Dec. 2011.

considerably higher safety standards. In the meantime, policymakers could raise the liability limit as a short-term alternative[203].

As difficult as it may be to envision the nuclear industry with the sort of nearly-perfect safety record that many environmentalists demand, there is a precedent that suggests nuclear power plants could be operated responsibly. Nuclear-powered submarines employed by the U.S. Navy use very similar technology, and have an excellent safety record[204]. Although the reactors employed in submarines differ slightly from those used in civil power plants, the technology is fundamentally the same. Moreover, nuclear submarines are high-risk systems that are mobile, operate secretly and in a hazardous environment, and are engaged in highly demanding exercises. Yet the Navy has managed to preserve a very impressive safety record:

> [The Navy] developed a culturally intensive system which coped with this amazing conjunction of threats. The system is both technical and human, multi-layered with tremendous richness and depth. It was inculcated by severe selection and continuous training. The submarine itself is merely the sharp visible tip of the system. While it seems an independent entity, it is merely one of the points of interaction where the technical, the bureaucratic, and the cultural systems interact to produce high reliability.[205]

The Navy has shown that nuclear technology can be operated safely, even in situations far more hazardous and demanding than those typically encountered in the civilian sector. A dedicated, well-informed, comprehensive effort must be made by the

[203] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.
[204] "Nuclear-Powered Ships." World Nuclear Association, Sept. 2011. Web. 04 Dec. 2011.
[205] Bierly, P. E. "Culture and High Reliability Organizations: The Case of the Nuclear Submarine." *Journal of Management* 21.4 (1995): 639-56. Print.

utilities, plant owners, and the NRC to run their plants with the discipline and competence exemplified by the Navy. This can be done. At root, a poor safety culture is a political problem, and environmentalists should demand that policymakers and regulatory agencies make a commitment to ensuring public safety at all costs.

> **Summary:** Environmentalists worry about the devastation—sick and dying people, permanent evacuations, and long-term contamination—that could be caused by a nuclear accident. They point out the ineffective regulation of the NRC, in particular citing the agency's poor safety culture and the emphasis on profit instead of safety as problematic. As nuclear plants age, the potential for breakdowns increases, and environmentalists are concerned that neither the NRC nor the plant owners are taking the necessary steps to ensure that plants are safe.

Even though there is evidence to suggest the ultimate health effects of radiation may not be as deadly as many people think, the concern about radiation and potential meltdowns is compelling and valid, and may represent the most formidable barrier to more nuclear development. Without more stringent, effective regulation, it is difficult to advocate for the expansion of the nuclear industry, especially given its history of negligence, accidents, and near-misses. Although it is not impossible to make the technical and regulatory changes necessary to improve the safety of nuclear power plants, such a significant shift will require significant effort, money, and political will, none of which may be available in the necessary quantities. Furthermore, even if the industry's safety practices could be dramatically improved, the magnitude of a possible nuclear disaster may ultimately be more important than its probability[206].

[206] Forsberg, C. W., and A. M. Weinberg. "Advanced Reactors, Passive Safety, and Acceptance of Nuclear Energy." *Annual Review of Energy* 15.1 (1990): 133-52. Print.

Concern #3: Waste disposal

It's a national concern…how we dispose of nuclear waste in a safe way, how we deal with this incredible amount of nuclear waste we have created over the years.[207]

--Tom Udall, U.S. Senator

One of the most enduring and vexing questions about nuclear power has been regarding waste disposal. In addition to the mill tailings produced during uranium ore extraction, the production of energy from nuclear fission creates other kinds of waste that require disposal. There are three many categories of radioactive waste[208]:

1. Low-level waste (LLW): LLW includes any items that have become contaminated with radioactive material or become radioactive through exposure to radiation, including clothing, tools, filters, rags, and laboratory-animal carcasses. There are currently four active LLW disposal sites in the U.S. At these facilities, the waste is stored aboveground or buried. This waste may only need to be stored for months.
2. Intermediate-level waste or "waste incidental to reprocessing" (WIR): WIR refers to byproducts that result from reprocessing spent fuel, as well as resins, chemical sludge, and other materials from nuclear plants. Much of this waste will be solidified in concrete or another substance, and then buried.
3. High-level waste (HLW): HLW is spent or "irradiated" nuclear fuel. Many of the components of this waste decay within a few days, but a significant remainder of the

[207] "ADM Interviews Tom Udall the New Mexico Attorney General (1991-1998) and Congressman for Military Nuclear Mess: Out of Sight, Out of Mind?" Interview. ADM Online. Web. 10 Dec. 2011. <http://www.cdi.org/ADM/1212/Udall.html>.

[208] "Radioactive Waste." U.S. Nuclear Regulatory Commission, 4 May 2011. Web. 05 Dec. 2011.

waste lasts up to tens of thousands of years. HLW requires special procedures and shielding in order to protect the health of workers and the general public. According to the EPA, defense-related HLW (as opposed to HLW from commercial power plants) comprises greater than 99% of the volume of HLW[209]. The vast majority of this waste is being stored in pools that remove heat and act as a radiation shield. A small portion of the waste is placed in dry storage casks. These are temporary measures: no HLW has been sent to permanent storage in the U.S.

The debate over waste disposal centers mainly on HLW: what should we do with spent fuel rods that remain highly radioactive for thousands of years (and in fact, may be more dangerous in a thousand years than they are now)?

According to the NRC, spent fuel rods can be safely stored in pools or casks for "100 years or more," and as of January 2011, there was an estimated 63,000 metric tons of HLW at American nuclear power plants, increasing at a rate of about 2,000 metric tons per year[210]. Worldwide, about 270,000 metric tons of HLW is in storage, increasing at a rate of about 12,000 metric tons per year[211]. 90% of HLW is currently stored in pools of water at designated storage sites or near the plants themselves[212].

Storing spent fuel rods in pools is a temporary solution. Long-term storage options for HLW are currently being explored after President Obama terminated plans to develop

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[209] "Radiation Protection: Spent Nuclear Fuel and High-Level Radioactive Waste." US Environmental Protection Agency, 8 July 2011. Web. 05 Dec. 2011.

[210] *Radioactive Waste*. Rep. U.S. Nuclear Regulatory Commission. Web. 4 Dec. 2011.

[211] "Nuclear Waste." Marathon Resources Ltd. Web. 05 Dec. 2011. <http://www.marathonresources.com.au/nuclearwaste.asp>.

[212] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.

the Yucca Mountain Nuclear Waste Repository in 2009[213]. Structuring and successfully executing a permanent waste disposal program is an incredibly complex, lengthy process that involves diverse stakeholders[214]. Identifying a potential site and designing a suitable repository is a technical challenge—scientists must analyze geologic conditions, weather forecasts, groundwater behavior, and human activity over time frames of thousands of years—but it also has significant political, economic, social, and cultural dimensions that can make resolution difficult.

Even without the social, political, or economic aspects, successfully building and operating a permanent repository is an extremely demanding task. Environmentalists point out the technical challenges and inevitable uncertainty associated with such a facility, including: preventing corrosion in storage canisters; the massive heat build-up generated

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[213] The debate about Yucca Mountain has been going on since the 1980s, when Congress established the Nuclear Waste Policy Act in an attempt to solve the problem of radioactive waste disposal. In 2002, Congress approved Yucca Mountain as a future deep geological repository storage facility. Since then, there has been considerable resistance from environmentalists and local residents, who claim that the site is not geologically stable. In 2009, Energy Secretary Steven Chu indicated that Yucca Mountain was no longer considered an option, and Obama significantly cut the budget of the Office of Civilian Radioactive Waste Management, eliminating funding for the development of the Yucca Mountain facility. Since then, the House of Representatives voted overwhelmingly to not defund the Yucca Mountain Project, and lawyers are questioning whether Obama has the authority to close the site. A cursory search will reveal numerous books, articles, and report on Yucca Mountain, "the most studied real estate in the country." For information regarding recent developments, see Tetreault, Steve. "Obama Budget Confirms End of Yucca Mountain Project." *Las Vegas Review-Journal*. 21 Feb. 2011. Web. 4 Dec. 2011; Kintisch, Eli. "House Panel Slams Obama's Decision to Shut Yucca Mountain." *Science* 9 June 2011. Web. 4 Dec. 2011; Rosen, James. "Obama Lacks Authority to Shutter Yucca Site, Court Told." *McClatchy Newspapers*. The McClatchy Company, 22 Mar. 2011. Web. 4 Dec. 2011; "FY2010 Energy Budget Shuts Yucca Mountain Nuclear Dump." *Environmental News Service*. 8 May 2009. Web. 4 Dec. 2011; Bullis, Kevin. "Q & A: Steven Chu." *Technology Review*. Massachusetts Institute of Technology, 14 May 2009. Web. 4 Dec. 2011; Hargreaves, Steve. "Nuclear Waste: Back to Yucca Mountain?" *CNNMoney*. CNN.com, 11 July 2011. Web. 5 Dec. 2011.

[214] Biedscheid, Jennifer, and Murthy Devarakonda. "The Nuclear Energy Debate and the Importance of Radioactive Waste Management." Editorial. *Journal of Hazardous, Toxic, and Radioactive Waste* January 2005. Print.

by radioactive decay and its effects on the facility; potential gas build-up as a result of corrosion or decay of organic material; the uncertainty associated with long-term radioactive decay and its associated physical and chemical effects; unidentified fractures or faults that could allow gas or radiation to escape, or water to seep in; future glaciations, earthquakes, or other large seismic events[215].

It is also imperative that nuclear waste is transported safely, creating another significant difficulty[216]. Although the industry has been transporting waste for 50 years without major mishaps, the quantities that have been shipped are quite small compared to the total amount of waste requiring disposal[217].

There is another major challenge when designing long-term repositories: how do we prevent future generations from accidentally penetrating the facility and releasing radiation? It is assumed that the location of the facility will be lost over its 10,000-year lifespan. To address this problem, the U.S. Department of Energy assembled a team of archaeologists, linguists, anthropologists, and other experts in order to design some sort of warning system[218].

Only a few countries have established centralized, permanent disposal sites. In the U.S., the Waste Isolation Pilot Plant (WIPP)—a deep geological repository—has been accepting nuclear waste since 1999. The waste is from the research and production of

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215 Wallace, Helen. *Rock Solid? A Scientific Review of Geological Disposal of High-level Waste*. Rep. Greenpeace EU Unit, Sept. 2010. Web. 5 Dec. 2011.

216 Committee on Transportation of Radioactive Waste. *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States*. Rep. The National Academies, 2007. Web. 5 Dec. 2011.

217 Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.

218 U.S. Department of Energy. Waste Isolation Pilot Plant. *How Will Future Generations Be Warned?* 5 Feb. 2007. Web. 5 Dec. 2011.

nuclear weapons, including shipments from Los Alamos National Laboratory and other Manhattan Project operations[219]. There are some scientists who have suggested that WIPP has the capacity to accept HLW from commercial reactors, even though it was not originally designed for this purpose[220]. No country has opened a permanent facility for commercial waste, though Finland and Sweden have made progress towards that end[221]. Other countries are looking for suitable sites or are currently using centralized interim storage[222]. Germany had been using an abandoned salt mine to store hundreds of tons of nuclear waste, but in 2008, reports emerged that water leaking from the area since the 1980s is radioactive. The German government is attempting to retrieve and relocate the waste by 2020, amid fears that the mine could contaminate the region[223].

In addition to a long-term repository, other alternatives—including launching the waste into space, ocean dumping or sub-seabed disposal—were considered, but the consensus among the international technical and scientific community is that a permanent underground facility is the best option.

Environmentalists say the unresolved problem of waste disposal is a compelling reason to halt nuclear development. As existing plants continue to operate, they will only add more HLW to the crowded "temporary" storage areas. The search for a suitable repository has stalled, and it does not appear as though a site will be identified any time

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[219] U.S. Department of Energy. Waste Isolation Pilot Plant. *Why WIPP?* 5 Feb. 2007. Web. 5 Dec. 2011.
[220] Buckner, Mel. "Nuke Waste Issue Critical." *The Augusta Chronicle*. 3 Dec. 2011. Web. 5 Dec. 2011.
[221] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.
[222] "Radioactive Waste Management." *World Nuclear Association*. July 2011. Web. 05 Dec. 2011.
[223] Owen, James. "Nuclear-Waste Pileup." *National Geographic*. 8 July 2010. Web. 5 Dec. 2011.

soon, especially with growing anti-nuclear sentiment, and the “not in my backyard” mentality that is sure to be found among local residents.

Evaluating Concern #3: Waste Disposal

Because we are discussing more generally the significance of nuclear waste, it should be noted that nuclear power is arguably “the only large-scale energy-producing technology which takes full responsibility for all its wastes and fully costs this into the product”[224]. Fossil fuel technologies have externalized most of the negative byproducts of electricity production, and big hydro has traditionally done a poor job of taking into account its environmental effects.

Nuclear reactors also produce a smaller volume of waste than fossil fuel technologies: spent fuel from a typical reactor weighs about 27 metric tons, and fits in a storage container that is 75 cubic meters. If the fuel is reprocessed, the highly radioactive waste can be placed in a storage canister that is 28 cubic meters. In comparison, a coal plant that produces equal amounts of electricity would release about 400,000 metric tons of ash annually[225].

Utilizing pools as a temporary storage solution seems to be inevitable right now, and most experts agree that this is acceptable if it is done correctly. Once the pools are full and

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[224] "Radioactive Waste Management." *World Nuclear Association*. July 2011. Web. 05 Dec. 2011.

[225] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.

the spent fuel is cooled, plant operators can store the waste in dry casks, which are significantly safer than the pools, and can hold the waste for at least 50 years[226].

Although many experts and scientists (including environmentalists) have suggested that temporary on-site storage is feasible and safe, Fukushima highlighted the dangers associated with disposing of spent fuel rods in pools: there are fears that the tsunami may have damaged the pools, causing leaks or fires if the water level gets too low. Either of these events could release radiation into the atmosphere[227]. These pools were designed to provide temporary storage, and generally are not durable enough to survive major natural disasters. Moreover, environmentalists have pointed out that the pools in Fukushima were not even filled to capacity, whereas many pools in the U.S. are full and densely packed[228]. Some U.S. plant owners have been granted authorization to increase the amount of spent fuel in these storage pools by as much as five times the amount allowed in their original license[229]. The spent fuel pools also represent a potential terrorist target, which will be discussed in the next section.

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[226] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

[227] Vartabedian, Ralph. "U.S. Nuclear Waste Problem Gains New Scrutiny." *Los Angeles Times*. 23 Mar. 2011. Web. 5 Dec. 2011.

It should be noted that the president and CEO of the Nuclear Energy Institute has insisted that the pools survived the accident "quite well." See Wald, Matthew L. "Spent Fuel Pools as a Bright Spot in Fukushima's Crisis." *The New York Times*. 26 July 2011. Web. 5 Dec. 2011.

[228] Galbraith, Kate. "A New Urgency to the Problem of Storing Nuclear Waste." *The New York Times*. 27 Nov. 2011. Web. 5 Dec. 2011.

[229] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

The government has taken a central role in providing for the storage and disposal of nuclear waste. In the same way that removing federally provided insurance would push the nuclear industry to improve safety practices, significantly ratcheting down government involvement with the waste disposal question could force the industry to be more proactive and aggressive about the issue[230]. However, the problem of waste disposal may be too big and too difficult for the industry to solve on its own, and it may require government assistance or oversight in order to ensure that the storage is safe.

A recent case study illuminates the importance of designing a disposal site to the highest standards, and the role government may have to play in order to ensure these standards are upheld. Waste Control Specialists (WCS), a Texas-based company owned by billionaire Harold Simmons, has opened a nuclear waste dump despite concerns by environmentalists, engineers, and geologists who said that the site was unfit to hold nuclear waste. Rather than license the dump, three staffers at the Texas Commission on Environmental Quality (TCEQ) resigned, citing fears that the dump could contaminate groundwater. WCS bought the property in 1995 and started converting it into a dump while lobbying the state legislature to pass a law that would authorize private companies to handle radioactive waste. In 2001, the state legislature passed such a law, and in 2008, WCS was granted a license to store LLW. Opponents to this plan have questioned whether the political decision-making was fair, impartial, and responsible: in 2008, the executive director of the TCEQ quit the agency to take a highly-paid job with WCS, and Simmons has been a major campaign contributor to a number of politicians who could have influenced the licensing process. Multiple environmental groups, including the Sierra Club, have sued

[230] De Roo, Guillaume. *Risk and Responsibility Sharing in Nuclear Spent Fuel Management*. Rep. Center for Energy and Environmental Policy Research, 2010. Print.

to overturn WCS's disposal licenses[231]. This case study illustrates the how concerns unrelated to health, safety, or the environment are tangled up with the issue of disposal, and the potential need for strong intervention by a central authority.

Fuel reprocessing also plays a role in waste disposal. Reprocessing spent nuclear fuel can serve a variety of purposes, including: the production of plutonium for weapons or fuel; closing the nuclear fuel cycle by producing fuel for fast reactors, which would greatly increase the energy extracted from uranium; recycling plutonium and recovering enriched uranium for use in thermal reactors (such as the LWRs that make up the bulk of the U.S. reactor fleet); extracting isotopes which can be used for medicine, agriculture, or industry[232]. Importantly, reprocessing can also reduce the volume of HLW, though it does not reduce the radiation hazards, as the HLV is merely concentrated into smaller volumes. The UCS have pointed out that it is the level of heat generated by the waste—not the volume of the waste—that determines how big a repository must be. Because reprocessing concentrates the HLW and does not remove certain heat-producing elements, it will not significantly change the size of the required disposal facility[233].[234]

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[231] Harkinson, Josh. "A Texas-Sized Plan for Nuclear Waste." *Mother Jones*. 28 Mar. 2011. Web. 5 Dec. 2011.
[232] Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.
[233] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.
[234] An interesting essay about intergenerational considerations argues that transmuting or reprocessing the waste for use in breeder reactors is an unnecessary burden. See Taebi, B., and AC Kadak. "Intergenerational Considerations Affecting the Future of Nuclear Power: Equity as a Framework for Assessing Fuel Cycles." *Risk Analysis* 30.9 (2010): 1341-362. Print.

Summary: Nuclear waste disposal is a tricky problem. There doesn't seem to be much movement in the development of a government-funded and -operated permanent repository. Now that the Yucca Mountain project has stalled (and is perhaps permanently canceled), environmentalists should pressure politicians and policymakers to identify alternative sites for long-term storage.

In the meantime, the NRC must ensure that on-site temporary storage is as safe as possible. This means building more fuel pools instead of overfilling existing pools, and transferring as much HLW as possible into dry casks (although this transfer process must be well-executed, as it has the potential to expose workers to radiation). Additional security is also necessary at these interim storage sites (see next section).

Unfortunately, it does not appear as though long-lived nuclear waste is avoidable. We must be prepared to safely sequester this waste for hundreds or thousands of years. Luckily, nuclear fission generates relatively small amounts of physical waste. This allows us to localize potential problems such as contamination, and it also makes effective oversight easier, as long as the regulating agency is active and willing to enforce rules designed to protect human health and the environment.

Concern #4: National security

I'm absolutely convinced that the threat we face now, the idea of a terrorist in the middle of one of our cities with a nuclear weapon, is very real and that we have to use extraordinary measures to deal with it.[235]

--Dick Cheney, former U.S. Vice President

There are two issues related to the broad idea of national security that anti-nuclear critics cite as problems with nuclear power: 1) peaceful nuclear energy programs create materials that can be used to make dangerous weapons, and the facilities can be misused/redirected in order to promote nuclear weapons proliferation; 2) nuclear power plants represent easy targets for terrorists, and a meltdown caused by an attack or sabotage has the potential to cause a lot of damage.

The first claim is that the same technologies used for nuclear power can be used to produce material for nuclear weapons, in particular highly enriched uranium (HEU) from uranium enrichment plants and plutonium from fuel reprocessing plants. It is also difficult to determine whether these nuclear facilities are being used to build weapons or produce energy. India and North Korea have used a research reactor to produce weapons-grade plutonium, and Iran appears poised to do the same[236]. This uncertainty alone could destabilize regions in which some countries are pursuing nuclear power: as neighboring countries being to feel threatened by possible nuclear weapons development, they might

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[235] Younge, Gary. "The War on Terror Has Been about Scaring People, Not Protecting Them." *The Guardian*. 3 Jan. 2010. Web. 10 Dec. 2011.
[236] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.

choose to act preemptively, as was the case when Israel bombed a reactor in Iraq in 1981[237]. These materials could then be used by the state, or acquired by terrorists[238].

One of the facts cited in one form or another by different environmentalists is the small amount of fissile material that is needed to make a bomb. Depending on the specific material used and the size of the desired explosive yield, about 6 pounds of Pu-239 or 35 pounds of U-235 is sufficient[239].

The necessary bomb-making material can be obtained from nuclear power plants, uranium enrichment plants, reprocessing plants, or from the fuel or waste stockpiles currently maintained in every country that has some nuclear power infrastructure[240]. In fact, nuclear power plants produce plutonium as a byproduct of electricity generation[241]. Although this plutonium is not ideal for fabricating military-grade weaponry, it could still be used to create a crude, yet powerful device[242]. It is not easy to fabricate a nuclear weapon, and no terrorist group has ever successfully employed a nuclear weapon, but many experts consider it a credible threat, and insist that it is taken seriously, especially

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[237] *Nuclear Power and Nuclear Weapons*. Rep. Nuclear Energy Information Services, 31 Aug. 2004. Web. 8 Dec. 2011.

[238] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

[239] Cochran, Thomas B., Christopher E. Paine, Geoffrey Fettus, Robert S. Norris, and Matthew G. McKinzie. *Position Paper: Commercial Nuclear Power*. Publication. Natural Resources Defense Council, 2005. Print; Allison, Graham. "Nuclear Terrorism - FAQs." *Nuclear Terrorism: The Ultimate Preventable Catastrophe*. Web. 08 Dec. 2011.

[240] Drey, Kay. "Nuclear Power Plant Fuel--a Source of Plutonium for Weapons?" Nuclear Information and Resource Service, 19 July 1996. Web. 8 Dec. 2011.

[241] Taylor, Theodore B. *Nuclear Power and Nuclear Weapons*. Rep. Nuclear Age Peace Foundation, July 1996. Web. 8 Dec. 2011.

[242] McKinzie. *Position Paper: Commercial Nuclear Power*. Publication. Natural Resources Defense Council, 2005. Print.

because such a weapon could cause massive destruction. A classified U.S. assessment of such a threat suggests

> Subnational group using designs and technologies no more sophisticated than those used in first-generation nuclear weapons could build a nuclear weapon from reactor-grade plutonium that would have an assured, reliable yield of one or a few kilotons (and a probably yield significantly higher than that).[243]

One kiloton is equal to 1,000 tons of TNT (kt TNT). "Little Boy" was about 12-15 kt TNT, and "Fat Man" was about 20-22 kt TNT. It is not hard to imagine how much damage such a weapon could do if detonated in a major metropolitan area. Reprocessing plants exacerbate the problem by changing the plutonium from a form that is highly radioactive and very difficult to steal in to a form that is not as radioactive and can be stolen more easily[244]. Concerns about nuclear weapons proliferation were central to the 1977 ban on nuclear fuel reprocessing instituted by President Jimmy Carter.

Uranium enrichment plants provide another option for obtaining bomb-making material. Many environmentalists point out how easy it is to design and construct such a facility: the plans can be stolen or purchased from rogue states, and most or all of the components necessary to construct the actual facility can be manufactured indigenously. Most power reactors use low-enriched uranium (LEU), which is typically between 3 and 5 percent U-235. A nuclear weapon required HEU, which is above 93 percent U-235, and so commercial reactor fuel cannot be used directly for making bombs (although HEU is still

[243] *Nonproliferation and Arms Control Assessment of Weapons-usable Fissile Material Storage and Excess Plutonium Disposition Alternatives*. Rep. U.S. Department of Energy, 2008. Print.
[244] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

used in some experimental and test reactors)[245]. Although commercial uranium enrichment facilities are designed to produce LEU, they are relatively easy to reconfigure in order to produce HEU[246].

Overall, rough estimates suggest that there are more than 1,500 metric tons of HEU, and about 500 metric tons of separated plutonium in global stockpiles. This amount of material could be used to build tens of thousands of nuclear bombs[247]. According to the Union of Concerned Scientists (UCS), the NRC does not require nuclear power facilities to protect this material as carefully as the Department of Energy requires weapons facilities to do. This is symptomatic of a larger problem: much of this potent fissile material is unaccounted for or poorly protected[248].

In addition to concerns that the spread of nuclear technology could increase the probability that nuclear weapons would be developed by governments or scavenged by terrorist groups, there are also concerns that nuclear facilities themselves represent attractive targets for sabotage or attack.

Since the terrorist attacks of September 11, 2001, more attention has been directed towards the vulnerability of nuclear facilities. Al-Qaeda operatives, including Khalid Sheikh Mohammed, the architect of the 9/11 attacks, told U.S. officials that nuclear power plants

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[245] "Reprocessing and Nuclear Terrorism." Union of Concerned Scientists, 21 Mar. 2011. Web. 8 Dec. 2011.
[246] Ibid.
[247] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.
[248] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

were, and remain, targets[249]. A number of different studies have suggested that current security measures are inadequate:

- Multiple studies have suggested that power plants are quite vulnerable to aircraft hazards (such as an intentional crash)[250]. In 2002, the NRC ordered plant owners to develop "specific plans and strategies" to respond to various safety threats, including the impact of an aircraft[251]. In 2009, the NRC published final rules that require all new nuclear power plants to incorporate design features that would protect the reactor core and containment structure, as well as fuel storage pools, from a crash[252]. However, the NRC rejected proposals that such requirements would be extended to existing reactors.
- Environmentalists also worry about the ability of plant owners to defend their facilities against a possible attack. The NRC requires nuclear plants to be able to guard against an assault by three individuals, armed with rifles. Some critics have suggested that this ignores the very real possibility that: there are more than three attackers, they are assisted from someone on the inside, and/or they have

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[249] Crumley, Bruce. "Are These Towers Safe?" *Time Magazine*. 12 June 2005. Web. 9 Dec. 2011.

[250] See Large, John H. "The Aftermath of September 11: Vulnerability of Nuclear Plants to Terrorist Attack." *Rethinking Nuclear Energy and Democracy After September 11, 2001* (2004): 33-40. International Physicians for the Prevention of Nuclear War. Web. 8 Dec. 2011; Holt, Mark, and Anthony Andrews. *CRS Report for Congress: Nuclear Power Plants: Vulnerability to Terrorist Attack*. Rep. 2007. Print; Holt, Mark, and Anthony Andrews. *CRS Report for Congress: Nuclear Power Plant Security and Vulnerabilities*. Rep. 2010. Print; Hirsch, Helmut. *Vulnerability of VVER-1000 Nuclear Power Plants to Passenger Aircraft Cras*. Rep. Hannover: Greenpeace International, 2001. Print; "German Nuclear Reactor Safety Test Finds Flaws." *Spiegel Online*. 17 May 2011. Web. 8 Dec. 2011.

[251] U.S. Nuclear Regulatory Commission. *Frequently Asked Questions About Security Assessments at Nuclear Power Plants*. 12 Mar. 2011. Web. 8 Dec. 2011.

[252] Holt, Mark, and Anthony Andrews. *CRS Report for Congress: Nuclear Power Plant Security and Vulnerabilities*. Rep. 2010. Print.

sophisticated weaponry (such as rocket-propelled grenades or sniper rifles). According to the UCS, when the NRC conducted simulated attacks to evaluate the security arrangements at nuclear facilities, the mock terrorists were able to "destroy" enough safety equipment to cause a meltdown at nearly *half* of the power plants tested[253]. A more recent study found that eight out of 112 mock attacks—about 7 percent—resulted in simulated destruction of the nuclear plant[254]. Guards have said that they are overworked and underpaid, inadequately armed and trained, too few in number[255], and unwilling to die to protect the plant[256]. Kathy Davidson, a former chief guar trainer at a nuclear plant south of Boston, said that security is "pathetic" and out of 29 in-house attack simulations, the attackers won 28. She also said that these deficiencies are well known within the industry, but left unaddressed[257]. In short, there are concerns that the NRC is not taking the threat of sabotage or attack seriously enough, both in terms of setting low security standards and actually enforcing those standards.

- Finally, some experts have suggested that spent fuel storage pools are especially vulnerable to attack. If attackers or saboteurs were able to expose spent fuel to air, it could catch fire, releasing radioactive particles into the atmosphere. In response to

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[253] Hirsch, Daniel, David Lochbaum, and Edwin Lyman. "The NRC's Dirty Little Secret: the Nuclear Regulatory Commission Is Still Unwilling to Respond to Serious Security Problems." *Bulletin of the Atomic Scientists*. 1 May 2003. Web. 8 Dec. 2011.

[254] Holt, Mark, and Anthony Andrews. *CRS Report for Congress: Nuclear Power Plant Security and Vulnerabilities*. Rep. 2010. Print.

[255] Crumley, Bruce. "Are These Towers Safe?" *Time Magazine*. 12 June 2005. Web. 9 Dec. 2011.

[256] Caldicott, Helen. *Nuclear Power Is Not the Answer*. New York: New York, 2006. Print.

[257] Crumley, Bruce. "Are These Towers Safe?" *Time Magazine*. 12 June 2005. Web. 9 Dec. 2011.

this threat, France has installed anti-aircraft missiles around its spent fuels ponds, and other countries are enhancing existing security measures[258].

Evaluating Concern #4: National Security

There are two separate issues that we must evaluate. The first is the concern about nuclear weapons proliferation, and the second is about security at nuclear power plants.

The idea that peaceful nuclear development will lead to increased nuclear proliferation is not compelling. As the UCS points out, "the United States and the international community can do little to prevent a determined nation from eventually acquiring nuclear weapons"[259]. State-sponsored nuclear weapons proliferation must be discouraged in other ways, such as the Treaty on the Non-Proliferation of Nuclear Weapons, which has been in effect since 1970. Nuclear weapons proliferation is a political problem, and it seems likely that the most effective way to deal with it is through international treaties, agreements, and sanctions. Whether we shut down nuclear reactors in the U.S. is unlikely to deter Iran or other rogue nations from developing nuclear programs—and weapons—of their own.

However, the poor oversight of fissile material and inadequate security at storage sites is concerning. The possibility of terrorists detonating a crude nuclear weapon may be very small, but its effects could be devastating, especially if it were used in a metropolitan

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[258] Zhang, Hui. *Radiological Terrorism: Sabotage of Spent Fuel Pool*. Rep. International Network of Engineers and Scientists Against Proliferation. Web. 8 Dec. 2011.
[259] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

area. Even if terrorists were unable to build a functioning nuclear bomb, these materials could still be used to create a “dirty bomb,” which could disperse radioactive material over a large area. Although dirty bombs would probably result in significantly less damage and cause few casualties, it could still lead to contamination and panic.

The solution to this problem is straightforward. Nations with nuclear capacity must make a commitment to consolidate their stockpiles of fissile material and increase security measures at storage sites and during transportation. At least in the U.S., such measures seem likely to be welcomed: “national security” is something nearly all politicians promote, and bolstering security forces in an attempt to prevent terrorists from creating nuclear weapons seems largely uncontroversial. More ambitious steps, such as placing uranium enrichment facilities under international control and prohibiting the production of plutonium, should be pursued as well.

A study conducted by a UCS physicist presents a hypothetical situation, in which there is a core meltdown at the Indian Point nuclear power plant, 35 miles upwind from Manhattan, as the result of a terrorist attack. The study found that 44,000 early fatalities were possible, and the radiological release could eventually cause over 500,000 latent cancer fatalities. Damages could range from hundreds of billions to trillions of dollars, and contamination could permanently displace millions of people. The study criticizes the NRC’s focus on the 10-mile emergency planning zone, and suggests that the impacts of a potential meltdown would extend far beyond these arbitrary boundaries[260].

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[260] Lyman, Edwin S. *Chernobyl on the Hudson? The Health and Economic Impacts of a Terrorist Attack at the Indian Point Nuclear Plant*. Rep. Riverkeeper, 2004. Print.

Even without such apocalyptic consequences, it is clear that the threat of sabotage and attack must be treated seriously. There is considerable evidence that suggests the NRC's standards and enforcement of those standards are not sufficient to adequately protect nuclear facilities from a "worst case scenario" terrorist attack. Inadequate security is not a problem unique to the U.S.: as recently as December 5th, 2011, Greenpeace activists broke into two French nuclear plants in an effort to highlight poor security[261].

The nuclear industry has responded to concerns about sabotage by asserting that the chance of a terrorist-induced meltdown is very small. Why, they say, would terrorists target a heavily defended nuclear power plant, when other attractive targets (such as chemical plants or dams) are more vulnerable? There is some merit to this statement, but it seems like this response is wanting, especially when we realize that terrorists may be most interested in creating fear and panic, which would undoubtedly accompany a meltdown or radiation release. Industry officials have also said that the government is responsible for defending against attacks of greater severity than the "design basis threat" (as decided by the NRC). However, the necessary mechanisms that would allow for such a response are currently non-existent: at this point, the government doesn't really have the capacity to provide a quick, effective response in the event of an attack on a nuclear facility[262].

This problem has a straightforward solution—enhance security at nuclear power plants and spent fuel pools—but it may prove difficult to implement. Attempted legislation

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[261] Amiel, Geraldine, and Inti Landauro. "Activists Enter French Nuclear Facilities." *The Wall Street Journal*. 5 Dec. 2011. Web. 8 Dec. 2011.
[262] Gronlund, Lisbeth, David Lochbaum, and Edwin Lyman. *Nuclear Power in a Warming World: Assessing the Risks, Addressing the Challenges*. Publication. Cambridge, MA: Union of Concerned Scientists, 2007. Print.

to enhance security has been blocked by industry opposition[263], and the NRC decided that it would not require plant owners to retrofit their reactors with steel cages that would protect them from aircraft strikes[264].

Clearly, this resistance from the industry and the NRC must be overcome. Environmentalists should push for legislation that would enhance security at existing plants, and require the NRC to strengthen and consistency enforce their security standards. In order to address the particular vulnerabilities of spent fuel pools, the industry should move spent fuel rods to protected dry casks as quickly as possible (according to the UCS, this could be done within six years).

Providing adequate security may also require other government agencies, such as the Department of Homeland Security, to take action. In any case, there should be a centralized effort made to determine the likely threats to and weaknesses of nuclear facilities, and clearly provide for a response to such threats. By bringing in other government agencies, we may be able to counteract the NRC's unwillingness or inability to enforce safety standards.

Environmentalists and experts have also suggested that the U.S. avoid reopening spent fuel reprocessing facilities. A closed nuclear fuel cycle (i.e. if reprocessing were the norm) would involve handling, processing, transporting, and storing large amounts of material that could be used for a bomb. Furthermore, this material would be relatively easy to conceal and transport once obtained by terrorist groups. The UCS and other environmental groups have suggested that the U.S. reinstate its ban on reprocessing spent

[263] Crumley, Bruce. "Are These Towers Safe?" *Time Magazine*. 12 June 2005. Web. 9 Dec. 2011.
[264] U.S. Nuclear Regulatory Commission. *Frequently Asked Questions About Security Assessments at Nuclear Power Plants*. 12 Mar. 2011. Web. 8 Dec. 2011.

fuel, reprocessing plants and the material they produce are especially attractive and vulnerable targets.

Summary: When environmentalists cite "national security" as a problem with nuclear power, they may be referring to one or more of a few different, specific issues. There are fears that the expansion of peaceful nuclear programs will enable states to build nuclear weapons. Concerns about nuclear weapons proliferation are not compelling: rogue states will try and develop nuclear weapons whether or not the U.S. and other nations close down commercial nuclear plants. However, it is true that nuclear facilities produce or use fissile material—notably HEU and plutonium—that could be stolen or obtained by terrorists and used to create a bomb. In light of this, the international community must make it a priority to improve security measures at such sites, increase the oversight of these materials, and reduce the size of nuclear stockpiles.

The more compelling national security issue is the vulnerability of nuclear plants to attack or sabotage. There is strong evidence that suggests nuclear facilities and spent fuel pools are poorly guarded and could be compromised by a sophisticated terrorist attack. Such an attack might lead to a meltdown, which could have devastating effects on the surrounding area. The NRC has been reluctant to adjust their safety standards in the wake of 9/11, and seems unable or unwilling to enforce their current standards. Better, more effective regulation is needed, and environmentalists should push the industry and the government to address these security concerns by: enhancing security, retrofitting reactors to protect against airplane crashes, moving spent fuel rods out of fuel ponds and into dry casks, and designing effective emergency plans that would govern a response to such an attack or meltdown. These vulnerabilities and shortcomings can be addressed, but it will require politicians and policymakers to insist upon the safety and security of nuclear facilities.

Chapter 4: Emerging Nuclear Technology

I think it is very important to make sure that we are doing everything we can to ensure the safety and effectiveness of the nuclear facilities that we have. We've got to budget for it. I've already instructed our nuclear regulatory agency to make sure that we take lessons learned from what's happening in Japan and that we are constantly upgrading how we approach our nuclear safety in this country.[265]

--Barack Obama, U.S. President

So where does all of this leave us? We have identified and analyzed four major concerns: the destructiveness of energy-intensive uranium mining, the possibility of a meltdown and the consequences of radiation release, the difficulties associated with storing nuclear waste, and fears that nuclear development will endanger national security.

Table 2 below presents these concerns in terms of their severity (i.e. how bad/potentially bad is the problem?), the likelihood or ease of amelioration (i.e. do we know how to fix this problem? Can we fix this problem? Is it likely that we will fix this problem?), and the overall assessment of the concern (i.e. all things considered, how serious is this problem?

[265] Associated Press. "Obama Defends Nuclear Energy." *Msnbc.com*. 16 Mar. 2011. Web. 10 Dec. 2011.

Table 2

	Severity	Likelihood/ease of amelioration	Overall
Uranium mining	Low/moderate	Low	Moderate
Radiation/meltdowns	High	Low/moderate	High
Waste disposal	Moderate	Low/moderate	Moderate
National security	Moderate/high	Moderate/high	Low

The most pressing problem with nuclear energy is the potential for radiation release and core meltdowns. Not only could a meltdown have potentially disastrous effects, but the physics of nuclear fission are inherently risky and volatile, nuclear plants are getting older and many components are subject to corrosion and deterioration, and drastically improving the safety culture within the NRC and the nuclear industry will be incredibly difficult. On the other end of the spectrum, national security concerns seem on the whole less compelling: although the potential consequences of a terrorist attack or sabotage could be significant, steps to help fix this problem are obvious, straightforward, and politically feasible. Concerns about uranium mining and waste disposal are somewhere in the middle, both in terms of severity and in the likelihood that we will actually make progress in addressing these issues.

Now that we have characterized the environmental critiques of nuclear energy, we have a rough baseline by which we can evaluate emerging nuclear technologies. This is especially useful considering the fast-paced nature of scientific research and engineering capability: we can see very quickly how new reactor designs or safety features might relate to these environmental concerns, and identify which sorts of technologies are worth endorsing and pursuing.

We will review a few recent advancements in nuclear technology, but before we do, it's important to be cognizant of a few things:

1. When discussing these advancements, it is often difficult to make informed conclusions unless you have an extensive background or expertise in nuclear or energy technologies. Because many of these "breakthroughs" are theoretical or have only been tested in a specific setting, there is a lack of hard data and experience upon which we can draw. As a result, it can often seem as though evaluating emerging nuclear technology is a "he said, she said" battle between different scientists and experts.
2. Again, technology changes so rapidly that it is important to look at the most recent sources available.

With this in mind, let's look at how this environmental model can be applied to a few recent innovations. There are many more emerging technologies than we can discuss here, so we will focus on some of the most interesting and promising advancements in the nuclear industry: the use of thorium as fuel, passive safety/inherently safe systems, and fast reactors.

Thorium as fuel

As the world's stocks of recoverable uranium ore shrink, some scientists are suggesting that we begin to use thorium as fuel. Thorium is a radioactive element, and it is extremely abundant. Some estimates suggest there is four times more thorium on Earth than there is uranium[266].

100 percent of all naturally occurring thorium is the isotope thorium-232, which can be transformed into fissile material via the absorption of a neutron, eventually decaying to uranium-233, which is long-lived, fissile, and can be used as reactor fuel. Thorium reactors would be designed so as to make it difficult to separate the U-233, and could even dilute the fuel with U-238, thus making the fuel extremely proliferation-resistant[267]. Thorium reactors also wouldn't produce any plutonium, and they would be significantly less likely to experience a core meltdown[268].

The other advantages to a thorium fuel cycle are that thorium-based reactors generally produce less long-lived radioactive waste than uranium-based reactors, and thorium is thought to be extremely potent as an energy source: Dr. Carlo Rubbia, a Nobel laureate, has suggested that one ton of thorium produces as much energy as 200 tons of uranium, or 3,500,000 tons of coal[269].

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266 Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.
267 Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.
268 Pasternack, Alex. "Thorium: World's Greatest Energy Breakthrough?" *CNN*. 17 Nov. 2011. Web. 10 Dec. 2011.
269 Evans-Pritchard, Ambrose. "Obama Could Kill Fossil Fuels Overnight with a Nuclear Dash for Thorium." *The Telegraph*. 29 Aug. 2010. Web. 10 Dec. 2011.

Thorium reactors would also incur higher safety costs than traditional nuclear reactors, and handling irradiated fuel is difficult due to isotopic compositions that produce potent alpha radiation[270].

China and India have both researched using thorium as fuel, and India (which has vast thorium reserves) has announced it will build a prototype thorium-based heavy water reactor[271], while China is using a molten salt reactor design pioneered in the U.S. in the 1960s[272]. Designs for thorium reactors have been around since the beginning of the nuclear era, but never received much attention in the U.S., and were eventually dropped or overshadowed by uranium-based technology.

The thorium fuel cycle has some obvious advantages over the traditional uranium fuel cycle. It is extremely proliferation-resistant, which would help address some aspects of national security concerns. Thorium reactors also seem like they might be improvements on uranium-based light water reactors (LWRs) in terms of radioactive waste. Additionally, because thorium can be used so efficiently and is so abundant, extraction would be easy and far less involved and dangerous than in uranium mines. [273]

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[270] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.

[271] Rahman, Maseeh. "India Plans 'safer' Nuclear Plant Powered by Thorium." *The Guardian*. 1 Nov. 2011. Web. 10 Dec. 2011.

[272] Evans-Pritchard, Ambrose. "Safe Nuclear Does Exist, and China Is Leading the Way with Thorium." *The Telegraph*. 20 Mar. 2011. Web. 10 Dec. 2011.

[273] For more information on thorium-based reactors, see Mead, Derek. "Can Thorium Generate Safe and Cheap Nuclear Power?" *Greentech Media*. 14 Nov. 2011. Web. 10 Dec. 2011; Boyle, Rebecca. "Development of Tiny Thorium Reactors Could Wean the World Off Oil In Just Five Years." *Popular Science*. 30 Aug. 2010. Web. 10 Dec. 2011; "Thorium." World Nuclear Association, 11 Nov. 2011. Web. 10 Dec. 2011; Radkowsky, A., and A. Galperin. "The Nonproliferative Light Water Thorium Reactor : A New Approach to Light Water Reactor Core

Passive safety/inherently safe systems

Some new reactors will incorporate "passive safety systems" or "inherently safe designs." Although passive safety systems and inherently safe systems are not necessarily the same, many designs incorporate features from both. Passive safety systems rely on gravity and natural circulation instead of pumps, and are thus greatly simplified, and can function without active operator intervention[274]. These simpler systems also have the effect of reducing construction cost and time.

Inherently safe designs are supposed to not require operator intervention for days, even in a loss-of-coolant event or other mechanical problem[275]. These systems also incorporate redundant safety components. One particularly intriguing design is the Pebble Bed Modular Reactor (PBMR), which uses helium gas to transfer heat from the reactor core. The fuel consists of small balls of uranium, coated in graphite. Theoretically, if the fuel begins to overheat, the rate of fission will automatically decrease, reducing the heat production, which will return the reactor to a stable state[276]. There have been issues with prototype PBMRs in the past, but China is pursuing a PBMR project, and South Africa is considering relicensing a PBMR demonstration plant that was closed after huge cost overruns[277].

Technology." *Nuclear Technology* 124 (1998): 215-22. Print; Kasten, Paul R. "Review of the Radkowsky Thorium Reactor Concept." *Science & Global Security* 7.3 (1998): 237-69. Print.

[274] Irvine, Maxwell. *Nuclear Power: a Very Short Introduction*. Oxford: Oxford UP, 2011. Print.

[275] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.

[276] Ibid.

[277] Bradsher, Keith. "Pressing Ahead Where Others Have Failed." *The New York Times*. 24 Mar. 2011. Web. 10 Dec. 2011.

Passive safety features and inherently safe designs are being touted as the future of nuclear power. They are incorporated into many of the Gen-IV facilities that are being developed and tested around the world.

Clearly, such improvements in safety technology—if indeed they function in the way proponents say they should—could drastically change how people view nuclear power. If the threat of meltdowns and major radiation releases is significantly lessened (or reduced to zero), the most compelling traditional critique of nuclear energy is no longer as relevant or applicable.[278]

Gen-IV fast reactors

"Fast reactors" are a class of reactors in which the fission chain reactor is sustained by fast neutrons. Unlike LWRs and traditional reactors, a fast reactor uses no neutron moderator, and must use fuel that is extremely fissile. The higher temperatures and pressures inside a fast reactor dramatically increase the efficiency of the reactor: some experts have suggested a closed fuel cycle with a fast reactor could ultimately lead to the

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[278] For more information on passive safety/inherently safe systems and PBMRs, see Ion, S., D. Nicholls, R. Matzie, and D. Matzner. "Pebble Bed Modular Reactor—the first Generation IV Reactor to Be Constructed." *Nuclear Energy* 43.1 (2004): 55-62. Print; Reitsma, Frederik. *The Pebble Bed Modular Reactor Layout and Neutronics Design of the Equilibrium Cycle*. Rep. American Nuclear Society, 2004. Print; Nicholls, D. R. "The Pebble Bed Modular Reactor." *Transactions of the Royal Society of South Africa* 56.2 (2001): 125-30. Print; "Future Energy." Pebble Bed Modular Reactor (Pty) Limited (PBMR). Web. 10 Dec. 2011. <http://www.pbmr.com/>; Thomas, Steve. "The Demise of the Pebble Bed Modular Reactor." *Bulletin of the Atomic Scientists*. 22 June 2009. Web. 10 Dec. 2011; Ingersoll, D.T. "Deliberately Small Reactors and the Second Nuclear Era." *Progress in Nuclear Energy* 51.4-5 (2009): 589-603. Print; Forsberg, C. W., and A. M. Weinberg. "Advanced Reactors, Passive Safety, and Acceptance of Nuclear Energy." *Annual Review of Energy* 15.1 (1990): 133-52. Print.

extraction of 99% of energy in uranium fuel, as opposed to current reactors, which extract about 1%[279]. Instead of using water as a coolant, fast reactors use liquid metal, molten salt, sodium, or gas, none of which significantly moderates (slow down) the fission chain reactor. Many of the Gen-IV designs—of which there are many versions—are fast reactors, and they have certain characteristics in common.

First, a fast reactor can significantly reduce the potency and lifetime of nuclear waste. Because fast reactors use fast neutrons and are so much more efficient, they create a relatively small mass of short half-life isotopes, reducing the lifetime of the waste from tens of thousands of years to a few centuries[280].

Secondly, some fast reactors can be configured to consume uranium, plutonium, or thorium-based fuels[281]. These reactors could be used to reduce the stockpiles of HEU and plutonium, consuming some of the most radioactive, most difficult to store, and most dangerous fuel. General Electric has proposed building a liquid-sodium fast reactor in the UK that would convert Britain's plutonium into electricity[282]. More generally, fast reactors do not require fuel from regular mining operations. According to one study, existing stores of plutonium and HEU, nuclear waste, and depleted uranium could provide enough fuel to supply the world's energy needs for 1000 years[283]. Fast reactors could also consume fuel

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[279] Archambeau, Charles, Randolph Ware, Tom Blees, Barry Brook, Yoon Chang, Jerry Peterson, Robert Serafin, Joseph Shuster, Evgeny Velikhov, and Tom Wigley.*The Integral Fast Reactor (IFR): An Optimized Source for Global Energy Needs*. Rep. 2011. Print.
[280] Chang, Yoon. *The Integral Fast Reactor*. Rep. Argonne National Laboratory. Print.
[281] Ferguson, Charles D. *Nuclear Energy: What Everyone Needs to Know*. Oxford: Oxford UP, 2011. Print.
[282] Harvey, Fiona. "GE and Hitachi Plan New Reactor to Burn UK Plutonium Stockpile."*The Guardian*. 30 Nov. 2011. Web. 10 Dec. 2011.
[283] Archambeau, Charles, Randolph Ware, Tom Blees, Barry Brook, Yoon Chang, Jerry Peterson, Robert Serafin, Joseph Shuster, Evgeny Velikhov, and Tom Wigley.*The Integral Fast Reactor (IFR): An Optimized Source for Global Energy Needs*. Rep. 2011. Print.

from breeder reactors indefinitely, and some scientists think that extracting uranium from seawater would become economical.

It is important to note that fast reactors are extremely difficult to build. The coolants can be corrosive or burn when exposed to air, and in general, fast reactor designs are more demanding. However, many of these reactors incorporate passive safety systems and inherently safe design. Theoretically, no operator action would be needed to shut these facilities down in the event of a malfunction[284].

It's easy to get excited about fast reactors. If the scientists and pro-nuclear experts are correct, fast reactors address many of the environmentalist's major concerns: fast reactors produce less waste; they can consume existing plutonium, HEU, depleted uranium, and decommissioned warheads as fuel; and they are extremely safe.

A small volume of less radioactive, short-lived waste would more or less solve the issue of waste disposal. We could store this waste with reasonable high confidence levels in an unsealed, underground repository[285]. Moreover, these reactors would need to be loaded only once, and the fuel will be recycled until it is completely depleted. This drastically reduces the risk of attack or sabotage during transportation or storage[286].

Fast reactors would simultaneously help address concerns about weapons proliferation and national security by consuming bomb-making material as fuel. Due to the abundance of such fuel, we also wouldn't have to initiate new mining operations, thus totally bypassing another of the four main environmental concerns.

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[284] Ibid.
[285] Ibid.
[286] Monbiot, George. "A Nuclear Solution Ticks All Our Boxes." *Today*. 10 Dec. 2011. Web. 10 Dec. 2011;

Fast reactors have been built and operated in the past (about 20 have been in operation since the 1950s), but no Gen-IV fast reactor has been built yet. There are international collaborative efforts to develop these reactors, and we could see Gen-IV commercial facilities before 2030. If fast reactors are as efficient and safe as proponents claim, they could completely change the discussion about nuclear energy, as they would avoid the majority of traditional critiques.[287]

We have seen how we can use the environmentalist's concerns about nuclear power as criteria with which we can evaluate emerging technologies. By using this approach faithfully, we ought to be able to assess new technologies fairly consistently, and identify the projects that seem particularly promising and worthy of more support.

All nuclear technologies are not created equal. Environmentalists must be able to distinguish between different types of reactors, fuel cycles, safety systems, etc. in order to

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[287] For more information on fast reactors, see *Fast Neutron Reactors*. World Nuclear Association, Nov. 2011. Web. 10 Dec. 2011; Davis, Dorothy. "GE Hitachi Proposes Small Modular Nuclear Fast Reactor as Solution to Legacy Plutonium Stockpile in the UK." *Penn Energy*. 5 Dec. 2011. Web. 10 Dec. 2011; Kirsch, Steve. "The Integral Fast Reactor (IFR) Project." Web. 10 Dec. 2011. <http://skirsch.com/politics/globalwarming/ifr.htm>; "China Connects First Fast Nuclear Reactor to Electricity Grid." Bloomberg, 21 July 2011. Web. 10 Dec. 2011; American Nuclear Society. *Fast Reactor Technology: A Path to Long-Term Energy Sustainabilit*. Nov. 2005. Web. 10 Dec. 2011; Hannum, William H., Gerald E. Marsh, and George S. Stanford. *Smarter Use of Nuclear Waste*. Rep. Scientific American, 2005. Web. 10 Dec. 2011; Till, Charles E. *Plentiful Energy and the IFR Story*. Rep. Sustainable Nuclear Center For Reactor Information, 2005. Print; Monbiot, George. "A Nuclear Solution Ticks All Our Boxes." *Today*. 10 Dec. 2011. Web. 10 Dec. 2011; Blees, Tom. *Prescription for the Planet: the Painless Remedy for Our Energy & Environmental Crises*. [Charleston, S.C.]: urge, 2008. Print; Podvig, Pavel. "History and Status of Fast Breeder Reactor Programs Worldwide." International Panel on Fissile Materials, 17 Feb. 2010. Web. 10 Dec. 2011; Waltar, Alan, and Donald Todd. "Sustainable Development of Nuclear Energy and the Role of Fast Spectrum Reactors." *Fast Spectrum Reactors*. By Pavel Tsetkov. Springer, 2012. 3-22. Print.

make fully informed decisions about which technologies or research initiatives to support, and what sorts of improvements are needed as development progresses.

Chapter 5: Moving Forward

I have tried to provide an objective assessment of nuclear power from the environmentalist's perspective—that is, one that emphasizes public health, safety, and the natural environment. I want to emphasize that this is by no means an exhaustive or comprehensive account of this issue. The amount of information about nuclear power is staggering: for every article or report I have cited here, there are 10 more about the same subject, many of which will come to different and divergent conclusions. Undoubtedly, there are aspects or dimensions of nuclear power that I have left out or missed. I provided copious citations in order to allow the reader to delve into my sources and make up her own mind regarding the validity of environmental critiques, and the appropriate course of action we ought to take in light of such critiques. In such a contentious, technical debate, it is crucial that we pay attention to the author or organization behind a report, as well as its date of publication. Energy technologies are changing rapidly, and the viability of nuclear power hinges largely on issues of safety, efficiency, cost, and reliability, all of which are highly variable based on scientific advancement.

Even as I have been writing this thesis, there have been major changes and breakthroughs in the energy industry. Over the past few months, solar power has passed[288] or is about to pass[289] grid parity (generating electricity via solar panels is at least as cheap as current grid power), and engineers are working on developing 3D solar panels, which

[288] Branker, K., M.J.M. Pathak, and J.M. Pearce. "A Review of Solar Photovoltaic Levelized Cost of Electricity." *Renewable and Sustainable Energy Reviews* (2011). Print.
[289] Baillie, Richard. "Solar Closes In on Grid Parity." *Renewable Energy World*. 13 Oct. 2011. Web. 10 Dec. 2011.

would produce as much energy on a cloudy day as on a sunny day[290]; a revised map of thermal points in the U.S. suggests that geothermal energy sources have the capacity to produce more than 10 times the energy of the installed capacity of coal power in the U.S.[291]; the EU climate change commissioner has said that off-shore wind power is cheaper than building new nuclear power plants[292]; Denmark has taken drastic steps to change its energy paradigm, with half of its electricity supplied by wind turbines by 2020[293], and 100 percent from renewable sources by 2050[294]; and so on, and so forth. It is possible that new studies, reports, and articles will supersede much of the content in this essay within the next few years[295].

Ultimately, we environmentalists ought to agree on two major points: the first is that we must quickly phase out harmful fossil fuel technologies that emit tons of GHG into the atmosphere and are the major drivers of anthropogenic climate change. And secondly, governments around the world must support the development of green technology and renewable energy sources.

Nuclear power falls somewhere between these two positions. If we had to choose whether to burn fossil fuels or split atoms for our electricity, we ought to pick nuclear

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[290] Shahan, Zachary. "3D Solar Panels from MIT." *Clean Technica*. 24 Nov. 2011. Web. 10 Dec. 2011.
[291] SMU Geothermal Laboratory. *A New Geothermal Map of the United States*. Google.org, 25 Oct. 2011. Web. 10 Dec. 2011.
[292] Harvey, Fiona, and Terry Macalister. "Wind Power Cheaper than Nuclear, Says EU Climate Chief." *The Guardian*. 17 Mar. 2011. Web. 10 Dec. 2011.
[293] AFP. "Wind Power to Make up Half of Danish Energy Use in 2020." *Physorg.com*. 25 Nov. 2011. Web. 10 Dec. 2011.
[294] Fraende, Mette. "Denmark Aims for 100 Percent Renewable Energy in 2050." *Reuters*. 25 Nov. 2011. Web. 10 Dec. 2011.
[295] For more information on the future of nuclear energy, see Montgomery, Scott L. *Asia's Emerging Nuclear Era: Climate Strategies & Implications for U.S. Policy*. Rep. Henry M. Jackson School of International Studies, 2011. Print; Forsberg, Charles W. *The Future of the Nuclear Fuel Cycle*. Rep. Massachusetts Institute of Technology, 2011. Print.

energy sources. And if we could choose between nuclear power and renewables, we ought to construct windmills and deploy solar cells. But for the moment, neither of these choices is realistic. Serious efforts to quickly phase out coal, petroleum, and natural gas will almost surely necessitate the construction of nuclear reactors. There will be energy deficits as we move away from fossil fuel technologies, and unless it is clear that we can provide sufficient amounts of energy with renewables, environmentalists should support nuclear development, and insist upon more nuclear research. This support should be skeptical and reserved: as we have seen, there are problems associated with nuclear energy, and environmentalists should simultaneously work to address the concerns outlined above. Reactors don't emit significant amounts of GHG, but that doesn't mean we ought to support such technology unconditionally. And conversely, skeptics should remember that nuclear power plants are—from an environmental standpoint—preferable to fossil fuel technology. Blind opposition to nuclear technology may leave us with the same coal plants that environmentalists agree are devastating our planet's climate, and its inhabitants.