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5

Environmental Damages: "Cutting Butter with a Chainsaw"

On the late summer evening of September 1, 1984, operators at the St. Lucie nuclear power plant in Florida, United States, observed something peculiar. The waters around the power plant's cooling vents, used to suck ocean water into the facility so that it could be condensed into steam, were unusually frothy. As the plant manager sent one of his workers to manually inspect the facility's intake screens, alarms began to ring in unison. The worker quickly reported back that a flotilla of jellyfish was "attacking" the power plant. Hundreds of thousands of moon jellyfish and sea nettles perished in the two-day assault, clogging the cooling system and forcing both reactors to shut down. Stacy Shaw, one of the operators of the facility, told the *New York Times* that "we had to shut down because we couldn't keep the flow of water that we need to run the plant."[1] Plant officials had to rig an elaborate "jellyfish trap" to keep the thousands of creatures floating in from Vero Beach and Stuart out of the cooling system.[2] Then, on September 8, the jellyfish departed and normal operations resumed.

What is striking about this example is that it is an instance where the natural environment — in this case, scores of jellyfish — was threatened by a nuclear power plant and decided to attack it. Most of the time, as this chapter shows, it is the other way around, with nuclear power plants and their affiliated infrastructure inducing four general types of environmental insults: land use impacts, water use and contamination, climate change, and medical and health risks. Underground, open-pit, and *in situ* leaching uranium mining can contaminate water, and have resulted in scores of accidents and environmental pollution in dozens of countries around the world. Nuclear waste storage, at both permanent and temporary storage sites, creates grave environmental concerns. Plant construction and operation have serious impacts on water availability and quality. Reactor vessels are so heavy that rivers may need to be dredged to get them where they need to go, and nuclear cooling systems use more water than any other electricity source, creating a variety of environmental impacts including thermal discharges, impingement, and entrainment, to say nothing of how accidents and spills can disperse tritium and other carcinogenic compounds into water supplies. In terms of climate change, the nuclear fuel cycle is energy-intensive, meaning every part of it has its own affiliated greenhouse gas emissions. In addition, the carbon footprint of nuclear facilities will only get worse as high-grade uranium ores are used up and plants get older, so much so that a typical reactor will be about as "clean" as fossil fuels within 30–40 years. The chapter finally mentions medical and health risks associated with nuclear power, including higher rates of cancer, birth abnormalities, and the presence of radioactive compounds such as strontium-90 found in the teeth of children living near nuclear power plants.

What makes nuclear power so bad for the environment? Nuclear fission produces some of the most hazardous elements on earth, and it also relies on brute force — controlling a nuclear reaction, the same one released in a weapon — instead of grace or properly scaled systems to generate electricity. The nuclear fuel cycle expends enormous amounts of energy to mine, leach, and enrich uranium from the earth, transport it, process it into fuel, place fuel assemblies into reactors, remove them for interim storage, and permanently sequester nuclear waste. The system is equivalent to "cutting butter with a chainsaw — inelegant, expensive, messy, and dangerous."[3]

Land Use

The deleterious impacts on land from the nuclear fuel cycle can be primarily divided into uranium mining and waste storage.

Uranium Mining

Uranium mining is water- and volume-intensive, since quantities of uranium are mostly prevalent at very low concentrations.[4] Uranium is mined in three different ways: underground mining, open-pit mining, and *in situ* leaching. Underground mining extracts uranium much like other minerals, such as copper, gold, and silver, and involves digging narrow shafts deep into the earth.[5] Open-pit mining, the most prevalent type, is similar to strip mining for coal, where upper layers of rock are removed so that machines can extract uranium. Open-pit mining ceased in the US in 1992 due to concerns about environmental contamination and the quality of uranium, as most ore there resides in lower-grade sandstone deposits.[6] Uranium miners perform *in situ* leaching by pumping liquids into the areas surrounding uranium deposits.[7] These liquids include acid or alkaline solutions to weaken the calcium or sandstone surrounding uranium ore.[8] Operators then pump the uranium up into recovery wells at the surface, where it is collected.[9] *In situ* leaching is more cost-effective than underground mining because it avoids the significant expense of excavating underground sites and often takes less time to implement.[10] Nonetheless, it uses significantly more water — as much as seven to eight gallons for every kilowatt-hour of nuclear power eventually generated.[11] Table 1 shows the top global uranium producers from 2002 to 2008, while Table 2 shows the top uranium mining companies. Canada, Kazakhstan, and Australia account for more than half of global production.

The process of uranium mining itself is very wasteful, regardless of the technique. To produce the 25 tons of uranium needed to keep a typical reactor fissioning atoms for one year, 500,000 tons of waste rock and 100,000 tons of mill tailings — toxic for hundreds of thousands of years — will be created, along with an extra 144 tons of solid waste and 1,343 m^3 of liquid waste.[14] Underground mining presents a "significant danger," since the radionuclides uranium-235, radium-226, radon, and strontium-21 accumulate in the soil and silts around uranium mines, often inhaled by miners in the form of radioactive dust.[15] Open-pit mining is prone to sudden emissions of radioactive gases and the degradation of land, as kilometer-wide craters are formed around uranium deposits, which interfere with the flow of groundwater as far as 10 km

Table 1: Global Production of Uranium, 2002–2008 (metric tons)[12]

Country	2002	2003	2004	2005	2006	2007	2008
Canada	11,604	10,457	11,597	11,628	9,862	9,476	9,000
Kazakhstan	2,800	3,300	3,719	4,357	5,279	6,637	8,521
Australia	6,854	7,572	8,982	9,516	7,593	8,611	8,430
Namibia	2,333	2,036	3,038	3,147	3,067	2,879	4,366
Russia	2,900	3,150	3,200	3,431	3,262	3,413	3,521
Niger	3,075	3,143	3,282	3,093	3,434	3,153	3,032
Uzbekistan	1,860	1,598	2,016	2,300	2,260	2,320	2,338
USA	919	779	878	1,039	1,672	1,654	1,430
Ukraine	800	800	800	800	800	846	800
China	730	750	750	750	750	712	769
South Africa	824	758	755	674	534	539	655
Brazil	270	310	300	110	190	299	330
India	230	230	230	230	177	270	271
Czech Republic	465	452	412	408	359	306	263
Romania	90	90	90	90	90	77	77
Germany	221	104	77	94	65	41	0
Pakistan	38	45	45	45	45	45	45
France	20	0	7	7	5	4	5
World	36,033	35,574	40,178	41,719	39,444	41,282	43,853
Tons of U_3O_8	42,529	41,944	47,382	49,199	46,516	48,683	51,716
Percentage of World Demand				65%	63%	64%	68%

Table 2: Top Uranium Mining Companies, 2008[13]

Company	Tons U	%
Rio Tinto	7,975	18
Cameco	6,659	15
Areva	6,318	14
Kazatomprom	5,328	12
ARMZ	3,688	8
BHP Billiton	3,344	8
Navoi	2,338	5
Uranium One	1,107	3
Paladin	917	2
GA/Heathgate	636	1
Other	5,543	13
Total	43,853	100

away.[16] All three types of uranium mines have been shown to release harmful rates of gamma radiation. At five separate mines in Australia — Nabarlek, Rum Jungle, Hunter's Hill, Rockhole, and Moline — gamma radiation levels exceeded safety standards in some cases by 50%, leading to "chronic" exposure to miners and workers.[17]

As is probably obvious to the reader by now, such mining produces a variety of negative environmental impacts. The most direct is occupational hazards. For instance, uranium miners are often exposed to excessively high levels of radon, and hundreds have died of lung cancer and thousands more had their lives shortened. According to reports by the International Commission on Radiological Protection, work-related deaths for uranium mining amount to 5,500–37,500 deaths per million workers per year, compared to 110 deaths for general manufacturing and 164 deaths for the construction industry.[18] Even more worrying is the evidence that there may be no "safe" level of exposure to the radionuclides at uranium mines. One longitudinal medical study found that low doses of radiation, spread over a number of years, are just as "dangerous" as acute exposure.[19]

A second hazard relates to the radioactive waste mines create. To supply even a fraction of the power stations the industry expects to be online worldwide in 2020 would mean generating millions of metric tons of toxic radioactive tailings every single year. These tailings contain uranium, thorium, radium, and polonium, and emit radon-222.[20] Quite simply, uranium mining results in "the unavoidable radioactive contamination of the environment by solid, liquid, and gaseous wastes."[21] A look at the history of uranium mining in 12 countries is most revealing, and troubling.

In Australia, the third-largest producer of uranium in 2008, a detailed investigation of the environmental impacts from the Rum Jungle mine found that it has discharged acidic liquid wastes directly into creeks that flow into the Finniss River and has also gradually eroded the lowlands adjacent to the creeks. Land has been contaminated with radium-226, and "accounting for the radium has been extremely poor with very little focus on radium uptake in the environment or current levels leaching from the site."[22] The Roxby Downs mine has polluted the Arabunna people's traditional land with 80 million tons of annual dumped tailings, in addition to the mine's daily extraction of 30 million liters of water from the Great Artesian Basin. The Ranger mine has seen 120 documented leaks, spills, and breaches of its tailings waste, which has seeped into waterways and contaminated the Kakuda wetlands. The Beverley mine has been fined for dumping liquid radioactive waste into groundwater.[23] The Olympic Dam mine, a vast open-pit mine, has generated windstorms carrying radioactive dust.[24] It also draws 15 million liters of water per day from the Great Artesian Basin, and has dumped five billion liters of toxic and acidic water from tailings into water sources.[25] It may thus come as no surprise that the independent Senate References and Legislation Committee, part of the Australian federal government, documented a pattern at uranium mines where "short-term considerations have been given greater weight than the potential for permanent damage to the environment."[26] In order to maximize production, environmental concerns at Australian uranium mines have been placed second to profits.

In the US, one of the countries with the longest history of uranium mining, mill tailings were discharged with impunity into water sources for most of the 1940s and 1950s. The radium leached from these tailings contaminated thousands of miles of the Colorado River system.[27] Another case occurred between 1966 and 1971, when thousands of homes and commercial buildings in the Colorado Plateau region were found to contain anomalously high concentrations of radon after having been built on uranium tailings taken from piles under the authority of the Atomic Energy Commission (AEC).[28] Wastes from uranium mines in New Mexico have polluted the water supplies of Crownpoint, Coyote Canyon, Mariano Lake, and Smith Lake, and the Diné people of the Navajo Nation living there have discovered aquifers containing more than 200 times the level of uranium considered safe by the World Health Organization (WHO). At a single Navajo reservation, more than 1,000 open mining pits still sit filled with radioactive slurry containing uranium, radium, arsenic, selenium, molybdenum, and other carcinogenic and toxic substances. Children are known to fall into such pits, and houses have been unknowingly built from actual piles of uranium tailings. The Yakama and Spokane reservations in Washington have found radioactive isotopes unique to spent fuel rods in fish caught along the Columbia River.[29] Another study found that, from 1967 until 1986, uranium mine dewatering managed to spread dissolved selenium and molybdenum into the Puerco River in Arizona such that it contaminated 65 km of land with high levels of alpha and beta radiation.[30]

To get a sense for how extremely lethal uranium mining is in the US, consider the case of the Shiprock facility in New Mexico. Of the 150 miners working at the mine, 38 have since died of radiation-induced cancer and another 95 have unusual serious respiratory ailments and cancers (meaning 89% of miners, on aggregate, displayed chronic illnesses). That facility, once closed, left 70 acres of raw untreated tailings almost as radioactive as the ore itself. Other studies have shown higher rates of miscarriages, cleft palates, and birth defects among communities living near uranium mines, to say nothing of the psychological damage and guilt miners feel for infecting their families and loved ones with radioactive particles and illnesses. One study recently argued that uranium mining creates "a health crisis of epidemic proportions" when done near communities.[31] The Jackpile mine in Laguna Pueblo, New Mexico, polluted most of the groundwater for the village of Paguate and spread "heavy contamination" throughout the entire Southwestern US. A local community center, the Jackpile Housing Project, and the tribal council headquarters were all unwittingly built with radioactive materials from the mine. Roads to the mine at Paguate were even repaired with low-grade uranium ore to cut down on asphalt costs. The miners that lived in these communities, as well as their families, also suffered highly elevated cases of lung cancer — rates six times higher than those predicted for ordinary uranium mining. Far from being an anomaly, 52 other mines spread across the canyons and mesas of New Mexico have discharged thousands of tons of tailings directly into rivers and streams.[32] As one environmentalist recently lamented, the result is that the once-pristine Southwest is now home to radioactive peach trees, plutonium-contaminated chilies, radioactive catfish in Cochiti Lake, and tritium-contaminated honeybees.[33]

In Russia, another country with a legacy of mining, the milling and processing of uranium at Streltsovsk, Krasnokamensk, and Bambakai has discharged radioactive pollutants into local water sources and seen tailings seep into water tables. Indoor radon levels within both the mines and nearby homes are "dangerously high," and the new mine at Khiagdinskii no longer bothers to monitor radiation exposure to workers and residents at all.[34]

In Kazakhstan, currently the world's second-largest producer of uranium, uranium mines have contaminated water wells and seeped millions of tons of radioactive sediment into the Koshkar-Ata Lake, which as it dries exposes residents of adjacent villages to radioactive dust.[35] Tajikistan's Leninabad region continues to suffer from high radiation levels caused by the Soviet-era uranium ore mining. Even though mining was halted in 1991, improper disposal of tailings and barely covered storage sites have resulted in radiation levels that are several times higher than internationally accepted standards. Uzbekistan and Kyrgyzstan are similarly threatened, as users of transboundary waters tainted by the chemicals in Tajik tailings, and as home to some of the 23 waste dump sites scattered across Central Asia's Ferghana Valley. With low public awareness about radiation or the harmful effects of these sites, villagers have unknowingly allowed livestock to freely graze and children to play in hazardous areas.

In Brazil, uranium mining and milling facilities have released radionuclides and toxic metals into surface waters along Poços de Caldas. One study of the environmental performance of uranium mines in Brazil found that tailing effluents and radioactive sulfates had seeped into local waterways, and that acid mine and waste rock drainage had spread radon-226, uranium-238, and other dangerous compounds into water supplies.[36]

In China, the country's largest uranium mine, No. 792, is reputed to dump untreated radioactive water directly into the Bailong River, a tributary of the Yangtze River.[37] In India, researchers from the Bhabha Atomic Research Centre in Mumbai found that underground uranium mines at Bhatin, Narwapahar, and Turamdih, along with the uranium enrichment plant at Jaduguda, have discharged mine water and mill tailings contaminated with radionuclides (such as radon) as well as residual uranium, radium, and other pollutants directly into local water supplies. The researchers noted that, since the quality of Indian uranium ore is relatively low, about 99% of the ore processed in mills emerges as waste and tailings.[38]

In South Africa, the Center for Nonproliferation Studies has documented that uranium miners inhale radon gas and radioactive ore dust well above recommended dose limits, and that uranium mines have contaminated water supplies with polluted run-off from mining dumps, seepages from tailings dams, and the discharge of untreated water. Streams around Johannesburg have been measured to contain uranium, sulfates, cyanide, and arsenic from uranium mines. Between 1968 and 1982, millions of tons of mine and mill wastes were generated at just four sites, and

30 billion gallons of improperly treated mine water were discharged into local arroyos and streams. A consequence has been contaminated livestock and abnormally high rates of cancer at some villages.[39]

In other developing countries and emerging economies, the impacts from uranium mining can be even more severe, since such governments often lack strong institutional capacity to enforce environmental regulations and statutes. In Africa, for example, the legacy of uranium mining is terrible health, water contamination, and egregious levels of pollution.[40] Uranium mining also raises serious questions about equity and indigenous people, as 70% of uranium deposits throughout the world are located on indigenous people's lands.[41]

Waste Storage

As Chapter 2 noted, the world's nuclear fleet creates about 10,000 metric tons of high-level spent nuclear fuel each year. About 85% of this waste is *not* reprocessed, and most of it is stored onsite in special facilities at nuclear power plants. Proponents of nuclear power are fond of pointing out that 1 kg of uranium can produce 50,000 kWh of electricity, whereas 1 kg of coal can only produce 3 kWh of electricity. Put another way, the energy released by 1 g of uranium-235 that undergoes fission is equal to 2.5 million times the energy released by burning 1 g of coal. What they do not tell you is that, because nothing is burned or oxidized during the fission process, nuclear plants convert almost all of their fuel to waste with little reduction in mass.

Both commercial fuel cycles are very wasteful. In the once-through cycle, used predominately by the US, Sweden, and Finland, fuel is burned in reactors and not reused, meaning that about 95% of it is wasted. In the closed-loop fuel cycle, utilized by Belgium, France, Germany, the Netherlands, Spain, and the UK, plutonium is extracted from spent fuel, recycled, and reprocessed, but 94% of the fuel is still wasted.[42]

Nuclear power plants therefore have at least five waste streams that contaminate and degrade land:

- They create spent nuclear fuel at the reactor site;
- They produce tailings at uranium mines and mills;

- They routinely release small amounts of radioactive isotopes during operation;
- They can catastrophically release large quantities of pollution during accidents; and
- They create plutonium waste.

Even reprocessing creates waste. For example, France, which reprocesses spent fuel to separate fissile material (pure waste) from usable plutonium, has contributed 1,710 m^3 of high-level waste globally — a number that is expected to jump to 3,600 m^3 by 2020.[43] Each 1,000-MW reactor, regardless of its fuel cycle, has about 15 billion curies of radioactivity, which is equivalent to the total amount of natural radiation found in all of the oceans.[44] As Figure 1 shows, it will take at least 10,000 years before high-level nuclear waste will reach levels of radiation considered safe for human exposure.

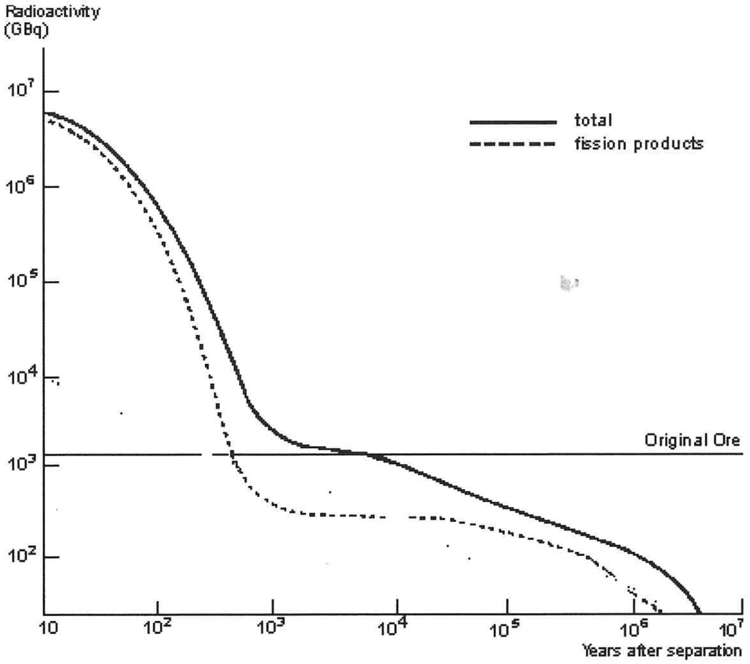

Figure 1: Decay in Radioactivity of High-Level Nuclear Waste

***Note*: The straight line shows the radioactivity of the corresponding amount of uranium ore.**

The amount of land needed to store nuclear waste can therefore become significant. In 2008, about 57,000 metric tons of uranium existed in the spent fuel inventory from US plants, as well as defense high-level waste. About 85% of this waste was placed 6 m deep in boric acid storage pools at reactor sites while the rest was loaded into 690 dry casks at 42 additional sites, bringing the total number to 131 sites in 39 states (depicted in Figure 2). The dry cask portion of the waste stream is expected to double between 2008 and 2012, and the total amount of waste will reach 119,000 tons by 2035.[45]

France, too, is running out of storage space and existing sites will likely be full by 2015. A 1991 law requiring the creation of a geologic storage facility underground was never implemented due to public opposition.[46] A South Korean underground repository for the permanent disposal of spent nuclear fuel will not be ready until 2041, but interim storage pools will likely reach maximum capacity by 2024.[47] The permanent waste repositories in Finland and Sweden have had all research conducted onsite by the companies themselves with no independent

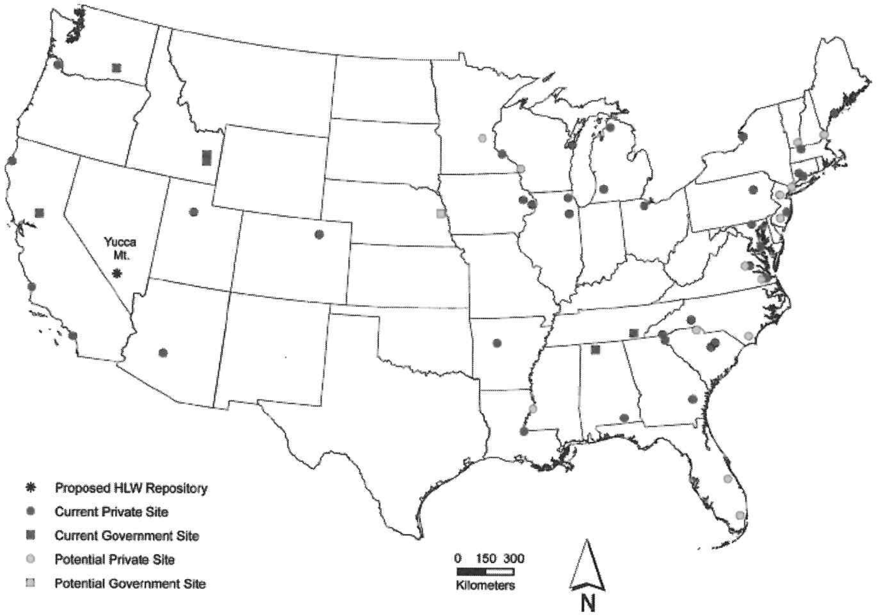

Figure 2: Current Spent Fuel Storage Installations in the United States, 2009

review; and the bedrock in both sites is believed to be less stable and full of more cracks than originally believed, with new evidence revealing that copper canisters could be corroded at the site within a century.[48]

Storage of nuclear waste faces a number of daunting challenges, articulated best by a comparative study of waste practices in the US and Japan conducted by researchers at Harvard University and the University of Tokyo.[49] The study identified four key problems with existing schemes to store nuclear waste. First, many of the repositories designed to be temporary are turning into permanent ones. Interim storage, as the name implies, is designed to store waste for a defined period of time where humans can directly monitor it. It is not a substitute for a permanent geologic repository, which must last hundreds of thousands of years. Temporary waste sites are not typically designed to handle contingencies such as earthquakes, tornadoes, and plane crashes, and can operate safely only for a short amount of time.

Second, most communities do not want to host a facility — even a temporary one — for storing nuclear waste. They are concerned about their community becoming a *de facto* site for waste for thousands of years, the health and environmental consequences of an accident, and lower property values. As the authors of the study noted, "local opposition has prevented many past proposed interim storage facilities and other nuclear facilities from being successfully established," and "such objections pose the largest obstacle to building adequate storage capacity for spent nuclear fuel." A recent 2010 assessment confirmed this conclusion by noting that "almost six decades after commercial nuclear energy was first generated, not a single government has succeeded in opening a repository for civilian high-level nuclear waste."[50]

Third, as touched upon in Chapter 3, existing waste sites are prone to accidents, fires, and safety risks. In 1996, as one example, after fuel had been loaded into a dry storage cask at Point Beach, Wisconsin, hydrogen inside the cask ignited as it was being welded and blew the three-ton lid off. The Nuclear Regulatory Commission (NRC) had to take repeated actions throughout the 1990s to address defective welds on dry casks that led to cracks and quality assurance problems; helium had leaked into some casks, increasing temperatures and causing accelerated fuel corrosion.

Fourth, as mentioned in Chapter 4, storing waste is expensive. The total undiscounted lifecycle cost for 40 years of dry cask storage for 1,000 tons of spent fuel, the amount generated by a typical reactor, is US$120–$250 million.[51] When extended to include the entire period that waste must be stored (at least 25,000 years), the costs associated with the existing global reactor fleet jump to a breathtaking US$11.3 trillion.

Even if it is perfected, future Generation IV technology will not solve the problem of radioactive waste. The radiotoxicity for the most hazardous forms of spent nuclear fuel will last at least 100,000 years. Partitioning and transmutation are considered theoretical ways of reducing the waste; but even if technically mastered through some sort of breakthrough, their potential is severely limited. Nuclear engineers at the CEA (*Commissariat à l'énergie atomique*) in France have warned that radiotoxicity can only be reduced by a factor of 10 if all plutonium is recycled, and by a factor of 100 if all minor actinides are burned.[52] This means that, at a minimum, spent fuel will remain dangerously radioactive for at least 1,000 to 10,000 years (or ten centuries), presuming a best-case scenario. Also, the technologies needed to attain this level of waste reduction — either fast reactors or accelerator-driven systems — will require technological breakthroughs in separating actinides, reprocessing advanced fuels, and coupling transmutation technologies to existing reactors. As one study concluded, no single country has successfully deployed partitioning and transmutation technologies, and no attempt has been made to pursue serious regional or international cooperation on these efforts.[53]

The nuclear waste issue, although often ignored in industry press releases and sponsored reports, is the proverbial elephant in the room stopping a nuclear renaissance. As one study concluded:

> The management and disposal of irradiated fuel from nuclear power reactors is an issue that burdens all nations that have nuclear power programs. None has implemented a permanent solution to the problem of disposing of high-level nuclear waste, and many are wrestling with solutions to the short-term problem of where to put the spent, or irradiated, fuel as their cooling pools fill.[54]

Until the issue of waste storage is resolved, the future of nuclear power is highly uncertain.

Water Use and Contamination

The nuclear industry's vast appetite for water has serious consequences, both for human consumption and for the environment. Apart from the water-related impacts of uranium mining, discussed above, three other stages of the nuclear fuel cycle — plant construction, plant operation, and nuclear waste storage — consume, withdraw, and contaminate water supplies. As a result of this monumental need for water, most nuclear facilities cannot operate during droughts and in some cases can actually cause water shortages. For instance, in Germany eight nuclear reactors had to be shut down simultaneously on hot summer days in 2009 for various reasons, many related to the overheating of equipment or of rivers. Droughts and extended periods of high temperature can therefore cripple nuclear power generation, and it is often during these times when electricity demand is highest because of air-conditioning and refrigeration loads and diminished hydroelectric capacity. This disconnect has been poignantly felt in European heat waves, such as in 2003 when France had to cut back 6 GW of capacity and several German reactors operated at 40% capacity.[55] A more recent episode occurred in 2007 in the Southwest of the United States, where nuclear plants were shut down due to lack of water.[56]

Plant Construction

The construction of nuclear power plants can have significant water-related needs and impacts. Some of the largest power plant components, such as turbines, boilers, and reactor cooling towers, have special shipping requirements. In Georgia, US, billions of gallons of water had to be released from Lake Lanier to raise water levels on the lower Chattahoochee River so that replacement steam generators could be shipped to the Farley nuclear power plant near Dothan, Alabama.[57] The Army Corps of Engineers even had to design and maintain a shipping channel from Savannah, Georgia, to Augusta, Georgia, so that power plant equipment could be moved on the river.[58] Since maintenance of the deep-water channel ended in 1979 and Lake Lanier is currently running low on water, power plant operators have warned that rivers in some parts of the South would have to be dredged to allow reactor upgrades and construction of new large power plants to occur.

Plant Operation

Nuclear reactors require massive supplies of water to cool reactor cores and spent nuclear fuel rods, and they use the most water compared to all other electricity-generating facilities, including conventional coal and natural gas facilities.[59] Because much of the water used by nuclear plants is turned to steam, substantial amounts are lost to the local water cycle entirely.

Almost all nuclear power plants employ one of two types of cooling cycles in their generation of electricity. Once-through cooling systems withdraw water from a source, circulate it, and return it to the surface body. As their name implies, once-through cooling systems (or "open-loop" systems) only use water once, as it passes through a condenser to absorb heat. Plant operators commonly add chlorine intermittently to control microbes that corrode pipes and materials. Operators may also add several toxic and carcinogenic chemicals such as hexavalent chromium and hydrazine. After it passes through the plant, heated and treated water is then discharged downstream from its point of intake to a receiving body of water. Since such cooling systems release heated water back to the source, they can contribute to evaporative loss by raising the temperature of receiving water bodies.[60]

Recirculating (or "closed-loop") systems withdraw water and then recycle it within the power system rather than discharge it. Recirculating systems, by recycling water, withdraw much less of it but tend to consume more. Since it is being reused, the water requires more chemical treatment to eliminate naturally occurring salts and solids that accumulate as water evaporates. To maintain plant performance, water is frequently discharged from the system at regular intervals into a receiving body of water or collection pond.[61] Plant operators call this water "cooling tower blowdown." Once the plants release blowdown, operators treat fresh water with chlorine and biocides before it enters the cooling cycle. Closed-loop systems rely on greater amounts of water for cleaning and therefore return little water to the original source.[62]

In aggregate, nuclear power plants are the most water-intensive of all types of power plants, as confirmed by Table 3 and Figure 3. One nuclear plant in Georgia withdraws an average of 57 million gallons of water every day from the Altamaha River, and it actually consumes 33 million gallons per day from the local supply (primarily as lost water vapor), which would be enough to service more than 196,000 Georgia homes.[63] The Shearon Harris nuclear reactor, operated by Progress Energy in New Hill, North Carolina (near Raleigh), sucks up 33 million gallons of water a day (and loses 17 million gallons per day due to evaporation). Duke Energy's McGuire plant on Lake Norman, North Carolina, draws in more than 2 billion gallons of water per day.[64] Southern Company's Joseph M. Farley nuclear plant in Dothan, Alabama, consumes about 46 million gallons of water per day (primarily as evaporative loss).[65] In the arid West, where water is scarce, the challenge of cooling nuclear plants is even more daunting. The Palo Verde plant in Arizona is capable of processing 90 million gallons of water for its cooling needs at the plant site each day.[66] Plant operators must purchase treated effluent from seven cities in the Phoenix metropolitan area and had to construct a 35-mile pipeline to carry water from a treatment facility to the plant, which received 22.5 billion gallons of treated effluent in 2000.[67]

Table 3: Water Intensity of Thermoelectric Power Generators[68]

Fuel	Cooling Process	Withdrawal (gal/kWh)	Consumption (gal/kWh)
Fossil/biomass/waste	Once-through cooling	20–50	~0.30
Fossil/biomass/waste	Closed-loop tower	0.30–0.60	0.30–0.48
Fossil/biomass/waste	Closed-loop pond	0.50–0.60	~0.48
Nuclear	Once-through cooling	25.00–60.00	~0.40
Nuclear	Closed-loop tower	0.50–1.10	0.40–0.72
Nuclear	Closed-loop pond	0.80–1.10	~0.72
Geothermal steam	Closed-loop tower	~2.00	~1.40
Solar trough	Closed-loop tower	0.76–0.92	0.76–0.92
Solar tower	Closed-loop tower	~0.75	~0.75
Natural gas combined cycle	Once-through cooling	7.50–20.00	0.10
Natural gas combined cycle	Closed-loop tower	~0.23	~0.18
Coal gasification (IGCC)	Closed-loop tower	~0.25	~0.20

Figure 3: Water Withdrawn and Consumed by Nuclear and Renewable Power Plants (gallons/MWh)

At the point of intake, thermoelectric plants bring water into their cooling cycles through specially designed structures. To minimize the entry of debris, water is often drawn through screens.[69] Seals, sea lions, endangered manatees, American crocodiles, sea turtles, fish, larvae, shellfish, and other riparian or marine organisms are frequently killed as they are trapped against the screens in a process known as *impingement*.[70] Organisms small enough to pass through the screens can be swept up in the water flow, where they are subject to mechanical, thermal, and toxic stress in a process known as *entrainment*.[71] Billions of smaller marine organisms, essential to the food web, are sucked into cooling systems and destroyed.[72] Smaller fish, fish larvae, spawn, and a tremendous volume of other marine organisms are frequently pulverized by reactor condenser systems.[73] One study estimated that more than 90% are scalded and discharged back into the water as lifeless sediment that clouds the water around the discharge area, blocking light from the ocean or river floor, which further kills plant and animal life by curtailing the production of oxygen.[74] During periods of low water levels, nuclear plants must extend intake pipes further into rivers and lakes; but as they approach the bottom of the water source, they often suck up sediment, fish, and other debris.[75] Impingement and entrainment consequently account for substantial losses of fish and exact severe environmental consequences.

For example, federal environmental studies of entrainment during the 1980s at five power plants on the Hudson River in New York — Indian Point, Bowline, Roseton, Lovett, and Danskammer — estimated grave year-class reductions in fish populations (the percent of fish killed within a given age class).[76] Authorities noted that power plants were responsible for age reductions as high as 79% for some species; and an updated analysis of entrainment at three of these plants estimated year-class reductions of 20% for striped bass, 25% for bay anchovy, and 43% for Atlantic tomcod.[77] Other researchers evaluated entrainment and impingement impacts at nine facilities along a 500-mile stretch of the Ohio River.[78] The researchers estimated that approximately 11.6 million fish were killed annually through impingement and 24.5 million fish from entrainment. The study calculated economic losses at about US$8.1 million per year.

The US Environmental Protection Agency (EPA) calculated impingement losses from power plants operating near the Delaware Estuary Watershed at more than 9.6 million age 1 equivalents of fish every year, or a loss of 332,000 pounds of fishery yield.[79] The EPA figured that entrainment-related losses were even larger at 616 million fish every year, or a loss of 16 million pounds of catch.[80] Put into monetary value, the recreational fishing losses from impingement and entrainment were estimated to be about US$5 million per year.[81]

Scientists also estimated that the cooling intake systems at the Crystal River Power Plant in Florida, a joint nuclear and coal facility, kill about 23 tons of fish and shellfish every year. As a result, top predators such as gulf flounder and stingray have either disappeared or changed their feeding patterns.[82] In other parts of Florida, the economic losses induced from four power plants — Big Bend, P.L. Bartow, F.J. Gannon, and Hookers Point — were estimated to be as high as US$18.1 million.[83] Similarly, in Southern California, marine biologists and ecologists found that the San Onofre nuclear plant impinged nearly 3.5 million fish in 2003.[84]

A less noticed, but still important, impact is that water intake and discharge often alter natural patterns of water levels and flows. Such flows, part of the hydrological cycle, have a natural rhythm that differs daily, weekly, and seasonally.[85] Plants and animals have adapted to these fluctuations, and such variability is a key component of ecosystem health.[86] However, withdrawals and discharges of water at nuclear plants alter this natural variability by withdrawing water during drought conditions or discharging it at different times of the year, with potentially serious (albeit not well-understood) consequences to ecosystem and habitat health.

Nuclear power plants also alter the temperatures of lakes, rivers, and streams.[87] The data on temperature at intake and discharge points collected by the US Energy Information Administration demonstrated that more than 150 once-through units had summer or winter discharges with water temperature deltas (large temperature differences between intake and discharge waters) greater than 25°F.[88] In some cases, the thermal pollution from centralized power plants can induce eutrophication — a process whereby the warmer temperature alters the chemical composition of the water, resulting in a rapid increase of nutrients such as nitrogen and phosphorus.[89] Rather than improving the ecosystem, such alterations usually promote excessive plant growth and decay, favoring certain weedy species over others and severely reducing water quality.[90] In riparian environments, the enhanced growth of choking vegetation can collapse entire ecosystems.[91] This form of thermal pollution has been known to decrease the aesthetic and recreational value of rivers, lakes, and estuaries, and complicate drinking water treatment.[92]

For example, a team of Indian scientists studying heated water discharges from the Madras Atomic Power Station located at Kalpakkam in India noted that substantial additions of sodium hypochlorite to seawater decreased viable counts of bacteria and plankton by 50% around the reactor site.[93] They also discovered that the plume of thermal pollution was greater at the power plant's coastal location because the tidal movements altered its direction and enhanced its magnitude. A team of Korean marine biologists and scientists utilized satellite thermal infrared images of the Younggwang nuclear power plant on the west coast of Korea and found that the plant's thermal pollution plume extended more than 100 km southward.[94] The researchers documented that the power plant directly decreased the dissolved oxygen content of the water, fragmented ecosystem habitats, and reduced fish populations.

Lastly, and most seriously, nuclear power plants create wastewater contaminated with radioactive tritium and other toxic substances that can leak into nearby groundwater sources. In December 2005, for example, Exelon Corporation reported to authorities that its Braidwood reactor in Illinois had, since 1996, released millions of gallons of tritium-contaminated wastewater into the local watershed, prompting the company to distribute bottled water to surrounding communities while local drinking water wells were tested for the pollutant.[95] When caught for its mistake, rather than admit responsibility, Exelon ran a sleek advertising campaign to convince citizens of Illinois that the tritium exposure was "natural" and "can be found in all water sources."[96] The incident led to a lawsuit by the Illinois Attorney General and the State Attorney for Will County, who claimed that "Exelon was well aware that tritium increases the risk of cancer, miscarriages, and birth defects, and yet they made a conscious decision to not notify the public of its risk of exposure."[97]

Similarly, in New York, a faulty drain system at Entergy's Indian Point Nuclear Plant on the Hudson River caused thousands of gallons of radioactive waste to be leaked into underground lakes.[98] The NRC accused Entergy of not properly maintaining two spent fuel pools that leaked tritium and strontium-90, cancer-causing radioactive isotopes, into underground watersheds, with as much as 50 gallons of radioactive waste seeping into water sources per day.[99]

Such examples are not isolated and have not been chosen selectively. As of February 2010, 27 of the 104 reactors operating in the US have been documented leaking radioactive tritium into watersheds.[100] In the UK, the Sellafield reprocessing facility has been accused of contaminating parts of the Irish Sea with radioactive pollutants[101]; and from 1967 to 1969, France dumped more than 12,000 m^3 of high-level waste from the reprocessing plant at Marcoule directly into the ocean.[102]

Nuclear Waste Storage

At reactor sites, even when not generating electricity, nuclear plants must use water continuously — often about 10% of the water needed for normal operation — to cool spent nuclear fuel rods. After the complete shutdown of a nuclear reactor, it continues to produce residual heat that takes days to decay significantly. Nuclear plants need water to remove the decay heat produced by the reactor core, and also to cool the equipment and buildings used to provide the core's heat removal. Service water must lubricate oil coolers for the main turbine and chillers for air-conditioning, in essence cooling the equipment that in turn cools the reactor. These service water needs can be quite high: 52,000 gallons of water are needed per minute in the summer to merely service the Hope Creek plant in New Jersey; 30,000 gallons per minute for the Millstone Unit 2 in Connecticut; and 13,500 gallons per minute for the Pilgrim plant in Massachusetts.[103]

Climate Change

From a climate change standpoint, nuclear power is no improvement over renewable energy resources, despite recent claims by the Nuclear Energy Institute that nuclear power is "clean-air energy."[104] Reprocessing and enriching uranium requires a substantial amount of electricity, often generated from fossil fuel-fired power plants; and uranium milling, uranium mining, uranium leaching, plant construction, and decommissioning all produce substantial amounts of greenhouse gases. As Chapter 2 explained, in order to enrich natural uranium, it is converted to uranium hexafluoride (UF_6) and then diffused through permeable barriers. In 2002, the Paducah uranium enrichment plant in Kentucky released 197.3 metric tons of freon, a greenhouse gas far more potent than carbon dioxide, through leaking pipes and other equipment.[105] Data collected from one uranium enrichment company revealed that it takes a 100-MW power plant running for 550 hours to produce the amount of enriched uranium needed to fuel a 1,000-MW reactor, of the most efficient design currently available, for just one year. According to the *Washington Post*, two of the US' most polluting coal plants, in Ohio and Indiana, produce electricity primarily for uranium enrichment.[106]

When one takes into account the carbon-equivalent emissions associated with the entire nuclear lifecycle, nuclear plants contribute significantly to climate change and will contribute even more as stockpiles of high-grade uranium are depleted. An assessment of 103 lifecycle studies of greenhouse gas-equivalent emissions for nuclear power plants found that the average CO_2 emission over the typical lifetime of a plant was about 66 g for every kilowatt-hour, or the equivalent of some 183 million metric tons of CO_2, in 2005.[107] The specific numbers from this study are presented in Table 4. If the global nuclear industry were taxed at a rate of US$24 per ton for the carbon-equivalent emissions associated with its lifecycle, the cost of nuclear power would increase by about US$4.4 billion per year.[108] A second, follow-up, peer-reviewed study found that the best-performing reactors had associated lifecycle emissions of 8–58 gCO_2/kWh, but that other reactors emitted more than 110 gCO_2/kWh.[109] A secondary impact is that, by producing large amounts of heat, nuclear power plants contribute directly to global warming by increasing the temperature of water bodies and micro-climates around each facility.[110]

The carbon-equivalent emissions of the nuclear lifecycle will only get worse (not better) because, over time, reprocessed fuel is depleted, necessitating a shift to fresh ore, and reactors must utilize lower-quality ores as higher-quality ones are depleted. Table 5 illustrates this clearly: with lower-grade uranium ore, the emissions profile from nuclear power plants almost doubles from 66 gCO_2e/kWh to over 112 gCO_2e/kWh. The Oxford Research Group projected that, because of this inevitable shift to lower-quality uranium ore, if the percentage of world nuclear capacity remains what it is today, by 2050 nuclear power would generate as much carbon dioxide per kilowatt-hour as comparable natural gas-fired power stations.[111] This bears repeating: at current levels of electricity generation, by 2050 nuclear plants will be producing as much greenhouse gas as some fossil fuel plants. With very low ore grades in use, some nuclear power plants currently emit the equivalent of 337 gCO_2/kWh, making them *already* close to the equivalent emissions from gas-fired power plants.[112]

For these reasons, an integrated sustainability analysis conducted in Australia found that nuclear plants are poor substitutes for other less greenhouse gas-intensive generators. The analysis demonstrated that wind turbines have one-third the carbon-equivalent emissions of nuclear power over their lifecycle; and hydroelectric turbines, one-fourth the carbon-equivalent emissions.[113] A separate study from *Nature* found that nuclear power plants emit two times more equivalent greenhouse gases than solar

Table 4: Lifecycle Greenhouse Gas Emission Estimates for Nuclear Power Plants

Location	Assumptions	Fuel Cycle	Individual Estimate (gCO_2e/ kWh)	Total Estimate (gCO_2e/ kWh)
Canada	CANDU heavy water reactor, 40-year lifecycle, high-quality natural uranium ore, enriched and charged with fossil fuel generators	Front end	0.68	15.41
		Construction	2.22	
		Operation	11.9	
		Back end	—	
		Decommissioning	0.61	
United Kingdom	35-year lifecycle, average load factor of 85%, uranium ore grade of 0.15%	Front end	56	84–122
		Construction	11.5	
		Operation	—	
		Back end	—	
		Decommissioning	16.5–54.5	
Switzerland	100-year lifecycle, Gösgen pressurized water reactor and Liebstadt boiling water reactor	Front end	3.5–10.2	5–12
		Construction	1.1–1.3	
		Operation	—	
		Back end	0.4–0.5	
		Decommissioning	—	
Switzerland, France, and Germany	40-year lifecycle, existing boiling water reactors and pressurized water reactors using UCTE nuclear fuel chains	Front end	6–12	7.6–14.3
		Construction	1.0–1.3	
		Operation	—	
		Back end	0.6 and 1.0	
		Decommissioning	—	
China	20-year lifecycle, once-through nuclear cycle using centrifuge technology	Front end	7.4–77.4	9–80
		Construction	1.0–1.4	
		Operation	—	
		Back end	0.6–1.2	
		Decommissioning	—	
United Kingdom	Analysis of emissions for construction of Sizewell B pressurized water reactor	Front end	—	11.5
		Construction	11.5	
		Operation	—	
		Back end	—	
		Decommissioning	—	

(*Continued*)

Table 4: (*Continued*)

Location	Assumptions	Fuel Cycle	Individual Estimate (gCO_2e/kWh)	Total Estimate (gCO_2e/kWh)
Germany	Analysis of emissions for a typical 1,250-MW German reactor	Front end	20	64
		Construction	11	
		Operation	—	
		Back end	33	
		Decommissioning	—	
United States, Europe, and Japan	40-year lifecycle, 85% capacity factor, mix of diffusion and centrifuge enrichment	Front end	12–21.7	16–55
		Construction	0.5–17.7	
		Operation	0.1–10.8	
		Back end	2.1–3.5	
		Decommissioning	1.3	
Japan	Analysis of base-case emissions for operating Japanese nuclear reactors	Front end	17	24.2
		Construction	2.8	
		Operation	3.2	
		Back end	0.8	
		Decommissioning	0.4	
Sweden and Japan	40-year lifecycle for Swedish Forsmark 3 boiling water reactor and 30-year lifecycle for Japanese boiling water reactor, advanced BWR, and fast breeder reactor	Front end	1.19–8.52	2.82–22
		Construction	0.27–4.83	
		Operation	—	
		Back end	1.19–8.52	
		Decommissioning	0.17	
Australia	Analysis of emissions for existing Australian light water reactors with uranium ore of 0.15% grade	Front end	4.5–58.5	10–130
		Construction	1.1–13.5	
		Operation	2.6–34.5	
		Back end	1.7–22.2	
		Decommissioning	0.1–1.3	
Australia	Analysis of emissions for existing Australian heavy water reactors with uranium ore of 0.15% grade	Front end	4.5–54	10–120
		Construction	1.1–12.5	
		Operation	2.6–31.8	
		Back end	1.7–20.5	
		Decommissioning	0.1–1.2	

(*Continued*)

Table 4: (*Continued*)

Location	Assumptions	Fuel Cycle	Individual Estimate (gCO_2e/kWh)	Total Estimate (gCO_2e/kWh)
Egypt	30-year lifecycle for a pressurized water reactor operating at 75% capacity	Front end	23.5	26.4
		Construction	2.0	
		Operation	0.4	
		Back end	0.5	
		Decommissioning	—	
World	Analysis of emissions for existing nuclear reactors	Front end	36	88–134
		Construction	12–35	
		Operation	—	
		Back end	17	
		Decommissioning	23–46	
World	Analysis of emissions for existing nuclear reactors	Front end	39	92–141
		Construction	13–36	
		Operation	—	
		Back end	17	
		Decommissioning	23–49	
World	Analysis of emissions for existing nuclear reactors assuming 0.06% uranium ore, 70% centrifuge and 30% diffusion enrichment, and inclusion of interim and permanent storage and mine land reclamation	Front end	16.26–28.27	112.47–165.72
		Construction	16.8–23.2	
		Operation	24.4	
		Back end	15.51–40.75	
		Decommissioning	39.5–49.1	
Japan	60-year lifecycle, light water reactor reference case, emissions from 1960 to 2000	Front end	5.9–118	10–200
		Construction	1.3–26	
		Operation	2.0–40	
		Back end	0.7–14	
		Decommissioning	0.1–2	

(*Continued*)

Table 4: (*Continued*)

Location	Assumptions	Fuel Cycle	Individual Estimate (gCO_2e/kWh)	Total Estimate (gCO_2e/kWh)
World	Analysis of emissions for construction and decommissioning of existing reactors	Front end	—	3
		Construction	~2	
		Operation	—	
		Back end	—	
		Decommissioning	~1	
United States	40-year lifecycle of 1,000-MW pressurized water reactor operating at 75% capacity factor	Front end	9.5	15
		Construction	1.9	
		Operation	2.2	
		Back end	1.4	
		Decommissioning	0.01	

energy and about seven times more than wind energy.[114] The author's own calculations, using exclusively peer-reviewed scientific literature, suggest that nuclear power plants are worse than every type of renewable energy generator (see Table 6). Further details on the climate benefits of renewable energy and energy efficiency are offered in Chapter 7.

Medical and Health Risks

As a final, health-related disadvantage, normally functioning nuclear reactors are still correlated with higher risks of cancer and unexplained deaths. Put simply, a proliferation of nuclear power plants inevitably means more nuclear workers and more residents exposed to low-level ionizing radiation, with increased health risks attendant to this exposure.[115]

Reactors create more than 100 dangerously radioactive chemicals, including strontium-90, iodine-131, and cesium-137 — the same toxins found in the fallout from nuclear weapons. Some of these contaminants, such as strontium-90, remain radioactive for 600 years; concentrate in the food chain; are tasteless, odorless, and invisible; and have been found in the teeth of babies living near nuclear facilities. Strontium-90 mimics milk as it enters the body and concentrates in bones and lactating breasts to cause bone cancer, leukemia, and breast cancer. Babies and children are 10–20 times more susceptible to its carcinogenic effects than adults.[116] Plutonium is so dangerous that one pound evenly distributed could cause cancer in every person on earth; also, it remains radioactive for 500,000 years.[117] It enters through the lungs and mimics iron in the body, migrating to bones (where it can induce bone cancer or leukemia) and to the liver

Table 5: Emissions for the Nuclear Fuel Cycle Relying on Lower-Grade Uranium Ore

Nuclear Process	Estimate (gCO_2e/kWh)
Front End (total)	16.26–28.27
Uranium mining and milling (soft and hard ores) (uranium grade of 0.06%)	10.43
Refining of yellowcake and conversion to UF_6	2.42–7.49
Uranium enrichment (70% UC, 30% diff)	2.83–8.03
Fuel fabrication	0.58–2.32
Construction (total)	16.8–23.2
Reactor Operation and Maintenance (total)	24.4
Back End (total)	15.51–40.75
Depleted uranium reconversion	2.10–6.24
Packaging of depleted uranium	0.12–0.37
Packaging of enrichment waste	0.16–0.46
Packaging of operational waste	1.93–3.91
Packaging of decommissioned waste	2.25–3.11
Sequestration of depleted uranium	0.12–0.35
Sequestration of enrichment waste	0.16–0.44
Sequestration of operational waste	1.84–3.73
Sequestration of decommissioned waste	1.98–2.74
Interim storage at reactor	0.58–2.32
Spent fuel conditioning for final disposal	0.35–1.40
Construction, storage, and closure of permanent geologic repository	3.92–15.68
Decommissioning (total)	39.5–49.1
Decommissioning and dismantling	25.2–34.8
Land reclamation of uranium mine (uranium grade of 0.06%)	14.3
Total	**112.47–165.72**

Table 6: Lifecycle Greenhouse Gas Emissions for Renewable, Fossil-Fueled, and Nuclear Sources of Electricity Supply

Technology	Capacity/Configuration/Fuel	Estimate (gCO_2e/kWh)
Wind	2.5 MW, offshore	9
Hydroelectric	3.1 MW, reservoir	10
Wind	1.5 MW, onshore	10
Biogas	Anaerobic digestion	11
Hydroelectric	300 kW, run-of-river	13
Solar thermal	80 MW, parabolic trough	13
Biomass	Forest wood co-combustion with hard coal	14
Biomass	Forest wood steam turbine	22
Biomass	Short rotation forestry co-combustion with hard coal	23
Biomass	Forest wood reciprocating engine	27
Biomass	Waste wood steam turbine	31
Solar photovoltaic	Polycrystalline silicon	32
Biomass	Short rotation forestry steam turbine	35
Geothermal	80 MW, hot dry rock	38
Biomass	Short rotation forestry reciprocating engine	41
Nuclear	Various reactor types	66
Natural gas	Various combined cycle turbines	443
Fuel cell	Hydrogen from gas reforming	664
Diesel	Various generator and turbine types	778
Heavy oil	Various generator and turbine types	778
Coal	Various generator types with scrubbing	960
Coal	Various generator types without scrubbing	1,050

(where it can cause primary liver cancer). It crosses the placenta into the embryo and, like the drug thalidomide, causes gross birth deformities; and it also has a "predilection for the testicles, where it induces genetic mutations in the sperm of humans and other animals that are passed on from generation to generation."[118]

Specific medical and epidemiological studies about nuclear power, radiation, and health are frightening, to say the least. One medical study found that those living within 10 km of the La Hague nuclear reprocessing plant in northwest France had a sevenfold increase in risk to the incidence of childhood leukemia.[119] A similar study found twice as much plutonium in the teeth of children living near the Sellafield nuclear reprocessing plant in the UK than in those further away.[120] Even the accident at Three Mile Island (TMI) is not as benign as it originally appeared. One comprehensive study divided the 10-mile area around TMI into 69 study tracts, and then assigned radiation dose estimates and correlated them with incidences of leukemia, lung cancer, and all other types of cancer. The study found that residents living around TMI had abnormally high rates for all three.[121]

One of the most comprehensive studies to date was conducted by the German Childhood Cancer Registry at the University of Mainz, known as the "Epidemiological Study on Childhood Cancer in the Vicinity of Nuclear Power Plants" (or *Epidemiologische Studie zu Kinderkrebs in der Umgebung von Kernkraftwerken* in German, abbreviated as "KiKK").[122] Researchers there looked at childhood cancers and leukemia in the areas around the country's 16 commercial nuclear power plants, and found a "strong" relationship between rates of cancer and proximity to nuclear facilities, especially for those living within 5 km of a plant. During the study period 1980–2003, children less than five years old living within 5 km of a nuclear power plant were more than twice as likely to develop leukemia compared to children living greater than 5 km away.

The depressing news is that the researchers presented many reasons why their findings are conservative, and underplayed the medical risks from nuclear power. They based their radiation risk model on data from the Japanese victims of Hiroshima and Nagasaki, but these survivors were exposed to a single flash of high-energy gamma rays from the atomic bombs. Most were also full-grown adults. Their model thus focused on external sources of radiation and did not take radioactive fallout into account. By contrast, Germans living close to nuclear power plants are chronically exposed over long periods of time, inhale or ingest radioisotopes such as tritium and carbon-14, and encompass a population of children and fetuses, making them quite unlike the Japanese sample. These nuclear power plants also expose their populations to alpha and beta emissions, in addition to gamma rays.

Another reason such estimates may be conservative is that new medical evidence firmly suggests that there may be no such thing as "safe" exposure to radiation. One massive study of 15 countries that monitored

407,391 workers for external radiation exposure, with a total follow-up of 5.2 million person-years, found that even low doses could trigger high rates of cancer.[123] Put another way, there is no safe threshold at which the human body can tolerate the unnatural levels of radiation produced by nuclear reactors and their components.

One can actually draw from existing studies to loosely quantify the health risk per nuclear reactor. Evidence from the US, home to 104 operating nuclear reactors at 65 sites, has documented elevated rates of leukemia and brain cancers at nuclear power plants. Joseph Mangano and his colleagues from the Radiation and Public Health Project estimated that roughly 18,000 fewer infant deaths and 6,000 fewer childhood cancers would occur over a period of 20 years if all reactors in the US were closed — in other words, each nuclear plant is associated with 175 infant deaths and 58 childhood cancers.[124] Applied globally, the world's existing 432 reactors likely cause 75,600 infant deaths (26 times the 2,900 who died in the terrorist attacks of September 11, 2001) and 25,056 childhood cancers every 20 years.

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6

Political and Social Concerns: "Broken Plowshare"

At the peak of the nuclear era, the US federal government initiated Project Plowshare, a program using nuclear weapons for "peaceful nuclear explosions." The Project was named directly from the Bible itself, specifically Micah 4:3, which states that God will beat swords into plowshares, and spears into pruning hooks, so that no country could lift up weapons against another. By 1961, the first detonation of the program occurred with Project Gnome, which exploded a 10-kiloton device in a salt dome to study isotopes near Carlsbad, New Mexico, followed by 26 other blasts over 11 years costing taxpayers more than US$770 million.

Proposed uses included building sea-level canals into deserts; widening the Panama Canal; constructing a new shipping lane through Nicaragua named the Pan-Atomic Canal; cutting pathways through mountains for highways; connecting inland river systems; creating underground aquifers in Arizona; and even exploding five nuclear weapons to produce a harbor in Cape Thompson, Alaska, along with a channel from the harbor to the ocean (aptly termed Project Chariot). Project Carryall, proposed by the Atomic Energy Commission (AEC) in 1963, would have detonated 22 nuclear weapons to excavate a massive road through the Bristol Mountains in the Mojave Desert so that the California Division of Highways could have an alternate route to Interstate 40 and the Santa Fe Railway could be extended.[1]