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The Immortal Waste

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Since December 1942—when Enrico Fermi successfully initiated the first nuclear fission reaction (Table 7.1)—millions of tons of nuclear waste have been accumulated as a result of a global race for power generation and weapon production. Today, in thirty nations 426 nuclear power reactors generate one sixth of the world's electricity production. Ninety-seven power reactors are under construction. A typical 1000 MW power reactor generates a large amount of nuclear waste. However, the significant part of the nuclear waste generated world wide is contributed by the nuclear weapons production. The International Atomic Agency (IAEA) has classified nuclear waste into three categories: high, intermediate and low level nuclear waste. (Table 7.2). The classification is based on waste's source, temperature and half-life.

For the last fifty years scientists have proposed various methods and techniques (Tables 7.3–7.4) for the permanent storage of nuclear waste but various governments around the world have not given serious consideration to this problem. As a result of this neglect, 80,000 tons of irradiated fuel and hundreds of thousands of tons of radiated waste are sitting in temporary storage sites.

Unlike chemical waste, whose toxicity can be neutralized or reduced by various techniques in order to minimize the adverse effects on environment and humans, the nuclear waste is radioactive (Table 7.5) and the potency of radioactivity can only be eliminated by natural decay. Depending on the type of element, it can take hundreds and thousands or even millions of years (Tables 7.6–7.8) for material decay to occur.

Accidental or intentional released radiation can rapidly spread through air and water to contaminate the environment. Radioactive waste from Soviet and U.S. weapons facilities has spread thousands of kilometers from the source contaminating the environment and people.

According to a 1991 study commissioned by International Physicians of Nuclear War "the fallout from the atmospheric atomic bomb testing has spread around the globe and will eventually cause an estimated 2.4 million cancer deaths." The accident at Chernobyl released 50 million curies into the environment, whereas the bombing of Hiroshima and Nagasaki released an estimated 1 million curies. The radiation released from Chernobyl will be responsible for an estimated 14,000 to 475,000 cancer deaths.

Nuclear energy provides over 17 percent of the world's electricity and displaces approximately 6 million barrels of oil per day. Today 426 nuclear power plants in 30 countries generate 318,271 MW. By 2000, in 32 countries 511 nuclear plants are estimated to generate 406,226 MW. In the U.S. 110 nuclear plants provide 19% of electricity. By 2000 more than 20% of electricity will be provided by 119 nuclear power plants. At first look the nuclear energy appears to be clean (i.e., it does not contribute to atmospheric emissions, but it generates the immortal nuclear waste, which possesses the greatest threat to the environment and people).

At present there is no permanent depository for high level nuclear wastes in the world. Yet there are about 426 nuclear power plants operating worldwide. Each nuclear

Table 7.1
Nuclear Energy: Chronology of Research and Development

1905	Albert Einstein developed the theory of the relationship between mass and energy. $E = mc^2$ i.e., energy is equal to the mass times the square of the speed of light.
1932	Preliminary work done by Frederic and Joliot-Curie led to the discovery of the neutron by James Chadwick of England.
1934	Enrico Fermi carried out a series of experiments in Rome that showed neutrons could cause the fission of many kinds of elements including uranium atoms.
1938	German scientists Otto Hahn and Fritz Strassman bombarded uranium with neutrons from a radium–beryllium source, and discovered a radioactive barium isotope among residual material. This indicated a new type of reaction–*fission*–took place. Some mass of uranium was converted to energy, thereby verifying Einstein's theory.
Dec. 2, 1941	A group of scientists led by Fermi initiated the first self-sustaining nuclear chain reaction in a laboratory at the University of Chicago.
July 16, 1945	The first atomic bomb was tested at Alamogordo, New Mexico, by the U.S. army under the code name "Manhattan Project."
Aug. 1, 1946	The Atomic Energy Act of 1946 established the AEC to control nuclear energy development and explore the peaceful uses of nuclear energy.
Dec. 20, 1951	The experimental Breeder Reactor I at Arco, Idaho, produced the first electric power from nuclear energy.
Dec. 8, 1953	President Eisenhower delivered his "Atoms for Peace" speech before the United Nations.
Jan. 21, 1954	The U.S. Navy launched the first nuclear-powered submarine, the U.S.S. *Nautilus,* which was capable of cruising 115,000 km (62,500 nautical miles) without refueling.
Aug. 30, 1954	President Eisenhower signed the Atomic Energy Act, which permitted and encouraged the participation of private industry in the development and use of nuclear energy and permitted greater cooperation with U.S. allies.
Jan. 10, 1955	The Atomic Energy Commission (AEC) announced the Power Demonstration Reactor Program. The AEC would cooperate with industry to construct and operate experimental nuclear power reactors.
Aug. 8–20, 1955	The first United Nations International Conference on peaceful uses of atomic energy was held in Geneva, Switzerland.
Sept. 2, 1957	The Price-Anderson Act granted financial protection to the public and to AEC licensees and contractors in the occurrence of a major accident involving a nuclear power plant.
Oct. 1, 1957	The International Atomic Energy Agency (IAEA) is established in Vienna, Austria, by the United Nations to promote the peaceful use of nuclear agency.
Dec. 2, 1957	The world's first large-scale nuclear power plant began operations in Shippingport, Pennsylvania.
July 21, 1959	The world's first nuclear powered merchant ship N.S. Savannah was launched in Camden, New Jersey.
Nov. 25, 1961	The U.S. Navy commissioned the world's largest ship, the U.S.S. *Enterprise*—a nuclear powered aircraft carrier capable of cruising up to 20 knots for distances up to 740,800 km (4,000,000 nautical miles) without refueling.
April 3, 1965	The first nuclear reactor in space (SNAP-10A) was launched.
March 5, 1970	The Treaty for Non-proliferation of Nuclear Weapons was ratified by the United States, the United Kingdom, the Soviet Union and 45 other nations.
1971	A total of 22 commercial nuclear power plants were in full operation in the United States.
August 1974	The federal government released the results of a safety study by Dr. Norman Rasmussen of MIT, which concluded that a meltdown in a power reactor would be extremely unlikely.

(continued)

Table 7.1
Nuclear Energy: Chronology of Research and Development, *(continued)*

Oct. 11, 1974	The Energy Reorganization Act of 1974 divided AEC functions between two newly formed agencies—the Energy Research and Development Administration (ERDA) and Nuclear Regulatory Commission (NRC).
1976	A total of 61 nuclear power plants with an aggregate capacity of 42,699 megawatts were producing 8.3% of electricity generated in the U.S.
March 28, 1979	The worst accident in a commercial reactor occurred at Three Mile Island (TMI) nuclear power station near Harrisburg, Pennsylvania. The cause was the loss of coolant from the reactor core due to mechanical and human errors. Without the cooling water surrounding the fuel, its temperature exceeded 5,000 degrees Farenheit, causing melting and damage to the reactor core. Due to the accident, the radioactive material normally confined to the fuel was released into the reactor's cooling water system.
1979	After the Three Mile Island accident the Nuclear Regulatory Commission (NRC) imposed stricter safety regulation and more rigid inspection procedures in order to improve the safety of nuclear reactors. The 12 percent of electricity produced commercially in the United States was generated by 72 licensed nuclear reactors.
1981	The Shippingport power station was shut down after 25 years of service.
1984	A total of 83 nuclear power reactors generated 14 percent of the electricity produced in the United States.
1986	The worst accident in nuclear history—the Chernobyl disaster—took place in the former Soviet Union on April 26.

Table 7.2
Nuclear Waste Classification

Type	*Characteristics*
High Level	Produced in two ways: (a) By reprocessing spent fuel to recover isotopes that can be used again as fuel. (b) Reactor fuel rods which contain long lived isotopes (with half-life of 30 years or more) Contains transuranic (heavier than uranium) elements. Most are harmful, highly radioactive, and must be handled and transported with shielding. Must be isolated from humans and environment for thousands of years. By 1990, 26,400 cubic meters of high level waste was generated.
Intermediate Level	Produced as reactor by-products and other material such as equipment, tools, etc. that have become radioactive. Less harmful, but cannot be handled and transported without shielding. By 1990, 3,400 cubic meters of Intermediate level waste was generated. IAEA estimates that by 1995 the rate of generation will be 3,800 cubic meters per year.
Low Level	Produced due to contamination of metal, paper, rags, etc. by radioactive material at power reactors, medical equipment, and other non-military sources. Contains no transuranic elements. Least harmful, can be handled and transported without shielding. By 1990, 370,000 cubic meters of low level waste was generated.

Source: "Nuclear Waste: The Challenge is Global," *IEEE Spectrum*, July 1990.

Table 7.3
Technical Options for Dealing with Irradiated Fuel

Method	*Process*	*Problems*	*Status*
Antarctica Ice Burial	Bury waste in ice cap	Prohibited by international law; low recovery potential, and concern over catastrophic failure	Abandoned
Geologic Burial	Bury waste in mined repository hundreds of meters deep	Difficulty predicting geology, groundwater flows, and human intrusions over long time period	Under active study by all nuclear countries as favored strategy
Long-term Storage	Store waste indefinitely in specially constructed buildings	Dependent on human institutions to monitor and control access to waste for long time period	Not actively being studied by gov'ts, though proposed by nongovernmental groups
Reprocessing	Chemically separate uranium and plutonium from fission products in irradiated fuel; decreases radioactivity by 3 percent	Increases volume of waste by 160-fold; poor economics; increases risk of nuclear weapons proliferation	Commercially under way in four countries; total of 16 countries have reprocessed or plan to reprocess irradiated fuel
Seabed Burial	Bury waste in deep ocean sediments	Possibly prohibited by international law; transport concerns; nonretrievable	Under active study by consortium of 10 countries
Space Disposal	Send waste into solar orbit beyond earth's gravity	Potential launch failure could contaminate whole planet; very expensive	Abandoned
Transmutation	Convert waste to shorter-lived isotopes through neutron bombardment	Technically uncertain whether waste stream would be reduced; very expensive	Under active study by United States, Japan, Soviet Union, and France

Source: Worldwatch Institute, *State of the World*, 1992, Norton.

power plant yields about 30 tons of high level waste. Therefore in very simplistic terms not accounting for various types of reactors, the world's high level nuclear waste approaches 15,000 tons annually.

In 1988, the United States proposed its only licensed permanent high level waste dumping site 1200 feet under Yucca Mountain, Nevada, for its 110 operating nuclear plants. Since the proposal of Yucca mountains, however, there remains little progress in this site becoming a reality since the plan is fraught with problems and technical difficulties. In the meantime, the U.S. Department of Energy says it cannot offer a permanent storage site until 2010 at

Table 7.4
Selected Country Programs on High-Level Waste Burial

Country	*Earliest Planned Year*	*Status of Program*
Argentina	2040	Granite site at Gastre, Chubut, selected.
Belgium	2020	Underground laboratory in clay at Mol.
Canada	2020	Independent commission conducting four-year study of government plan to bury irradiated fuel in granite at yet-to-be-identified site.
China	none announced	Irradiated fuel to be reprocessed; Gobi desert sites under investigation.
Finland	2020	Field studies being conducted; final site selection due in 2000.
France	2010	Three sites to be selected and studied; final site not to be selected until 2006.
Germany	2008	Gorleben salt dome sole site to be studied.
India	2010	Irradiated fuel to be reprocessed; waste stored for 20 years, then buried in yet-to-be-identified site.
Italy	2040	Irradiated fuel to be reprocessed and waste stored for 50–60 years before burial in clay or granite.
Japan	2020	Limited site studies; cooperative program with China to build underground research facility.
Netherlands	2040	Interim storage of reprocessing waste for 50–100 years before eventual burial, possibly in the seabed or in another country.
Soviet Union	none announced	Eight sites being studied for deep geologic disposal.
Spain	2020	Burial in unidentified clay, granite, or salt formation.
Sweden	2020	Granite site to be selected in 1997; evaluation studies under way at Aspo site near Oskarshamn nuclear complex.
Switzerland	2020	Burial in granite or sedimentary formation at yet-to-be-identified site.
United States	2010	Yucca Mountain, Nevada, site to be studied and, if approved, receive 70,000 tons of waste.
United Kingdom	2030	Fifty-year storage approved in 1982; explore options including seabed burial.

Source: Worldwatch Institute, *State of the World*, 1992, Norton.

Table 7.5
Types of Radiation

Mode of Radiation	*Sources*	*Penetrating Power*	*Approx. Distance Traveled in Air*	*Shielding Material*
alpha α	Fission and fission products	Very small	5 cm	Paper
Beta β	Fission, fission products, activation products	Small	300 cm at 1 MeV	Water, plastic, wood
Gamma γ	Fission, fission products, activation products	Very large		Lead, plastic, paraffin
Neutron n	Fission	Very large		Water, plastic, paraffin

Table 7.6
Radioactive Decay

Type of Radiation	*Nuclide*	*Half-Life*
α	uranium-238	4.47 billion years
β	thorium-234	24.1 days
β	protactinium-234	1.17 minutes
α	uranium-234	245,000 years
α	thorium-230	8,000 years
α	radium-226	1,600 years
α	radon-222	3.823 days
α	polonium-218	3.05 minutes
β	lead-214	26.8 minutes
β	bismuth-214	19.7 minutes
α	polonium-214	0.000164 second
β	lead-210	22.3 years
β	bismuth-210	5.01 days
α	polonium-210	138.4 days
	lead-206	stable

Source: *Radiation Doses, Effects and Risks,* United Nations Environment Programs, Nairobi, Kenya.

the earliest and the wastes continue to pile up. Some of the problems associated with the Yucca mountain plan are as follows.

LOCATION PROBLEMS

- The Department of Energy did not follow Nevada procedures and did not receive proper state authorization for the site.
- Nevada does not want the repository—NIMBY (Not in My Back Yard)—and passed a resolution in 1990 against storing radioactive wastes anywhere in Nevada's borders.
- The dump site was based wholly on political considerations and science's role in this decision was minimal.
- There is a young active volcano within 7 miles of the site and 32 active faults on the site itself. This renders the site unstable and also suggests that through these faults, contaminated water could escape through a network of geologic cracks. (Federal requirements prohibit the construction of a nuclear waste repository where water can travel 5 km from the burial site in less than 100 years.)

Table 7.7
Half-Lives of Radioactive Elements

Element (Symbol-Mass No)	*Half-life (years)*	*Decay Mode*
Uranium		
U-232	72	α, β
U-233	1.59×10^5	α, β
U-235	7.03×10^8	α, β
U-236	2.34×10^7	α, β
U-238	4.46×10^9	α, β
U-239	23.5 minutes	α, β
Plutonium		
Pu-239	2.41×10^4	α, β
Tellurium		
Te-130	2×10^{21}	β
Indium		
In-115	5.1×10^{14}	β

- The site is probably among the most highly mineralized areas on the continent. Two of North America's largest gold mines are 15 to 20 miles away, and gold and silver have been found at Yucca Mountain, making the site vulnerable to prospectors.
- Two years of planning have progressed for this site.

Table 7.8
Radioactivity and Thermal Output Per Metric Ton of Irradiated Fuel from a Light-Water Reactor

Age (years)	*Radioactivity (curies)*	*Thermal Output (watts)*
At Discharge	177,242,000	1,595,375
1	693,000	12,509
10	405,600	1,268
100	41,960	299
1,000	1,752	55
10,000	470	14
100,000	56	1

SOURCES: Ronnie B. Lipschultz, *Radioactive Waste: Politics, Technology and Risk* (Cambridge, MA: Ballinger Publishing Company, 1980); J.O. Biomeke et al., Oak Ridge National Laboratory, *Projections of Radioactive Wastes to Be Generated by the U.S. Nuclear Power Industry,* National Technical Information Service, Springfield, VA, February 1974.

Table 7.9
Major Nuclear Accidents

United States	*Soviet Union*
1951, Detroit Accident in a research reactor. Overheating of fissionable material because permissible temperatures had been exceeded. Air contaminated with radioactive gases.	**September 1957** Accident at reactor near Chelyabinsk. A spontaneous nuclear reaction occurred in spent fuel, causing a substantial release of radioactivity. Radiation spread over a wide area. The contaminated zone was enclosed within a barbed wire fence, and ringed by a drainage channel. The population was evacuated and the topsoil removed; livestock was destroyed and buried in pits.
24 June 1959 Meltdown of part of fuel rods due to failure of cooling system at experimental power reactor in Santa Susanna, California.	**7 May 1966** Prompt neutron power surge at a nuclear power station with a boiling-water nuclear reactor in the town of Melekess. Two people were exposed to severe doses of radiation.
3 January 1961 Steam explosion at an experimental reactor near Idaho Falls, Idaho. Three people died.	**7 January 1974** Explosion of reinforced concrete gasholder for the retention of radioactive gases in No. 1 reactor of Leningrad nuclear power station.
5 October 1966 Partial core melt due to failure of cooling system at the Enrico Fermi reactor, near Detroit.	**6 February 1974** Rupture of intermediate loop in No. 1 reactor at the Leningrad nuclear power station due to boiling of water. Three people were killed. Highly radioactive water with pulp from filter powder discharged into the environment.
19 November 1971 Almost 53,000 gallons (200,000 liters) of water contaminated with radioactive substances from an overflowing waste storage tank at Monticello, Minnesota, flowed into the Mississippi River.	**October 1975** Partial destruction of the core at No. 1 reactor of the Leningrad nuclear power station. About one and a half million curies of highly radioactive gases were discharged into the environment.
28 March 1979 Core melt due to loss of cooling at the Three Mile Island nuclear power station. Radioactive gases released into the atmosphere and 172,000 cubic feet of liquid radioactive waste was discharged into the Susquehanna River. Population evacuated from vicinity of disaster.	**31 December 1978** No. 2 unit at the Byeloyarsk nuclear power station was heavily damaged by a fire started when a roof panel in the turbine fell onto a fuel tank. The reactor was out of control. In the effort to supply emergency cooling water to the reactor, eight persons were exposed to severe doses of radiation.
7 August 1979 About one hundred people received a radiation dose six times higher than the normal permissible level due to the discharge of highly enriched uranium from a plant producing nuclear fuel near the town of Irving, Texas.	**September 1982** Destruction of the central fuel assembly of No. 1 reactor at the Chernobyl nuclear power station due to errors by the operational staff. Radioactivity was released into the immediate vicinity of the plant and into the town of Pripyat, and staff doing repair work were exposed to severe doses of radiation.
25 January 1982 A broken tube in a steam generator in the R.E. Ginna nuclear power plant, near Rochester, New York. A breakdown in the cooling system caused a leak of radioactive substances into the atmosphere.	**October 1982** Explosion of generator in No. 1 reactor of the Armyanskaya nuclear power station. The turbine hall burned down.
30 January 1982 Near the town of Ontario, New York, a breakdown in the cooling system caused a leak of radioactive substances into the atmosphere.	**27 June 1985** Accident in No. 1 reactor of the Balakovo nuclear power station. During start-up activities, a relief valve burst. Fourteen people were killed. This accident was due to errors made in haste and nervousness by inexperienced operational staff.
28 February 1985 At the Virgil C. Summer nuclear power station, in Jenkinsville, South Carolina, the reactor became critical too soon, leading to an uncontrolled nuclear power surge.	
19 May 1985 At the Indian Point 2 nuclear power station, near New York City, there was a leakage of several hundred gallons of radioactive water, some of which entered the environment outside the facility.	
1986 Webbers Falls, Oklahoma, explosion of a tank containing radioactive gas at a uranium enrichment plant. One person was killed, eight others injured.	

Table 7.10
List of Nuclear Reactors

	Reactors In Operation	*Electricity Generated (megawatts)*	*Percent of Electricity*	*Reactors Under Construction*
NORTH & CENTRAL AMERICA				
Canada	18	12,185	15.6	4
Cuba	0	0	0	2
Mexico	1	654	—	1
U.S.	110	98,331	19.1	4
SOUTH AMERICA				
Argentina	2	935	11.4	1
Brazil	1	628	.7	1
EUROPE				
Belgium	7	5,500	60.8	0
Bulgaria	5	2,585	32.9	2
Czechoslovakia	8	3,264	27.6	8
East Germany	6	2,102	10.9	5
Finland	4	2,310	35.4	0
France	55	52,588	74.6	9
Hungary	4	1,645	49.8	0
Italy	2	1,120	—	0
Netherlands	2	508	5.4	0
Romania	0	0	0	5
Spain	10	7,544	38.4	0
Sweden	12	9,817	45.1	0
Switzerland	5	2,952	41.6	0
U.K.	39	11,242	21.7	1
West Germany	24	22,716	34.3	1
Yugoslavia	1	632	5.9	0
ASIA				
China	0	0	0	3
India	7	1,374	1.6	7
Iran	0	0	0	2
Japan	39	29,300	27.8	12
Pakistan	1	125	0.2	1
South Korea	9	7,200	50.2	2
Taiwan	6	4,924	35.2	0
USSR	46	34,230	12.3	26
AFRICA				
South Africa	2	1,842	7.4	0
TOTALS	426	318,271	—	97

Source: International Atomic Energy Agency (IAEA), Vienna.

TECHNICAL PROBLEM

The site will accommodate 63,500 tons of high-level waste. Radioactive waste already exceeds 22,500 tons (which, according to the Department of Energy, should remain isolated from the environment for 10,000 years). It would take 28 years every workday to fill the site. By the end of 28 years there will be tens of thousands more tons of waste to deal with and there will be no room for the new waste. Additionally, trucks and other means of moving the waste would be arriving from all parts of the country at 90 minute or more frequent intervals, posing serious safety and transportation questions.

During the past half-century, a number of major nuclear accidents has taken place at various nuclear reactors in the Soviet Union and the United States (Table 7.9), resulting in the contamination of environment. But it was the accident at Chernobyl that finally destroyed the myth of nuclear energy being a clean energy source. At a little past 1:24 a.m. on April 26, 1986, two mammoth explosions blew apart Unit Four of the Chernobyl nuclear power plant. The plant is located about 70 miles north of Kiev, the capital of Ukraine, a republic of the former Soviet Union. The roof of the plant was blown off and radioactive gasses and materials were released in the atmosphere, reaching up to eleven hundred meters. According to

Scenario I

Los Angeles, July 12, 20XX

The powerful earthquake (7.7 on the Richter scale) that shook the city this morning has severely damaged the core of XXXXXX nuclear reactor. A radioactive gas cloud has escaped into the atmosphere. Efforts are being made to contain the radioactivity.

Response:

Discuss how this accident could have been avoided. Are nuclear power stations better or worse than fossil fuel power generating stations?

Scenario II

Dateline: January 30, 20XX

A ship containing 50,000 cubic meters of nuclear waste returned to New York after visiting South America, Africa, and Asia in search of potential dump sites. All Third-World countries have refused to accept the nuclear waste, despite lucrative offers.

Today, the U.S. nuclear waste volume has reached 10 million cubic meters, compared with 500,000 cubic meters in the 1990s. Due to the saturation of temporary storage sites for nuclear waste, and because of a lack of proper planning and development of permanent storage for nuclear waste in the last century, the world's nuclear waste volumes have reached alarming levels. The potential leakage from temporary storage sites poses the greatest threat to the environment.

Action Item/Response:

Going back to 1960, draw a time-line, and label it by proposing appropriate action taken in each decade that could have prevented the nuclear waste dilemma the world faces today.

Time line: ______________________________

1950 1960 1970 1980 1990 2000 2010 2020 2030 20XX

Scenario III

Dateline: February 19, 20XX

Today the U.N. Security Council passed a resolution demanding the African republic of BANGO to accept 500,000 tons of nuclear waste for permanent storage. All African and Third-World countries have protested against this resolution. The government of BANGO has announced that it will not comply with the U.N. resolution. The U.N. is also considering a proposal for establishing common storage sites in Third-World countries for the nuclear waste generated by developed countries.

Response:

Discuss the implications of the U.N. resolution against BANGO. Is the U.N. justified in asking Third-World countries to accept the nuclear waste generated by the developed countries?

Scenario IV

St. Louis, April 1, 20XX

A train carrying high-level nuclear waste from a nuclear power plant in Illinois collided with an east-bound freight train while crossing a bridge over the Mississippi River. The cars containing waste canisters were badly damaged. Due to the colossal impact of the accident, many canisters ripped open and some fell into the river.

Response:

Discuss the impact of this accident on the environment. Should the transfer of high-level waste by train be allowed to continue?

recent estimates, more than 50 million curies were released as a result. The cause of the accident was the flawed design of the RBMK reactor (large power boiling reactor). After the accident, Soviet scientists were reluctant to modify the design of the RBMK reactor, but eventually modified it to make it safer. Forty RBMK type reactors are still operating in Eastern Europe and former Soviet states. And in 25 countries, 426 atomic power plants (Table 7.10) continue to operate and generate enormous amounts of nuclear waste.

What appear to be a clean source of energy are a few megawatts of low-cost power for today's consumption. But in the long run, these will cause an immortal radioactive contamination of the environment. With the growing amount of nuclear waste and limited technical options for its storage and disposal, it is just a matter of time until major accidents happen, resulting in contamination of the environment.

If there ever was an element that deserved a name associated with hell, it is plutonium. This is not only because of its use in atomic bombs—which certainly would amply qualify it—but also because of its fiendishly toxic properties, even in small amounts.

—Robert E. Wilson

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