DISPOSAL OF SPENT NUCLEAR FUEL IN THE UNITED STATES AND EUROPE: A PERSISTENT ENVIRONMENTAL PROBLEM

*Charles de Saillan**

* Charles de Saillan is an attorney with the New Mexico Environment Department, where he handles matters involving air quality, surface and groundwater quality, hazardous waste, and site remediation. His responsibilities include environmental compliance and permitting at Los Alamos National Laboratory, the birthplace of the atomic bomb. This Article is based on the thesis paper the author wrote for the Master in Environmental and Energy Law (LL.M.) program at Katholieke Universiteit in Leuven, Belgium.

The author thanks Prof. Dr. Geert van Calster, K.U. Leuven, Belgium, and Geoffrey H. Fettus, Senior Project Attorney, Natural Resources Defense Council, Washington, D.C., for their helpful comments on drafts of this Article.

The danger for humanity is not that man invents, but that he does not master what he has created.[1]

Jean-Pierre Chevènement, French Minister
of Research and Technology
October 1981

I. Introduction

On August 27, 1956, the first full-scale commercial nuclear power reactor, with a capacity of fifty megawatts ("MW"), began operation at Calder Hall in Great Britain.[2] In December 1957, the first commercial nuclear power reactor in the United States, producing 60 MW, began operating in Shippingport, Pennsylvania.[3] In April 1959, the first commercial reactor in France, the 40 MW G2 reactor at Marcoule, began operation.[4] Today, there are 436 commercial nuclear reactors operating in thirty-one countries around the world.[5] Another 122 commercial nuclear reactors, including those at

---

[1] Journal Officiel de la République Française [J.O.] [Official Gazette of France], Oct. 6, 1981, p. 1510 (Fr.), *quoted and translated in* Luther J. Carter, Nuclear Imperatives and Public Trust: Dealing with Radioactive Waste 315 (1987).

[2] David Bodansky, Nuclear Energy: Principles, Practices, and Prospects 42 (2d ed. 2004). Two small, experimental reactors in the United States and the Soviet Union had generated electric power earlier. *See id.* at 42 n.19; U.S. Dep't of Energy, No. DOE/NE-0088, The History of Nuclear Energy 13 (2000).

[3] Bodansky, *supra* note 2, at 31.

[4] Gabrielle Hecht, The Radiance of France: Nuclear Power and National Identity After World War II 65–68, 95 (1998). Electric power generation evidently was only a secondary purpose of the Marcoule G2 reactor. Its primary purpose was to produce plutonium ultimately used for French nuclear weapons. *Id.* at 69–73.

[5] *See* Int'l Atomic Energy Agency [IAEA], *Nuclear Power Reactors in the World*, at 11 tbl.1, IAEA Doc. RDS-2/29 (Sept. 4, 2009) [hereinafter IAEA, *Nuclear Power Reactors*];

Calder Hall, Shippingport, and Marcoule, have been permanently shut down, most of them after years of operation.[6]

While the nuclear power industry has been in decline in recent decades, particularly in the United States and Europe, many observers are predicting a renaissance.[7] In the last few years, several factors have made nuclear power an increasingly attractive alternative to energy policy makers. First, manufacturers have developed a so-called "fourth generation" of reactors, based on improved design, that are safer and more efficient than most reactors now operating.[8] Second, as a relatively efficient, reliable, less polluting alternative to fossil-fuel combustion, nuclear power presents an attractive option for developing countries expanding their economies.[9] Third, some countries see it as a means to reduce their dependence on foreign-imported fossil fuels.[10] Fourth, electric power generated from nuclear fuel, rather than fossil fuels, is virtually free of greenhouse gas emissions that contribute to global climate change. Many countries are struggling to reduce emissions under the Kyoto Protocol,[11] under the European Directive on greenhouse gas emissions,[12] or under national laws or policies.[13] Nuclear power is viewed by some observers as a means to provide reliable electric power without carbon emissions,[14] and proponents of nuclear power have particularly touted its environmental

Lithuania Shuts Soviet-Built Reactor, BOSTON GLOBE, Jan. 1, 2010, at 3 (noting shutdown of one reactor operational at time of the IAEA report).

[6] *See* IAEA, *Nuclear Power Reactors*, *supra* note 5, at 51 tbl.16; *Lithuania Shuts Soviet-Built Reactor*, *supra* note 5 (noting shutdown of one additional reactor).

[7] *See, e.g.*, *Atomic Renaissance*, ECONOMIST, Sept. 8, 2007, at 71; W.J. NUTTALL, NUCLEAR RENAISSANCE (2004); Peter D. Cameron, *The Revival of Nuclear Power: An Analysis of the Legal Implications*, 19 J. ENVTL. L. 71 (2007) (U.K.); Roland M. Frye, Jr., *The Current "Nuclear Renaissance" in the United States, Its Underlying Reasons, and Its Potential Pitfalls*, 29 ENERGY L.J. 279 (2008). *But see* SHARON SQUASSONI, CARNEGIE ENDOWMENT FOR INT'L PEACE, NUCLEAR ENERGY: REBIRTH OR RESUSCITATION? (2009); J.C. Sylvan, Feature, *Nuclear Power: Renaissance or Relapse?*, SUSTAINABLE DEV. L. & POL'Y, Fall 2007, at 18.

[8] *See* BODANSKY, *supra* note 2, at 444–47.

[9] *See, e.g.*, Andrew C. Kadak, *Nuclear Power: "Made in China,"* BROWN J. WORLD AFF., Fall/Winter 2006, at 77, 79–83; Ling Zhong, *Nuclear Energy: China's Approach Towards Addressing Global Warming*, 12 GEO. INT'L ENVTL. L. REV. 493, 502–08 (2000).

[10] *See, e.g.*, ALAN M. HERBST & GEORGE W. HOPLEY, NUCLEAR ENERGY NOW 62–73 (2007); MASS. INST. OF TECH., THE FUTURE OF NUCLEAR POWER 20–21 (2003), *available at* http://web.mit.edu/nuclearpower.

[11] Kyoto Protocol to the United Nations Framework Convention on Climate Change, Dec. 10, 1997, 37 I.L.M. 22. Protocol signatories that are developed nations, including Australia, Canada, Japan, and most of the nations of Europe, must reduce emissions of carbon dioxide and other greenhouse gases.

[12] Directive 2003/87/EC of the European Parliament and of the Council, 2003 O.J. (L 275) 32.

[13] For example, although the United States has not signed the Kyoto Protocol, Congress has proposed legislation to reduce greenhouse gas emissions. *See, e.g.*, Clean Energy Jobs and American Power Act, S. 1733, 111th Cong. (2009); American Clean Energy and Security Act of 2009, H.R. 2454, 111th Cong. (2009); Lieberman-Warner Climate Security Act of 2007, S. 2191, 110th Cong. (2007).

[14] *See, e.g.*, MASS. INST. OF TECH., *supra* note 10, at 17–18; Fred Bosselman, *The Ecological Advantages of Nuclear Power*, 15 N.Y.U. ENVTL. L.J. 1, 41–42 (2007); Richard Rhodes & Denis Beller, *The Need for Nuclear Power*, FOREIGN AFF., Jan./Feb. 2000, at 30, 30–32.

benefits.[15] In a widely-quoted commentary, Dr. Patrick Moore, a former member of Greenpeace now working for industry, recently stated that "[n]uclear energy is the only large-scale, cost-effective energy source that can reduce [carbon dioxide] emissions while continuing to satisfy a growing demand for power."[16]

Opponents of nuclear power urge a more precautionary approach. They warn of the multifaceted and often interrelated dangers nuclear power poses: the incidental exposure of workers and the public to ionizing radiation, the potential for catastrophic nuclear accidents, the proliferation of nuclear technology and material that can be used to fabricate nuclear weapons, and the continuing generation of spent fuel and other dangerous high-level radioactive wastes that require proper management long into the future.[17]

High-level waste management and disposal has been one of the more intractable problems with nuclear power. As a byproduct of more than fifty years and thousands of terawatt hours of electric power generation, nuclear reactors have produced — and continue to produce — a perplexing future legacy of growing stockpiles of spent nuclear fuel and other high-level radioactive wastes. Approximately 190,000 metric tons of high-level radioactive waste is now in temporary storage awaiting disposal.[18] Most is in the form of spent nuclear fuel rods, but a substantial portion consists of residues from reprocessing spent nuclear fuel. These wastes will remain dangerously radioactive, and must therefore be isolated, for hundreds of thousands of years — much longer than human civilization has been in existence. There is a further danger that insecure or improperly managed waste might fall into the hands of criminals or terrorists.[19] Yet none of the more than thirty nations with operating or once-operating commercial nuclear reactors have constructed a repository or other facility for the permanent disposal of this waste. Instead, the waste has been placed in temporary storage more or less indefinitely.

---

[15] The recent literature advocating a renewed emphasis on nuclear power for electric generation, often for environmental reasons, is extensive. *See, e.g.*, HERBST & HOPLEY, *supra* note 10; WILLIAM TUCKER, TERRESTRIAL ENERGY: HOW NUCLEAR ENERGY WILL LEAD THE GREEN REVOLUTION AND END AMERICA'S ENERGY ODYSSEY (2008); Bosselman, *supra* note 14; Rhodes & Beller, *supra* note 14.

[16] Patrick Moore, *Going Nuclear*, WASH. POST, Apr. 16, 2006, at B1; *see also* Patrick Moore, *Foreword* to IAN HORE-LACY, NUCLEAR ENERGY IN THE 21ST CENTURY 4 (2006).

[17] *See, e.g.*, Karl S. Coplan, *The Intercivilizational Inequities of Nuclear Power Weighed Against the Intergenerational Inequities of Carbon Based Energy*, 17 FORDHAM ENVTL. L. REV. 227 (2006); Arjun Makhijani, *Atomic Myths, Radioactive Realities: Why Nuclear Power Is a Poor Way to Meet Energy Needs*, 24 J. LAND RESOURCES & ENVTL. L. 61 (2004); Benjamin K. Sovacool & Christopher Cooper, *Nuclear Nonsense: Why Nuclear Power Is No Answer to Climate Change and the World's Post-Kyoto Energy Challenges*, 33 WM. & MARY ENVTL. L. & POL'Y REV. 1 (2008).

[18] E. Amaral, K. Brockman & H.G. Forsström, *International Perspectives on Spent Fuel Management*, *in* IAEA, *Management of Spent Fuel from Nuclear Power Reactors*, at 18, IAEA Doc. STI/PUB/1295 (July 31, 2007).

[19] *See* NAT'L RESEARCH COUNCIL, SAFETY AND SECURITY OF COMMERCIAL SPENT NUCLEAR FUEL STORAGE 33–34 (2006).

This Article examines the problem of high-level radioactive waste from commercial nuclear power generation, focusing on the legal and institutional frameworks established in various countries to address the problem. It looks primarily at five countries with advanced nuclear power programs — the United States, the United Kingdom, France, Sweden, and Finland — to see which approaches have made the most progress towards reaching a solution, and why. Part II of the Article gives some background and context for the issue by surveying the history, current status, and likely future of the global nuclear power industry. Part III describes the generation of spent nuclear fuel from the operation of nuclear power plants. Part IV describes the storage of spent fuel, which is now the universal management practice — largely by default — but which can perhaps also serve as a satisfactory short-term management strategy while permanent disposal is developed. Part V describes spent fuel reprocessing, an approach that does surprisingly little to solve the disposal problem, in part because reprocessing generates a secondary stream of high-level radioactive waste. Part VI then examines in some detail the efforts of the five countries to develop programs and select repository sites for the ultimate disposal of spent fuel and other high-level radioactive waste, focusing on site selection, licensing, and substantive technical standards in each country. This examination demonstrates that the nuclear waste problem has not been solved in any of these countries, although the Nordic countries seem to be close to a solution. Part VII then proposes a framework for resolving the waste management problem by recommending several institutional, procedural, and technical criteria for the development of a permanent disposal facility. This framework could be incorporated into national or international legal regimes. It would include a siting body and government regulatory agency that are independent of significant political interference; a transparent site selection and licensing process that encourages meaningful public and local community participation; and technical standards that would ensure containment of radioactive wastes and limit exposure to humans and the environment. Finally, Part VIII offers some conclusions, including the author's opinion on the wisdom of expanding nuclear power generation notwithstanding the unresolved waste disposal issue.

II. The Global Nuclear Power Industry

A. *The History of the Nuclear Power Industry*

The fifty-year history of nuclear power development resembles a long "boom-and-bust" cycle. At its inception, proponents of nuclear power, or "atomic energy" as it was called, predicted a utopian society powered by fleets of atomic plants providing clean, cheap, and abundant electricity,[20]

[20] *See* Daniel Ford, The Cult of the Atom 29–31 (1982). Interestingly, in a science fiction novella written in 1913, more than forty years before the Calder Hall reactor began

electricity that would be "too cheap to meter."[21] This enthusiasm foreshadowed vigorous growth of nuclear power in the 1960s and 1970s. Worldwide, construction began on 161 new commercial reactors from 1961 through 1970, and 241 new reactors from 1971 through 1980.[22]

In the 1980s, however, nuclear power plant construction declined precipitously, and it has remained moribund to the present. Construction began on only eighty-seven new reactors from 1981 through 1990, thirty new reactors from 1991 through 2000, and thirty-four new reactors from 2001 through 2008.[23] Two factors generally account for this decline. The first is the increasingly exorbitant costs of nuclear power plant construction.[24] The problem is well illustrated by construction of the Shoreham nuclear power plant on Long Island, New York, which suffered huge cost overruns and was never licensed to operate.[25] The second factor is public concern over nuclear power plant safety, which was greatly exacerbated by two serious reactor accidents, at Three Mile Island in Middletown, Pennsylvania and at Chernobyl, Ukraine.[26] Over the past few years, in response to the Chernobyl accident, many central and eastern European nations have phased out some of their older, Soviet-era nuclear power plants,[27] in several cases as a condition to joining the European Union ("EU").

---

operating, the British writer H.G. Wells described the advent of nuclear power plants with remarkable prescience. Telling his story from the point of view of a future historian looking back on the twentieth century, Wells wrote, "It was in 1953 that the first Holsten-Roberts engine brought induced radio-activity into the sphere of industrial production, and its first general use was to replace the steam-engine in electrical generating stations." H.G. WELLS, THE WORLD SET FREE 51 (E.P. Dutton & Co. 1914).

[21] BODANSKY, *supra* note 2, at 32 (quoting a 1954 speech by Lewis L. Strauss, then Chairman of the U.S. Atomic Energy Commission).

[22] IAEA, *Nuclear Power Reactors*, *supra* note 5, at 21 tbl.7.

[23] *Id.*

[24] *See, e.g.*, Michael Grunwald, *Nuclear's Comeback: Still No Energy Panacea*, TIME, Dec. 31, 2008, http://www.time.com/time/magazine/article/0,9171,1869203,00.html.

[25] *See* DAVID P. MCCAFFREY, THE POLITICS OF NUCLEAR POWER: A HISTORY OF THE SHOREHAM NUCLEAR POWER PLANT (1990).

[26] On March 28, 1979, a malfunctioning valve at the Three Mile Island 2 reactor resulted in loss of cooling water and a partial meltdown of the reactor core. *See* REPORT OF THE PRESIDENT'S COMM'N ON THE ACCIDENT AT THREE MILE ISLAND (1979), *available at* http://www.threemileisland.org/downloads/188.pdf; J. SAMUEL WALKER, THREE MILE ISLAND: A NUCLEAR CRISIS IN HISTORICAL PERSPECTIVE (2004). On April 26, 1986, Unit 4 at Chernobyl underwent a partial meltdown of the reactor core, releasing a tremendous amount of radiation. *See* IAEA, *The International Chernobyl Project: Technical Report — Assessment of Radiological Consequences and Evaluation of Protective Measures* (May 1991), *available at* http://www-ns.iaea.org/projects/chernobyl.htm; R.F. MOULD, CHERNOBYL RECORD (2000).

[27] In 1995, the U.S. Department of Energy produced a report listing the most dangerous operating nuclear power reactors in the world. The ten reactors were Bohunice 1 and 2 in Slovakia, Ignalina 1 and 2 in Lithuania, Kola 1 and 2 in Russia, Kozloduy 1 and 2 in Bulgaria, and Chernobyl 1 and 3 in Ukraine. *See* William J. Broad, *U.S. Lists 10 Soviet-Built Nuclear Reactors as High Risks*, N.Y. TIMES, July 23, 1995, at 10. Only the Kola units are still operating. *See* IAEA, *Nuclear Power Reactors*, *supra* note 5, at 47–50 tbl.16; *Lithuania Shuts Soviet-Built Reactor*, *supra* note 5.

B. *The Nuclear Power Industry Today*

Although nuclear energy has not lived up to the high expectations of its early proponents, it nevertheless supplies a significant proportion of the world's electric power. Currently, 436 nuclear power reactors are in operation in thirty countries throughout the world, as detailed in Table 1.[28] In 2008, nuclear power plants supplied 2597.8 terawatt hours, or roughly 18% of the world's electric power.[29]

In the United States, 104 commercial nuclear power reactors are currently in operation — more than in any other country — which supplied 19.7% of U.S. electric power in 2008.[30] In addition, twenty-eight formerly operating nuclear power reactors have now been permanently shut down; nine have been fully decommissioned.[31] After a boom of nuclear power plant construction in the late 1960s through the 1970s, the industry has experienced a lull in the United States, as in much of the rest of the industrialized world. New construction of a nuclear plant has not commenced since 1978,[32] although construction of the Watts Bar 2 Unit in Tennessee, begun in 1972, was suspended in 1985 and resumed in 2007.[33] An operating license for a reactor has not been issued since 1996.[34] Again, the decline is largely attributed to high costs of construction and safety concerns.[35] Nevertheless, as discussed in Part II.C below, there may soon be a resurgence of nuclear power plant construction in the United States.

The United Kingdom has nineteen nuclear power reactors currently in operation, which supplied 13.5% of its electric power in 2008.[36] Four of the operating reactors in the United Kingdom are of the old Magnox design,[37] so-called because the fuel rods are fabricated with magnesium oxide cladding.[38] Most of the other reactors are newer advanced gas-cooled reactors.[39] In addition, twenty-six reactors in the United Kingdom, most of them Magnox reactors, have been permanently shut down.[40]

---

[28] *See* Table 1, *infra* accompanying note 55.

[29] IAEA, *Nuclear Power Reactors*, *supra* note 5, at 11 tbl.1.

[30] *Id.* All the U.S. plants are either pressurized water reactors or boiling water reactors.

[31] *Id.* at 50–51 tbl.16, 54–55 tbl.17.

[32] *Id.* at 41–45 tbl.14.

[33] *Id.* at 29 tbl.13; Duncan Mansfield, *TVA OKs Second Watts Bar Nuclear Reactor*, ASSOCIATED PRESS ONLINE, Aug. 2, 2007.

[34] U.S. NUCLEAR REGULATORY COMM'N, NUREG-1350, VOL. 21, 2009–2010 INFORMATION DIGEST 36 fig.21 & tbl.8 (2009). The Nuclear Regulatory Commission ("NRC") issued an operating license for the Watts Bar 1 reactor in Tennessee in 1996. *Id.*

[35] *See supra* notes 24–26 and accompanying text.

[36] IAEA, *Nuclear Power Reactors*, *supra* note 5, at 11 tbl.1.

[37] *Id.* at 40–41 tbl.14; *see also* NUCLEAR DECOMMISSIONING AUTH., THE MAGNOX OPERATING PROGRAMME (MOP8) 15 (2007) (U.K.). Only the United Kingdom still operates carbon dioxide–cooled, graphite-moderated reactors. *See id.*

[38] BODANSKY, *supra* note 2, at 179.

[39] IAEA, *Nuclear Power Reactors*, *supra* note 5, at 40–41 tbl.14. The United Kingdom also has one operating pressurized water reactor, the Sizewell-B reactor, which began operation in 1995. *Id.*

[40] *Id.* at 49–50 tbl.16; NUCLEAR DECOMMISSIONING AUTH., *supra* note 37, at 15.

France has fifty-eight nuclear reactors in operation, second only to the United States. Nuclear reactors provided an impressive 76.2% of France's electric power in 2008, the highest of any country.[41] All of the reactors are pressurized water reactors.[42] France has another twelve nuclear reactors that have been permanently shut down, most of them gas-cooled, graphite-moderated reactors.[43] France commissioned thirteen new reactors between 1990 and 2000,[44] and, in December 2007 began construction of a new advanced design reactor, the Flamanville-3 Nuclear Power Plant on the Normandy coast.[45] All of France's nuclear power plants are operated by Electricité de France ("EDF"), a state-owned corporation.[46]

Sweden currently has ten operating nuclear power reactors, which supplied 42% of the country's electric power in 2008.[47] Three more reactors in Sweden, including the controversial Barsebäck 1 and 2 reactors, have been permanently shut down.[48] Responding to a 1980 national referendum calling for an eventual phaseout of nuclear power,[49] the Swedish Parliament enacted legislation in 1987 prohibiting the licensing of any new nuclear power plants.[50] In addition, Swedish political leaders made commitments to phase out existing nuclear power plants completely by 2010, but that commitment was later abandoned.[51]

Finland has four nuclear power reactors currently in operation, which supplied 29.7% of its electricity in 2008.[52] In 2005, construction com-

---

[41] IAEA, *Nuclear Power Reactors*, *supra* note 5, at 10 tbl.1.

[42] *Id.* at 32–34 tbl.14.

[43] *Id.* at 47 tbl.16. The Phénix reactor in Marcoule, a small-scale fast neutron breeder reactor, was closed in 2009. *Another Drop in Nuclear Generation*, WORLD NUCLEAR NEWS, May 5, 2010, http://www.world-nuclear-news.org/EE_Another_drop_in_nuclear_generation_0505102.html.

[44] AUTORITÉ DE SÛRETÉ NUCLÉAIRE, ANNUAL REPORT: NUCLEAR SAFETY AND RADIATION PROTECTION IN FRANCE IN 2008, at 328 (2009) (Fr.), *available at* http://annual-report2008.asn.fr.

[45] IAEA, *Nuclear Power Reactors*, *supra* note 5, at 28 tbl.13; *see also* Steven Erlanger, *French Plans for Energy Reaffirm Nuclear Path*, N.Y. TIMES, Aug. 17, 2008, at A6.

[46] IAEA, *Country Nuclear Power Profiles (France)*, at 314, 318–20 (2003), *available at* http://www-pub.iaea.org/MTCD/publications/PDF/cnpp2003/CNPP_Webpage/PDF/2003/. The Phénix reactor was run jointly by EDF and the French Commissariat à l'energie atomique.

[47] IAEA, *Nuclear Power Reactors*, *supra* note 5, at 10 tbl.1.

[48] *Id.* at 49 tbl.16. Since its construction in the mid-1970s, the Barsebäck plant provoked opposition and protests due to its proximity to Malmö, Sweden's third largest city, and Copenhagen in neighboring Denmark. *See* Ragnar E. Löfstedt, *Fairness Across Borders: The Barsebäck Nuclear Power Plant*, 7 RISK 135 (1996).

[49] *See* WILLIAM D. NORDHAUS, THE SWEDISH NUCLEAR DILEMMA 34–35 (1997).

[50] 5(a) § Lag om kärnteknisk verksamhet [Act on Nuclear Activities] (Svensk författningssamling [SFS] 1984:3) (Swed.); *see also* Org. for Econ. Co-Operation & Dev. [OECD], *Nuclear Legislation in OECD Countries: Sweden*, at 5 (2008).

[51] Ragnar E. Löfstedt, *Playing Politics with Energy Policy: The Phase-Out of Nuclear Power in Sweden*, ENVIRONMENT, May 2001, at 20, 25–26.

[52] IAEA, *Nuclear Power Reactors*, *supra* note 5, at 10 tbl.1.

menced on the Olkiluoto-3 reactor of advanced design,[53] but the project is far behind schedule and substantially over budget.[54]

TABLE 1. THE NUCLEAR POWER INDUSTRY WORLDWIDE[55]

	No. of Reactors Currently Operating	No. of Reactors Shut Down	No. of Reactors Under Construction	% of 2008 Energy Production	Notes
North America					
United States	104	28	1	19.7	
Canada	18	3	—	14.8	All reactors are CANDU (Canadian deuterium uranium) pressurized heavy-water reactors. Several are scheduled for refurbishment in the next few years.
Mexico	2	—	—	4.0	
South America					
Argentina	2	—	1	6.2	
Brazil	2	—	—	3.1	
Europe					
United Kingdom	19	26	—	13.5	
France	58	12	1	76.2	The Phénix reactor in Marcoule, a small-scale fast neutron breeder reactor, was closed in 2009.
Germany	17	19	—	28.3	2002 legislation provides for the structured phase-out of nuclear power by 2020.
Belgium	7	1	—	53.8	2003 legislation will require all nuclear power plants to shut down within forty years after commencement of operation. Under this law, Belgium's newest plants will shut down by 2025.
Netherlands	1	1	—	3.8	

[53] *Id.* at 28 tbl.13; *see also* Lizette Alvarez, *Finland Rekindles Interest in Nuclear Power*, N.Y. TIMES, Dec. 12, 2005, at A15.

[54] James Kanter, *Not So Fast, Nukes*, N.Y. TIMES, May 29, 2009, at B1.

[55] *See* IAEA, *Nuclear Power Reactors*, *supra* note 5, tbls.1, 6, 13, 14 & 16 (data compiled by author). "Notes" information compiled from additional sources: for Canada, *see* CANADIAN NUCLEAR SAFETY COMM'N, 2008–09 ANNUAL REPORT 45–47 (2009); for France, *see Another Drop in Nuclear Generation*, *supra* note 43; for Germany, *see* Gesetz zur geordneten Beendigung der Kernenergienutzung zur gewerblichen Erzeugung von Elektrizität [Act on the Structured Phase-Out of Nuclear Power for the Commercial Production of Electricity], Apr. 22, 2002, BGBl. I, at 1351 (F.R.G.); for Belgium, *see* Wet houdende de geleidelijke uitstap uit kernenergie voor industriële elektriciteitsproductie [Act on the Phase-Out of Nuclear Energy for the Purposes of the Industrial Production of Electricity], Jan. 31, 2003, Belgisch Staatsblad [Official Gazette of Belgium], Feb. 28, 2003, p. 9879 (Belg.); for Slovakia, *see* Act Concerning the Conditions of Accession of the Czech Republic et al., Protocol No. 9, art. 1, Sept. 23, 2003, 2003 O.J. (L 236) 954; for Lithuania, *see id.* Protocol No. 4, art. 1, 2003 O.J. (L 236) 944; *Lithuania Shuts Soviet-Built Reactor*, *supra* note 5; for the Russian Federation, *see* SERGEI KHARITONOV, BELLONA FOUND., THE LENINGRAD NUCLEAR POWER PLANT AS A MIRROR OF THE RUSSIAN ATOMIC ENERGY INDUSTRY 13 (2004); for Armenia, *see* John M. Gleason, *The Decision to Reactivate a First-Generation Soviet Nuclear Power Plant: Conceptual and Decision-Analytic Frameworks*, 8 RISK 39, 39, 62 (1997); for China, *see* Kadak, *supra* note 9, at 78.

	No. of Reactors Currently Operating	Shut Down	Under Construction	% of 2008 Energy Production	Notes
Sweden	10	3	—	42.0	
Finland	4	—	1	29.7	
Switzerland	5	—	—	39.2	
Spain	8	2	—	18.3	
Italy	—	4	—	—	
Czech Republic	6	—	—	32.5	
Slovakia	4	3	—	56.4	Two reactors (Bohunice 1 and 2) were shut down as a condition of European Union accession.
Hungary	4	—	—	37.2	
Lithuania	—	2	—	72.9	Both reactors (Ignalina 1 and 2) were shut down as a condition of European Union accession. Both were RBMK-1500 model reactors, similar to the Chernobyl-4 reactor.
Slovenia	1	—	—	41.7	
Bulgaria	2	4	2	32.9	The four closed reactors were shut down as a condition of European Union accession.
Romania	2	—	—	17.5	
Former USSR					
Russian Fed'n	31	5	8	16.9	Eleven operating reactors (at Leningrad Nuclear Power Plant, Kursk and Smolensk) are the same RBMK-1000 model as the Chernobyl-4 reactor. One is a fast neutron breeder reactor.
Ukraine	15	4	2	47.4	The four Chernobyl reactors have been permanently shut down, and the badly damaged Chernobyl-4 reactor has been encased in a concrete sarcophagus.
Armenia	1	1	—	39.4	Both of Armenia's reactors (Metzamor 1 and 2) were shut down for safety reasons in 1989 after an earthquake. Armenia and Russia entered into a bilateral nuclear cooperation treaty to reopen Metzamor-2 in 1995.
Kazakhstan	—	1	—	—	
Asia					
Japan	55	3	2	24.9	
South Korea	20	—	5	35.6	
China	11	—	11	2.2	Three operating plants (Qinshan 1, 2, and 3) are indigenous, designed by Chinese engineers and built with Chinese-manufactured parts.
Taiwan	6	—	2	19.6	
India	17	—	6	2.0	Most are pressurized heavy water reactors; one reactor under construction is a fast neutron breeder reactor.
Pakistan	2	—	1	1.9	
Iran	—	—	1	—	
Africa					
South Africa	2	—	—	5.3	
Total	436	122	44		

C. *The Future of the Nuclear Power Industry*

Despite its slowdown in many Western countries in recent years, nuclear power generation has the potential to expand tremendously in the next few decades.[56] According to the International Atomic Energy Agency ("IAEA"), nuclear power generation is expected to increase by an amount ranging from 17% to as much as 92% between 2007 and 2030.[57]

According to the IAEA, as of December 31, 2008, forty-four reactors were under construction in fourteen countries, including the first nuclear plant in Iran.[58] Some forty-seven additional reactors are planned for future construction in seven countries, mostly developing countries, including twenty-four planned reactors in China.[59] Western countries, eager to sell nuclear technology to developing countries, have encouraged this trend. For example, French President Nicholas Sarkozy has called nuclear power "the energy of the future" and supports the export of French nuclear power to the developing world; he has proposed to sell French nuclear reactors to the United Arab Emirates, Morocco, and Libya.[60] The United States recently signed an agreement to provide nuclear technology to India.[61]

There is a significant potential for the expansion of nuclear power generation in the developed world, as well. As we have seen, the nuclear reactors under construction include units in France, Finland, and the United States.[62] Although Germany and Belgium have enacted legislation to phase out nuclear power,[63] it remains to be seen how long these laws will remain in effect. German Chancellor Angela Merkel has expressed opposition to the nuclear phaseout.[64] In the United States, as of June 30, 2009, the Nuclear Regulatory Commission ("NRC") had received applications for combined construction and operation licenses for twenty-eight new reactors at eighteen power plants.[65] In Canada, the Canadian Nuclear Safety Commission has recently received license applications for construction of up to eight new reactors.[66] These proposed reactors are not included in the IAEA list of forty-seven "planned" reactors as they have not yet been licensed.

---

[56] *See supra* notes 7–16 and accompanying text.

[57] IAEA, *Energy, Electricity and Nuclear Power: Developments and Projections — 25 Years Past and Future*, at 67, IAEA Doc. STI/PUB/1304 (Jan. 29, 2008).

[58] IAEA, *Nuclear Power Reactors*, *supra* note 5, at 28–29 tbl.13.

[59] *Id.* at 26–27 tbl.12.

[60] Molly Moore, *Sarkozy Pushes Nuclear Energy in Mideast*, WASH. POST, Jan. 20, 2008, at A22; *see also Power Struggle*, ECONOMIST, Dec. 6, 2008, at 81.

[61] Press Release, U.S. Dep't of State, U.S. and India Release Text of 123 Agreement (Aug. 3, 2007), *available at* http://merln.ndu.edu/archivepdf/india/state/90157.pdf; *see also* Peter Baker, *Senate Approves India Nuclear Treaty*, N.Y. TIMES, Oct. 2, 2008, at A8.

[62] *See supra* notes 33, 45, 53 and accompanying text.

[63] *See supra* note 55 and accompanying table.

[64] *Merkel Nudges for Nuclear Power Comeback*, SPIEGEL ONLINE, Mar. 7, 2007, http://www.spiegel.de/international/germany/0,1518,492202,00.html.

[65] U.S. NUCLEAR REGULATORY COMM'N, *supra* note 34, at 43.

[66] CANADIAN NUCLEAR SAFETY COMM'N, *supra* note 55, at 50–51.

III. The Generation of Spent Nuclear Fuel

Operation of a nuclear power plant generates a mass of highly radioactive spent fuel that must be properly managed. Most nuclear power plants are fueled with enriched uranium oxide — uranium in which the concentration of the fissible isotope uranium-235 has been increased above natural levels — although a few reactor designs use different types of fuel.[67] The enriched uranium oxide is formed into small pellets about 0.8 centimeters in diameter and placed in zirconium alloy tubes three or four meters long and one centimeter in diameter, which comprise the fuel rods. The fuel rods are bundled into fuel assemblies of several hundred rods. The typical commercial reactor core contains hundreds of assemblies and thousands of individual fuel rods.[68]

As the reactor operates, uranium-235 atoms are split into atoms of lighter elements, such as strontium and cesium. This nuclear fission releases both fast-moving neutrons, which propagate the chain reaction, and energy in the form of heat, which powers the reactor. At the same time, some neutrons are captured, forming heavier isotopes of uranium, neptunium, plutonium, americium, and curium.[69] After about three years, the concentration of fission products increases and the uranium-235 decreases such that the chain reaction can no longer be sustained. Periodically, the nuclear reactor must be shut down, and the "spent" fuel removed and replaced with fresh fuel.[70]

When spent fuel is removed from the reactor, it emits extremely high levels of ionizing radiation, including intense gamma radiation.[71] The source of much of this radiation is the fission byproducts that have accumulated in the fuel. The continuous radioactive decay taking place in the spent fuel generates considerable heat, so it is also thermally hot.[72] The material is very dangerous and must be handled remotely. A person standing a meter away from a nuclear assembly that has been out of the reactor for several years could receive a lethal dose of radiation within minutes.[73] Many of the fission byproducts in spent fuel are relatively short-lived, with half-lives of a few hours or a few days, so much of the radioactivity in spent fuel dissipates rapidly.[74] After one year, the level of radioactivity in spent nuclear fuel is

---

[67] Bodansky, *supra* note 2, at 205.

[68] *Id.* at 185–86.

[69] *Id.* at 209 tbl.9.2; James H. Saling & Audeen W. Fentiman, Radioactive Waste Management 56 (2d ed. 2002).

[70] Bodansky, *supra* note 2, at 213.

[71] *See generally id.* at 630–36 (discussing types of ionizing radiation).

[72] *Id.* at 239–40.

[73] Lisbeth Gronlund, David Lochbaum & Edwin Lyman, Union of Concerned Scientists, Nuclear Power in a Warming World 43 (2007).

[74] Bodansky, *supra* note 2, at 239–40. A half-life is the period of time it takes for the decay of fifty percent of the atoms in a given radioactive isotope. *Id.* at 663.

about 1.3% of the original level.[75] Nevertheless, some of the fission byproducts in spent fuel take much longer to decay. Beta-emitters such as cesium-137, strontium-90, and plutonium-241 have half-lives of decades and remain dangerous for several centuries. Other byproducts remain dangerous for tens or even hundreds of thousands of years.[76]

Worldwide, the nuclear power industry generates approximately 10,500 metric tons of heavy metal ("MTHM") spent fuel each year.[77] The IAEA estimates that the rate of generation will increase to 11,500 MTHM per year by 2010.[78] The total quantity of spent fuel that has been generated is about 280,000 MTHM. Roughly one-third of this spent fuel has been reprocessed, leaving about 190,000 MTHM awaiting disposal.[79] The IAEA estimates that the total quantity of spent fuel needing disposal will be as much as 445,000 MTHM by 2020.[80]

IV. The Storage of Spent Nuclear Fuel

Temporary storage of spent nuclear fuel is necessary to allow it to cool before it is moved to a more permanent facility. But interim storage of spent nuclear fuel, for periods up to 100 years, has also been proposed as a management strategy.[81] The spent fuel can be kept in interim storage while a permanent facility is planned and constructed, provided that it is managed properly. The experience of the five countries discussed below serves to illustrate these points.

A. *A General Description of Spent Fuel Storage*

Currently, most spent nuclear fuel is stored temporarily, but often indefinitely, at the reactor site or, in some countries, at a centralized storage facility or at a reprocessing facility.[82] Because spent fuel is extremely radioactive for the first few years after it is removed from the reactor, it is very dangerous to handle. On-site storage for the short term allows the spent fuel to cool, both radioactively and thermally, before it is transported off-site for

[75] *Id.* at 239.

[76] *Id.* at 239–41. These byproducts include technicium-99, neptunium-237, plutonium-239, and plutonium-240. *Id.*

[77] IAEA, *Annual Report 2007*, at 22, IAEA Doc. GC(52)/9 (2008). Spent nuclear fuel is usually measured in metric tons of heavy metal, which includes both the remaining uranium fuel and its fission byproducts, and the zirconium cladding and other metal components of the nuclear fuel assemblies, which have become highly irradiated.

[78] Amaral et al., *supra* note 18, at 17.

[79] *Id.* at 18.

[80] *Id.*

[81] Nuclear Energy Agency, OECD, *The Role of Storage in the Management of Long-Lived Radioactive Waste*, at 27, OECD Doc. NEA No. 6043 (Dec. 1, 2006) [hereinafter OECD, *The Role of Storage*].

[82] IAEA, *Country Nuclear Fuel Cycle Profiles*, at 9–10, IAEA Doc. STI/DOC/010/425 (2d ed. 2005) [hereinafter IAEA, *Country Profiles*].

long-term storage, reprocessing, or disposal.[83] Indeed, most nuclear power plants were designed to store spent fuel on-site for a period of time.

Spent fuel assemblies are usually stored on-site in water filled containment pools, sometimes ironically referred to as "swimming pools," located near to the nuclear reactor. Circulating water in the containment pools serves to cool the spent fuel assemblies and to shield the radiation.[84] However, because final repositories for spent fuel do not exist, nuclear plant operators in many countries have had to store much larger quantities of spent fuel on-site for much longer periods than originally anticipated.[85]

To supplement storage capacity, many plants are now using dry cask storage. The spent fuel assemblies are placed in a specially designed steel and concrete container, which is filled with an inert gas and bolted and welded shut.[86] First used in the United States in 1986,[87] similar forms of dry storage are now common throughout the world.[88]

In some countries, notably Sweden, spent fuel is eventually moved off-site for temporary storage at an interim storage facility. Other countries are considering this approach as on-site storage capacity steadily decreases. In those countries that reprocess spent fuel — the United Kingdom and France — some spent fuel is also stored off-site at the reprocessing facility.

B. *Spent Fuel Storage in the United States and Europe*

1. *The United States*

As of 2009, the United States has approximately 60,000 MTHM spent fuel in storage, and the quantity is increasing by approximately 2000 MTHM per year.[89] This waste is stored mostly at the reactor sites, including reactors that have now been shut down, but some of it is stored at a few off-site facilities. It is stored in both containment pools and dry casks.[90] The NRC regulates the storage of spent nuclear fuel, both on and off the reactor site, through licenses and regulations. The temporary storage of spent fuel in containment pools on-site at operating power plants is generally covered under the license for the plant. However, reconfiguration of a containment pool to increase its capacity requires an amendment to the license.[91]

---

[83] OECD, *The Role of Storage*, *supra* note 81, at 18.
[84] SALING & FENTIMAN, *supra* note 69, at 62–65.
[85] *See infra* text accompanying notes 130–135 (discussing issues with spent fuel storage).
[86] U.S. NUCLEAR REGULATORY COMM'N, *supra* note 34, at 77.
[87] BODANSKY, *supra* note 2, at 255.
[88] *See* IAEA, *Country Profiles*, *supra* note 82, at 23–87.
[89] U.S. NUCLEAR REGULATORY COMM'N, *supra* note 34, at 76.
[90] *Id.* at 76–83.
[91] *See* Lower Alloways Creek Twp. v. Pub. Serv. Elec. & Gas Co., 687 F.2d 732 (3d Cir. 1982) (affirming NRC action amending a plant's license to increase the plant's containment pool storage capacity).

The temporary storage of spent fuel in dry casks is also subject to licensing requirements under the NRC regulations.[92] The requirements differ depending on whether the storage installation is on or off the reactor site, as explained below. As of 2009, fifty-four dry storage installations had been licensed; they held thousands of spent fuel assemblies in 1100 individual dry casks.[93]

Dry cask storage *on* the reactor site requires only a general license, or "license by rule."[94] No license application is necessary for such storage, although the operator must first notify and register the casks with the NRC.[95] The casks must be of a design approved and certified by the NRC.[96] A general license for dry cask storage terminates twenty years after the date the cask is first used, but it can be renewed for another twenty years.[97] In June 2009, thirty-nine installations were covered by general licenses.[98]

Dry cask storage at an installation *off* the reactor site requires a site-specific license from the NRC.[99] The maximum duration for a site-specific license is twenty years, although the license may be renewed for another twenty years.[100] As of June 2009, the NRC had issued fifteen site-specific licenses for storage installations.[101] The NRC recently proposed to extend the maximum term for initial and renewed storage licenses of both types from twenty to forty years.[102]

The United States has also considered the development of a "monitored retrievable storage" facility to store spent nuclear fuel temporarily until a final disposal facility begins operation. The Nuclear Waste Policy Act of 1982 ("NWPA")[103] required the Department of Energy ("DOE") to study the feasibility of such a facility and to submit to Congress a proposal for the construction of one.[104] DOE proposed three candidate sites, a preferred site and two alternates, all of them in Tennessee.[105] The DOE proposal was met with considerable political opposition from the state,[106] as well as an unsuc-

---

[92] *See* 10 C.F.R. § 72.2 (2009).

[93] U.S. NUCLEAR REGULATORY COMM'N, *supra* note 34, at 77, 79.

[94] 10 C.F.R. § 72.210.

[95] *Id.* § 72.212(b)(1).

[96] *Id.* § 72.214.

[97] *Id.* § 72.212(a)(3).

[98] U.S. NUCLEAR REGULATORY COMM'N, *supra* note 34, at 83.

[99] *See* 10 C.F.R. § 72.6(e).

[100] *Id.* § 72.42(a).

[101] U.S. NUCLEAR REGULATORY COMM'N, *supra* note 34, at 83.

[102] *See* License and Certificate of Compliance Terms, 74 Fed. Reg. 47,126, 47,128 (Sept. 15, 2009).

[103] Pub. L. No. 97-425, 96 Stat. 2201 (codified as amended at 42 U.S.C. §§ 10101–10270 (2006)).

[104] *Id.* § 141(b), 96 Stat. at 2242 (current version at 42 U.S.C. § 10161(b)); *see also* Nicholas Kirkpatrick Brown, *Monitored Retrievable Storage Within the Context of the Nuclear Waste Policy Act of 1982*, 52 TENN. L. REV. 739 (1985).

[105] Announcement of Identification of Candidate Sites for a Proposal to Congress for a Monitored Retrievable Storage Facility, 50 Fed. Reg. 16,536 (Apr. 26, 1985).

[106] ROBERT VANDENBOSCH & SUSANNE E. VANDENBOSCH, NUCLEAR WASTE STALEMATE 76–79 (2007).

cessful legal challenge.[107] In 1987, Congress expressly annulled the DOE proposal[108] and barred DOE from proceeding further with monitored retrievable storage until DOE had developed a site for a final repository.[109] Consequently, DOE has made little progress towards identifying a site for monitored retrievable storage.[110]

2. *The United Kingdom*

The United Kingdom has been reprocessing much of its spent nuclear fuel, which has reduced the volume of spent fuel in storage. The United Kingdom has approximately 423 MTHM spent fuel in storage as of 2008.[111] Some of the spent fuel is stored in dry containers at the Wylfa nuclear power plant.[112] But most of the spent fuel is transported from the reactor sites to the reprocessing facility at Sellafield, and then stored in pools prior to reprocessing.[113] Reprocessing has generated a large quantity of high-level radioactive liquid waste, also stored at Sellafield. This waste is treated by vitrification and will ultimately need to be disposed of.[114] Recognizing that a disposal facility will not be operating for many years, the U.K. government has determined that "a robust programme of interim storage must play an integral part in the long-term management strategy."[115] An interim storage facility would "hold waste for as long as it takes to identify and construct a geological disposal facility."[116] Accordingly, the U.K. Nuclear Decommissioning Authority is reviewing long-term storage options.[117]

3. *France*

France also reprocesses much of its spent nuclear fuel. France has approximately 11,300 MTHM spent fuel in storage.[118] The spent fuel is sent from the power plants to the reprocessing facility at La Hague for cooling in pools prior to reprocessing.[119] As in the United Kingdom, reprocessing has

---

[107] Tennessee v. Herrington, 806 F.2d 642 (6th Cir. 1986).

[108] Pub. L. No. 100-203, tit. V, § 142(a), 101 Stat. 1330-227, 1330-232 (1987) (codified at 42 U.S.C. § 10162(a)).

[109] *Id.* §§ 145(b)(1), 148(d)(1), 101 Stat. at 1330-234, 1330-235 (codified at 42 U.S.C. §§ 10165(b), 10168(d)(1)).

[110] VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 79. Efforts to locate a monitored retrievable storage facility on an Indian reservation have also been unsuccessful, largely due to political opposition. *See id.* at 97–104.

[111] Nuclear Energy Agency, OECD, *Nuclear Energy Data*, at 52 tbl.8.2, OECD Doc. NEA No. 6816 (Sept. 4, 2009) [hereinafter OECD, *Nuclear Energy Data*].

[112] IAEA, *Country Profiles*, *supra* note 82, at 85.

[113] *See id.*; *see also infra* Part V.B.2.

[114] *See infra* notes 166–167 and accompanying text.

[115] DEPARTMENT FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS ET AL., MANAGING RADIOACTIVE WASTE SAFELY: A FRAMEWORK FOR IMPLEMENTING GEOLOGICAL DISPOSAL 24, 2008, Cm. 7386 (U.K.) [hereinafter DEFRA, GEOLOGICAL DISPOSAL].

[116] *Id.*

[117] *Id.* at 26.

[118] OECD, *Nuclear Energy Data*, *supra* note 111, at 60 tbl.8.2.

[119] IAEA, *Country Profiles*, *supra* note 82, at 42.

generated high-level liquid waste, which is treated by vitrification and stored at La Hague for eventual disposal.[120] But France is considering the development of new interim storage facilities. Under the Planning Act of 2006, the government must conduct studies and investigations towards either creating new storage facilities or modifying existing facilities by 2015 for the storage of long-lived high-level and intermediate-level radioactive waste.[121]

4. *Sweden*

Sweden has approximately 4893 MTHM spent fuel in storage as of 2008.[122] Spent fuel is stored in pools on the reactor site for at least nine months.[123] During the late 1970s, Sweden sent its spent fuel to the United Kingdom for reprocessing at Sellafield.[124] Since 1985, the spent fuel has been sent to the Central Interim Storage Facility for Spent Nuclear Fuel ("CLAB"), located near the Oskarshamn nuclear power plant.[125] All Sweden's nuclear power plants, and CLAB, are located along the coast; spent fuel is transported to CLAB in a specially-designed ship, the *M/S Sigyn*.[126] At CLAB, the waste is stored in underground pools more than thirty meters below the ground surface. The spent fuel will remain at the interim storage facility for a minimum of thirty years to allow further radioactive decay before ultimate disposal in a repository.[127]

5. *Finland*

Finland has approximately 1684 MTHM spent fuel in storage at its two nuclear power stations.[128] The Loviisa power plant has a relatively small interim storage facility, while the Olkiluoto power plant has a larger spent fuel containment pool.[129]

C. *Issues with Spent Fuel Storage*

Storage of spent fuel has created a number of problems, especially given the nearly universal delays in locating and approving a suitable permanent disposal facility. In the United States, some reactor sites are now stor-

---

[120] AGENCE NATIONALE POUR LA GESTION DES DÉCHETS RADIOACTIFS, RADIOACTIVE WASTE AND RECOVERABLE MATERIAL IN FRANCE 17 (2006) (Fr.).

[121] Law No. 2006-739 of June 28, 2006, Journal Officiel de la République Française [J.O.] [Official Gazette of France], June 29, 2006, art. 3-3, p. 9721 (Fr.).

[122] OECD, *Nuclear Energy Data*, *supra* note 111, at 60 tbl.8.2.

[123] SVENSK KÄRNBRÄNSLEHANTERING AB, CLAB: CENTRAL INTERIM STORAGE FACILITY FOR SPENT NUCLEAR FUEL 2 (2006) (Swed.), *available at* http://www.skb.se/upload/publications/pdf/clabEng.8.3.pdf.

[124] *See* IAEA, *Country Profiles*, *supra* note 82, at 72, 77.

[125] SVENSK KÄRNBRÄNSLEHANTERING AB, *supra* note 123, at 2, 4.

[126] *Id.* at 2.

[127] *Id.* at 2, 4.

[128] OECD, *Nuclear Energy Data*, *supra* note 111, at 60 tbl.8.2.

[129] IAEA, *Country Profiles*, *supra* note 82, at 31–32.

ing up to five times as much spent fuel in their containment pools as was permitted in their original operating licenses.[130] The containment pools at some reactor sites have been reconfigured to hold more fuel assemblies more closely together.[131] This reconfiguration lessens water circulation around the spent fuel assemblies and increases the risk of a fire if there is a loss or partial loss of coolant, which could release dangerous amounts of ionizing radiation.[132] In addition, poorly managed storage of spent fuel has released radionuclide contamination into the environment. In the United States, containment pools at several nuclear power plants have leaked, releasing radioactive isotopes into groundwater.[133]

Nevertheless, with proper management, spent nuclear fuel can be stored safely and without significant harm to the environment. In particular, dry cask storage seems to be effective.[134] Temporary storage can provide an interim solution while disposal options are carefully considered and developed. However, interim storage must not be viewed as an endpoint: it must not be used as a convenient means to indefinitely postpone development of a facility for final disposal of radioactive wastes.[135]

V. THE REPROCESSING OF SPENT NUCLEAR FUEL

In the early days of nuclear power, planners assumed that spent fuel invariably would be reprocessed to recover the fissile uranium and plutonium isotopes.[136] The recovered uranium and plutonium would then be recycled as fresh fuel in what was known as a "closed-loop nuclear fuel cycle."[137] Several countries, particularly those with existing nuclear weapons programs, undertook to build reprocessing facilities for spent nuclear

---

[130] GRONLUND ET AL., *supra* note 73, at 47.

[131] SALING & FENTIMAN, *supra* note 70, at 66.

[132] NAT'L RESEARCH COUNCIL, *supra* note 19, at 23–24 (2006); Coplan, *supra* note 17, at 235.

[133] *See* Karl S. Coplan, *The Externalities of Nuclear Power: First, Assume We Have a Can Opener . . .* , 35 ECOLOGY L. CURRENTS 17, 19 (2008), http://elq.typepad.com/currents/2008/04/currents35-04-coplan-2008-0411.html. At the Indian Point nuclear power plant in Buchanan, New York, cracks were discovered in the concrete wall of the containment pool in September 2005. An investigation revealed that tritium, strontium-90, and nickel-63 had been released into groundwater and were discharging into the Hudson River. U.S. Nuclear Regulatory Comm'n Region 1, Inspection Report Nos. 05000003/2007010 and 05000247/2007010, Indian Point Nuclear Generating Station Units 1 & 2, at 1–4 (May 13, 2008), *available at* http://www.nrc.gov/reading-rm/adams.html (Accession No. ML081340425).

[134] The OECD's Nuclear Energy Agency concluded in 2006 that, "[l]ong-lived solid radioactive waste and spent nuclear fuel has been stored safely and securely in all OECD member countries now for several decades." OECD, *The Role of Storage*, *supra* note 81, at 38.

[135] *See id.* at 14 (An endpoint is "a final step in the management of a given waste, beyond which no further transport, conditioning or active care of the waste is necessary. Thus, storage . . . cannot be an endpoint by definition.").

[136] *See, e.g.*, William Hannum, Gerald E. Marsh & George S. Stanford, *Smarter Use of Nuclear Waste*, SCI. AM., Dec. 2005, at 84, 86.

[137] Most early nuclear engineers envisioned a closed-loop life cycle scenario for nuclear fuel involving reprocessing of spent fuel and use of the reprocessed fuel to generate more electricity. As discussed *supra* Part IV.A, most countries have instead temporarily stored

fuel from their commercial reactors. Some of these projects were eventually abandoned.[138] Today commercial reprocessing facilities operate in five countries: France, the United Kingdom, Russia, India, and Japan.[139] Although these facilities reprocess a significant quantity of spent fuel, reprocessing has not provided a satisfactory solution to the high-level waste disposal problem. Among other drawbacks, reprocessing itself produces an acidic, highly radioactive waste stream that must be managed and disposed of. These drawbacks are illustrated by the experience of the United States, the United Kingdom, and France, as discussed below.

A. *A General Description of Spent Fuel Reprocessing*

Though a variety of methods have been developed or proposed to reprocess spent fuel,[140] the so-called PUREX process (plutonium and uranium extraction) is the only method currently used for commercial spent fuel reprocessing. The first step in the PUREX process is to mechanically cut up the fuel rods into pieces and dissolve the spent fuel in nitric acid. An organic solvent, usually tributyl phosphate diluted with kerosene, is then introduced into the solution to extract the plutonium and uranium oxides. Next, the organic phase containing the preferentially extracted plutonium and uranium is partitioned from the aqueous phase containing the highly radioactive fission byproducts. The plutonium and uranium are then chemically stripped into separate streams, and the solvent is cleaned and recycled.[141] This process is usually repeated three times to attain a high level of recovery — greater than ninety-nine percent.[142]

The separated plutonium and uranium oxides can then be fabricated into mixed oxide ("MOX") fuel for reuse in certain nuclear reactors.[143] Most reactors can operate with at most one-third MOX fuel, due to the different properties of the plutonium in the MOX fuel.[144] After it has been used to fuel the reactor, spent MOX fuel is not reprocessed a second time but is placed in storage for eventual disposal.[145]

The residual aqueous-phase raffinate from the PUREX process, which is very acidic and laden with dangerously radioactive actinides, must be

---

spent fuel with the expectation that it will be permanently disposed of in a geologic vault or similar repository. *See, e.g.*, SALING & FENTIMAN, *supra* note 84, at 2–8.

[138] *See, e.g.*, *infra* notes 147–149 and accompanying text (describing this process in the United States).

[139] IAEA, *Spent Fuel Reprocessing Options*, at 11, IAEA Doc. TECDOC-1587 (Oct. 17, 2008) [hereinafter IAEA, *Spent Fuel*].

[140] *See generally id.*

[141] *See* SALING & FENTIMAN, *supra* note 69, at 108–11; NAT'L RESEARCH COUNCIL, NUCLEAR WASTES: TECHNOLOGIES FOR SEPARATION AND TRANSMUTATION 40–42, 147–50 (1996). These references both contain more detailed descriptions of the PUREX process.

[142] SALING & FENTIMAN, *supra* note 69, at 109.

[143] BODANSKY, *supra* note 2, at 116. In practice, however, MOX fuel is usually fabricated from freshly mined uranium, which is less costly. GRONLUND ET AL., *supra* note 73, at 49.

[144] *See* BODANSKY, *supra* note 2, at 216–17.

[145] GRONLUND ET AL., *supra* note 73, at 49.

managed as high-level radioactive waste. The waste is usually vitrified by mixing it into a matrix of molten borosilicate glass. Once it has cooled, the vitrified waste is placed in metal containers for storage and ultimate disposal.[146]

B. Spent Fuel Reprocessing in the United States and Europe

1. *The United States*

Currently, there is no commercial reprocessing of spent nuclear fuel in the United States, although a reprocessing program was initiated in the 1960s. In 1966, Nuclear Fuel Services received a license from the U.S. Atomic Energy Commission (predecessor to the NRC) to operate a commercial PUREX reprocessing plant at West Valley, New York. The facility operated from 1966 until 1972, when it shut down.[147] During its operation, the facility reprocessed 194 MTHM spent fuel.[148] Other reprocessing facilities were constructed in Illinois and South Carolina but never attained commercial operation.[149]

The U.S. government's position on reprocessing changed in 1974 when India exploded a nuclear weapon in the state of Rajasthan.[150] The weapon's plutonium was isolated with reprocessing equipment imported for "peaceful purposes."[151] Rightly concerned about the dangers of nuclear proliferation, President Ford announced that the United States would no longer view reprocessing as a necessary step in the nuclear fuel cycle. He called on other nations to place a three-year moratorium on the export of reprocessing technology.[152] In 1977, President Carter indefinitely deferred domestic efforts at reprocessing and continued the export embargo.[153] Although President Reagan reversed the ban on domestic reprocessing in 1981,[154] the nuclear industry has not taken the opportunity to invest in the technology. In 2006, the George W. Bush Administration proposed a Global Nuclear Energy Partner-

---

[146] *See* BODANSKY, *supra* note 2, at 214–15.

[147] CARTER, *supra* note 1, at 98–105 (describing the history of the West Valley reprocessing facility).

[148] IAEA, *Spent Fuel*, *supra* note 139, at 72 tbl.I-2.

[149] *See* NAT'L RESEARCH COUNCIL, *supra* note 141, at 165–66; *see also* CARTER, *supra* note 1, at 105–09.

[150] *See* Joseph S. Nye, *Nonproliferation: A Long-Term Strategy*, 56 FOREIGN AFF. 601, 605-06 (1978).

[151] GRONLUND ET AL., *supra* note 73, at 39.

[152] *See* Statement on Nuclear Policy, 3 PUB. PAPERS 2763, 2767–68 (Oct. 28, 1976).

[153] *See* Nuclear Power Policy: Remarks and a Question-and-Answer Session With Reporters on Decisions Following a Review of U.S. Policy, 1 PUB. PAPERS 581, 582–83 (Apr. 7, 1977). Responding to President Carter's statement, the NRC terminated licensing proceedings for reprocessing facilities. *See* Mixed Oxide Fuel: Order, 42 Fed. Reg. 65,334 (Dec. 30, 1977); Mixed Oxide Fuel: Memorandum of Decision, 43 Fed. Reg. 20,575 (May 12, 1978). The nuclear industry unsuccessfully challenged the Commission's action. *See* Westinghouse Elec. Corp. v. U.S. Nuclear Regulatory Comm'n, 598 F.2d 759 (3d Cir. 1979).

[154] *See* Statement Announcing a Series of Policy Initiatives on Nuclear Energy, PUB. PAPERS 903, 904 (Oct. 8, 1981).

ship ("GNEP") for expanded worldwide nuclear power production.[155] As a key component of the GNEP proposal, the United States would provide other nations with a reliable supply of nuclear fuel, and it would take back the spent fuel for reprocessing at a commercial facility in the United States, thus avoiding the spread of reprocessing technology.[156] However, the Obama Administration substantially curtailed GNEP in 2009, and is "no longer pursuing domestic commercial reprocessing."[157]

2. *The United Kingdom*

The United Kingdom has been reprocessing its spent nuclear fuel since the 1960s. British Nuclear Fuels Limited ("BNFL"), a government-owned corporation, operates a vast reprocessing facility at Sellafield (formerly Windscale), in Cumbria on the Irish Sea in northwestern England.[158] BNFL operates two PUREX reprocessing plants at Sellafield, the Magnox Reprocessing Plant ("B205") and the Thermal Oxide Reprocessing Plant ("THORP"). B205 began commercial operation in 1964 to reprocess spent fuel from Britain's Magnox reactors, and it is scheduled to be shut down in 2012.[159] Through the end of 2006, B205 had reprocessed some 42,000 MTHM spent Magnox fuel.[160] THORP began operating in March 1994 to reprocess spent uranium oxide fuel from the United Kingdom and from foreign countries.[161] But THORP has been plagued with operational problems and delays in fulfilling its contracts, and BNFL expects to shut the plant down by 2020.[162] Through 2006, BNFL had reprocessed 5800 MTHM spent uranium oxide fuel in THORP.[163] In 1996, BNFL completed construction of a MOX plant at Sellafield to fabricate MOX fuel.[164]

The liquid raffinate from reprocessing, which has been accumulating since the 1950s, is stored in twenty-one high-activity storage tanks at the Highly Active Liquor Evaporation and Storage Plant ("B215") at Sel-

---

[155] Press Release, U.S. Dep't of Energy, Department of Energy Announces New Nuclear Initiative (Feb. 6, 2006), *available at* http://www.ne.doe.gov/newsroom/2006PRs/nePR020606.html.

[156] *See* U.S. DEP'T OF ENERGY, GNEP-167312, Rev. 0, GLOBAL NUCLEAR ENERGY PARTNERSHIP STRATEGIC PLAN 1–10 (2007); *see also* U.S. DEP'T OF ENERGY, REPORT TO CONGRESS: SPENT NUCLEAR FUEL RECYCLING PROGRAM PLAN (2006) (describing GNEP's reprocessing component in greater detail).

[157] Notice of Cancellation of the GNEP Programmatic Environmental Impact Statement, 74 Fed. Reg. 31017, 31018 (June 29, 2009); *see also GNEP Turns to the World*, NUCLEAR ENG'G INT'L, May 7, 2009, at 9 (discussing cancellation of the domestic portion of the GNEP program).

[158] ERIK MARTINIUSSEN, BELLONA FOUND., NO. 8-2003, SELLAFIELD 10 (2003).

[159] *Id.* at 20–21.

[160] IAEA, *Spent Fuel*, *supra* note 139, at 72 tbl.I-2.

[161] MARTINIUSSEN, *supra* note 158, at 21. BNFL had contracts with plant operators in Germany, Italy, Japan, the Netherlands, Spain, Sweden, and Switzerland to reprocess spent fuel. *Id.* at 22.

[162] *Id.* at 21–24.

[163] IAEA, *Spent Fuel*, *supra* note 139, at 72 tbl.I-2.

[164] MARTINIUSSEN, *supra* note 158, at 26.

lafield.[165] It is first treated in evaporators, producing a concentrate called highly active liquor. The liquor is then vitrified at the Sellafield waste vitrification plant and placed in steel containers.[166] The containers are stored at the Sellafield compound pending ultimate disposal.[167] Approximately 1400 cubic meters (m^3) of high-level liquid waste and high-level vitrified waste is stored at the Sellafield facility.[168] In addition, the U.K. government has not yet decided whether to recycle into MOX fuel, or dispose of, the remaining stocks of plutonium and uranium separated from the spent fuel.[169] Approximately 3300 m^3 of plutonium and 80,000 m^3 of uranium are also stored at Sellafield.[170]

3. *France*

France has also been reprocessing spent fuel from commercial reactors since the 1960s, and it is considered the leader in commercial reprocessing. The first French reprocessing plant, the UP1 PUREX plant located in Marcoule in the Rhône Valley, was operated by the French Compagnie générale des matières nucléaires ("COGEMA") for civilian reprocessing from 1965 until it shut down in 1998.[171] Before its closure, the UP1 plant had reprocessed 18,000 MTHM spent fuel from France's gas-cooled reactors.[172] In 1966, COGEMA opened a second PUREX plant for the same purpose, the UP2 plant at La Hague. In 1976, COGEMA modified the UP2 plant to reprocess spent fuel from light water reactors, and in 1994 it upgraded and expanded the plant.[173] COGEMA built the UP3 PUREX plant, also at La Hague, in 1989 to reprocess spent fuel from foreign reactors, although it now serves domestic reactors, as well.[174]

The UP2 and UP3 plants at La Hague continue to operate, though they are now run by the French energy company AREVA NC, the successor to COGEMA. Through 2006, approximately 12,700 MTHM spent fuel from French reactors, and another 10,000 MTHM from foreign reactors, had been reprocessed at the two La Hague facilities.[175] The reprocessed plutonium, although not the uranium, is transported to the AREVA NC MELOX plant in

---

[165] *See* NUCLEAR INSTALLATIONS INSPECTORATE, HEALTH & SAFETY EXECUTIVE, THE STORAGE OF LIQUID HIGH LEVEL WASTE AT BNFL, SELLAFIELD 8–9 (2000) (U.K.).

[166] MARTINIUSSEN, *supra* note 158, at 64; *see also* COMM. ON RADIOACTIVE WASTE MGMT., MANAGING OUR RADIOACTIVE WASTE SAFELY 20 (2006) (U.K.) (describing the vitrification). As of 2001, the plant had generated 2280 containers of vitrified waste. MARTINIUSSEN, *supra* note 158, at 65.

[167] MARTINIUSSEN, *supra* note 158, at 66.

[168] DEFRA, GEOLOGICAL DISPOSAL, *supra* note 116, at 20.

[169] *See id.* at 17–18.

[170] *Id.* at 20.

[171] M. Giroux et al., *The Back-End of the Fuel Cycle in France: Status and Prospects, in* IAEA, *Spent Fuel*, *supra* note 139, at 85–86.

[172] IAEA, *Country Profiles*, *supra* note 82, at 34.

[173] Giroux et al., *supra* note 171, at 86.

[174] *See id.* at 83, 86. The company has contracts to reprocess spent fuel generated in Belgium, the Netherlands, Germany, Switzerland, and Japan. *See id.* at 83.

[175] *Id.* at 86; IAEA, *Spent Fuel*, *supra* note 139, at 72 tbl.I-2.

Marcoule for fabrication into MOX fuel assemblies.[176] EDF is required to use this MOX fuel in twenty of its commercial nuclear reactors.[177]

High-level liquid radioactive waste from the PUREX process is vitrified and placed in steel canisters for ultimate disposal.[178] By the end of 2005, AREVA NC had generated over 15,000 canisters of vitrified high-level radioactive waste.[179] AREVA NC has not been using the separated uranium in its new fuel production — as it is cheaper to use newly mined uranium — and has been using the separated plutonium for MOX fuel only very slowly. Consequently, the company has a stockpile of thousands of metric tons of separated uranium and nearly fifty metric tons of separated plutonium.[180]

C. *Issues with Spent Fuel Reprocessing*

Reprocessing spent nuclear fuel has proven to be very problematic and costly, and it is questionable whether it can be technically and economically practical. First, reprocessing does not solve the high-level waste disposal problem. As we have seen, reprocessing generates a significant volume of highly radioactive and very acidic liquid waste that itself must be managed as high-level radioactive waste. Moreover, although reprocessing reduces the total volume of waste, it does not significantly reduce its heat output, and it is the level of heat, not volume, that determines the capacity of the disposal facility. Consequently, reprocessing does not significantly reduce the size of the repository.[181] Furthermore, the uranium recovered from reprocessing — which comprises about ninety-five percent of the volume of the spent fuel — is presently more expensive to fabricate into fuel than is fresh uranium ore, leading reprocessing countries like France to stockpile recovered uranium instead of using it.[182] Similarly, only a fraction of the recovered plutonium is needed for MOX fuel fabrication, and the surplus may ultimately need to be managed as waste.[183] Finally, once MOX fuel is used in a reactor and becomes "spent," it is not reprocessed a second time and

[176] Giroux et al., *supra* note 171, at 90.

[177] *Id.* at 89; GRONLUND ET AL., *supra* note 73, at 51.

[178] AGENCE NATIONALE POUR LA GESTION DES DÉCHETS RADIOACTIFS, *supra* note 120, at 17.

[179] Giroux et al., *supra* note 171, at 91.

[180] GRONLUND ET AL., *supra* note 73, at 51.

[181] *Id.* at 49. If the facility's temperature exceeds water's boiling point, its integrity can be compromised. *Id.*

[182] *See id.*

[183] In the United Kingdom, for example, "stocks of separated plutonium far exceed" the quantity that could be used for MOX fuel in U.K. reactors. SELECT COMMITTEE ON SCIENCE AND TECHNOLOGY, MANAGEMENT OF NUCLEAR WASTE, 1998–9, H.L. 41-65, at 65 (U.K.) [hereinafter SELECT COMMITTEE, MANAGEMENT]. A House of Lords Committee recommended in 1999 that a "minimum strategic stock" of civil plutonium be maintained, and that the remainder be declared waste. *Id.* at 66. As of June 2008, the government had not reached a decision on the issue. DEFRA, GEOLOGICAL DISPOSAL, *supra* note 116, at 18.

must eventually be disposed of.[184] Thus, reprocessing does rather little to solve the disposal problem.

Second, reprocessing facilities have created significant environmental and public health problems. For example, because of leaks, spills, and other operational problems at the West Valley reprocessing plant, workers were frequently exposed to radiation levels above regulatory limits.[185] When the plant shut down in 1972, a large quantity of radioactive waste remained on the site, buried underground or stored in tanks.[186] The reprocessing plants at Sellafield have a long history of discharging radionuclides into the Irish Sea and into the atmosphere.[187] Consequently, it is estimated that the Irish Sea is contaminated with some 200 kg of plutonium, making it the most radioactively contaminated marine area in the world.[188] Discharges of radioactive waste from La Hague into the English Channel have also caused environmental and possible public health problems.[189]

Third, reprocessing of spent fuel enhances the possibilities for nuclear proliferation by separating the plutonium in the fuel from the more dangerously radioactive isotopes. Because spent fuel is highly radioactive, emitting lethal gamma radiation from fission byproducts, spent fuel must be handled remotely, by machine, to avoid a lethal radiation dose. As a result, as one study noted, "even terrorists willing to die for their cause would have little time to handle such . . . material before becoming acutely ill."[190] Plutonium, by contrast, emits alpha particles that are harmful only if inhaled or ingested, and can be handled relatively easily.[191] Reprocessing makes the plutonium more readily usable for fabricating a nuclear weapon by removing the "protection" provided by the gamma radiation.[192] As of 2005, the global stockpile of commercially separated plutonium was about 250 metric tons, which, by a crude measure, is enough plutonium to make 30,000 nuclear weapons.[193]

---

[184] *See* GRONLUND ET AL., *supra* note 73, at 49. France, which uses a significant amount of MOX fuel in its reactors, ships the spent MOX fuel to the reprocessing facility for indefinite storage. Frank N. von Hippel, *Rethinking Nuclear Fuel Recycling*, SCI. AM., May 2008, at 88, 89.

[185] *See* CARTER, *supra* note 1, at 98–102.

[186] *See id.* at 102–05. In 1980, by act of Congress, DOE took responsibility for treatment and disposal of liquid high-level radioactive waste stored in the tanks. *See id.* at 103; West Valley Demonstration Project Act, Pub. L. No. 96-368, 94 Stat. 1347 (1980) (codified at 42 U.S.C. § 2021a (2006)). The estimated cleanup cost to taxpayers was $700 to $800 million. CARTER, *supra* note 1, at 103.

[187] *See* MARTINIUSSEN, *supra* note 158, at 32–35, 38–39; WISE-PARIS, DOC. NO. PE 303.110, POSSIBLE TOXIC EFFECTS FROM THE NUCLEAR REPROCESSING PLANTS AT SELLAFIELD (UK) AND CAP DE LA HAGUE (FRANCE) 34–39 (2001).

[188] *See* MARTINIUSSEN, *supra* note 158, at 43.

[189] *See* WISE-PARIS, *supra* note 187, at 56–67.

[190] GRONLUND ET AL., *supra* note 73, at 43.

[191] *See id.* at 48.

[192] FRANK VON HIPPEL, INT'L PANEL ON FISSILE MATERIALS, RESEARCH REPORT NO. 3, MANAGING SPENT FUEL IN THE UNITED STATES: THE ILLOGIC OF REPROCESSING 3–4 (2007), *available at* http://www.fissilematerials.org/ipfm/site_down/rr03.pdf.

[193] *Id.* at 3.

Fourth, reprocessing has proven to be economically infeasible. One premise underlying the interest in reprocessing in the 1960s and 1970s was that naturally occurring uranium was a relatively scarce resource. Since then, large uranium deposits have been discovered in Canada and Australia.[194] Moreover, a recent study concluded that the costs of using reprocessed MOX fuel are roughly four times greater than the costs of using enriched uranium oxide fuel from mined uranium ore.[195] Although EDF uses MOX fuel in several of its nuclear power reactors, it is required to do so by French law.[196] BNFL in the United Kingdom does not use the MOX fuel it produces in its reactors.[197]

Because of these problems, most countries with nuclear power programs have elected not to reprocess spent nuclear fuel. Recently, several independent academic studies in the United States have affirmed that reprocessing is not a practical solution to the problem of spent nuclear fuel disposal.[198]

VI. The Disposal of Spent Nuclear Fuel

A. *A General Description of Spent Fuel Disposal*

The final disposition of spent nuclear fuel, or the high-level waste produced by reprocessing spent nuclear fuel, remains one of the most difficult problems with nuclear power. The many options that have been considered[199] — and mostly rejected — include using rockets to shoot the waste into the sun,[200] burying the waste beneath the deep seabed,[201] and burying the waste near the surface and monitoring it indefinitely.[202] Another option, akin to reprocessing, is transmutation of the waste into less radioactive and shorter-lived isotopes.[203]

---

[194] *See id.* at 7–8.

[195] *See* MASS. INST. OF TECH., *supra* note 10, at 44, 145–51.

[196] GRONLUND ET AL., *supra* note 73, at 51.

[197] MARTINIUSSEN, *supra* note 158, at 10.

[198] *See* NAT'L RESEARCH COUNCIL, *supra* note 141, at 2; MASS. INST. OF TECH., *supra* note 10, at 86; *cf.* UNIV. OF CHICAGO, THE ECONOMIC FUTURE OF NUCLEAR POWER A5-1 (2004) (noting reprocessing "would not materially affect the economic competitiveness of nuclear energy").

[199] *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 6–15.

[200] *See, e.g.*, Robin Dusek, Note, *Lost in Space?: The Legal Feasibility of Nuclear Waste Disposal in Outer Space*, 22 WM. & MARY ENVTL. L. & POL'Y REV. 181, 195–96 (1997).

[201] *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 13; Charles D. Hollister & Steven Nadis, *Burial of Radioactive Waste Under the Seabed*, SCI. AM., Jan. 1998, at 60. Deep seabed disposal, while technically feasible, is contrary to London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, Dec. 29, 1972, 26 U.S.T. 2403, 1046 U.N.T.S. 120. The Convention prohibits the dumping of wastes or other matter listed in Annex I. *Id.* art. IV. Annex I to the Convention lists "[h]igh level radioactive wastes . . . as unsuitable for dumping at sea." *Id.* Annex I(6).

[202] *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 8–10.

[203] *See id.* at 21–29; NAT'L RESEARCH COUNCIL, *supra* note 141, at 49–86.

The most widely accepted method for permanent disposal is in a land-based deep geologic repository. Each of the five subject countries plan to use this approach for the ultimate disposal of spent fuel and other high-level radioactive wastes. This Part examines the legal framework for high-level waste disposal in each of these countries, focusing on site selection, licensing, and substantive technical standards.

B. *Spent Fuel Disposal in the United States and Europe*

1. *The United States*

The United States has by far the largest inventory of spent fuel in storage pending ultimate disposal.[204] A triumvirate of government agencies, each with authority over a different aspect of the disposal problem, has undergone a lengthy and tortuously complex process to find a solution. By law, Congress has given DOE responsibility for selecting sites for disposal, the NRC responsibility for licensing the disposal facility, and the Environmental Protection Agency ("EPA") responsibility for setting environmental protection standards for the facility. As one court observed while reviewing this process, nuclear waste disposal "has vexed scientists, Congress, and regulatory agencies for the last half-century."[205] At this writing, it appears that the process has largely failed.

a. *Site Selection in the United States*

The United States has been considering disposal of nuclear waste in a geologic repository since the 1950s. In 1957, the National Academy of Sciences ("NAS") first recommended geological disposal as a feasible method for management of high-level radioactive waste.[206] During the 1960s and 1970s, DOE and its predecessor agencies investigated a number of possible disposal sites in various types of geologic formations, including salt formations in Kansas, basalt at the Hanford reservation in Washington, tuff at Yucca Mountain in Nevada, and salt deposits of the Salina Basin in the Great Lakes region. These investigations ran into strong political opposition and were abandoned.[207]

---

[204] *See* OECD, *Nuclear Energy Data*, *supra* note 111, at 60 tbl.8.2.

[205] Nuclear Energy Inst., Inc. v. EPA, 373 F.3d 1251, 1257 (D.C. Cir. 2004). This fifty-year history is partially recounted in CARTER, *supra* note 1, at 129–230; VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 35–198; and J. SAMUEL WALKER, THE ROAD TO YUCCA MOUNTAIN (2009).

[206] NAT'L RESEARCH COUNCIL, THE DISPOSAL OF RADIOACTIVE WASTE ON LAND (1957). The NAS committee, part of the Division of Earth Sciences, was "convinced that radioactive waste can be disposed of safely in a variety of ways and at a large number of sites in the United States." *Id.* at 3.

[207] *See* CARTER, *supra* note 1, at 145–76; VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 36–38.

Congress sought to compel a resolution of the issue with the enactment of the NWPA.[208] As part of the NWPA, Congress expressly found that the accumulation of spent nuclear fuel was a national problem; that such waste posed potential risks and needed safe and environmentally sound disposal; and that appropriate precautions were necessary to assure that spent fuel would not adversely affect public health and safety and the environment for present and future generations.[209] Congress further found that "[s]tate and public participation in the planning and development of repositories is essential."[210] Among the primary purposes of the legislation were establishing a schedule for the siting, construction, and operation of repositories that will be protective of the public and the environment; assigning responsibility to the federal government for disposal of spent nuclear fuel; and creating a fund comprised of payments from nuclear power plants to ensure that the costs of disposal of spent fuel are borne by the generators of such wastes.[211] Significantly, Congress adopted deep geologic repositories as the method of disposal of spent nuclear fuel in the NWPA.[212]

The NWPA established a byzantine procedure and an impossibly short schedule for the selection of repository sites.[213] It required DOE to nominate five sites for site characterization for the first repository, and another five for the second repository.[214] The NWPA required DOE to consider "the advantages of regional distribution";[215] the unwritten understanding was that the first site would be located in a western state, and the second in an eastern state.[216] DOE would then narrow the nominated sites,[217] and for those sites the President approved as candidate sites, DOE would conduct a detailed physical characterization.[218] DOE was also required to hold a public hearing on nominated and approved candidate sites and conduct an environmental

---

208 Nuclear Waste Policy Act of 1982, Pub. L. No. 97-425, 96 Stat. 2201 (1983) (codified as amended at 42 U.S.C. §§ 10101–10270 (2006)).

209 *See id.* § 111(a)(1), (2), (7), 96 Stat. at 2207 (current version at 42 U.S.C. § 10131(a)(1), (2), (7)).

210 *Id.* § 111(a)(6), 96 Stat. at 2207 (current version at 42 U.S.C. § 10131(a)(6)).

211 *See id.* § 111(b)(1), (2), (4), 96 Stat. at 2207–08 (current version at 42 U.S.C. § 10131(b)(1), (2), (4)).

212 The Act defines "repository" as a system licensed by the NRC for "the permanent deep geologic disposal of high-level radioactive waste and spent nuclear fuel." *Id.* § 2(18), 96 Stat. at 2204 (current version at 42 U.S.C. § 10101(18)); *see also* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 55.

213 *See* NAT'L RESEARCH COUNCIL, SOCIAL AND ECONOMIC ASPECTS OF RADIOACTIVE WASTE DISPOSAL 13 (1984) (noting the "tight schedule" could produce "insufficient attention to local concerns" or "inappropriate compromises").

214 NWPA § 112(b)(1)(A), (C), 96 Stat. 2201, 2208 (current version at 42 U.S.C. § 10132(b)(1)(A), (C)).

215 *Id.* § 112(a), 96 Stat. at 2208 (current version at 42 U.S.C. § 10132(a)).

216 *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 73.

217 NWPA § 112(b)(1)(B), (C), 96 Stat. 2201, 2208 (current version at 42 U.S.C. § 10132(b)(1)(B), (C)) (requiring recommendation of three initial sites by January 1, 1985, and three subsequent sites by July 1, 1989).

218 *See id.* § 113, 96 Stat. at 2211–12 (current version at 42 U.S.C. § 10133).

impact assessment.[219] After completing these steps for at least three sites, DOE could recommend to the President one site for the first repository and sites for subsequent repositories; the President could then recommend the sites to Congress.[220] Once the President made a recommendation, the governor or legislature of the state in which the site was to be located had sixty days — a remarkably short time — to object by submitting a notice of disapproval, or the selection would become final and effective.[221] But Congress reserved for itself the final site selection decision, and could pass a resolution approving the site, notwithstanding the state's disapproval.[222]

Once a repository site was selected, the NWPA established a short schedule for licensing. DOE was required to submit a license application to the NRC within ninety days after final site selection. The NRC was to approve or disapprove the application within three years.[223]

The nuclear power plant operators would pay the cost of developing the repositories. The NWPA established a Nuclear Waste Fund to be used for the identification, licensing, construction, operation, and decommissioning of the repositories, and authorized DOE to enter into contracts with power plant operators. Under the contracts, the plant operators would pay fees into the Fund, and in exchange DOE would take title to the spent fuel and begin disposing of it by January 31, 1998.[224]

The NWPA also limited the quantity of spent fuel that could be disposed of in the first repository to 70,000 MTHM.[225] The purpose of this limitation was to ensure that a second repository would be opened in another geographic location.[226]

It would be an understatement to say that the NWPA was not implemented as Congress had envisioned. The site selection process quickly fell behind schedule. In 1984, DOE issued guidelines[227] and draft assessments of

---

[219] *Id.* §§ 112(b)(1)(E), (2), 114(a)(1), (f), 96 Stat. 2209, 2213, 2216 (current version at 42 U.S.C. §§ 10132(b)(1)(E), (2), 114(a)(1), (f)). The environmental impact statement would be conducted pursuant to the National Environmental Policy Act of 1969, 42 U.S.C. §§ 4321–4370.

[220] *See* NWPA § 114(a)(1), (2)(A), 96 Stat. at 2213–14 (current version at 42 U.S.C. § 10134(a)(1), 2(A)). The President was obligated to make a recommendation for the first repository by March 31, 1987, and for the second repository by March 31, 1990, although he could extend these deadlines for up to one year. *Id.* § 114(a)(2), 96 Stat. at 2214 (current version at 42 U.S.C. § 10134(a)(2)).

[221] *Id.* § 116(b)(2), 96 Stat. at 2220 (current version at 42 U.S.C. § 10136(b)(2)). In several states, particularly in the West, the legislature only meets for a few months out of the year and would have considerable difficulty meeting this deadline. *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 56.

[222] NWPA § 115(c), 96 Stat. 2201, 2217 (current version at 42 U.S.C. § 10135(c)).

[223] *Id.* § 114(b), (d), 96 Stat. at 2214 (current version at 42 U.S.C. § 10134(b), (d)).

[224] *Id.* § 302, 96 Stat. at 2257–61 (current version at 42 U.S.C. § 10222(a)). By regulation, DOE published standard terms for such contracts. *See* 10 C.F.R. § 961.11 (2010).

[225] NWPA § 114(d), 96 Stat. at 2215 (current version at 42 U.S.C. § 10134(d)).

[226] Richard B. Stewart, *U.S. Nuclear Waste Law and Policy: Fixing a Bankrupt System*, 17 N.Y.U. ENVTL. L.J. 783, 794 (2008).

[227] General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories, 49 Fed. Reg. 47,714 (Dec. 6, 1984) (codified at 10 C.F.R. § 960 (2010)). DOE was approximately five months late in issuing the guidelines. Several states and an environmental

nine sites, and accepted public comments on the assessments.[228] In May 1986, DOE nominated five of the sites for the first repository.[229] That year it also recommended three of those sites to the President for characterizations: Yucca Mountain, Nevada, a volcanic tuff formation; Deaf Smith County, Texas, a bedded salt formation; and Hanford, Washington, a basalt formation.[230] These recommendations came nearly one and a half years late. Almost immediately, the state of Nevada filed a lawsuit challenging the Yucca Mountain recommendation.[231] Also in May 1986, Energy Secretary Herrington announced that DOE would delay indefinitely identifying a second site.[232] This decision was widely perceived as motivated by politics: the Republican administration feared losses in key Senate races taking place in four eastern states under consideration for a repository.[233] According to the NWPA sponsor, Rep. Morris Udall, "to help a few office seekers in the last election, the administration killed the eastern repository program, shattering the delicate regional balance at the heart of the 1982 Act." The program, he lamented, "is in ruins."[234] Furthermore, as it became apparent that DOE would not meet the 1998 deadline to begin disposal, DOE declared that it did not have an unconditional contractual obligation to accept the spent fuel by that date in the absence of a repository.[235] But several utilities that had been paying the fees successfully appealed, and DOE's determination was vacated.[236]

Congress responded to the delay and controversy by enacting the Nuclear Waste Policy Amendments of 1987.[237] Most significantly, the legislation directed the selection of Yucca Mountain as the site for the repository.[238]

organization challenged the guidelines, unsuccessfully. Nevada v. Watkins (*Watkins II*), 939 F.2d 710 (9th Cir. 1991).

[228] Availability of Draft Environmental Assessments for Proposed Site Nominations and Announcement of Public Information Meetings and Hearings, 49 Fed. Reg. 49,540 (Dec. 20, 1984).

[229] Nomination of Five Sites for the First High-Level Nuclear Waste Repository, 51 Fed. Reg. 19,783 (June 2, 1986).

[230] *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 61, 64.

[231] Nevada v. Watkins (*Watkins I*), 914 F.2d 1545, 1550 (9th Cir. 1990), *cert. denied*, 499 U.S. 906 (1991); *see also* CARTER, *supra* note 1, at 407; VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 65. The challenge was not successful.

[232] *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 72.

[233] *See* Stewart, *supra* note 226, at 796 n.35.

[234] 133 CONG. REC. 37,068 (1987).

[235] Final Interpretation of Nuclear Waste Acceptance Issues, 60 Fed. Reg. 21,793, 21,793–94 (May 3, 1995).

[236] Ind. Mich. Power Co. v. U.S. Dep't of Energy, 88 F.3d 1272 (D.C. Cir. 1996). Subsequently, courts have found DOE liable to electric utilities for damages for breach of contract. *See, e.g.*, Carolina Power & Light Co. v. United States, 573 F.3d 1271 (Fed. Cir. 2009), *reh'g denied*, No. 2008-5108, 2009 U.S. App. LEXIS 26471 (Fed. Cir. Nov. 3, 2009); Yankee Atomic Elec. Co. v. United States, 536 F.3d 1268 (Fed. Cir. 2008).

[237] Pub. L. No. 100-203, tit. V, subtit. A, 101 Stat. 1330-227 (1987) (codified in scattered sections of 42 U.S.C. ch. 108 (2006)).

[238] The legislation made the site characterization requirements of the NWPA applicable only to Yucca Mountain, and required DOE to cease site-specific activities at all other candidate sites. *See* 42 U.S.C. §§ 10133, 10172(a)(1).

The legislation left unchanged the procedures for state disapproval and congressional override, but the procedures now applied only to Nevada.[239]

Nevertheless, it was not until February 14, 2002, nearly fifteen years later, that DOE recommended the Yucca Mountain site to President George W. Bush. The next day, President Bush recommended the site to Congress.[240] As expected, on April 8 the Nevada Governor issued a notice of disapproval, which Congress then overrode.[241] After more than twenty years, Yucca Mountain had formally been selected as the first and only U.S. repository for the disposal of high-level radioactive waste. Ironically, only a few years later, DOE estimated that the volume of spent fuel destined for Yucca Mountain would exceed the design capacity of the repository — 70,000 MTHM — by 2010.[242] It remains unclear whether Yucca Mountain will ever receive any waste for disposal. The Obama Administration opposes the Yucca Mountain facility and has begun phasing out funding for the project; according to Energy Secretary Chu, "[b]oth the President and I have made clear that Yucca Mountain is not a workable option."[243]

b. Licensing in the United States

The Atomic Energy Act requires DOE to obtain a license from the NRC to operate a geologic disposal site,[244] subject to NRC's technical conditions.[245] Although the NWPA established a tight licensing schedule, it was never followed. In September 2008, DOE submitted an application to the NRC for Yucca Mountain; the NRC docketed the application and is now reviewing it.[246] Not surprisingly, Nevada has challenged the application,[247] and the NRC will allow public hearings on the license.[248] However, DOE

---

[239] *See id.* § 10135.

[240] *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 139–40.

[241] Approval of Yucca Mountain Site, Pub. L. No. 107-200, 116 Stat. 735 (2002) (codified at 42 U.S.C. § 10135 note); *see* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 140 (discussing history).

[242] U.S. DEP'T OF ENERGY, NO. RW-0595, THE REPORT TO THE PRESIDENT AND THE CONGRESS BY THE SECRETARY OF ENERGY ON THE NEED FOR A SECOND REPOSITORY 5 (2008). According to DOE, it is technically feasible to expand the design capacity of Yucca Mountain substantially. *Id.* at 7–9. However, because the 70,000 MTHM limit is mandated by the NWPA, such expansion would require an act of Congress. *See supra* note 225 and accompanying text.

[243] *The President's Fiscal Year 2010 Budget for the Department of Energy: Hearing Before the Sen. Budget Comm.*, 111th Cong. 3 (Mar. 11, 2009) (statement of Steven Chu, Sec'y of Energy).

[244] *See* 42 U.S.C. § 2077(a); *see also* 10 C.F.R. § 60.3 (2009).

[245] *See* 10 C.F.R. §§ 63.42–.43.

[246] Fact Sheet, Nuclear Regulatory Comm'n, Licensing Yucca Mountain 2 (Apr. 2009), *available at* http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-yucca-license-review.html.

[247] Press Release, Nev. Office of the Attorney Gen., Nevada Points Out at Least 229 Objections in Petition Filed Friday to Deny License for Nuclear Waste Dump Planned for Yucca Mountain (Dec. 19, 2008) (on file with the Harvard Law School Library).

[248] *See* 10 C.F.R. § 2.309(a) (2009); *see also* 10 C.F.R. pt. 2, subpts. C, J (2009).

has moved to withdraw the application, so it is an open question whether those hearings will ever take place.[249]

c. Technical Standards in the United States

Under the NWPA, EPA was to issue "generally applicable standards" to protect the environment from releases of radiation from underground nuclear repositories by 1984.[250] After a lengthy and litigious process, EPA issued final revised standards in December 1993.[251] However, the generally applicable EPA standards would not apply to Yucca Mountain. In 1992, having directed DOE to select the Yucca Mountain site, Congress also directed EPA to issue separate environmental standards exclusively for Yucca Mountain. EPA was to contract with the NAS to perform a study and make "findings and recommendations on reasonable standards for protection of the public health and safety" from releases from the Yucca Mountain repository.[252]

The NAS issued its report in 1995.[253] Based on this report, EPA promulgated health protection standards for Yucca Mountain in 2001.[254] EPA set standards to protect public health during the placement of spent fuel and after closure of the repository, and to protect groundwater.[255] The standards were to be met for a period of 10,000 years.[256] Environmental groups and the State of Nevada, among others, challenged these standards in court.[257] Although the court generally upheld the standards, it vacated the 10,000-year compliance period,[258] finding that it did not appropriately address the period that the NAS report found to present the highest risk of radiation releases, from 10,000 years to 1,000,000 years after disposal.[259]

On October 15, 2008, EPA issued revised environmental protection standards comprised of four distinct numerical standards.[260] Three standards set maximum annual limits on public exposure to radiation during emplace-

---

[249] Press Release, U.S. Dep't of Energy, Department of Energy Files Motion to Withdraw Yucca Mountain License Application (Mar. 3, 2010), *available at* http://www.energy.gov/news/8721.htm.

[250] NWPA § 121(a), 96 Stat. 2201, 2228 (current version at 42 U.S.C. § 10141(a) (2006)).

[251] *See* Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes, 58 Fed. Reg. 66,398, 66,398 (Dec. 20, 1993) (recounting history).

[252] Energy Policy Act of 1992, Pub. L. No. 102-486, § 801(a)(1), (2), 106 Stat. 2776, 2921–22 (1992) (codified at 42 U.S.C. § 10141 note).

[253] NAT'L RESEARCH COUNCIL, TECHNICAL BASES FOR YUCCA MOUNTAIN STANDARDS (1995).

[254] Public Health and Environmental Radiation Protection Standards for Yucca Mountain, 66 Fed. Reg. 32,074 (June 13, 2001).

[255] *Id.* at 32,132–35.

[256] *Id.* at 32,097.

[257] Nuclear Energy Inst., Inc. v. EPA, 373 F.3d 1251 (D.C. Cir. 2004).

[258] *Id.* at 1257.

[259] *Id.* at 1266–73.

[260] Public Health and Environmental Radiation Protection Standards for Yucca Mountain, 73 Fed. Reg. 61,256 (Oct. 15, 2008) (codified at 40 C.F.R. pt. 197 (2009)).

ment,[261] after permanent closure, and resulting from human intrusion into the repository.[262] To comply with the court's ruling, the standards apply for a period of 1,000,000 years, but after 10,000 years the standards are substantially less stringent.[263] The fourth standard protects groundwater, but only for the first 10,000 years.[264] Moreover, the standards must be met only in the "accessible environment," the area five to ten kilometers away from the facility.[265] Thus, application of the groundwater standards is substantially limited, both temporally and spatially.

As in the original 2001 regulations, the revised 2008 regulations require DOE to consider "geology, hydrogeology, and climate" in demonstrating compliance.[266] But the 2008 regulations go further, requiring DOE to assess "the effects of seismic and igneous scenarios," and "the effects of increased water flow through the repository as a result of climate change."[267] Other than the extended compliance period — which does not cover the groundwater standard — and the specific requirements for assessing compliance, the final revised standards are very similar to the original, vacated standards, and the State of Nevada has also challenged these revised standards.[268]

2. *The United Kingdom*

The United Kingdom has produced commercial nuclear power since the 1950s, and has been reprocessing spent nuclear fuel rather than directly dis-

---

[261] The dose limit to a member of the public in the general environment is 150 microsieverts (15 millirems) for the first 10,000 years. 40 C.F.R. § 197.4. A "member of the public" is anyone other than a radiation worker. *Id.* § 197.2.

[262] The dose limits to a maximally exposed member of the public resulting from human intrusion are 150 microsieverts (15 millirems) for the first 10,000 years after disposal, and 1 millisievert (100 millirems) for the period from 10,000 to 1,000,000 years after disposal. *Id.* § 197.25. A "maximally exposed individual" is one who lives near the repository at the highest concentration of radionuclides and who obtains two liters of drinking water per day from a well drilled into groundwater with the highest concentration of radionuclides. *Id.* § 197.21. "Human intrusion" means any human activity that breaches the Yucca Mountain disposal facility. *Id.* § 197.12.

[263] For the first 10,000 years following disposal, the dose limit for a maximally exposed member of the public is 150 microsieverts (15 millirems), but after 10,000 years it is 1 millisievert (100 millirems). *Id.* § 197.20(a)(1)–(2).

[264] *Id.* §§ 197.30, 197.31. The maximum limits for radionuclides in groundwater are 5 picocuries per liter for radium, 15 picocuries per liter for gross alpha activity, and 40 microsieverts (4 millirems) for beta activity, in a "representative volume" of water. *Id.* § 197.30 tbl.1. These standards are identical to the maximum contaminant levels for drinking water supplies established under the Safe Drinking Water Act. *See id.* § 141.66.

[265] *Id.* § 197.30. The "accessible environment" extends approximately ten kilometers from the site "in the predominant direction of groundwater flow" (i.e., to the south), and five kilometers beyond the facility in every other direction. *Id* § 197.12.

[266] *Id.* § 197.15.

[267] *Id.* § 197.36(c)(1), (2). The NAS had recommended that climate change, seismicity, and volcanism be considered in assessing compliance. NAT'L RESEARCH COUNCIL, *supra* note 253, at 91–95.

[268] Press Release, Nev. Office of the Attorney Gen., Attorney General Catherine Cortez Masto Files Challenge to Yucca Mountain Radiation Standard (Oct. 10, 2008), *available at* http://www.state.nv.us/nucwaste/policy.htm.

posing of it.[269] But reprocessing in the United Kingdom has produced a substantial quantity of high-level waste requiring proper disposal.[270] Despite the long history of its nuclear power industry, neither the industry nor the U.K. government had paid much attention to disposal of radioactive waste until the mid 1970s.[271] Since that time, despite a flurry of government reports, very little progress has been made in finding a solution. The United Kingdom attempted to locate a disposal site with little participation from the public or the local community; as in the United States, the effort failed largely due to local opposition.

a. Site Selection in the United Kingdom

The disposal question came to the forefront in 1976, when the Royal Commission on Environmental Pollution published a report — commonly called the Flowers Report after its principal author — addressing nuclear power.[272] The report stated bluntly: "Radioactive waste management is a profoundly serious issue."[273] It concluded that "[t]here should be no commitment to a large programme of nuclear fission power until . . . a method exists to ensure the safe containment of long-lived, highly radioactive waste for the indefinite future."[274] The Flowers Report recommended that a statutory body be established to advise the government on radioactive waste management, and that an executive agency be established to develop and manage waste disposal facilities.[275]

In response, the Government created the Radioactive Waste Management Advisory Committee in 1978 and the Nuclear Industry Radioactive Waste Management Executive in 1982.[276] The latter became a government owned corporation, U.K. Nirex Limited ("Nirex"), in 1985.[277] Nirex was to construct and operate land disposal facilities only for low- and intermediate-level waste.[278] The Government decided that high-level waste would be stored aboveground for approximately fifty years prior to disposal, allowing the radioactivity to decay so the waste could be more easily handled.[279] Thus, the Government effectively postponed for years any action on a disposal facility for high-level waste.

---

269 *See supra* Part V.B.2.

270 U.K. reprocessing has produced approximately 1400 m^3 of high-level liquid waste and high-level vitrified waste. DEFRA, GEOLOGICAL DISPOSAL, *supra* note 116, at 120.

271 *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 225.

272 ROYAL COMMISSION ON ENVIRONMENTAL POLLUTION, SIXTH REPORT: NUCLEAR POWER AND THE ENVIRONMENT, 1976, Cm. 6618 (U.K.). The principal author, Sir Brian Hilton Flowers, is a noted British physicist.

273 *Id.* at 164.

274 *Id.* at 202.

275 *Id.* at 162–63.

276 *See* SELECT COMMITTEE, MANAGEMENT, *supra* note 183, at 19.

277 OECD, *Nuclear Legislation in OECD Countries: United Kingdom*, at 33 (2003).

278 SELECT COMMITTEE, MANAGEMENT, *supra* note 183, at 19.

279 *Id.* at 20.

Even the limited effort to locate a site for low- and intermediate-level disposal proved unsuccessful. In 1983, Nirex announced its choice of a former anhydrite mine in Bellingham for disposal of long-lived intermediate-level waste.[280] The announcement met with strong local opposition, and the plan was dropped.[281] In 1989, Nirex began investigating sites in Sellafield and Dounreay; after some exploratory drilling, Nirex decided to focus on Sellafield, and proposed to construct a rock characterization facility to test the suitability of the site geology. In 1994, the local authority with competence over land use matters refused Nirex's planning application. Nirex appealed, and following a public inquiry, the Secretary of State for Environment denied the application on both substantive and procedural grounds.[282] The decision, according to one analysis, "stopped dead in its tracks, the search for a long-term disposal route for intermediate level radioactive waste."[283]

This setback prompted a reexamination of radioactive waste disposal policy in the United Kingdom.[284] In 1999, the House of Lords Select Committee on Science and Technology issued a report urging the government to develop "a fully comprehensive policy for the long-term management of all nuclear waste."[285] The report concluded that the "preferred approach" for high-level waste disposal is emplacement in a geologic repository following a period of surface storage.[286] Regarding public participation, the report concluded "public acceptance of a national plan for management of nuclear waste is essential" and must be achieved at both the local and national levels, and that "[o]penness and transparency in decision-making are necessary to gain public trust."[287] The report recommended that the government undertake a public consultation, and it also recommended an organization be established to oversee implementation of the radioactive waste disposal policy.[288]

Partially in response to the Select Committee report, the Government began a public consultation process in September 2001, to develop and implement a radioactive waste management policy that "earns broad public support across the UK."[289] The consultation paper invited public views on methods for public participation in developing the radioactive waste man-

---

[280] *Id.*; *see also* STAN OPENSHAW ET AL., BRITAIN'S NUCLEAR WASTE: SITING AND SAFETY 105–06 (1989).

[281] SELECT COMMITTEE, MANAGEMENT, *supra* note 183, at 20.

[282] *Id.* at 20–21.

[283] PARLIAMENTARY OFFICE OF SCIENCE & TECHNOLOGY, REPORT 106 SUMMARY, RADIOACTIVE WASTE — WHERE NEXT?, 1997, at 1 (U.K.).

[284] VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 226.

[285] SELECT COMMITTEE, MANAGEMENT, *supra* note 183, at 67.

[286] *Id.*

[287] *Id.*

[288] *Id.*

[289] *See* DEPARTMENT FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS ET AL., MANAGING RADIOACTIVE WASTE SAFELY: PROPOSALS FOR DEVELOPING A POLICY FOR MANAGING SOLID RADIOACTIVE WASTE IN THE UK, 2001, at 9 (U.K.) [hereinafter DEFRA, PROPOSALS].

agement policy,[290] and on the institutions that would develop and implement that policy.[291] It proposed a "programme for action" consisting of research on the feasibility of waste management options, further public consultation, a decision on a waste management strategy in 2006, and enactment of any necessary legislation in 2007.[292]

In November 2003, the Secretary of State for Environment, Food, and Rural Affairs, and environment Ministers in Scotland, Wales and Ireland appointed a panel of experts, the Committee on Radioactive Waste Management ("CoRWM"), to review options for long-term management of radioactive waste and to recommend the best option.[293] In July 2006, CoRWM issued its final report.[294] It recommended, among other things, geological disposal as the best approach for long-term management; interim storage until geological disposal can be implemented; continued public engagement and community involvement in decisions, including siting of radioactive waste facilities; and an independent body to oversee implementation, including research, development, and siting of facilities.[295] The Government accepted or agreed with all of the recommendations.[296]

In June 2007, the Government began a new consultation on the management of radioactive waste, focusing on the technical aspects of geologic disposal, and the process and criteria to be applied in siting a geologic disposal facility.[297] The Government invited public views on these issues from June through November 2007; it received 181 comments, to which it published a response.[298] As a result of this consultation, the Government published a white paper in June 2008 setting forth a very general framework for radioactive waste management.[299] The paper states the government's policy that "[g]eological disposal is the way higher activity radioactive waste will be managed in the long-term."[300] It commits to public and stakeholder engagement throughout the process.[301] The paper further commits that site selection will be based on "voluntarism," meaning that communities would

[290] *Id.* at 41–48. The Select Committee criticized this primary component of the consultation as "consultation on a consultation." SELECT COMMITTEE ON SCIENCE AND TECHNOLOGY, RADIOACTIVE WASTE MANAGEMENT, 2003–4, H.L. 200, at 11 (U.K.).

[291] DEFRA, PROPOSALS, *supra* note 289, at 49–55.

[292] *See id.* at 56–60.

[293] COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT, FIRST ANNUAL REPORT 2004, 2004, Doc. 735, at 4 (U.K.). CoRWM is comprised of a Chair and twelve members. *Id.* at 36.

[294] COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT, MANAGING OUR RADIOACTIVE WASTE SAFELY: CORWM'S RECOMMENDATIONS TO GOVERNMENT, 2006, Doc. 700 (U.K.) [hereinafter CoRWM, RECOMMENDATIONS].

[295] *See id.* at 111–15.

[296] *See* DEPARTMENT FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS, RESPONSE TO THE REPORT AND RECOMMENDATIONS FROM THE COMMITTEE ON RADIOACTIVE WASTE MANAGEMENT (CoRWM), 2006, at 6–15 (U.K.).

[297] *See* DEPARTMENT FOR ENVIRONMENT, FOOD AND RURAL AFFAIRS ET AL., MANAGING RADIOACTIVE WASTE SAFELY: A FRAMEWORK FOR IMPLEMENTING GEOLOGIC DISPOSAL, 2007 (U.K.).

[298] *Id.* at 11.

[299] *See id.*

[300] *Id.* at 10.

[301] *See id.* at 32–33.

voluntarily express an interest in hosting a geological disposal facility and would participate in the site selection process.[302] The community would have the option to withdraw from the process at any time until construction begins.[303] By emphasizing public participation and community "volunteerism" in the paper, the Government effectively recognizes the problem is mostly a social one rather than a technical one.[304]

Thus far, the United Kingdom has made remarkably little progress in establishing a facility for the final disposal of its high-level radioactive waste. After three decades of failed efforts to find solutions to the problem of long-term radioactive waste disposal,[305] the U.K. Government has settled on geological disposal; it has committed to public participation and community acceptance in site selection; and it has produced a general framework document that contains few specific details.

b. Licensing in the United Kingdom

Under the Nuclear Installations Act of 1965,[306] the geologic disposal facility will require a license to operate. The Health and Safety Executive ("HSE"), the operational arm of the Health and Safety Commission, has responsibility for issuing such licenses,[307] and may impose conditions addressing safety, management, or disposal.[308] As the successor to Nirex, the Nuclear Decommissioning Authority ("NDA") will have the responsibility to obtain the license and operate the facility,[309] but the NDA is many years away from seeking an operating license.

c. Technical Standards in the United Kingdom

The U.K. government has not adopted any technical standards for high-level radioactive waste disposal facilities. No doubt this is partially because it is still a long way from locating a site. Nevertheless, the United Kingdom has established standards applicable to all nuclear facilities to protect members of the public from the effects of ionizing radiation, pursuant to the Radioactive Facilities Act.[310]

---

[302] *See id.* at 47–60.
[303] *Id.* at 47.
[304] *See* Cameron, *supra* note 7, at 79.
[305] *See* CoRWM, Recommendations, *supra* note 294, at 3.
[306] Nuclear Installations Act, 1965, c. 57 (U.K.).
[307] Health & Safety Executive, The Licensing of Nuclear Installations 4, 2007 (U.K.), *available at* http://www.hse.gov.uk/nuclear/notesforapplicants.pdf.
[308] *See* Nuclear Installations Act, 1965, § 4. HSE has issued a set of thirty-six standard conditions that apply to all licenses. Health & Safety Executive, Nuclear Site License Conditions (effective Apr. 1, 2000) (U.K.), *available at* http://www.hse.gov.uk/nuclear/silicon.pdf.
[309] *See* DEFRA, Geological Disposal, *supra* note 116, at 34.
[310] Health & Safety Executive, Safety Assessment Principles for Nuclear Facilities 97, 1st rev. 2006 (U.K.), *available at* http://www.hse.gov.uk/nuclear/saps. The standard limits radiation exposure to the public to an annual dose of 1 millisievert (100 millirems). *Id.*

3. *France*

France has a large nuclear power industry, also dating back to the 1950s, which now supplies nearly eighty percent of its electrical power. Like the United Kingdom, France reprocesses its spent nuclear fuel.[311] Nevertheless, reprocessing has generated a significant quantity of high-level radioactive waste that must be disposed of. Although France has planned to dispose of this waste in a deep geologic repository for more than twenty years, it has not yet selected a site for the repository. As in the United Kingdom, France's initial efforts failed to involve the local community and consequently were unsuccessful.

a. *Site Selection in France*

The French government took the first steps towards locating an underground disposal site in 1987, when it began an investigation to characterize the geology of four potential sites. It took these steps without any public involvement. The investigation was met with strong local opposition, and was suspended in 1990.[312] A parliamentary commission investigated the disposal question, and concluded that a different approach to site selection was necessary. The report emphasized the need for "responsibility, transparency . . . and democracy" in the site selection process.[313]

As a consequence, on December 30, 1991, the French Parliament enacted Law 91-1381 for research on the management of radioactive waste.[314] The law required that high-level radioactive waste be managed in a manner that is protective of nature, the environment, and health, and considers the rights of future generations.[315] The law commenced a program of research into, among other options, retrievable or irretrievable disposal in deep geological formations, conducted through the construction of underground laboratories.[316] The law gave the French National Agency for the Management of Radioactive Wastes ("ANDRA") responsibility for the research and made ANDRA an independent agency.[317] Before constructing an underground laboratory at any location, ANDRA was to consult with local government officials and with the local public.[318]

---

[311] *See supra* Part V.B.3.

[312] VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 221.

[313] *Id.*

[314] Law No. 91-1381 of Dec. 30, 1991, Journal Officiel de la République Française [J.O.] [Official Gazette of France], Jan. 1, 1992, p. 10 (codified as amended at CODE ENVIRONMENTAL [C. ENVTL.] arts. L542-1 to L542-14) (Fr.). The law is commonly called Loi Bataille after its sponsor, MP Christian Bataille.

[315] C. ENVTL. art. L542-1.

[316] *Id.* art. L542-3.

[317] *Id.* art. L542-12. ANDRA is the abbreviation for the Agence nationale pour la gestion des déchets radioactifs. Previously, ANDRA had been part of the Commissariat à l'energie atomique. *See* OECD, *Nuclear Legislation in OECD Countries: France*, at 45–46 (2003).

[318] C. ENVTL art. L542-13.

In 1994, following consultations with local communities, four sites were proposed for underground laboratories: La-Chapelle-Bâton in the Vienne Department, a granite formation overlain by sedimentary rock; Marcoule in the Gard Department, a clay formation; and two areas, later combined, at the border of the Meuse and Haute-Marne Departments, both clay formations.[319] In 1996, ANDRA submitted license applications to construct underground laboratories at these sites. In 1998, the government granted the license for the Meuse/Haute-Marne site.[320] The Vienne site was dropped for geological reasons, while the Gard site was dropped due to local opposition.[321] In 2000, ANDRA began construction of the underground laboratory near Bure in Meuse.[322] ANDRA has also begun another consultation to locate a site in a granite formation in France.[323]

In June 2006, the French Parliament attempted a fresh start by enacting the Radioactive Materials and Waste Planning Law,[324] which substantially amends the provisions of Law 91-1381. The 2006 Law provides for the disposal of high-level radioactive waste in a deep geological formation,[325] and extends the schedule for research on a disposal site, requiring that the repository be commissioned by 2025.[326] It provides that the waste emplaced in the repository must be retrievable for at least 100 years.[327] The 2006 Law makes explicit requirements for public participation, including a public debate on any license application.[328] It also requires that a local information and oversight committee, comprised of national and local elected officials and various stakeholders, be established in each community hosting an underground laboratory, to be consulted on issues related to the community or the environment.[329]

It remains to be seen whether the 2006 Law can be successfully implemented according to schedule. Even assuming that it is implemented on time, France is still several years away from selecting a site for its high-level radioactive waste repository.

---

[319] Nuclear Energy Agency, OECD, *Safety of Geological Disposal of High-level and Long-lived Radioactive Waste in France*, at 18, OECD Doc. NEA No. 6178 (2006) [hereinafter OECD, *Geological Disposal in France*].

[320] *Id.*

[321] NAT'L RESEARCH COUNCIL, DISPOSITION OF HIGH-LEVEL WASTE AND SPENT NUCLEAR FUEL 137 (2001). The primary opposition in Gard came from vineyard owners, who expressed concern that a nuclear waste disposal site in the area would harm the image of the local wine appellation, Côtes du Rhône. *Id.*

[322] OECD, *Geological Disposal in France*, *supra* note 319, at 18.

[323] *Id.*

[324] Law No. 2006-739 of June 28, 2006, J.O., June 29, 2006, p. 9721 (Fr.).

[325] *Id.* art. 6-I.

[326] *Id.* art. 3.

[327] *Id.* art. 12.

[328] *Id.*

[329] *Id.* art. 18.

b. Licensing in France

Under the French Environmental Code, ANDRA is required to obtain an operating license for the repository.[330] A license is prepared by the General Directorate for Nuclear Safety and Radiation Protection ("DGSNR"),[331] the primary regulatory authority, and signed by the Prime Minister.[332] The 2006 Radioactive Materials and Waste Planning Law establishes a schedule for licensing the repository, requiring that a license application be reviewed by 2015.[333]

c. Technical Standards in France

France has established a general standard for radiation protection for members of the public.[334] Like the United Kingdom, France has not adopted any binding technical standards specifically for deep geological repositories. The Nuclear Safety Authority ("ASN")[335] has set a basic safety rule for radioactive waste repositories, which applies for 10,000 years.[336] The rule is not legally binding, however; it merely sets forth fundamental objectives to guide the development of the repository.[337]

4. *Sweden*

Despite its relatively small population, Sweden has a prominent nuclear power industry, which began in the 1960s and now supplies nearly half its electrical power. Until the 1970s, the Swedish government assumed that spent fuel from Swedish reactors would be reprocessed, most likely in other countries, and gave little attention to the nuclear waste issue.[338] But since that time, Sweden has made considerable progress in selecting a site for the disposal of spent fuel, and is close to approving a final selection. Unlike the

---

330 C. ENVTL. art. L. 542-7 (Fr.).

331 DGSNR is the abbreviation for the Direction générale de la sûreté nucléaire et de la radioprotection.

332 OECD, *Nuclear Legislation in OECD Countries: France*, *supra* note 317, at 10. The license decree must be approved by the Minister for Health, or if he does not act on it, adopted by the Council of Ministers. *Id.*

333 Law No. 2006-739 of June 28, 2006, J.O., June 29, 2006, art. 3, p. 9721 (Fr.).

334 Law No. 2001-215 of Mar. 8, 2001, J.O., Mar. 10, 2001, p. 3869 (Fr.). The general standard is 1 millisievert (100 millirems) per year. *Id.*

335 ASN is the abbreviation for Authorité de sûreté nucléaire, also known as the Directorate for the Safety of Nuclear Installations, or Direction de la sûreté des installations nucléaire (DSIN).

336 The safety rule sets a dose limit of 0.25 millisieverts (25 millirems) per year. ASN, Règle fondamentale de sûreté [Basic Safety Rule], RFS-III.2.f, §3.2 (1991) (Fr.); *see also* Nuclear Energy Agency, OECD, *Regulating the Long-term Safety of Geological Disposal*, at 38, OECD Doc. NEA No. 6182 (2007) [hereinafter OECD, *Regulating Long-term Safety*] (describing French rule).

337 *See* WISE-PARIS, *supra* note 187, at 49 (explaining that the ASN basic safety standards "are in no way legally binding regulations").

338 GÖRAN SUNDQVIST, THE BEDROCK OF OPINION: SCIENCE, TECHNOLOGY AND SOCIETY IN THE SITING OF HIGH-LEVEL NUCLEAR WASTE 57–60 (2002).

other countries examined so far, Sweden took early steps to involve the local community in site selection. It also established an independent, industry-owned siting body, and adopted fairly rigorous technical standards. The Swedish regulatory agency has not, however, been free of political influence.

a. Site Selection in Sweden

Sweden took its first step towards addressing the nuclear waste problem in 1977 when the Swedish Parliament enacted the Nuclear Power Stipulation Act.[339] The Stipulation Act provided that a nuclear power plant could obtain an operating license only if the owner of the reactor demonstrated how and where the spent nuclear fuel or reprocessing waste could be disposed with absolute safety; if the spent fuel was to be reprocessed, the owner was further required to have a contract providing for reprocessing.[340] A Parliamentary committee report provided guidance on the interpretation of the "absolute safety" requirement, stating that a "very high level of safety" is required, but that a "'draconian' interpretation of the safety requirements is not intended."[341]

At the time the Stipulation Act took effect, two nuclear reactors — Ringhals-3 and Forsmark-1 — were close to completion and subject to the demonstration requirement.[342] The legislation prompted the nuclear power industry to establish the Swedish Nuclear Fuel Supply Company ("SKBF"), later the Swedish Nuclear Fuel and Waste Management Company ("SKB"), a separate corporation with the purpose of developing a disposal facility for spent fuel.[343] SKBF entered into a contract for reprocessing the spent fuel at the COGEMA UP3 plant in France. It hastily prepared a plan, dubbed "KBS" for "nuclear fuel safety," for disposal of the high-level reprocessing waste in a deep geological repository.[344] In December 1977, the electric power utility Vattenfall AB submitted to the Swedish Government an application for a license to begin fueling the Ringhals-3 reactor. The application included a copy of the COGEMA contract and the KBS report, and Vattenfall claimed that these documents demonstrated compliance with the Stipulation Act.[345] But the KBS report did not identify the actual location of the

[339] Lag om särskilt tillstånd att tillföra kärnreaktor kärnbränsle (Villkorslagen) [Nuclear Power Stipulation Act] (SFS 1977:140) (Swed). The Stipulation Act was the result of an elaborate compromise among pro- and anti-nuclear power factions within the Swedish Parliament. *See* Carter, *supra* note 1, at 291–95.

[340] *See* Sundqvist, *supra* note 338, at 77.

[341] *Id.* at 79.

[342] Carter, *supra* note 1, at 293.

[343] IAEA, *Country Nuclear Power Profiles (Sweden)*, at 886 (2003). SKBF is the abbreviation for Svensk Kärnbränsleförsörjning AB; SKB is the abbreviation for Svensk Kärnbränslehantering AB.

[344] *See* Sundqvist, *supra* note 338, at 77. KBS is the abbreviation for Kärnbränslesäkerhet.

[345] *See id.* at 79.

geologic repository, and for this reason, the government rejected the application.[346]

The utilities then conducted further studies of bedrock at two potential repository sites, Finnsjön and Sternö, and submitted another license application in February 1979.[347] The government charged the Swedish Nuclear Power Inspectorate ("SKI")[348] with determining whether the application was adequate.[349] SKI formed an advisory group of eight expert geologists; after reviewing the data, seven of the eight concluded there were technical flaws in the application and recommended against approval.[350] Despite the contrary recommendation of its own experts, the SKI Board approved the application on March 27, 1979, and the government adopted the decision in June.[351] The decision appears to have been influenced more by politics than by science — not insignificantly, a more pro-nuclear government had come into power in October 1978, shortly after the initial application had been rejected.[352] With this decision, the Forsmark-1 and the Ringhals-3 reactors eventually came on-line in 1980 and 1981,[353] although there was as yet no real resolution of the waste disposal question.

In 1984, the Parliament enacted more comprehensive legislation, the Nuclear Activities Act,[354] that replaced the Stipulation Act and other outdated laws. The 1984 Act is still in effect. It eliminates the requirement of "absolute safety," but requires the operator of a nuclear power plant to ensure the safe handling and final storage of nuclear waste.[355] The reactor operator, in consultation with other operators, must conduct a research and development program on the safe handling and disposal of spent nuclear fuel.[356] The written program must be submitted to the government authority, now the Swedish Radiation Safety Authority ("SSM"), for review and approval; it must be reviewed every three years, and SSM may place conditions on the program.[357] Thus, the responsibility to locate a disposal site remains with the nuclear power industry.

In addition, the Swedish Environmental Code as amended requires that the government generally may only license a nuclear facility, including a

---

[346] *See id.* at 85–88.

[347] *Id.* at 90. The Finnsjön site is located west of the town of Östhammer in east-central Sweden, and the Sternö site is located south of the town of Karlshamn on the south-east coast. *Id.*

[348] SKI is the abbreviation for Statens Kärnkraftinspektion. In 2008, the Swedish Radiation Safety Authority (Strålsäkerhetsmyndigheten or SSM) took over the responsibilities of SKI and the former Swedish Radiation Protection Institute (Statens Strålskyddsinstitut or SSI). OECD, *Nuclear Legislation in OECD Countries: Sweden*, *supra* note 50, at 14.

[349] SUNDQVIST, *supra* note 338, at 87.

[350] *Id.* at 88, 90.

[351] *Id.* at 91.

[352] *See* CARTER, *supra* note 1, at 296–97; VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 232.

[353] IAEA, *Nuclear Power Reactors*, *supra* note 5, at 40 tbl.14.

[354] Lag om kärnteknisk verksamhet [Nuclear Activities Act] (SFS 1984:3) (Swed.).

[355] *See* 10 § *id.*

[356] *See* 12 § *id.*

[357] *See id.*

repository, if the municipality approves.[358] The government may license a facility without the approval of the municipality only if the facility is of the utmost importance to the national interest and no alternate location for the facility is available.[359] The Environmental Code also requires consultation with interested members of the public, county officials, municipalities, and other stakeholders on any plan to locate a spent nuclear fuel repository.[360] It also requires that an environmental impact statement be prepared, with public notice and an opportunity to comment.[361]

SKB began the formal site selection process in 1992, inviting all 286 municipalities across Sweden to submit feasibility studies assessing potential repository sites.[362] Only eight municipalities would actually conduct such studies. Initially, two municipalities in the northern interior, Malå and Storuman, responded favorably.[363] Once the studies were completed, Storuman in 1995 and Malå in 1997 held referenda, and local voters declined further consideration of a repository.[364] SKB next approached five municipalities with existing nuclear facilities, of which three (Nyköping, Oskarshamn, and Östhammar) conducted feasibility studies.[365] SKB then approached several municipalities with neighboring nuclear facilities, and three (Älvkarleby, Hultsfred, and Tierp) also conducted feasibility studies.[366] The results of these six studies were favorable, as each study concluded that suitable repository sites existed in the respective municipalities.[367] In 2000, SKB proposed three sites — the Laxemar site in Oskarshamn, the Forsmark site in Östhammar, and a third site in Tierp — for further investigation.[368] In 2002, Tierp exercised its veto authority under the Environmental Code and withdrew from further consideration, while Oskarshamn and Östhammar decided to approve further site investigations.[369] To meet the consultation requirements of the Environmental Code, SKB held early consultations at Oskarshamn and Östhammar in 2002.[370] Since then, it has held more than

---

[358] *See* Miljöbalk [MB] [Environmental Code] 17:6 (Swed.).

[359] *Id.*

[360] *See id.* 6:4-5.

[361] *See id.* 6:1, 6:8.

[362] ROLF LIDSKOG & ANN-CATRIN ANDERSSON, SVENSK KÄRNBRÄNSLEHANTERING AB, THE MANAGEMENT OF RADIOACTIVE WASTE: A DESCRIPTION OF TEN COUNTRIES 70 (2002); SUNDQVIST, *supra* note 338, at 21.

[363] SUNDQVIST, *supra* note 338, at 21.

[364] *See* LIDSKOG & ANDERSSON, *supra* note 362, at 70; SUNDQVIST, *supra* note 338, at 186–90.

[365] *See* SUNDQVIST, *supra* note 338, at 21, 192–98. A low- and intermediate-level waste treatment facility is located in Nyköping. Oskarshamn is the site of the Oskarshamn nuclear power plant, and Östhammar is the site of the Forsmark nuclear power plant. LIDSKOG & ANDERSSON, *supra* note 362, at 70 n.11.

[366] *See* SUNDQVIST, *supra* note 338, at 21, 201–04. Älvkarleby and Tierp border Östhammar, while Hultsfred borders Oskarshamn. LIDSKOG & ANDERSSON, *supra* note 362, at 70 n.11.

[367] *See* SUNDQVIST, *supra* note 338, at 194–95, 198, 203.

[368] LIDSKOG & ANDERSSON, *supra* note 362, at 70.

[369] VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 236.

[370] SVENSK KÄRNBRÄNSLEHANTERING AB, EXTENDED CONSULTATIONS ACCORDING TO THE ENVIRONMENTAL CODE: COMPILATION 2004, at 16 (2005).

thirty separate consultations on the candidate sites, including public meetings, meetings with county and municipal officials, and meetings with citizen groups.[371] On June 3, 2009, SKB announced the selection of the Forsmark site in Östhammar for the repository.[372] The Government must still approve a license for the facility.

b. Licensing in Sweden

The 1984 Nuclear Activities Act requires any person constructing or operating a nuclear installation to obtain a license from SSM.[373] SSM is authorized to place conditions on licenses for purposes of safety.[374] SKB expects to submit a license application to SSM for the Forsmark repository site in 2010.[375]

c. Technical Standards in Sweden

Under the 1984 Swedish Nuclear Activities Act, reactor operators must collaboratively develop a program on the safe handling and disposal of spent nuclear fuel.[376] To comply with this law, the Swedish nuclear power industry has adopted a "nuclear fuel safety" method, dubbed KBS-3, for the final disposal of spent nuclear fuel.[377] The KBS-3 method is based on geologic disposal augmented by a series of passive barriers to contain the radioactivity,[378] in accordance with Swedish safety regulations.[379] The spent fuel rods will be placed in copper canisters.[380] The canisters will be placed in a deep geologic repository excavated in stable granite bedrock at a depth of approximately 500 meters.[381] The space around the canisters will then be backfilled with bentonite clay, a highly impermeable material.[382] The canisters, the bentonite clay, and the rock will provide multiple barriers to the migration of

---

[371] *See id.*

[372] Press Release, Svensk Kärnbränslehantering AB, SKB Selects Forsmark for the Final Repository for Spent Nuclear Fuel (June 3, 2009) (on file with the Harvard Law School Library).

[373] 5 § Lag om kärnteknisk verksamhet [Nuclear Activities Act] (SFS 1984:3) (Swed.).

[374] 8 § Förordning om kärnteknisk verksamhet [Nuclear Activities Ordinance] (SFS 1984:14) (Swed.).

[375] Press Release, Svensk Kärnbränslehantering AB, *supra* note 372.

[376] 12 § SFS 1984:3 (Swed.).

[377] *See* SWEDISH NUCLEAR FUEL & WASTE MGMT. CO., DEEP REPOSITORY FOR SPENT NUCLEAR FUEL 4–5 (2003) [hereinafter SKB, DEEP REPOSITORY].

[378] *Id.* at 7.

[379] *See* 2 § Statens kärnkraftinspektions föreskrifter om säkerhet vid slutförvaring av kärnämne och kärnavfall [SKI Regulations Concerning Safety in Connection with the Disposal of Nuclear Material and Nuclear Waste] (Statens kärnkraftinspektions författningssamling [SKIFS] 2002:1) (Swed.).

[380] SKB, DEEP REPOSITORY, *supra* note 377, at 7. Copper is very resistant to corrosion and can last for many thousands of years under the right conditions. *See* B. Rosborg & L. Werme, *The Swedish Nuclear Waste Program and the Long-Term Corrosion Behaviour of Copper*, 379 J. NUCLEAR MATERIALS 142, 147–48 (2008).

[381] SKB, DEEP REPOSITORY, *supra* note 377, at 2–3.

[382] *Id.* at 7.

radioactivity, ensuring safety.[383] The Swedish government has approved the KBS-3 method.[384]

Two laws enacted in 1988, the Radiation Protection Act[385] and the Radiation Protection Ordinance,[386] establish standards for protection of human health and the environment from the effects of radiation. The Swedish Radiation Protection Institute ("SSI")[387] set a maximum annual dose to an individual in the geographical area of any nuclear facility, including a repository.[388] SSI also set safety regulations applicable to a closed repository for spent nuclear fuel, which limit the risk of harmful effects to an exposed individual.[389] The repository's operation and closure must also protect biological diversity from radiation.[390]

5. *Finland*

Finland has a relatively small nuclear power industry, with four operating reactors that supply just over one-fourth of its electrical power and another reactor under construction. Nevertheless, Finland has made significant progress — more than any other country — towards solving the spent fuel disposal problem. Like Sweden, Finland has actively involved the public and the local community. It has established an independent siting body. And it has adopted the fairly rigorous Swedish technical standards.

a. *Site Selection in Finland*

In 1983, the Finnish government adopted a long-term plan for research and development of a repository for spent nuclear fuel, with site selection by 2010.[391] The government conducted research on bedrock across the country.

---

[383] *See id.*

[384] LIDSKOG & ANDERSSON, *supra* note 362, at 69.

[385] Strålskyddslag [Radiation Protection Act] (SFS 1988:220) (Swed.).

[386] Strålskyddsförordning [Radiation Protection Ordinance] (SFS 1988:293) (Swed.).

[387] SSI is now part of SSM. *See supra* note 348.

[388] *See* 5 § Statens strålskyddsinstituts föreskrifter om skydd av människors hälsa och miljön vid utsläpp av radioaktiva ämnen från vissa kärntekniska anläggningar [SSI Regulations on the Protection of Human Health and the Environment from the Releases of Radioactive Substances from Certain Nuclear Facilities] (Statens strålskyddsinstituts författningssamling [SSI FS] 2000:12). The maximum annual dose is 0.1 millisieverts (10 millirems). *Id.*

[389] *See* 5 § Statens strålskyddsinstituts föreskrifter om skydd av människors hälsa och miljön vid slutligt omhändertagande av använt kärn-bränsle och kärnavfall [SSI Regulations on the Protection of Human Health and the Environment in connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste] (SSI FS 1998:1) [hereinafter SSI Management Regulations]. The maximum total excess cancer risk to an exposed individual is one in one million (10^{-6}). *Id.* This level is equivalent to 0.015 millisieverts (1.5 millirems) per year. *See* OECD, *Regulating Long-term Safety*, *supra* note 336, at 45.

[390] *See* 6 § SSI Management Regulations, *supra* note 389.

[391] VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 237; LIDSKOG & ANDERSSON, *supra* note 362, at 35–36.

Based on this research, it preliminarily selected five sites, representing each type of bedrock in Finland, for further characterization.[392]

In 1987, the Finnish Parliament passed the Nuclear Energy Act.[393] The Act prescribes a detailed process for siting and licensing the construction of significant nuclear facilities, including repositories for nuclear waste.[394] The process includes notice to the public and to local authorities, the opportunity for local residents and other interested parties to present opinions in writing, and a public hearing.[395] The municipality where the facility is to be located must approve siting.[396] The process culminates in a decision-in-principle by the government, which must be ratified by Parliament.[397] Once the license is issued, the Finnish Radiation and Nuclear Safety Authority ("STUK") is responsible for its administration.[398] Significantly, the Act also provides that a licensee whose operations generate nuclear waste is responsible for all waste management measures and costs.[399] It also authorizes the government to require a plan to meet this responsibility from each licensee.[400] Under this authority the Finnish Ministry of Trade and Industry issued the Nuclear Energy Decree, which requires each operator of a nuclear power plant to submit a detailed plan on nuclear waste management measures annually.[401]

In response to this requirement, the two nuclear power plant operators formed Posiva Oy in 1995, a separate company with the responsibility to locate, develop, construct, and operate a repository for spent nuclear fuel in Finland.[402] By 1997, the number of sites under consideration was winnowed down to four: Äänekoski, Olkiluoto in Eurajoki, Kuhmo, and Hästholmen Island in Loviisa.[403] Posiva conducted environmental impact assessments for these sites from 1997 to 1999, and held a number of meetings with the public and other interested parties.[404] A majority of the citizens in Olkiluoto and Loviisa favored a nuclear disposal repository, while a majority in Äänekoski and Kuhmo were opposed.[405]

---

[392] LIDSKOG & ANDERSSON, *supra* note 362, at 36. The five sites were in Äänekoski, Eurajoki, Hyrynsalmi, Kuhmo, and Sievi. *Id.*

[393] Ydinenergialaki [Nuclear Energy Act] (Suomen säädöskokoelma [SDK] 990/1987) (Fin.).

[394] *See* 11 § *id.*

[395] *See* 13 § *id.*

[396] 14 § *id.*

[397] *See* 11, 15 §§ *id.*

[398] *See* 55 § *id.*; OECD, *Nuclear Legislation in OECD Countries: Finland*, at 15 (2008) [hereinafter OECD, *Nuclear Legislation in Finland*]. STUK is the abbreviation for Säteilyturvakeskus.

[399] 9 § SDK 990/1987.

[400] *See* 28 § *id.*

[401] *See* 74 § Ydinenergia-asetus [Nuclear Energy Decree] (SDK 161/1988).

[402] VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 237; LIDSKOG & ANDERSSON, *supra* note 362, at 35.

[403] LIDSKOG & ANDERSSON, *supra* note 362, at 36.

[404] *Id.* at 36–38.

[405] *Id.* at 36.

In late 1999, Posiva applied for a decision-in-principle selecting the Olkiluoto site in Eurajoki.[406] The Council of Eurajoki approved the repository by a 20 to 7 vote in 2000.[407] The government selected Olkiluoto in 2001[408] and in May 2001, the Finnish Parliament overwhelmingly ratified the selection.[409] Thus, Finland was the first, and so far the only, country to select a site for disposal of spent nuclear fuel. Construction of the Olkiluoto repository is scheduled to begin in 2015, with operation to begin in 2020.[410]

b. Licensing in Finland

The Finnish Nuclear Energy Act requires licenses for the construction and operation of nuclear waste disposal facilities, among other nuclear facilities.[411] Posiva expects to submit a construction license application to STUK for the Olkiluoto facility in 2012, but excavation of an underground characterization facility at the site is already underway.[412]

c. Technical Standards in Finland

The Finnish Nuclear Energy Act provides that a nuclear power plant operator is responsible for all waste management measures[413] and must have a plan to meet this responsibility.[414] Accordingly, Posiva adopted the Swedish KBS-3 design for its repository,[415] which is in accordance with government regulations.[416]

In addition, government regulations set radiation protection standards for spent nuclear fuel disposal facilities, both during operation and after closure. The regulations set a maximum annual dose to exposed members of the public during normal operations[417] and a higher dose from two postulated accident scenarios.[418] The regulations also limit the annual long-term dose to

---

[406] OECD, *Nuclear Legislation in Finland*, *supra* note 398, at 4.

[407] VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 237.

[408] LIDSKOG & ANDERSSON, *supra* note 362, at 37. The government later revised the decision-in-principle to apply to spent fuel from the Olkiluoto nuclear power plant, which is currently under construction. OECD, *Nuclear Legislation in Finland*, *supra* note 398, at 4.

[409] LIDSKOG & ANDERSSON, *supra* note 362, at 38. The Parliament vote was 159 to 3, with 37 members absent. *Id.*

[410] POSIVA OY, ONKALO UNDERGROUND ROCK CHARACTERISATION FACILITY AT OLKILUOTO, EURAJOKI, FINLAND 2–3 (2006).

[411] *See* 3(5), 8, 16–20 §§ Ydinenergialaki (SDK 990/1987).

[412] Press Release, Posiva Oy, Posiva Aiming to Submit a License Application in 2012 for the Construction of a Final Disposal Facility (Mar. 15, 2010) (on file with the Harvard Law School Library).

[413] *See* 28 § SDK 990/1987.

[414] *See* 74 § Ydinenergia-asetus (SDK 161/1988).

[415] LIDSKOG & ANDERSSON, *supra* note 362, at 35–36; *see also supra* text accompanying notes 377–383.

[416] *See* 11 § Valtioneuvoston asetus ydinjätteiden loppusijoituksen turvallisuudesta [Government Decree on the Safety of Disposal of Nuclear Waste] (SDK 736/2008) (Fin.).

[417] The maximum annual exposure during normal operations is 0.1 millisieverts (10 millirems). 3(3) § *id.*

[418] The maximum annual exposure resulting from an accident likely to occur at least once every 1000 years, but less often than once every 100 years, is 1 millisievert (100 millirems).

exposed members of the public; this standard applies, at a minimum, over several millennia.[419]

VII. Proposed Criteria to Govern the Disposal of High-Level Radioactive Waste

The final disposal of spent nuclear fuel and other high-level radioactive waste is a difficult problem that each of the thirty or so countries with a nuclear power program will need to resolve. Even if the world's 436 nuclear power reactors were immediately shut down, approximately 190,000 metric tons of high-level radioactive waste would still need to be disposed of.[420] As the examples of the United States, the United Kingdom, France, Sweden, and Finland show, there are enormous challenges to finding a long-term solution to this problem.

However, as the experiences of Sweden and Finland suggest, the problem is not insurmountable. A nuclear waste disposal site can be selected with minimal controversy and designed using techniques that are deemed — within the current capabilities and limitations of science — to be protective of health and the environment for present and future generations. Drawing from the varied experiences of the five countries examined in Part VI, this Part identifies and discusses several essential criteria — institutional, procedural, and technical — which should form the framework for the selection of a disposal site. These criteria could be formally adopted into the legal regime of countries seeking a disposal site, and could further be adopted as part of an international legal regime through a convention or treaty.[421]

A. *Institutional Criteria*

1. *An Independent and Credible Waste Management Body*

The first institutional criterion for siting a waste disposal facility is the creation of an independent and credible waste management body. The responsibility of the management body is to locate, design, construct, and operate the disposal facility.

The management body in the United States, DOE, is the archetypical government agency that has lost its credibility with the public. DOE is a successor to the Atomic Energy Commission ("AEC").[422] The often-con-

The maximum annual exposure resulting from an accident expected to occur less often than once every 1000 years is 5 millisieverts (500 millirems). 3(4) § *id.*

[419] The maximum long-term annual dose is below 0.1 millisieverts (10 millirems). 4 § *id.*

[420] *See supra* note 79 and accompanying text.

[421] Several authors have discussed the possibility of an international repository. *See, e.g.*, Vandenbosch & Vandenbosch, *supra* note 106, at 245–46.

[422] The AEC was created by Congress in 1946. Act of Aug. 1, 1946, ch. 724, § 2(a), 60 Stat. 755, 756. It was entrusted with exclusive authority over atomic energy. *See* Pac. Gas & Elec. Co. v. State Energy Res. Conservation & Dev. Comm'n, 461 U.S. 190, 206–07 (1983).

flicting responsibilities of the AEC included promotion of atomic energy for peaceful purposes and management of the military nuclear weapons program.[423] Congress abolished the AEC in 1974,[424] and eventually transferred much of the AEC responsibilities, including the nuclear weapons complex, to DOE.[425] The nuclear weapons program under both the AEC and DOE operated in near-total secrecy, and it often pursued its goals at the expense of public health and the environment.[426] Even today, DOE retains a "culture of secrecy and arrogance."[427] DOE further lost its credibility during the site selection process under the 1982 NWPA. DOE provoked a contentious and adversarial relationship with states and local communities,[428] and it allowed the process to be largely driven by political considerations.[429] More recently, DOE has disclosed that it relied on falsified data supporting the Yucca Mountain repository.[430]

In contrast, the management body in Sweden, SKB, has established a fair degree of public confidence. According to one observer, after Storuman and Malå rejected plans to locate a repository in their communities, SKB fully "respected the outcome of the referendum," and the "whole experience became trust building."[431] SKB and Posiva, the management body in Finland, have also conducted intensive programs of public participation, starting early in the site selection process, as described above.[432] These programs have enhanced the credibility of the management bodies with the public.

To be effective, the waste management body must operate with transparency and accountability. It must be independent from political interference while at the same time be responsive to the concerns of the public. And it must avoid any conflicts of interest. A waste management body can be structured in any of several ways: as an independent government agency, as a public corporation, as a private corporation, or as a hybrid public-private corporation. Each has distinct advantages and disadvantages.[433]

First, the management body can be a separate, independent government agency. France and the United Kingdom have followed this option. Under the 1991 French law on research into the management of radioactive wastes,

---

[423] *See, e.g.*, 42 U.S.C. §§ 2011, 2013 (1958).

[424] *See* Energy Reorganization Act of 1974, Pub. L. No. 93-438, § 104(a), 88 Stat. 1233, 1237 (codified at 42 U.S.C. § 5814(a) (2006)).

[425] *See* 42 U.S.C. § 7151(a).

[426] As former U.S. Secretary of Energy James D. Watkins acknowledged, environmental problems "have resulted from a 40-year culture cloaked in secrecy and imbued with a dedication to the production of nuclear weapons without a real sensitivity for protecting the environment." H.R. REP. NO. 102-111, at 3 (1989), *reprinted in* 1992 U.S.C.C.A.N. 1287, 1289.

[427] Stewart, *supra* note 226, at 811.

[428] *See* James Flynn et al., *Overcoming Tunnel Vision: Redirecting the U.S. High-Level Nuclear Waste Program*, ENVIRONMENT, Apr. 1997, at 6, 9.

[429] *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 65–66.

[430] *See Yucca Mountain Project: Have Federal Employees Falsified Documents?: Hearing Before the Subcomm. on the Fed. Workforce and Agency Organization of the H. Comm. on Government Reform*, 109th Cong. 32 (2005) (statement of Nevada Att'y Gen. Brian Sandoval).

[431] NAT'L RESEARCH COUNCIL, *supra* note 321, at 75.

[432] *See supra* text accompanying notes 371–372, 395, 404.

[433] *See* Stewart, *supra* note 226, at 811–13.

ANDRA was made into an independent agency.[434] In October 2006, the U.K. Government transferred responsibility for implementing geological disposal from Nirex, a publicly-owned corporation, to the NDA, an independent government agency.[435] An advantage to this approach is that an independent agency is usually more accountable and transparent. For example, unlike a privately held corporation, a government agency is usually subject to laws providing for public access to government information.[436] On the other hand, if the agency is not created with sufficient independence, it can be improperly influenced by the politics of repository siting, as happened to DOE in the United States.

Second, the management body can be a publicly-held corporation. The former Nirex in the United Kingdom is an example of this approach. An advantage of a public corporation is that it retains greater independence than a government agency. A disadvantage of a public corporation is that it may be less receptive to public participation than a government agency, as apparently was the case with Nirex.

Third, the management body can be a privately-held corporation. Both Sweden and Finland have taken this approach. Under the laws of these countries, management and disposal of spent nuclear fuel is the responsibility of the electric power plant operators.[437] The plant operators have formed SKB in Sweden and Posiva in Finland, and these corporations have implemented the siting process, including public participation, pursuant to national law and under government oversight. This approach places the responsibility for disposition of nuclear waste on the parties that create that waste in the first place. Further, a private corporation generally has the advantage of greater flexibility and efficiency.[438] It is also more insulated from political pressures. And because it is not part of the government, it has less opportunity to improperly influence the regulatory agency. On the other hand, a private corporation may be less open to public participation, although this has not been the case with SKB or Posiva.

Fourth, the management body can be a hybrid public-private corporation, with a portion of its shares owned by the government and a portion owned by private industry.[439] Although this approach is something of a compromise, a hybrid corporation can be formed with many of the advantageous qualities of both a public and a private body. A hybrid corporation can be made subject to public access to information laws, but retain sufficient independence to operate efficiently and without significant political interference.

---

[434] *See supra* note 317 and accompanying text.

[435] *See* DEFRA, GEOLOGICAL DISPOSAL, *supra* note 116, at 34.

[436] *E.g.*, Freedom of Information Act, 5 U.S.C. § 552 (2006); Council Regulation 1049/2001, Regarding Public Access to European Parliament, Council and Commission Documents, 2001 O.J. (L 145) 43 (EC).

[437] *See supra* text accompanying notes 355–357 and 399–401.

[438] *See* Stewart, *supra* note 226, at 812.

[439] Professor Stewart has suggested this approach, referring to other U.S. hybrid corporations as examples. *See id.* at 812–13.

2. *An Independent and Credible Regulatory Agency*

The second institutional criterion for siting a waste disposal facility is an independent government regulatory agency. The responsibilities of the regulatory agency are to issue the license for the disposal facility, to monitor and inspect the facility to assess compliance with health, safety, and environmental standards, and to enforce those standards if they are violated.

All of the five countries examined in this Article have regulatory agencies established to meet these responsibilities, although some are more effective than others. The NRC, for example, was established as an independent agency with licensing and enforcement authority. But it is often criticized as an ineffective regulator. Like DOE, the NRC is a successor to the old AEC, and most of the NRC staff came from the AEC.[440] The NRC tends to be secretive and pro-nuclear industry; it is viewed by many as having been captured by the industry it regulates.[441] The Swedish SSM, as another example, has apparently attained a higher degree of public confidence. According to the results of a 2001 survey in fifteen EU countries, the public in Sweden is the most trusting of national radioactive waste management agencies.[442] However, SSM has been subject to political influence in the past.[443] Perhaps significantly, the government of Sweden never pursued a nuclear weapons program, which may help to explain why SSM is institutionally more open and credible in the public's view. Finland likewise never developed nuclear weapons, and STUK also has a relatively high degree of public credibility.[444]

To be effective, the regulatory agency must have adequate funding and the necessary technical expertise to fulfill its regulatory and oversight responsibilities. The regulatory agency must have the authority to place conditions on a facility license to protect the public health and the environment. The agency must have the legal authority to enter a facility at any time to conduct an inspection, both during construction and operation and after closure. The agency must have the power to enforce the law if violations are discovered, and to impose monetary penalties that create a meaningful deterrent to future violations. It must operate with transparency and accountability. It must be sufficiently independent of political influence, and completely independent of the industry it regulates. Further, it should be separated, to the greatest extent practicable, from any nuclear weapons program.

---

[440] *See* WALKER, *supra* note 26, at 96.

[441] *See* NAT'L RESEARCH COUNCIL, RISK AND DECISIONS ABOUT DISPOSITION OF TRANSURANIC AND HIGH-LEVEL RADIOACTIVE WASTE 142 (2005) ("NRC is perceived by some to be a captured regulator, serving the interests of the nuclear industry."); Mark Seidenfeld, *Bending the Rules: Flexible Regulation and Constraints on Agency Discretion*, 51 ADMIN. L. REV. 429, 464–65 (1999) (describing industry capture of the NRC and concluding "the NRC is perceived as an agency heavily beholden to the industry it regulates").

[442] VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 234.

[443] *See supra* notes 350–352 and accompanying text.

[444] *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 238.

B. *Procedural Criteria*

1. *Transparency*

The first procedural criterion is that the site selection process must be transparent. Transparency refers to the degree that the reasoning behind government decisions is clear and available to the public.[445] Given the tendency towards government secrecy in matters related to nuclear energy, many of the early, unsuccessful attempts at selecting disposal sites were the outcome of a closed, opaque decision-making process.

For example, the process in the United States that led to the still-uncertain selection of the Yucca Mountain site was seriously lacking in transparency. DOE's reasoning in its initial winnowing of the list of candidate sites was not apparent, and often seemed to be without any technical or scientific justification.[446] Even more problematic, the 1987 legislation that ultimately selected Yucca Mountain was drafted by a House-Senate conference committee in meetings that were not open to either the press or the public. No transcript was made of the committee deliberations.[447] The U.K. process that led to the failed Nirex proposal also was conducted with little transparency.[448] Nirex did not allow free access to information, it did not explain the reasoning behind its decisions, and it did not indicate how or even if the concerns of interested parties or members of the public were taken into account.[449] In France, the initial investigations to locate a disposal site in the late 1980s were conducted without notifying the public or local communities.[450] By contrast, SKB in Sweden has made substantial efforts to provide information on its activities to the public and to municipal officials.[451] It has regularly released to the public comprehensive reports of its plans and activities, written in lay terms.[452]

To succeed in selecting a disposal site with a minimum of public opposition, both the waste management body and the regulatory agency must follow an open and transparent process. The waste management body and the regulatory agency should publicize their activities through public notifications and announcements sent to all stakeholders. They should hold regular public meetings, and detailed workshops and seminars, to educate

---

[445] IAEA, *Factors Affecting Public and Political Acceptance for the Implementation of Geological Disposal*, at 16, IAEA Doc. TECDOC-1566 (Nov. 23, 2007) [hereinafter IAEA, *Public Acceptance*].

[446] *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 60–66.

[447] *See id.* at 86–87.

[448] *See* IAEA, *Public Acceptance*, *supra* note 445, at 32.

[449] *See id.* at 33.

[450] *See* NAT'L RESEARCH COUNCIL, *supra* note 321, at 136.

[451] *See* IAEA, *Public Acceptance*, *supra* note 445, at 29. During the development of the siting process in Sweden, local elected officials from the candidate municipalities, as well as public interest groups, demanded transparency. The IAEA concluded that "these demands have been satisfied to a great extent." *Id.*

[452] *See id.* at 30.

stakeholders on the site selection process and relevant technical issues. They should issue written reports and post on public websites pertinent information, such as meeting dates, copies of activity reports and schedules, and data from investigations. After a decision has been made, the regulatory agency should explain the basis for that decision in writing, with supporting documents compiled in an administrative record.

In addition to Sweden and Finland, other countries are starting to adopt a more open and transparent approach. Recognizing the early failures in the United Kingdom, for example, the 2006 CoRWM report recommends stakeholder engagement in waste management decisions, including facility siting.[453] The U.K. government's 2008 white paper promises a range of activities to involve stakeholders, increase transparency, and raise public awareness of the issues, including holding workshops and seminars, and posting information on the NDA website.[454]

2. *Public Participation*

The second procedural criterion for siting a disposal facility is that the site selection process must be subject to public participation. Public participation can be roughly defined in this context as "organized processes adopted by elected officials, government agencies, or other public- or private-sector organizations to engage the public in environmental assessment, decision making, management, monitoring, and evaluation."[455] Public participation goes hand-in-hand with transparency; if the public is well informed through an open and transparent process, it is better able to participate meaningfully. Public participation can also improve the quality and legitimacy of decisions and enhance trust and understanding among decision makers and stakeholders.[456]

The public often has not been given an opportunity to participate meaningfully in decisions on the disposal of nuclear waste. The U.S. process leading to the ostensible selection of Yucca Mountain is a prominent example of such failure. The 1982 NWPA, despite an express congressional finding that "public participation in the planning and development of repositories is essential in order to promote public confidence in the safety of disposal,"[457] established a schedule that did not allow enough time for meaningful public participation.[458] Further, when Congress selected the Yucca Mountain site in the 1987 amendments, it disregarded and effectively nullified the prior participation proceedings, including hearings and written

[453] CoRWM, RECOMMENDATIONS, *supra* note 294, at 113.

[454] *See* DEFRA, GEOLOGICAL DISPOSAL, *supra* note 116, at 32–33.

[455] NAT'L RESEARCH COUNCIL, PUBLIC PARTICIPATION IN ENVIRONMENTAL ASSESSMENT AND DECISION MAKING 11 (2008).

[456] *See id.* at 226; *see also* Thomas O. McGarity, *Public Participation in Risk Regulation*, 1 RISK 103, 112 (1990).

[457] NWPA § 111(a)(6), 96 Stat. at 2207 (current version at 42 U.S.C. § 10131(a)(6) (2006)).

[458] *See supra* note 213–223 and accompanying text.

public comments submitted to DOE on the draft site assessments.[459] Passage of the 1987 law completely undermined public confidence in the site selection process.

In the United Kingdom, the process leading to the selection — later abandoned — of the Sellafield site is another example. Nirex conducted a closed process, with no open debate, and no opportunities for interested persons to participate. As in the United States, the process was driven by predetermined deadlines, without consideration of stakeholder needs.[460] The process was later criticized as a "decide-announce-defend" approach.[461] In France as well, the early site-selection activities in the 1980s were conducted without any public participation.[462]

In contrast, both Sweden and Finland have actively engaged the public in the site selection process. In Sweden, SKB has met regularly with affected municipalities and interested local citizens.[463] Between 2002 and 2007, it held more than fifty consultations with municipalities, citizens, and other stakeholders.[464] In Finland, Posiva has likewise held regular open meetings with the public and discussion group meetings with smaller groups of stakeholders.[465]

To be successful, the management body and regulatory agency should begin public engagement in the vicinity of the candidate site early in the process. They should hold meetings with the general public, and consult with other interested stakeholders. Meetings and consultations should continue throughout the process. When the agency is ready to make a final selection, the public should be given the opportunity to comment on the proposed site decision and influence the decision in a meaningful way.

As with transparency, other countries have recently adopted such measures for greater public participation. In the United States, the National Research Council has recommended public involvement, starting early and continuing throughout the process, as an essential factor in furthering the site-selection effort.[466] The U.K. government's 2008 white paper commits to public consultation during the initial planning, and before the final decision on a disposal facility.[467] In France, the 2006 Radioactive Materials and Waste Planning Law provides that a public debate must precede any application for a license to construct a repository.[468]

---

[459] *See* VANDENBOSCH & VANDENBOSCH, *supra* note 106, at 62; Nomination of Five Sites for the First High-Level Nuclear Waste Repository, 51 Fed. Reg. 19,783, 19,784 (1986); *supra* note 237–239.

[460] *See* IAEA, *Public Acceptance*, *supra* note 445, at 32–33.

[461] CoRWM, RECOMMENDATIONS, *supra* note 294, at 16.

[462] *See* CARTER, *supra* note 1, at 328 (stating that the ANDRA site-selection process "makes not the slightest bow to the concept of public participation").

[463] *See* IAEA, *Public Acceptance*, *supra* note 445, at 30.

[464] *See* SVENSK KÄRNBRÄNSLEHANTERING AB, CONSULTATIONS ACCORDING TO THE ENVIRONMENTAL CODE: COMPILATION 2007, 18–20 (2008).

[465] *See* LIDSKOG & ANDERSSON, *supra* note 362, at 37–38.

[466] NAT'L RESEARCH COUNCIL, *supra* note 321, at 139.

[467] DEFRA, GEOLOGICAL DISPOSAL, *supra* note 115, at 45.

[468] Law No. 2006-739 of June 28, 2006, J.O., June 29, 2006, art. 12, p. 9721 (Fr.).

3. *Local Community Acceptance*

The third procedural criterion for selection of a disposal site is acceptance by the local community. This criterion may be particularly difficult to achieve.[469] Local community opposition to the siting of a waste disposal facility — particularly a *nuclear* waste disposal facility — is a predictable "not-in-my-backyard" ("NIMBY") reaction.[470] As one sponsor of U.S. legislation wryly remarked, "I have discovered that the siting of a nuclear waste repository will never be made on the basis of popular demand."[471] Such a reaction is not inevitable, however.

As we have seen, local governments have objected to proposed repository sites in all five countries, and they often were able to block those proposals. In the United States, Nevada's persistent, vigorous objections have delayed indefinitely, and may ultimately prevent, the opening of the Yucca Mountain repository. In the United Kingdom, the Cumbria County Council denied approval for an intermediate-level disposal facility in Sellafield, completely derailing that process. In France, local opposition, sometimes including violent demonstrations, effectively blocked several proposed radioactive waste disposal facilities.[472] Even the Swedish municipalities of Storuman, Malå, and Tierp rejected a spent fuel repository, and the Finnish municipalities of Äänekoski and Kuhmo expressed sufficient opposition to cause the siting authorities to look elsewhere.[473]

On the other hand, the municipalities of Oskarshamn (Laxemar site) and Östhammar (Forsmark site) in Sweden have affirmatively *accepted* siting a spent nuclear repository. So has the municipality of Eurajoki (Olkiluoto site) in Finland.[474] Thus, the predictable NIMBY reaction can be overcome.

Despite the serious potential obstacle it presents, local community acceptance should be a prerequisite to the siting of a spent fuel repository. The laws of Sweden and Finland expressly provide for a local veto of any proposed repository.[475] In the United Kingdom, the 2008 government white paper recommends that a geologic repository be located based on

---

[469] In the United States, the National Research Council concluded that public acceptance of a high-level radioactive waste disposal site "may be elusive" for the foreseeable future. NAT'L RESEARCH COUNCIL, ONE STEP AT A TIME: THE STAGED DEVELOPMENT OF GEOLOGIC REPOSITORIES FOR HIGH-LEVEL RADIOACTIVE WASTE 59 (2003).

[470] *See* MICHAEL B. GERRARD, WHOSE BACKYARD, WHOSE RISK: FEAR AND FAIRNESS IN TOXIC AND NUCLEAR WASTE SITING 67–120 (1994) (discussing local opposition in the United States); *see also* Michael B. Gerrard, *Fear and Loathing in the Siting of Hazardous and Radioactive Waste Facilities: A Comprehensive Approach to a Misperceived Crisis*, 68 TUL. L. REV. 1047 (1994).

[471] Congressman Morris K. Udall, Chairman, House Comm. on Interior and Insular Affairs, *quoted in* Charles H. Montange, *Federal Nuclear Waste Disposal Policy*, 37 NAT. RESOURCES J. 309, 310 (1987).

[472] *See* NAT'L RESEARCH COUNCIL, *supra* note 321, at 136–37.

[473] *See supra* text accompanying notes 364, 369, and 405.

[474] *See supra* text accompanying notes 369 and 407.

[475] *See supra* notes 358 and 396 and accompanying text.

"voluntarism," in which the local municipality offers to host the disposal site.[476] The municipality would have the right to withdraw from further consideration at any time until just prior to the start of construction.[477] The white paper also recommends financial incentives to the municipality.[478]

Furthermore, a local veto should not be overridden for political reasons. Although Swedish law allows the national government to override a veto, the override applies only under narrow circumstances,[479] and it has never been used. The NWPA in the United States authorized the host state to disapprove a site that the President had recommended, but also authorized Congress to make the final selection, notwithstanding state disapproval. Not surprisingly, after President Bush recommended the Yucca Mountain site to Congress in 2002, Nevada disapproved the recommendation, and Congress promptly approved the site, effectively overriding the state disapproval.[480] The result was to intensify local resentment.

C. *Technical Criteria*

Finally, there are several technical criteria that must be adopted. There is a widely-accepted, international scientific consensus that disposal of spent nuclear fuel and other high-level radioactive wastes in a deep geological repository is feasible and practicable.[481] All five of the subject countries have adopted this disposal method. Although the technical solution is perhaps somewhat less difficult than the political solution, deep geological disposal presents several technical issues that must be addressed.

1. *Geologic and Engineered Barriers*

The first technical criterion is that the repository must make use of multiple barriers to contain radioactive waste and prevent it from migrating into the environment. Multiple barriers include waste canisters, buffer materials, backfill, seals, plugs, and the host rock itself.[482] For example, the KBS-3 method developed in Sweden places considerable emphasis on redundant multiple barriers created by copper canisters, bentonite clay, and granite host rock.[483] U.S. regulations also provide for multiple barrier systems.[484]

---

[476] *See* DEFRA, GEOLOGICAL DISPOSAL, *supra* note 115, at 47–60.
[477] *Id.* at 56–57.
[478] *See id.* at 57–60.
[479] *See supra* notes 358–359 and accompanying text.
[480] *See supra* notes 240–241 and accompanying text.
[481] *See* NAT'L RESEARCH COUNCIL, *supra* note 321, at 21, 67; Nuclear Energy Agency, OECD, *Moving Forward with Geological Disposal of Radioactive Waste*, at 7, OECD Doc. NEA No. 6433 (2008).
[482] *See* OECD, *Engineered Barrier Systems and the Safety of Deep Geologic Repositories*, at 9, OECD Doc. EUR 19964 EN (2003) [hereinafter OECD, *Engineered Barrier Systems*].
[483] *See* SKB, DEEP REPOSITORY, *supra* note 377, at 7.
[484] *See* 40 C.F.R. § 191.14(d) (2009).

Engineered barriers — such as waste canisters, buffers, and backfill material — should serve as the primary means to contain radionuclide migration. Again using the KBS-3 method as an example, the Swedish designers report that the corrosion-resistant copper canisters and the low-permeability bentonite clay backfill are each independently expected to prevent the migration of radionuclides for a million years or longer.[485] In the United States, the waste canisters are made of a non-corrosive alloy and capped with a titanium drip shield.[486] Redundant engineered barriers can partially compensate for uncertainties in the understanding of the host rock.[487]

Geologic barriers — the host rock — should serve as a secondary but equally important means to prevent migration of radionuclides. Many types of host rock can serve this function.[488] Several factors should be taken into account in selecting a site with the requisite host rock. First, a site should not be selected if the host rock, or a nearby geologic formation, contains valuable minerals such as oil, natural gas, or metal ores.[489] Second, a site should be in an area that is geologically stable, without significant seismic activity, ideally for at least several million years. Seismic activity has been a troublesome issue at the Yucca Mountain site, which has been the locus of recent earthquakes.[490] In contrast, the Precambrian rock of the Baltic Shield in Sweden and Finland has been stable for millions of years. Third, a site should be located in host rock with low hydraulic conductivity (or low permeability), so that the movement of groundwater will not act to transport radionuclides from the repository into a regional aquifer. A relatively impermeable rock formation may contain fractures that create preferential and unpredictable pathways for groundwater movement. Such fracture flow is another problem that has plagued Yucca Mountain.[491] Fourth, a site should be located in host rock with favorable geochemistry, which can serve to retard the migration of radionuclides.[492] The various characteristics of the

[485] OECD, *Engineered Barrier Systems*, *supra* note 482, at 17, 24–25, 54.

[486] Allison M. Macfarlane & Rodney C. Ewing, *Introduction* to UNCERTAINTY UNDERGROUND: YUCCA MOUNTAIN AND THE NATION'S HIGH-LEVEL NUCLEAR WASTE 1, 17, 20 fig.1.10 (Allison M. Macfarlane & Rodney C. Ewing eds., 2006).

[487] NAT'L RESEARCH COUNCIL, *supra* note 321, at 86.

[488] For example, the Yucca Mountain site is in volcanic tuff. OECD, *Engineered Barrier Systems*, *supra* note 482, at 13. Another repository in the United States, the Waste Isolation Pilot Plant near Carlsbad, New Mexico, which is used to dispose of transuranic radioactive waste from nuclear weapons production, is constructed in a salt bed. CHUCK MCCUTCHEON, NUCLEAR REACTIONS: THE POLITICS OF OPENING A RADIOACTIVE WASTE DISPOSAL SITE 1–2 (2002). The likely repository site in France is in a clay formation. NAT'L RESEARCH COUNCIL, *supra* note 321, at 55. The repository sites in Sweden and Finland are in granite or other crystalline rock. *See id.* at 54, 61.

[489] Such a restriction is included in the U.S. siting regulations. *See* 40 C.F.R. § 191.14(e).

[490] *See* David Applegate, *The Mountain Matters*, *in* UNCERTAINTY UNDERGROUND, *supra* note 486, at 105, 116.

[491] *See* June Fabryka-Martin et al., *Water and Radionuclide Transport in the Unsaturated Zone*, *in* UNCERTAINTY UNDERGROUND, *supra* note 486, at 182–83.

[492] *See* David L. Bish & J. William Carey et al., *The Importance of Mineralogy at Yucca Mountain*, *in* UNCERTAINTY UNDERGROUND, *supra* note 486, at 217.

host rock can be determined in an underground research laboratory through an *in situ* rock characterization study.[493]

2. *Limits on Human Exposure*

The second technical criterion is that the repository must be designed to meet a radiation exposure standard that protects human health. As discussed in Part VI.B, each of the five subject countries has established radiation exposure standards for protection of public health. Some of those standards apply specifically to nuclear facilities while other standards apply more generally. There is a significant variation in the maximum annual dose among these national standards, ranging from the relatively less protective French standards to the relatively more protective Swedish and Finnish standards.[494] Yet they all meet internationally accepted guidelines set by the IAEA,[495] the International Commission on Radiological Protection ("ICRP"),[496] and Euratom.[497] Nevertheless, given the scientific uncertainties inherent in predicting risk many thousands of years into the future, a precautionary approach should be taken.[498] A more protective standard, such as that of Sweden and Finland, should be adopted.

3. *Limits on Environmental Exposure*

The third technical criterion is that the repository should also be designed to meet standards for protection of the environment. In the United States, the EPA regulations include standards for protection of groundwater.[499] These standards have been quite controversial, however. The nuclear power industry challenged the groundwater standard for Yucca Mountain as unnecessary given the human health protection standards, though the lawsuit was ultimately dismissed.[500] It is certainly prudent and sensible to establish a standard for the protection of groundwater. However, the EPA standard applies only for the first 10,000 years after closure of the facility, even though the highest levels of radioactivity are expected to occur after 10,000 years. And the standard applies only outside an arbitrary

---

[493] *See* NAT'L RESEARCH COUNCIL, *supra* note 321, at 88–90.

[494] *See supra* notes 261–264;, 310, 334, 336;, 388–389, 417–419 and accompanying text.

[495] IAEA, *IAEA Safety Standards for Protecting People and the Environment: Geological Disposal of Radioactive Waste*, at ¶ 2.12, IAEA Doc. No. WS-R-4 (May 2006) (maximum annual dose of 1 millisievert to members of the public).

[496] *See* Public Health and Environmental Radiation Protection Standards for Yucca Mountain, 73 Fed. Reg. 61,256, 61,265 (Oct. 15, 2008) (discussing the ICRP standard of 1 millisievert).

[497] Council Directive 96/29, Laying Down Specific Standards for the Protection of Health of Workers and the General Public against the Dangers Arising from Ionising Radiation, art. 13(2), 1996 O.J. (L 314) 20 (Euratom) (maximum annual dose of 1 millisievert to members of the public).

[498] *See generally* Daniel Bodansky, *Scientific Uncertainty and the Precautionary Principle*, ENVIRONMENT, Sept. 1991, at 4.

[499] 40 C.F.R. pt. 191, subpt. C (2009).

[500] Nuclear Energy Inst., Inc. v. EPA, 373 F.3d 1251, 1278–84 (D.C. Cir. 2004).

boundary or "controlled area" around the site.[501] Such limitations suggest that the engineered and geologic barriers will not be effective, and thus undermine confidence in the system. According to one critic, the EPA standard "allows for a plume of radioactive contamination that will spread several miles from the repository toward existing farming communities that depend solely on groundwater and perhaps through future communities closer to the site."[502] In Europe, neither Sweden nor Finland has adopted a groundwater standard for nuclear repositories, although the likely repositories in those countries will be constructed below the water table. Nor has the United Kingdom or France adopted such a standard.

Sweden has established other standards — ecological standards — for protection of the environment. The Swedish regulations provide that the repository must be operated and closed in a manner that protects biological diversity and sustainable use of biological resources.[503] This standard is very general, however, and may be difficult to apply. None of the other subject countries have adopted an ecological standard.

4. *Timescale*

The fourth criterion is that the radiation protection standards must be met for an appropriate period of time. Prediction of risk is very difficult over the many centuries that spent nuclear fuel must remain isolated.[504] Some countries, such as Sweden, do not specify in their laws a time period during which the human health risk standard must be met. The Swedish regulations can be interpreted as having no limitation, but it is unclear. The United States regulations initially required the standards to be met for 10,000 years. Environmental groups and the state of Nevada successfully challenged this limitation, maintaining that EPA had failed to follow the recommendations of the NAS, which stated that the highest risk from exposure to radiation released from the repository would likely occur after a period on the order of 1,000,000 years. EPA then added a revised standard to apply from 10,000 to 1,000,000 years.[505] This longer application of the standard is appropriate and supported by scientific evidence.

VIII. Conclusions

The problems associated with the management and disposal of high-level radioactive waste from commercial nuclear power plants have not been

---

[501] *See* 40 C.F.R. §§ 197.12, 197.30.

[502] *Nuclear Fuel Management and Disposal Act: Hearing on S. 2589 Before the S. Comm. on Energy and Natural Resources*, 109th Cong. at 41 (2006) (statement of Geoffrey H. Fettus, Senior Project Attorney, Natural Resources Defense Council).

[503] *See* 6 § SSM Management Regulations, *supra* note 389.

[504] *See* Nuclear Energy Agency, OECD, *The Handling of Timescales in Assessing Post-Closure Safety*, at 15, OECD Doc. NEA No. 4435 (2004).

[505] *See supra* text accompanying notes 262–274.

solved. Not a single country has yet begun construction of a repository for permanent disposal of spent nuclear fuel or other high-level radioactive wastes. Not a single country has issued a license for such construction. Only in Finland, which has a relatively small nuclear program, has the final selection of a repository site been completed, although in Sweden the waste management body has preliminarily selected a site subject to government approval. While several countries reprocess spent nuclear fuel, reprocessing has done little to reduce the waste disposal problem.

In several countries, the process for developing and locating a repository site has been flawed. The process has been closed and opaque, with little meaningful public participation, and a disregard for the concerns of the local community. Politics has prevailed over science. As a consequence, the government institutions involved in the process have lost credibility with the public and often with elected officials. A further consequence has been strong public opposition to repository proposals, which has often succeeded in blocking those proposals.

Nevertheless, the high-level radioactive waste disposal problem must be resolved, and it can be resolved, as the examples of Sweden and Finland suggest. To be successful, countries must establish a framework for development and location of a repository that includes, at a minimum, the criteria proposed herein. It must include both a siting body and a regulatory agency that are independent and credible; a process that is open and transparent, allows public participation, and empowers the local community to decide whether or not to host a repository; and technical standards that feature redundant engineered and geologic barriers that protect health and the environment from the effects of radiation from a repository, and that are based on assessment of the risk for approximately one million years after closure. Temporary storage of waste can be effectively employed as an interim strategy while possible repository sites are discussed and developed. Until such a framework is in place, the expansion of an existing national nuclear power program, or the initiation of such a program, would be very unwise.