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*Reprinted from*

ENERGY & ENVIRONMENT

VOLUME 19 No. 3+4 2008

MULTI-SCIENCE PUBLISHING CO. LTD.
5 Wates Way, Brentwood, Essex CM15 9TB, United Kingdom

# THE US EFFORT TO DISPOSE OF HIGH-LEVEL RADIOACTIVE WASTE

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**ABSTRACT**

This paper reviews the history of the US effort to dispose of high-level radioactive waste created by operating nuclear fission reactors for military and commercial purposes. The history is considered here in three parts: the period beginning in 1957 and ending with passage of the Nuclear Waste Policy Act in 1982; implementation of that Act over the period 1982 to 2005; and recent plans to promote a nuclear power "renaissance", including the initiation of the Global Nuclear Energy Partnership in 2006. To date, disposal has not been accomplished, and many observers doubt that disposal will occur during the next several decades. The history of the disposal effort features a series of decision-action cycles in which objectives were formulated, decisions were taken, actions were implemented, and outcomes occurred. The decision-action process is examined here with attention to the roles and objectives of major stakeholders, the relation of those objectives to governmental decisions, and the extent to which the actual outcomes have corresponded with the objectives.

## 1. INTRODUCTION

Nuclear fission reactors in the USA have produced large amounts of "high-level" radioactive waste. For half a century, the US federal government has conducted programs to dispose of this material. The effort has involved a large investment of financial, political and scientific capital. Yet, disposal has not been accomplished, and many observers doubt that disposal will occur during the next several decades.

It is important to understand the reasons for this disappointing outcome. The lessons from US experience can inform future plans for creation and disposal of high-level radioactive waste in the USA and other countries. The US inventory of this type of waste now consists primarily of spent (i.e., no longer usable) fuel from commercial reactors, and their continued operation adds to the inventory. Extension of their operating licenses, and the construction of new commercial reactors, would further increase the inventory. As the inventory grows, it will become increasingly important to assess the prospects for future disposal. Understanding the lessons of experience must be an important part of that assessment.

In the absence of disposal, high-level radioactive waste remains in close proximity to humans and their environment. The risk of a radioactive release to the environment, arising from accident or malice, accumulates over time. Compounding that risk, much of the commercial spent fuel is currently stored under water in tightly packed pools. Loss of water from such a pool could lead to a large release of radioactive material to the atmosphere, through mechanisms discussed below.

This paper reviews the history of the US disposal effort, and identifies major factors that influenced the effort. The history features a series of decision-action cycles in which objectives were formulated, decisions were taken, actions were implemented, and outcomes occurred. The decision-action process is examined here with attention to the roles and objectives of major stakeholders, the relation of those objectives to governmental decisions, and the extent to which the actual outcomes have corresponded with the objectives. The history of the disposal effort is considered here in three parts: the period beginning in 1957 and ending with passage of the Nuclear Waste Policy Act (NWPA) in 1982; implementation of that Act over the period 1982 to 2005; and recent plans to promote a nuclear power "renaissance", including the initiation of the Global Nuclear Energy Partnership (GNEP) in 2006.

## 2. NUCLEAR FISSION TECHNOLOGY AND TERMINOLOGY

Nuclear fission has occurred naturally. In 1972, Francis Perrin discovered that nuclear fission reactions had occurred in uranium ore deposits in Oklo, Gabon, about 1.7 billion years ago. The world's first human-constructed nuclear fission reactor began operating at the University of Chicago in December 1942, as part of the Manhattan Project that developed nuclear weapons for the USA. Since then, numerous nuclear reactors have been built in the USA, for production of nuclear-weapon materials, naval propulsion, research and related functions, and electricity production (Cochran et al, 1987; Nero, 1979). At present, one-fifth of US electricity is generated from heat released in 104 commercial nuclear reactors, which are cooled and moderated by light water (NRC, 2007).

With the exception of some small, prototypical reactors, all nuclear reactors built in the USA have employed solid fuel, in the form of discrete fuel assemblies. In the commercial reactors, the fuel assemblies consist of clusters of long, narrow, zirconium alloy tubes containing uranium oxide pellets. After several years of use in a reactor, fuel assemblies are designated as "spent" and are discharged from the reactor. Each spent fuel assembly contains a large inventory of radioactive isotopes in the form of fission products, activation products, and actinides (heavy elements such as plutonium).

Spent fuel can be stored intact. Alternatively, it can be sent to a chemical separation plant – a "reprocessing" plant – where the plutonium is extracted for use in nuclear weapons or as reactor fuel. Unburned uranium is also extracted, and might be re-used in reactors. Most of the remaining radioactive inventory in the spent fuel emerges from the plant as a stream of "high-level" radioactive waste in liquid form. That material can be stored as a liquid, or it can be converted to a solid form (e.g., a borosilicate glass-filled canister) for further storage and eventual disposal. Decay of the radioactive isotopes in spent fuel, or in the liquid or solid high-level waste derived from it, generates a substantial amount of heat. Thus, these waste forms must be cooled by natural or artificial means. Their radioactive inventory will remain hazardous for many millennia.

If spent fuel is not reprocessed, it can be categorized in two different ways. First, it can be regarded as a resource, because it contains plutonium and unburned uranium that could be extracted in the future by reprocessing. Second, it can be designated as waste that will eventually be sent for disposal. For practical purposes, spent fuel in the second category is a form of high-level waste, whether or not it is formally classified as such, because it has a large radioactive inventory. Almost all of the spent fuel from US commercial reactors has not been reprocessed, and is currently designated as waste. Some stakeholders oppose that designation. They argue that the plutonium in the spent fuel is a valuable resource because it could be extracted for use as reactor fuel. Additional plutonium could be created in "breeder" reactors by converting uranium-238, the non-fissile, dominant isotope of natural uranium. These arguments have a significant current influence on the US effort to dispose of high-level radioactive waste, as discussed below.

Reactors and reprocessing plants are part of a nuclear fuel cycle that begins with uranium mining, ends with waste disposal, and includes decommissioning of worn-out facilities. During the cycle, fission occurs in commercial, military or research reactors. At various points, the fuel cycle generates streams of radioactive waste in gaseous, liquid and solid forms. Some of the waste streams are discharged to the environment. At modern facilities, those waste streams contain a comparatively small inventory of radioactivity. Other waste streams ultimately yield solid packages that are designated for disposal as "low-level" or "transuranic" (actinide-containing) waste. The remaining waste streams are forms of high-level waste. Some high-level waste streams, such as intact spent fuel, are created in solid form. Liquid high-level waste streams would be converted to solid form before being sent for disposal. Ultimately, the various high-level waste streams would yield four categories of solid package that would be sent for disposal. The packages could contain intact spent fuel, solidified liquid waste from reprocessing, a portion of the solid waste from decommissioning of reactors, or surplus plutonium from the US nuclear-weapon stockpile.

Quantities of high-level waste are typically measured in metric tons of heavy metal (MTHM), either directly or as an equivalent. That unit refers to the mass of heavy elements (uranium, plutonium, etc.) initially placed in a reactor as fresh fuel. At least 50,000 MTHM of commercial spent fuel is currently being stored across the USA (NRC, 2007). The present fleet of commercial reactors is expected to produce at least 80,000 MTHM of spent fuel over the duration of the reactors' 40-year operating licenses (Macfarlane, 2001). Reactors that receive 20-year license extensions, as most are expected to do, will produce additional spent fuel. Thus, the present fleet of commercial reactors could produce over 120,000 MTHM of spent fuel. Other components of the US inventory of high-level waste arise from programs conducted by the federal government, primarily for naval propulsion and for production of nuclear-weapon materials, especially plutonium and tritium. These components include up to 2,500 MTHM of spent fuel and 11,500 MTHM equivalent of reprocessing waste (DOE, 2002).

The concept of "disposal" of high-level radioactive waste refers, in the USA, to removal of the waste from the Earth's surface, with the aim of creating a very small impact on humans and their environment over subsequent millennia. A variety of options for disposal of high-level waste have been considered, as discussed below. The current preference is for emplacement of waste packages in a mined, underground "repository" within the mainland USA. For a period of decades after emplacement, the packages would be retrievable.

## 3. MAJOR STAKEHOLDERS

The federal government is the dominant stakeholder regarding high-level radioactive waste in the USA. Since 1946, the US Atomic Energy Commission (AEC) and its successor agencies, first the Energy Research and Development Administration (ERDA) and now the Department of Energy (DOE), have operated the reactors and other facilities used to produce plutonium, tritium and other materials for nuclear weapons. These agencies have also provided research and development and fuel-cycle services for research reactors and the propulsion reactors operated by the US Navy. In addition, these agencies effectively created the commercial nuclear industry, and have assumed the responsibility for disposing of all US high-level radioactive waste. The Nuclear Regulatory Commission (NRC), which took over many of the AEC's regulatory functions in 1975, regulates the safety and security of the commercial nuclear sector, with input from the Environmental Protection Agency (EPA). Other federal agencies are responsible for a range of functions that support the management, transport and disposal of radioactive waste. The US Congress enacts relevant legislation, and allocates funds to high-level radioactive waste programs on an annual basis. Within the Congress, a number of committees in the House of Representatives and the Senate are involved with issues related to radioactive waste.

The next most powerful stakeholder regarding high-level radioactive waste is the nuclear industry. More precisely, this industry is a cluster of stakeholders that typically collaborate on policy issues. The Nuclear Energy Institute represents their political interests. Collectively, they have strong influence in the Congress. The owners of the US fleet of 104 commercial reactors form the core of this cluster. Other industry stakeholders include the companies that finance, build and service nuclear facilities. When the commercial reactors were first built, they were owned by electric utility companies that were vertically integrated (i.e., they produced and distributed electricity). Those companies were mostly private entities whose prices were regulated by state governments. In the 1990s, a wave of electricity deregulation affected a number of states. As a result, many reactors are now owned by "merchant" power companies that sell electricity in nominally competitive markets. These companies have a strong incentive to minimize their production costs. They typically purchased reactors at a large discount, taking advantage of the financial restructuring that followed massive cost overruns and numerous project cancellations during a wave of reactor construction that peaked in the 1970s and 1980s. During that wave, a total of 97 commercial reactors were under construction or planned across the USA, and then cancelled (NRC, 2007).

State and local governments are direct stakeholders in regard to high-level radioactive waste when actual or proposed reactors, reprocessing plants, waste-storage facilities, repository sites, or waste-transport routes are on their territory or nearby. Many state and local governments across the USA are in this category. These governments have comparatively little power to directly influence decisions related to nuclear issues in general, or high-level waste issues in particular. They can intervene in proceedings before the NRC, regarding the establishment of generic rules or the licensing of particular nuclear facilities, but these interventions are rarely successful. As an alternative, state and local governments generally exert their influence indirectly, through national political channels. For example, during the campaigning cycle that precedes each presidential election, state and local officials, party organizations, and citizen groups have opportunities to influence presidential candidates and party platforms. Through such channels, the concerns of state and local governments have substantially influenced the federal government's effort to dispose of high-level radioactive waste.

Citizens are the ultimate stakeholders. They are, however, rarely consulted directly regarding their views on issues related to nuclear power. Instead, citizens' views are expressed through local, state and national political channels, where concerns about nuclear issues can be diluted by concerns about a range of policy issues. In particular instances, public opinion about nuclear power or radioactive waste can be a salient issue in an election campaign. Some citizens, who have strongly-held concerns about nuclear issues, become involved with groups that campaign for environmental protection, peace, and other causes. There are many local campaigning groups across the USA, some specializing in nuclear issues, others covering a range of issues. Some campaigning groups (e.g., Greenpeace, Friends of the Earth, Sierra Club) operate nationally or internationally. Activities conducted by campaigning groups include public education, media outreach, lobbying, intervention in NRC proceedings, and litigation. The funds and other resources commanded by all the campaigning groups, taken together, are small by comparison with the resources commanded by the federal government and the nuclear industry. There is no significant citizen-based campaigning effort in support of the nuclear industry.

A comparatively small but significant group of stakeholders in the radioactive waste arena can be loosely described as the "nuclear intelligentsia". These people are based in universities, policy research organizations (i.e., "think tanks"), government or private laboratories, public-interest groups, etc. They develop the technical and policy options that are available to the nation. Their perspectives and values vary, but they typically share a familiarity with academic modes of discourse. Funding for the work of the nuclear intelligentsia is provided by various public and private sources. The federal government and the nuclear industry are by far the major providers of this funding. It is common for a member of the nuclear intelligentsia to work on both civil and military applications of nuclear technology. The most prestigious setting for this type of work is the National Academy of Sciences. The Academy is an autonomous body that is often commissioned by the federal government or the Congress to render an opinion on technical or policy issues related to nuclear technology. Committees of scientists are formed to address these issues.

## 4. MAJOR PERSPECTIVES

The US stakeholder groups described above are not monolithic units. There are many subgroups within them, with widely varying perspectives, interests and objectives regarding issues related to radioactive waste. This diversity can be confusing, but patterns can be discerned. Those patterns derive more from overall attitudes to commercial nuclear power than from attitudes specific to radioactive waste. A simplified but analytically useful approach is to divide the stakeholders into three categories regarding their objectives for commercial nuclear power. These categories are: nuclear expansionists; nuclear incrementalists; and nuclear skeptics.

The "nuclear expansionists" seek or expect a large expansion in the role of nuclear power. As a corollary, they favor reprocessing and breeder reactors, because they see uranium ore reserves as being insufficient to support the expected number of commercial reactors. Stakeholders of this persuasion were influential during the early decades of the commercial nuclear industry. For example, in 1972 the AEC predicted that 1,200 GWe of nuclear generating capacity would be in operation across the USA in 2000. As a corollary, the AEC and the nuclear industry assumed that spent fuel from commercial reactors would be reprocessed, and that a fleet of breeder reactors would be deployed. Events soon showed that the AEC's view was unrealistic, and capacity predictions were repeatedly lowered. In 1978, DOE (AEC's successor agency) predicted, as a "low" estimate, that 160 GWe of nuclear capacity would be in operation across the USA in 2000 (Lipschutz, 1980). The actual US nuclear generating capacity at present (using 2005 data) is 98 GWe (NRC, 2007). Reprocessing of commercial spent fuel ceased in 1972 and was banned by the federal government in 1977. Construction of the first commercial breeder reactor, the Clinch River reactor, was canceled in 1983. In recent years, the political fortunes of the nuclear expansionists have revived. That revival is illustrated by the federal government's promotion of the Global Nuclear Energy Partnership, as discussed below.

The "nuclear incrementalists" favor commercial nuclear power, but they seek or expect a smaller increase in nuclear generating capacity than is envisioned by the expansionists. The views of this group can be represented by a study published by the Massachusetts Institute of Technology (MIT) in 2003 (Ansolabehere et al, 2003). The MIT authors see no need for reprocessing or breeder reactors during at least the next 50 years. They offer an illustrative scenario for the expansion of nuclear generation, in which nuclear power accounts for 30 to 50 percent of US electricity production and 21 to 36 percent of worldwide electricity production in 2050. In this scenario, US production of electricity from nuclear power in 2050 is 3 to 6 times higher than in 2000, and worldwide production is 4 to 6 times higher. The postulated increase in nuclear generation is ambitious by historical standards, and assumes that a variety of significant obstacles are overcome. For example, this scenario assumes that reactors can be deployed in many countries without an increased risk of proliferation of nuclear weapons. Achieving that outcome would require the avoidance of situations such as the Iranian government's present dispute with other governments regarding the enrichment of uranium. Iran argues that its enrichment capacity is intended to support commercial reactors, while the opposing governments argue that Iran may produce highly-enriched uranium for use in nuclear weapons.

Stakeholders in the third category – the "nuclear skeptics" – doubt the merits of commercial nuclear power. They seek or expect a decline in its use. Some argue that nuclear power can and should be phased out, even during an effort to dramatically reduce greenhouse gas emissions from electricity generation (Makhijani, 2007). Others argue that scenarios for expansion of nuclear generation are fanciful, and that the commercial nuclear industry is in terminal decline (Schneider and Froggatt, 2007). Some stakeholders advocate the closure of reactors that are now operating. In November 2007 the Governor and the Attorney General of New York State called for early closure of the two reactors operating at the Indian Point site, on the grounds that these reactors pose an especially high risk (Sullivan and Wald, 2007).

## 5. EARLY EFFORTS ON HIGH-LEVEL WASTE DISPOSAL: 1957-1982

The first phase of the federal government's effort to dispose of high-level waste fits neatly into the quarter century, 1957 through 1982. In 1957, the AEC first began to plan for disposal, and in 1982 the Nuclear Waste Policy Act was enacted.

The National Academy of Sciences issued a report in 1957, finding that the most promising method for disposing of high-level radioactive waste was to place the waste in a repository constructed in an underground salt deposit. The AEC's disposal planning began in the same year, but moved slowly at first. Eventually, the AEC accepted the Academy's advice, and initiated Project Salt Vault in 1963. To test the concept of disposal in salt, that project placed some electrically-heated canisters and canisters of real waste in holes bored in salt in an abandoned salt mine under the town of Lyons, Kansas. Although cracking of the stainless steel canisters was observed, the AEC announced in 1970 that testing was complete, and that the Lyons mine would be used for the permanent disposal of transuranic and high-level wastes. The AEC made that announcement despite a call by the Kansas government for further study of the site. Subsequent investigations revealed that the site was penetrated by boreholes that had been drilled by prospectors searching for oil and gas, and that parts of an active salt mine in the vicinity were as close as 500 meters to the Lyons mine. That knowledge, and pressure from citizens and the Kansas government, caused the AEC to cancel the project in 1973. Experience with Project Salt Vault provided important lessons (Lochbaum, 1996; Lipschutz, 1980; Colglazier, 1982). Two major deficiencies in the AEC's approach were evident. First, the AEC exhibited a low level of scientific and technical professionalism, which some observers attributed to the low status of radioactive waste work within the organization. Second, the AEC attempted to ignore concerns expressed by a state government, even though the concerns were based on sound science.

During the life of Project Salt Vault, the AEC and the nuclear industry assumed that all US commercial spent fuel would be reprocessed (NRC, 1979). The first reprocessing plant that was intended to receive this fuel was constructed at West Valley, New York, and commenced operation in 1966. By 1972, after the plant had reprocessed 640 MTHM of fuel, operation was suspended to allow modification of the plant and a doubling of its capacity. The estimated cost of the modifications rose dramatically due to imposition of more stringent safety criteria by the AEC's regulatory arm in 1973 and 1974. As a result, the West Valley plant did not resume operation and was closed in 1976 (Lochbaum, 1996).

The West Valley experience, together with expected trends in the prices of uranium, reprocessing, and plutonium fuel fabrication, convinced many analysts that reprocessing of commercial spent fuel was not economically indicated. Also, during the 1970s there was growing concern in the USA that separation of plutonium in reprocessing plants and the use of plutonium as a reactor fuel around the world would promote the proliferation of nuclear weapons (Keeny et al, 1977). This concern led President Ford to impose a moratorium on reprocessing in 1976, and President Carter to ban reprocessing in 1977. A reprocessing plant that had been constructed at Barnwell, South Carolina, did not open. The reprocessing ban was lifted by President Reagan in 1981, but since that time the US nuclear industry has shown no inclination to invest in reprocessing.

When spent fuel is discharged from a commercial reactor, it is initially stored in a water-filled pool adjacent to the reactor. Each commercial reactor in the present US fleet employs a pool whose dimensions reflect the assumption that all spent fuel will be reprocessed. The pool is sized to accommodate a few years' discharge of spent fuel, providing interim storage before the fuel is taken to a reprocessing plant (NRC, 1979). Thus, termination of reprocessing in the 1970s created a need for additional capacity for storing spent fuel. That need could have been met by constructing new storage facilities, either at reactor sites or elsewhere. Instead, the nuclear industry adopted a cheaper alternative – increasing the density of storage in the existing pools – that was eventually implemented across the US reactor fleet. Originally, the pools were equipped with open-frame, low-density storage racks. Now, every pool is equipped with high-density storage racks in which fuel assemblies are packed almost as tightly as they would be in a reactor core. To prevent criticality, plates of neutron-absorbing material are placed between the fuel assemblies. This configuration would suppress convection of air or steam if water were lost from a pool, thereby inhibiting the removal of heat produced by radioactive decay. Thus, in the event of water loss, the zirconium alloy cladding of spent fuel could ignite spontaneously after a period of exposure to air. The resulting fire would spread across the pool, and a large amount of radioactive material would be released to the atmosphere. Loss of water could arise as a result of an accident or an attack (Alvarez et al, 2003; National Research Council, 2006).

The risk of a fire in a high-density spent-fuel pool was recognized by scientists in 1979. Nevertheless, the practice of storing spent fuel in high-density pools was supported by the NRC, and continues today (Thompson, 2007). From the mid-1970s onward, various stakeholders supported or tolerated this practice, at differing times and for differing reasons. For the nuclear industry and the NRC, high-density pools provided a comparatively cheap option for storing spent fuel. For ERDA and DOE, which successively took over the AEC's responsibility for disposing of high-level waste, the availability of the pool-storage storage option reduced the pressure for early implementation of a disposal option. For stakeholders concerned about the proliferation of nuclear weapons, the pool-storage option reduced the pressure for a resumption of reprocessing. For some citizen groups that opposed nuclear power, the pool-storage option was tolerable because of its limited capacity. These groups pointed to the absence of a disposal option for spent fuel, and the limited storage capacity of the pools, as grounds for early closure of commercial reactors. In recent years, however, citizen groups and other stakeholders have become vigorous opponents of high-density pool storage, as discussed below.

After the failure of Project Salt Vault, the AEC, followed by ERDA and then DOE, studied a variety of options for the disposal of high-level radioactive waste. The preferred option continued to be the emplacement of waste packages in a mined, underground repository within the mainland USA. In 1980, DOE published an environmental impact statement (EIS) for the management of commercially generated high-level waste (DOE, 1980). At that time, the national inventory of commercial spent fuel, including fuel in reactor cores, was about 10,000 MTHM. DOE stated that disposal in a mined repository was the proposed action, but also stated that research and development would continue on two alternative actions: disposal in sediment beneath the deep ocean; and disposal in very deep boreholes. Other alternatives had been considered but were no longer being pursued. These included: disposal in ice sheets; construction of a repository under a remote island; insertion of waste packages into a solar orbit; injection of liquid waste into deep wells; and transmutation.

The EIS estimated the number of mined repositories that would be required in the future, given various scenarios for the development of commercial nuclear power. The most ambitious scenario that was considered was one in which nuclear generating capacity across the USA rose to 250 GWe in 2000 and 500 MWe in 2040. DOE estimated that disposal of the spent fuel produced by 2040 would require the construction of 2 to 7 repositories (DOE, 1980).

DOE's preparation of the EIS was a sign of growing pressure by influential stakeholders for a more vigorous, targeted effort to develop a high-level waste disposal option. Citizens and state and local governments were unhappy that inventories of commercial spent fuel were growing and no disposal option was available. The nuclear industry and the federal government were anxious to demonstrate that the use of nuclear power would not be constrained by the lack of a disposal option. These political pressures led, though complex negotiations, to Congressional enactment of the Nuclear Waste Policy Act of 1982.

The NWPA called for the construction of two repositories. The first repository would be in a western state, and its capacity would be limited to 70,000 MTHM. DOE subsequently determined that 63,000 MTHM of that capacity would be used for commercial spent fuel. The second repository would be constructed in the eastern part of the mainland USA. Congress intended that the first repository would not have sufficient capacity to accommodate the expected national inventory of high-level waste. By requiring two repositories, in different parts of the country, Congress sought to create an understanding that the burden of hosting a repository, or a transport route to a repository, would be equitably shared. In further pursuit of the concept of equity, the NWPA required owners of commercial reactors to contribute to the cost of repository construction and operation by paying a fee of 0.1 cents for each kW-hour of nuclear-generated electricity. The Act also required DOE to begin the disposal of commercial spent fuel by 1998. EPA was given the responsibility for developing a standard for radiation exposure of the public as a result of leakage of radioactive material from a repository (Flynn et al, 1995).

At the end of a 25-year period during which the federal government had made little progress in disposing of high-level radioactive waste, the NWPA appeared to offer a new approach. Supporters of the Act saw it as a practical, equitable, science-based framework for the sequential development of two repositories that would accommodate the expected national inventory of high-level waste. Events since 1982 have not fulfilled that vision.

## 6. IMPLEMENTATION OF THE NWPA: 1982-2005

The first test of the NWPA occurred in 1985, when DOE nominated three potential repository sites in the western USA for detailed study. The sites were: Yucca Mountain, Nevada (volcanic tuff); Hanford, Washington (basalt); and Deaf Smith, Texas (bedded salt). Each of these sites was at or near a location where DOE conducted activities related to the US arsenal of nuclear weapons. Thus, local communities had long familiarity with, and economic ties to, nuclear activities. It was clear that DOE had selected at least one of these sites – Hanford – not on technical grounds, but because local communities would be comparatively likely to accept a repository (Flynn et al, 1995). This test of the NWPA demonstrated that politics, not science, would be the dominant factor in decision making.

The second test occurred in 1986, when DOE announced the locations of twelve potential repository sites in nine states in the eastern part of the USA, where most of the commercial reactors are located. These sites were to be studied to determine their technical suitability for construction of the second national repository. Announcement of these eastern locations triggered widespread public opposition, threatening the election prospects of powerful politicians. As a result, six months after identifying the twelve eastern sites, DOE suspended its effort to develop a repository in the east. In 1987, Congress made that decision permanent by passing an amendment to the NWPA. At the same time, through another amendment, Congress narrowed the study of western sites to one location – Yucca Mountain. There was ample evidence that Congress' decision to focus the repository development effort entirely on Yucca Mountain was driven primarily by political considerations. Nevada has a comparatively small population and, therefore, a small Congressional delegation. Faced with public opposition to repository development, delegations from more powerful states exploited Nevada's political weakness, ignoring the principles of equity that were embodied in the NWPA (Flynn et al, 1995). One outcome has been Nevada's sustained commitment to opposing the Yucca Mountain repository through technical argument, litigation, and lobbying.

Although Congress exhibited little interest in the technical merits of the Yucca Mountain site, some scientists and DOE managers argued that the site has technical advantages. At this site, the repository would consist of mined galleries within a mass of welded tuff formed by flow of volcanic ash 13 million years ago. DOE argues that new volcanic activity at this site is unlikely. The local climate is arid, surface water is limited, and aquifers are far below the surface. The repository would be at least 200 meters below the surface and 160 meters above the water table (DOE, 2002). DOE's concept was that the repository would be dry, thereby preserving the integrity of waste packages and limiting the water-borne leakage of radioactive material to the environment over the many millennia during which the material would be hazardous. However, investigations have revealed that about 10 percent of the volume of the tuff rock consists of water, which moves slowly through pores but can move quickly through open fractures. Also, air moves freely through the rock via interconnected fractures (Carter and Pigford, 2005). These moist, oxidizing conditions would rapidly degrade waste packages, including the uranium oxide pellets in spent commercial fuel, and would promote the dissolution and transport in groundwater of radioactive isotopes, including neptunium-237 and technetium-99, that would be important contributors to long-term radiation dose due to repository leakage. For these reasons, every other proposed repository in the world would be located below the water table, in reducing conditions. The proposed Yucca Mountain repository is unique in being located in the unsaturated zone, where oxidizing conditions prevail (Ansolabehere et al, 2003; Ewing and Macfarlane, 2002). Thus, DOE's pursuit of a dry repository concept may have been a fundamental strategic error.

Any mined repository that is located at the depth of the proposed Yucca Mountain repository would experience some amount of leakage of radioactive material to the accessible environment, leading to radiation doses to human populations. Leakage amounts and radiation doses are estimated using theoretical models that feature numerous assumptions. Models show that the dose to an exposed individual could peak tens or hundreds of millennia after repository closure (National Research Council, 1983). Under the NWPA, the process of licensing a repository such as Yucca Mountain would involve DOE submitting modeling findings to the NRC. Then, NRC would make two determinations. First, are the modeling findings credible? Second, are those findings compatible with a radiation exposure standard established by the EPA? During the licensing process, interested parties such as the state of Nevada would critique the DOE models and NRC's evaluation of those models, and would offer their own findings. The process would address dose models in great detail, and could continue for years.

As directed by the NWPA, EPA developed a radiation exposure standard for repositories. EPA's standard sought to protect human populations by limiting the leakage from a repository. For each of a set of radioactive isotopes, EPA specified a limit on the cumulative leakage to the accessible environment over a period of 10,000 years, per 1,000 MTHM of high-level waste placed in the repository. For example, the cumulative leakage of carbon-14 was limited to 100 Curies (3.7 TBq) per 1,000 MTHM of waste. EPA required that there be less than one chance in 10 of exceeding the leakage limit, and less than one chance in 1,000 of exceeding ten times the leakage limit (Hunter et al, 1987). From the perspective of public health, the EPA standard had one major strength and two major weaknesses, assuming that compliance with the standard could be assured. The major strength was that the EPA standard protected the entire worldwide population in the future, by limiting the total population dose that could arise from leakage from a repository in the USA. One major weakness was that the permissible leakage was expressed in Curies per 1,000 MTHM of waste. Thus, the total permissible leakage would continue to grow if commercial reactors continued to operate. The second major weakness was that EPA placed no limit on leakage to the accessible environment after 10,000 years, despite studies showing that leakage of risk-significant isotopes to the environment could peak at hundreds of millennia (National Research Council, 1983).

In the late 1980s, DOE concluded that a repository at Yucca Mountain would experience atmospheric leakage of carbon-14 in excess of the EPA limit. DOE then prevailed on Congress to pass an amendment to the NWPA in 1992, requiring EPA to establish a new radiation exposure standard that would be unique to Yucca Mountain. Other repositories would be licensed according to the previous standard. The new standard would not limit the leakage of radioactive material. Instead, it would limit the radiation dose to the most exposed individual. EPA issued draft and final versions of the new standard in 1999 and 2001, respectively. Both versions limited individual radiation dose to 15 millirem (0.15 mSv) per year during the first 10,000 years, with no limit thereafter. Nevada and other parties successfully challenged this standard in a federal court. In 2004 the court ordered EPA to prepare a standard that covered times much longer than 10,000 years. EPA issued a draft version of a revised standard in 2005. No final version had been issued by the end of 2007. The revised standard limits the estimated mean individual dose to 15 millirem (0.15 mSv) per year during the first 10,000 years and the estimated median individual dose to 350 millirem (3.5 mSv) per year for the period from 10,000 years to 1 million years. The switch from the mean estimate to the median estimate would significantly amplify the increase in public-health risk in the later period. EPA's two-tier standard is clearly designed to accommodate DOE's expectation that the peak individual dose attributable to the Yucca Mountain repository would occur after 10,000 years. One estimate by DOE has put that dose at about 150 millirem (1.5 mSv) per year, occurring after about 480,000 years (DOE, 2002). EPA's dose limit of 350 millirem (3.5 mSv) per year is far above the National Academy of Science's recommendation of 2 to 20 millirem (0.02 to 0.2 mSv) per year, sharply contradicts EPA's previous rejection of a dose limit of 25 millirem (0.25 mSv) per year as being too high, and would be the weakest radiation exposure standard in the industrialized world (Holt, 2007; Nevada Commission, 2006).

DOE needs a two-tier dose limit because leakage from the Yucca Mountain repository to ground water is projected to increase substantially after the first 10 or 20 thousand years. Basic properties of the site, including the characteristics of the tuff rock and the placement of waste in the unsaturated zone under oxidizing conditions, would give the repository a comparatively low capability to retain radioactive material. To compensate, DOE proposes to package waste in containers made of durable, nickel-based "Alloy 22". Also, titanium drip shields would be placed over the containers, to prevent liquid water from contacting the containers. DOE expects that the containers and drip shields – which are described as "engineered barriers" – might remain intact for about 20,000 years (DOE, 2001). Substantial leaching of radioactive material into ground water would not begin until the engineered barriers had degraded. Thus, DOE believes that the repository could comply with a low limit of radiation exposure for the first 10 or 20 thousand years, but not thereafter. EPA has been willing to accommodate this feature of the repository by adjusting its radiation exposure standard, although that adjustment contradicts EPA's previous standards and widely-accepted principles of public health. This approach by DOE and EPA violates one of the fundamental principles that underlay the NWPA – namely, that containment of radioactive material in a repository should rely primarily on the properties of geologic media, not on engineered barriers (Holt, 2007; Ewing and Macfarlane, 2002).

The NWPA required DOE to begin receiving spent fuel from commercial reactors by 1998, for placement in a repository. DOE's failure to meet that deadline has spawned numerous lawsuits by reactor owners. According to DOE estimates, the federal government will be liable for $7 billion of payments to reactor owners if the Yucca Mountain repository opens by 2017, with a further $0.5 billion of liability for each year of additional delay (Holt, 2007). DOE currently estimates that the repository will open in 2017, but other observers predict further delay or cancellation of the entire Yucca Mountain project. The project faces numerous obstacles (Holt, 2007; Nevada Commission, 2006). Three examples are illustrative. First, there have been chronic problems with quality assurance, and in 2005 it was revealed that quality assurance documents had been falsified. Second, DOE announced in 2005 a fundamental re-design of the system for packaging commercial spent fuel for emplacement in Yucca Mountain. The new system obliges reactor owners to package spent fuel in sealed containers that are ready for emplacement. That concept creates major problems of planning and quality assurance, and the proposed standardized container is not compatible with containers that many reactor owners are now using for dry storage of spent fuel. Third, DOE's plan for retrieval of waste packages and emplacement of drip shields may be unworkable because practical factors, including dust buildup and corrosion of steel rails over time, would preclude long-term access to galleries inside the repository using remote-controlled machinery. DOE's plan allows for retrieval during a "monitoring" period after the emplacement of waste packages. That period would be followed by a "closure" period during which the drip shields would be emplaced and other actions would be taken to close the repository. Until recently, DOE had stated that the monitoring period could be as long as 300 years (DOE, 2002). Now, in apparent recognition of factors such as dust buildup over time, DOE states that the monitoring period would be no more than 50 years (DOE, 2007a). DOE officials have experience with underground conditions at Yucca Mountain because DOE bored a curving tunnel, 5 miles (8 km) long and 25 feet (7.6 m) in diameter, within the mountain between 1994 and 1997, and is conducting studies in alcoves off the tunnel (Holt, 2007).

In the absence of a repository, inventories of spent fuel at commercial reactors are growing. Many spent-fuel pools are filled at or near their capacity. According to the NRC website (www.nrc.gov, accessed in December 2007), all the pools at operating reactors across the USA will be filled to capacity by 2014. To allow continued operation of the reactors, their owners are building independent spent fuel storage installations (ISFSIs) at the reactor sites. There has also been discussion and planning for construction of ISFSIs at sites away from reactors. For example, a proposed away-from-reactor ISFSI in Utah, with a capacity of 40,000 MTHM of spent fuel, received a license from the NRC in 2006 (NRC, 2007). However, the US Department of Interior subsequently issued decisions that block the project (Holt, 2007). Most observers now assume that the Utah ISFSI will not open. Overall, with minor exceptions dating from several decades ago, no away-from-reactor ISFSI exists, and none is currently anticipated.

At a contemporary ISFSI in the USA, spent fuel is stored dry, in a helium atmosphere inside a stainless steel container that is cooled by natural convection of air and is shielded by a concrete overpack. A typical container could hold about 10 MTHM of fuel. The containers, inside their overpacks, are arrayed on concrete pads in the open air. This storage mode does not pose the high risk of an atmospheric release that arises from high-density storage of spent fuel in a pool. Nevertheless, the reactor owners intend to continue using their pools at high density, periodically offloading the longer-discharged fuel assemblies from each pool to an ISFSI in order to clear space in the pool to accommodate newly-discharged fuel assemblies. In the event of loss of water from a pool, the newly-discharged fuel assemblies would rapidly heat up to the ignition temperature of their zirconium alloy cladding. Thus, the reactor owners are pursuing a strategy for interim storage of spent fuel that involves a comparatively high risk of a large, inadvertent release of radioactive material to the atmosphere. The NRC allows this strategy to continue, despite a confirmation by the National Academy of Sciences that spent fuel in a high-density pool could ignite if the pool experienced a loss of water (National Research Council, 2006).

The radioactive isotope cesium-137 would account for most of the offsite radiation exposure if a fire occurred in a spent-fuel pool. At the Indian Point site in New York State, where two commercial reactors are operating, the pool adjacent to each reactor is expected to hold about 70 million Curies (2.6 million TBq) of cesium-137 during the next three or more decades. That is a typical inventory for the pool at a US commercial reactor. A fire in a spent-fuel pool could arise in various ways as a result of an accident or an act of malice. Either type of event could also involve the adjacent reactor. Tens of percent of the cesium-137 in a pool could be released to the atmosphere if a fire occurred in the pool. For comparison, the Chernobyl reactor accident of 1986 released about 2.4 million Curies (90,000 TBq) of cesium-137 to the atmosphere. Cesium-137 accounted for most of the offsite radiation exposure attributable to the Chernobyl accident (Thompson, 2007).

The risk of a fire in a spent-fuel pool could be largely eliminated by re-equipping pools across the USA with low-density, open-frame racks, as was the practice when the pools were designed. ISFSIs at reactor sites could be expanded to accommodate spent fuel that could no longer be accommodated in the pools. The incremental cost of the necessary ISFSI expansion across the USA has been estimated at $3.5 to 7 billion (Alvarez et al, 2003). That investment could avoid a comparable expenditure several decades in the future, when the reactors are decommissioned. For comparison, the NWPA-mandated fees paid to the federal government by reactor owners for disposal of high-level radioactive waste, and the interest earned on the resulting funds, totaled $26 billion through 2006. DOE had spent $6.7 billion of these funds on its disposal effort through 2006 (Holt, 2007).

Three factors operating during the past decade have increased the level of concern of a range of stakeholders regarding the risk of a spent-fuel-pool fire. First, pools across the USA are storing spent fuel at or near their full capacity. Second, ISFSIs are available as an alternative to high-density storage in pools. Third, the risk of an attack on a commercial nuclear facility has become more salient since the attacks on the World Trade Center and the Pentagon in 2001. As concern has grown, state and local governments have joined citizen groups in calling for an end to high-density pool storage. Currently, the states of California, New York and Massachusetts are engaged in litigation against the NRC on this matter. Citizen groups that previously opposed the establishment of ISFSIs, on the grounds that expanded storage capacity for spent fuel allows continued operation of reactors, would now accept an expansion of ISFSIs to eliminate high-density storage in pools.

Some citizen groups have expressed concern that present ISFSIs are not sufficiently robust against attack, and a group in California is engaged in litigation against the NRC on this matter. Their concern could be addressed by placing the containers below ground or inside mounds of earth and gravel. Holtec, a vendor of technology for storing spent fuel, has developed an ISFSI design in which the fuel containers would be below ground, protected by robust lids. A design of that type could protect an ISFSI against a range of potential attacks. The NRC does not currently require such a level of protection and, to date, no reactor owner has purchased Holtec's system. That situation might change as a result of litigation, increased pressure from stakeholders, or a changed perception of the risk of attack.

The NRC licenses an ISFSI for a period of 20 years, with the potential for repeated renewals. Many observers believe that the ISFSI containers, and their concrete overpacks, could have useful lives of a century or more. An ISFSI is comparatively cheap to maintain, once it has been established. These factors lead some observers to suggest, as an alternative to opening the Yucca Mountain repository, that the explicit national strategy for management of commercial spent fuel should be to store the fuel in pools and ISFSIs at reactor sites for at least the next several decades. Other observers argue that this strategy already exists by default, because the Yucca Mountain repository is unlikely to open and would, in any case, lack the capacity to accommodate the entire national inventory of spent fuel.

Various stakeholders are now willing to tolerate a strategy in which spent fuel from the present reactor fleet is stored at reactor sites for the next several decades. Some stakeholders in that category seek the early closure of reactors, while others accept the operation of the present reactors through the duration of their initial or extended operating licenses. In principle, the same strategy could be used to manage the spent fuel from a fleet of new reactors. In practice, however, a strategy of at-reactor storage could generate significant political opposition to the construction of new reactors. Thus, stakeholders who favor the construction of new reactors tend to recommend other strategies for managing spent fuel. For example, some members of the nuclear intelligentsia at MIT, who typify the incrementalist position on nuclear power, envision an increase in US nuclear generating capacity by a factor of 3 to 6 by 2050. They see a need to store "some" spent fuel at reactor sites, but recommend that most of the fuel be stored at centralized facilities, potentially for "many" decades. They note that storing the spent fuel keeps open the option of reprocessing in the future (Ansolabehere et al, 2003).

The federal government and the nuclear industry continue to argue that disposal of spent fuel in the Yucca Mountain repository will occur. Their motives for taking this position are clear. They recognize that cancellation of the Yucca Mountain project could cast doubt on their credibility, thereby undermining support for the construction of new reactors. They face opposition from state governments to an explicit strategy of spent-fuel storage rather than disposal (Holt, 2007). Also, DOE seeks to avoid the growing financial liability to reactor owners that would result from its continuing failure to accept commercial spent fuel for disposal. That liability is not limited to the 63,000 MTHM of commercial spent fuel that would be emplaced at the Yucca Mountain repository under the 70,000 MTHM total capacity limit specified by the NWPA. Thus, DOE has examined the technical feasibility of accommodating about 130,000 MTHM of commercial spent fuel in the repository (DOE, 2007a). At the same time, politically influential groups within the federal government and the nuclear industry are calling for a revival of reprocessing, as part of a renaissance of nuclear power. Those groups offer a new strategy for the nuclear fuel cycle, whereby reprocessing is used not only to extract plutonium from spent fuel, but also to reduce the thermal output of high-level waste, so that a substantially greater amount of waste (per nuclear-generated kW-hour) could be accommodated in the Yucca Mountain repository. The thermal load of a repository, per unit of volume and in aggregate, is a major determinant of the repository's capacity.

## 7. EFFORTS TO PROMOTE A NUCLEAR-POWER RENAISSANCE: 2005-2007

The Global Nuclear Energy Partnership, which was announced by DOE in 2006, has dominated recent political discussion in the USA about a renaissance of nuclear power. Before reviewing that discussion, it is useful to recall some related proposals that were made in the years prior to 2006. As mentioned above, in 2003 an MIT group called for incremental growth of nuclear electricity generation, without reprocessing. The postulated growth would employ "Generation III" reactors whose design reflects a comparatively small evolutionary change from the design of reactors in the present fleet (Ansolabehere et al, 2003). A competing faction of the nuclear intelligentsia, many of whose members are based in national laboratories administered by DOE, has called for an expansionist policy. In 2002, members of that faction issued, under DOE auspices, a "technology roadmap" proposing the development and use of a range of "Generation IV" reactors. These reactors would push against engineering limits in a variety of respects. Some reactor types would produce hydrogen as well as electricity, thereby providing fuel for use in vehicles and other applications. Reactors would be deployed in such large numbers that uranium reserves would become depleted during the latter part of the 21st century. To prepare for that eventuality, large-scale reprocessing would begin during the next few decades, and breeder reactors would be deployed beginning in about 2030. The availability of repository space to accommodate high-level waste would be a significant constraint on the envisioned growth of the reactor fleet. To address that constraint, new technologies for reprocessing and fuel recycle would allow a larger amount of high-level waste (per nuclear-generated kW-hour) to be placed in each repository (NERAC/GIF, 2002). Overall, the Generation IV technology roadmap was highly ambitious. It assumed major technological advance across several fronts, an implementation plan that unfolds over a century or longer, strong centralized control by national governments and supra-national entities, and public acceptability of these actions.

In proposing GNEP, DOE adopted the expansionist viewpoint underlying the Generation IV technology roadmap. That viewpoint was combined with the concept, which has been discussed on various occasions over a period of decades, of limiting the number of countries that possess uranium-enrichment and reprocessing capabilities. However, in developing specific plans for GNEP activities within the USA, DOE narrowed its focus sharply. Programs to develop Generation IV reactor technologies were phased out or de-emphasized. GNEP's primary goal in the USA, according to DOE statements in early 2007, is to construct and operate three new facilities: a reprocessing plant for commercial spent fuel; a recycling reactor; and a fuel-cycle research facility. DOE argues that these facilities would demonstrate technologies that allow the effective capacity of the Yucca Mountain repository to be increased by a factor of 10 to 100, thereby allowing the repository to meet US needs through the 21st century. The capacity increase would be achieved in two ways (DOE, 2007b). First, reprocessing plants would remove the fission products, cesium-137 (half-life = 30 years) and strontium-90 (half-life = 29 years), from spent fuel. These radioactive isotopes would be stored at the surface until they had decayed to a level such that they could be sent for disposal as low-level waste. Second, reprocessing plants would remove undesired, long-lived actinides from spent fuel. These actinides would be fissioned in recycling reactors, which would be sodium-cooled, fast-spectrum reactors. Together, these two actions would, according to DOE, substantially reduce the volume, thermal output and radio-toxicity of high-level radioactive waste sent to a repository.

The claimed benefits from GNEP are reminiscent of the AEC's optimism at the beginning of the 1970s regarding reprocessing and breeder reactors. That optimism turned out to be unfounded. Programs to deploy reprocessing plants and breeder reactors were phased out as the 1970s unfolded. After DOE announced the GNEP program, numerous observers compared it to the AEC's programs, and argued that it is impractical and unwise. Observers pointed out, for example, that the GNEP program would involve the storage of massive amounts of cesium-137 and strontium-90 in surface facilities for a period of centuries, but DOE does not explain how that storage would be accomplished and does not discuss the risks or public acceptability of that storage. During 2007, a committee convened by the National Academy of Sciences unanimously recommended the termination of the GNEP program (National Research Council, 2007). By the end of 2007, DOE had already de-emphasized its plans to construct a reprocessing plant and a recycling reactor, and was focusing on the development of a fuel-cycle research facility. Development of that facility might go forward, but at a comparatively low pace and scale. These trends suggest that GNEP may be a short-lived policy initiative. The net effect of the initiative could be to diminish DOE's credibility and reduce support for opening the Yucca Mountain repository. Stakeholders who are concerned about hazards associated with the management of high-level radioactive waste might conclude that DOE's plans for GNEP reveal a lack of good technical judgment.

While pursuing the above-mentioned initiatives on Generation IV reactors and reprocessing, the federal government has also taken actions to encourage the construction of new, Generation III reactors. The NRC licensing process has been "streamlined" by reducing opportunities for state and local governments and citizen groups to intervene in the process. Tax credits are available for up to 6 GWe of new nuclear capacity, and regulatory risk insurance is available for up to 6 new reactors. Loan guarantees may be available. There is discussion in Congress about assigning a price to greenhouse gas emissions, which would favor the construction of new reactors. It is difficult to forecast the trend in reactor construction that might emerge as a result of these and other factors. The federal government recognizes that lack of a repository for spent fuel could inhibit construction of new reactors (Parker and Holt, 2007).

## 8. LIKELY TRENDS IN MANAGEMENT OF HIGH-LEVEL WASTE

US experience in managing high-level radioactive waste since 1957 shows that any prediction of future trends in this area will be uncertain. Many predictions that were made in the past were not fulfilled. With that caveat, likely future trends can be projected.

On balance, a range of technical and political factors suggest that the Yucca Mountain project will lose momentum and eventually be cancelled, and that commercial spent fuel will remain at reactor sites for at least the next several decades. A likely accompaniment to that outcome is that arrangements would be made whereby the federal government would take title to the fuel in situ, paying a storage fee to the reactor owners. With those arrangements, at-reactor storage would be the cheapest option available to the federal government over the next several decades. Stakeholders who view spent fuel as a resource could support extended storage, especially since DOE has now abandoned the concept that spent fuel could be retrieved from the Yucca Mountain repository for many decades. Extended storage would defer a decision about reprocessing, thus satisfying stakeholders who oppose reprocessing. Governments of states that host commercial reactors would not be pleased with an explicit policy of at-reactor storage, but would avoid the political stress associated with road and rail transport of spent fuel to Yucca Mountain or a centralized storage facility. The federal government could potentially compensate the displeased states through actions not related to nuclear power.

The mode of at-reactor storage would be a combination of wet storage in pools and dry storage in ISFSIs, until reactors are shut down. Some time after each reactor is shut down, its pool would be emptied and storage thereafter would be exclusively in an ISFSI. Pools might continue to be used at high density, creating a significant ongoing risk of a large release of radioactive material due to a fire in a pool. Alternatively, pressure from concerned stakeholders, perhaps supplemented by changed perceptions of the risk of an attack on a nuclear facility, would lead to the adoption of measures to reduce the risk of a pool fire. The most effective measure would be to re-equip pools with low-density, open-frame racks. Also, stakeholder pressure and changed perceptions of risk might result in the adoption of measures to improve the robustness of ISFSIs against attack.

Adoption of an explicit policy of at-reactor storage could tend to inhibit the construction of new commercial reactors. The strength of that effect is difficult to predict at present. Ironically, if the inhibiting effect turns out to be strong, the stakeholders most responsible for that outcome would be the nuclear industry and the factions in the federal government that favor increased nuclear generation. Those stakeholders have been intent on developing a repository, and determined to use their political influence to that end. Through their political influence, the principles underlying the NWPA have been successively relaxed. Now, the Yucca Mountain project and the institutions supporting it lack the credibility that the NWPA sought to create.

Continued accumulation of commercial spent fuel, in the absence of a repository, would raise important questions about the sustainability of nuclear power. People and governments around the world increasingly demand that engineered systems are designed according to the principles of sustainability, and the OECD Nuclear Energy Agency has discussed those principles in the context of nuclear power (NEA, 2000). From a sustainability perspective, continued accumulation of spent fuel could be seen in two ways. One observer could view the plutonium in the spent fuel as an energy resource that will be useful to future generations. That observer must assume that future generations will rely heavily on nuclear fission power, and will possess capabilities for reprocessing, use of plutonium, and disposal of high-level waste. A different observer could prioritize the passing on to future generations of a stock of natural, built and human capital that maximizes the opportunities for future generations to make their own choices about technologies and social arrangements. To the second observer, passing on a large stock of spent nuclear fuel could encumber future generations with hazardous material that they do not want, and would therefore be immoral. In the USA, there is no systematic, national debate about the respective merits of these opposing perspectives.

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