RADIOACTIVE WASTES AND THE SAVANNAH RIVER SITE

Robert Alvarez
Senior Scholar
Institute for Policy Studies
February 2013

TABLE OF CONTENTS

ABSTRACT……………………………………………………………………2

INTRODUCTION ………………………………………………………………. 2

CONSOLIDATED STORAGE
OF SPENT NUCLEAR FUEL AT SRS…………………………….....4

REROCESSING……………..…………………………………………………7

NUCLEAR WASTE DISPOSAL ISSUES ………………………………..8

MILITARY HIGH-LEVEL RADIOACTIVE WASTES AT SRS………9

APPENDIX

RADIOACTIVE WASTES FROM LARGE-SCALE
REPROCESSING OF U.S. SPENT NUCLEAR POWER FUEL
…………………………………………………………..……………………15

ENDNOTES……………………………………………………………………20

Tables and Figures

Table 1 Estimated Intermediate and Long-lived
Radioactivity in U.S. Spent Nuclear Fuel……………………………………10

Table 2 PUREX Waste Streams…………………………………………..16

Figure 1 Comparison of radioactivity between
SRS HLW Tanks and Interim Storage
of ~5000 metric tons of Spent Fuel from Closed Reactors………………… 9

Figure 1 Radioactivity in Defense High-Level Radioactive Wastes………..11

ABSTRACT

The Savannah River Site is being promoted for interim storage and reprocessing of power reactor spent fuel (SNF). Several implications should be considered by the public about this proposal:

(a) A pilot interim storage site proposed by the Energy Department for SNF would likely involve hundreds to thousands of shipments of dry canisters. According to the U.S. Government Accountability Office in 2011, spent nuclear fuel is *"considered one of the most hazardous substances on earth."*

(b) A pilot consolidated SNF storage site would likely involve approximately 5,000 metric tons of SNF from 17 reactors and a failed reprocessing plant in Illinois. The amount of intermediate and long-lived radioactivity from these wastes is more than twice that already stored at SRS from military reprocessing high-level radioactive wastes. SRS has the largest concentration of these wastes in the U.S. and is behind schedule and over-budget in dealing with its own high-level radioactive wastes.

(c) Even if a geological repository were to open, SNF stored at SRS would likely remain there for decades to come. SNF storage from power plants will be needed for at least 100 years.

(d) There is no economic, safety or waste management advantage to reprocessing or "fast "reactors for the foreseeable future. Reprocessing releases much more radioactivity into the environment than reactors, and is estimated to cost several hundred billion dollars. "Fast" reactors have been tried for more than 60 years and have not been proven to be economic or safe.

(e) As noted recently by Charles Macmillan, Director of the Energy Department's Los Alamos National Laboratory, "I'm concerned that in the current fiscal crisis, it may no longer be practical to plan and build very large-scale nuclear facilities."[1]

INTRODUCTION

In January 2010, President Barack cancelled the Yucca Mountain spent nuclear fuel repository. Subsequently, a Presidential "Blue Ribbon Commission on America's Nuclear Future was convened to reboot the country's five-decade-plus effort to manage its high-level radioactive waste.

The problems the commission considered are far from new. In 1957 the National Academy of Sciences warned "[t]he hazard related to radioactive waste is so great that no element of doubt should be allowed to exist regarding safety." In that same year the academy recommended that the U.S. government establish deep geologic disposal as the best solution to the problem. In 1982, after embarrassing failures by the Atomic Energy

Commission (the predecessor of the Nuclear Regulatory Commission (NRC) and the Energy Department) to select a waste site on its own, Congress enacted the Nuclear Waste Policy Act began the selection process for multiple sites throughout the United States. This process was scrapped five years later due to eastern states derailing the selection process. At that time Congress voted to make Yucca Mountain the only site to be considered. Yet Yucca's proposed opening date slipped by more than 20 years as the project encountered major technical hurdles and fierce local and state opposition.

In January 2012, the Blue Ribbon panel recommended, among other things:

* Development of a "new consent-based process for selecting and evaluating sites and licensing consolidated storage and disposal facilities in the future:"

* Establishment of "a new waste management organization" to replace the role of the Energy Department with "a new independent, government-chartered corporation."

The panel also concluded: "There is no benefit to reprocessing at this time [and] no currently available or reasonably foreseeable reactor and fuel cycle technology developments – have the potential to fundamentally alter the waste challenge this nation confronts..."[2]

In January 2013 the U.S. Department of Energy issued it strategy for the management and disposal of spent power reactor fuel and military high-level radioactive wastes. Key elements of it plan include:

- Establishment of a pilot interim storage facility by 2021 for spent nuclear fuel from closed reactors. Currently, there are 17 closed commercial power reactors with spent fuel stored onsite. Announcements were recently made to close two more reactors in Wisconsin and Florida. By the 2021 there may be additional closed reactors.
- Establishment of a larger interim storage spent nuclear fuel storage facility by the year 2025. The option of expanding the pilot interim storage facility is not ruled out; and
- To make a permanent geologic repository for permanent disposal available by 2048.

In the meantime, the U.S. Congress is beginning to address the recommendations of the Blue Ribbon Commission, but no formal legislative proposal has yet been presented in the U.S. Senate. Members of the House of Representatives continue to promote reestablishing the Yucca Mountain site. It is unclear what might happen relative to the reopening of the Nuclear Waste policy Act.

CONSOLIDATED STORAGE OF SPENT NUCLEAR FUEL AT SRS

Because of its proximity to most of the nation's reactors, access to ports, and its nuclear material processing history, the Savannah River Site (SRS) in South Carolina is considered by some to be a prime candidate for the interim storage and reprocessing of spent power reactor fuel. Reprocessing if looked upon by its advocates as a means to reduce the burden of geological disposal and to utilize extracted plutonium as fuel in new generation of reactors.

According to spent nuclear fuel data from the Nuclear Energy Institute, a pilot storage facility might store as much as 5,000 metric tons containing more than one billion curies of intermediate and long-lived radioactive wastes. This more than twice the radioactivity currently contained in high-level wastes stored at the SRS site, which already has the single largest concentration of radioactivity of any DOE site.

Assuming 5,000 metric tons of commercial spent power reactor fuel is sent by rail to SRS this result in 280 to 500 shipments.[3] If sent by truck, this could result in approximately 2,500 shipments.[4] If a pilot storage facility were expanded at SRS to accommodate 20,000 metric tons of spent fuel this could result in as many as 2,000 shipments by rail or 10,000 shipments by truck.[5]

Long-term Storage before Disposal

The U.S. Congressional Research Service (CRS) has concluded that, "under any scenario for waste acceptance into a permanent repository or an interim consolidated storage site, long-term storage of SNF will be required for a considerable time."[6] The CRS also concludes, "SNF storage is expected to be needed for more than 100 years."[7]

Going dry for safety

Characteristics of Spent Nuclear Fuel

As uranium fuel is irradiated in a reactor radioactive elements are created when the atoms of uranium-235 and other heavy isotopes are split (fission) as well as by absorption (activation) of neutrons in the atoms of many other isotopes. The fuel is enriched above its naturally-occurring fraction of 0.7 percent of U-235 to as much as 4.8 percent at so it can serve as the primary isotope needed for fission and thus, the generation of energy.

Some 400 pellets made of slightly enriched ceramic uranium dioxide (U02) are stacked in zirconium metal alloy tubes and sealed at both ends. The gap between the rods and pellets of approximately 152 micrometers is filled with helium to a pressure of 10 bar or 145 pounds per square inch. Thickness of the rod cladding is between 0.04-0.8 mm (0.00157 to 0.00314 inches)[8] –15 to 30 times less than a computer disc (CD/DVD) [9] and slightly thicker than heavy-duty aluminum foil used in kitchens. [10]

Hundreds of rods are fitted into a long rectangular-shaped. The rods are held in the assembly by an end plate, a structural guide tube, as pacer grid and end fitting. All told there are some 20 million fuel pellets in a typical pressurized water reactor fuel core. (See Figure)

The assemblies spend as long as 6 years undergoing irradiation and are replaced with fresh fuel when the reactors are shut-down every two years.

When the reactor is shut down, the spent fuel being removed contains a myriad of radioactive isotopes with different half-lives including longer lived radioisotopes, notably cesium- 137 (half-live=30 years), along with very long-lived fission products (i.e. iodine-129, Technetium-99, Cs-135) and actinides (plutonium-239, americium-241) that have half-lives ranging from tens of thousands to millions of years.

To reduce safety hazards, operators should take steps to store all spent fuel that is more than five years old in dry, hardened storage containers. The casks used in dry storage systems are designed to resist floods, tornadoes, projectiles, fires and other temperature extremes, and other unusual scenarios. A cask typically consists of a sealed metal cylinder that provides leak-tight containment of the spent fuel. Each cylinder is surrounded by additional steel, concrete, or other material to provide radiation shielding to workers and everyone else.

Casks can be placed horizontally or set vertically on a concrete pad, with each assembly being exposed to an open channel on at least one side to allow for greater air convection to carry away heat. In hardened dry-cask storage—the safest available design for such systems—the casks are enclosed in a concrete bunker underground. The German nuclear industry took these same steps 25 years ago, after several jet crashes and terrorist acts at nonnuclear locations.

The National Academy of Sciences has concluded that dry-cask storage offered several advantages over pool storage. Dry-cask storage is a passive system that relies on natural air circulation for cooling, rather than requiring water to be continually pumped into cooling pools to replace water lost to evaporation caused by the hot spent fuel.

Also, dry-cask storage divides the inventory of spent fuel among a large number of discrete robust containers, rather than concentrating it in a relatively small number of pools.

Yet today, only 25% of the spent fuel at most U.S. reactors are stored in such systems, and the NRC has not taken strong steps to encourage their use. Nuclear reactor owners use dry casks only when there is no longer enough room to put the waste in spent-fuel pools. Without a shift in NRC policy, reactor pools will still hold enormous amounts of radioactivity, far more than provided for in the original designs, for decades to come.

There is money at hand to accomplish these important safety improvements. In our 2003 study, we estimated that the removal of spent fuel older than five years could be accomplished with existing cask technology in 10 years and at a cost of $3 billion to $7 billion. The expense would add a marginal increase of approximately 0.4 to 0.8% to the retail price of nuclear-generated electricity.

Decay Heat

Control of decay heat is a key safety factor for spent fuel storage and its final disposal in a geological repository. Storage of spent nuclear fuel in pools requires continuous cooling for an indefinite period to prevent decay heat from igniting the zirconium cladding and releasing large amounts of radioactivity into the environment.

Zirconium cladding of spent fuel is chemically very reactive in the presence of uncontrolled decay heat. According to a 2006 panel of the National Academy of Sciences decay heat build-up in spent fuel the presence of air and steam:

> " is strongly exothermic – that is, the reaction releases large quantities of heat, which can further raise cladding temperatures… if a supply of oxygen and or steam is available to sustain the reactions.. The result could be a runaway oxidation – referred to as *a zirconium cladding fire* – that proceeds as a burn front (e.g., as seen in a forest fire or fireworks sparkler)..As fuel rod temperatures increase, the gas pressure inside the fuel rod increases and eventually can cause the cladding to balloon out and rupture.[original emphasis] "[11]

The Nuclear Regulatory Commission (NRC) has performed several studies to better understand this problem. In 2001, the NRC concluded:

> "… it was not feasible, without numerous constraints, to establish a generic decay heat level (and therefore a decay time) beyond which a zirconium fire is physically impossible."[12]

In terms of geologic disposal, decay heat, over thousands of years, can cause waste containers to corrode, negatively impact the geological stability of the disposal site and enhance the migration of the wastes. [13] At the now cancelled Yucca Mountain geological disposal site in Nevada decay heat from spent fuel would require approximately 2,500 cubic feet of storage space and ventilation, for each cubic foot of spent fuel.[14]

Although reprocessing can reduce the volume of waste to be disposal geologically, it does not reduce decay heat which is a key determining factor for the safety and suitability of a geologic waste repository. Most of the high-heat radioactive materials from reprocessing remain in the waste stream and pose the same challenge for disposal.

REPROCESSING

In order to recycle uranium and plutonium in power plants, spent fuel has to be treated to chemically separate these elements from other highly radioactive byproducts. As it chops and dissolves used fuel rods, a reprocessing plant releases about 15 thousand times more radioactivity into the environment than nuclear power reactors and generates several dangerous waste streams. If placed in a crowded area, a few grams of waste would deliver lethal radiation doses in a matter of seconds. They also pose enduring threats to the human environment for tens of thousands of years.

Europe reprocessing has created higher risks and has spread radioactive wastes across international borders. Radiation doses to people living near the Sellafield reprocessing facility in England were found to be 10 times higher than for the general population. Denmark, Norway, and Ireland have sought to close the French and English plants because of their radiological impacts. Discharges of Iodine 129, for example, a very long-lived carcinogen, have contaminated the shores of Denmark and Norway at levels 1000 times higher than nuclear weapons fallout. Health studies indicate that significant excess childhood cancers have occurred near French and English reprocessing plants Experts have not ruled out radiation as a possible cause, despite intense pressure from the nuclear industry to do so.

Nuclear recycling in the U.S. has created in one of the largest environmental legacies in the world. Between the 1940's and the late 1980's, the Department of Energy (DOE) and its predecessors reprocessed tens of thousands of tons of spent fuel in order to reuse uranium and make plutonium for nuclear weapons.

By the end the Cold War about 100 million gallons of high-level radioactive wastes were left in aging tanks that are larger than most state capitol domes. More than a third of some 200 tanks have leaked and threaten water supplies such as the Columbia River. The nation's experience with this mess should serve as a cautionary warning. According to DOE, treatment and disposal will cost more than $100 billion; and after 26 years of trying, the Energy Department has processed a small fraction of these wastes for disposal. By comparison, the amount of wastes from spent power reactor fuel recycling in the U.S. would dwarf that of the nuclear weapons program – generating about 25 times more radioactivity.

Costs

In 1996 by the National Academy of Sciences released an extensive study on the feasibility of recycling nuclear fuel. It was an intriguing idea because of its promise to eliminate weapons-usable plutonium and to reduce the amount of waste that had to be buried, where it could conceivably seep into drinking water at some point in its multimillion-year-long half-lives.

The Academy concluded that it would cost up to $730 billion (in 2012 and take 150 years to accomplish the transmutation of plutonium. Ten years later the idea remains as costly and technologically unfeasible as it was in the 1990s. The NAS panel also concluded that this program was uneconomical and would require a federal subsidy of $44 to $146 billion (2012 dollars).[15] In 2007 the Academy once concluded that "there is no economic justification for going forward with this program at anything approaching a commercial scale."

NUCLEAR WASTE DISPOSAL ISSUES

The problem of high-level radioactive waste disposal is far from new. In 1957 the National Academy of Sciences warned that "[t]he hazard related to radioactive waste is so great that no element of doubt should be allowed to exist regarding safety." In that same year the academy recommended that the U.S. government establish deep geologic disposal as the best solution to the problem. In 1982, after embarrassing failures by the Atomic Energy Commission (the predecessor of the Nuclear Regulatory Commission (NRC) and the Energy Department) to select a waste site on its own, Congress enacted the Nuclear Waste Policy Act, which began the selection process for multiple sites throughout the United States. This process was scrapped five years later due to eastern states derailing the selection process. At that time Congress voted to make Yucca Mountain the only site to be considered. Yet Yucca's proposed opening date slipped by more than 20 years as the project encountered major technical hurdles and fierce local and state opposition.

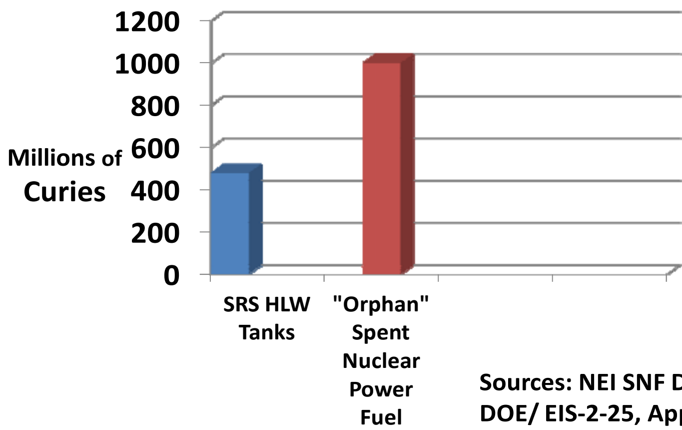
There are 104 U.S. commercial nuclear reactors operating at 65 sites in 31 states that are holding some of the largest concentrations of radioactivity on the planet in onsite spent fuel pools. The pools, typically rectangular or L-shaped basins about 40 to 50 feet deep, are made of reinforced concrete walls four to five feet thick and stainless steel liners. Basins without steel liners are more susceptible to cracks and corrosion. Most of the spent fuel ponds at boiling water reactors are housed in reactor buildings several stories above ground. Pools at pressurized water reactors are partially or fully embedded in the ground, sometimes above tunnels or underground rooms.

According to estimates provided by the Department of Energy, as of this year this spent fuel contains a total of approximately 12 billion curies of long-lived radioactivity (Table 1).[10] As mentioned, of the 65,000 metric tons estimated by the Nuclear Energy Institute to be generated by the end of 2011, 75 percent is in pools, while the remainder is in dry storage casks.

“Orphan Wastes”

Currently there are 14 decommissioned reactors where the spent fuel remains. [16]In the past few months, announcements have been made to close two more reactors. [17]Additionally, there is a failed reprocessing site in Morris Illinois, storing spent fuel from 6 mostly closed reactors in pools – requiring more stable dry storage. [18] There is approximately 5,000 metric tons spent fuel from these sources.[19] containing a total of about 1 billion curies of intermediate and long-lived radioactive isotopes.[20] This is more than twice the radioactivity stored in the 40 high levels radioactive waste tanks at the Savannah River Site. (see Figure 1).

Figure 1 Comparison of radioactivity between SRS HLW Tanks and Interim Storage of ~5000 metric tons of Spent Fuel from Closed Reactors



Sources: NEI SNF Data (12-31-2011)
DOE/ EIS-2-25, Appendix A.

Table 1 Estimated Intermediate and Long-lived Radioactivity in U.S. Spent Nuclear Fuel

Isotope	Half Life (yrs)	Radioactivity (Ci)
Hydrogen-3	12.3	10,200,000
Carbon-14	5,700	95,000
Chlorine-36	300,000	750
Iron-55	2.7	420,000
Cobalt-60	5.3	27,000,000
Nickel-59	76,000	160,000
Nickel-63	100	22,000,000
Selenium-79	64,000	30,000
Krypton-85	10.7	150,000,000
Strontium-90	29	3,000,000,000
Zirconium-93	1,500,000	160,000
Niobium-93m	16	110,000
Niobium-94	24,000	56,000
Technetium-99	210,000	950,000
Ruthenium-106	1	4,700
Palladium-107	6,500,000	8,800
Cadmium-133m	14	1,500,000
Antimony-125	2.8	3,600,000
Tin-126	1,000,000	59,000
Iodine-129	17,000,000	2,400
Cesium-134	2.1	5,800,000
Cesium-135	2,300,000	36,000
Cesium-137	30	4,500,000,000
Promethium-147	2.6	18,000,000
Samarium-151	90	25,000,000

Isotope	Half Live (yrs)	Radioactivity (Ci)
Europium-154	8.6	120,000,000
Europium-155	4.8	22,000,000
Actinium-227	2.2	0.97
Thorium-230	75,000	18
Protactinium-231	33,000	2.1
Uranium-232	69	2600
Uranium-233	160,000	3.9
Uranium-234	250,000	84,000
Uranium-235	720,000,000	1,000
Uranium-236	23,000,000	18,000
Uranium-238	4,500,000,000	20,000
Plutonium-241	14	3,200,000,000
Plutonium-238	88	240,000,000
Americium-241	430	220,000,000
Curium-244	18	120,000,000
Plutonium-240	6,500	36,000,000
Plutonium-239	24,000	24,000,000
Americium-243	7,400	1,900,000
Americium-242/242m	140	1,600,000
Curium-242	0.45	1,300,000
Curium-243	29	1,300,000
Plutonium-242	380,000	140,000
Neptunium-237	2,100,000	30,000
Curium-245	8,500	29,000
Curium-246	4,800	6,300
		~12 billion Ci

Source: DOE/EIS-0250 Appendix A.

MILITARY HIGH LEVEL WASTES AT SRS

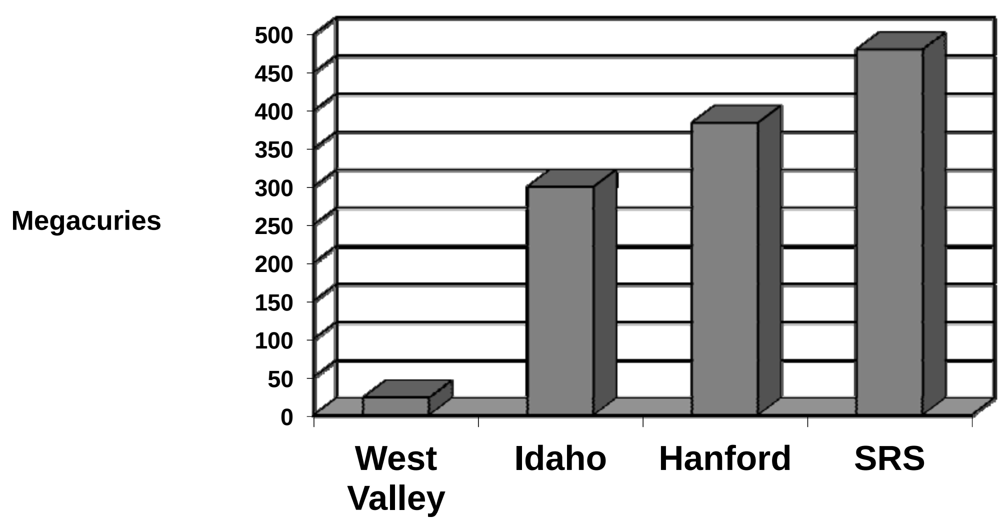
For nearly 50 years the United States operated several large reprocessing plants to chemically separate 100 tons of plutonium from spent production reactor fuel for nuclear weapons. DOE has also accumulated spent nuclear fuel from past material production, research and naval reactors. As of 2001, DOE high-level wastes and spent fuel contained about 2.4 billion curies.[21]

About 100 million gallons of high-level radioactive wastes from reprocessing were generated and are stored in large underground tanks at the Hanford site in Washington, the Idaho National Engineering Laboratory and the Savannah River Site in South Carolina. Many tanks have leaked and threaten water supplies. High-level radioactive wastes resulting from production of nuclear explosives in the United States are among the largest and most dangerous byproducts of the nuclear age. According to the National Research Council in 2006:

> "The Department of Energy's (DOE's) overall approach for managing its tank wastes is the following: To the maximum extent practical, retrieve the waste from the tanks (and bins in Idaho); separate (process) the recovered waste into high- and low-activity fractions; and dispose of both remaining tank heels and recovered low-activity waste on-site in a manner that protects human health and the environment." [22]

Figure 1

Radioactivity in DOE High-Level Wastes



DOE also has about 2,700 metric tons of spent reactor fuel. There are 256 types of spent fuel in the DOE inventory, and only a few have been analyzed. Most of this fuel is (2,100 metric tons) is at the Hanford Site. Smaller amounts of spent nuclear fuel associated with nuclear weapons production are stored at the Savannah River Site. Spent nuclear fuel from the Naval Nuclear Propulsion Program is stored at the DOE's Idaho

National Engineering Laboratory (INL) and for a short time, at some naval nuclear shipyards. The DOE will also assume responsibility for fuel from some special-case commercial nuclear reactors, foreign research reactors, and certain domestic research and test reactors.

The Savannah River Site

Approximately 126,300 m^3 of alkaline high-level waste or 34 million gallons that has accumulated at the Savannah River Site over the past three decades is currently stored underground in carbon-steel tanks. The current inventories consist of alkaline liquid, sludge, and salt cake that were generated primarily by the reprocessing of nuclear fuels and targets from plutonium production reactors. The sludge is formed after treatment with caustic agents. Salt cake results when the supernatant liquor is concentrated in waste treatment evaporators. The high-level waste consists of 58,100 m^3 of liquid and 68,200 m^3 of solid material having a total radioactivity of approximately 500 million curies. The SRS tank farm constitutes more than 70 percent of the total radioactivity of all DOE high-Level radioactive wastes. [23] These wastes are in two basic forms –sludge and salts. The sludge, which results from settling of metals and radionuclides and takes up about 2.8 million gallons and contains about 320 million curies, [24] which is about 10 percent of the waste volume.[25] There are about 31.2 million gallons of HLW salts containing about 160 million curies. About 50 percent of the salt form is “salt cake,” which resulted from evaporation of tank liquid and about 16 million gallons of salt-bearing solution, known as “supernate.” The saltcake and supernate contain about 95 percent of the cesium in the tank waste at SRS.[26]

Tank farms at the Savannah River Site contain 24 single-shell and 27 double-shell tanks for storing high-level waste. The DOE plans to remove the liquid waste from these tanks by 2035. The Defense Waste Processing Facility (DWPF) began construction in 1982 and operation in 1996 with the goals of processing SRS tank wastes for geological and onsite disposal. The total life cycle cost for the DWPF is approximately $20 billion. [27]

After more than 25 years, DOE has processed less than about 11 percent of radioactivity in SRS wastes. At least 99 percent of the radioactivity was to be removed from the wastes and then mixed with molten glass in a process known as vitrification for disposal in the proposed Yucca Mountain repository in Nevada. But DOE declared in 2002 there is insufficient space at Yucca and that 60 percent of its high-level waste canisters will have to wait indefinitely for the opening of a second repository. Since 2001, DOE’s top cost-cutting objective has been to eliminate the need to vitrify at least 75 percent of the waste scheduled for geological disposal. In its drive to make fewer high-level waste canisters, DOE intends to leave greater amounts of radioactivity disposed on site.

The costs to stabilize and dispose DOE’s defense high-level wastes are estimated in excess of $110 billion (2007 dollars).[28] At the Savannah River Site, DOE estimates that the total costs for high-level waste management and processing is approximately $20 billion.[29]

THE "ONCE TROUGH" AND "CLOSED" NUCLEAR FUEL CYCLES

For 30 years the U.S. has refrained from reprocessing commercial spent power reactor fuel to use plutonium in power plants. Instead intact spent fuel rods were to be sent directly to a repository – a "once through" nuclear fuel cycle. Radioactive materials in spent fuel are bound up in ceramic pellets and are encased in durable metal cladding, planned for disposal deep underground in thick shielded casks.

Although the U.S. continued to reprocess spent fuel from military reactors, the "once through" fuel cycle was adopted by President Carter in 1977 for commercial nuclear power. Three years earlier, India had exploded a nuclear weapon using plutonium separated from power reactor spent fuel at a reprocessing facility. President Ford responded in 1976 by suspending reprocessing in the United States. President Carter converted the suspension into a ban, while issuing a strong international policy statement against establishing plutonium as fuel in global commerce. President Carter's decision reversed some 20 years of active promotion by DOE's predecessor, the U.S. Atomic Energy Commission (AEC), of the "closed" nuclear fuel cycle. The AEC had spent billions of dollars in an attempt to commercialize reprocessing technology to recycle uranium and provide plutonium fuel for use in "fast" nuclear power reactors. Reprocessing consists of mechanical chopping of irradiated fuel elements, followed by the dissolution of spent fuel in nitric acid. The dissolved fuel is then treated with a mixture of solvents in several complex steps to separate plutonium, uranium, and other isotopes. This process, known as PUREX (Plutonium URanium EXtraction), was developed in the 1950's by the United States for the chemical separation of plutonium for use in nuclear weapons.

Recycling advocates are seeking to overturn this long-standing policy and point to a new generation of "fast" reactors to breakdown plutonium so it can't be used in weapons. Since the 1940's, it was understood that "fast" reactors generate more subatomic particles, known as neutrons, than conventional power plants and it is neutrons which split uranium atoms to produce energy in conventional reactors. The U.S. actively promoted plutonium-fueled fast reactors for decades because of the potential abundance of neutrons, declaring that they held the promise of producing electricity and making up to 30 percent more plutonium than they consumed.

With design changes, fast reactors are, ironically, being touted in the U.S. as a means to get rid of plutonium. However, the experience with "fast reactors" over the past 50 years is laced with failure. At least 15 "fast" reactors have been closed due to costs and accidents in the U.S., France, Germany, England, and Japan. There have been two fast reactor fuel meltdowns in the United States including a mishap near Detroit in the 1960's. Russia operates the remaining fast reactor, but it has experienced 15 serious fires in 23 years.

Plutonium makes up about 1 percent of spent nuclear fuel and is a powerful nuclear explosive, requiring extraordinary safeguards and security to prevent theft and diversion. It took about 6 kilograms to fuel the atomic bomb that devastated Nagasaki in 1945. Unlike plutonium bound up in highly radioactive spent nuclear fuel, separated plutonium does not have a significant radiation barrier to prevent theft and bomb making, especially by terrorists.

Plutonium is currently used in a limited fashion in nuclear energy plants by being blended with uranium. Known as mixed oxide fuel (MOX), it can only be recycled once or twice in a commercial nuclear power plant because of the buildup of radioactive contaminants. According to a report to the French government in 2000, the use of plutonium in existing reactors doubles the cost of disposal.

The unsuccessful history of fast reactors has created a plutonium legacy of major proportions. Of the 370 metric tons of plutonium extracted from power reactor spent fuel over the past several decades, about one third has been used. Currently, about 200 tons of plutonium sits at reprocessing plants around the world – equivalent to the amount in some 30,000 nuclear weapons in global arsenals.

Reprocessing Commercial Spent Nuclear Fuel at SRS

A spent fuel storage facility for reprocessing at SRS would likely have the capacity to contain about 10,000 to 20,000 MTU. (The French reprocessing plant run by Cogema has a storage capacity of 14,400 MTU)[30] The spent fuel could be stored in pools of water, as the case in France and England. If the spent fuel is stored in a dry mode, this would translate into 1,000 to 2,000 casks (assuming current approved designs are used). Last year, the House Energy and Water Appropriations Committee stated that:

> "In the Committee's view, any such integrated spent fuel recycling facility must be capable of accumulating sufficient volumes of spent fuel to provide efficient operation of the facility. A first test of any site's willingness to host such a facility is its willingness to receive into interim storage spent fuel in dry casks that provide safe storage of spent fuel for 50 to 100 years or longer." [31]

A large reprocessing plant would have to operate for approximately 30-40 years to handle 105,000 metric tons of spent fuel that DOE estimates will be generated. A reprocessing plant would require a capacity of 2,500- 3,000 MTHM per year.[32]

The estimated total amount of radioactivity in spent power reactor fuel generated by 2030 would be approximately 11.8 to 19.4 billion curies. [33] By comparison, this is about 24 to 45 times the amount of radioactivity estimated by DOE in 2001 in the high-level wastes at SRS.[34]

APPENDIX

RADIOACTIVE WASTES FROM LARGE-SCALE REPROCESSING OF U.S. SPENT NUCLEAR POWER FUEL

Plutonium-239 -- The total amount of plutonium239 in separated transuranics from U.S. commercial spent fuel is approximately 645 metric tons. [35] This is more than 6 times the amount produced for the U.S. nuclear arsenal from 1944 to 1988, and more than two and a half times the amount produced worldwide for nuclear weapons.[36] Previous reprocessing experience in the U.S. and other countries has been based on using the PUREX technology. Worldwide stocks of separated plutonium from civilian nuclear power spent fuel have currently grown to 250 metric tons – enough to fuel more than 30,000 nuclear weapons.[37] This huge supply of nuclear explosive materials is accumulating at reprocessing plants in Western Europe, Russia, Japan and India. Efforts to "burn-up" these stocks of plutonium in "fast" reactors have proven difficult, costly and slow.[38] Only about one-third of this plutonium has been used as fuel in power reactors, leaving a surplus of about 200 tons of weapons-usable plutonium in civilian hands.

Transuranics -- Assuming the claims made by DOE researchers that 99 % of the transuranics (TRU) from commercial spent power reactor fuel could be recovered [39]– as much as 63 million curies of TRU waste could be left behind in process losses.[40] This is approximately 24 times current TRU waste inventories at all DOE sites.[41] These wastes would be quite radioactive and would require a greatly expanded remote handling at SRS to process them for disposal in a geological disposal site. In particular, plutonium-241, plutonium-238, americium 241, and 242m have significant specific activities.

Table 2 PUREX Waste Streams

Type	Disposition
Effluent Gases	
Krypton-85 (dissolver off-gas)	released /untreated
Iodine-129 (dissolver off-gas)	~90% removed
Carbon-14 (dissolver off-gas)	released/untreated
Tritium	released/untreated
Solids and Liquids	
High-Level Wastes	some vitrified
Low-Activity Wastes (spent solvents, resins)	shallow burial
Fuel Cladding and Hardware	geological disposal
Stabilized Liquid Wastes	shallow burial
Analytical Wastes	shallow burial
Contaminated Equipment	shallow burial
Greater than Class C wastes (transuranics)	geological disposal
Liquid High-Level Waste Storage -- highly Radioactive: generates heat	shallow storage

-- stored in large, cooled underground tanks to allow for decay of short-lived radionuclides	

Source: U.S. NRC 2006

Uranium – Approximately 90 percent of spent nuclear fuel separated by weight from a reprocessing plant are uranium isotopes, principally U-238. During irradiation in a reactor other uranium isotopes are produced, which contaminate the U-238. Of particular concern is uranium-232 contamination. U-232 is 60 million times more radioactive than uranium-238. This is due to high-energy gamma radiation emitted in the decay scheme of U-232 daughter products (thorium-228, radium-244, and thalium-228). Typically, U-232 is currently stored at DOE sites in amount that are 5 to 50 parts per million.[42] Even though U-232 concentrations are small, in the range of 10 to 100 grams commingled in 2 tons of U-233, its gamma radiation constitutes a potentially significant external hazard.

Another contaminant of concern is uranium-236. U-236 is a neutron absorber which impedes the chain reaction, and means that a higher level of U-235 enrichment is required in the product to compensate. DOE has not estimated what the costs would **be** for a new re-enrichment facility to process some 94,000 tons of previously irradiated uranium. Currently, a new enrichment facility that the United States Uranium Enrichment Corporation (USEC) is seeking to build is estimated at $2.3 billion.[43] Being lighter, both isotopes tend to concentrate in the enriched (rather than depleted) output, so reprocessed uranium which is re-enriched for fuel must be segregated from enriched fresh uranium.

Current DOE research indicates that uranium recovered from reprocessing is likely to be disposed as waste. However, according to the results of a DOE-sponsored experiment using actual spent fuel, "The criterion to contain less than 100nCi/g of TRU is most difficult to meet, requiring a decontamination factor from plutonium of >10 5. If the uranium is destined for recycle in reactor fuel, it purity requirements are greater…"[44]

Long Lived Fission Products – Long lived fission products from high-level radioactive waste which dominate human exposures over long periods of time include I-129 (15.7 million year half-life), Cs-135 (2.3 million year half-life), Tc-99 (210,000 year half-life), Sn-126 (100,000 year half-life) and Se-79 (65,000 year half-life).

Removal of cesium-135 (half-life 2.3 million years) in a reprocessing plant is not considered feasible because of the difficulties in isotopic separation from highly active Cs-137.[45] [46] About 36,000 to 60,000 curies of this radionuclide could be generated and remain in wastes for permanent surface disposal. [47] By comparison, this amount of Cs-135 is several orders of magnitude more than in high-level radioactive wastes at SRS.[48] [49]After 600 years Cs-135 will become the dominant source of radioactivity and human doses over long periods of time could be significant.[50]

Carbon 14 inventories in spent fuel are large. With a half-life of 5,700 years, C-14 is also naturally occurring and widely distributed in nature and is present in all organic compounds. During the chopping and dissolution phases, a reprocessing plant could release between 95,000 to 160,000 curies of Carbon-14, none of which DOE contemplates recovering. While individual doses are small , C-14 poses risks to large populations. Using a cost benefit analysis adopted by the U.S. Nuclear Regulatory Commission ($1,000 per person per rem), the costs of reducing the amount of C-14 released from reprocessing U.S. spent nuclear fuel by 50 percent is $19 billion. [51] By comparison, the contribution of C-14 produced in nuclear reactors and from DOE sites is estimated to be less than 600 curies per year.[52]

Wastes containing Iodine-129 are of concern. Reprocessing plants have contributed the largest quantities of I-129 into the global environment. For instance, the Sellafield facility in England and the La Hague facility in France released a cumulative total of 1,440 Kg (250 curies) of I-129 -- 32 times more than the quantities released from atmospheric weapons tests.[53] Beginning in 1994, direct releases from Sellafield and La Hague were 220 Kg/yr (40 Ci) and 18 Kg/yr (3.2 Ci) into the ocean and atmosphere respectively. Cold War-era weapons materials reprocessing at SRS has resulted in the largest measurable concentrations of I-129 in North America in the Savannah River. Spent nuclear fuel could contain as much as 3,900 curies of I-129 which is 62 times more than in DOE defense high-level wastes at Hanford and SRS. [54] [55] Assuming 95 **percent** recovery, this could result in 120 curies released into the environment – about twice that contained in HLW at SRS and Hanford. The long-term doses from several curies of I-129 are an obstacle to onsite disposal of secondary wastes associated with high-level waste processing at the Hanford site. [56]

There would be between 950,000 and 1.6 million curies of Tc-99 in spent nuclear fuel. The current research target is to capture at least 95 percent of this radionuclide.[57] Assuming this goal can be achieved, about 47,500 to 80,000 curies of Tc-99 could be discharged into the environment. The total Tc-99 in SRS high-level wastes is estimated at 48,000 curies.[58]

Tritium – The amount of tritium released from a reprocessing plant is considerable. With a half-life of 12.3 years, tritium is very mobile and readily absorbed in the environment. It poses both a localized and global risk of exposure. Tritium is released as a gas when the fuel is chopped and dissolved. The total tritium that can be released during reprocessing of LWR spent fuel is in the range of 800,000 to 1 million curies per year[59] – which is comparable to the tritium releases at SRS from the 1950's to the 1990's.[60] The retention and isolation of tritium has not been adopted because it is expensive as it requires relatively long term storage for 50 to 100 years and subsequent disposal. Since tritium is also a key ingredient for nuclear weapons, its retention and storage would also require increased safeguards, material control and accountancy.

Noble Gases – Other radioactive gases released during chopping and dissolution also include isotopes of krypton and xenon. Because they are chemically inert, these gases are released from the reprocessing stack directly into the atmosphere. Of particular concern is Kr-85, which has a half-life of 11 years. Like tritium and carbon-14, Kr-85 poses both local and global exposure risks. In 1994, the La Hague reprocessing plant released nearly

5 million curies of Kr-85 into the atmosphere – perhaps half of the input of Kr-85 released world-wide from nuclear activities.[61] The inventory of Kr-85 in U.S. spent nuclear fuel would be in the range of 150 to 250 million curies. By comparison, the amount of Kr-85 estimated to have been released at the DOE's SRS site from 1954 to 1989 is approximately 15 million curies.[62] Thus, assuming 90 percent recovery, Kr-85 releases would be about comparable or greater than SRS releases.

Costs

The costs associated with spent reactor fuel recycling were provided at the request of DOE in 1996 by the National Research Council of the National Academy of Sciences. The NAS panel concluded that the plan envisioned under GNEP would cost some $730 billion (2012 dollars) and require "approximately 150 years to accomplish the transmutation."[63] Capital and operating costs for a reprocessing plant in the U.S, according to the NAS, would range from $30 to $150 billion.[64] The NAS panel also concluded that this program was uneconomical and would require a federal subsidy of $44 to $146 billion (2012 dollars).[65]

There were several principal issues identified by the panel which would effectively increased costs:

- "…the magnitude of the development and demonstration program required before wide-scale implementation of a transmutation strategy can be implemented;
- difficulty in obtaining a government financial commitment because of the expected high cost of transmutation technology development/implementation and the difficult-to-quantify benefits to public health and safety; and
- difficulty in attracting private capital due to the perceived high technical/economical/institutional risk of reprocessing/transmutation projects relative to alternative opportunities for investment capital, resulting a higher cost of capital due to the higher perceived risk."[66]

A more recent analysis done in July 2006 by the DOE's Idaho National Laboratory (INL) concluded:

> "The specific designs and methods for separation in a future fuel recycle facility have not yet been determined. There are limited cost data available on new recycle facility costs that would be applicable to a United States facility construction application. The AFCI program has compiled historical reports and studies on recycling and has determined that there are very large cost uncertainty ranges for these facilities."[67]

The 2006 INL analysis indicates that two thirds of the total costs for a reprocessing plant would be operational. As a first-of-a-kind facility, a large-scale UREX+ facility may have a lower annual processing capacity, which would significantly affect economic viability of this project. For instance, a 50% reduction in capacity would double the per unit cost.[68]

Given these risks, the analysis concluded that “the lowest unit costs and lifetime costs follow a fully government-owned financing strategy, due to government forgiveness of debt as sunk costs.”[69]A separate INL study done in December 2006, underscores this finding, by indicating that the cost of the UREX+ process would be about $1,279 per kilogram of spent fuel.[70] This indicates that the price of uranium would have to increase to about $400 per pound – more than four times the current price in order for reprocessing to be economical.[71]

Costs associated with reductions in radioactive effluent emissions from reprocessing are considerable. For instance:

- The retention and isolation of tritium requires storage for 100 years and subsequent disposal. In 1986, SRS researchers estimated the cost of controlling H-3 discharges from a reprocessing facility at $2.7 billion (2007 dollars).[72]

- In 2002, British Nuclear Fuels estimated that the costs of retaining and disposing of Krypton-85 discharged from its reprocessing plant would be $500 to $600 million. [73]

- Disposal of wastes from process losses of cesium and strontium could result in considerable expense. Assuming 99 percent Cs and Sr lost to process is disposed as low-level wastes, under current DOE onsite disposal requirements at SRS, a large volume may be generated greater than projected for DOE wastes. Currently, DOE’s life-cycle estimate for disposal of SRS tank wastes onsite of $2.8 billion.[74]

- The life cycle costs of decay storage of cesium and strontium remain uncertain. However, based on data from the British reprocessing plant at Sellafield, the decay storage of cesium and strontium would cost about $18.9 billion for operating costs associated with treating the wastes and $11.2 billion for 600 year interim storage (2007 dollars). [75]

ENDNOTES

[1] NextGov. Com. U.S. lab ready to shelve costly facility plan, February 22, 2013, http://www.nextgov.com/emerging-tech/2013/02/us-nuclear-lab-ready-shelve-costly-facility-plan/61468/?oref=ng-dropdown

[2] Blue Ribbon Commission on America's Nuclear Future, Report to the Secretary of Energy, January 2012.

[3] International Panel on Fissile Materials, Managing Spent Fuel from Nuclear Power Reactors, Experience and Lessons from Around the World, September 2011, p. 128.

[4] Ibid.

[5] Ibid.

[6] James D. Werner, U.S. Spent Nuclear Fuel Storage, Congressional Research Service, May 24, 2012.

[7] Ibid.

[8] U.S. Department of Energy, Argonne National Laboratory, Nuclear Fuel, April 2011.

[9] Graham Sharpless, CD and DVD Disc Manufacturing, Deluxe Global Media Services Ltd., July 2003.p 3. http://cddvdreplications.com/help/technology/downloads/tech_docs/replication.pdf

[10] Desmond Fraser, Electromagnetic Engineering and Aluminum Foil, Rheintech Laboratories, Inc., August 3, 2011. http://www.rheintech.com/blog/archives/884

[11] National Research Council, Board on Radioactive Waste Management, Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, National Academes Press (2006), p. 38-39. http://www.nap.edu/openbook.php?record_id=11263&page=38 ,http://www.nap.edu/openbook.php?record_id=11263&page=39

[12] U.S. Nuclear regulatory Commission, Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, October 2000, P. ix.. http://pbadupws.nrc.gov/docs/ML0104/ML010430066.pdf

[13] R. Wigeland, T.Taiwo, M. Todosow, W. Halsey, J. Gehin, Options Study – Phase II ,Department of Energy, Idaho National Laboratory, INL/EXT-10-20439, September 2010. http://www.inl.gov/technicalpublications/Documents/4781584.pdf

[14] U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Yucca Mountain Science and Engineering Report Rev. 1, Technical Information Supporting Site Recommendation Consideration, Report DOE/RW-0539-1 (North Las Vegas, NV: U.S. DOE, 2002).

[15] National Research Council, Nuclear Wastes: Technologies for Separations and Transmutation, National Academy of Sciences, (1996), National Academy, p. 82.

[16] Nuclear Energy Institute, Spent Fuel Data as of December 31, 2011.

[17] Matthew Wald, Aging and Expensive, Reactors Face Mothballs, *New York Times*, October 23, 2012.

[18] Op Cit Ref. 5.

[19] Op. Cit Ref. 5.

[20] U.S. Department of Energy, Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada, DOE/EIS-2050, February 2002, Appendix A. Tables A-9 and 10.

[21] John F. Ahearne, Analysis of U.S. Experience with Spent Fuel, An International Spent Nuclear Fuel Storage Facility: Proceedings of an International Workshop, (2005) National Academy of Sciences, P. 16. (Ahearne 2005)

[22] National Research Council, Nuclear and Radiation Studies Board, Tank Waste Retrieval, Processing, and On-site Disposal at Three Department of Energy Sites: Final Report, 2006 (Hereafter Known as NAS 2006)
[23] OP Cit. Ref. 4.

[24] The SRS Citizen's Advisory Board, High-Level Waste Salt Disposition Alternatives To In Tank Precipitation Process Supplemental Environmental Impact Statement, Recommendation No. 81, March 23, 1999.

[25] National Research Council, Board on Radioactive Waste Management, Committee on Radionuclide Separations Processes for High-Level Wastes at the Savannah River Site, Evaluation of Criteria For Selecting A Salt Processing Alternative For High-Level Waste at the Savannah River Site: Interim Report, April 2001, National Academy Press, Washington D.C. Appendix C. p 18, (hereafter known as NAS 2001)

10 Ibid

[27] U.S. Department of Energy, Congressional Budget Request for Fiscal Year 2002, Environmental Management, Executive Budget Summary, Project Baseline Summaries, Washington, D.C.

[28] United States General Accounting Office, Report to the Chairman, Subcommittee on Oversight and Investigations, Committee on Energy and Commerce, House of Representatives, "Nuclear Waste: Challenges to Achieving Potential Savings in DOE's High-Level Waste Cleanup Program," GAO-03-593, June 2003. pp, 17, 20 (Hereafter known as GAO-03-593). "Uncontrolled cost overruns, numerous schedule delays, and unsuccessfully attempts to develop treatment processes have pushed the overall estimated cost of the high-level waste program from about $63 billion in 1996 (when the first comprehensive estimates were developed) to nearly $105 billion in 2003."

[29] U.S. Department of Energy, Fiscal Year 2002 Budget to the Congress, Office of Environmental Management, Executive Budget Summary, Funding Distribution by Baseline Summary, pp. 93-95, Washington, D.C.
[30] International Atomic Energy Agency, Survey of wet and dry spent fuel storage, July 1999, P. 14, Table IV. http://www-pub.iaea.org/MTCD/publications/PDF/te_1100_prn.pdf

[31] American Institute of Physics, Bulletin of Science Policy News News, Number 70 : May 24 , 2006, http://www.aip.org/fyi/2006/070.html
[32]W. Brent Boore and David H. MCGuire, Deployment Options for a Spent Fuel Treatment Facility in the United States, Westinghouse Savannah River Company, U.S. Department of Energy, Waste Management 04, Conference Proceedings, February 29, March 4, 2004.

[33]U.S. Department of Energy, Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada, DOE/EIS-0250, February 2002, Appendix A. Tables A-9, A-10, A-11. (Hereafter known as DOE 2002.)

[34] NRC 2006

[35] DOE 2002 Appendix A.

[36] U.S. Department of Energy, Plutonium: The First 50 Years, United States Plutonium Production, Acquisition, and Utilization from 1944 through 1994 http://www.osti.gov/html/osti/opennet/document/pu50yrs/pu50yc.html#ZZ15, 20

[37] Frank von Hippel, Managing Spent Fuel in the United States, the Illogic of Reprocessing, A research report of the International Panel on Fissile Materials, January 2007, http://www.fissilematerials.org/ipfm/site_down/ipfmresearchreport03.pdf

[38] Ibid.
[39] James J. Laidler, Separations Technology Development, Argonne National Laboratory, U.S. Department of Energy, undated, http://nstg.nevada.edu/Atw/pdffiles/laidler%20092601a.ppt#341,2,
[40] DOE 2002, Table A-11. (TRU inventory in 63,000 MTHM = 3,846,305,300 curies)

[41] DOE 2001. p. 5.6
[42] U.S. Department of Energy, Highly-Enriched Uranium Working Group Report on Environmental, Safety and Health Vulnerabilities Associated with the Department's Storage of Highly-Enriched Uranium, Volume I, DOE/EH-025, p. 4.

[43] Associated Press, USEC Ups Cost Estimate for Plant, February 13, 2007. http://biz.yahoo.com/ap/070213/apfn_uranium_plant.html?.v=1
[44] Op Cit Ref. 18.
[45] International Atomic Energy Agency, Status and trends in Spent Fuel Reprocessing, IAEA-TECDOC-1467, September 2005, p. 27.

[46] Hisham Zerriffi, Annie Makhijani, The Nuclear Alchemy Gamble, An Assessment of Transmutation as a Nuclear Waste Management Strategy, Institute for Energy and Environmental Research, May 2005.

[47] DOE 2002, Table A-11.

[48] NAS 2000, p. 78(Direct Grout of the supernate stream of SRS HLW contains 800 nCi/l)
[49] Westinghouse Savannah River Corporation, High-level Waste System at SRS, January 2005, p. 26. http://srnl.doe.gov/emsp/day1_overv/savan-river.pdf (84,000,000 million gallons of soluble tank wastes are estimated to be treated).

[50] National Research Council, Improving the Scientific Basis for Managing DOE's Excess Nuclear Material and Spent Nuclear Fuel, (2003), National Academy Press. P. 54.

[51] Chris G. Flum, Carbon 14 Releases from an Unsaturated Repository,: A Senseless but Expensive Dilemma, U.S. Department of Energy, Proceedings of the Symposium on Waste Management, Tucson Arizona, February 28-March 4, 1993. http://www.osti.gov/bridge/servlets/purl/140591-whFAeO/native/140591.pdf
[52] Argonne National laboratory, Carbon-14, Human Health Fact Sheet, August 2005.
[53] J. E. Moran, S. Oktay, P.H. Santschi, D. R. Schink,U. Fehn and G. Snyder, World-Wide Redistribution of 129Iodine from Nuclear Fuel Reprocessing Facilities Results from Meteoric, River, and Seawater Tracer Studies, Lawrence Livermore National Laboratory, UCRL-JC-130056, October 1998.

[54] U.S. Department of Energy, Tank Waste Inventory Network System (TWINS) Best Basis Inventory, CH2M HILL, Richland, WA. September 2003. (Hereafter known as TWINS Data 2003.)

[55] Westinghouse Savannah River Corporation, High-level Waste System at SRS, p.4.

[56] Robert Alvarez, Reducing the Risks of High-Level Radioactive Wastes at Hanford, Science and Global Security, 13:43–86, 2005.
[57] J.J Laidler, Chemical Separations Technologies for the U.S. Accelerator Transmutation of Waste Program, Argonne National Laboratory, 2002.
[58] Westinghouse 2003
[59] Op Cit Ref. 11

[60] U.S. Centers for Disease Control, Dose Reconstruction at the U.S. Department of Energy's Savannah River Site, Community Summary, http://www.cdc.gov/nceh/radiation/Savannah/CommSum2-3.pdf
[61] Anthony Turkevich, Lester Winsberg, Howard Flotow, and Richard M. Adams, The radioactivity of atmospheric krypton in 1949–1950, Proceedings of the National Academy of Sciences, USA, v.94(15); Jul 22, 1997.

[62] Centers For Disease Control, Radiation Assessment Corporation, SRS Dose Reconstruction project, Appendix C, Supplemental Information for Creation of Source Terms, August 2006, p. C-5.

[63] National Research Council, Nuclear Wastes: Technologies for Separations and Transmutation, National Academy of Sciences, (1996), National Academy, p. 82., (Hereafter known as NRC 1996.)

[64] NRC 1996 p. 78
[65] Ibid.
[66]NRC 1996 P.417..
[67] David Shropshire, Jess Chandler, Financing Strategies for a Nuclear Fuel Cycle Facility, 14th International Conference on Nuclear Engineering, Idaho National Laboratory, ICONE 14-89255, July 17-20, Miami, Florida, USA.

[68] Ibid.
[69] Ibid
[70] David Shropshire, Kent Williams, J.D. Smith, and Brent Boore, Advanced Fuel Cycle Economic Sensitivity Analysis, INL/EXT-06-11947, December 2006, P. 14.

[71] Steve Fetter, Testimony before the Subcommittee on Energy, Committee on Science, United States House of Representatives, July 15, 2005 http://gop.science.house.gov/hearings/energy05/july%2012/fetter.pdf
[72] Richard Benjamin and Donald C. Hampson, An evaluation of Retention and Disposal Options for Tritium in Fuel Reprocessing, Savannah River Laboratory and Oak Ridge National Laboratory, (1987), DP-MS-87-52
[73] Environment Agency, Summary Document, Proposed Decision for the Future of Radioactive Waste from British Nuclear Fuels plc Sellafield, August 2002 http://www.environment-agency.gov.uk/commondata/acrobat/BNFLSummaryDecisionDocument.pdf
[74] Westinghouse Savannah River Company, High-level Waste Division, Waste Incidental to reprocessing Evaluation for Disposing Saltcake to Saltstone, HLW-SDT-2001-0028, Rev. 1, February 2002, P. 2002.
[75] Committee On Radioactive Waste Management, United Kingdom, Dilute and Disperse, August 2004, CoRWM Document No. 630. p. 7.