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RADIOACTIVE WASTES AND THE GLOBAL NUCLEAR ENERGY PARTNERSHIP

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ABSTRACT

The U.S. Department of Energy's (DOE) Global Nuclear Energy Partnership (GNEP) is being promoted as a program to bring about the expansion of world-wide nuclear energy. To meet this goal DOE proposes to significantly reduce the amount of high-level radioactive waste for geological disposal and to reduce proliferation risks by transmuting fissionable materials into less troublesome isotopes. Crucial to the GNEP plan is using a new, unproven type of chemical reprocessing of spent fuel from power reactors in the United States and possibly other nations.

Unlike direct disposal of spent nuclear fuel rods, reprocessing involves chemical separation of radioisotopes and creates multiple waste streams. It also releases large volumes of radioactivity into the environment, typically by factors of several thousand compared with nuclear reactors. DOE claims that the new reprocessing technology under development will not pose these problems. But it is important to consider the following:

- In order to free up space in a geological repository, the major preponderance of the radioactivity in spent power reactor fuel would be stored and disposed in shallow burial near water supplies. By contrast, much smaller amounts of similar radioactive materials from past reprocessing at DOE sites are to be geologically disposed because they are considered to pose significant risks to the human environment.

- Under the GNEP plan, separation of cesium and strontium from spent nuclear fuel could result in the storage and near surface disposal after 300 years of the single largest concentration of lethal, high-heat radioactive wastes in the United States and possibly the world. According to DOE spent nuclear fuel estimates, these wastes would still be highly radioactive after 300 years. In order to meet DOE's tank waste disposal requirements at the Savannah River Site (SRS) in South Carolina, after 300 years, separated cesium and strontium would have to be diluted into a volume of more than 1 million cubic meters, enough to fill the Empire State Building.

- Unprecedented amounts of long-lived radioactive wastes could be disposed in the near surface and pose increased contamination risks for thousands of years. For instance, the amounts of cesium-135 that could be disposed under GNEP could be several thousand times greater than generated after decades of U.S. nuclear weapons material production. With a half-life of 2.3 million years, a panel of the National Research Council warned in 2000 that onsite disposal of a much smaller quantity of Cs-135 in wastes at SRS "represents a long term safety concern."

- A clearly defined disposition path for recovered uranium, which constitutes more than 95 percent of spent nuclear fuel by weight, appears to be lacking. Contaminants in the uranium will require it to be re-enriched at a new and costly facility. Otherwise, this uranium will have to be disposed, leaving a small fraction of spent fuel materials to be actually recycled.

Major uncertainties have prompted DOE researchers to advocate full federal financing, in the tens of billions of dollars, followed by forgiveness of sunk costs as the key to establishing the GNEP program. The Energy Department's troubled experience with defense high-level wastes should also serve as a cautionary warning. With an estimated liability of more than $100 billion, and after 25 years, DOE has treated less than one percent of the radioactivity from past reprocessing for geological disposal. By contrast, the magnitude of radioactive wastes generated under GNEP could be unprecedented and fraught with potentially greater safety and financial risks.

DOE lacks a credible plan for the safe management and disposal of radioactive wastes stemming from the GNEP program. This plan should address waste volumes, disposition paths, site specific impacts, regulatory requirements and life-cycle costs. *Given past failures to address waste problems before they were created, DOE's rush to invest major public funds for deployment of reprocessing should be suspended.*

I. EXECUTIVE SUMMARY

DOE plans to use an unproven aqueous reprocessing technology known as UREX+ (URanium EXtraction) and expects to separate uranium for recycle or disposal, transuranics for transmutation in "fast" reactors, and fission products for either surface storage or geological disposal. An engineering demonstration of this technology is several years away. If this proves successful, a single large scale plant with a throughput of 2,500-3,000 tons of spent fuel per year is planned to go on line around 2030. At that time, DOE projects that about 105,000 metric tons (Metric Tons Heavy Metal) of nuclear spent fuel would be generated by the U.S. nuclear power fleet. Because of its proximity to most of the nation's reactors, access to ports, and its nuclear material processing infrastructure, the Savannah River Site (SRS) in South Carolina is considered a prime candidate for a spent nuclear fuel reprocessing plant. SRS currently stores the nation's largest inventory of radioactivity in high-level wastes.

During the course of operation, a reprocessing plant could store 10,000 to 20,000 metric tons of spent fuel either in dry casks or pools capable of ensuring safe containment for 50 to 100 years. According to DOE's data, spent power reactor fuel would contain approximately 12 to 19.4 billion curies by the time reprocessing commences. This is about 24 to 45 times the radioactivity currently contained in high-level wastes stored at the SRS site. Based on DOE's recovery goals for UREX+, waste generation and environmental discharges are likely to be considerable:

- Approximately 7.5 to 12.4 billion curies of cesium-137 and strontium-90 could be separated for decay storage. After 300 hundred years DOE proposes to dispose of the material as low-level wastes. (*See Figure 1 on page 4.*) No other nation has adopted this proposed disposal policy. The amounts of cesium and strontium from reprocessing to be ultimately disposed in the near surface could be about 10 to 20 times greater than in all of DOE's defense high-level wastes scheduled for geological disposal. Because of large potential concentrations, the time frame for decay storage could be 600 years or more before these wastes meet low-level waste disposal criteria. Moreover, there are no federal standards nor safety criteria that govern this situation such as disposal timelines, radiological concentrations, heat controls, protective waste forms and packaging. The absence of such standards has resulted in about 121 million curies of cesium and strontium capsules separated from high-level wastes at Hanford now being stored in pools inside a building built in the 1940's. After less than 25 years, these encapsulated sources have experienced costly leaks.

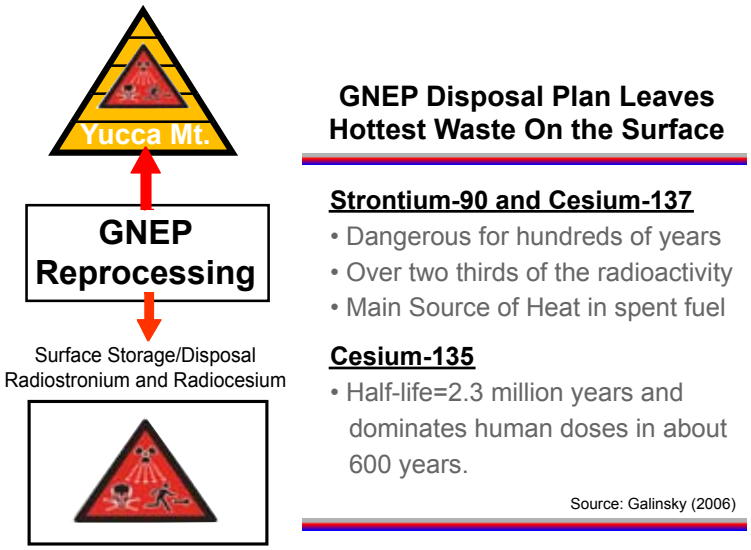
- Chemical separation of cesium-135 from highly active cesium-137 is not feasible, and such large quantities of this long-lived radionuclide, thousands of times greater than in all DOE defense high-level wastes, could also be disposed in the near surface. After 600 years Cs-135 could become a significant source of contamination. With a half-life of 2.3 million years, a panel of the National Research Council warned in 2000 that onsite disposal of a much smaller quantity of Cs-135 in wastes at SRS "represents a long term safety concern."

- Separated transuranics would contain as much as 638 metric tons of plutonium-239 — more than two and a half times the amount produced worldwide for nuclear weapons. Assuming 99 percent recovery, (TRU) process losses could contain as much as 24 times more radioactivity than TRU wastes generated for nuclear weapons during the Cold War. These wastes are highly radioactive, and will require costly remote handling and nuclear criticality controls. TRU wastes from the UREX process will constitute a unique waste stream that was not previously envisioned for disposal the the Yucca Mountain site. If they are required to meet DOE's current geological disposal criteria for remote-handled transuranic wastes, the projected volume could be as much as 65 times greater than from nuclear weapons production.

- Assuming 90 percent recovery, approximately 57,000 to 95,000 tons of uranium could be separated. Because of increased levels of uranium-236 that reduce fissionability, recycle of uranium will require a new, large-scale re-enrichment facility. However, DOE research indicates there may be difficulties in removing transuranic elements. If so, recovered uranium may not be suitable for recycle in power reactors and may require disposal in a geological repository, which is not currently authorized by law.

- Gaseous discharges such as tritium (H-3), carbon-14 (C-14), krypton-85 (Kr-85), techtnetium-99 (Tc-99) and iodine-129 (I-129) could be considerable. Assuming DOE's recovery goals can be achieved, environmental discharges of Tc-99 (half-life of 218,000 years) are comparable to the inventories in high-level wastes at SRS and the Hanford site. Environmental discharges of Iodine-129 (half-life of 15.7 million years) could be up to three times than in DOE defense high-level wastes at SRS and Hanford. Long-term doses from the disposal of a far less amount of I-129 remain an obstacle for onsite disposal of tank wastes at Hanford.

Figure 1



Costs

The domestic experience with commercial reprocessing does not inspire confidence. According to a recent review by the U.S. Nuclear Regulatory Commission (NRC), after 6 years, "significant radiation protection problems" led to the closure of the only operational commercial reprocessing plant near Buffalo, N.Y. in 1972. Cleanup of this plant is estimated by DOE to cost taxpayers $4.5 billion and take 40 years. More recently, DOE researchers found that "there are very large cost uncertainty ranges for these facilities." For instance:

- According to a DOE study done in December 2006, the per-unit cost for reprocessed material would double if process capacity does not exceed 50 percent.
- Another recent DOE analysis implies that if uranium were recycled, the current price for uranium would have to increase four fold for a UREX+ facility to be economically competitive.
- The same analysis found that reprocessing, waste management and transmutation costs would consume would add as much as 33 percent of the price for nuclear generated electricity.
- Based on recent estimates by the U.S. Uranium Enrichment Corporation, a new enrichment facility of the scale to recycle recovered uranium would cost $2.3 billion.

Other cost estimates suggest that reprocessing costs may exceed costs for geological disposal. In 1996, a panel of the National Academy of Sciences (NAS) assessed elements of the GNEP initiative and concluded that capital and operating costs for a reprocessing plant that would handle 62,000 metric tons ranged from $30 to $150 billion.

Additional waste processing and disposal costs associated with UREX+ may be considerable:

- According to British Nuclear Fuels, Limited the control and disposal of krypton gas would cost about $600 million.
- DOE research indicates that control and disposal of tritium discharges would be in excess of $2 billion.
- Based on estimates developed by an advisory panel of the British government in 2004, costs for decay storage are approximately $30 billion.

II. INTRODUCTION

In February 2006, U.S. Energy Secretary Samuel W. Bodman launched the Global Nuclear Energy Partnership (GNEP). Echoing his predecessors of the 1950's and 1960's, Bodman declared, "GNEP brings the promise of virtually limitless energy to emerging economies around the globe, in an environmentally friendly manner while reducing the threat of nuclear proliferation." To meet these claims GNEP is supposed to overcome two major obstacles to nuclear energy growth: radioactive waste disposal and nuclear weapons proliferation.

The details as to how this effort will work internationally are not clear. However, the problem of nuclear waste disposal in the United States is perhaps the most important obstacle the GNEP will have to overcome.

This report provides a general picture of the magnitude of waste streams from a large-scale reprocessing plant at the DOE's Savannah River Site (SRS) in South Carolina. Because of its proximity to the nation's reactor fleet, access to ports, and its nuclear material processing infrastructure, the SRS meets several criteria to be chosen as the site for a spent nuclear fuel reprocessing plant. DOE plans to deploy such a facility around 2030.[1] Radiological inventory data used in this report was developed by DOE in 2002. These data provide a decay-corrected estimate for 51 radionuclides in 63,000 and 105,000 metric tons estimated by DOE to be in spent nuclear fuel proposed for disposal at the Yucca Mountain Site in Nevada. (*See Table 3 page19.*)

III. THE "ONCE THROUGH" AND "CLOSED" NUCLEAR FUEL CYCLES

Recognizing the extraordinary hazards of high-level radioactive wastes, Congress passed the Nuclear Waste Policy Act in 1982 requiring they be disposed in deep geologic repositories so as to protect humans for at least hundreds of millennia. Under the Act, 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.

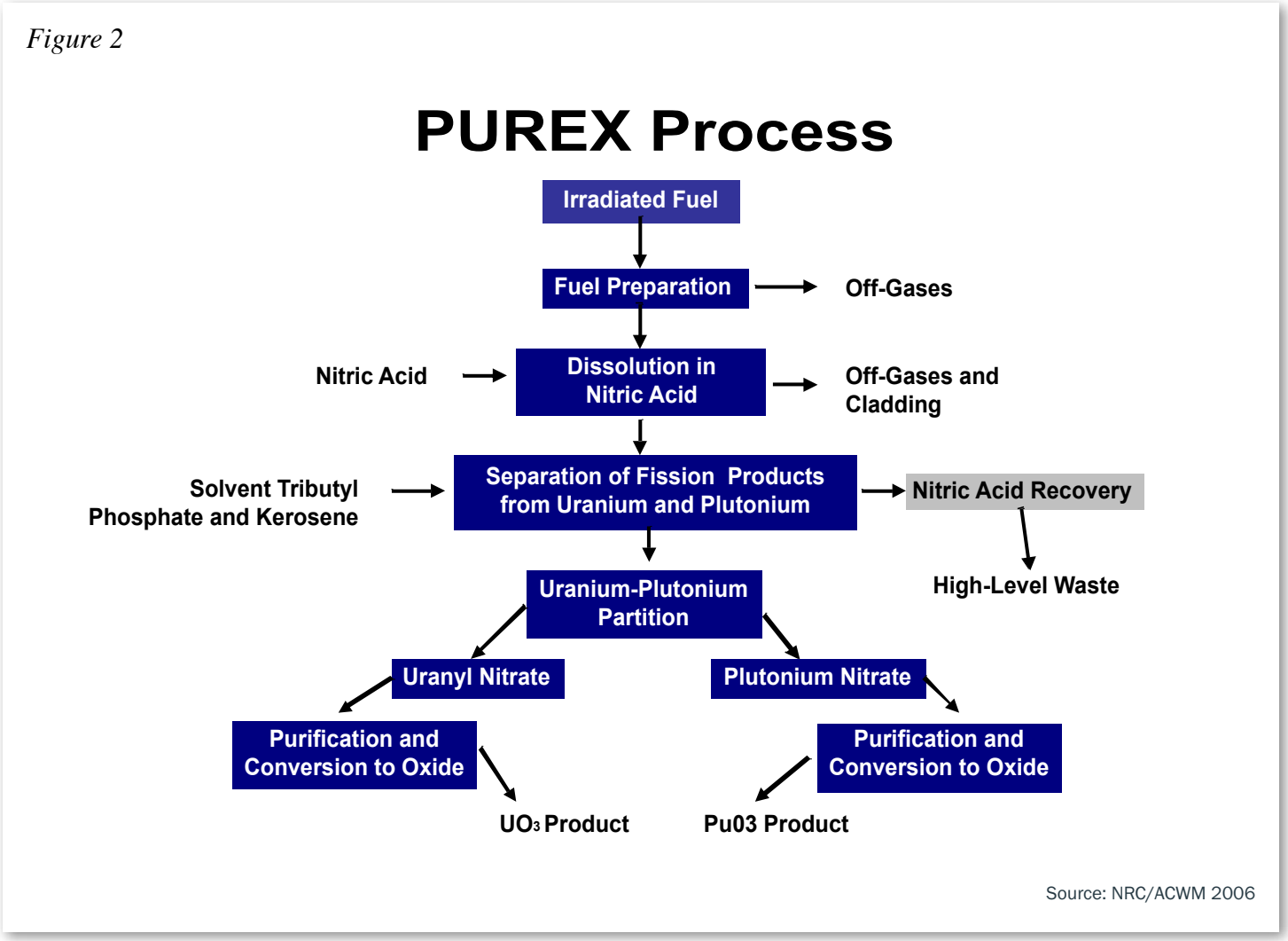
The "once through" nuclear fuel cycle was adopted by President Carter in 1977. Three years earlier, India exploded a nuclear weapon using plutonium separated from power reactor spent fuel at a reprocessing facility. President Ford responded in 1976 by suspending reprocessing in the United States. President 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. (*See Figure 2 page 7*)

It was reasoned 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. Because of their potential abundance of neutrons, plutonium-fueled fast reactors held the promise of producing electricity and also making up to 30 percent more fuel than they consumed.

In contrast to existing power reactors in the United States, a fast reactor uses different coolants, such as liquid sodium, so the neutrons remain at high energies and can be captured by uranium atoms — to produce plutonium-239, which would subsequently be extracted and remanufactured into new plutonium fuel — a closed cycle.

In 1974, the AEC declared that by the end of the 20th century some 1000 reactors would be on line in the United States.[2] As a result, the AEC predicted that world uranium supplies would be rapidly exhausted.[3] And so large-scale reprocessing and fast reactors would have to be deployed, no later than the mid 1980's. However, this prediction never materialized. Uranium supplies swelled into a world-wide glut, while nuclear power growth turned out to be a small percentage of what was predicted. The only U.S. commercial reprocessing plant in the U.S. operated near Buffalo, NY, between 1966 and 1972. Operations were suspended at the West Valley Site in 1972, when significant radiation protection problems forced the plant's shutdown for upgrades. The plant was permanently shut down in 1976 after it was determined that the site could not meet regulatory requirements to process commercial spent fuel. During the six years of operation, the plant processed approximately 640 metric tons of spent nuclear fuel, about three-fourths of which was provided by the AEC (60 percent of the total was from U. S. defense reactors). Over 600,000 gallons of liquid high-level radioactive waste was produced during reprocessing. The radioactive waste cleanup was estimated in 2001 by the DOE to take over four decades with a total cost to the federal government and the State of New York at $4.5 billion. By 1982, proliferation concerns combined with technical and cost problems, led to the abandonment of commercial reprocessing in the United States and an end of federal funding for breeder reactors.

Figure 2



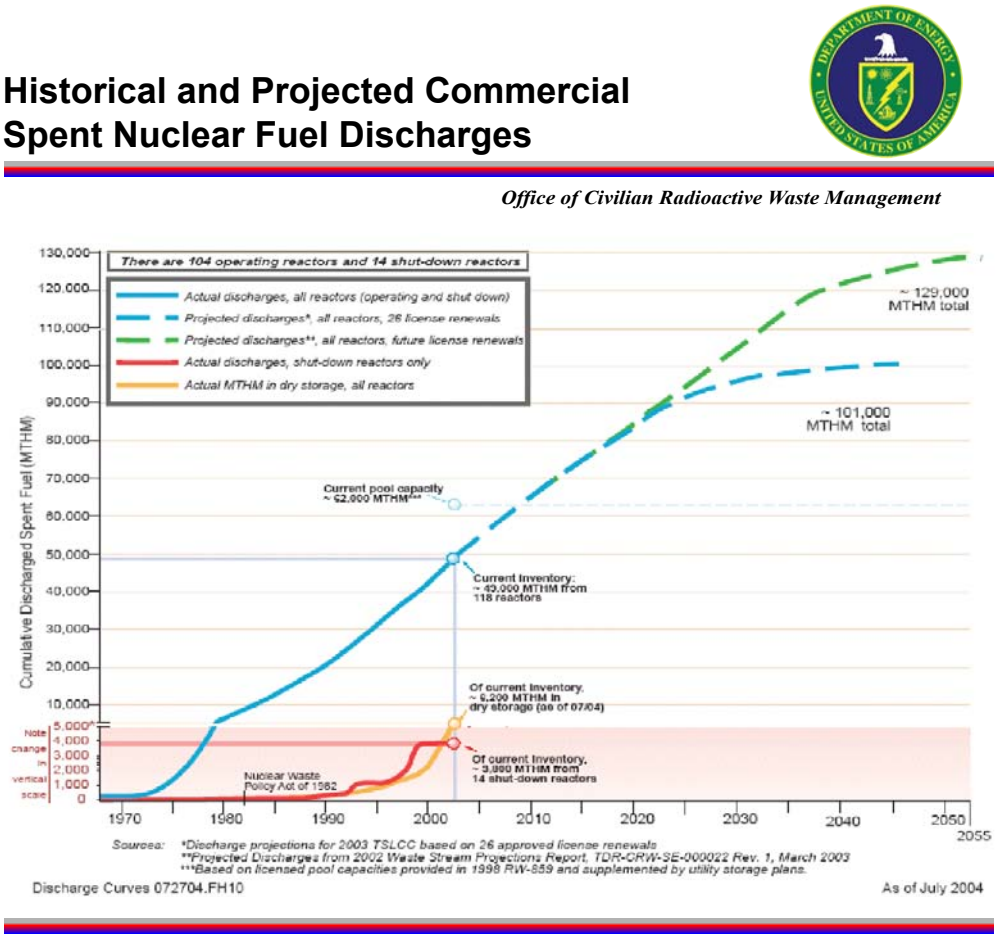
Source: NRC/ACWM 2006

IV. NUCLEAR WASTE DISPOSAL PROBLEMS

Twenty-five years after the Nuclear Waste Policy Act was enacted, the government's nuclear waste disposal program is being impacted by legal challenges, technical problems, scandal and congressional funding cuts. As a result, the schedule for the proposed Yucca Mountain disposal site in Nevada has slipped almost two decades past the original opening date of January 1998. The 1982 Nuclear Waste Policy Act imposes a limit of 70,000 metric tons of high-level radioactive wastes. If that amount is exceeded, the law requires a second repository to be selected. Under the law, DOE spent fuel and high-level wastes are to make up no more than 10 percent of this limit.

The DOE concluded in 2004 that 63,000 metric tons of nuclear spent fuel could be stored in the Yucca Mountain site, but continued operation of reactors would generate about 105,000 metric tons by 2030. In effect, by the time the Yucca Mountain Site would be full, nuclear power plants will have accumulated nearly the same amount of spent fuel stored at reactor sites today — requiring the establishment of a second repository. (*See figure 3.*) In response to these problems, DOE is seeking to restore the closed fuel cycle through deployment of large-scale nuclear reprocessing and "fast" reactors. By doing this, GNEP proponents claim that a much smaller amount of high-level nuclear waste would have to be disposed in a geological repository, while troublesome stocks of weapons materials would be greatly reduced. Instead of using fast reactors to make more fuel than they consume, GNEP advocates propose to harness this technology to transmute or "burn" long-lived radioactive materials, such as plutonium into less problematic isotopes.

Figure 3



V. DEFENSE HIGH LEVEL WASTES

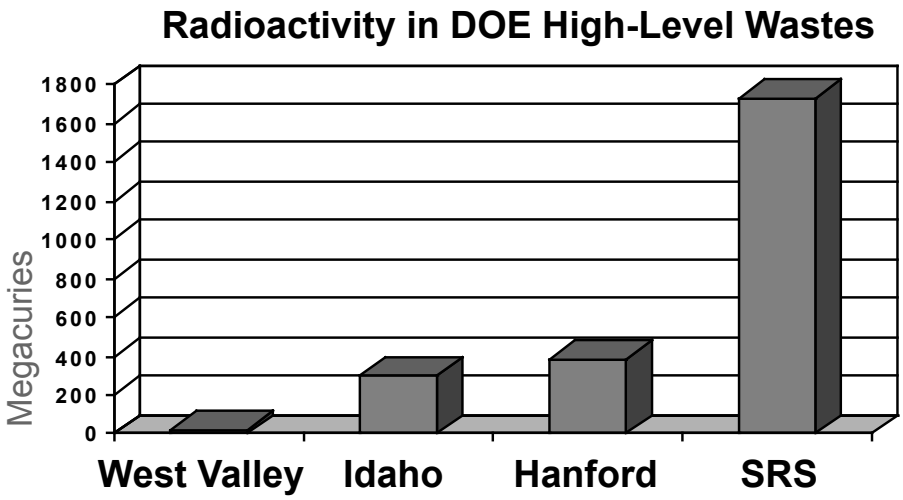
Now, through GNEP, the DOE is seeking to resurrect the vision of a "closed" fuel cycle possibly at the Savannah River Site. For nearly 50 years the United States operated several large reprocessing plants to chemically separate 100 tons of plutonium from spent production reactor fuel for nuclear weapons. DOE has also accumulated spent nuclear fuel from past material production and research reactors. As of 2001, DOE high-level wastes and spent fuel contained about 2.4 billion curies.[4] (*See Figure 4.*)

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." [5]

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 (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.

Figure 4



Source: DOE 2001

Idaho National Engineering Laboratory (INEL)

From 1953 to 1991, INEL reprocessed a variety of nuclear fuels, primarily for recovery of the uranium-235 from naval propulsion reactors. Unlike other DOE sites, high-level wastes generated from reprocessing were not neutralized. Instead, wastes were converted to granular solids by calcination. The wastes were processed in a heated (400 to 600°C) fluidized-bed calciner where they underwent thermal decomposition to metallic oxides or fluorides, water vapor, and nitrogen oxides. The solids were transported to stainless steel bins for interim storage. The bins are partially buried and are grouped within concrete vaults designed to last 500 years. As of August 1998, five of the seven bins were filled, one was partially full, and one was empty. Calcined HLW is approximately 4,000 cubic meters in volume, and contains about 41 million curies. DOE has no plans to chemically remove radionuclides from the calcined wastes for onsite and geological disposal. These wastes are expected to be put into a form suitable for monitored geological disposal.

Roughly 500,000 curies are contained in 882,600 gallons liquid sodium bearing wastes, which are stored in 11 tanks at the site. DOE is seeking to process these wastes using steam reforming for onsite disposal.

West Valley

About 2,180 m^3 of high-level waste is stored at the West Valley Demonstration Project (WVDP) facility and consists of 2,040 m^3 of liquid alkaline waste and 140 m^3 of solid waste (consisting of alkaline sludge and inorganic zeolite ion-exchange medium). The alkaline waste is stored in an underground carbon-steel tank, and the zeolite waste is stored in an underground carbon-steel tank covered by an aqueous alkaline solution. Reprocessing was discontinued at the WVDP in 1972. No additional high-level waste has been generated since.

In June 1996, the vitrification of HLW into glass logs was initiated at the WVDP. The glass logs are two feet in diameter by 10 feet long. By 2002, a total of 275 canisters were produced awaiting geological disposal.

Hanford

High-level radioactive wastes resulted from the production of nuclear materials to fuel the U.S. nuclear arsenal. (*See Figure 4*) Between 1944 and 1987 the U.S. Department of Energy's Hanford Site produced 67.4 metric tons of plutonium of which 54.5 m tons were for use in nuclear weapons.[6] After treatment and subsequent radioactive decay, the Hanford high-level wastes currently contain approximately 194 megacuries in 54 million gallons of waste stored in large underground tanks. (*See Table 3* *page 19*) From a time perspective, radionuclides in the tanks pose potentially significant risks to health and natural resources for 300 to more than 200,000 years. More than 96 percent of total radioactivity in the tank wastes comes from cesium-137 and strontium-90 (half-lives of 30 and 29 years respectively). These high levels of radiostrontium and radiocesium pose safety concerns because of decay heat build-up during storage, retrieval, and processing. Hanford's wastes also have substantial amounts of long-lived fission products and transuranics.

Hanford's waste tanks contain complex mixtures that fit into 89 separate chemical profiles. They are in the forms of sludge, salts and supernate. The Hanford high-level waste treatment plant is currently under design and construction. Because of project management failures, capital costs have significantly increased and the schedule for startup of the plant has been moved to 2019.

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.[7] These wastes are in two basic forms –sludge and salts. The sludge, which results from settling of metals and radionuclides, takes up about 2.8

million gallons and contains about 320 million curies,[8] which is about 10 percent of the waste volume.[9] 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.[10]

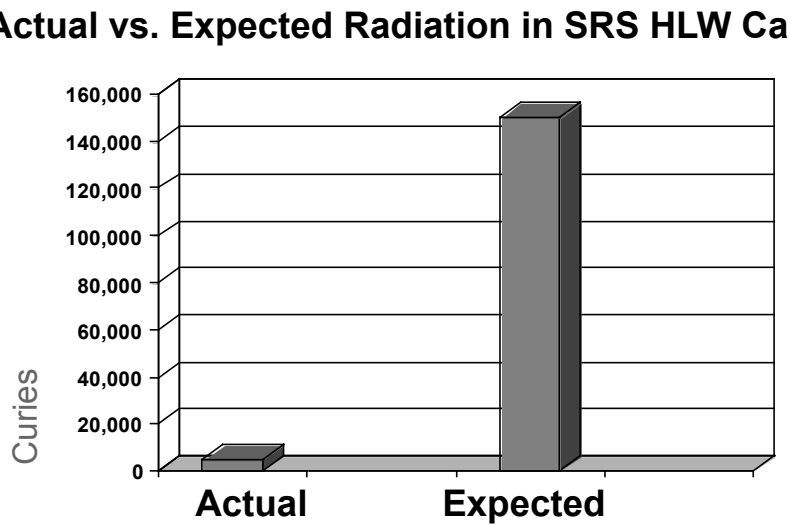
Tank farms at the Savannah River Site contain 24 single-shell and 27 double-shell tanks for storing high-level waste. The DOE plans to remove the liquid waste from these tanks by 2035. The Defense Waste Processing Facility (DWPF) began construction in 1982 and operation in 1996 with the goals of processing SRS tank wastes for geological and onsite disposal. The total life cycle cost for the DWPF is approximately $20 billion.[11]

After more than 20 years, DOE has processed less than 3 percent of radioactivity in SRS wastes.[12] This is especially troublesome since vitrified waste canisters at SRS currently contain in average less than 3 percent of the radioactivity predicted by DOE. (*See Figure 5*) In 2002 DOE projected that each high-level waste canister would have to contain approximately 150,000 curies of radioactivity so as to meet the disposal criteria for the Yucca Mountain site.[13] However, in 2006, the average canister produced at the Savannah River vitrification plant was about 4, 829 curies.[14]

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.)[15] At the Savannah River Site, DOE estimates that the total costs for high-level waste management and processing is approximately $20 billion.[16]

Figure 5



As of January 31, 2006, 2044 canisters containing a total of 10 million curies were produced.

Source: NAS 2006

VI. STORAGE AND REPROCESSING

DOE estimates that 175 shipments per year over 24 years will be required to move an accumulated spent fuel inventory of 63,000 metric tons. If SRS were to serve as the primary reprocessing operation for the United States this would translate into 4,200 shipments.[17] This does not include shipments from other countries.

A spent fuel storage facility for reprocessing at SRS would likely have the capacity to contain about 10,000 to 20,000 metric tons. (The French reprocessing plant run by Cogema has a storage capacity of 14,400 MTU.)[18] 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."[19]

A large reprocessing plant would have to operate for approximately 30-40 years to handle between 63,000 and 105,000 metric tons of spent fuel. According to DOE, a reprocessing plant would require a capacity of 2,500- 3,000 metric tons per year.[20]

VII. RADIOACTIVE WASTES FROM REPROCESSING

In May 2006, the Energy and Water Appropriations Committee of the U.S. Congress also expressed concerns over the DOE's lack of cost data for GNEP:

> "The Department has failed to produce a complete accounting of the estimated volumes, composition, and disposition of the waste streams that will be involved in GNEP. The Department has also failed to produce even the most rudimentary estimate of the life-cycle costs of GNEP. Before the Department can expect the Congress to fund a major new initiative, the Department should provide Congress with a complete and credible estimate of the life-cycle costs of the program."[21]

The GNEP program is seeking to develop an aqueous reprocessing technology called UREX+ (URanium EXtraction). UREX+ involves a series of five solvent extraction process steps that would separate spent nuclear fuel into seven product and waste streams,[22] including:

- Iodine-129 (half-life of 15.7 million years) for geological disposal
- U3O8 for recycle in light water reactors or disposal as low-level wastes
- Neptunium-237 and plutonium isotopes for mixed oxide fuel in light water reactors
- Technetium-99 (half-life of 210,000 years) for geological disposal
- Americium and curium for fast-reactor fuel
- Cesium and strontium for decay storage and surface disposal
- Mixed fission products for repository disposal

UREX+ has no proven history of success and is several years away from an engineering scale demonstration. Chemical separations and waste treatment are more complex than the PUREX process, and involve several technologies that have yet to be demonstrated beyond the laboratory scale. (*See Figure 6 page14.*)

As Tables 1 indicates, a typical civilian reprocessing plant, based on the PUREX technology, has the following general waste streams and disposition paths:

Table 1 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 – stored in large, cooled underground tanks to allow for decay of short-lived radionuclides	shallow storage

Source: NRC 2006

Figure 6

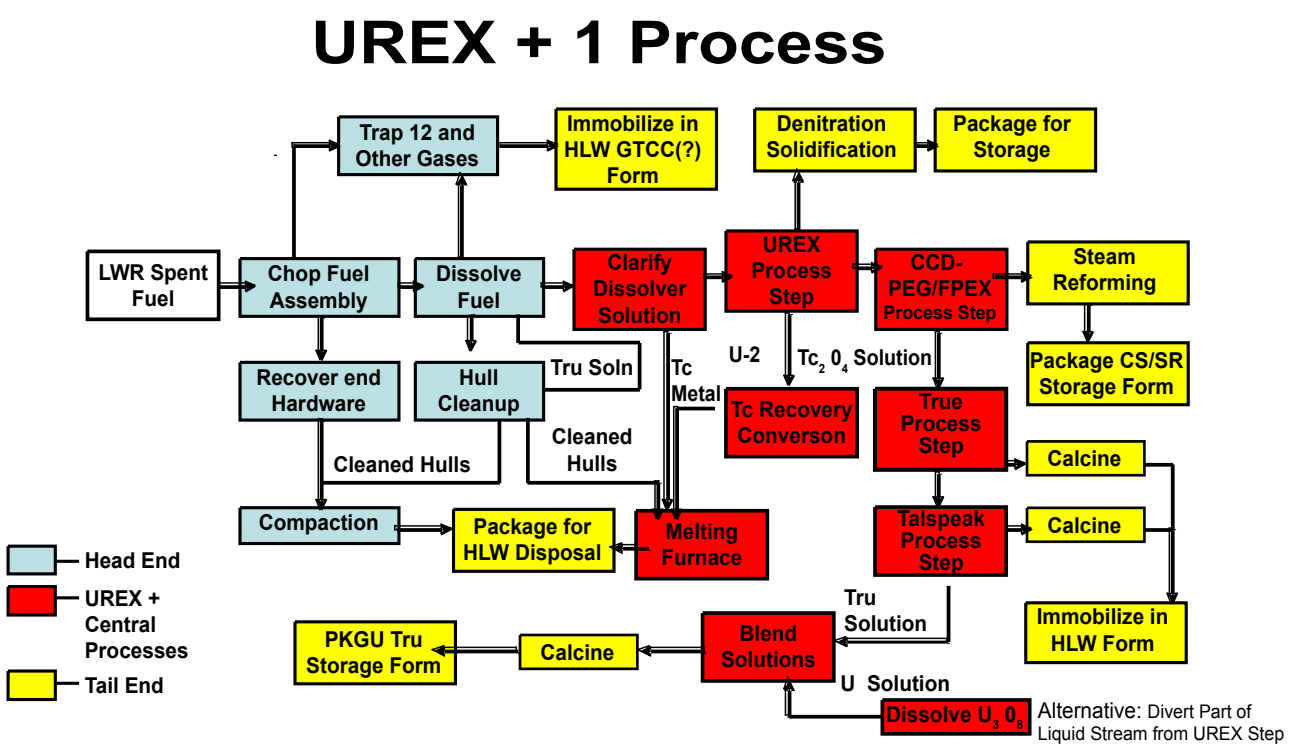


Table 2 UREX+ Waste Streams

Waste Type	Disposition
Hull and Cladding Wastes	geological disposal
Hull and Cladding Wastes	geological disposal
Iodine-129 scrubber wastes	geological disposal
Krypton 85/compressed gas	100+ year decay storage
Carbon-14 gas retained	geological disposal
Technetium-99	geological disposal
Cesium and Strontium Wastes	decay storage/surface disposal
Incinerated Spent solvents	shallow land disposal
Vessel Off gases (H-3)	released/untreated
Off-Gas Control System Wastes	shallow land or geological disposal
Uranium	recycle, or shallow land disposal
Transuranic wastes	geological disposal
Contaminated equipment	shallow land burial
Analytical Wastes	shallow land burial

Source: NRC 2006

By comparison, the UREX+ technology is planned to not generate significant amounts of liquid wastes. Cost and performance data for large-scale deployment do not yet exist.[23] As Table 2 (*page 14*) indicates the assumed waste streams from the UREX differ from those of the PUREX process, particularly with respect to off-gas recovery and surface storage/disposal of cesium and strontium wastes.

Total Radioactivity — The estimated total amount of radioactivity in spent power reactor fuel generated by 2030 would be approximately 11.8 to 19.4 billion curies.[24] By comparison, this is about 27 to 45 times the amount of radioactivity estimated by DOE in 2001 in the high-level wastes at SRS.[25]

Plutonium-239 — The total amount of plutonium 239 in separated transuranics from U.S. commercial spent fuel would be as much as 638 metric tons.[26] This is more than 6 times the amount produced for the U.S. nuclear arsenal from 1944 to 1988,[27] and more than two and a half times the amount produced worldwide for nuclear weapons. 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.[28] 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.[29] 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.

Decay Storage of Fission Products — The GNEP plan envisions the separation and permanent surface storage /disposal of radioactive wastes, principally Cs-137 and Sr-90, which nominally take about 300 to 600 years to decay to safe levels. After 30 years of operation, approximately 7.5 to 12.4 billion curies (not decay corrected) could be separated and are likely to remain at the site.

DOE researchers suggest these wastes could be converted into granular solids using steam reforming. Steam reforming processes waste in a high-temperature fluidized bed under a slight vacuum. The process is expected to destroy organics, nitrates and nitrites. Additives are expected to incorporate radionuclides, sulfate, chlorine and fluorine into a granular waste form.

Specific criterion for waste form leachability for the 300-600 year decay time has not been established, much less for considerable quantities of Cs-135 in the wastes that pose safety concerns for tens of thousands of years. Nor has the granular product from steam reforming been assessed for leachability, which may also require development of high integrity packaging to meet disposal requirements. Additional processing may also be necessary, such as putting the granular product into a monolithic form, in order to meet waste disposal requirements. DOE-sponsored research suggests that cesium and strontium wastes should be stored in a water pool for 30 to 50 years prior to transfer for near surface-underground decay storage and disposal.

By comparison, in the early 1970's approximately 131 million curies (decay corrected 1995) of cesium and strontium were separated and concentrated in 15 metric tons from defense high-level wastes at the Hanford site to reduce decay heat in waste tanks. According to the 2003 report by a panel of the National Academy of Sciences, these wastes "have been described as the nation's most lethal single source of radiation other than inside an operating reactor."[30] They were concentrated as salts and placed in stainless steel capsules for storage in pools. It was envisioned that these sealed sources would be used for commercial purposes such as food irradiation. However, this effort ceased after a capsule leaked at a commercial site in 1988 resulting in $50 million in cleanup costs.[35] They are now stored at a 1940's era facility awaiting disposal in a geological repository.[31] While DOE has agreed with the State of Washington that the cesium and strontium capsules should be disposed in a geological repository, no credible plan has emerged to accomplish this plan. Dose rates range from 8,600 to 18,000 rems/hour for the Cs-137 capsules and from 20 to 420 rems/hour for the Sr-90 capsules. Concentrations are so great that the National Research Council panel concluded that it would take approximately 800 years for the strontium to decay to a level acceptable as low-level waste.[32]

Concentrations of cesium and strontium in SRS waste tanks represent no more than a few percent of the total volume. However, if disposed on site, these radionuclides could remain a major dose contributor for 15 to 20 half-lives (450 to 600 years.)[34] It is therefore likely that the 300 year time-frame proposed by DOE for surface storage and disposal of cesium and strontium extracted from spent power reactor fuel could be substantially longer before concentrations reach the level allowed for low-level waste disposal. The existing regulatory framework

for radioactive waste disposal does not address near surface decay storage and disposal of cesium and strontium from spent nuclear fuel.

According to DOE spent fuel data, these wastes would still be highly radioactive after 300 years. Approximately 12.1 million curies would remain. If this quantity was to meet DOE tank waste disposal requirement for strontium and cesium at SRS, it would have to be diluted in more than one million cubic meters of waste volume. (DOE projects that 3 to 5 million curies[35] of primarily strontium and cesium will be disposed in about 410,000 cubic meters[36] of grout, known as "saltstone.") Assuming 90 percent recovery, as much as 1.2 billion curies of cesium and strontium could be lost to process. If one percent of the cesium and strontium lost to process were disposed as Class A low-level wastes this would result in more than 1 million cubic meters which is comparable to the total projected volume of low-level wastes from all DOE sites.[37]

Transuranics — Assuming that 99 percent of the transuranics (TRU) from commercial spent power reactor fuel could be recovered[38] – as much as 63 million curies of TRU waste could be left behind in process losses.[39] This is approximately 24 times more radioactivity than in current TRU waste inventories at all DOE sites.[40] 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.

Current law prohibits disposal of GNEP waste at Waste Isolation Pilot Plant (WIPP), since it is only for defense-related TRU. However, TRU wastes generated by the UREX process will constitute a separate an unique waste stream. DOE has yet to specify the disposition of TRU wastes from reprocessing. Waste volumes also appear to exceed the limits set by federal law. For purposes of comparison, if TRU wastes lost to process were to be packaged to meet the current waste acceptance criteria for disposal at the DOE's WIPP, this would yield approximately 1.3 million drums of remote-handled TRU wastes, which is about 65 times greater than DOE's remote handled TRU wastes projected for disposal (20,000 drums).[41] The total amount of radioactivity in TRU waste from a reprocessing plant would be 8 times greater than allowed for disposal at WIPP under the Land Withdrawal Act of 1996 (P. L. 104-201, 110 Stat. 2422.)[42] Preliminary cost estimates for the characterization of DOE's remote-handled TRU wastes range from $400 million to $6 billion.[43] The estimated life-cycle cost for disposal of current DOE TRU wastes at WIPP is $ 17.6 billion (2007 dollars.)[44]

Uranium — More than 95 percent of spent nuclear fuel 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 amounts that are 5 to 50 parts per million.[45] 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 5,000 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.[46] 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 suggests that uranium recovered from reprocessing may be disposed as waste or recycled for use in nuclear power plants. 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..."[47]

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 ac-

tive Cs-137.[48] [49] About 36,000 to 60,000 curies of this radionuclide could be generated and remain in wastes for permanent surface disposal.[50] By comparison, this amount of Cs-135 is several orders of magnitude more than in high-level radioactive wastes at SRS.[51] [52] After 600 years Cs-135 will become the dominant source of radioactivity and human doses over long periods of time could be significant.[53]

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 could be substantial.[54]

Assuming 90 perccent recovery, as much as 16,000 curies of carbon-14 could be released. 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.[55]

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.[56] Beginning in 1994, direct releases from Sellefield 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 Rive. 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.[57] [58] 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.[59]

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 radionulide in the UREX process.[60] 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.[61]

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[62] – which is comparable to the tritium releases at SRS from the 1950's to the 1990's.[63] 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 2004, the La Hague reprocessing plant released about 7.7 million curies of Kr-85 into the atmosphere — perhaps half of the input of Kr-85 released worldwide from nuclear activities.[64] The inventory of Kr-85 in U.S. spent nuclear fuel is in the range of 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.[65] Thus, assuming 90 percent recovery, Kr-85 releases would be about 60 percent greater than SRS releases.

VIII. COSTS

Recently, the DOE submitted its budget request to the U.S. Congress for Fiscal Year 2008. DOE is requesting $405 million for GNEP, of which $395 million will be the Advanced Nuclear Fuel Cycle Initiative within the DOE's Office of Nuclear Energy.[66] DOE is aggressively pursuing concurrent strategies of research and development and technology deployment. However, DOE has yet to provide baseline life-cycle cost estimates and an overall procurement strategy.

The costs associated with major elements of GNEP 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 $500 billion and require "approximately 150 years to accomplish the transmutation."[67] Capital and operating costs for a reprocessing plant in the U.S, according to the NAS, would range from $30 to $150 billion.[68] The NAS panel also concluded that this program was uneconomical and would require a federal subsidy of $30 to $100 billion.[69]

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."[70]

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."[71]

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 percent reduction in capacity would double the cost per unit.[72]

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."[73] A separate INL study done in December 2006 underscores this finding, indicating that the cost of the UREX+ process would be about $1,279 per kilogram of spent fuel.[74] 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.[75]

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

- 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).[76]
- 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.[77]
- As mentioned previously, disposal of one percent of process losses from cesium and strontium extraction as low-level waste could result in more than 1 million cubic meters. Currently, DOE's life-cycle estimate of 410,000 cubic meters for disposal of SRS tank wastes onsite is $2.8 billion.[78]
- Life cycle costs of decay storage of cesium and strontium remain uncertain. However, based on data from the Sellafield reprocessing plant, 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).[79]

Table 3 Estimated Radioactivity in U.S. Spent Nuclear Fuel

Isotope	Half Life (yrs)	Grand Total 63,000 MTHM (Curies)	Grand total 105,000 KT MTHM (Curies)
Hydrogen-3	1.23E+01	1.60E+07	2.60E+07
Carbon-14	5.70E+03	9.50E+04	1.60E+05
Chlorine-36	3.00E+05	7.50E+02	1.20E+03
Iron-55	2.70E+00	4.20E+05	7.00E+05
Cobalt-60	5.30E+00	2.70E+07	4.50E+07
Nickel-59	7.60E+04	1.60E+05	2.70E+05
Nickel-63	1.00E+02	2.20E+07	3.70E+07
Selenium-79	6.40E+04	3.00E+04	5.00E+04
Krypton-85	1.07E+01	1.50E+08	2.50E+08
Strontium-90	2.90E+01	3.00E+09	5.00E+09
Zirconium-93	1.50E+06	1.60E+05	2.70E+05
Niobium-93m	1.60E+01	1.10E+05	1.80E+05
Niobium-94	2.40E+04	5.60E+04	9.30E+04
Technetium-99	2.10E+05	9.50E+05	1.60E+06
Ruthenium-106	1.00E+00	4.70E+03	7.90E+03
Palladium-107	6.50E+06	8.80E+03	1.50E+04
Cadmium-133m	1.40E+01	1.50E+06	2.50E+06
Antimony-125	2.80E+00	3.60E+06	6.00E+06
Tin-126	1.00E+06	5.90E+04	9.80E+04
Iodine-129	1.70E+07	2.40E+03	3.90E+03
Cesium-134	2.10E+00	5.80E+06	9.70E+06
Cesium-135	2.30E+06	3.60E+04	6.00E+04
Cesium-137	3.00E+01	4.50E+09	7.5E+09
Promethium-147	2.60E+00	1.80E+07	2.90E+07
Samarium-151	9.00E+01	2.50E+07	4.30E+07
Europium-154	8.60E+00	1.20E+08	2.10E+08
Europium-155	4.80E+00	2.20E+07	3.60E+07
Actinium-227	2.20E+00	9.70E-01	1.60E+00
Thorium-230	7.50E+04	1.80E+01	2.90E+01
Protactinium-231	3.30E+04	2.10E+00	3.40E+00
Uranium-232	6.90E+01	2.60E+03	4.30E+03
Uranium-233	1.60E+05	3.90E+00	6.50E+00

Isotope	Half Life (yrs)	Grand Total 63,000 MTHM (Curies)	Grand total 105,000 KT MTHM (Curies)
Uranium-234	2.50E+05	8.40E+04	1.40E+05
Uranium-235	7.20E+08	1.00E+03	1.70E+03
Uranium-236	2.30E+07	1.80E+04	3.00E+04
Uranium-238	4.50E+09	2.00E+04	3.30E+04
Plutonium-241	1.40E+01	3.20E+09	5.30E+09
Plutonium-238	8.80E+01	2.40E+08	4.00E+08
Americium-241	4.30E+02	2.20E+08	3.70E+08
Curium-244	1.80E+01	1.20E+08	2.00E+08
Plutonium-240	6.50E+03	3.60E+07	6.00E+07
Plutonium-239	2.40E+04	2.40E+07	4.00E+07
Americium-243	7.40E+03	1.90E+06	3.10E+06
Americium-242/242m	1.40E+02	1.60E+06	2.60E+06
Curium-242	4.50E-01	1.30E+06	2.20E+06
Curium-243	2.90E+01	1.30E+06	2.20E+06
Plutonium-242	3.80E+05	1.40E+05	2.30E+05
Neptunium-237	2.10E+06	3.00E+04	5.00E+04
Curium-245	8.50E+03	2.90E+04	4.80E+04
Curium-246	4.80E+03	6.30E+03	1.00E+04

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