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Strategic Planning for Defense High-Level Waste and Spent Fuel Disposal

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I. Nuclear Waste Disposal Challenges

Recognizing that spent nuclear fuel and high level radioactive waste is among the planet's most dangerous material, Congress passed the Nuclear Waste Policy Act (NWPA) in 1982. The law required all such nuclear waste to be disposed of in a deep geologic repository so as to protect humans for at least hundreds of millennia. Under the Act, intact spent fuel rods from power reactors were to be sent directly to a repository -- a "once through" nuclear fuel cycle. High level waste from nuclear weapons production, much of which requires processing before disposal, was also designated for permanent burial deep underground.

Twenty-five years after the NWPA was signed into law, the government's nuclear waste disposal program is being impacted by legal challenges, technical problems, scandal and congressional funding cuts. The Department of Energy is in the midst of yet another contentious impasse over the disposal of commercial spent nuclear fuel. Legal and policy uncertainty have left the high level waste disposal program with uncertain goals and diminishing prospects for success. Delays in deciding the scientific feasibility of permanent disposal at the Yucca Mountain site in Nevada continue. Nuclear utilities and public utility commissions have convinced a federal appeals court that the DOE must honor a January 1998 deadline to accept spent fuel referenced in the 1982 Nuclear Waste Policy Act (NWPA).

Obscured in this controversy are several major issues which need to be addressed before satisfactory management and disposal of nuclear wastes can be achieved. Among them are requirements for secure interim storage, tradeoffs with near surface versus geologic burial, and technical and equity considerations involved with permanent disposal. Unfortunately, the solutions currently advocated in Federal Court and the U.S. Congress represent a short-term, piecemeal fix to fundamental, structural problems. The policy and technical challenges of nuclear waste disposal remain as they did in 1982 - solving them will require a renewed political consensus based on knowledge and insights acquired since then.

In 2002 the DOE concluded that 63,000 metric tons of nuclear spent fuel could be stored in the Yucca Mountain site – however, continued operation of reactors will generate more than 100,000 metric tons by 2046. By the time the Yucca Mountain Site reaches its

capacity limit, nuclear power plants will have accumulated nearly the same amount of spent fuel as is now stored at reactor sites – requiring the establishment of a second repository.

In the aftermath of the September 11th terrorist attacks, the nation's 104 commercial nuclear reactor and dozens of federal nuclear weapons sites were put on high security alert. The U.S. government has long considered these facilities to be potential terrorist targets, and has begun to implement programs to safeguard against such threats. But is enough being done? In 2005, a committee of the National Research Council commissioned by the U.S. Congress concluded that the risks of a terrorist attack against spent nuclear fuel storage pools should not be dismissed. The panel concluded that "under some conditions, a terrorist attack that partially or completely drained a spent fuel pool could lead to a propagating zirconium cladding fire and release large quantities of radioactive materials to the environment."[1]

Nations like Germany have been protecting spent power fuel against terrorist attacks using dry, hardened storage modes for some 20 years. Dry casks are also a growing part of at-reactor storage capacity in the U.S. The costs of establishing a safe and secure national storage program for power reactor spent fuel may be too high for reactor owners looking to cut costs in a deregulated environment. But the costs of doing little or nothing may prove incalculable.

The cost of spent nuclear fuel management, including storage and disposal, accounts for only a small fraction of nuclear generated electricity. To reduce both the consequences and probability of a spent-fuel-pool fire, we propose that all spent fuel be transferred from wet to hardened dry storage within five years of discharge. The cost of on-site dry-cask storage for an additional 35,000 tons of older spent fuel is estimated at $3.5–7.0 billion dollars, or 0.03–0.06 cents per kilowatt-hour generated from that fuel. The transfer to dry storage could be accomplished within a decade.

We recommend that the U.S. Congress and the DOE establish a special panel from the National Academy of Sciences to undertake a comprehensive baseline review of the elements required for long-term interim storage of commercial spent nuclear fuel. Key elements of the review should include:

- Projections for spent fuel storage duration
- Costs of hardening spent fuel pools and dry storage sites
- Allocation of costs for storage
- Repository capacity needed for spent fuel

The nation's commitment to resolve the legacy of its nuclear weapons production is unfulfilled. The United States has spent more than $6 trillion on its nuclear weapons systems, but has increasingly shortchanged its obligations to States, Tribal governments, and communities most affected by the legacy of developing atomic weapons. The difference between restored sites or sacrifice zones often hinges on fractions of a percent of the cost of the nation's nuclear arsenal. Rather than face difficult issues of risk, cost

and equity squarely, de facto policies have arisen allowing for reclassification, and near surface burial, of nuclear waste. Current law forbids reclassification of high level waste in Washington State, but allows it in South Carolina (SRS) and Idaho (INEL). DOE's efforts to self-regulate onsite disposal of high-level wastes at SRS and INEL are designed to reduce the geological disposal volumes of defense high-level wastes.

In order to accommodate the burgeoning inventory of spent reactor fuel, DOE has decided to reduce to less than half of the glass logs expected to be generated for all DOE high-level wastes. Meanwhile, more than 2,000 canisters have been produced at SRS, which contain less than 3 percent of the expected radioactive loadings. Given that HLW canisters have considerably less radioactivity than assumed, while DOE is limiting the number of canisters to be produced - this means that more radioactivity will be disposed onsite.

Moreover, after 25 years, DOE has processed less than 0.1 percent of the radioactivity in all defense high-level wastes for disposal. DOE's strategy, adopted in the early 1980's, to partition high-level wastes so as to allow for onsite disposal and to reduce geological disposal volumes, has encountered technological failure, delays and growing costs.

We recommend that the U.S. Congress and the DOE establish a special panel from the National Academy of Sciences to undertake a comprehensive baseline review of the DOE's strategy for defense high-level waste processing and disposal. Key elements of the review should include:

- Means to ensure safe containment of wastes prior to processing
- Reduction of technological risks associated with pretreatment of soluble and insoluble wastes
- Assessment of waste forms that can assure long-term integrity
- Evaluation of risks from wastes already released into the environment, and
- Development of risk-based disposal criteria based on radiotoxicity and concentration
- Repository capacity needed for defense high-level waste

It is clear that the repository program must be revisited for the most practical of reasons – it cannot hold the waste. The inventory of commercial spent fuel will exceed the repository capacity by 2009. Most high level radioactive waste canisters will be stranded at former weapons production sites, assuming they are ever produced from military waste now a half century old. The 90% allocation of repository capacity to commercial waste may be driving near surface burial of high level radioactive waste in a number of states.

The repository itself is mired in technical problems. The viability of the Yucca Mountain repository has been diminished by scientific evidence as well as project mismanagement. More water flow exists at Yucca Mountain than was expected. Titanium drip shields are considered necessary to keep water off disposal canisters which remain toxic for hundreds of thousands of years. The Environmental Protection Agency has increased the

acceptable radiation dose for exposure to repository waste by twenty times the current limit - for those who may live more than 10,000 years from now.

Despite these fixes, technical obstacles and legal challenges by the State of Nevada have created significant roadblocks for the repository program. 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 current reality is very clear. The DOE will not be able to either physically accept custody of spent fuel or begin to emplace spent fuel in a repository until the year 2020, at the earliest, if at all. The pressures being felt by nuclear utilities from deregulation are further amplified by having to pay additional costs for interim storage. Under these circumstances, the storage options for utilities are limited to building additional on-site capacity at the commercial reactors. A legislative alternative to ensuring adequate on-site storage is now moving through the Congress. This initiative, known as the Global Nuclear Energy Partnership (GNEP) can only compromise the scientific integrity of the repository characterization program at Yucca Mountain and make temporary storage facilities a *de facto* repository.

DOE is now 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.

Assuming near perfection in recoverability, the magnitude of radioactive wastes generated at a large-scale civilian spent fuel reprocessing plant in the United States would exceed those generated at DOE sites from decades of nuclear weapons production. Management of wastes from a civilian spent fuel reprocessing plant would add tens of billions of dollars to DOE's existing liability of $110 billion for past reprocessing activities.

Devising a permanent solution to the problem will require rethinking the basic components of the nuclear waste management system. The present requirements for extended interim storage must be balanced with the eventual need for permanent disposal. Policymakers will need to consider safeguards for interim storage of these materials, costs for storage, and equitable cost allocation. Immediate safety and security threats must be balanced with the long-term risks of nuclear waste. Evaluation of the SNF and HLW management programs, which are quite distinct, should be weighed against uniform national objectives for safety, human health, and environmental protection.

II. Commercial Spent Nuclear Fuel

Commercial spent nuclear fuel (SNF) in the United States is a byproduct of nuclear electricity generation. Currently, about 60,000 metric tons of this material is stored at reactor sites around the nation.[2] As 104 nuclear power plants continue to generate electricity, another 2,000 to 2,500 tons of SNF are added to the inventory each year.[3] By 2009, the inventory of SNF will exceed the capacity allocated for disposal in the first geologic repository.[4] Congress set a combined limit for disposal of SNF and HLW in the Yucca Mountain repository at 70,000 metric tons heavy metal[5].

The graph below, produced in 1994, shows the total inventory of SNF projected to be in storage based on hypothetical repository start dates.[6] The most recent repository start date projected by the Department of Energy is now 2020.[7]

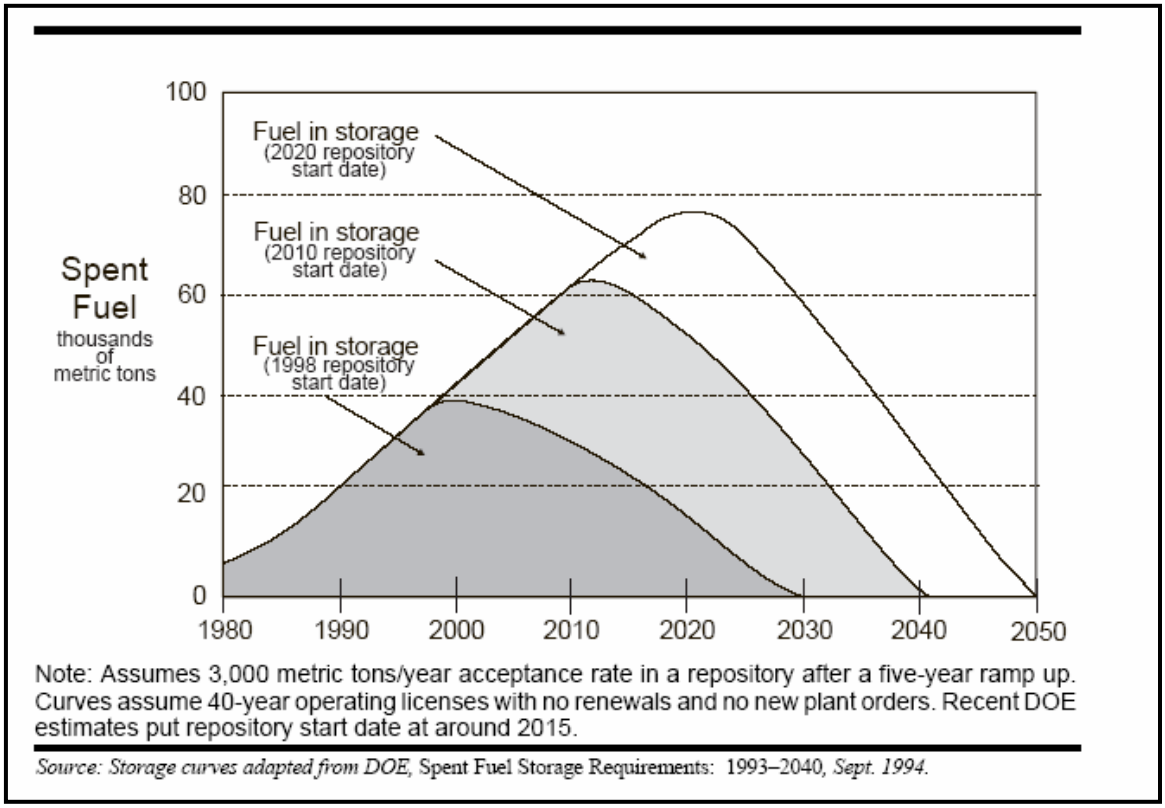


Figure 1.

Below is a graph developed ten years later by the Department of Energy, showing projected SNF discharges to 2055. While this graph does not show the drawdown in SNF inventory based on repository operations, it does indicate total discharges of 129,000 MTHM by 2055, more than double the current repository limit.

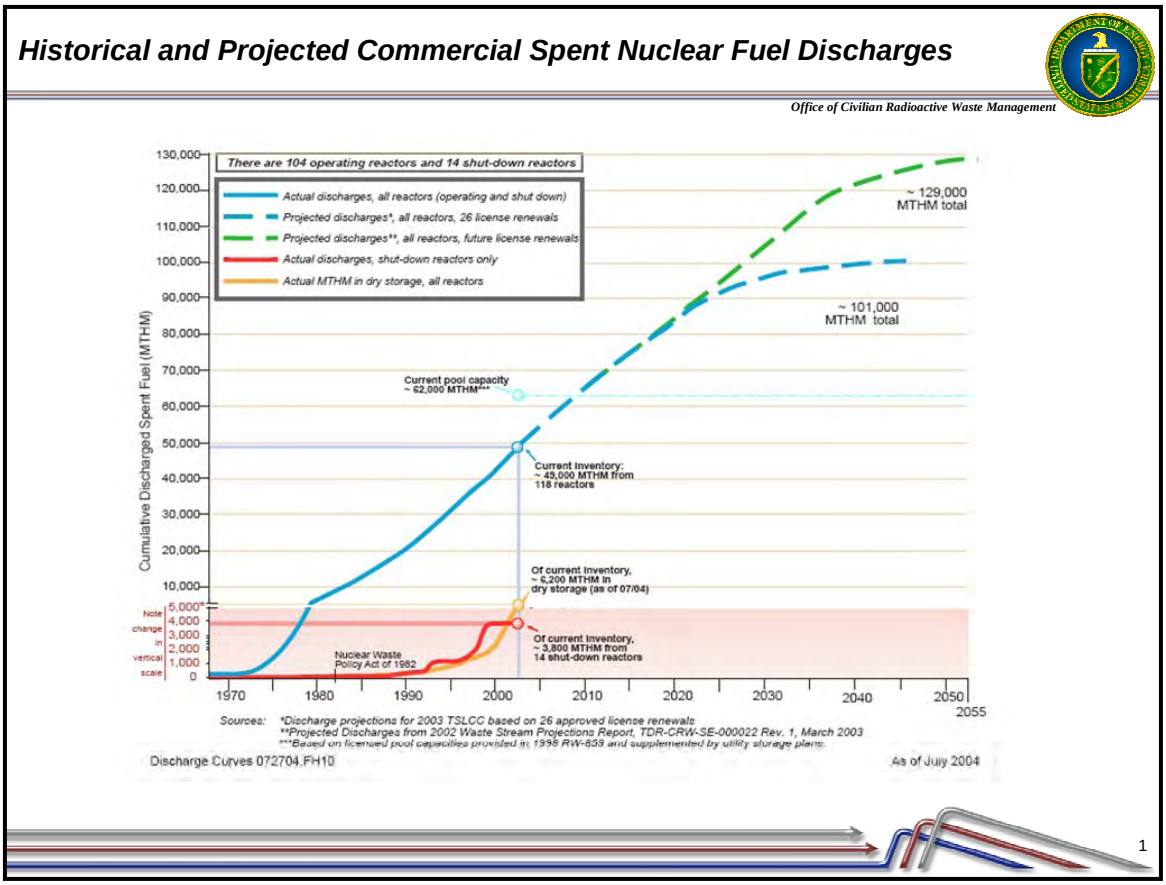


Figure 2.

In addition to spent fuel from commercial reactors, about 2,500 metric tons of Department of Energy SNF left over from the nation's nuclear weapons program is also stored and awaiting disposal.[8] The amount of DOE SNF will not increase in the years ahead, however, since the United States has ended production of plutonium for nuclear weapons. At present, DOE SNF accounts for about 4 percent of total SNF, and will decline as a percentage of the total SNF inventory in the years ahead.

The map below shows locations around the country with SNF storage sites.[9] The stars show commercial SNF storage sites, while the large dots show DOE SNF locations.

Figure A-1. Locations of commercial and DOE sites and Yucca Mountain.

Figure 3.

The following map is another view of SNF storage sites, with blue lines representing quantities of SNF in reactor spent fuel pools, red lines showing amounts in dry storage, and yellow representing DOE SNF.[10]

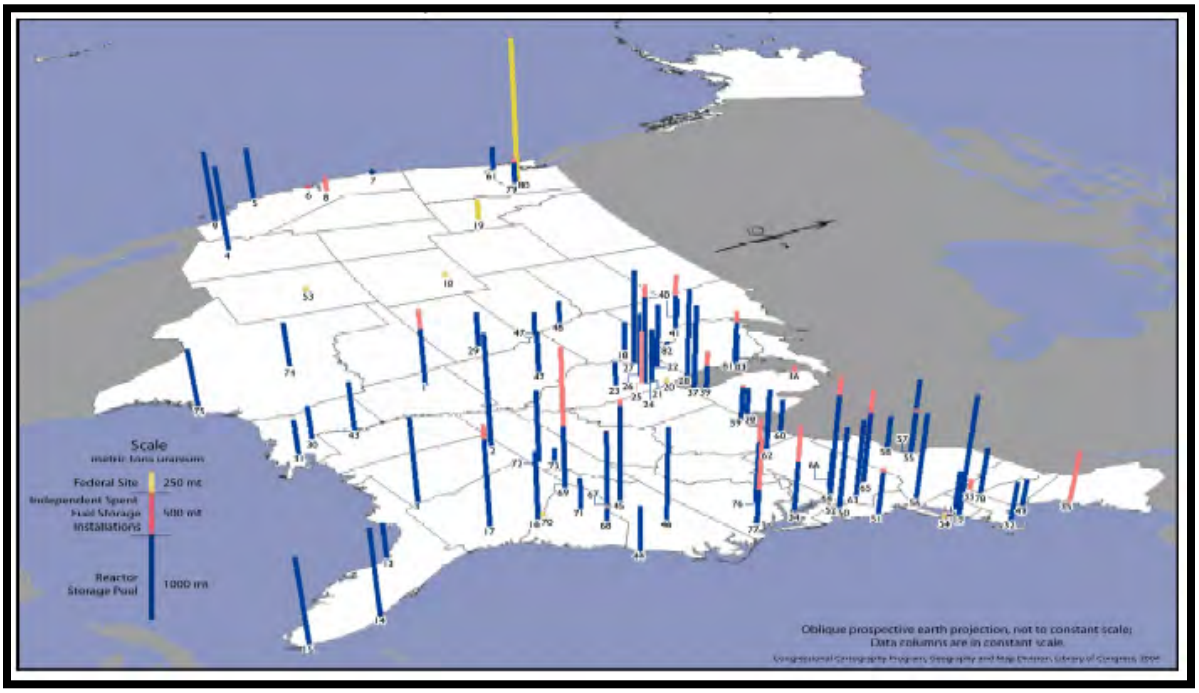


Figure 4.

SNF originates in nuclear reactors. Nuclear reactor fuel consists of uranium pellets in a ceramic form packed into metal tubes, which are bundled into packages called fuel assemblies. See figure below.[11] The assemblies are about 15 feet long, and weigh between 320 and 660 kg, and can be handled by workers without shielding until they are irradiated in the reactor core.[12]

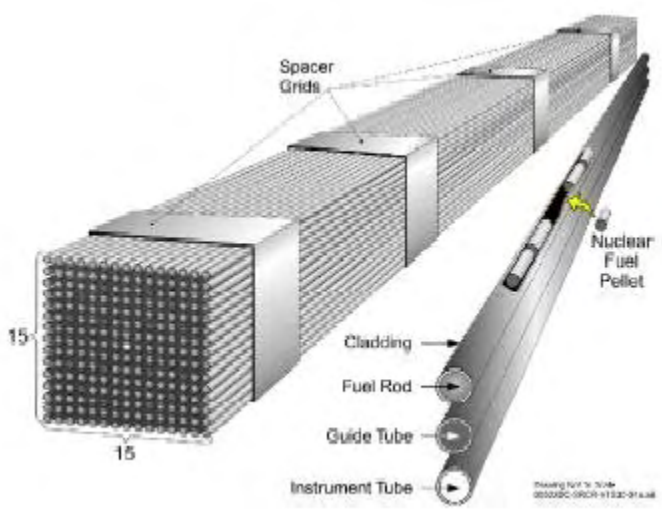
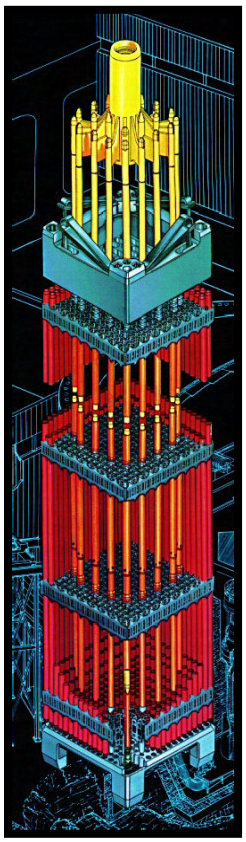


Figure 5.

In a reactor, the fuel produces heat from atomic fission (splitting of uranium atoms) to generate electricity, and in doing so becomes intensely radioactive. As the uranium disintegrates into other elements and becomes depleted, fission byproducts accumulate and interfere with the nuclear reaction. As the nuclear reaction becomes increasingly inefficient, it eventually reaches a point where the fuel is considered 'spent.' Every 18 to 24 months, about one third of the fuel in the reactor is replaced with new uranium fuel assemblies.

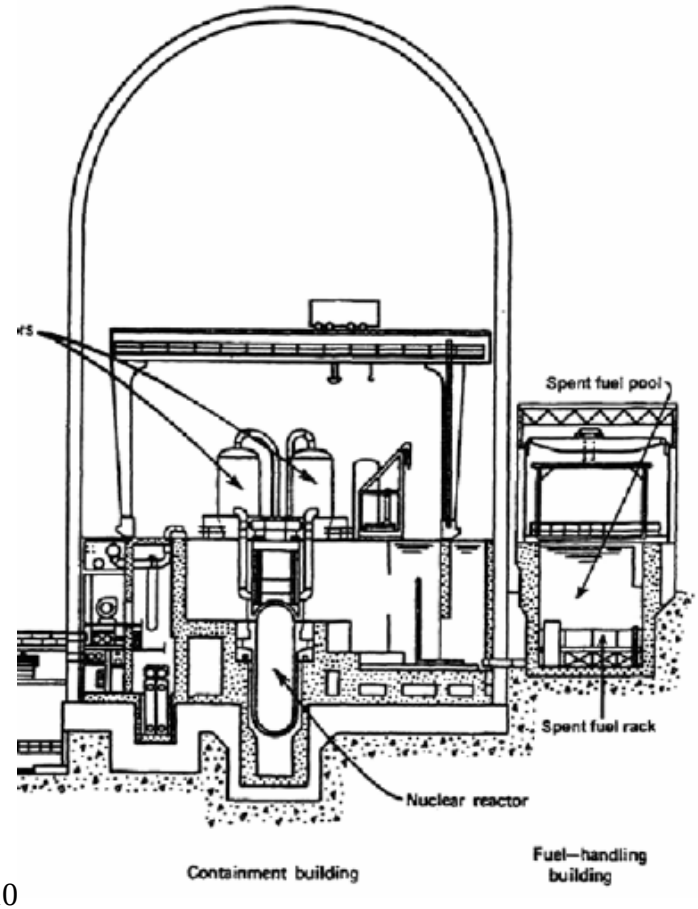


The diagram at the right shows a fuel assembly with the uranium fuel rods (red) packed into a rectangular array and held together with spacers (blue). The control rods (yellow) are lowered or raised in the assembly to adjust the neutron flux in the core, which regulates the power output of the reactor. (Courtesy Westinghouse)

Spent fuel removed from the reactor must be stored in a safe location. When spent fuel is removed from the core, it is transferred underwater through a channel to a steel lined concrete basin. The SNF is placed in racks on the bottom of the basin, immersed in about 40 feet of water which cools the uranium rods and shields workers from radiation.

At this point, the SNF is thermally hot and highly radioactive – standing next to the unshielded SNF would be fatal in a matter of minutes[13]. In addition, the decay heat in the basin can produce about 4 megawatts of thermal energy shortly after transfer of a load of SNF into pool storage.[14]

At left is a schematic of a pressurized water reactor showing the spent fuel pool to the right of the reactor containment structure.[15]



SNF is some of the most toxic waste ever created. Some radionuclides (radioactive atoms) in SNF emit high energy radiation which can damage or kill cells of living organisms at a distance. Others are toxic only if ingested by eating, drinking, or breathing. Some radionuclides decay to harmless levels within days or weeks, while others remain hazardous for hundreds of

thousands of years. This combination of SNF characteristics, posing both acute and persistent hazards, has created difficult considerations for policymakers.

Below is a table which shows the surface dose rate of SNF discharged from a reactor – approximately 500 Rem is considered to be a fatal dose of radiation, while much smaller levels can cause permanent health effects.

Table 2.1.2 Radiological Characteristics of Commercial Spent Nuclear Fuel

SNF Age (Years Cooled)	Total Activity (Curies)	Surface Dose Rate (Rem/Hour)
1	2,500,000	234,000
5	600,000	46,800
10	400,000	23,400
50	100,000	8,640

Source: U.S. DOE, DOE/NE-0007, 1980.

Table 1.

The following is a brief explanation of the potential radiation effects of SNF:

> "Even after ten years of cooling, spent nuclear fuel emits dangerous levels of gamma and neutron radiation. A person standing one yard away from an unshielded spent fuel assembly could receive a lethal dose of radiation (about 500 rems) in less than three minutes. A 30 - second exposure (about 85 rems) at the same distance could significantly increase the risk of cancer and/or genetic damage."[16]

Search for a Permanent Solution

Scientists and policymakers have been grappling with high level nuclear waste disposal for decades. When Congress passed the Nuclear Waste Policy Act (NWPA) of 1982, it found that:

> ". . . radioactive waste creates potential risks and requires safe and environmentally acceptable methods of disposal - a national problem has been created by the accumulation of spent nuclear fuel from nuclear reactors and radioactive waste from reprocessing of spent nuclear fuel . . . Federal efforts during the past 30 years to devise a permanent solution to the problems of civilian radioactive waste disposal have not been adequate . . ."[17]

A quarter century later, the problems of civilian radioactive waste disposal remain. No permanent solution has been found, and almost all SNF is still stored at commercial reactor sites. In fact, most SNF will remain at reactor sites for decades, barring some

unexpected event which mandates immediate disposal. Even with optimistic projections for initiating operations at a geologic repository, most SNF will remain in storage for many years as a result of the transportation and staging logistics for repository operations.

Congress set a deadline for the Department of Energy to accept ownership of SNF from nuclear utilities in the Nuclear Waste Policy Act:

> (A) following commencement of operation of a repository, the Secretary shall take title to the high-level radioactive waste or spent nuclear fuel involved as expeditiously as practicable upon the request of the generator or owner of such waste or spent fuel; and
>
> (B) in return for the payment of fees established by this section, the Secretary, beginning not later than January 31, 1998, will dispose of the high-level radioactive waste or spent nuclear fuel involved as provided in this subtitle.

As stated earlier, despite the most optimistic projections by the Federal government to begin accepting SNF by 2017, the director of the DOE program in charge of disposal has said that 2020 is a more realistic date. Even if the 2020 date were somehow met, it would take at least an additional thirty years to transfer the SNF inventory to Yucca Mountain. In its most recent report which ranks the priority of acceptance of SNF (based on the oldest SNF having the highest acceptance priority) the Department of Energy shows the rate at which SNF will be transferred from storage to a repository[18]:

Table 1. Projected Nominal Waste Acceptance Rates for Spent Nuclear Fuel

Year	SNF (MTU)
2010	400
2011	600
2012	1,200
2013	2,000
2014	3,000
2015	3,000
2016	3,000
2017	3,000
2018	3,000
2019	3,000

Table 2.

In this table, the units for SNF are MTU, or metric tons of uranium, which is roughly equivalent to MTHM. It can be seen from these figures that a repository opened in 2020 would not be able to transfer the existing backlog of SNF (by that time about 80,000 metric tons, at 3,000 MTHM per year) until about 2057. By then, an additional 50,000 metric tons of SNF might have been discharged from existing reactors, assuming that license renewals extend the operations of existing reactors. Therefore, without any new

reactors coming on line in the United States, storage of SNF at interim facilities may extend until 2075 or so, assuming a repository opens (perhaps optimistically) by 2020.

As a result of the delay by DOE in accepting SNF for disposal, a coalition of nuclear utilities have sued the government, claiming that $56 billion is owed them for their costs in managing SNF from their reactors. The utilities claim they should be reimbursed for payments made to the government, as well as costs for their storage of SNF until 2030.[19]

No Disposal Site

The Yucca Mountain Project repository, proposed as the "permanent solution" to the nuclear waste problem, has been met with determined resistance by the State of Nevada since the site was designated by Congress in 1987. Congress overrode a veto of the site by the Governor of Nevada on July 9, 2002. The State of Nevada has continued to challenge the site in the courts. Notwithstanding any legal challenges, with Harry Reid of Nevada now U.S. Senate Majority Leader, the Yucca Mountain Project has been effectively placed on life support.

Permanent disposal of nuclear waste will require a geologic repository. Until such time as a national repository begins waste disposal operations, interim storage of SNF is the only viable option for management of this material. The planning in 1982 did not foresee extended storage of SNF at or near reactor sites. At that time it was envisioned that Federal government repository development would allow acceptance of title to SNF packages only seventeen years hence – that time has now been extended to at least 38 years.

The SNF storage problem, however, may be less problematic than was once thought. Commercial nuclear reactors have been operating without a repository since the first commercial reactor at Shippingport began selling electricity in 1958.[20] The 104 reactors still in operation supply about 20% of U.S. electricity. Failure by the government to take ownership of SNF of behalf of the public has, to date, not created any major obstacles for operation of nuclear reactors.

When the Nuclear Waste Policy Act was amended in 1987 to single out one permanent disposal site, all SNF was to be permanently shipped to Yucca Mountain in Nevada. Yucca Mountain was not selected based upon its technical merits to permanently isolate waste, but rather on the calculation of Senator Bennett Johnston, the prime author of the 1987 amendments to the NWPA. Senator Johnston, an advocate for the nuclear power industry, determined that the State of Nevada was the logical place to dispose of the country's SNF and HLW, and would not have the political influence to stop it.

In the meantime, twenty years of research has revealed that Yucca Mountain has significant technical deficiencies with respect to isolating nuclear waste. Once thought to be an ideal site because of the arid environment, the volcanic tuff of Yucca Mountain has been found to be damp enough that titanium 'drip shields' are considered necessary to keep moisture off the disposal canisters. Hinting at the potential failure of Yucca

Mountain to meet common radiation exposure limits the Bush Administration has proposed raising the radiation dose limit for exposure to Yucca Mountain nuclear waste to 350 millirem per year, following the first 10,000 years of repository operation.[21] This contrasts with the general standards for exposure to nuclear emissions, which are generally 15 mrem per year for the Environmental Protection Agency and 25 mrem per year for the Nuclear Regulatory Commission.

Regardless of when, or if, Yucca Mountain opens as the nation's repository, SNF storage has become the interim solution to a problem for which the government has no permanent solution for at least a decade, and possibly for many decades. Though storage may be the nation's near-term answer to the problem, much work remains to ensure that a serious accident with SNF does not occur. To appreciate the hazards posed by SNF, it is helpful to look at the steps by which the material moves from the reactor core to longer term interim management.

SNF from Reactor to Storage

The first phase of SNF management involves transfer of the irradiated assemblies from the reactor core to steel lined concrete basins filled with water, located in the reactor building or adjacent to it. The spent fuel pools have two primary functions: they shield workers from the intense ionizing radiation produced by the waste, and they keep the SNF from melting as a result of the heat generated by radioactive decay. The photo below shows how SNF assemblies are stored underwater.[22]

Source: Nuclear Energy Institute.

As the SNF cools over several years, there is no longer a requirement that it remain in the spent fuel pool. However, the nuclear industry has adopted a practice known as "dense compaction" as the least cost method of storing the SNF at reactor facilities. Such compaction of SNF creates an elevated risk of a radiological release in the event that the spent fuel basin were somehow breached and a loss of water occurred.

The following graph illustrates the number of spent fuel pools projected to reach their capacity for storage of SNF[23]. As can be seen, in several years, the spent fuel basins at all commercial reactors in the United States will have reached their capacity.

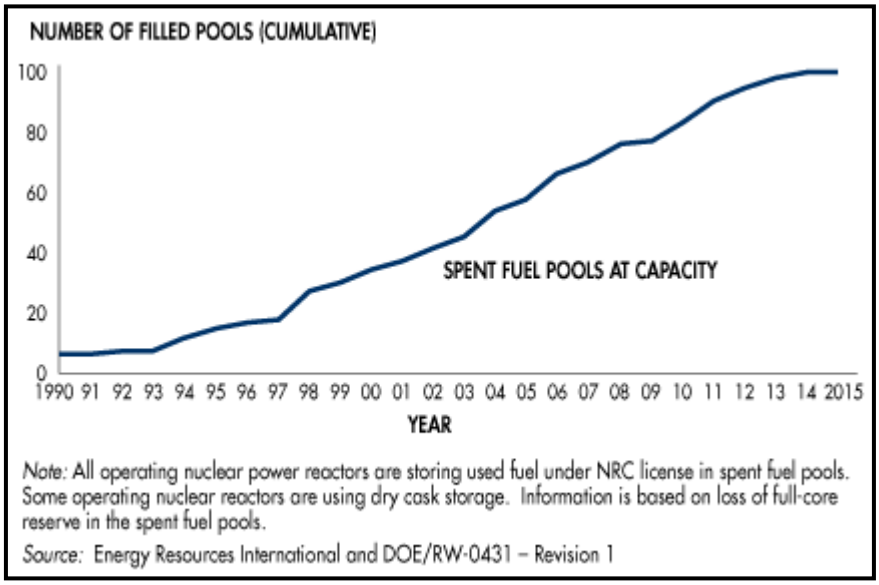


Figure 6.

As spent fuel pools have begun to fill at reactor sites around the country, SNF has begun to be transferred into large steel and concrete containers, called dry storage casks. After the SNF assemblies are removed from the spent fuel basins and loaded into the dry casks, they are moved to an area near the reactor site. This second phase of SNF storage is inherently safer than keeping the waste in water filled pools, because it does not rely on active management and because the waste is stored in a less dense configuration.

The final phase of SNF management involves disposal of the SNF about one half mile below the surface in a geologic repository where it must be isolated from the accessible environment for more than ten thousand years. Although there has been discussion of transferring SNF from dry storage to consolidated storage at regional centers around the country, there are no plans to do so at the present. There are political obstacles to such consolidation, and the technical and financial incentives to do so are limited.[24] (07 APS)

For decades to come SNF will be stored in spent fuel pools, followed by dry storage in containers at reactor sites.

Immediate Hazards

For years, safety concerns for SNF centered primarily on events (human error, earthquakes, tornadoes, etc.) which might accidentally release radioactive debris from SNF basins into the environment. SNF transferred from the reactor core is placed in a deep water filled pool, to shield workers and to prevent the SNF from melting. The primary concern during this phase is any event which could cause the water in the pool to drain away, resulting in a fire which could disperse radioactive waste into the atmosphere, not unlike a Chernobyl event.

Recently, attention has shifted to potential security risks from a terrorist attack on a site storing SNF. Such an explosive or a missile attack could disperse radioactive material into the surrounding area resulting in physical damage to the fuel rods. The greatest consequence of such an action would remain the potential for a fire resulting from a breach in the SNF pool.

Vulnerabilities inherent with SNF storage have been reexamined in light of the 2001 terrorist attacks, which has led to reviews regarding security requirements. The potential risks from an accident or attack on a spent nuclear fuel pool have been analyzed and the need for safety and security measures considered.[25] Upgrading security at SNF storage sites has been resisted by the nuclear industry based on increased costs. The cost of more secure SNF storage, however, is likely to far outweigh the cost of an accident or successful terrorist attack at one of these facilities.

Long Term Hazards

Unlike common debris, extraordinary precautions must be taken when disposing of SNF. Within the spent uranium rods exist a wide assortment of radionuclides, each with its own unique chemical and radioactive characteristics. The hazard of SNF evolves over time, as radionuclides decay into new elements, each with their own lesser or greater hazards.

In the early life of the spent fuel, almost all of the radioactive emissions come from two elements: Strontium 90 and Cesium 137. This arises from how uranium splits into fragments in the nuclear reactor, and from the relatively short half-life of these two isotopes. When thinking about permanent disposal of SNF, radionuclides which decay to relatively small quantities within 100 years are not considered very challenging – it is those constituents which may be radioactive for hundreds of thousands of years, or longer, which are of the greatest concern.

Strontium and cesium each have a half life of around 30 years, so one half of the element will have decayed into other elements in that interval. After ten half lives, only about one-tenth of one percent of the original strontium and cesium will remain. Though 300 years is longer than the United States has been in existence, it is a short interval on the time scale of concern for SNF disposal.

Under the Nuclear Waste Policy Act, all SNF must be disposed of in a geologic repository. The fundamental principle behind this law is that SNF hazards persist so long that only isolation by deep geologic strata can ensure the safety of future generations – in other words, there cannot be confidence that societal institutions with the capability or will to manage such waste will exist that far into the future.

Costs – Now and Later

The costs associated with interim storage of SNF are cited as a primary factor in the need for a repository. In fact, such costs are a relatively small fraction of the lifecycle costs of producing nuclear electricity. The basic formula for allocating the costs of SNF management and disposal were set out by Congress, as described in this Department of Energy summary:

> The Nuclear Waste Policy Act of 1982 (NWPA) provides for two types of fees to be paid by utilities for management and disposal of commercial spent nuclear fuel: an ongoing fee of 1 mil (one tenth of a cent) per kilowatt-hour (kWh) of electricity generated and sold on or after April 7, 1983, and a one-time fee for electricity generated and sold prior to April 7, 1983. The NWPA directed that the utility fees be paid into the Nuclear Waste Fund, a separate account established in the U.S. Treasury. Nuclear Waste Fund balances through September, 2001 totaled over $10 billion[26].

Congress, to fund the disposal of SNF, requires that nuclear utilities charge their customers 0.1 cents per kilowatt hour, paid into the government's Nuclear Waste Fund (NWF). For customers paying ten cents per kilowatt hour for nuclear generated electricity, the contribution to fund management and disposal of SNF is one percent of their electricity bill. The Department of Energy describes the NWF program as follows:

> The fee provides for intergenerational equity; i.e., it ensures that the beneficiaries of nuclear power pay for the costs of disposal of the wastes. These fees are deposited in the NWF. The NWF is to be used for development and implementation of a radioactive waste management system in accordance with the NWPA, including a potential permanent geologic repository. Any fees received in excess of annual funding requirements are invested in U.S. Treasury obligations at prevailing rates. Management of the NWF (also referred to as "the Fund") is an important element of the program, considering that the Fund must cover the cost of activities that extend far beyond the operating life of current nuclear power plants[27].

Policymakers had not contemplated SNF storage at reactor sites for decades when thinking about permanent disposal of nuclear waste. The Department of Energy had commitments to nuclear utilities to accept SNF by January, 1998 as part of the overall management and disposal system. Since that time, a number of nuclear utilities have sued, claiming that extra costs associated with long term on site storage (estimated at about a half billion dollars per year) are owed them by the government.

> "DOE has estimated that every year of delay in opening the Yucca Mountain repository will cost the Federal government an additional $1 billion per year, with a conservative estimate of $500 million in legal liability for failure to take title to commercial spent fuel, and another $500 million to monitor and guard defense spent fuel and high level radioactive waste at DOE sites," *Report on the Energy and Water Development Appropriations Bill, 2006,* U.S. House of Representatives Appropriations Committee, Report 109-86, May 18, 2005, p. 125.[28]

Nuclear utilities have requested the courts to award them $56 billion in damages for potential costs of storing SNF until the government accepts receipt of the material.[29]

As events would have it, permanent disposal of SNF is more technically and politically difficult than was once thought. There are good arguments for establishing a permanent disposal path for SNF – such a solution must be found at some point. If SNF is secured in a repository, the potential for accidents from natural disasters or terrorist attacks is lessened. However, such risks must be balanced against the risks to human health and the environment from permanent disposal, and the irreversible consequences thereof.

SNF, securely stored, poses a fairly low risk to the public and the environment. Once SNF has decayed for thirty years, it contains about half the radioactivity which could be released into the environment in a transportation accident. Regardless of arguments for disposal sooner or later, no permanent disposal site for SNF exists at the present, and interim storage is the only near term answer to management of the material.

As summarized in a Congressional Research Report to Congress:

> "Current law provides arguments for both sides of the debate over spent fuel storage. On one hand, the Nuclear Waste Policy Act establishes a statutory timetable for DOE to begin taking spent fuel from nuclear power plants, to minimize long-term storage at reactor sites. But because the law forbids DOE from taking spent fuel until a permanent repository is approved for construction, long-term storage at reactor sites appears to be the current policy by default. Congress now is being asked to determine which of those conflicting principles should take precedence, or whether other steps should be taken to mitigate the problems created by delays in the federal nuclear waste program."[30]

The Interim Solution for SNF – Dry Storage

In his statement to Congress in 2001, then Chairman of the Nuclear Regulatory Commission Richard Meserve stated:

> ”In the past several years, the Commission has responded to numerous requests to approve spent fuel cask designs and independent spent fuel storage installations for onsite dry storage of spent fuel. These actions have provided an interim approach pending implementation of a program for the long-term disposition of spent fuel. The ability of the Commission to review and approve these requests has provided the needed additional onsite storage of spent nuclear fuel, thereby avoiding plant shutdowns as spent fuel pools reach their capacity. The Commission anticipates that the current lack of a final disposal site will result in a large increase in on-site dry storage capacity during this decade.”[31]

The Nuclear Regulatory Commission has reviewed the adequacy of dry storage of SNF long before enactment of the Nuclear Waste Policy Act, and has found dry storage to be an acceptable interim solution to SNF management. The following is a summary of the NRC’s 1990 review of dry storage, under a system known as a Waste Confidence Determination, or WCD:

> “In the Commission’s 1990 re-evaluation of its WCD, the Commission modified Finding 4 to state that spent fuel generated in any reactor can be stored safely and without significant environmental impacts for at least 30 years beyond the licensed life for operation, including the term of revised or renewed licenses. On dry storage, the Commission found that (1) the material degradation processes of spent fuel in dry storage are well understood; (2) dry storage systems are simple, passive, and easily maintained; (3) both the NRC and dry storage operators have gained experience with dry storage that confirms the Commission’s 1984 conclusions; and (4) the Commission maintains regulatory authority over any spent fuel installation (55 FR 38474, 38509; September 18, 1990) . . . The environmental assessment found that almost 40 years of experience attests to the safety of passive dry storage technologies, beginning with the extended vault and drywell tests conducted by INEL in 1964 on liquid metal fast breeder reactor fuel, and12 years of research into passive dry storage technology in the United States and abroad.”[32]

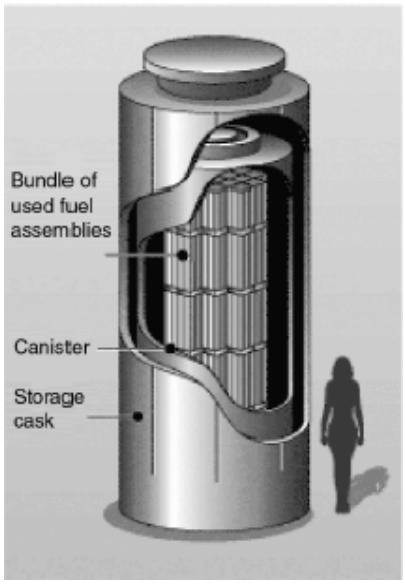
The map below shows sites of reactors with spent fuel basins, as well as sites with dry storage.[33]

Figure 1: Locations for Wet and Dry Storage Sites for Commercial Spent Nuclear Fuel and Yucca Mountain, as of April 2003

Sources: DOE and NRC (data); GAO (presentation).

Figure 7.

The schematic below shows how a number of SNF assemblies can be packaged in a canister, which is then placed in the storage cask.[34] Such casks can be stored on a concrete pad, as shown in the accompanying photo.



Another mode of dry cask storage involves horizontal placement in concrete vaults, as shown in the photos below. This mode of storage offers greater security measures, since the SNF is stored below grade and is further protected by the reinforced concrete vaults.[35]

Another option which has been considered for SNF dry storage is consolidation of the material at regional centers. In its review of the benefits of consolidating SNF at one or more regional sites around the country, the American Physical Society Nuclear Energy Study Group found the following:

- There are no substantive safety or security reasons for establishing consolidated interim storage.
- There are no compelling cost savings to the Federal government associated with consolidated interim storage, so long as Yucca Mountain is not delayed well beyond its currently planned opening.
- There is sufficient space at all operating nuclear reactors to store all spent nuclear fuel in pools and in existing or additional dry casks that will be discharged even with plant license extensions. Although, some states may limit the amount of dry storage at a reactor site.[36]

The additional costs of SNF interim storage at reactor sites may be considered another cost of doing business for the utilities, and a fairly insignificant one at that. At an annual nationwide cost of one half billion dollars per year, the cost to ratepayers would be less than one percent of the cost of nuclear generated electricity. When a nuclear power plant stops generating electricity and its ratepayers stop paying into the disposal fund, there is still a need to manage the SNF. The costs of such management must be borne by the utility and its ratepayers, or by taxation on the general public.

The real policy concern for the nuclear industry is not SNF storage costs, but the perception that the SNF waste problem is unsolvable, and that the risks of storage (or perceived risks) are unacceptably high It will be very difficult for the nuclear power

industry to gain financing and regulatory approval for new reactors without a permanent solution to the SNF disposal problem.

III. Defense High Level Wastes

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.[37] (See Figure 1)

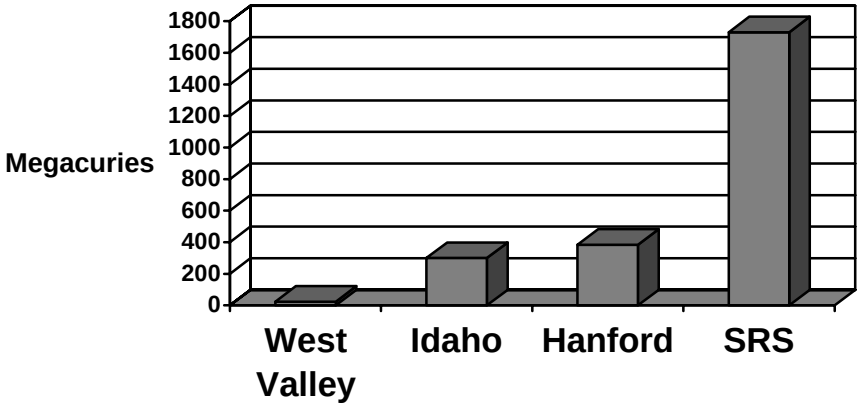
About 100 million gallons of high-level radioactive wastes from reprocessing were generated and are stored in large underground tanks at the Hanford site in Washington, the Idaho National Engineering Laboratory and the Savannah River Site in South Carolina. Many tanks have leaked and threaten water supplies. 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 Academy of Sciences (NAS), the fate of these deadly materials could impact the human environment of major regions of the United States for tens of thousands of years. According to the NAS 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." [38]

DOE has about 3,000 metric tons of spent reactor fuel.(see Table 1) The DOE reprocessed most of its spent nuclear fuel in the facilities at INEEL, the Hanford Site, and the Savannah River Site. However, some spent nuclear fuel remains because of U.S. Government decisions to stop

Figure 1

Radioactivity in DOE High-Level Wastes



Source DOE 2001.

reprocessing. Most of this fuel came from the Hanford Site N-Reactor, a dual-purpose reactor designed to produce plutonium for use in nuclear weapons and to generate electricity for commercial use. 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 INEEL and, for 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.

- Between 1944 and 1989, the Hanford site operated nine reactors primarily for the production of approximately 67 metric tons of plutonium. Currently Hanford is storing 2,096 metric tons of spent N-reactor fuel. The N-reactor fuel has been conditioned and repackaged for dry storage. Sources of the other spent nuclear fuel at the site total about 5 tons included single-pass Hanford production reactors, the Fast Flux Test Facility, Shippingport Core H, and miscellaneous test facilities.

- The Idaho National Engineering Laboratory INEEL stores about 300 metric tons of Spent fuel in several areas three areas, including:: Argonne National Laboratory-West; Idaho Nuclear Technology and Engineering Center; Naval Reactors Facility; Power Burst Facility; Test Area North; and the Test Reactor Area. Spent nuclear fuel is kept in a variety of dry and wet configurations.

- The Savannah River Site in South Carolina stores 200 metric tons of spent or about 8 percent of DOE's total inventory. This fuel is stored in the Receiving Basin for Off-site Fuels (RBOF), in three reactor disassembly basins, and in basins in the F- and H-Area Canyons. About 50 percent of the fuels in the SRS basins consist of uranium clad in stainless steel or zircaloy.

Table 1 DOE Spent Nuclear Fuel

Generator or Storage Site	Existing (1995)		Future Increases (through 2035)		Total (2035)	
	MTHM[a]	Percent	MTHM	Percent	MTHM	Percent
DOE Sites						
Hanford Site	2132.44	80.6	0.00	0.0	2132.44	77.8
Idaho National Engineering and Environmental Laboratory	261.23	9.9	12.92	13.5	274.14	10.0
Savannah River Site	206.27	7.8	0.00	0.0	206.27	7.5
Oak Ridge Reservation	0.65	<0.1	1.13	1.2	1.78	<0.1
Other DOE Sites	0.78	<0.1	1.50	1.6	2.28	<0.1
Naval Nuclear Propulsion Reactors	0.00[b]	0.0	55.00	57.6	55.00	2.0
Foreign Research Reactors	0.00	0.0	21.70	22.7	21.70	0.8
Non-DOE Domestic						
Domestic Research and Test Reactors[c]	2.22	<0.1	3.28	3.4	5.50	0.2
Special-Case Commercial SNF at non-DOE locations[d]	42.69	1.6	0	0	42.69	1.6
Total[e]	2646.27		95.53		2741.80	
Percent of 2035 total	96.5		3.5		100.0	

[a] MTHM = metric tons of heavy metal.
[b] The existing inventory of Naval Nuclear Propulsion Program spent nuclear fuel (10.23 MTHM) stored at the INEEL is included in the INEEL total.
[c] Includes research reactors at commercial, university, and government facilities.
[d] The total inventory of spent nuclear fuel from special case commercial reactors is 186.41 MTHM. The 42.69 MTHM listed here is that stored at the Babcock & Wilcox Research Center, Fort St. Vrain Reactor, and West Valley Demonstration Project. The remaining special-case commercial spent nuclear fuel is stored at the INEEL, the Oak Ridge Reservation, and the Savannah River Site, and is included in the totals for those locations.
[e] Numbers may not sum due to rounding.

Source: EPA 2002

The 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. (See Figure 2) The bins are partially buried and are grouped within concrete vaults –designed to last 500 years. As of August 1998, five of the seven bin sets are filled, one is partially full, and one is empty. Calcine HLW is approximately 4,000 cubic meters in volume, and contains about 41 million curies. (See Table 2) 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. Steam-reforming involves injecting superheated steam, along with the

material to be treated and co-reactants into a fluidized bed reactor where water evaporates, organic materials are destroyed, and waste constituents are converted to a granular, leach-resistant solid.

Table 1 Inventory of Radioactive Waste by Type at the Idaho National Laboratory

Type of Waste	Volume (m^3)	Radioactivity (Ci)
Total tank and bin waste[a]	~5,000	35-36 million
Comprising		
Treated Sodium-bearing waste in tanks	~ 500-800	~520,000
Calcine waste in bins	4,400	35 million
Waste leaked into environment from pipes and valves[b]	107	37,000
Service wastewater injected to aquifer[c]	45 million	22,000
Stored transuranic waste[d,e]	65,000	343,000
Buried transuranic-contaminated waste and soil[d,e]	37,000	297,000
Low-level waste (including mixed) stored	2,200	Not available
Low-level radioactive waste in disposal cells[d]	158,000	12 million
TOTAL	>45 million	>49 million

NOTE: Shaded entries are wastes that ultimately are expected to remain on-site. These data are from different sources, are measured or estimated at different times, and did not indicate quantified uncertainties. This table does not include spent nuclear fuel stored on-site (i.e., from naval and test reactors as well as from Fort St. Vrain and Three Mile Island) or contaminated soil at the evaporation ponds, which have been remediated. 1 Ci = 3.7×10^{10} Bq.

[a] Lockie, 2005a. Decay corrected to 2012.
[b] Cahn, 2005. Not decay corrected, therefore an overestimate.
[c] DOE-ID, 2003a. Radioactivity not decay corrected. 99.8% of the radioactivity is tritium.
[d] DOE, 2001b.
[e] As of 1996.

Source NAS 2006

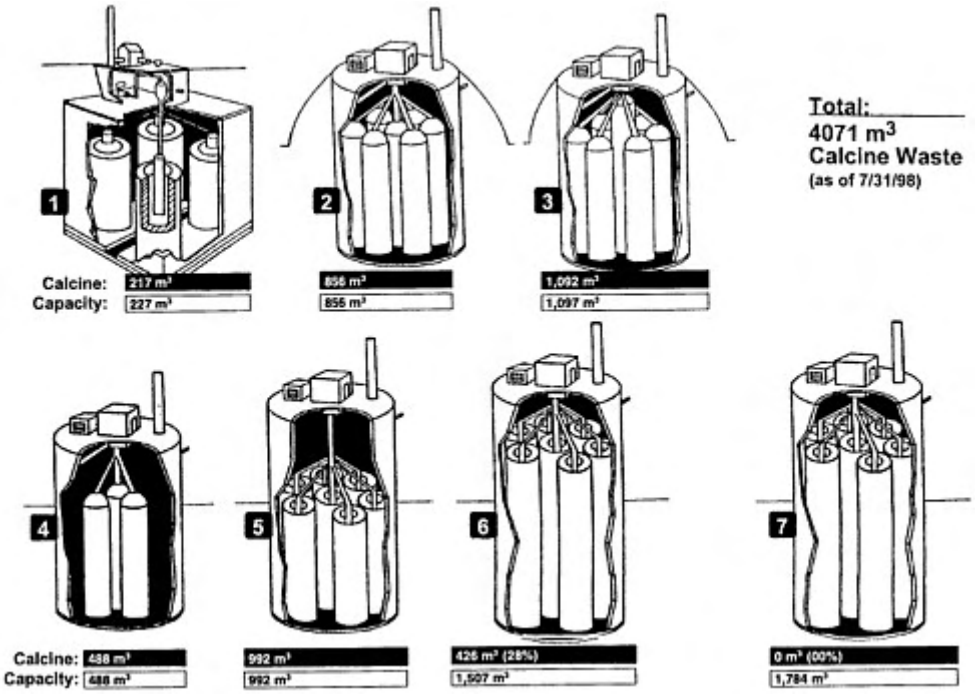


Figure 2 A diagram showing the arrangement of bins inside each of the seven bin sets. SOURCE: DOE 1998.

West Valley

About 2,180 m^3 of high-level waste is stored at the 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.

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. [39] 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, [40] which is about 10 percent of the waste volume.[41] 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.[42] (See Table 2).

Table 2 Inventory of Radioactive Waste at the Savannah River Site

Type of Waste	Volume (m^3)	Radioactivity (Ci)
Total waste in the tanks comprising[a]	138,000	426 million
Sludge`	9,800	203 million
Saltcake	62,000	12 million
Supernate	66,000	211 million
Vitrified high-level waste[b]	1,500	10 million
Stored transuranic waste[c,d]	11,000	490,000
Buried transuranic-contaminated waste and soil[c]	4,500	18,500
Low-level waste stored[c]	15,276	1.3 million[d]
Low-level radioactive waste in disposal cells[c]	698,000	11 million[e]
Saltstone as of 2005	25,000[f]	225[f]
Saltstone (DOE projected)	410,000[a]	3-5 million[a]
E Area vaults	117,000[g]	10 million[g]
Old Burial Ground	Unknown[h]	4.5 million[h]
Tanks at closure (DOE projected)	140[i]	0.72 million[i]
TOTAL	> 867,000	446.6 million

NOTE: Shaded area lists wastes that are expected to remain on-site. The data are from different sources, are measured or estimated at different times, and did not indicate quantified uncertainties. This table does not include spent fuel from research reactors. 1 Ci = 3.7×10^{10} Bq.

Source: NAS 2006

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. [43]The DWPF is made up of several processes including:

- **Pretreatment.** This involves separation of radionuclides from soluble wastes, and chemical washing of insoluble tank sludges, prior to making feed for the melter. According to DOE, pretreatment "represents a significant portion of the HLW management costs and of the technical risk."

- **Feed Preparation and Melters.** Preparing chemically balanced and homogeneous feed is of utmost importance. The inability to have proper feed can cause: (a) short-accidents, melter failure and inadequate glass quality.

- **The Off-Gas System.** In effect, the melter serves to produce glass and as

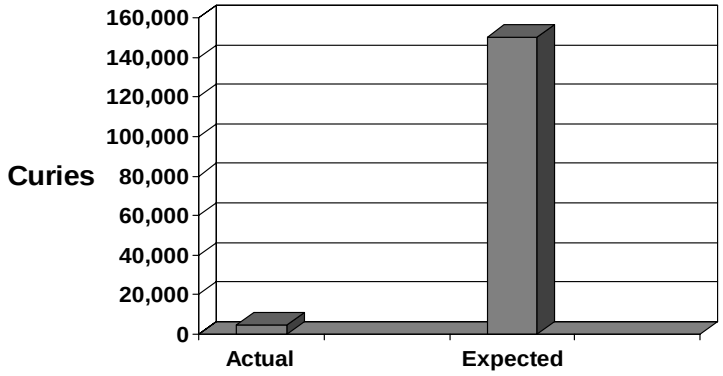
an incinerator which releases large amounts of contaminated carbon dioxide, nitrous oxide, and molten, radioactive, and nonradioactive particulates. The offgas system must capture and processes these materials to prevent hazardous materials from entering the environment.

- **Secondary Wastes.** The DWPF generates a considerable volume and high concentrations of wastes from sludge washing, ion exchange, and other processes. In Failed melters and related equipment are of particular concern because they are likely to contain large, irremovable concentrations of high-level radioactive wastes.

After more than 20 years, DOE has processed less than 3 percent of radioactivity in SRS wastes.[44] This is especially troublesome since vitrified waste canisters at SRS currently contain on the average less than 3 percent of the radioactivity predicted by DOE. (See Figure 3) 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. [45] However, in 2006, the average canister produced at the Savannah River vitrification plant was about 4, 829 curies. [46]

Figure 3

Actual vs. Expected Radiation in SRS HLW Canisters



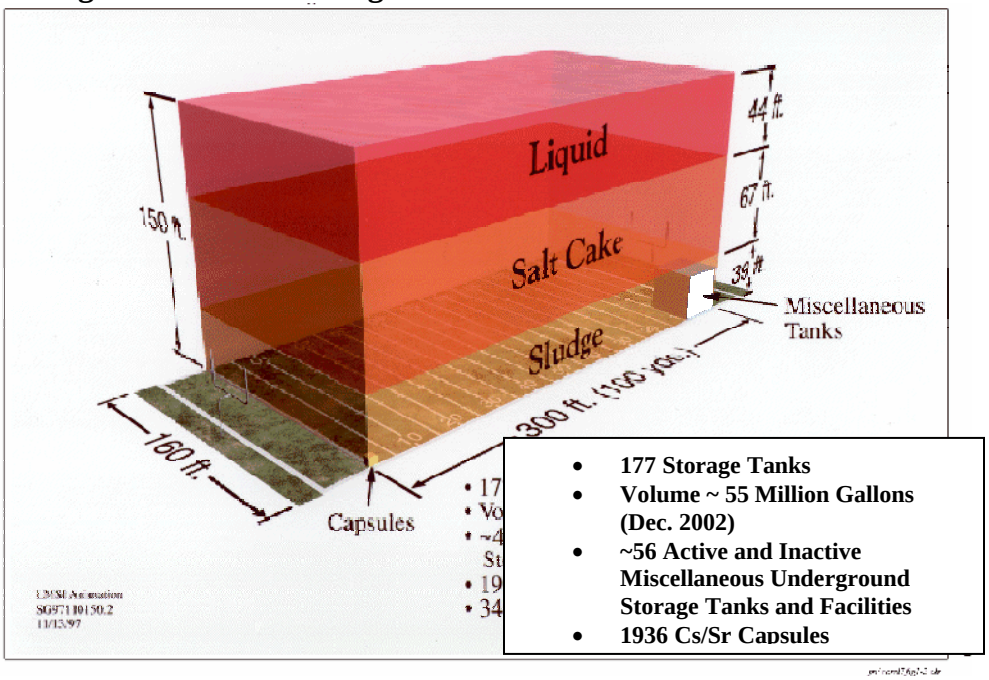
As of January 31, 2006, 2044 canisters containing a total of 10 million curies were produced. Source: NAS 2006

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 produced 67.4 metric tons of plutonium of which 54.5 Metric tons were for use in nuclear weapons.[47] Reactor fuel production facilities, nine reactors, four chemical separations plants, plutonium processing facilities, nuclear laboratories and 177 large-scale underground nuclear waste tanks made up the heart of the complex. It was,

until the mid-1960s, the largest nuclear material production complex of its kind in the world.

Figure 4 Volumes of High-Level Radioactive Waste at Hanford



HLW Storage at Hanford -- The basis for high-level waste management was established in World War II and was designed to meet production deadlines and limit costs associated with building new tanks. Because wastes coming out of the reprocessing plants were acidic, a decision was made to neutralize them by adding sodium hydroxide (lye) and water so they could be stored in cheaper carbon steel tanks, rather than high quality stainless steel tanks. Other nations, notably France, Japan and England store their reprocessed wastes in an acidic form in stainless steel tanks.

Over the years, the imperative to produce plutonium and to avoid waste storage and treatment costs, led to practices which resulted in large amounts of waste discharges to the ground, dangerous chemical and thermal reactions in the tanks, numerous large tank leaks, and accelerated deterioration of tank structural integrity.

Hanford's High-Level Waste Tanks -- There are 149 single shell tanks that range in capacity from 55,000 to 1 million gallons. They were built between 1943 and 1964. The SSTs are clustered in 12 "Tank Farms." No wastes have been added to the SSTs since 1980. Of these, 67 tanks are estimated to have leaked over 1 million gallons; [48] and some SST wastes have contaminated groundwater 150 feet beneath the tanks. The single-shell tanks contain ~ 132,500[49]cubic meters (crystallized salt (saltcake), sludge and liquid. The SST's are estimated to contain about 110 million[50] curies of radioactivity.

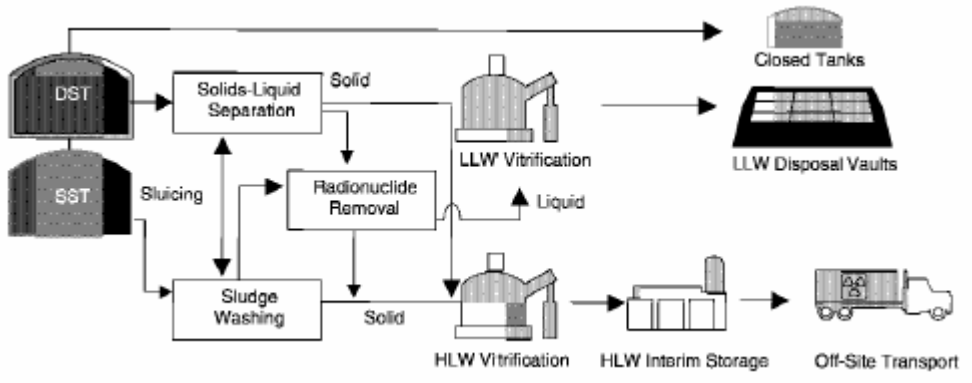
The Hanford Tank Waste Remediation System -- TWRS (1990-2002) In 1996, the DOE issued its Final Environmental Impact Statement for the Tank Waste Remediation

System (DOE/EIS-0189).According to the DOE's Record of Decision the department was to manage and dispose of Hanford's high-level wastes in two phases:

- "…The demonstration phase, which will last approximately 10 years, includes the retrieval and treatment of a portion of the waste from the double-shell and single-shell tanks. The waste will be separated into low-activity waste and high-level waste through physical and chemical processes and then treated in demonstration-scale facilities….
- Phase II … will begin after Phase I and will last approximately 30 years….. The tank waste will be retrieved and separated into low-activity waste and high-level waste. The low-activity waste will be immobilized and disposed of onsite in near-surface disposal facilities. The high-level waste will be vitrified, temporarily stored onsite, and transported offsite for disposal in a national geologic repository."[51] (see Figure 5)

Figure 5 Simplified Flow Sheet for the Tank Waste Remediation System (TWRS)

1996-2002



Source: NAS Research Needs for High Level Wastes Stored in Bins and Tanks at U.S. Department of Energy Sites, 2001.

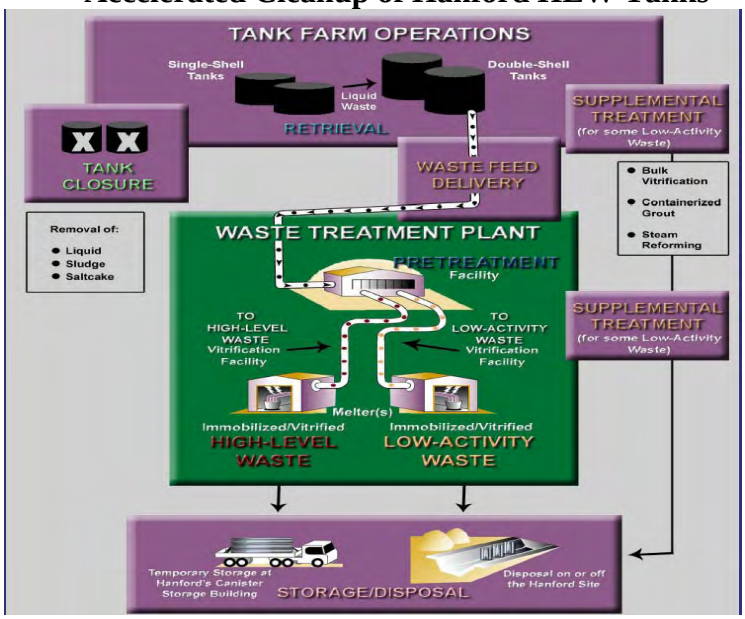
the U.S. Environmental Protection Agency (EPA) and the DOE. Under the TPA Agreement, several milestones were established for the design, construction, operation and processing of

the Hanford tank wastes. [52] Under the Tri-Party Agreement, the TWRS project would complete the pretreatment and immobilization of low activity wastes (LAW) by December 2028 and half of all HLW waste would be treated by around 2050. DOE's goal was to have all wastes treated by 2028, which would have required a four fold increase in processing capacity.

The Performance Management Plan for the Accelerated Cleanup Of the Hanford Site (2002- present)-- On May 1, 2002, the DOE issued the "Performance Management Plan for the Accelerated Cleanup of the Hanford Site. [53] As mentioned , a central element

of the Plan is the processing and disposal of high-level waste and the subsequent closure of all Hanford's high-level radioactive waste tanks by 2034. To carry out this goal, on March 2003, the department issued the Integrated Mission Acceleration Plan [54] for the disposition of Hanford's high-level defense wastes. (see Figure 6)

Figure 6 Simplified Flow Chart for Accelerated Cleanup of Hanford HLW Tanks



Source: Office of River Protection June 2003

technology is undergoing performance assessment and has yet to be demonstrated using actual

DOE has also reduced the capacity to vitrify low-level waste at the Waste Treatment Plant on the assumption that: "Ultimately, supplemental treatment technologies may be required to process 60 to 70 percent of wastes previously scheduled for ILAW vitrification in the WTP." This statement implies that the great preponderance of wastes in Hanford's 149 SSTs, would not undergo removal of radionuclides, as is the case for wastes treated in the WTP and would be disposed onsite – leaving behind significantly greater amounts of radioactivity.

How Much Radioactivity Can DOE leave Behind at Hanford ? -- The DOE's Accelerated Cleanup Plan raised concerns about the direct disposal of a substantially larger amount of radioactivity from Hanford's high-level waste tanks. As mentioned previously, DOE's basic approach to HLW processing and disposal involves:

- separation of long-lived and high-concentration radionuclides from tank wastes for immobilization into glass for geological disposal;

- separation of radionuclides that are short-lived (<300 years) and in concentrations that will not pose long-term human health risks for disposal as "low activity" wastes on site.

In order to implement this approach, the DOE sought the approval of the Nuclear Regulatory Commission (NRC), in 1997. Under the present system, unless the NRC determines that DOE's designation of low activity wastes (LAW)/incidental waste is not HLW, the waste must be disposed of as HLW in a geologic repository.

Since DOE states that it expects to treat 60 to 70 percent of the wastes originally scheduled for low-level waste glassification in the Waste Treatment Plant with supplemental technologies, it is likely that substantially more wastes than from the 62 tanks identified in the IMAP could be directly disposed onsite. However, for illustrative purposes, this report's analysis assumes that wastes in the remaining 115 tanks will be processed for further separation of radionuclides in the Waste Treatment Plant. (See Table3).

Table 3 Comparison of Onsite Disposal of Radionuclides in Low Activity Wastes At Hanford(Curies)

Radionuclide	DOE Estimate Approved by NRC in 1997 (a)	62 IMAP Tanks Scheduled for Closure and Supplemental Waste Treatment (b) (c)	115 Tanks Scheduled for Processing in Waste Treatment Plant (b)	177 Tank Total ILAW
Cesium 137	9,750,000 (d)	10,900,000 (d)	2,370,000 (d,e)	13,300,000 (d)
Strontium-90	6,800,000 (d)	15,500,000 (d)	6,380,000 (d,f)	21,900,000 (d)
TRU (g)	10,000	46,000	18,840 (h)	64,840
Technetium-99	<30,000	<7,200	<22,800	<30,000
Carbon-14	<5,300	<1,300	<4,000	<5,300
Iodine-129	<51	<14	<34	<48
Tritium	<10,000	<4,100	<5,900	<10,000
Tin-126	<1,600	<140	<460	<600
Selenium-79	<1,000	<20	<114	<134
Uranium	<1,000	<150	<850	<1,000
Total	16,600,000	26,500,000	8,800,000	35,300,000

(a) WHC-SD-WM-TI-699 Rev. 2 (1996), P. 4-1. This estimate includes the disposition of wastes in all 177 double and single-shell Hanford tanks.
(b) Estimates derived from Tank Waste Inventory Network System, September 2003.
(c) Accelerated Retrieval and Interim Closure Schedule table 4.3, Potentially Low Curie Low-Activity Waste Tanks Table 4.6 (This estimate excludes wastes in tanks C-104,106,107,S-105,106, and 112 scheduled to go to the Waste Treatment Plant, and is based on disposition of wastes in 62 SSTs.)
(d) Daughter products of Cs-137 (mBa-137) and Sr-90 (Y-90) included.
(e) WHC-SD-WM-TI-699 Rev. 2 (1996) methodology. 3 percent of Cs,Ba-137 inventory.

(f) WHC-SD-WM-TI-699 Rev. 2 (1996) methodology. 3.78 MCi soluble Sr,Y-90 plus 3 percent of insoluble Sr,Y-90 inventory.
(g) Transuranic wastes as defined by the NRC.
(h) WHC-SD-WM-TI-699 Rev. 2 (1996) methodology. 9,600 Ci soluble TRU plus 3 percent of insoluble TRU inventory.

NO ROOM IN THE REPOSITORY

By 1990, the DOE announced its basic goal was to process and dispose of high-level wastes (HLW) in all tanks at SRS and Hanford. However, it soon became apparent that geological disposal of all of Hanford's high-level wastes alone would result in the production of some 220,000 glass logs,[55] which increased waste shipments, and potential costs.

The 1982 Nuclear Waste Policy Act imposes a limit of 70,000 MTHM limit on the proposed Yucca Mountain site. [56] If that amount is exceeded, the law requires a second repository to be selected. DOE spent fuel and high-level wastes are to make up no more than 10 percent of this limit.

Reducing the geological disposal of high-level wastes involves a complex system of waste fractionation[57] and multiple ion-exchange processes,[58] which were incorporated into Hanford's Tank Waste Remediation System (TWRS) in 1996. First, soluble liquids, and salts, comprising more than 80 percent of the total volume – which DOE calls "low-activity" (LAW) wastes are to be separated from the remaining "high-level" waste sludge. Soluble wastes contain about half of the total radioactive inventory including about 96 percent of the total cesium-137 and the bulk of several long-lived radionuclides such as technetium 99, selenium 79, iodine 129, and carbon 14. Insoluble tank sludge contains about 95 percent of the total strontium-90 inventory and more than 90 percent of the long-lived transuranics.

Using separations technologies, DOE was to remove at least 98 percent of the radioactivity from soluble wastes to allow for their disposal onsite. [59] The treated insoluble sludges were to be combined with the separated radionuclides from LAW processing and vitrified in the HLW glass melter and would be stored on site to await geological disposal. Decontaminated "low-activity" waste would also be rendered into glass. [60]As a result, the TWRS project was expected to generate approximately 14,500 high-level glass canisters (15,700 cubic meters) and more than 100,000 low-activity glass packages (271,000 cubic meters).[61]

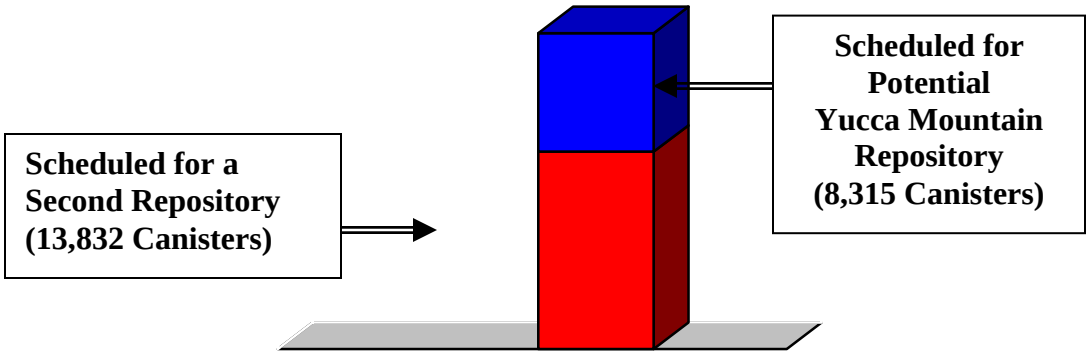
In February 2004, however, DOE stated that "Yucca Mountain does not have the space for all defense HLW waste."[62] In order to accommodate the burgeoning inventory of spent reactor fuel,[63] DOE has decided to reduce the amount to be disposed to less than half of the glass logs expected to be generated for all DOE high-level wastes. [64] Assuming a proportional cut in disposal, the allocation at SRS and Hanford will be reduced by over 60 percent. Thousands of high-level waste canisters are expected to remain at these sites, awaiting disposal in a second repository. (See Figure 7)

DOE's decision to curtail geological disposal of defense HLW is derived from hypothetical assumptions made in 1985 that a typical canister produced at the Savannah River Site would be the equivalent of 0.5 MTHM.[65] Since defense high-level wastes have nearly all uranium removed as a result of reprocessing, it is difficult to make comparisons based on the uranium content in commercial spent reactor fuel. Given this problem, the DOE assumed that each canister would contain 150,000 Ci.[66] Based on this formula, DOE estimated in 1985, that approximately 21,000 canisters would be "approximately equivalent to 10,000 MTHM of commercial HLW."[67]

DOE assumption of the total number of canisters to be sent for disposal in a repository was also "based on in-situ disposal of older wastes which are not readily retrievable from the 149 single-shell tanks."[68]

Risk-based criteria, based on radioactive concentration or radiotoxicity were identified by the National Research Council in 1999, which would allow disposal of "the complete inventory of DOE HLW." [69] DOE concurred in 2002, finding that disposal of all projected HLW canisters "would not change the cumulative impacts."

Figure 7 Disposal of DOE High-Level Waste Canisters



Source: DOE/EIS-0250, Appendix A.

Under the Final Environmental Impact Statement for the Yucca Mountain, issued in 2002, the repository does not have space limitations that would prevent the disposal of 22,100 canisters, but DOE has chosen to ignore risk-based approaches to defense HLW allocation because they "would change the number of canisters ...analyzed for the Proposed Action."[70] Based on the current average radionuclide concentration in HLW canisters produced at the Savannah River Site, the total number of canisters and shipments to Yucca Mountain could be substantially larger, with commensurate cost increases.

In 1996, National Research Council noted that technical factors, would not limit defense high-level waste disposal in Yucca . "Since the repository capacity is specified in tons of heavy metal equivalent, [disposal of 220,000 canisters] may not seriously affect the rules for eventual

disposal in a geological repository." However, "their large number would surely exacerbate problems … which in turn, would present challenges to public acceptability." [71]

In its Record of Decision, DOE fails to address major inconsistencies in the 1985 criteria used to justify limited disposal of defense high-level wastes. While DOE concedes that all projected HLW defense canisters can be disposed in the potential Yucca Mountain disposal site, using criteria based on radionuclide concentration and toxicity, DOE has not provided quantifiable arguments against using these criteria. It may be that operational and disposal costs are high; or that there are physical and social obstacles that limit defense HLW disposal in the potential Yucca Mountain site. However, these concerns are not articulated in DOE's policy documents limiting disposal of defense high-level radioactive wastes. Rather, DOE appears to rely on outdated assumptions and vague assertions.

Originally, 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.

In 2004 the U.S.Congress

IV. THE GLOBAL NUCLEAR ENERGY PARTNERSHIP

Summary

The U.S. Department of Energy's Global Nuclear Energy Partnership (GNEP) is being promoted as a program for reducing the amount of high-level radioactive waste for geological disposal and transmuting fissionable materials into less troublesome isotopes. Crucial to the GNEP plan is the chemical reprocessing of spent fuel from power reactors in the United States and possibly other nations. The magnitude of radioactive wastes generated at a large-scale civilian spent fuel reprocessing plant in the United States would be unprecedented. Assuming near perfection in recoverability, environmental releases of radioactive wastes could exceed that from 50 years of U.S. nuclear weapons production. For instance, the separation and decay storage of cesium and strontium from spent nuclear fuel will result in the *de facto* surface disposal of the largest, most lethal accumulation of radioactive wastes in the United States. Given the DOE's record in addressing its Cold War waste legacy, the promise of GNEP does not inspire confidence.

Reprocessing and Radioactive Wastes

DOE plans to use an 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. This report provides a preliminary analysis of radioactive waste generation at a large nuclear spent fuel reprocessing facility using the UREX + technology at the DOE's Savannah River Site (SRS) in South Carolina.

According to DOE about 63,000 metric tons (MTHM) of nuclear spent fuel would be available for reprocessing after 2011. During the course of operation, interim storage of spent nuclear fuel at a reprocessing plant would contain 10,000 to 20,000 metric tons in dry casks capable of ensuring safe storage for 50 to 100 years. The facility would operate for 25 to 40 years and handle approximately 11 billion curies -- more than 6 times than in high-level wastes at the SRS site. The plant would generate significant amounts of radioactive wastes. For instance:

- Gaseous wastes discharged by reprocessing such as tritium (H-3), carbon-14 (C-14), radioiodine, and krypton-85 (Kr-85) are considerable. Annual environmental discharges of H3 and C-14 would average approximately 500,000 curies and 3,100 curies respectively. C-14 releases would be some 8,000 times greater than from all U.S. nuclear power plants and DOE facilities.

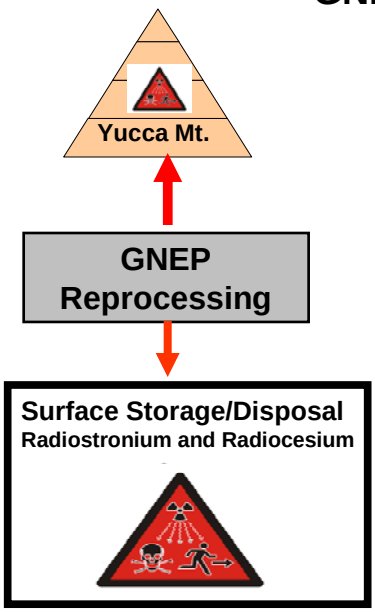
- Separated transuranics would contain 360 metric tons of plutonium-239. Assuming 99 % recovery, some 38 million curies of transuranic (TRU) wastes would be generated -- 14 times more than all TRU wastes in the DOE. TRU wastes from reprocessing would well exceed disposal limits at DOE's Waste Isolation Pilot Project in New Mexico.

- Some 6 billion curies of Cs-137 and Sr-90 would be separated for "decay storage" and ultimate surface disposal as low-level wastes. The quantities of cesium and strontium in nuclear spent fuel are 3,000 times more than DOE currently plans for onsite disposal of these radionuclides at SRS from defense high-level wastes.

- With a half-life of 2.3 million years, the chemical separation of Cs-135 from highly active Cs-137 is not feasible. About 36,000 curies of cesium-135 would be present in spent nuclear fuel and should render cesium wastes from reprocessing unacceptable for onsite surface disposal. After 600 years Cs-135 would become the dominant source of radioactivity and human doses over long periods of time could be significant.

Figure 8

GNEP Disposal Plan Leaves Hottest Waste on the Surface



Strontium-90 and Cesium-137

-- **Dangerous for hundreds of years**

-- **Over two thirds of the radioactivity**

-- **Main Source of Heat in spent fuel**

Cesium-135

half-life= 2.3 million years and dominates human doses in about 600 years.

Source: Galinsky (2006)

Costs

DOE has yet to provide life-cycle cost estimates for GNEP. In 1996, however, 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 ranged from $65 to $168 billion (in 2007 dollars). In 2004, a preliminary estimate by a panel of the British government suggested that processing and decay storage of cesium and strontium would cost approximately $30 billion.

Costs for defense high-level radioactive waste resulting from reprocessing of production reactor spent fuel are estimated by DOE to be in excess of $110 billion. SRS stores the largest concentration of defense high-level wastes in the United States. After spending more than 20 years, and billions of dollars, DOE has processed less than 3 percent of the radioactivity in the SRS tanks.

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.

The "Once Through" and "Closed" Nuclear Fuel Cycles -- Recognizing that nuclear power spent fuel is among of the planet's most dangerous material, Congress passed the Nuclear Waste Policy Act in 1982 requiring it 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. In response, President Carter banned reprocessing in the United States, 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 to recycle uranium and provide plutonium fuel for use in "fast" nuclear power reactors. . Reprocessing consists of mechanical chopping of irradiated fuel elements, 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.

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 a less effective coolant, 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 remanufactures 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.[72] As a result, the AEC predicted that world uranium supplies would be rapidly exhausted. [73] 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. By 1982, proliferation concerns combined with technical and cost problems, led to the abandonment of commercial reprocessing in the U.S. and an end of federal funding for breeder reactors.

GNEP -- 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,[74] including:

- Iodine-129 (half-life= 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=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+ is has no proven history of success at an industrial scale and is still being developed at DOE laboratories.

Previous reprocessing experience in the U.S. and other countries has established reprocessing capabilities using the PUREX technology. Worldwide stocks of separated plutonium from civilian nuclear power spent fuel have grown to 250 metric tons – enough to fuel more than 30,000 nuclear weapons.[75] 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.[76]

Spent Power Reactor Fuel Shipments -- DOE estimates that 175 shipments per year over 24 years will be required to move the accumulated inventory of spent nuclear fuel 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.[77] This does not include shipments from other countries.

Storage and Reprocessing -- 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)[78] 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." [79]

A large reprocessing plant would have to operate for approximately 30-40 years to handle 63,000 to 101,000 metric tons of spent fuel that DOE estimates will be generated. A reprocessing plant would require a capacity of 2,500- 3,000 MTHM/yr plant.[80]

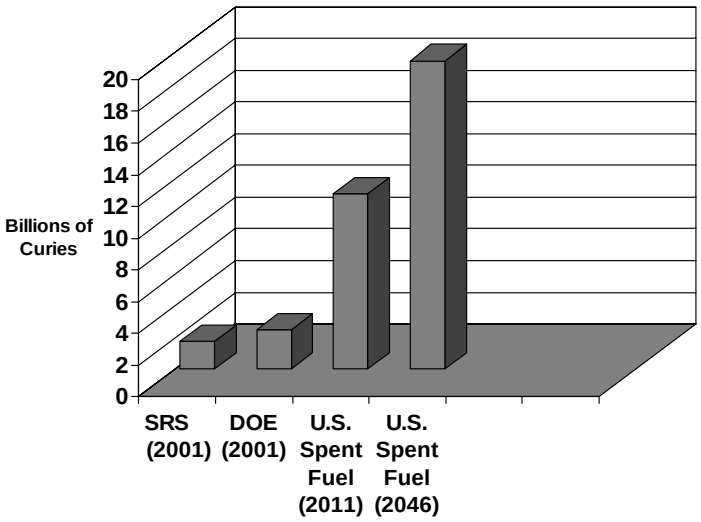
Radioactive Wastes and GNEP -- In May 2006, the Energy and Water Appropriations Committee of the U.S. Congress also expressed concerns over the DOE's lack of cost data for GNEP:

> "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."[81]

This report provides an initial analysis of the radiological issues and waste streams that are likely to generated by the GNEP. The analysis is based on radioactive inventory estimates developed by the U.S. Department in Energy in its 2002 Programmatic Impact Statement for the proposed Yucca Mountain Site. [82]

Total Radioactivity -- The estimated total amount of radioactivity in spent power reactor fuel generated by 2011 would be approximately 11 billion curies. [83] By comparison, this 6.4 times the amount of radioactivity estimated by DOE in 2001 in the high-level wastes at SRS.[84] [85] By 2046, DOE estimates that power reactor spent fuel will contain approximately 19.4 billion curies – more than 11 times than currently in SRS high-level wastes. (See figure 8.)

Figure 8
Comparison of High-Level Radioactive Waste Inventories for SRS, DOE and GNEP

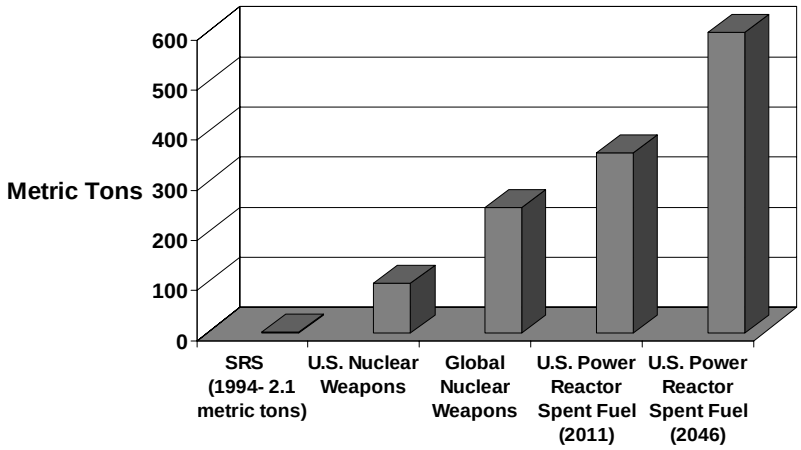


Spent fuel that could be sent to SRS for reprocessing would contain about 132 to 244 times the amount of cesium-137, [86] [87] [88] 228 -391 times the amount of strontium-90[89] and 263 to 444 times the amount of techtetium-99 released from world-wide nuclear weapons tests. [90]

Plutonium-239 -- The total amount of plutonium239 that would be separated from U.S. commercial spent fuel would be approximately 360 to 600 metric tons.[91] This is 3.6 to 6 times the amount produced for the U.S. nuclear arsenal from 1944 to 1988.[92] (See Fig. 9)

Figure 9

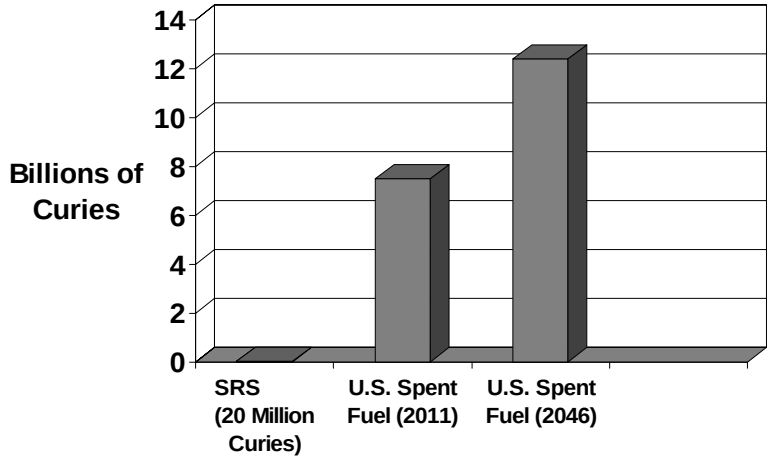
Plutonium-239 Inventories



Decay Storage of Fission Products -- The GNP plan envisions the separation and permanent surface storage/disposal of radioactive wastes, principally Cs-137 and Sr-90, which nominally take about 300 years to decay to safe levels. This would result in about 6 billion curies that would be separated to remain permanently at the site[93] – about 15 times the total amount of Cs-137 and Sr-90 in HLW tanks at SRS. The amount of Cs-137 and S-90 would also be about 3,000 to 6,000 times more than DOE envisions disposing onsite from defense high-level wastes at SRS.[94] However, radioactive concentrations can extend the time by which these radionuclides will decay to levels deemed safe. For instance, the concentrations of cesium and strontium in SRS waste tanks (more than 30 times less than in spent nuclear fuel) represent no more than a few percent of the total volume. However, if disposed on site, these radionuclides would remain a major dose contributor for 15 to 20 half-lives (450 to-600 years.) [95]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. (See figure 10.)

Figure 10

Comparison of GNEP Onsite Disposal of Cs-137 and Sr-90 with SRS



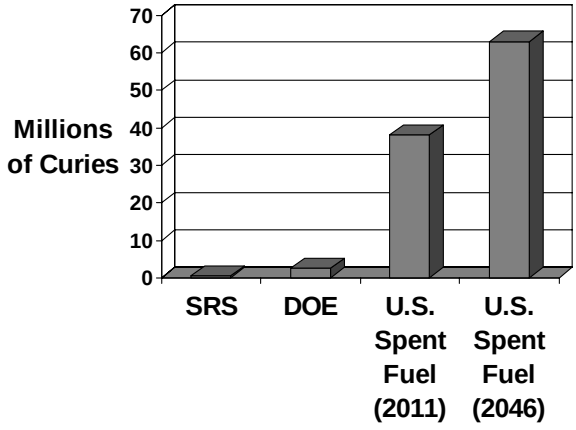
Transuranics -- Assuming the claims made by DOE researchers that 99 % of the transuranics (TRU) from commercial spent power reactor fuel would be recovered [96]– about 38 to 63 million curies of TRU waste would be left behind.[97] This is approximately 14 to 24 times current TRU waste inventories at all DOE sites.[98] (See Figure 11) These wastes would be quite radioactive and will 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. By comparison, if TRU wastes from a new reprocessing plant at SRS were to be packaged to meet the current waste acceptance criteria for disposal at the DOE's Waste Isolation Pilot Plant (WIPP), this would yield approximately 760,000 to 1.3 million drums remote handled TRU wastes and would exceed the total amount of radioactivity allowed for disposal at WIPP under the Land Withdrawal Act of 1996 (P. L. 104-201, 110 Stat. 2422) by 5 to 8 times.. [99] [100] Preliminary cost estimates for the characterization of DOE's remote-handled TRU wastes range from $400 million to $6 billion. [101] The estimated life-cycle cost for disposal of current DOE TRU wastes at WIPP is $16 billion.

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 ^{232}U 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.[102] 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. 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.

Figure 11

Comparison of DOE and GNEP Transuranic Waste Inventories



Assuming 99 Percent Recovery under GNEP

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).

Of particular concern is Cs-135. Removal of this radionuclide in a reprocessing plant is not considered feasible because of the difficulties in isotopic separation from highly active Cs-137.[103] [104] About 36,000 to 60,000 curies of this long lived radionuclide would be generated and remain in wastes for permanent surface disposal. [105] By comparison, this amount of Cs-135 is several orders of magnitude more than in high-level radioactive wastes at SRS. [106] [107] After 600 years Cs-135 will become the dominant source of radioactivity and human doses over long periods of time could be significant.[108]

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 would release between 95,000 to 160,000 curies of Carbon-14, none of which DOE contemplates recovering. While individual are small, C-14 poses risks to large populations. Using a cost benefit analysis adopted by the U.S. Nuclear Regulatory Commission DOE ($1,000 per person rem), the costs of reducing the amount of C-14 released from reprocessing U.S. spent nuclear fuel by 50 percent is $19 billion.

[109] 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.[110]

Wastes containing I-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 the La Hague facility in France released accumulative total of 1,440 Kg(250 curies) --32 times more than from atmospheric weapons tests. [111] 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 reprocessing at SRS has resulted in the largest measurable concentration of I-129 in the Savanna River – more than any river in North America.

Spent nuclear fuel would contain 2,400 to 3,900 curies of Iodine-129 which is 38 to 62 times than in DOE defense high-level wastes at Hanford and SRS. [112] [113] At the Hanford site, the long-term doses from 5 curies of I-129 are an obstacle to onsite disposal of secondary wastes associated with high-level waste processing. [114]

Tritium – The amount of tritium released from a reprocessing plant is considerable. With a half-life of 12.3 years, tritium is very mobile 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[115] – which is comparable to the tritium releases at SRS from the 1950's to the 1990's. [116] 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, and material control and accountancy.

Noble Gases – Other radioactive gases released during chopping and dissolution also include isotopes of krypton and xenon. Because of 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 Cap-de-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. [117]

Reprocessing Costs -- Recently, the Department of Energy 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. [118]

The costs associated with the GNEP were first addressed at the request of DOE in 1996 by the National Research Council of the National Academy of Sciences (NAS). The NAS panel concluded that the plan envisioned under GNEP would cost some $500 billion and require approximately 150 years to accomplish the transmutation."[119] Capital and operating costs for a reprocessing plant in the U.S, according to the NAS would range from 50 to 130 $billion.[120] The NAS panel also concluded that a this program was uneconomical and would require a federal

subsidy between $30 to 100 billion. [121] The Bush Administration has offered nothing to reconcile GNEP with the cost estimates provided by the NAS.

Costs associated with reductions in radioactive effluent emissions from reprocessing are considerable. 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 DOE ($1,000 per person rem), the costs of reducing the amount of C-14 released from reprocessing U.S. spent nuclear fuel by 50 percent is $19 billion. [122] 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. In 1986, SRS researchers estimated the cost of controlling H-3 discharges from a reprocessing facility at $2.7 billion (2007 dollars).[123]

The life cycle costs of decay storage of Cesium and strontium remain uncertain. However, based on preliminary data from the British reprocessing plant at Sellafield, the decay storage of cesium and strontium envisioned under the GNEP initiative would cost about $18.9 billion for operating costs associated with vitrification of the wastes and $11.2 billion for 600 year interim storage (2007 dollars). [124] This does not include the costs of isotopic separation of Cs-135 and its subsequent disposition.

V. A NEW NATIONAL STORAGE STRATEGY

The Nuclear Waste Policy Act was the product of a fragile and complicated compromise involving the nuclear industry, environmental, and non-proliferation groups, the nuclear weapons program, members of Congress, and the White House. The earlier consensus that took shape in the late 1970's and early 1980's served as the foundation for the current framework of nuclear waste disposal planning. How do the policy objectives which were formulated twenty-five years ago, and which shaped the NWPA, hold-up in today's reality?

Waste Management and Disposal Objectives: Then and Now

Need for Early Disposal

- **Then** - Demonstration of spent fuel disposal was needed to resume U.S. orders for reactors.

- **Now** – New federal subsidies provided by the U.S. Congress in 2004, may stimulate new reactor orders.

- **Then** -- Early disposal was supported by environmentalists so future generations would not be saddled with this legacy of protecting the human environment for hundreds of millennia.

- **Now** -- Technical uncertainties associated with predicting long-term disposal risks combined with the large and growing inventory of nuclear weapons production materials,

in the aftermath of the Cold War, requires that the safe storage of wastes must become a priority, while preserving disposal options for future generations to decide.

Assure that spent fuel would not be reprocessed.

- **Then** -- Spent fuel proliferation risks were considered to be high due to assumptions of significant worldwide nuclear power growth. Plutonium "breeder" reactors were soon to be deployed placing weapons-grade materials into commerce. Rapid disposal of unreprocessed spent fuel would reduce this danger and convince other nations to follow the U.S. example.

- **Now** -- The United States is now actively promoting reprocessing and the deployment of "fast" reactors as way to increase demand for nuclear power. DOE is seeking to restore the closed fuel cycle through deployment of large-scale nuclear reprocessing and "fast" reactors. By doing this, proponents of DOE's Global Nuclear Energy Partnership (GNEP) initiative, 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.

Regional Equity

- **Then** -- Since most of the nation's nuclear power plants are in the east, there was an implicit understanding that there would be two repositories -- one in the east and one in the west.

- **Now** -- Only one repository is under consideration at the Yucca Mountain site in Nevada.

Technical Obstacles

- **Now** -- The Cold War is over. Nuclear weapons sites are shutdown. Treatment and disposal of a substantially larger amount of defense high-level wastes from the weapons program are now high priorities.

If geological disposal is to be objectively examined in terms of the suitability of the Yucca Mt. Site, solutions for interim spent fuel storage should not be established by default, as is now the case. There is a need for a national high-level waste storage strategy. The financial responsibilities for the life-cycle management and disposal responsibilities for closed nuclear power plants are not well defined. Given these issues, a national high-level waste storage strategy should be based on the following elements:

- the acceptance of title for commercial spent fuel is part of an overall agreement between the U.S. Government and utilities that clearly defines financial responsibilities for spent fuel storage and disposal, as well as reactor decontamination and decommissioning.
- management responsibilities for commercial and DOE spent fuel are consolidated.

- DOE and commercial spent fuel storage should consist primarily of dry durable storage facilities subject to NRC licensing.

- spent fuel management is institutionally separate from geological disposal efforts.

- DOE initiates a site suitability process for a mix of site-specific and consolidated dry cask spent fuel storage facilities under National Environmental Policy Act.

There are other elements of a national strategy that are beyond the scope of this paper that require a careful and thorough review. Funding mechanisms are among the most important. In particular, the implications of utility deregulation on the Nuclear Waste Fund are not fully understood. For instance, the accelerated closure of reactors will mean that fee contributions to the Fund drawn from the utility rate base will be reduced. Use of the Fund to pay for interim storage has to take into account the individual competitive advantages and disadvantages of nuclear utilities in the marketplace.

APPENDIX A

The 1982 Nuclear Waste Policy Act (NPWA)

The 1982 "Nuclear Waste Policy Act" provided the first comprehensive approach to high-level nuclear waste disposal. The Act was based on a Final Environmental Impact Statement prepared in 1980, which found that deep geological disposal was the safest solution. It established a process to select a permanent geological disposal site; and authorized the siting of an interim "Monitored Retrievable Storage" (MRS) facility for spent commercial reactor fuel. In general terms, the Act :

- established processes and schedules for siting of two geologic repositories -- with an implicit understanding that if the first repository was sited in the west, then the second repository should be in the east. To reinforce this understanding, the first repository was only authorized to store up to 70,000 metric tons of wastes -- about half of the total amount of wastes expected be generated at that time. The DOE was given a deadline of January 31, 1998 to begin accepting wastes for disposal.

- created a "Nuclear Waste Fund" to pay for disposal. Under the fund, DOE entered into contracts with nuclear utilities who made payments at the rate of 1.0 mill- per-kilowatt-hour out of the consumer rate base. A onetime payment to the Fund was also required to be made by nuclear utilities based on electric generation prior to the law's enactment.[125]

- authorized the disposal of DOE's defense high-level wastes in the same repository for commercial spent fuel. DOE would pay its share of the costs out of annual budgets.

- did not commit the DOE to specific processes and schedules as was the case for commercial spent fuel.

- directed DOE to study the need and feasibility of a monitored retrievable storage facility (MRS) for centralized temporary storage of commercial reactor spent fuel at three alternative sites deploying two different designs. The MRS was implicitly intended by Congress as a backup or alternative to a repository.

- directed the NRC and the Environmental Protection Agency (EPA) to promulgate environmental and safety standards for disposal.

The law effectively "grand-fathered" nine candidate sites including salt deposits in the west, midwest and south and Department-operated nuclear reservations which were identified by the DOE beginning in 1976. Soon after passage of the Act, the selection process for the "first round" repository site by DOE in six western and southeastern states ignited a firestorm of controversies. Three "first round" sites were then approved in 1986 by President Reagan at Deaf Smith County, Texas, Hanford, Washington and Yucca Mountain in Nevada. A process to select "second-round" sites in the Northeast, Southeast and Midwestern regions, which were narrowed to seven locations, was indefinitely postponed by DOE Secretary Herrington in 1986. The MRS site selection process was equally controversial. Instead of selecting an MRS site as an alternative to a repository, DOE integrated the central temporary storage facility into an overall repository operation. Three prospective MRS sites in Tennessee were then chosen over the strenuous objections of the state.

Details and tangible steps concerning storage of defense high-level wastes under the Act, in terms of quantities, schedules, and other issues have yet to be even spelled out. As previously mentioned, an amount well over 10,000 metric tons of vitrified glass logs containing defense high-level wastes and 3,000 metric tons of DOE spent fuel are estimated for disposal.

The 1987 Amendments to the NWPA

By 1987, faced with upcoming Congressional and Presidential elections and major controversy throughout the country over potential disposal sites, the fragile consensus that served as the basis for the 1982 Act, unraveled. Adding to the political costs were burgeoning financial costs associated with a multi-site selection process. In December of that year, the Congress adopted sweeping changes in the Act, over the strong objections of the Nevada delegation and its allies:

- The DOE was directed to study only the Yucca Mountain site for suitability as a repository. All other "first" and "second-round" site development efforts were terminated. The 70,000 ton limit on storage in the repository remained -- leaving the question of a second repository for a future time.

- Monitored Retrievable Storage (MRS) for commercial spent reactor fuel could only could be sited and licensed in parallel with the licensing of the repository by the NRC.

The amount of waste stored in an MRS was also limited so that it could not become a *de facto* repository.

- A " Nuclear Waste Negotiator" position was created and charged to seek willing states and or Indian tribes willing to host a repository or an MRS facility.

- A " Nuclear Waste Technical Review Board" was created to provide scientific oversight of the DOE high-level waste program.

    - **Then** -- Technical obstacles for early disposal could be overcome within 20 years and the benefits of early disposal were assumed to outweigh the benefits of storage.

        - **Now** -- Major technical challenges remain -- such as showing that a repository will perform as required by isolating wastes for 10,000 years or more. The scientific community urges that resolution of technical questions not be driven by unrealistic schedules. There is a scientific consensus that spent fuel can be safely stored above ground for 300 years.

Waste disposal and nuclear arms production

- **Then** -- Disposal of weapons wastes was not a high priority and was not to interfere with the Cold War nuclear arms buildup

The amendments to the NWPA stressed, that at anytime Yucca Mountain was found unsuitable, studies would be stopped. The DOE then had to report to Congress within six months on a recommended course of action.

The Regulatory Framework

The NRC issued revised licensing regulations for repositories in 1986 which established a 10,000-year containment criteria. The NRC implementing regulations were based on EPA repository standards in issued in 1985. The EPA standards were subsequently struck down in the U.S. Court of Appeals (First Circuit), in part because of concern over adequacy of groundwater protection in conformance with the Safe Drinking Water Act. In response to the court decision, as part of the 1992 Energy Policy Act, the Congress established a three step process: (1) The National Academy of Sciences was directed to provide recommendations to the EPA as to the content of the new regulation; (2) EPA was to re-promulgate its regulation (40CFR191) consistent with the NAS recommendations; and (3) The NRC was to modify its existing regulations to conform to the new EPA standard. This process will take several more years before actual environmental and safety standards are promulgated.

The DOE's Office of Civilian Radioactive Waste

The 1987 amendments to the NWPA required DOE's Office of Civilian Radioactive Waste (RW) to completely restructure its program. Site selection activities at other sites were quickly terminated and a focused program of research, testing, analysis and assessments necessary to achieve an NRC repository license at the Yucca Mountain site was set up. From this effort came a 6,000 page " Site Characterization Plan."

In order for the program to begin fresh characterization activities at Yucca Mountain, new environmental permits were required -- many that could only be granted by the state of Nevada.

The process of obtaining permit from Nevada turned into a protracted three-year battle where DOE and the state exchanged lawsuits. The net effect of this impasse was the inability of the DOE to perform tangible work to determine the scientific suitability of a repository at Yucca Mountain. Credibility in the RW program approach eroded commensurate with slipped schedules and the dramatic increases in cost estimates. Reports from the National Academy of Sciences, the Presidential appointed Nuclear Waste Technical Review Board, and others underscored an angry pronouncement by the then most influential member of Congress on this issue, Senator Bennett J. Johnston, who in March 1992 stated that "the program is broke."

In the summer of 1992, after the courts ruled in favor of the DOE and after Congressional threats to curtail Nevada's' legal authorities, DOE began new site investigations. Excavation was completed on a ramp, 25 feet in diameter and 1000 feet deep below the top of Yucca Mountain to provide necessary scientific and engineering data to determine the suitability of the site. Next construction was launched of a five-mile tunnel into the

Mountain began, which is now completed. The tunnel will serve as an *in situ* test bed. Also, over 80% of the surface-based testing needed for licensing of the repository is complete.

A repository "Validation Assessment" report is to be completed next year. It will include a performance assessment and contain a cost estimate and a plan for completing the license application.

Major technical challenges remain -- such as demonstrating that a repository will perform as required by isolating wastes for 10,000 years or more. The NAS " Board on Radioactive Waste Management" and the "Technical Review Board" emphasize that the Yucca Mountain program is a first-of-a-kind endeavor and urge that the DOE not be driven by unrealistic schedules. At this time, the NRC and the "Technical Review Board" agree that there is no reason to disqualify the Yucca Mountain site based on what has been learned to date.

Under current circumstance, the DOE finds that the earliest possible date for the opening of a repository to accept and emplace wastes is in the year 2010, versus the 1998 statutory date written into contracts between DOE and utilities. Recognizing this problem, DOE has pursued several avenues without success to provide a government capability to begin accepting waste by the 1998 deadline. The Office of Nuclear Waste Negotiator has been unsuccessful in securing agreements with states and Indian tribes to participate in a voluntary siting process.

The DOE has investigated the possibility of using siting a storage facility on an existing Federal site with all of the predictable difficulties that this entails. Also, DOE is exploring the possibility of providing "multipurpose" canisters which would be used to store excess spent fuel at reactor sites and then serve as transportation and storage canisters at an MRS or a repository. Both options involve several outstanding technical and institutional issues that remain to be analyzed before any decisions are reached.

The Nuclear Waste Fund

In 1987, with the enactment of the Gramm/Hollings/Rudman Budget Act, and the 1990 Budget Adjustment Act, the Nuclear Waste Fund ceased to be a stand-alone revolving fund that operated on a "user-fee" principal. Fees generated from the fund were placed in the General Fund Account of the U.S. Treasury with provisions that allowed for the accrual of interest to paid out, as if it were still a separate revolving account. However, if the funds were to be collected at once, there are serious concerns about the impacts this would have on federal programs that would be cut because of a draw down in the General Fund.

In its place the Department's Office of Civilian Radioactive Wastes (RW) receives annual funding from a combination of money from the Nuclear Waste Fund and from appropriations provided for through the federal government's defense spending (050)

account. About two thirds of RW's annual budget is paid for from the 050 Account and the remainder from fees collected by utilities.

The rationale for this allocation is based on the argument that the DOE has been slow in providing for its contribution for disposal of defense wastes, and that RW is using funds to address disposal requirements for DOE defense wastes. Some members of Congress contend that this is a consumer tax on nuclear power, since only one third of the funds collected from utility fees actually go to the RW program.

Table 2 Estimated Radioactivity in U.S. Spent Nuclear Fuel (a)

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	7.40E+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
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

, 2002, Appendix A.

[1] National Research Council, Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage Board on Radioactive Waste Management Safety and Security of Commercial Spent Fuel Storage, (NRC 2005)

[2] U.S. Nuclear Regulatory Commission / Nuclear Reactors / Power Reactors http://www.nrc.gov/reactors/power.html

[3] U.S. Nuclear Fuel Cycle Projections 2000-2025, Energy Information Administration, U.S. Department of Energy, 2003 http://www.eia.doe.gov/cneaf/nuclear/page/forecast/projection.html

[4] 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, (hereinafter YMP FEIS) Volume II, Appendixes A through O, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, DOE/EIS-0250, July, February, 2002.

[5] The quantity of spent fuel is measured in metric tons of heavy metal (MTHM). Heavy metal refers to elements with atomic number greater than 89 – in SNF, almost all heavy metal is uranium. The current disposal limit for the first national repository was set by Congress at 70,000 MTHM for all SNF and HLW. In 1995, the U.S. Department of Energy (DOE) allocated 90% of the Yucca Mountain geologic repository, or 63,000 MTHM, for commercial SNF disposal. The remaining 10% was allocated for defense high-level radioactive waste (4,667 MTHM) and defense SNF (2,333 MTHM). Ibid

[6] 96 Nuclear Waste Technical Review Board, *A Report to Congress and the Secretary of Energy, Nuclear Waste Technical Review Board*, Dr. John E. Cantlon, Chairman, *March 1996*

[7] Las Vegas Review-Journal, "Yucca director downplays project timeline, He says nuclear waste repository unlikely to open before 2020," November 30, 2006.

[8] U.S. Department of Energy Environmental Management website: DOE > Environmental Management > DOE Environmental Management (EM) – Spent Nuclear Fuel. www.em.doe.gov/Pages/spentfuel.aspx

[9] 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, (hereinafter YMP FEIS) Volume II, Appendixes A through O, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, DOE/EIS-0250, July, February, 2002.

[10] Congressional Research Service Report for Congress, "Spent Nuclear Fuel Storage Locations and Inventory", Anthony Andrews, Specialist in Industrial Engineering and Infrastructure Policy Resources, Science, and Industry Division, December 21, 2004

[11] U.S. Department of Energy, Office of Civilian Radioactive Waste Management, OCRWM Program Briefing, Spent Nuclear Fuel, http://www.ocrwm.doe.gov/about/pm/programbrief/briefing.htm

[12] U.S. Department of Energy, DOE Integrated Database Report, web.em.doe.gov/idb96/tab14.html.

[13] State of Nevada, Nuclear Waste Project Office, "Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste to a Repository", Factsheet, May 20, 1999, http://www.state/nv.us/nucwaste/

[14] Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, National Research Council, National Academies of Science, ISBN: 0-309-10511-0, 2006, http://www.nap.edu/catalog/11263.html

[15] Ibid

[16] State of Nevada, Nuclear Waste Project Office, "Transportation of Spent Nuclear Fuel and High-Level Radioactive Waste to a Repository", Factsheet, May 20, 1999, http://www.state/nv.us/nucwaste/

[17] Nuclear Waste Policy Act of 1982, Public Law 97-425, (96 Stat. 2201).

[18] U.S. Department of Energy, Office of Civilian Radioactive Waste Management, "Acceptance Priority Ranking and Annual Capacity Report," DOE/RW-0567, July 2004.

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[20] U.S. Department of Energy, Energy Information Administration, http://eia.doe.gov/cneaf/nuclear/page/nuc_reactors/superla.html

[21] American Nuclear Society, "The EPA Radiation Standard for Spent-Fuel Storage in a Geological Repository", November, 2006

[22] U.S. General Accounting Office, Report to the Chairman, Subcommittee on Energy and Air Quality, Committee on Energy and Commerce, U.S. House of Representatives, "Spent Nuclear Fuel – Options Exist to Further Enhance Security, July, 2003.

[23] U.S. Nuclear Regulatory Commission, Radioactive Waste > Spent Fuel Storage > Nuclear Fuel Pool Capacity, http://www.nrc.gov/waste/spent-fuel-storage/nuc-fuel-pool.html

[24] American Physics Society, Panel on Public Affairs, "Consolidated Interim Storage of Commercial Spent Nuclear Fuel, A Technical and Programmatic Assessment," February 2007

[25] Robert Alvarez, "What about the spent fuel?", Bulletin of the Atomic Scientists, Vol. 58, No. 1, January/February 2002.

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[50] Gasper p. 3

[51] U.S. Department of Energy, Record of Decision for the Tank Waste Remediation System, 1996, http://www.hanford.gov/eis/0244f/rod.html.

[52] The TPA Milestones for HLW processing included: (1) M-50-04 – Start hot operations for HLW pretreatment facility by June, 30, 2008; (2) M-50-04-T01 – Submit conceptual design of HLW pretreatment facility by March 31, 1998;(3) M-50-04-T02 – Initiate definitive design of pretreatment facility by November 30, 1998; (4) M-50-04-T03 – Start construction of HLW pretreatment facility by June 30, 2001; (5) M-51-00 – Complete vitrification of Hanford HW by December 31, 2028; (6) M-51-03 – Initiate hot operations of HLW vitrification facility by December 2009; (7) M-51-03-T01 – Submit conceptual design for HLW vitrification facility by December 31, 1998; (8) M-51-03-T04 – Complete construction of the HLW vitrification facility by December 31, 2007; (10) M-61-00 – Complete pretreatment and immobilization of Hanford LAW by December 2028.

[53] DOE/RL-2002-47, Rev. D, August, 2002.

[54] CH2MHill, Integrated Mission Acceleration Plan, RPP 13678, Rev. 0, March 2003.

[55] NAS 1996, p 94.

[56] 42 U.S.C. 10114 (d) "The Commission decision approving the first such application shall prohibit the emplacement in the first repository of a quantity of spent fuel containing in excess of 70,000 metric tons of

heavy metal *or a quantity of solidified high-level radioactive waste resulting from the reprocessing of such a quantity of spent fuel until such time as a second repository is in operation.*" [Emphasis added]

[57] NUREG 1747, p. 1. Table 2, pp. 1-3. "DOE uses the term LAW to denote .Low Activity Waste….LAW is predominantly a liquid phase with soluble species such as nitrates and cesium; it may also contain up to 2 percent suspended solids or solids otherwise entrained by the waste transfers. Three envelopes of LAW have been defined; Envelope A is .standard,. Envelope B contains higher levels of cesium, and Envelope C contains higher levels of strontium and TRU…. LAW would come from the liquid phases of the DSTs and from solids washing operations. From a regulatory perspective, LAW is still HLW and has high radiation levels requiring handling within shielded structures. DOE identifies the solid phases as HLW,. defined as Envelope D. …Envelope D contains cesium, strontium, and TRUs as the radionuclides. Metal oxides, hydroxides, nitrates, phosphates, and aluminates constitute the bulk of the chemical species."

[58]U.S. Department of Energy, Technical Basis for Classification of Low-Activity Waste Fraction from Hanford Site Tanks Westinghouse Hanford Corporation, WHC-SD-WM-TI-699, September 1996. (Hereafter known as WHC-SD-WM-TI-699.)

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[60] 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, Table A-28. (Hereafter known as DO/EIS-0250.) DOE estimates that the total amount of chemicals in HLW glass forms at Hanford is 44,000 Kgs., compared to the total 15.1 million kilograms currently estimated in storage tanks

[61] DOE/EIS-0250, February 2002, Appendix A, p. A-39.

[62] Statement of Jurisdiction, U.S. Ninth Circuit Court of Appeals, Re: NRDC v. Abraham, 244 F.3d 742 (9th Cir. 2003), January 29, 2004, p. 40.

[63] DOE/EIS-0250, February 2002, Appendix A, Tables A-8, A-20 and A-27, at pages A-16, and A-40, respectively. Based on these tables, DOE has determined that approximately 63,000 metric tons of the total capacity of Yucca Mountain should be reserved for commercial spent nuclear fuel. The remaining 7,000 metric tons (or 10 percent) of the repository's capacity would be available for the disposal of 2,333 metric tons of DOE spent nuclear fuel and approximately 8,315 canisters (4,667 metric tons) containing solidified high-level radioactive waste from all defense sources. DOE estimates, however, that if all commercial nuclear facilities licenses are extended for ten years, by 2046 there will be in existence approximately 105,000 metric tons of commercial spent nuclear fuel, and that by 2035 there will be approximately 2,500 metric tons of DOE spent nuclear fuel and 22,280 canisters of DOE HLW.)

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