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# Reducing the Risks of High-Level Radioactive Wastes at Hanford

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High-level radioactive wastes resulting from plutonium production at the U.S. Department of Energy's (DOE) Hanford site in Washington State are among the largest and most dangerous byproducts of the nuclear arms race. The Energy department announced plans in 2002 to terminate its environmental mission at Hanford and all other DOE sites over the next 30 years. During this time, DOE intends to dispose of approximately 90 percent of Hanford's high-level wastes onsite, process the remainder into glass for geological disposal, and permanently close 177 large tanks, and related infrastructure. Central to the department's goal at Hanford is to speed up, perhaps, the most expensive, complex, and risky environmental project in the United States. Estimated life-cycle costs for processing Hanford's wastes are between $41.6 and $56.9 billion. No country has processed anything quite like Hanford's large and complex brew of wastes.

## PROCESSING RISKS

The accident consequences at Hanford's Waste Treatment Plant are comparable to those accidents at a large nuclear reactor. During design and construction of a nuclear facility, DOE is required by regulation to estimate the frequency of unmitigated risks of major nuclear accidents, which do not account for preventive features that would lessen the consequences of an accident. This approach defines the "safety envelope" contained in documented nuclear safety analyses, required for the regulation of design, constructions, and operation of a nuclear facility. Its purposes are to encourage higher margins of safety and to envelop uncertainties inherent with first-of-a-kind, hazardous operations.

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After three and a half years of involvement at Hanford, NRC found in 2001 that DOE contractors consistently downplayed the severity of potential accidents. NRC estimated that the overall unmitigated risk of major radiological and chemical accidents at Hanford's high-level waste operations was 2.4E-2/yr, translating into a 50-50 chance over an estimated 28 years of operation of the facility. According to NRC more than two-dozen significant safety issues and 50 specific topics remained unresolved.

Existing engineering controls and administrative methods can reduce accident risks at the Hanford Waste Treatment Plant to acceptable levels, with the possible exception of glass melters, designed to mix radioactive wastes with molten glass. They will be the largest in the world and pose potentially the most severe accident consequences. NRC found that further analysis was required to determine if melter risks could be reduced to levels acceptable for reactor accidents. But, NRC warned that "few tests appear to be planned to verify safety parameters prior to construction."

DOE's experience with glass melters does not inspire confidence. Since 1991 there have been at least eight melter-related accidents and failures at DOE sites, including two steam explosions.

Storage problems stemming from Cold War practices add significant risks to waste processing. More than a third of Hanford's tanks have leaked approximately one million gallons, contaminating groundwater that eventually enters the Columbia River. The structural integrity of dozens of aged tanks "represent immediate concerns," says the Nuclear Regulatory Commission (NRC). As a result of an early decision to neutralize acidic reprocessing wastes, all of Hanford's tanks generate potentially flammable and explosive gases from radiolysis. This problem is exacerbated by hundreds of added chemicals.

One of Hanford's most troublesome tanks, SY 101, was found in October 2003, after it was declared safe, to have a sufficient amount of retained gas to reach 100 percent of the lower flammable limit for hydrogen. As wastes are retrieved and processed, the risks of fires and explosions can increase, and these will be a concern throughout the project life. Current estimates indicate that hydrogen build-up in pipes at the Waste Treatment Plant could be tens to hundreds of times greater than assumed.

"On many occasions, there was an implication that regulatory reviews were not allowed to impact cost and schedule," NRC concluded. Since 2001, when NRC involvement ended at the Hanford Waste Treatment Plant, DOE appears to not have heeded NRC's numerous concerns. Instead, programmatic demands to reduce cost and save time, have led to relaxed safety requirements, higher construction costs, and increased worker exposures and injuries. A recent DOE inquiry found that construction workers expressed fear of retaliation, particularly job loss, for reporting safety, medical, and labor relations issues. As a result of these growing problems, construction has been curtailed and design work has to be revisited, causing further delays.

## DISPOSAL RISKS

Stating that the planned Yucca Mountain geological repository "does not have the space," DOE seeks to greatly expand on-site burial of defense high-level wastes at several sites. The underlying bases for this policy were established in 1985. They assume that a high-level waste canister contains the radiological equivalent of 0.5 metric tons heavy metal of spent power reactor fuel, and that the preponderance of wastes in Hanford's tanks would be effectively abandoned. Current data from 1,500 high-level waste packages produced at the Savannah River Site indicate that canisters contain less than 10 percent of the predicted radioactivity. DOE is also prohibited by a federal environmental compliance agreement from abandoning Hanford tanks. Given these circumstances, DOE's policy to further reduce high-level waste canister production will to lead to the on-site disposal of substantially larger amounts of radionuclides.

Before DOE initiated an accelerated cleanup plan in 2002, at least 98 percent of the total radioactivity was to be removed from soluble wastes at Hanford, under a 1997 agreement with the NRC staff prior to on-site disposal, as incidental wastes. Instead, DOE intends to bury wastes on-site from dozens of tanks without radionuclide separation, as well as undetermined amounts of tank residuals, and failed processing equipment containing high-level wastes. As a result, at least 35 megacuries of radioactivity could be disposed on-site at Hanford—more than twice the amount agreed to in 1997 by the NRC staff.

Prior to 2004, the NRC determined what constitutes high-level wastes at DOE sites for geological disposal. Last year the US Congress authorized the DOE to self-regulate high-level waste disposal, with NRC consultation. However, the Hanford site was excluded from this provision. NRC has exercised sits authority through staff-level consensus agreements. NRC's passive approach has resulted in DOE disposal actions, which for all practical purposes are irreversible. In the case of Hanford, it appears that DOE can ignore an agreement with NRC staff, without regulatory consequence.

The National Research Council recently concluded that knowledge of the fate and transport of tank wastes into the Columbia River is tenuous, at best; and that premature failure of environmental barriers is likely. Current estimated disposal of iodine-129 (17 million year half-life) from processing wastes, appear to violate DOE's waste performance requirements and could contaminate groundwater in excess of EPA drinking water limits for thousands of years.

The impacts of past operations and additional onsite disposal have not been assessed on the Hanford Reach, the last free flowing stretch of the Columbia River, which runs though the site. Higher priority is being given to the transfer of more than 87 percent of the Hanford site over the next eight years to the Interior Department's Hanford Reach National Monument. The likelihood of thousands of people visiting the Monument has not been factored into DOE's

nuclear accident scenarios, or disposal decisions. Of particular concern is the high vulnerability to environmental contaminants of thousands of tribal people living near Hanford.

This was underscored in 2002 by the U.S. Environmental Protection Agency which found that fish near the site have the highest contaminant concentrations in the Main Stem Columbia River Basin. EPA estimated that lifetime fatal cancer risks from fish consumption to tribal people are as high as 1 in 50. Usually, EPA takes regulatory action when contaminant risks exceed 1 in 10,000 to 1 in 1,000,000. Around the time the EPA study was released, DOE set a radiation standard to protect fish from Hanford's radionuclides that would result in doses to tribal people several hundred times greater than allowed by the Environmental Protection Agency.

## PROJECT MANAGEMENT ISSUES

Since the Hanford waste treatment plant is a first-of-a-kind endeavor, safety and operability of this project is highly dependent on knowledge of physical and chemical properties of the wastes. However, the National Research Council finds that Hanford waste data "is of little value in designing chemical remediation processing." In light of these uncertainties, worldwide high-level waste vitrification experience encourages extraordinary caution be exercised at Hanford. But DOE has raised the stakes by deciding to forego a pilot plant using actual Hanford wastes and to concurrently design and construct a full-scale facility.

Over the past 20 years, less than five percent of all defense high-level wastes have been processed, while incurring soaring costs, projected to exceed $100 billion. DOE's inability to manage these projects is a major factor behind these difficulties. For instance, a 20-year failure to pretreat soluble wastes at the Savannah River Site has resulted in a loss of $500 million, with projected costs of $1.8 billion. The U.S. General Accounting Office attributes this problem to a management culture based on an "undocumented policy of blind faith in its contractors' performance." Growing Congressional concern has resulted in recent reports by the National Research Council, which found:

- Environmental projects suffer from major delays and are about 50 percent more expensive than comparable federal and private-sector projects;
- Up-front project planning is inadequate;
- There is no consistent system for evaluating project risks; and
- DOE is not in control of many of its projects.

Capital costs for the Hanford vitrification plant are a relatively small portion of the total life-cycle costs for the project. The failure to address critical

uncertainties in the design and construction of the plant could significantly impact processing and disposal costs and the overall success of this endeavor. DOE's policy to put concurrent design and construction on a "fast track" has led to costly and time-consuming mistakes.

The most significant shortcoming to date has been DOE and the contractor's failure to heed warnings by the Energy department's Defense Nuclear Facility Safety Board in 2003 to increase hardening against earthquakes in a seismically active region similar to that as California. As a result, in March 2005, DOE had to suspend construction work on facilities that would process the preponderance of the wastes, in order to double the seismic design standard.

## RECOMMENDATIONS

To reduce the risks of Hanford's high-level wastes this article makes the following recommendations.

- The Nuclear Regulatory Commission should be authorized to regulate the design and construction of Hanford's waste processing operations and certify the safety of storage tanks.
- Risk-based criteria identified by the DOE that would allow for the geological disposal of all DOE HLW canisters should be adopted.
- More restrictive limits for on-site disposal of tank wastes should be imposed on the permanent on-site disposal of high-level tank wastes. These limits should be developed with affected states, Indian tribes and public stakeholders. This should be done under existing law, through formal rulemaking by the NRC.
- The Energy department should build pilot operations for high-level waste pretreatment, feed preparation, and melters using actual Hanford wastes.
- DOE should strengthen its oversight of this project by establishing a full-time Hanford high-level waste processing project management group, reporting to the Assistant Secretary for Environmental Management.

The costs, complexity and risks of the Hanford high-level waste project plant rival those of the U.S Space Shuttle program, but have far greater potential consequences to the human environment. Yet it remains for the most part, an expensive curiosity in national policy deliberations. Given the stakes involved, the price of continued obscurity of this legacy of the nuclear arms race may prove to be incalculable.

## HANFORD HISTORY

In January 1943, just weeks after the world's first self-sustaining nuclear chain reaction took place at the University of Chicago, the Hanford site in the steppe shrub desert of Southeastern Washington was selected to make plutonium for the first atomic weapons. Its relative isolation and close proximity to the large water and electrical supplies from the Columbia River made the 560-square-mile site a seemingly ideal location. Over the next 44 years, until U.S. Energy Secretary John Herrington announced that the nation was "awash in plutonium,"[1] Hanford's nine reactors had produced 67.4 metric tons of this fissile material.[2]

As Cold War memories fade, the sobering aftermath of the nuclear arms race is no more apparent than at Hanford, where the nation's most hazardous byproducts of nuclear weapons production are stored. With nearly 60 percent of the nation's defense high-level radioactive waste,[3] Hanford's legacy is in a league unto itself in terms of magnitude and risk.

The United States started to come to terms with this problem when the Congress established a process to dispose of geologically defense and civilian high-level radioactive waste in the 1982 Nuclear Waste Policy Act. The following year, borosilicate glass was selected by the U.S. Department of Energy (DOE) as the preferred disposal form for defense high-level wastes. Vitrified wastes from Hanford, and four other sites,[4] would then be disposed along with DOE and commercial spent power reactor fuel in the same repository.

After more than 20 years of fits, starts, and soaring costs, less than five percent of the nation's defense high-level wastes have been processed.[5] At Hanford, DOE is still in the stages of design and construction. The success of this unprecedented endeavor, estimated to cost between $41.6 and $56.9 billion,[6] depends largely on the resolution of three key questions.

1. Can the processing of Hanford's high-level wastes be done safely?
2. Can DOE "fast track" a full-scale, first-of-a-kind operation, without significant technological failures?
3. Will the shallow on-site disposal of radioactive wastes from Hanford's tanks ensure adequate protection of health and natural resources from the present to thousands of years from now?

## HANFORD'S HIGH-LEVEL WASTES

High-level wastes were generated by dissolution of 119,271 MTU (metric tons uranium) of spent reactor fuel[7] and the subsequent solvent extraction of plutonium and other materials.[8] Because of their highly intense radioactivity they must be handled remotely in heavily shielded structures. Until recently, their

long-term hazards required that they be disposed so as to protect the human environment for up to 10,000 years.[9] However, this standard was struck down by the United States Court of Appeal,[10] citing the National Research Council's finding that peak radiation doses "might occur tens to hundreds of thousands of years into the future."[11]

In making these wastes at Hanford, five chemical processes were utilized.[12] After treatment and subsequent radioactive decay,[13] the Hanford high-level wastes currently contain approximately 194 megacuries[14] in 54 million gallons (204,000 cubic meters) stored in large underground tanks.[15] (See Table 1). From a time perspective, radionuclides in the tanks pose potentially significant risks to health and natural resources for 300 to more than 200,000 years.[16]

More than 96 percent of total radioactivity in the tank wastes comes from cesium-137 and strontium-90 (half-lives of 30 and 29 years respectively). These high levels of radiostrontium and radiocesium pose safety concerns because of decay heat build-up during storage, retrieval, and processing.[17] Hanford's wastes also have substantial amounts of long-lived fission products and transuranics. The amount of technetium-99 produced at Hanford (200,000 year half-life) is nearly nine times more than that released from all world-wide atmospheric nuclear weapons tests.[18] Because of its rapid mobility, Tc-99 can

**Table 1:** Hanford high-level waste inventory.

| Radionuclides (Ci) | | Radionuclides (cont) | | Other analytes (Kg) | |
|---|---|---|---|---|---|
| 3H | 1.04E+04 | 152Eu | 1.71E+03 | F | 1.08E+06 |
| 90Y | 4.99E+07 | 14C | 3.01E+03 | Al | 8.05E+06 |
| 90Sr | 4.99E+07 | 137Cs | 4.62E+07 | Fe | 1.25E+06 |
| 60Co | 8.08E+03 | 137mBa | 4.37E+07 | La | 3.69E+04 |
| 234U | 2.21E+02 | 129I | 4.79E+01 | Pb | 7.84E+04 |
| 106Ru | 1.02E+03 | 227Ac | 1.30E+02 | Mn | 1.65E+05 |
| 134Cs | 1.82E+04 | 243Am | 1.52E+01 | Hg | 1.83E+03 |
| 233U | 5.08E+02 | 239Pu | 6.88E+04 | Ni | 1.16E+05 |
| 244Cm | 2.88E+02 | 235U | 9.14E+00 | K | 9.18E+05 |
| 238Pu | 4.23E+03 | 228Ra | 6.24E+01 | Si | 8.01E+05 |
| 63Ni | 1.28E+05 | 242Cm | 1.44E+02 | Na | 4.80E+07 |
| 242Pu | 8.29E-01 | 154Eu | 1.02E+05 | Sr | 3.96E+04 |
| 226Ra | 2.38E+02 | 229Th | 2.58E+01 | Cr | 6.05E+05 |
| 237Np | 1.33E+02 | 151Sm | 3.35E+06 | U Total | 6.02E+05 |
| 241Pu | 1.25E+05 | 93Zr | 4.42E+03 | Zr | 4.09E+05 |
| 240Pu | 1.22E+04 | 243Cm | 1.24E+01 | Bi | 5.61E+05 |
| 99Tc | 2.85E+04 | 79Se | 1.32E+02 | Ca | 2.55E+05 |
| 232U | 4.25E+01 | 126Sn | 6.00E+02 | Cl | 8.64E+05 |
| 125Sb | 2.49E+04 | 236U | 5.92E+00 | TIC as | |
| 231Pa | 2.72E+02 | 113mCd | 1.65E+04 | CO3 | 9.80E+06 |
| 59Ni | 1.37E+03 | 93mNb | 3.86E+03 | TOC | 1.27E+06 |
| 155Eu | 7.69E+04 | 232Th | 8.12E+00 | PO4 | 5.32E+06 |
| 241Am | 1.43E+05 | 238U | 2.01E+02 | NO3 | 5.48E+07 |
| | | **TOTAL** | **1.94E+08** | NO2 | 1.21E+07 |
| | | | | SO4 | 3.66E+06 |
| | | | | **TOTAL** | **1.51E+08** |

Source: Tank Waste Inventory Network System, Best Basis Inventory, September 2003.

contaminate water supplies for thousands of years. Waste tanks also contain more than 1,000 kilograms of plutonium-239.[19]

Hanford's waste tanks contain complex mixtures that fit into 89 separate chemical profiles.[20] Chemical concentrations in each of the tanks widely vary by as much as 100 percent.[21] Sodium (Na+) makes up approximately 80 percent of the cationic content by weight, followed by aluminum (Al) at around 5 percent wt. There are also large concentrations of cations from construction materials such as iron (Fe3+), nickel (Ni2+) and chromium (Cr3+).[22] The dominant chemical anion in tanks is nitrate (NO3), which constitutes about two-thirds of the weight. Other abundant anions include hydroxides (OH), nitrites (NO2), and carbonates (CO3-2), phosphate (PO4-3), chlorine (Cl), fluoride (F), silicates (SiO4-2), and sulfates (S04-2).[23]

Although radioactive materials make up about one percent of Hanford's waste volume, they are enough to make the wastes highly dangerous, with exposure levels inside the tanks as high as 10,000 rad per hour.[24] There are

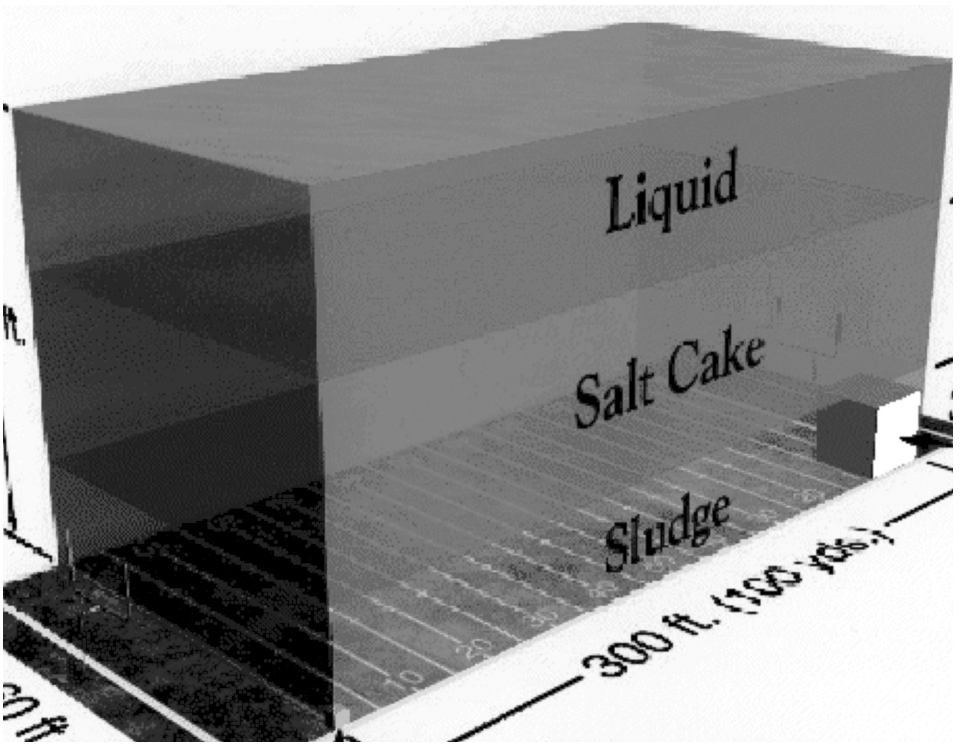


**Figure 1:** Volume and Radionuclide concentration in Hanford HLW. Soluble wastes are ~80 percent of the volume and contain ~50 percent of the total radioactivity. About 96 percent of the radioactivity in soluble wastes is cesium-137. Insoluble sludge contains ~95 percent of the total Sr-90, and >90 percent of the total transuranics. (Adapted from: DOE/RL-98-34.)

several forms and layers of wastes, which are "heterogeneous in all phases, both within a given tank and among different tanks."[25] (See Figure 1). Generally, the wastes are in three basic forms.

- **Sludge:** A dense, water insoluble component that has settled to the bottom of the tank to form a thick layer of varying consistencies;
- **Saltcake:** A crystallized salt waste formed above the sludge, which is mostly water soluble; and
- **Liquid:** Above or between the denser layers and sometimes embedded in saltcake are liquids of water, dissolved salts, and other chemicals called supernate.

The basis for high-level waste management at Hanford was established in World War II to meet production deadlines and limit waste storage costs. Because wastes coming out of the reprocessing plants were acidic, the U.S. government decided to neutralize them by adding sodium hydroxide (lye) and water so that cheaper carbon steel could be used to line the tanks, rather than more expensive high quality stainless steel. The decision to maintain a high PH, to reduce corrosion of the steel liners, substantially increased the volume of wastes.[26]

The wastes are stored in two general types of tanks (see Figures 2 and 3).

**Single Shell Tanks (SST)**—There are 149 SSTs with a single 1/4-inch carbon steel wall liner surrounded by concrete. They range in capacity from 55,000 to 1 million gallons, and were built between 1943 and 1964. The SSTs are

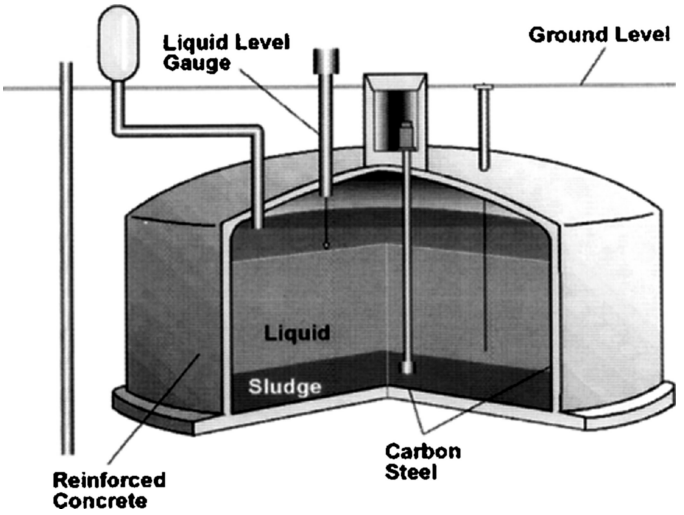


**Figure 2:** Single-Shell Tank. (Source: Pacific Northwest National Laboratory.)

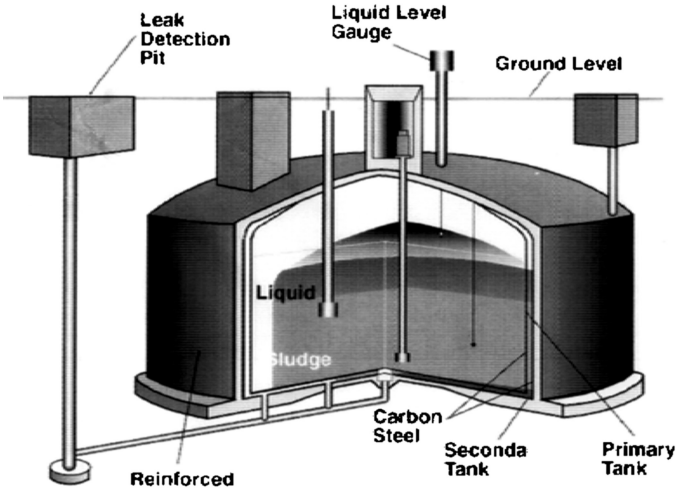


**Figure 3:** Double-Shell Tank. (Source: Pacific Northwest National Laboratory.)

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.[27] The single-shell tanks store about 132,500 cubic meters of saltcake, sludge, and liquid containing 110 million curies of radioactivity.[28] About 90 percent of SST wastes are sodium nitrates and nitrites. About 75 percent of the radioactivity in these tanks comes from strontium-90 concentrated in sludge and 24 percent from cesium-137 in soluble liquids and saltcake.

**Double-Shell Tanks**—Between 1968 and 1986, 28 tanks with double steel liners, were constructed with a capacity of 1 to 1.16 million gallons. They contain about 83,279 cubic meters or 23 million gallons of mostly liquids (~80 percent), as well as sludges and salts.[29] The estimated amount of radioactivity in the DSTs is about 80 million curies (Cs-137 = 72 percent and Sr-90 = 27 percent).[30] As in single-shell tanks, wastes are primarily composed of sodium salts, and also have additional metal hydroxides, phosphates, carbonates and sulfates. None of the DSTs has leaked, but at least one has experienced major corrosion problems.[31] A technical basis for controlling corrosion of double–shell tanks through chemistry controls has thus far proven illusive.[32]

## CONSEQUENCES OF THE PRODUCTION IMPERATIVE

Efforts to keep waste storage expenses down during the period of nuclear weapons production, created significant problems. Approximately 120 to 130 million gallons of high-level wastes were discharged to the ground.[33] Wastes were transferred extensively, between tanks, without adequate

**Figure 4:** Diatomaceous earth in Hanford Tank 104-U (capacity, 530,000 gallons). (Source: Pacific Northwest National Laboratory.)

documentation,[34] and with little regard for chemical compatibility, heat loads or radioactive concentrations. Nearly 300 chemicals and chemical products were added during the course of waste processing,[35] including at least 5,000 tons of organics.[36] Additionally, hundreds of tons of cement,[37] and diatomaceous earth,[38] (see Figure 4) were dumped in several tanks. Wastes were evaporated, permitted to boil, and corrosion combined with the settling of high-heat sludges at the bottom of tanks resulted in the failure of steel liners.

These practices now pose major unresolved questions about Hanford's waste characterization, affecting safety and disposal. Subsequently, this situation was made worse by decades of neglect, causing more than a third of Hanford's tanks (67 SSTs) to leak high-level wastes, some that reached groundwater which eventually enters the Columbia River.[39]

In the summer of 1990 several Congressional and DOE investigations identified serious safety concerns regarding risks of explosions and fires in Hanford's high-level waste tanks.[40] All told, 60 tanks were placed on a "watch list" required by Congress, which were reviewed and analyzed. By August 2001, the Energy Department announced it had resolved all HLW tank safety issues[41] that surfaced earlier.[42]

Around the same time, however, the U.S. Nuclear Regulatory Commission warned that Hanford's HLW tanks "represent immediate concerns" particularly because of aging and deterioration.[43] The emphasis on safety of waste processing, NRC pointed out, should not overshadow the waste tanks because of "considerable environmental and public risk posed by continued operation

of the tanks with their associated leakage and potential for collapse and explosion."[44]

All of Hanford's HLW waste tanks generate potentially flammable gases.[45] Radiation, decay heat and chemical changes in the wastes generate toxic, flammable, and potentially explosive gases, such as hydrogen, nitrous oxide, ammonia and volatile organics, which can build up in the wastes and be rapidly released during retrieval.[46] NRC-sponsored research indicates that "even very small releases can collect in equipment or in poorly ventilated tanks and result in a flammable gas hazard."[47]

One of Hanford's most troublesome and, perhaps, most dangerous tanks, SY-101, continues to present potentially significant risks, decades after its dangers were first discovered. In October 2003, after the tank was declared safe and wastes were added several months earlier, SY 101 was reported to have "the propensity to undergo a large buoyant displacement gas release event and has sufficient retained gas [hydrogen] to achieve 100 percent of the lower flammability limit."[48]

## NO ROOM AT THE REPOSITORY?

By 1990, the DOE announced its basic goal was to process and dispose of high-level wastes (HLW) in all of Hanford's 177 tanks. However, it soon became apparent that geological disposal of all of Hanford's high-level wastes would result in the production of some 220,000 glass logs,[49] 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.[50] 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[51] and multiple ion-exchange processes,[52] 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.[53] The treated insoluble sludges were to be combined with the separated radionuclides

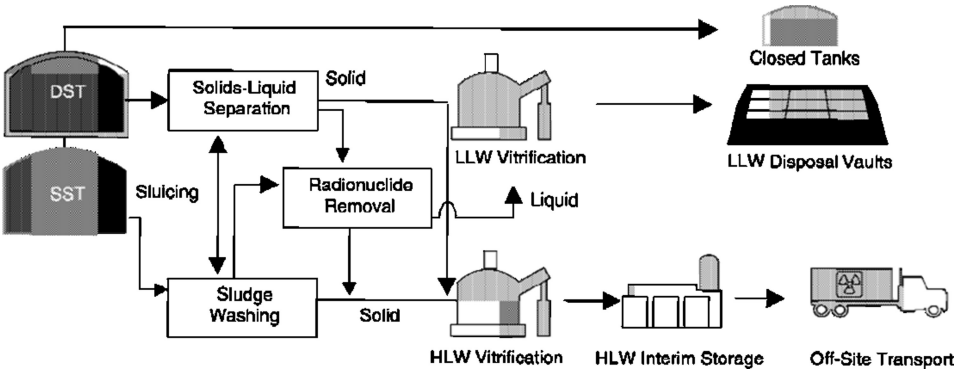


**Figure 5:** Simplified flow sheet for the Tank Waste Remediation System (TWRS) 1996–2002. (Source: NAS Research Needs for High Level Wastes Stored in Bins and Tanks at U.S. Department of Energy Sites, 2001.)

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.[54] 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).[55] (See Figure 5.)

In February 2004, however, DOE stated that "Yucca Mountain does not have the space for all defense HLW waste."[56] In order to accommodate the burgeoning inventory of spent reactor fuel,[57] 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.[58] Assuming a proportional cut in disposal, Hanford's allocation will be reduced by over 60 percent. Thousands of high-level waste canisters are expected to remain at Hanford and other sites, awaiting disposal in a second repository. (See Figure 6.)

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

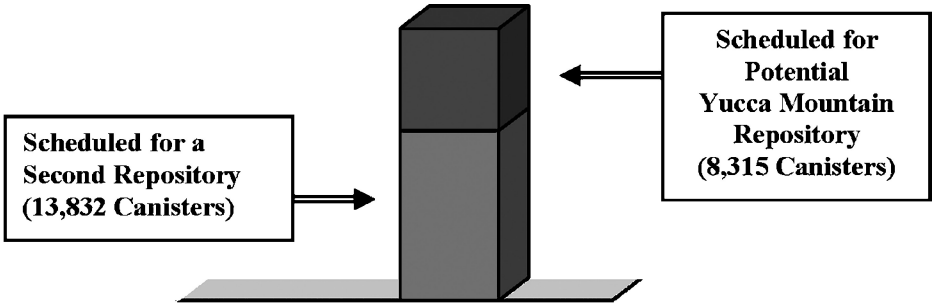


**Figure 6:** Projected disposal of DOE High-Level Waste canisters scheduled for a second repository (13,832 Canisters), scheduled for potential Yucca Mountain Repository (8,315 Canisters). (Source: DOE/EIS-0250, Appendix A.)

Savannah River Site would be the equivalent of 0.5 MTHM.[59] 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.[60] Based on this formula, DOE estimated in 1985, that approximately 21,000 canisters would be "approximately equivalent to 10,000 MTHM of commercial HLW."[61]

DOE's 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."[62]

Actual production data show that DOE's criteria are not supported by current waste loading in HLW glass canisters at SRS. Since 1996, some 1,500 canisters produced at the Savannah River Site each contain an average of 3,500[63] curies to 10,500 curies.[64]

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."[65] DOE concurred in 2002, finding that disposal of all projected HLW canisters "would not change the cumulative impacts."

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."[66] 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."[67]

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.

## MAJOR CHALLENGES

### "Fast-Tracking Safety"

Vitrification of Hanford's high-level wastes requires a high degree of safety, particularly since it is the largest, first-of-a-kind project and also the largest project of its kind in the world.[68] (See Appendix A.) The waste treatment plant involves processing of tens of megacuries of radiochemicals, posing potential risks of leaks, nuclear criticalities, explosions, fires and large environmental releases.[69] The U.S. Nuclear Regulatory Commission considers the Hanford high-level waste vitrification plant as having radiological inventories and accident consequences comparable to a nuclear power plant.[70] Key radionuclides considered as exposure hazards during processing include carbon-14, strontium-90, iodine-129 and cesium-137.[71]

Until 2001, the NRC was in the process of establishing safety regulation of the Hanford high-level waste vitrification plant through a Memorandum of Understanding, signed in January 1997.[72] Because the vitrification plant was to be privately owned, the MOU was intended to develop a regulatory program that would allow for the transition to NRC regulation.

In assuming this new responsibility the NRC encountered major differences in safety regulation between NRC and DOE. For instance, DOE self-regulates safety primarily through a system of "Orders,"[73] which are not on their own, legally binding, but rather are enforced as contract requirements. Under DOE cost-plus contracts, the DOE must pay for any additional costs for compliance with safety orders. Since they are not subject to the Administrative Procedures Act, DOE Orders can be changed at individual sites, without public knowledge or involvement.

The Defense Nuclear Facilities Safety Board (DNFSB) was created in 1988 and provides independent oversight of DOE defense nuclear facilities.[74]Since its inception the DNFSB has been involved in safety issues pertaining to Hanford's high-level waste activities. The DNFSB does not have regulatory authority and can only make recommendations to the Secretary.

By contrast, NRC has a well-developed system of formal regulations that have the force of law, are subject to the Administrative Procedures Act, and are issued to licensees as mandatory requirements.

However, in May 2000, DOE ended privatization at Hanford for cost reasons.[75] The DOE subsequently terminated NRC's involvement and reestablished self-regulation under its traditional, cost-plus, management and operations (M&O) contract system.

In its June 2001 report the NRC identified over two dozen significant safety issues and over 50 specific topics in the current design and approach which remained to be resolved.[76] "Several scenarios involving large radiochemical inventories (in tanks), flammable gases, organic ion exchange resin interactions, glass melters, and cold chemical effects," according to the NRC, "were found to have potential accident consequences to the workers and the public of significant severity and risk."[77]

The NRC found that plant "has more stored chemical energy for prompt potential events directly involving the radionuclides in their mobile forms,"[78] and thus, radiological consequences to members of the public could result in doses in the hundreds or thousands of rem.

In arriving at this conclusion, the NRC was actively involved in the development of the Documented Safety Analysis (DSA), a required safety document that extends to the design, construction, and operation of a nuclear facility.[79] The DSA includes a comprehensive hazard analysis associated with accident scenarios that could result in significant consequences to members of the public and the environment. In turn, the hazard analysis is required by regulation to include estimates of the frequency of unmitigated risks, which do not take into account preventative features that would lessen the consequences of an accident, "other than initial conditions and the basic physical realities of a given operation."[80] This approach is supposed to envelope uncertainties that provide adequate safety margins.

The NRC found that DOE did not "appear to adequately address the significance of unmitigated events." DOE's "implicit assumptions" would result in "less severe consequences" and "may result in overlooking and not identifying safety controls and their requirements, including reliabilities." NRC reported "there still is an apparent bias ... to implicitly rate hazards in a mitigated manner ... Thus, it is not clear that safety requirements are being adequately identified and categorized."[81]

In this context, the NRC estimated the total unmitigated risk of major accidents involving large radiation releases, such as a melter steam explosion or a resin fire, at the Hanford vitrification plant was 2.4E-2/yr (annual risk of 2.4 percent).[82] This translates into a 50–50 chance of a major accident over 28 years of operation.[83] (See Table 2.)

Chemicals also pose significant hazards. Tank failures containing nitric acid and anhydrous ammonia could cause severe injuries and death and "render the facility uninhabitable" to an area extending beyond a mile.[84]

However, NRC found that (with the exception of the glass melters) existing "mitigation methods exist that are compatible with the regulations and offer the potential for reducing process accident risk to more acceptable levels (circa 2E-6/yr)."[85]

A melter steam explosion constituted more than 50 percent of the unmitigated risk of a catastrophic accident[86] and NRC staff expressed concerns

**Table 2:** Unmitigated accidents at the hanford high-level waste treatment plant.

| Event | Unmitigated consequence impact, receptor at 100 meters, rem | Part 70 consequence category | Estimated frequency (uncontrolled event/yr) | Likelihood (probability) bin | Unmitigated impact risk, yr-1 |
|---|---|---|---|---|---|
| LAW tank failure | 3,000–6,300 | High | 2E-5 | Unlikely | 3E-5 to 6E-5 |
| HLW tank failure | 6,000–12,000 | High | 2E-5 | Unlikely | 6E-5 to 1.2E-4 |
| Cesium tank—loss of cooling/boiling (1,000 gal) | 25,000 | High | 1E-6 | Unlikely | 1.25E-3 (30 percent of total unmitigated risk) |
| Melter/canister failure, cold cap dispersal | 14,500 | High | 1E-3 | Unlikely | 7E-4 (3 percent of total unmitigated risk) |
| Cesium eluting, resin/nitrate interaction | 3,400 | High | 1E-3 | Unlikely | 1.7E-3 (7 percent of total unmitigated risk) |
| Hydrogen deflagration/ LAW heel | 20,000 | High | 1E-5 | Unlikely | 1E-4 |
| Melter/Steam explosion | 26,000 | High | 1E-3 | Unlikely | 1.3E-2 (54 percent of total unmitigated risk) |

Source: NUREG 1747, Table 4.

that "few tests appear to be planned to verify safety parameters prior to construction."[87,88] NRC's concluded that DOE and its contractors had sufficient knowledge and capabilities to mitigate the likelihood probability to 1E-4.[89]

"Further analysis" was required, however, to determine if melter risks could meet probabilities acceptable under NRC regulations for reactors and fuel cycle facilities (10 CFR 70).[90]

Based on review of the nine high-level radioactive waste and several low-level and mixed waste vitrification facilities throughout the world, NRC-sponsored research points out that "operating limits on chemical composition, redox control, and glass properties such as viscosity, electrical resistivity, phase separation and liquidious temperature should be established before start of the radioactive process."[91] Failure to meet these conditions have led to serious problems. For instance, since 1991, there have been eight melter-related incidents and failures in the DOE complex.[92,93] (See Table 3.)

On one instance, on 21 April 1996 pressurized steam vented rapidly through the melted glass the Oak Ridge low-level, In Situ Vitrification (ISV) plant and caused an explosion that expelled 20,000 kgs of glass, spewing hot fragments over 100 meters from the melter site.[94]

Of major concern to the NRC was that, proposed designs "do not consider prevention and controls [and] do not include important auxiliary effects in the analyses, such as common mode failures, operability, recoverability, and plant habitability for operators"[95] The NRC concluded that "regulatory and safety issues associated with a much larger facility do not appear to have been considered . . . On many occasions, there was an implication that regulatory reviews were not allowed to impact cost and schedule . . .[96]

However, since the NRC ended its relationship, DOE has taken steps to "reduce conservatism" in its high-level waste safety controls at Hanford to "allow work to be performed more quickly."[97] As a result DOE and its contractors have significantly curtailed safety analyses and oversight, reduced operational safety procedures, and eliminated DOE approval of important changes in safety analyses and subsequent construction decisions.

Efforts to "reduce conservatism" have now, however, proven to be costly and time consuming. In 2003 the Defense Nuclear Facility Safety Board took issue with the design assumptions about earthquakes stating that the Hanford site could experience destructive seismic activity 15% greater than California sites.[98] In March 2005, after subsequent testing, the Energy department was compelled to suspend construction for facilities that would handle a preponderance of wastes and to increase the design standard from 20 percent to 40 percent.[99]

DOE's preference for administrative over engineering controls, because they cost less is also of concern. According to NRC, DOEs approach "appears to rely extensively on operator actions to prevent or mitigate the

**Table 3:** Summary of melter-related incidents in the DOE.

| Incident | Corrective action | Lessons learned |
|---|---|---|
| *Savannah River DWPF* Wicking of the glass stream during pouring resulted in plugging of the discharge orifice on a regular basis. (1997) | The discharge shut was modified to reduce wicking and in addition, remote equipment was installed to clean a plugged orifice. | Future melter designs should account for wicking of glass pour streams. |
| *West Valley WVDP* The transposition of a weld symbol at the dam and trough interface in engineering drawings was the root cause for glass seepage onto discharge wall. Missing weld resulted in separation between dam and trough. (1996) | Since the incident occurred during cold operations, hands on repairs were conducted, and operations were subsequently resumed. | Rigorous design review check and control should be implemented. |
| *West Valley WVDP* The ceramic nozzle liners failed due to insufficient thermal expansion allowance. (1997) | The nozzle liners were redesigned. | Selection of materials and design of components should undergo evaluation prior to radioactive operations. |
| *West Valley WVDP* Formation of glass fibers in the discharge section led to the blockage of the discharge orifice. This was the result of high air-inflow through the discharge orifice to the melter.(1996) | Flow-reducing orifice was installed to reduce airflow. | Operating limits for airflow rates, pressure, and temperature should be established prior to start of process. |
| *Savannah River* The mixed low-level radioactive waste vitrification facility in the M-area suffered an electrode failure that caused accelerated corrosion and failure of molybdenum electrodes. This was partially attributed to the failure of cooling systems for the electrodes. (1997) | Melter replaced. | Corrosivity of the melt and its compatibility with the components should be established before melter operations. Performance of the melter should be continually assessed during operations via quality assurance programs and safety audits. |
| *Fernalds* A nonradioactive melter failed, dumping 6,000 kg of glass on the floor due to degradation of the melter components caused by incompatible feed chemicals. (1996) | The facility was shut down. | Corrosivity of the melt and its compatibility with the components should be established before melter operations. Performance of the melter should be continually assessed during operations via quality assurance programs and safety audits. |

*(Continued on next page)*

**Table 3:** Summary of melter-related incidents in the DOE. *(Continued)*

| Incident | Corrective action | Lessons learned |
|---|---|---|
| *Oak Ridge National Laboratory* A radioactive waste In situ Vitrification Plant experienced a steam explosion which resulted in the release of off gas and an expulsion of 20,000 kgs of molten glass, spewing fragments 100 m from the melter site. (1996) | Recommended corrective actions included diversion of standing water around the pit, installation of flow-monitors and curved vent pipes beneath the melt to provide alternate paths for steam, submelt pressure measurement, and video monitoring of the melt surface. | Melters should have safeguards designed to account for not only normal operating conditions, but also for abnormal conditions such as steam explosion. |
| *Hanford* A large-scale test of In situ Vitrification on a buried 6000-gal tank resulted in a steam explosion which raised the off-gas hood 12 in. from the ground and the expulsion of molten soil. (1991) | The facility was shut down. | The cause was ascribed to sealing of the walls of the tank to the melt body precluding normal pathway for dissipation of steam from the melt. |

Sources: Vijay Jain, Process Safety Issues Associated with Melter Operations During Vitrification of Radioactive Wastes, Proceedings of the XVIII International Congress on Glass, 2000, and ORNL/ER-371.

effects of chemical hazards. . . . The normally accepted practice and NRC regulatory emphasis are minimization of the reliance upon administrative controls."[100]

A key safety concern where engineering controls are important is fireproofing and fire suppression. The Waste Treatment Plant will be handling large quantities of flammable materials. However, DOE and its contractors are cutting costs by reducing steel fireproofing and fire suppression requirements. In 2000, the NRC objected to this approach because it would "severely limit any future modifications" and "lack of fire suppression capability along with lack of steel protection in the same area makes administrative control of combustibles the only defense measure . . ."[101]

In April 2003, the Office of Environmental Management's Director of for Safety and Engineering at DOE's Headquarters, reiterated the NRC's concerns regarding a decision made by ORP to reduce fire protection requirements at the Waste Treatment Plant.[102] It was pointed out that one of the areas, which was given a "low" combustible rating would have to withstand fires that are "equivalent of 2,370 pounds of wood in an area the size of an individual office." Moreover, "the construction contractor has also proposed a combustible decontamination coating in lieu of stainless steel on all surfaces which will appreciably add to the combustible loading in these spaces."[103]

Like the NRC, the headquarters review found that "administrative controls are not an approach that would be intentionally selected for new facilities

during construction where complying with the standards is relatively easy and could avoid controls."[104]

In January 2004, however the Office of River Protection (ORP) concurred with the contractor to reduce fireproofing in its design approach. According to the staff of the Defense Nuclear Safety Board, "it is not known how the analysis will address fires when the sprinkler suppression system is inoperable."[105]

Finally, the growing number of worker exposures and injuries in the Hanford tank farms, and construction mistakes over the past two years provide warning of potentially more serious problems to come. Over the past two years, despite admonitions from DOE researchers about occupational dangers,[106, 107] several workers have been exposed to tank vapors. For instance, in July 2003, 12 workers breathed in radioactive materials, and contaminated their skin, while working in a pit near a high-level waste tank. "The health physics technician counting contamination samples unsuccessfully tried to stop the work,"[108] despite the high number of workers being put at risk. Some 90 workers have reported illnesses and injuries to site medical professionals, claiming they were caused by from exposure to tank vapor exposure.[109] This has resulted in investigations by the State of Washington, the U.S. Congress and the DOE's Office of Inspector General.[110, 111]

In February 2005, Waste Treatment Plant construction workers reported to DOE "a chilling effect with regard to fear of retaliation for reporting safety, medical, and labor relations issues. Approximately 20% of the workers interviewed described harassment, intimidation, and fear of termination when using the first aid facility on the site or after using a private physician and an equal percentage voiced the belief that when individuals raise safety concerns, those individuals are targeted for future lay off lists."[112]

## ONSITE DISPOSAL

DOE's accelerated cleanup program will result in direct on-site disposal of a substantially larger amount of radioactivity from Hanford's high-level waste tanks than agreed by the NRC staff in 1997. In an effort to reduce the amount of wastes to be processed in the vitrification plant, contents from dozens of Hanford tanks are to be processed, without radionuclide separation, using bulk vitrification and possibly other "supplemental" technologies[113] for permanent on-site disposal, leaving behind substantially larger amounts of radioactivity on-site.

To accomplish its objectives to reduce the number of HLW canisters and to leave more radioactivity on-site, DOE is seeking to reclassify high-level wastes as "incidental."[114] In July 2003, a federal district court ruled that DOE does not have the authority to reclassify high-level wastes.[115] The following year Congress enacted legislation which authorized the DOE to self-regulate HLW disposal with NRC consultation. However, Hanford was excluded from this

provision. After vigorous protest by Washington State's US Senate Delegation. Also, sludge from deteriorated spent reactor fuel at the Hanford K-basins[116] and wastes from a dozen tanks[117] are designated as "potential transuranic wastes" for disposal in the DOE's Waste Isolation Pilot Project (WIPP) in New Mexico. Attempts to dispose of Hanford HLW tank wastes implicitly raises the question: Will WIPP, by default, become the second repository for thousands of HLW canisters which DOE claims it has no room for in Yucca Mountain?

Concurrent with the design and construction of treatment facilities, 40 tanks are scheduled to be emptied and "interim" closed within the next two years.[118] Such tanks are expected to have all retrievable wastes removed and to be in a stable state for final closure.[119] Once wastes are removed, cement will be poured in the tanks to immobilize yet-to-be determined concentrations of residual long-lived radionuclides.

The scientific underpinning for disposal decisions at Hanford should be a sound understanding of the fate and transport of tank wastes in the environment. Even though a large amount of wastes were discharged or leaked into the soil, DOE's current understanding of contaminant mobility "is inadequate to fully support cleanup, closure, or performance assessment-related decisions."[120]

The closure of 177 large tanks and many miles of underground pipes and related infrastructure will leave behind significant amounts of residual high-level wastes. According to DOE-sponsored research, radionuclides from tank closure represent "one of the most significant long-term dose contributors on site . . . However, the radionuclide release rate from these solids is virtually unknown."[121]

Under current regulations, the NRC still determines what constitutes high-level wastes for geological disposal at Hanford.[122,123,124] However, NRC has chosen to exercise its authority through staff-level agreements with the DOE. NRC has yet to issue a formal determination by rulemaking, or other means, regarding on-site disposal of defense high-level wastes. This regulatory approach has allowed DOE to proceed with actions, such as disposal of HLW tank residuals at the Savannah River Site, which for all practical purposes are irreversible. It also, in the case of Hanford, allows DOE to disregard agreements with NRC staff, without regulatory consequences.

Given these circumstances, the NRC staff provisionally agreed to a plan by DOE in 1997, to remove radionuclides from soluble high-level wastes to allow their on-site disposal.[125] This agreement was specifically based on estimates provided by DOE that:

1. Radionuclide removal to the maximum extent technically and economically practical will leave no more than 9.8 MCi Cs-137(including barium-137 m decay product)and 6.8 MCi Sr-90 (including yttrium- 90 decay product) low activity wastes.[126]

2. Removal of TRU as required . . . will ensure all solidified LAW is <100 nCi TRU/g.

3. All disposal requirements including those defined by the performance assessment required by DOE Order will be met.[127]

NRC staff found that DOE's plan "is not sufficient to make an absolute determination at this time."[128] Moreover, if DOE did not utilize separation technologies embodied in the Tank Waste Remediation System,[129] and if there were large increases in tank inventory data, "the incidental waste classification must be revisited by DOE and the NRC consulted."[130]

Based on activities outlined in the Integrated Mission Acceleration Plan for the processing and disposal of Hanford's high-level wastes,[131] the Energy department is:

- seeking to dispose of substantially larger quantities of radionuclides than agreed to by the NRC staff; (See Table 4)
- proceeding to dispose of wastes with significantly greater radionuclide inventories than provided to NRC staff; and
- failing to demonstrate compliance with waste performance assessments.

DOE has identified wastes in 62 tanks, which are to be retrieved and immobilized using "supplemental" technologies without additional removal of radionuclides.[132] Waste from these tanks combined with decontaminated low-activity wastes coming from the treatment plant could result in the onsite disposal of more than three times the strontium-90 and over than six times the transuranics agreed to by the NRC staff.

Waste inventory data, particularly for transuranics have increased since DOE entered into the 1997 agreement with the NRC. As Figure 8 indicates transuranics increased nearly three-fold. (See Figure 8)

Relative to meeting the terms of the 1997 agreement to perform waste performance assessment, a major concern is the groundwater impact from iodine-129. DOE was informed by CH2MHILL, Hanford's HLW tank farm contractor, in September 2003, that: "iodine is a key driver in the risk assessment and the inventory of iodine is uncertain for tank waste and secondary waste."[133] Iodine-129 is of concern, because of its very long half-life and potential to harm the human thyroid. DOE estimates that five curies of I-129 from the disposal of secondary processing wastes are a dominant dose contributor.[134] In January 2004, the DOE provided it first performance assessment for on-site low-activity waste disposal, in which it indicates that on-site disposal of Hanford tank wastes meets expected requirements.[135]

However, this amount would result in drinking water concentrations of iodine-129 that are 22 times higher than the EPA's maximum concentration limit (MCL), if proper methods are used.[136] Instead, DOE bases its estimates

**Table 4:** On-site radionuclide disposal in low-activity wastes at Hanford (curies).

| Radionuclide | On-site IAW disposal agreed by NRC staff in 1997 (a) | 62 tanks scheduled for supplemental waste treatment b) (c) | 115 tanks scheduled for waste treatment plant (b) | Accelerated cleanup 177 tanks total on-site LAW |
|---|---|---|---|---|
| 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.

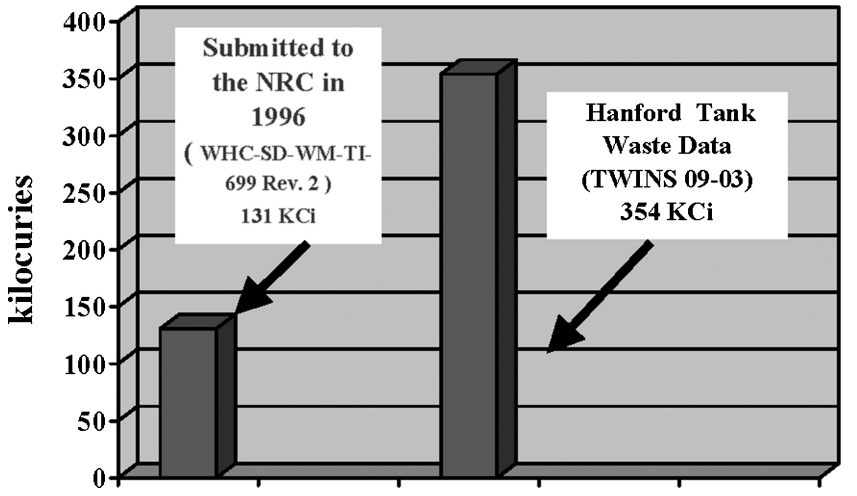


**Figure 7:** Increase of Transuranics in Hanford Tanks submitted to the NRC in 1996 (HC-SD-WM-TI-699 Rev. 2) 131 Kci Hanford Tank Waste Data (TWINS 09-03) 354 Kci Kilocuries.

on a whole body dose (MCL of 1pCi/L = 0.18 mrem/yr).[137] In doing so, DOE ignored a universally accepted principle that retained radioiodine concentrates almost exclusively in the thyroid, not the whole body. Moreover, DOE's dose estimation methodology ignores EPA standards and DOE's own orders.

## REDUCING SAFETY RISKS

The risks of high-level waste processing at Hanford, based on a preliminary estimate by the NRC, are comparable to those of U.S. manned space program.[138] As the largest, first-of-a-kind process handling large volumes of ultrahazardous materials, safety risks are compounded by inadequate waste characterization data and a lack of processing experience with actual wastes. Given these knowledge gaps, risk assumptions, design and construction decisions require strong elements of conservatism to envelope major uncertainties. Conservative parameters may overestimate risks, but result in a high margin of safety and public confidence.

Given the large risks involved, Congress should authorize the Nuclear Regulatory Commission to license the construction and operation of the Hanford vitrification plant; and certify the safety of stored high-level radioactive wastes. The NRC has invested three and half years at Hanford, and could effectively resume a transition to external regulation that can provide a consistent and comprehensive approach to tank waste storage and processing.[139] Legislation enabling NRC regulation should clearly define roles and responsibilities, such as:

- DOE retains title to all high-level radioactive wastes;

- NRC regulation of the vitrification plant would fall under 10 CFR Part 70 which governs nuclear fuel cycle facilities;
- The contractor would hold the license and DOE would not be subject to direct NRC fee assessment; and
- The certification of high-level waste storage tanks would be licensed under 10 CFR Part 76, because these are existing facilities being certified rather than licensed.

NRC has estimated that 32 full time staff equivalents would be required to carry out the work, which corresponds to $8 million per year. These costs are required to be recovered by charges levied on the licensee. Since NRC has already developed regulations and guidance, the annual costs may be lower for regulatory transition. Moreover, the total costs of NRC regulation are a small portion—less than half of one percent—of the total program cost.

## REDUCING ON-SITE DISPOSAL RISKS

DOE's efforts to dispose of substantially larger quantities of radionucides on-site from high-level wastes are premised on establishing "risk-based end states." Modeling of the natural attenuation of radionuclides over periods of hundreds to thousands of years is a limited approach that does not factor in:

- dramatic shrinkage of controlled areas at the Hanford site within eight years,
- accident scenarios involving the processing of high-level wastes,
- the high existing vulnerability of tribal people to environmental contaminants, and
- integration of natural resource risks with human health risks.

Over coming years, DOE plans to lift radiological controls over large swaths of the Hanford site for transfer to the U.S. Interior department's Fish and Wildlife Service. The transfer is intended to reduce DOE overhead expenses, while expanding the Hanford Reach National Monument.[140] More than 87 percent of the land DOE currently occupies will be shifted to Interior, by 2012 opening public access for thousands of people.[141] Even though potential vitrification accidents "show a significant distance effect,"[142] DOE's assumes that Hanford's current security perimeter of 6.8 to 9.3 miles (11,000 to 15,000 meters), will indefinitely serve as the boundary for public exposures.[143] To be more protective, NRC's guidance, which sets the public dose, including collocated workers, at the "fence line" of 100 meters should be adopted.[144]

Underscoring the need for public health conservatism is recent evidence indicating that tribal people living near Hanford are the most vulnerable to harm

from environmental contaminants. The Environmental Protection Agency reported in 2002 that fish in the Hanford Reach have the highest concentrations of contaminants in the Columbia River Basin, and that tribal people who eat fish from the Hanford Reach have up to a 1 in 50 lifetime risk of contracting fatal cancers.[145]

Because the tribal lifestyle is heavily dependant upon subsistence food gathering, protection of natural resources and human health are intrinsically linked. DOE has yet to make this connection. For instance, around the same time the EPA fish contaminant study was released, DOE set a standard limiting radiation exposure to fish in the Hanford Reach to no more than one rad (radiation absorbed dose) per day.[146] If a tribal adult eats fish so exposed from technetium-99, the annual human dose would be about 8.3 rems.[147]

As DOE seeks to transfer large parcels of the Hanford site to the Department of Interior, no comprehensive health and ecological risk assessments have been done as required under the Superfund Act.

Given these circumstances, NRC's 1997 provisional staff approval for the on-site disposal of 16.6 megacuries of radionuclides remaining in soluble tank wastes should be reconsidered, with the objective of significantly reducing this radiological contaminant burden. Towards this goal, the NRC should actively consult with the EPA, Washington State, Oregon and affected Indian tribes to establish comprehensive, formal limits on tank closure, HLW processing and disposal. A comprehensive health and environmental risk assessment of the Columbia River should be done in accordance with the Superfund Act.

Finally, the Nuclear Regulatory Commission should be funded by Congress to make a formal determination by rulemaking to allow on-site disposal of those high-level wastes which can be deemed as "incidental."

In DOE's haste to terminate its environmental mission, the Congress, federal and state regulators, and the Interior Department must actively ensure that DOE is not heeding advice that "sometimes the environmentally preferable course of action is to do little or nothing."[148]

## REDUCING PROJECT RISKS

DOE should cease its "fast-track" approach and follow numerous expert recommendations to build and operate "pilot" operations using actual Hanford high-level wastes. This was done at DOE's West Valley Vitrification Demonstration Project in New York, and would establish the necessary experiential basis for feed preparation, pretreatment and melter technologies. It was not done at the Savannah River Site for high-level, soluble waste pretreatment, which resulted in a 20-year failure costing $500 million with $1.8 billion estimated for a technological replacement. By virtue of the magnitude of the environmental, safety, and financial risks involved, processing of Hanford's high-level wastes is

of national importance and should have a commensurate level of project management attention by the Energy Department.

DOE has a history of failed projects, cost overruns, and delays,[149] which prompted the U.S. Congress in 1998 to seek the assistance of the National Research Council. The Council subsequently issued several reports[150,151] which found that:

- Environmental projects suffer from major delays and are about 50 percent more expensive than comparable federal and private-sector projects;
- Up-front project planning is inadequate;
- There is no consistent system for evaluating project risks; and
- DOE is not in control of many of its projects and had virtually abdicated its ownership role in overseeing and managing its contracts and contractors.

For over a decade, the DOE environmental cleanup program has been identified by the U.S. General Accounting Office as a "high-risk" program vulnerable to waste fraud and abuse. GAO describes DOE's management culture as one of "least interference" based on an "undocumented policy of blind faith in its contractors' performance."[152] The National Research Council also stresses a greater role by DOE:

> . . . as the custodian of public funds, [DOE] should not abrogate to contractors project definition, acquisition strategy decisions, and project oversight. To effectively fulfill its project management responsibilities, DOE needs to expand its investment in human capital to develop a corps of qualified project managers commensurate with the value and complexity of its projects.[153]

As an environmental project unrivaled in its scope, risk, and expense, the management and oversight responsibility for the success of this project should not be abdicated to contractors. DOE must go well beyond its Cold War role of serving primarily as funding administrator.

DOE should begin by establishing a full-time multidisciplinary, Hanford HLW Project Management Group, reporting to the Assistant Secretary of Environmental Management. This approach is well established by the DOE's Office of Science and has been endorsed by the NAS as a proven way to enhance the success of large complex projects.

Concurrently, the pool of talent in the DOE and the private sector to carry out DOE's complex nuclear cleanup tasks is shrinking, which reduces competition and can negatively impact the successful outcome of multibillion-dollar high-risk projects.

In order to address these structural problems DOE should seriously consider establishing a special program to educate and train students in the necessary fields to prevent further erosion of key skills and knowledge that is fast

disappearing in the DOE complex. A model that DOE should consider is the one established by the Office of Naval Reactors, which recruits and pays for the education of qualified college students, in exchange for government service. The scope of this recommendation is well beyond the issues covered in this article but it, nonetheless deserves serious attention by the DOE and the Congress.

## APPENDIX A

### Technological Issues

The basic process to be deployed at Hanford of melting silica and adding materials to form glass has been around for some 2000 years. The melters to be used at Hanford are a joule-type with a ceramic lined furnace that is heated to a temperature of 1,150°C. by passing electric current through the glass by electrodes to produce borosilicate glass.[154] (See Figure 8.)

Worldwide, there are five high-level waste, and two low-level and mixed low-level waste vitrification plants that have used joule-heated melters.[155] While it is considered a mature technology with 20 years of experience, these types of melters have low glass production rates.[156] With an average design life of 3–5 years, several melters have experienced major problems, "such as breach of a

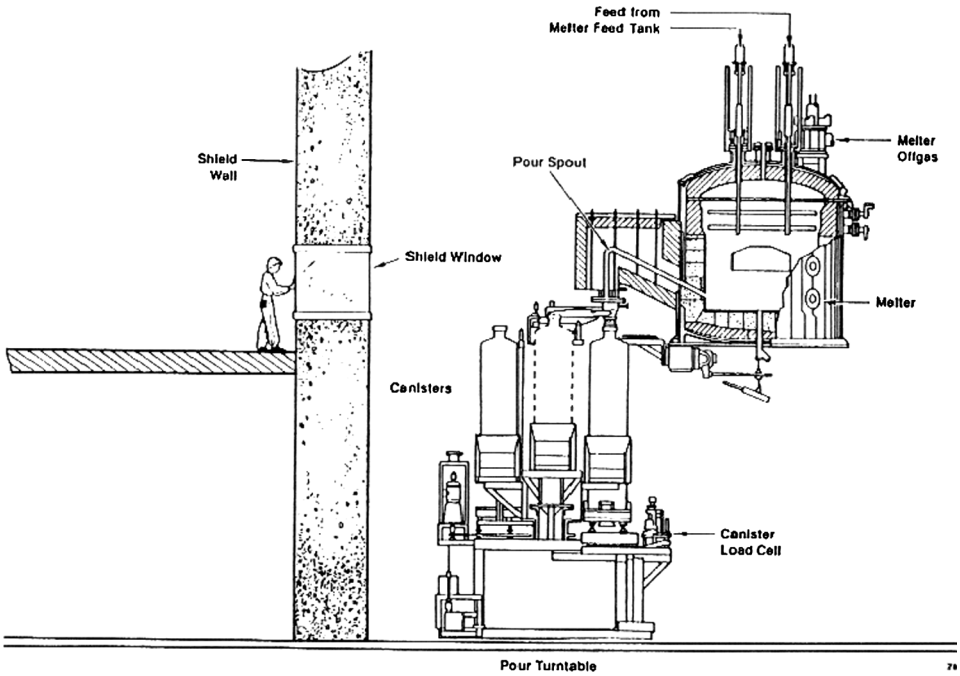


**Figure 8:** Handford waste vitrification plant melter/turntable. (Source: DOE/RL-900009.)

melter vessel, allowing molten glass to leak/drop out of the melter, uncontrolled off gas from the melter, failure of the joule-heating system, and plugging of the glass pour drain."[157]

The Hanford vitrification plant will have the largest melters in the world—two for high-level wastes and the other for low-activity wastes. Initially the TWRS program was to begin with a relatively small, pilot plant that would process between 6 to 13 percent of Hanford's tank waste. This would have allowed verification of design and technical approaches with minimal economic, programmatic, and safety risk.

For instance, according to NRC-sponsored research the use of surrogate wastes, as is the case with current Hanford melter tests, may prove inadequate because "actual Hanford wastes may be more reactive."[158] But the pilot plant was scrapped, despite recommendations by the NAS, NRC, GAO and DOE's construction contractor.[159] Instead the Energy department has decided to concurrently design and construct a full industrial-scale operation based on the concept of "learn by doing."[160]

As noted in 2001 by a DOE- sponsored review of nuclear waste vitrification melters: "Construction costs, although important, are not major determinants in life-cycle cost. . . . , High-level waste operating cost savings from increased waste loading or throughput may not be attainable without corresponding throughput improvements (or additional facilities) in retrieval, pretreatment, and low-level waste vitrification."[161] DOE's approach is already facing "potentially large cost and schedule overruns and performance shortfalls," predicted two years ago by the National Research Council.[162] For instance, in February 2004, it was discovered that an already installed waste processing tank did not meet safety inspection requirements after seven similar vessels were more than 94 percent fabricated, with similar flaws. Dozens of the welds in other waste processing tanks were also found to be "undersized or undercut, or have inadequate contouring." Apparently Bechtel and the fabricator did not check to see if tank construction comported with design drawings.[163] As a result of problems like these, estimated construction costs for the treatment plant have grown by more than 25 percent, from $4.35 Billion to $5.78 Billion.[164]

In the absence of pilot operations using actual Hanford Wastes, DOE faces several major challenges:

**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."[165] At Hanford, processes to remove corrosive metals, such as chromium, from tank sludge "are not effective."[166,167] The inability to remove sulfate adversely impacts low-activity waste glass production, which remains an important concern. Moreover, DOE has not been able to demonstrate that large-scale decontamination of soluble

wastes can work—as witnessed by the 20-year failure at the Savannah River pretreatment facility estimated to cost more than $2.3 billion in lost and future expenses.[168]

**Feed Preparation and Melters.** Preparing chemically balanced and homogeneous feed is of utmost importance because "the melter is quite unforgiving of batching errors."[169] This task is made difficult because knowledge of the characteristics of Hanford's wastes, according to the National Research Council, "is of little value in designing chemical remediation processing."[170] The inability to have proper feed can cause: (a) short-circuiting of melter electrodes by the phase separation of chromium, ruthenium, rhodium, and palladium from the melting glass;[171] (b) corrosion of the melter lining, clogging of the outflow of the glass melt to the canisters; (c) ruining the integrity of glass from chromium, phosphorus oxide, and sodium sulfate;[172] and (d) major accidental releases.[173] High radiation fields that require remote repairs and potentially frequent melter replacement,[174] exacerbate these problems.

**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 off-gas system must capture and processes these materials to prevent hazardous materials from entering the environment. Pumping excessive or chemically incompatible feed to the melter can cause large pressure surges, which could result in failure of the system and potentially large accidental releases.[175]

**Process Controls.** The Waste Treatment Plant will have to rely upon a complex set of engineering, administrative and operational controls, including a computer-based system that would control all aspects of facility and process operations. Understanding potential radiological, flammable, chemical, and explosive hazards and the efforts to mitigate these hazards requires accurate characterization of the chemical compositions and radionuclide concentrations at each stage of the Hanford Waste Treatment Plant process.[176] For instance, knowledge of particle size distribution and particle density of wastes, essential to design waste transfer systems such as pipes and pumps to prevent plugging, flammable gas buildup, equipment failures and accidents, remains elusive at Hanford.[177,178] Hydrogen explosions in nuclear facility piping is not an abstract issue, as there have been two hydrogen explosions in boiling water primary system pipes and an additional 25 hydrogen fires in reactor facilities and reactor pumps.[179]

**Secondary Wastes.** The Waste Treatment Plant will generate a considerable volume and high concentrations of wastes from sludge washing, ion exchange, and other processes.[180] In September 2003, DOE's contractor reported that analysis "shows significant impact from secondary wastes and thermal processes."[181]

Failed melters and related equipment are of particular concern because they are likely to contain large, irremovable concentrations of high-level

wastes.[182,183] DOE plans to dispose of failed melters in an onsite trench[184] even though Hanford "currently does not have the capability to . . . dispose of failed, highly contaminated processing equipment."[185] DOE researchers advise that, "it is unacceptable to place this waste form in relatively uncontrolled long-term storage and to continue to add more of the same and other equipment. . . ."[186]

**Bulk Vitrification.** Bulk vitrification is a supplemental treatment technology which is expected to process 60 to 70 percent of single-shell tank wastes. It involves the superheating of wastes mixed with soils containing glass-forming materials (i.e., silica, sand) with large electrodes in a large metal container. When the wastes are glassified the electrodes (melter) remain embedded in the glassified material and are disposed with the waste. Numerous bulk vitrification containers are planned, with a test project using wastes from a Hanford tank scheduled for next year. Like the melters in the Waste Treatment Plant, the success and safety of bulk vitrification will be very dependant on pretreatment and feed preparation. Several processing steps prior to vitrification have to be worked out such as: dissolution of salts for retrieval, recrystallization, chemical pretreatment, and a high-degree of moisture reduction in soil and feed. As mentioned bulk vitrification poses potentially serious long-term groundwater impacts from secondary wastes.[187] A steam explosion in 1991 at Hanford, using in situ vitrification with a 6,000 gallon tank, should serve as warning, as DOE proceed with its initial efforts to deploy this technology.

## NOTES AND REFERENCES

1. Robert Alvarez and Arjun Makhijani, Radioactive Waste: the Hidden Legacy of the Nuclear Arms Race, *Technology Review*, July 1988.

2. U.S. Department of Energy, Plutonium: The First 50 Years, United States Plutonium Production, Acquisition, and Utilization from 1944 through 1994 http://www.osti.gov/html/osti/opennet/document/pu50yrs/pu50yc.html#ZZ15, 20 July 2004.

3. U.S. Department of Energy, Summary data on Radioactive Waste, Spent Nuclear Fuel and Contaminated Media, Office of Environmental Management, 2001.

4. The Savannah River Site, Aiken SC, the Idaho National Laboratory, Idaho Falls, ID, the West Valley Vitrification Demonstration Project, West Valley, NY, and Oak Ridge National Laboratory, Oak Ridge, TN.

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

6. GAO-03-593, 2003. p. 17 and p. 20.

7. U.S. Department of Energy, "Review of Generation and Flow of Recycled Uranium at Hanford, " Richland Operations Office, DOE/RL-2000-43, Executive Summary, p. 2.

8. AEC, 1970. "Siting of Commercial Fuel Reprocessing Plants and Related Waste Management Facilities, 10 CFR Part 50, 'Licensing of Production and Utilization Facilities,'" Federal Register, Vol. 35, No. 17530-17533, Atomic Energy Commission, Washington, D.C., November 14, 1970. Under this regulation high-level wastes are defined as, "aqueous wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent in a facility for reprocessing irradiated reactor fuels."

9. U.S. Environmental Protection Agency, 40 CFR part 197, p. 10.

10. U.S. Court of Appeals for the District of Columbia Circuit, Nuclear Energy Institute v. the Environmental Protection Agency, No. 01-1258, July 9, 2004.

11. National Research Council. Board on Radioactive Waste Management, *Technical Basis for Yucca Mountain Standards*, National Academies Press, Washington, D.C., 1995, p. 2.

12. They include: (1) Bismuth Phosphate (BiP04) Process (1944–1956), (2) REDOX Process (1952–1967); (3) Solvent uranium extraction from waste tanks (1952–1958); (4) PUREX Process (1956–1972, 1983–1990); and (5) Cesium and strontium solvent extraction from High-Level Tank Wastes (1968–1985).

13. National Research Council, Board on Radioactive Waste Management, *Science and Technology for Environmental Cleanup at Hanford*, National Academies Press, Washington, D.C, 2001, p. 21. Between 1944 and 1988, some 530 million gallons containing more than 800 megacuries (uncorrected for decay) were generated at Hanford.

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

15. Hanlon, Waste Tank Summary Report for Month Ending December 31 2002, HNF-EP-0182, Rev. 177, February 2003, Prepared for the U.S. Department of Energy Assistant Secretary for Environmental Management, pp A-2. B-4.

16. Timothy J. Jarvis, Stewardship and the United States Nuclear Weapons Production Wastes: An Introduction, *Environmental Progress*, 21(2):72 (2002).

17. Between the late 1960s and mid 1980s, Hanford removed approximately 130 megacuries of radiostrontium and radiocesium (decay-corrected) from several waste tanks to mitigate the risks of boiling wastes.

18. K. Tagami and S. Uchidas (2000). Global Fallout Technetium-99 Levels in Japanese Paddy Soils. *Proceedings of the IRPA 10 Conference*, Hiroshima May 2000 (available online at http://www.irpa.net/irpa10/cdrom/00362.pdf), July 2004. The total amount of technetium-99 that was produced in all worldwide aboveground nuclear weapons tests together can be calculated based on the data in the 1988 report of the "United Nations Scientific Committee on the Effects of Atomic Radiation" (UNSCEAR, 1988). Based on the UNSCEAR estimate of cesium-137 production in the weapons tests (960 PBq = 26 million curies) and the technetium-99 to cesium-137 ratio of 1:7,100 at time of detonation, the total amount of technetium-99 that was produced in all worldwide aboveground nuclear weapons tests together was about 3,600 curies.

19. TWINS Data 2003. The estimated plutonium-239 inventory is 68,800, curies, which is equivalent to 1.032 metric tons.

20. American Chemical Society, "Hanford's Vitrification Challenge," *Technology News*, December 12, 2002.

21. Steven F. Agnew, Hanford Tank Chemical and Radionuclide inventories HDW Model Rev. 4, LA-UR-96-3860, Los Alamos National Laboratory.

22. U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Hanford Tank Waste Remediation System High-Level Waste Chemistry Manual, Center for Nuclear Waste Regulatory Analysis, NUREG/CR-5717, 1999, p. 1–12. (Hereafter known as NUREG/CR-5717).

23. U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, *Hanford Tank Waste Remediation System High-Level Waste Chemistry Manual*, Center for Nuclear Waste Regulatory Analysis, NUREG/CR-5717, 1999, p. 1–12. (Hereafter known as NUREG/CR-5717).

24. National Research Council, Board on Radioactive Waste Management, *Research Needs for High-Level Waste Stored in Tanks and Bins at U.S. Department of Energy Sites*, 2001. National Academies Press, Washington, D.C, p. 18.

25. National Research Council, Board on Radioactive Waste Management, *Nuclear Wastes: Technologies for Separations and Transmutation* (1996) National Academies Press, Washington, D.C (Hereafter known as NAS Technologies). P 89.

26. NAS Technologies p. 92.

27. B. M. Hanlon, Waste Tank Summary Report for Month Ending December 31, 2002, HNF-EP-0182, Rev. 177. CH2MHILL Hanford Group, Richland, WA.

28. K. A. Gasper, Environmental Management Science Program Workshop Hanford Tank Farm Overview, CH2MHill Hanford Group, May 6, 2003. p. 3.

29. Ibid.

30. TWINS Data 2003.

31. Defense Nuclear Facilities Safety Board, March 30, 2001 TO: K. Fortenberry, Technical Director, FROM: D. Grover and M. Satan, Hanford Site Representatives, SUBJ: Activity Report for the Week Ending March 30, 2001 (Hereafter known as DNFSB Staff Report) According to this report: "Corrosion has reduced the thickness on the interior side of the primary liner as much as 19.4 percent at a corresponding to a former waste level. The waste was out of specification for years at that level. The current waste level is below this band. The actual thinning may be substantially larger since there was extensive pitting on parts of the annulus side of the primary liner and this pit depth was not quantified by this analysis."

32. Defense Nuclear Facility Safety Board, Letter to: Paul M. Golan, Acting Assistant Secretary for Environmental Management, U.S. Department of Energy, From: John Conway, Chairman, January 18, 2005. According to the Letter: "In a recent report by a panel sponsored by the Hanford tank farms contractor and composed of nationally known chemistry and corrosion experts, Expert Panel Workshop for Hanford Site Double-Shell Tank Waste Chemistry Optimization, RPP-RPT-22126, it was stated,'... due to the paucity and fragmentary nature of the available relevant DST corrosion data, it is not currently possible to provide a clear technical basis for DST waste chemistry controls. . . .' Without a clear technical basis for DST corrosion control, changes or exemptions to the technical safety requirements (TSRs) introduce a high degree of uncertainty. The Expert Panel did endorse operating outside established chemistry control limits contingent upon the successful completion of its recommendations. The Board agrees with the Expert Panel's conclusions and recommendations."

33. National Research Council, Board on Radioactive Waste Management, *Science and Technology for Environmental Cleanup at Hanford*, Academies Press, Washington, D.C.

2001, Table 2.2 on p. 22. Total radioactivity discharged is estimated between 65,000 to 4.7 million curies.

34. NUREG/CR-5751, p. 1–9 "Records on the contents and volumes of wastes transferred to tanks are typically incomplete or nonexistent."

35. NUREG/CR-5751, p. 3-2.

36. NUREG/CR-5751, p. 3-6.

37. Vadose Zone Characterization Project at the Hanford Tank Farms, Tank Summary Data Reports for Tank BY-105, Prepared by the U.S. Department of Energy, Grand Junction Office, Grand Junction, Colorado., GJ-HAN-22, March 1996 http://www.gjo.doe.gov/programs/hanf/BYReport/bytsdr/By-105/report/content.htm, 20 July 2004 (Hereafter known as Tank Farm Summary Data Report.).

38. Tank Farm Summary Data Report for Tanks TX116 (95 tons) & 117 (41 tons), SX-133 (41 tons), TY-106 (30 tons), U-104 (60 tons) http://www.gjo.doe.gov/programs/hanf/TXREPORT/REPORT/tsdr.html, 20 July 2004.

39. DOE-ORP 2002–03, p. 10.18.

40. Thomas W. Lippman, Danger of Explosion at Nuclear Plant Covered Up, Energy Department Probe Says, *Washington Post*, August, 1, 1990.

41. Safety issues included ferrocyanide ignition, high heat, nuclear criticality, flammable organic materials, and flammable gasses.

42. U.S. Department of Energy, Press Release, Final 24 tanks removed from watch list, August 27, 2001.

43. Overview and Summary of NRC Involvement with DOE in the Tank Waste Remediation System-Privatization (TWRS-P) Program, NUREG-1747 June 29, 2001. p. 249 (Hereafter known as NUREG-1747).

44. NUREG-1747, p. 253.

45. R. E. Gephart and R. E. Lundgren. Hanford Tank Cleanup: A Guide to Understanding the Technical Issues. PNNL-10773. Richland, WA: Pacific Northwest National Laboratory. 1997.

46. U.S. Department of Energy, Defense Nuclear Facility Safety Board (DNFSB) Hanford Staff Reports, February 15, 2002, August 2, 2002, October 25, 2002. (Hereafter known as DNFSB Staff Report). According to these weekly reports, during waste retrieval, flammable gasses trapped in the salts, such as hydrogen, methane, and ammonia are released into the tank headspace. Since the initiation of the accelerated cleanup program in early 2002, several tanks undergoing waste transfers have experienced gas releases above the lower explosive limits of 25 percent, requiring work stoppage.

47. NUREG/CR-5717, p. xvii.

48. DNFSB Staff Report October 10, 2003.

49. NAS 1996, p 94.

50. 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]

51. 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."

52. 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.)

53. U.S. Nuclear Regulatory Commission, Letter to: Mr. Jackson Kinzer, Office of Tank Remediation System, U.S. Department of Energy, Richland Operations Office, From: Carl J. Paperiello, Director, Office of Nuclear Material Safety and Safeguards, June 9, 1997.

54. 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.

55. DOE/EIS-0250, February 2002, Appendix A, p. A-39.

56. 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.

57. 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 10 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.

58. DOE/EIS-0250 February 2002, Appendix A., p. 40.

59. U.S. Department of Energy, an Evaluation of Commercial Repository Capacity for the Disposal of Defense High-Level Waste, DOE/DP0021/1 June 1985.

60. U.S. Nuclear Regulatory Commission. Memorandum for Joseph Browning, Director, Division of Waste Management, From: Neil J. Numarck, Policy and Program Control Branch, Subject: Clarification of DOE-Richland Comments on Defense Waste Commingling Study, March 14, 1985.

61. Ibid.

62. Ibid.

63. Arjun Makhijani, and Michelle Boyd, Nuclear Dumps by the Riverside: Threats to the Savannah River from Contamination at the Savannah River Site, Institute for Energy and Environmental Research, March 11, 2001, Takoma Park MD, p. 22.

64. Mathew Wald, An Effort on Atomic Waste is Called a Failure, *New York Times*, March 11, 2004.

65. National Research Council, Board on Radioactive Waste Management, *Alternative High-Level Waste Treatments at the Idaho National Engineering and Environmental Laboratory*, National Academy Press, Washington, D.C. pp. 85–86. "Another Possible conversion could be based on radioactivity measured in curies, using the fact that 1 MTHM of SBF with a burnup of 30,000 megawatt-days contains approximately 300,000 curies (Ci) after 10 years of cooling. As a result. 0.5MTHM correspond to approximately 150,000 Ci of HLW (rather than to one Savannah River-size canister). Still another conversion could be based on radiotoxicity, using regulatory release limits in 10CFR part 20 to compare the long-term performance of commercial SNF to DOE HLW based on the long-lived radionuclides in each contribute to the radiotoxicity after 1 to 10 millennia."

66. DOE/EIS-0250, February 2002, p. 8.6

67. NAS Technologies. P 94.

68. NUREG-1747, p xi. "The melters present several issues, due to their size, capacities, and surface area fluxes, all of which would make the LAW melters become the largest for radwaste vitrification in the world.

69. NUREG-1747, Table 4. pp.55–57.

70. NUREG-1747, p. 26.

71. NUREG/CR-5717, p. 1–18.

72. NUREG-1747, p. 199. The NRC areas of involvement included: Organization and General Information, Safety and Regulatory Activities, Inspections, Seismic and Structural Considerations, Hazards and Safety Analyses, Standards Approval Package (Safety Requirements Document and Hazardous Analysis Report) and Initial Safety Analysis Report, Radiation Safety and Dose Assessment Methodology Standard Review Plan, Criticality Safety Process and Chemical Safety, Standards Approval Package (Safety Requirements Document and Hazard Analysis Report) and Initial Safety Analysis, Fire Protection, Explosion Protection Issues, Environmental Protection, Standards Approval Package (Safety Requirements Document and Hazard Analysis Report) and Initial Safety Analysis Report, Quality Assurance.

73. U.S. Department of Energy, Directives, Office of Management Communication, http://www.directives.doe.gov/directives/current.html

74. Pub. L. 100-456. September 29, 1988 and United States Code, Section 2286. The responsibilities of the DNFSB are to review and evaluate standards, conduct investigations, analyze design and operational data, review facility design and construction, and make recommendations to the Secretary of Energy, authority to conduct hearings, establish reporting requirements for the Secretary of Energy, and assign resident inspectors at DOE defense nuclear facilities.

75. John Stang, Energy Department Ends BNFL Contract, *Tri-City Herald*, May 9, 2000. The privatization effort unraveled when BNFL presented a cost estimate that escalated to $15.2 billion for Phase I, instead of the expected $6.9 billion.

76. NUREG-1747, p. xi.

77. NUREG-1747, p. x.

78. NUREG-1747, p. 26.

79. 10 CFR 830.204, "A documented analysis of the extent to which a nuclear facility can be operated safely with respect to workers, the public, and the environment, including a description of the conditions, safe boundaries, and hazard controls that provide the basis for ensuring safety."

80. U.S. Department of Energy, University of California National Laboratory, Lawrence Livermore Hazard Analysis Procedure for Hazard Category 2 and 3 Nuclear Facilities Revision 1 September 2002, p. 3-2.

81. NUREG 1747, p. 169.

82. NUREG-1747, p. 50.

83. Assuming that the chances of an accident are 2.4E-02 per year, then the chances of NOT having an accident each year is 1.0 minus that value, or (1-2.4E-02). The chances of NOT having an accident at the end of two years would be (1-2.4E-02) × (1-2.4E-02) or (1-2.4E-02) ^2. Likewise, the chances of NOT having an accident at the end of N years would be (1-2.4E-02) ^N. Using N = 28, (1-2.4E-02) ^28 = 0.506518. This equates to essentially a 50 percent of NOT having an accident within 28 years.

84. NUREG-1747, p. 51.

85. NUREG-1747, p. xi.

86. NUREG-1747, Table 4.

87. NUREG-1747, p. 172.

88. NUREG-1747, p. x i. "The melters present several issues, due to their size, capacities, and surface area fluxes, all of which would become the largest for radwaste vitrification in the world. However, the experiential base, particularly from the perspective of potential ES&H concerns, is limited ... The melter designs also have several unique attributes, including a thin gap between the cooling coils and the outer steel casing, and drainage holes. More information and analyses would be required to ascertain the safety ramifications if these melter designs are used by the new contractors."

89. NUREG 1747, Table 5 p. 60.

90. NUREG 1747, p. 60.

91. Ibid.

92. U.S. Department of Energy, Technical Evaluation of the In Situ Vitrification Melt Expulsion at the Oak Ridge National laboratory on April 21, 1996, Oak Ridge Tennessee, ORNL/ER-377.

93. U.S. Department of Energy, Environmental Health and Safety Independent Investigation of the In Situ Vitrification Melt Expulsion at the Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL/ER-371, August 1996, p. 7.

94. Ibid.

95. NUREG-1747, p. 54.

96. NUREG-1747, p. 134–135.

97. IMAP, p. 8.4.

98. DNFSB, Staff Issue Report, Design Basis Earthquake Ground Motion Criteria for theHanford Site and Waste Treatment Plant, July 16, 2004.

99. Annette Cary, Vit plant needs more quake protection, *Tri-City Herald*, February 25, 2005. P. A-1.

100. NUREG-1747, p. 103.

101. NUREG-1747, p. 183.

102. Memorandum for Roy Schepens, Manager, Office of River Protection, From: Sandra Johnson, Director for the Office of Safety and Engineering, Subject Fire Protection for

Waste Treatment Plant, April 17, 2003. (Hereafter known as "Memo to Schepens from Johnson.")

103. Ibid.

104. Ibid.

105. DNFSB Staff Report, January 16, 2004.

106. U.S. Department of Energy, Office of Environmental Management, FY 2002 Integrated Technology Plan for the River Protection Project DOE/ORP-2002-03, p. 5.22 (Hereafter known as DOE/ORP-2002-03) Just prior to these problems emerging, DOE researcher warned: "The release of toxic gases, including the release rate and control mechanisms, must be better understood to develop compliance strategies for applicable environmental, safety, and health regulatory requirements .... No specific activity is currently under way to address this newly identified need.... As an example, construction activities associated with Tank 241-C-106 required pit access to install sluicing hardware and other equipment. The dose rate experienced in the 241-C-106 pits was 40 R/hr. After investing $2 million and 5 months, worker dose had been reduced to only 20 R/hr."

107. DOE/ORP-2002-03, 4.15.

108. DNFSB Staff Report July 11, 2003.

109. Clare Gilbert and Tom Carpenter, Knowing Endangerment: Worker Exposure to Toxic vapors at the Hanford Tank Farms, Government Accountability Project, September 2003, Washington, D.C.

110. Matthew L. Wald and Sara Kershaw, Wider Investigation Sought at Nuclear Site, *New York Times*, February 26, 2004. P. A-16.

111. Blaine Harden, Waste Cleanup May Have Human Price, *Washington Post*, March 6, 2004. P. A-1.

112. DNFSB Staff Report, February 4, 2005.

113. U.S. Department of Energy, Integrated Mission Acceleration Plan, CH2MHill, RPP 13678, Rev. 0, March 2003, (Hereafter known as IMAP). Specific technologies under active consideration include: **Steam Reforming**—"Steam reforming processes waste in a high-temperature fluidized bed under a slight vacuum. Superheated steam and additives are injected into the bed creating reducing and oxidizing zones." The process is expected to destroy organics, nitrates and nitrites. Additives are expected to incorporate radionuclides, sulfate, chlorine and fluorine into a granular waste form; and **Grout**—Grouting involves mixing wastes with compounds and conditioners such as Portland cement, fly ash, and slag to produce a cement-like waste form. In order to achieve regulatory requirements for low-level waste disposal, the dilution of radionuclides can significantly increase waste disposal volumes. Based on further performance assessments, it appears that bulk vitrification is being selected as the preferred "supplemental" technology.

114. U.S Department of Energy, Order 435.1.

115. *NRDC v. Abraham*, 244 F.3d 742 (9th Cir. 2003).

116. *The Hanford Reach*, A Publication of the U.S. Department of Energy's Richland Operations Office for all site employees, August 16, 1999, p. 7.

117. IMAP, pp. 4–18, 19

118. IMAP, p. ES-2.

119. M. Elmore and C. Henderson, *Summary of High Level Waste Tank Lay-Up Activities Supporting the Tanks Focus Area, Fiscal Years 2001–2002*, Pacific Northwest

National Laboratory, PNNL-13901, May 2002, Interim closure involves "placing tanks that no longer contain any retrievable waste and are considered to be into a safe, stable, and minimum maintenance condition until final closure could occur. This state of pre-final closure (otherwise known as interim closure, operational closure, etc.) was termed tank lay-up."

120. DOE/ORP-2002-03, p. 10.18) "Notably, borehole logging in SX Tank Farm revealed 137Cs at depths of 40 meters (130 ft), significantly deeper than predicted by current models. Further investigations, including the drilling of two additional wells, confirmed the presence of migrated cesium in the formation. The report issued by the RPP Vadose Zone Expert Panel concluded that cesium migration was poorly understood and that insufficient data were available to validate migration models . . . Furthermore, the vadose zone cleanup schedule for the 200 Areas could be delayed if the mobility status of deeply distributed contaminants is unknown or inadequately characterized well in advance. For example, if it is eventually determined that retrieval of TRU-contaminated soil down to 40 m or more beneath Plutonium Finishing Plant cribs is required, the cleanup schedule could be greatly impacted by excavation and handling costs that could approach 1 billion dollars or more. Similar excavation requirements for leaking SSTs could drive the costs of cleanup higher by several orders of magnitude. The sooner this issue is resolved, the sooner more accurate technical, financial, and schedule forecasts can be made"

121. DOE/ORP-2002-03, pp. 10.4, 10.6).

122. Energy Reorganization Act of 1974, P.L. 93-438, Oct. 11, 1974, 88 Stat. 1233, (U.S.C. Title 42, Sec. 5801 et seq.).

123. The Nuclear Waste Policy Act, P.L. 97-425, Jan. 7, 1983, 96 Stat. 2201 (Title 42, Sec. 10101 et seq.).

124. Nuclear Waste Policy Amendments Act of 1987, P.L. 100-203, title V, subtitle A, Sec. 5001-5065, Dec. 22, 1987, 101 Stat. 1330-227 to 1330-255. According to NRC (NUREG-1747, p. 215.). "Under the present system, unless the NRC determines that this LAW/incidental waste is not HLW, the waste must be disposed of as HLW in a federal repository."

125. NRC 1997 Approval Letter.

126. NUREG/CR-5751, p. 1–18, "The daughters of Sr-90 and Cs-137 –Y-90 and Ba-137m respectively – are at or near a state of transient equilibrium (i.e. equal radioactivity) with their parents and should be included in the inventory."

127. WHC-SD-WM-TI-699 Rev. 2 1996) pp. ES vi, vii.

128. U.S. Nuclear Regulatory Commission, Letter to: Mr. Jackson Kinzer, Office of Tank Remediation System, U.S. Department of Energy, Richland Operations Office, From: Carl J. Paperiello, Director, Office of Nuclear Material Safety and Safeguards, June 9, 1997. (Hereafter known as NRC 1997 Approval Letter.)

129. WHC-SD-WM-TI-699.

130. Ibid.

131. IMAP.

132. IMAP, Tank wastes scheduled for onsite disposal using "supplemental technologies" are found in IMAP (Accelerated Retrieval and Interim Closure Schedule Table 4.3, and 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, wastes in tanks identified as potential transuranic wastes and, thus is based on disposition of wastes in 62 SSTs.

133. Ibid.

134. DOE/EIS-0286F, Table L.1.

135. U.S. Department of Energy, "Final Hanford Site Solid (Radioactive and Hazardous) Waste Program Environmental Impact Statement Richland, Washington" (HSWEIS), (Hereafter known as DOE/EIS - 0286F), January 2004, Table 5.15, p. 5.291, Comment: Table 5.15 of the HSWEIS provides the fraction of Maximum Contaminant Levels for Tc-99 and I-129 for several ILAW disposal sites at Hanford. The fraction of I-129 MCL (1.0 pCi I-129/L) ranges from 0.3 to 1.3. The preferred location near PUREX is 0.3 MCL. The sum of fractions MCL for Tc-99 and I-129 is 0.6 to 2.4 for various Hanford sites. The HSWEIS also identifies the Waste Treatment Plant (WTP) wastes for disposal at Hanford as containing 22 Ci I-129 in the ILAW glass and 5 Ci I-129 in grouted LLW (Liquid Effluent Treatment Facility, LETF, waste) in Table L.1. The balance of the retrieved tank waste I-129 inventory is assumed to be vitrified in HLW glass.

136. 10 CFR Part 141.16 states: Sec. 141.16 Maximum contaminant levels for beta particle and photonradioactivity from man-made radionuclides in community water systems. (a) The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the total body or any internal organ greater than 4 millirem/year. (b) Except for the radionuclides listed in Table A, the concentration of man-made radionuclides causing 4 mrem total body or organ dose equivalents shall be calculated on the basis of a 2 liter per day drinking water intake

137. DOE/EIS - 0286F, p. 5.291.

138. John Rennie, Editor's Commentary: The Cold Odds against Columbia, Scientific American.Com, p. 1. "Assuming that NASA's 0.7-percent-per-mission risk estimate is correct, then over 113 missions the likelihood that one shuttle will be destroyed reaches about 55 percent." http://www.sciam.com/article.cfm?articleID=000E76D3-F389-1E43-89E0809EC588EEDF, July 20, 2004.

139. NUREG-1747, p. 16. During the period of NRC involvement, the agency had 15 staff experts, with an average experience of 20 years in their respective fields, as well as NRC's federally-funded research capabilities to focus solely on the Hanford HLW management program.

140. The Monument was established in 2000 by the President of the United States and encompasses the last free-flowing 51-mile stretch of the Columbia River, which flows through Hanford. The uniquely preserved steppe shrub environment at Hanford supports numerous species of birds, mammals, reptiles, and amphibians, including some recognized as species of concern by state and federal governments. The Reach is also the last spawning habitat for some 80 percent of wild Chinook salmon in the Pacific Northwest and shelters food and cultural resources and important archaeological sites that are vital to thousands of Native American people.

141. U.S. Department of Energy, Hanford Performance Management Plan Rev. D - August 2002, Table 1, p. iv. http://www.hanford.gov/docs/rl-2002-47/rl-2002-47.pdf, July 20, 2004

142. NUREG-1747, p. 62.

143. Ibid.

144. 10 CFR 20.

145. U.S. Environmental Protection Agency, Region 10, Columbia River Basin Fish Contaminant Survey, 1996–1998, EPA 910-R-02-006. A scientific fish consumption survey was first performed which estimated that daily average consumption of fish as 389

grams per day. Then a total of 281 samples of fish and eggs were collected from 24 study sites sampled in the Columbia River Basin, where tribal people traditionally fish. The fish and eggs were analyzed for 132 chemicals of which 92 were detected. The EPA then used its risk assessment models, hazard indices to interpret the risks of measured contaminants.

146. U.S. Department of Energy, Technical Standard, A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota, DOE-STD-1153-2002.

147. Dose to fish: 1 rad/d Corresponding activity in fish: $\sim 2 \times 10E+6$ Bq/kg, Eating 389 g/d of fish with $2 \times 10E+6$ Bq/kg for one year results in an effective dose of 0.0828 Sv or 8.28 rems.

148. Robert H. Nelson, *From Waste to Wilderness: Maintaining Biodiversity on Nuclear Bomb-Building Sites*, Competitive Enterprise Institute, Washington D.C. (2001) pp. 17.

149. U.S. General Accounting Office, Department of Energy: Opportunities to Improve Management of Major System Acquisitions. Report to the Chairman, Committee on Governmental Affairs, U.S. Senate GAO/RCED-97-17, (1996), Washington, D.C. (Between 1980 and 1996 GAO reported that 31 of 80 DOE major system acquisition projects had been terminated prior to completion, 34 were continuing although over budget, and 15 had been completed.)

150. National Research Council, Committee to Assess the Policies and Practices of the Department of Energy to Design, Manage, and Procure Environmental Restoration, Waste Management, and Other Construction Projects, *Improving Project Management in the Department of Energy*, National Academies Press, Washington D.C (1999).

151. National Research Council, Committee for Oversight and Assessment of U.S. Department of Energy Project Management, *Progress in Improving Project Management at the Department of Energy, 2001 Assessment*, National Academies Press, Washington D.C., (2003), p. 4 (Hereafter known as NAS-DOE Project Management 2001).

152. U.S. General Accounting Office, Report to Chairman, Subcommittee on Energy and Power Committee on Commerce, House of Representatives, Department of Energy: Contract Reform Is Progressing, but Full Implementation Will Take Years, GAO/RCED-97-18, December 1996, p. 2.

153. National Research Council, Committee for Oversight and Assessment of U.S. Department of Energy Project Management. *Progress in Improving Project Management at the Department of Energy, 2002 Assessment*, National Academies Press, Washington D.C., (2003), p. 3.

154. In the melting process, soda and lime particles normally found in soft glass, are replaced with boron oxide. Because the boron oxide particles are so small, they hold the silicate particles together more closely with aluminum oxide and sodium oxide into in a much stronger glass.

155. U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Survey of Waste Solidification Process Technologies, Center for Nuclear Waste Regulatory Analyses, NUREG/CR-6666, (2001), p. 7. (Hereafter known as /CR-6666). HLW operations include the Pamela facility in Mol, Belgium, the West Valley Demonstration Project in New York (USA), the Defense Waste Processing Facility at the Savannah River Site, (SC), the Tokai Vitrification Plant in Japan, and the Mayak facility in Russia. The Pamela and Mayak facilities were closed in 1991 and 1997, respectively. Low-level and mixed low-level operations include: the M-Area vitrification plant at the Savannah River Site, and the Fernald Silo Waste Vitrification System in Ohio. The Fernald plant closed due to technological failure in 1996.

156. NUREG/CR-6666, p. 127.

157. NUREG/CR-6666, p. 136.

158. NUREG/CR-5751, P. 8-4.

159. GAO-03-593, pp. 33–35.

160. IMAP, p. 4–17.

161. Ahearne et al., p. 6.

162. Ibid.

163. DNFSB Staff Report February 20, 2004.

164. Annette Cary, Officials to Review Vit Plant Costs, *Tri-City Herald*, January 29, 2004. P. B-1.

165. DOE/ORP-2002-03, P. 5.20.

166. DOE/ORP-2002-03, P. 8.31.

167. John Ahearne et al., "High-Level Waste Melter Review Report, U.S. Department of Energy, Office of Environmental, Management, Tanks Focus Area Report, July 2001, p. 4. ". . . the data supporting the current 0.77 leach factor and 1.0 percent glass solubility used by the Study Team are not strongly substantiated." (Hereafter known as "Ahearne et al.")

168. United States General Accounting Office, Report to the Ranking Minority Member, Committee on Commerce, House of Representatives, Nuclear Waste: Process to Remove Radioactive Waste From Savannah RiverTanks Fails to Work GAO/RCED-99-69, April 30, 1999.

169. M. D. Boersma and J. L. Mahoney, Glass Making Technology for High-level Waste, E. I. du Pont de Nemours and Company, Savannah River Plant, Aiken, South Carolina, August 1986.

170. U.S. National Academy of Sciences, Board on Radioactive Waste Management, *Technologies for Separations and Transmutation*, Academy Press, Washington D.C. (1996), p. 89.

171. NUREG -1747, p. 16.

172. Dhanpat Rai, Pacific Northwest National Laboratory Linfeng Rao, Lawrence Berkeley National LaboratorySue B. Clark, Washington State University Nancy J. Hess, Pacific Northwest National Laboratory, Speciation, Dissolution, and Redox Reactions of Chromium Relevant to Pretreatment and Separation of High-Level Tank Wastes Project ID: 65368, U.S. D.O.E. Environmental Management Science Program, 2000.

173. NUREG-1747, p.207 Based on world-wide experience, NRC estimates that the frequency of corrosion failures in the melter area could be as high as one 1.2E-2/yr.

174. U.S. Department of Energy, Office of River Protection, Site Need Statement, RL-WT080, October 18, 2001.

175. T. Bond Calloway, Jr., Chris T. Randall, and Victor R. Buch, Characterization of Off Gas Flow Surges in the DWPF Melter (U), Westinghouse Savannah River Company Savannah River Technology Center Aiken, SC 29808 Presentation to American Institute of Chemical Engineers Spring 1999 Conference, Houston TX, March 15–19, 1999 "Large surges can cause shutdown of the melter feed, switchover to the backup off gas system and inadvertent glass pours. Very large surges (>2 inwc) are relieved to the Melt Cell through a Seal Pot spreading contamination to Melt Cell equipment. While the Melt Cell is a shielded and remotely operated area of the plant, spread of contamination is not desirable from a maintenance perspective. Melter pressure is controlled using a standard PID algorithm with some additional features that are designed to rapidly

bring the melter pressure back to a normal operating set point (−5 inwc) whenever the system is outside the normal operating range of −2 to −10 inwc."

176. U.S. Nuclear Regulatory Commission, Programmatic review of paper entitled "PRETREAT: Graphical User Interface-Based Spreadsheet Model for Hanford Tank Waste Pretreatment Processes," Center for Nuclear Waste Regulatory Analyses, February 4, 2000. Keeping track of every element of pretreatment, alone, at the WTP involves the use of a complex computer model capable of processing large amounts of data—involving as many as 20 different worksheets.

177. DOE/ORP-2002-03, p. 6.14 This remains an unresolved issue and according to DOE "despite pipeline plugging over many years at Hanford, the technologies for removing plugs are still not well developed."

178. DNFSB Staff Report,December 10, 2004. "Preliminary calculations indicate that much of the black and hot cell piping can accumulate hydrogen volumes that are tens to hundreds of times greater than what has been considered to bea *de minimus* level."

179. DNFSB Staff Report, October 29, 2004.

180. Defense Nuclear Facility Safety Board, Letter from John Conway, Chairman to: the Honorable Spencer Abraham, Secretary of Energy, March 23, 2001. (At the Savannah River Site, the failure to address proper treatment of secondary sludge wash wastes led to the clogging of waste evaporators with significant concentrations of highly enriched uranium—creating criticality safety concerns. Moreover, the inability to process these led to the reactivation of aged single-shell tanks, which subsequently leaked. For more than a year, the Defense Waste Processing Plant at SRS was generating and storing a far larger amount of waste than it was treating.)

181. Letter (with Attachments) from: E. S. Aromi, President and General Manager, CH2M HILL, to: R. J. Schepens, Manager, Office of River Protection, U.S. Department of Energy, September 12, 2003. (Hereafter known as Aromi.)

182. NUREG-1747, p. 122. The NRC pointed out that, "For the failed HLW melter, the great majority of the vitrified waste would have to be removed in order to meet near-surface disposal requirements. It was not clear how this could be accomplished for a melter without bottom drains."

183. IMAP, p. 2.5.

184. DOE/EIS-0250, February 2002, Appendix A, Table A-41, Comment: DOE estimates at least 11 failed melters from the Savannah River Site and the West Valley Demonsotration Vitrification Plant, containing 1,052 tons of radioactive materials, generaing 46 times the decay heat of a HLW canister.

185. DOE/ORP-2002-03, pp. 7.38, 7.27.

186. Ibid.

187. Aromi.